User documentation

HyGEARS® v4

HyGEARS THE GEAR PROCESSOR®

September 2020

Table of Contents

1 EULA

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2 Windows Basics

HyGEARS has been designed and coded to be run in the Windows Operating System. Therefore, it is assumed that the user basically knows how to use Windows. It is strongly recommended to refer to the Microsoft Windows User's Guide to ensure proper understanding of this operating environment.

However, a few points will be presented here in order to offer the first time user the fundamentals for running HyGEARS in Windows.

Files

Computer data is stored in files, which is a form of folder containing information. Computer programs, also called applications, are a special type of file, which include commands to the operating system instructing certain operations to take place. Data files are another file type in which information is saved.

For example, in HyGEARS, gear sets or geometries will be created for which the Roughing and Finishing Summaries are established. In order to keep this data to be able to continue working on it at a later stage, the gear set can be saved in a data file in a specified sub-directory.

A sub-directory is simply a kind of drawer in a cabinet in which the files are put.

Mouse Operations

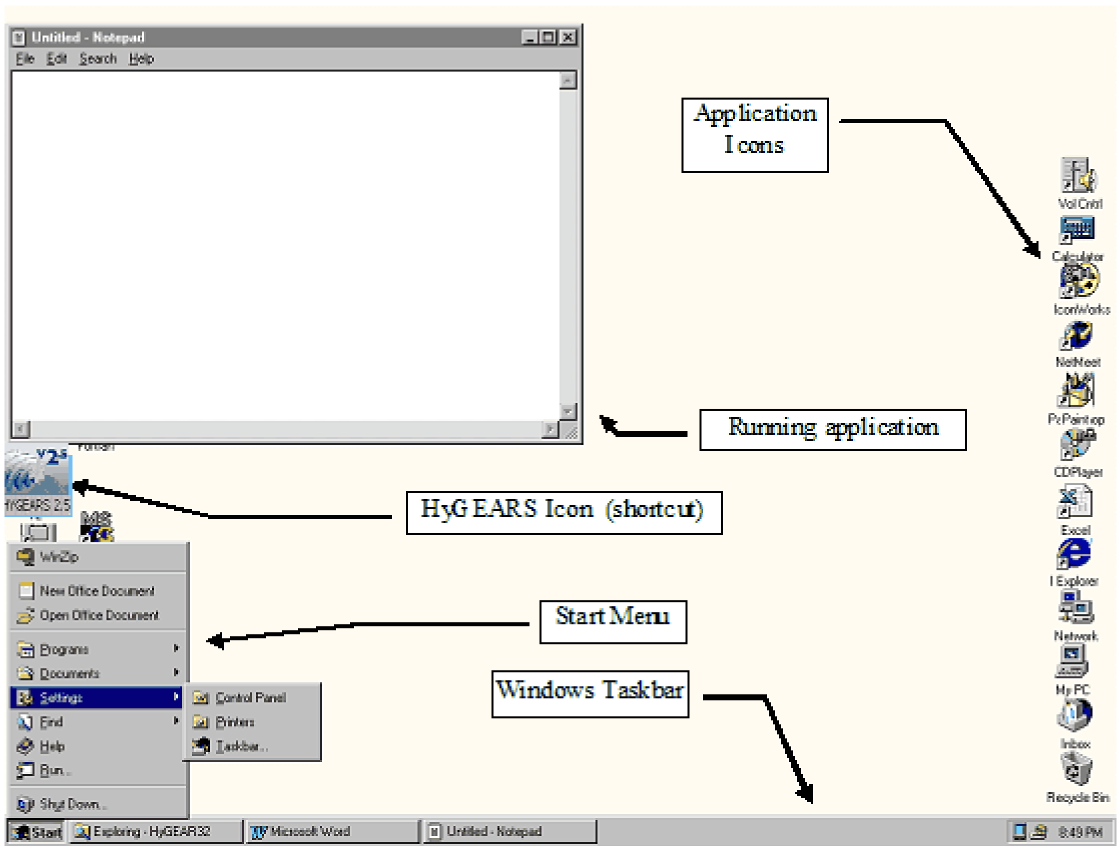
Windows provides everything needed to manage applications and data files easily and efficiently. Generally speaking, all user actions are initiated by mouse clicks.

The pointer shape can change depending on the action undertaken or its location on screen. For example, when computations are taking place in HyGEARS, the pointer shape becomes a hourglass indicating the user to wait until the function being performed is completed, after which the pointer retakes its original shape.

By locating the pointer on the name of a function in a menu, on a command button, or on an icon, and clicking with the left mouse button, the operating system will understand that the user wants to initiate the action over which the mouse pointer is resting, and will start the computer program, initiate the command of a given button, or give access to the functions of a menu.

Therefore, to start HyGEARS for example, simply bring the mouse pointer over the HyGEARS icon, if it is installed on your Desktop, and double-click (two rapid consecutive clicks of the left mouse button).

The Screen Desktop



The screen itself can be considered as a desktop on which a number of tools are available.

Most windows possess three small buttons in their upper right corner,

to minimize the window	(_), after which the window will be iconized and use very little desktop space,
to maximize the window	(□), after which the window will take up all the space on the screen,
to close the window	(**X**)

To restore the state of a minimized window, simply click on its icon in the taskbar.

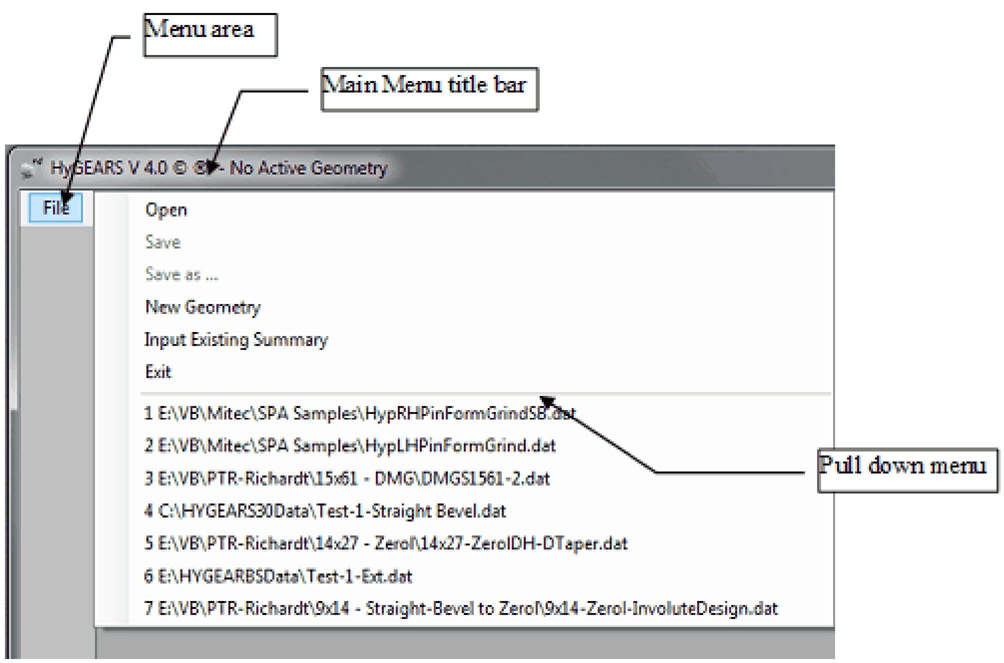
Windows and icons can be installed anywhere on the screen simply by dragging them to wherever is desired. Dragging is done by placing the mouse pointer over the icon to move, or on the title bar of the window to move, pressing on the left mouse button and moving the mouse pointer while keeping the left mouse button pressed. The window or icon will change aspect and will follow the location of the mouse pointer.

The Control Box menu in the upper left corner of any window offers another way of performing these operations. For more information about the Control Box use, click on the Control Box of any open application and try the options offered in the pull-down menu.

Pull Down Menus

One of the nicer features of the Windows Operating Environment is the so-called Pull Down Menus, which are smaller windows containing the names of actions to be performed.

In Summary, menu entries give access to Pull Down menus which then give access to functions.



Running HyGEARS

When HyGEARS is running, it offers a Main Menu window, as shown above, from which initial tasks can be made, such as creating a new Geometry, retrieving a Geometry data file, configuring HyGEARS, or accessing various graphic functions. The HyGEARS Graphic

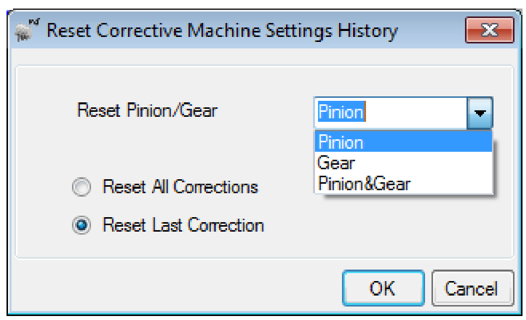
User Interface is discussed in detail and the reader is invited to read thoroughly this section of the documentation.

In this documentation, specific functions will often be referred to. In order to positively identify the correct sequence each time, the following convention will be used:

The File + Open combination can be replaced by the “Alt”+”F”+”O” keyboard sequence, but it will be symbolized by the File->Open sequence in this documentation. Therefore, the Graphics->Tooth sequence means the following Graphics + Tooth mouse click combination, which can be replaced by the “Alt”+”G”+”T” keyboard sequence.

Drop Down List Boxes and Command Buttons

Often, it is desired to offer many choices to the user. An elegant way to do so is to use Drop Down List Boxes which display the default or user selection, and offer a list of choices when the drop down feature of the list box is clicked with the left button mouse. Drop Down List Boxes are used frequently throughout HyGEARS.



For example, the above window displays an input field titled “Reset Pinion-Gear” and shows the input field default selection to be “Pinion”. To change the default selection, a click of the left mouse button on the arrow to the right of the input field will reveal the contents of a Drop Down List Box in which the current selection is highlighted, and from which a selection can be made by clicking on the desired choice.

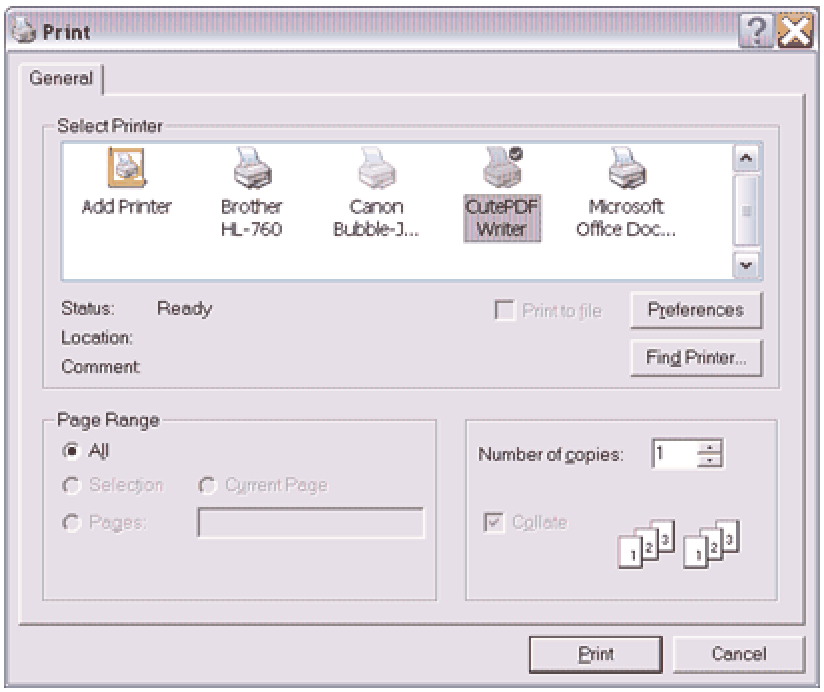
Two command buttons appear at the bottom of the window. Command buttons are used throughout HyGEARS to initiate an immediate action. In the above window, two actions can be initiated:

OK	to accept the selection and continue the process;
Cancel	to abort the selection and stop the process.

Throughout HyGEARS, pressing the “Return” or “Enter” keyboard key does the same as clicking on the OK button, while pressing the “Esc” key does the same as clicking on the Cancel button.

Printer Selection Dialog Box

Many built–in Windows tools are used in HyGEARS for the convenience of the user. One such tool is the Windows Printer Selection Dialog Box, shown below, where a series of options are offered at the user before any printing operation.



Select Printer printers installed on your computer. Refer to the Windows documentation to change or add printers.

Preferences enables the user to change the behavior of the printer, such as paper size, graphic resolution, etc.

Print Range in HyGEARS, this option is normally set to “All”.

Number of Copies controls the number of printed copies. It is normally set to 1.

3 HyGEARS Simulation

This section introduces basic concepts about the HyGEARS vector simulation of gear cutting processes, Tooth Contact Analysis (TCA) and resulting Transmission Error, Contact Pattern and Loaded Tooth Contact (LTCA), for the user to understand and fully appreciate the possibilities offered by this software.

This section is divided in seven major topics:

What is vector simulation ?

Simulation of the pinion and gear cutting processes.

Tooth Contact Analysis and Transmission Error.

Contact Pattern and Transmission Error.

Loaded Tooth Contact Analysis.

General gear set design guidelines.

Corrective Machine Settings (Closed Loop) and The HyGEARS Surface Matching Algorithm.

3.1 What is Vector Simulation

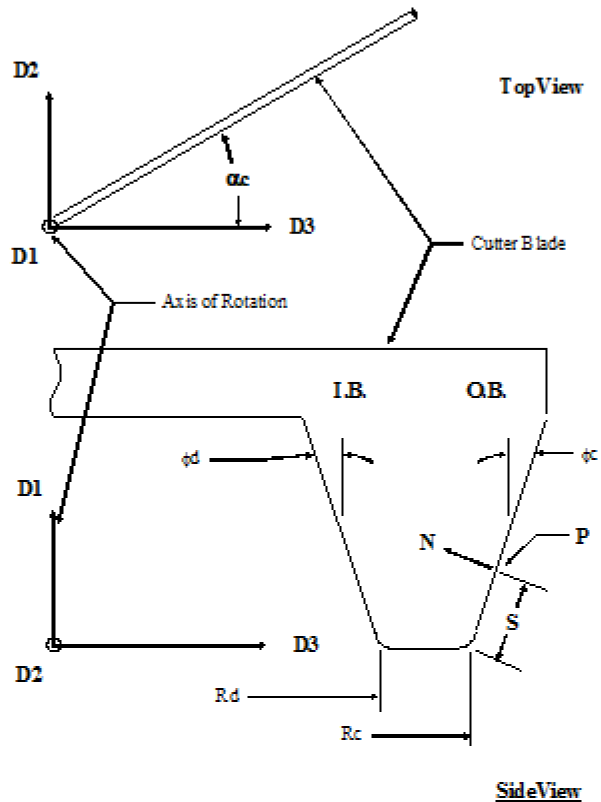
HyGEARS uses vector simulation to accurately simulate the pinion and gear cutting processes, and then calculate the Path of Contact, Transmission Error, Contact Pattern and load sharing between meshing tooth pairs.

Vectorial simulation of gear cutting processes was first introduced by Baxter of the Gleason Works in the early 1960s. It has since been widely used in the gear industry and research laboratories, particularly because it is well suited for computer applications.

In short, it is a vector representation of the shapes, relative movements and meshing conditions of a cutter and work, or of meshing gear tooth surfaces. In HyGEARS, vector simulation is extended to all applications to tooth surface geometry.

To be able to properly apply vector simulation, manufacturing components, for example, must be defined in reference frames to which movements, positions and orientations are applied. Knowing the movements, positions and orientations given to each reference frame, it is possible to determine the vector transformations from one reference frame to another.

The following figure illustrates a pinion cutter in its definition reference frame. In HyGEARS, the reference frames used to define the cutters are respectively D1D2D3 for the pinion and C1C2C3 for the gear.



The above figure represents top and side views of a pinion cutter blade edge revolving about axis of rotation D1, similar to the cutters used to cut spiral bevel and hypoid pinion and gear teeth using a face milling cutter. Only one cutter blade edge is needed to reproduce the cutting process of one tooth flank, provided that the blade edge dimensions used are those of the finishing blade.

In practice, cutters have several equally spaced blades that cut small flat surfaces on the teeth of the workpiece; a proper combination of work and cutter rotation speed ensures very small flats and thus a smooth tooth surface.

In the above figure, fd is the blade angle of the inside blade (I.B.) while fc is the blade angle of the outside blade (O.B.). The cutter blade rotates about axis D1, its instantaneous angular position relative to axis D3 being given by angle ac. The I.B. and O.B. blade point radii are respectively Rd and Rc.

When cutting, a series of points **P** along the blade edge of the cutter will come in contact with the work; each point **P** is known by its position **S** along the blade edge and the angular position ac of the blade edge. The normal to the blade edge at any point **P** is **N**, and is therefore the normal to the tooth being cut.

Thus, the following equation gives a general definition of contact point vector **D** between cutter and work in the pinion cutter reference frame D1D2D3:

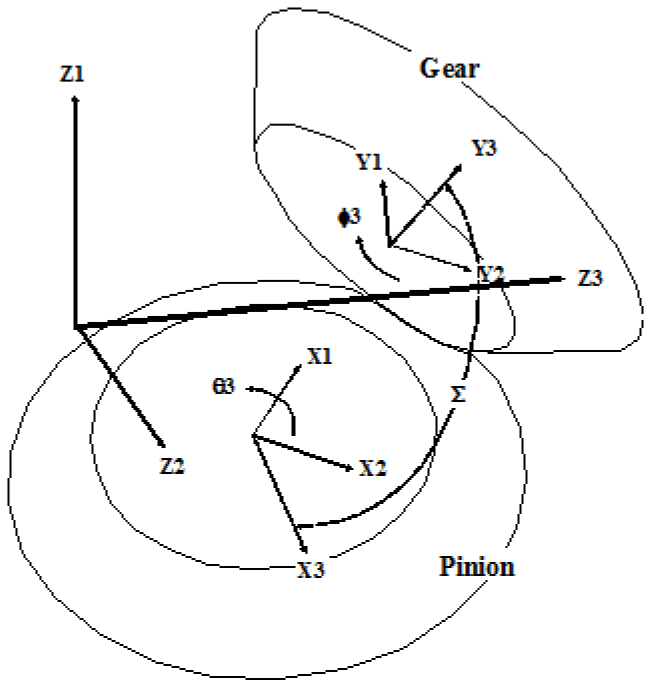
$$D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha c) & \sin(\alpha c) \\ 0 & -\sin(\alpha c) & \cos(\alpha c) \end{bmatrix} \begin{bmatrix} S\cos(\phi) \\ 0 \\ (R \pm S\sin(\phi)) \end{bmatrix}$$

while the following equation gives a general definition of a cutter normal vector **N** in the pinion cutter reference frame D1D2D3 at all times:

$$N = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha c) & \sin(\alpha c) \\ 0 & -\sin(\alpha c) & \cos(\alpha c) \end{bmatrix} \begin{bmatrix} \sin(\phi) \\ 0 \\ \mp\cos(\phi) \end{bmatrix}$$

where **R** is the I.B. or O.B. point cutter radius, f is I.B. or O.B. blade angle, **S** is the position of point **P** along the blade edge, and ac is the cutter rotation angle at time t. In HyGEARS, this concept is used at all stages of pinion and gear tooth cutting, for both generated and non generated gear teeth.

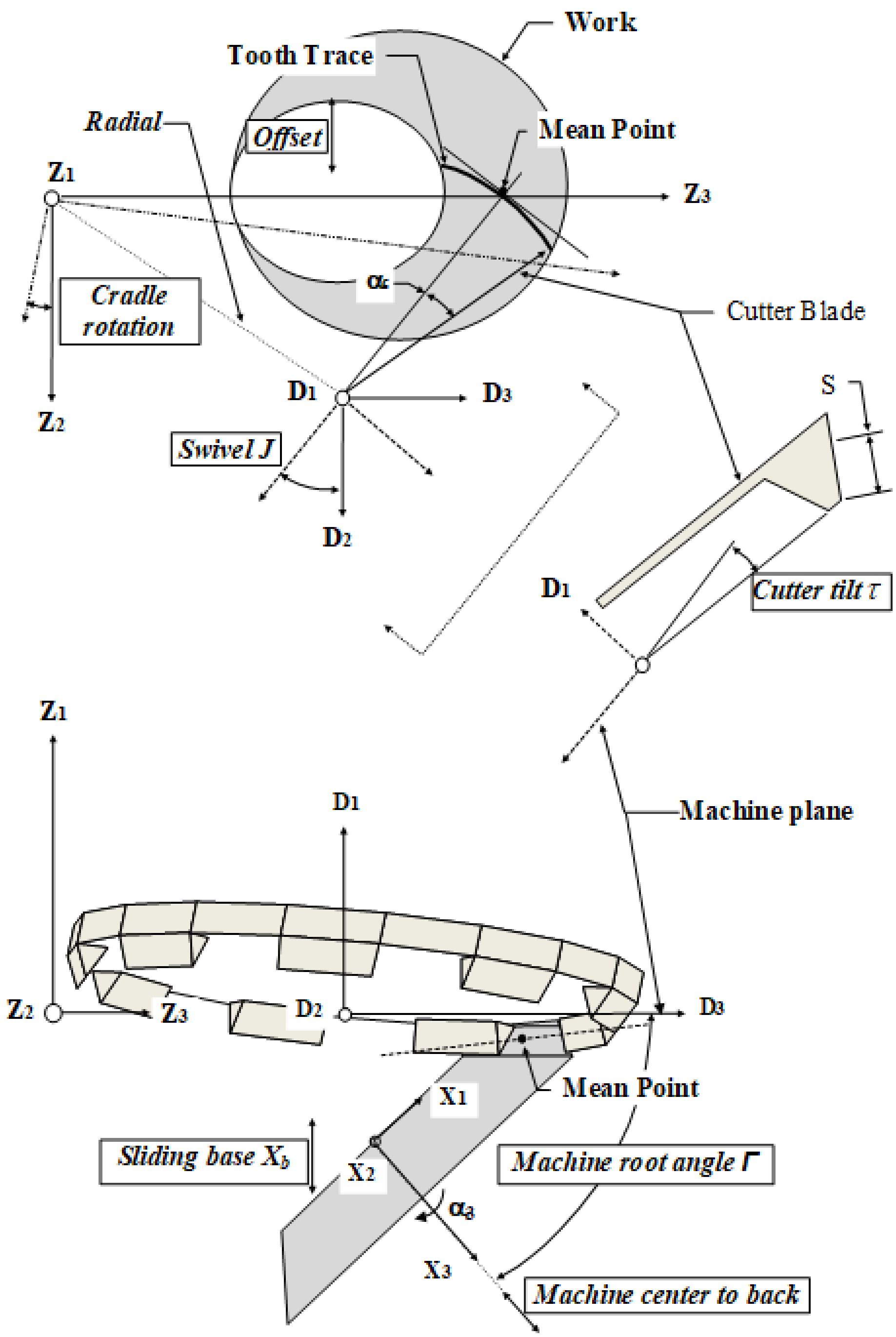
The figure below illustrates the main reference frames used in HyGEARS to locate the pinion and the gear, which will be referred to later in the documentation (the same reference frames apply for spur/helical gears):



Z1Z2Z3:	is the general reference frame in which every other reference frame is located through appropriate vectorial transformations.
X1X2X3:	is the pinion reference frame in which the pinion tooth surface is defined; axis X3 is the axis of rotation and angle q3 is the angle of rotation.
Y1Y2Y3:	is the gear reference frame in which the gear tooth surface is defined; axis Y3 is the axis of rotation and angle f3 is the angle of rotation.

The axes of rotation of the pinion and gear, respectively X3 and Y3, define the shaft angle S. For spiral-bevel, hypoid and straight-bevel gears, this angle is normally 90°, although values below and above are sometimes used. For spur/helical gears, it is set to 0°.

In the following figure, the main components needed to simulate a spiral-bevel or hypoid generator, capable of cutter tilt, are shown. Some of these components will be used in the following paragraphs.


Work
Tooth Trace
Radial
Offset
Mean Point
Z1
Z3
Cradle rotation
Cutter Blade
Z2
D1
D3
S
Swivel J
D2
D1
Cutter tilt τ
Z1
D1
Machine plane
Z2
Z3
D2
D3
Mean Point
X1
Sliding base Xb
X2
Machine root angle Γ
α3
X3
Machine center to back

3.2 Simulation of Cutting Processes

HyGEARS reproduces the Gleason process for cutting bevel gear teeth, where the tooth lengthwise depth is not constant, thereby avoiding undercutting problems near the toe of the tooth and producing teeth whose bending stiffness is more constant from toe to heel.

Since the pinion and gear tooth depth is not constant, meshing conditions will not be conjugate profilewise. While it is usual to mismatch the teeth in the lengthwise direction to reduce their sensitivity to position and alignment errors, the non-conjugate nature of the Gleason process means that the Contact Pattern will not be acceptable unless modifications are made to the pinion machine setup to compensate for non-conjugacy.

Fundamentally, two basic cutting processes are in use, producing either generated or non-generated gear teeth, whatever the cutting tool used. Beyond the basic cutting processes, tools vary and may be face milling cutters, such as those presented in the figures above and below, hobbing cutters, not presented nor yet supported in this HyGEARS version, and grinding wheels generally applied to the face milling process.

Generated Tooth Cutting Process

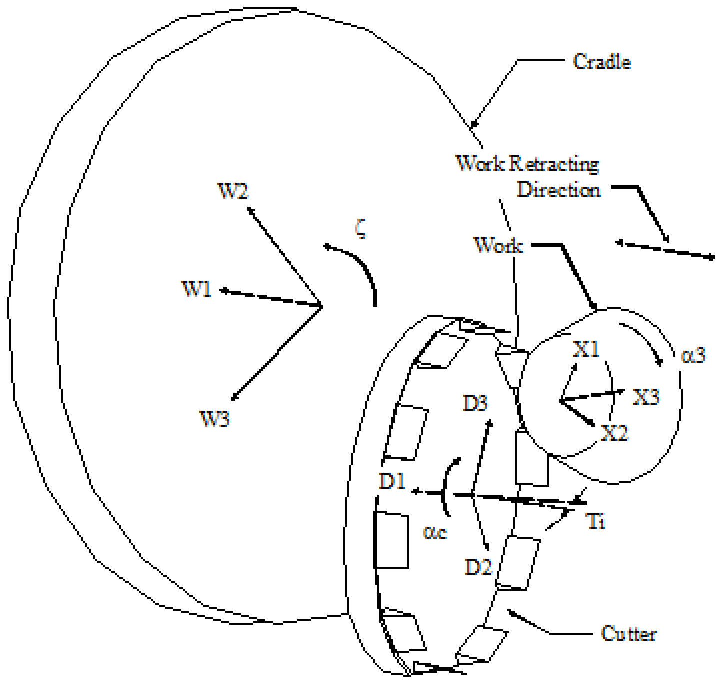
The generated tooth cutting process involves relative motion between a workpiece and a cutter supported on a cradle, as shown in the following figure.

The cradle supports a cutter rotating about axis D1, whose angular position is ac. In some applications, the cutter axis is tilted relatively to the cradle, as shown by tilt angle Ti, in order to reproduce a generating gear member whose pitch cone angle is different from 90, or to improve meshing conditions, or when the mating member is non-generated, or such that cutters with given blade angles can be used in different applications.

When both the pinion and gear members are generated, the pinion and gear machine settings are calculated such that they are conjugate to approximately the same crown gear, and the pinion cutter tilt is therefore used to match the pressure angles of both members at a set point.

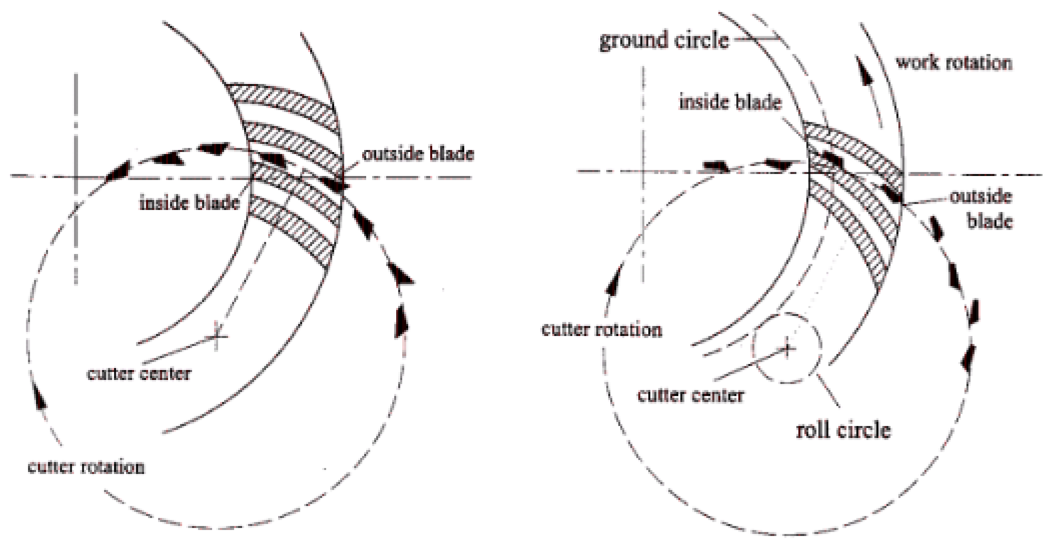
When the gear member is not generated, the gear member tooth is considered as the pinion tooth cutting tool, which means that the pinion cutter tilt will be used to both match the orientation of the gear tooth and the pressure angles of both members at a set point.

As the cradle rotates of angle z about axis W1 while carrying the cutter, the work rotates of angle a3 about axis X3 while its position relative to the machine body remains fixed. The work to cradle speed ratio is called the ratio of roll, and is adjusted using gear trains in older machines where it is called the decimal ratio, while it is computer controlled using servo-motors in more recent generating machines.



Face-milling generation is a process requiring indexing, which means that the cutter is initially set not to touch the work, and the cradle is then put in rotation, carrying the cutter along, as the work also starts rotating. As cradle rotation proceeds, the cutter blades will progressively cut the space between two teeth until the cutter has left the work. The work is then retracted in a direction normal to the cradle, the cradle is returned to its original location, the work is indexed and brought back in place, and the process is repeated, cutting each tooth space until the job is completed

In face-hobbing generation indexing is continuous and, therefore, the work does not have to be retracted. Lower production times result, along with a generally better overall surface finish. The cutter blades are arranged in groups, and because of the internal machine gear train, following blade groups cut following tooth spaces, as shown in the figure below.

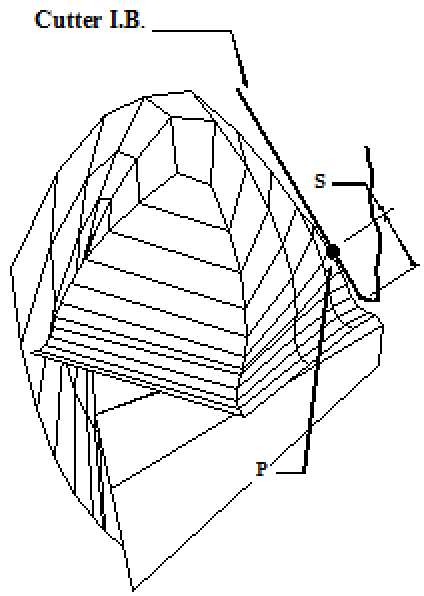


Face Milling **Face Hobbing**

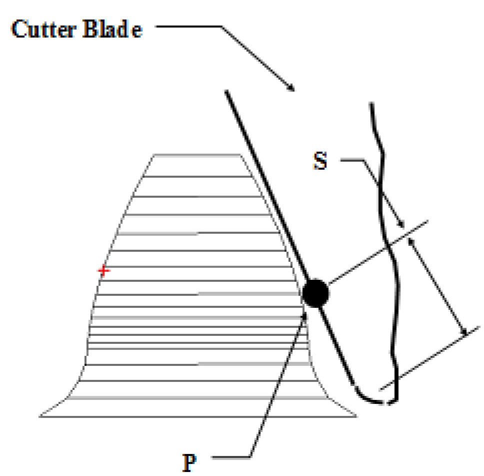
For pinions and gears generated using the Gleason face-milling process, machine setup can essentially be done in several different ways, all of which are supported in HyGEARS:

Spread Blade	where both the convex (I.B., inside blade) and concave (O.B., outside blade) tooth flanks are cut simultaneously; spread blade is normally used for pinion roughing, and for generated gear member roughing and finishing;
Duplex Helical	where both the convex (I.B.) and concave (O.B.) tooth flanks are cut simultaneously; this time, however, an advancing or retracting motion is imposed to the workpiece as generation proceeds; the addition of this helical motion offers more control over the bias of the Contact Pattern;
Fixed Setting	where the convex (I.B.) and concave (O.B.) tooth flanks are cut in two passes, thus on two different machines in a production environment; fixed setting is normally used for pinion finishing and uses cutter tilt;
Modified Roll	where the convex (I.B.) and concave (O.B.) tooth flanks are cut in two passes, thus on two different machines in a production environment; modified roll is normally used for large gear sets on machines that normally do not have cutter tilt.

The following figure shows a generated hypoid pinion tooth. Note the strong tooth profile curvature produced by the generating process. It is clear that the blade shown in the figure below comes in contact only over a small portion of the tooth flank, depending on the feed rate. The location of the blade to profile contact point **P** along the blade edge is **S** as introduced earlier.



The following figure shows a generated spur pinion tooth. Again, note the strong tooth profile curvature produced by the generating process.



Non-Generated Tooth Cutting Process

As the gear member tooth number grows larger, the profile of a generated tooth becomes closer to a straight line. In order to reduce the complexity of cutting machines and production costs by reducing cutting time, it is usual, when the speed ratio of a gear set is above 3.5:1, to cut the gear member without generating movement. This is applicable only to spiral-bevel and hypoid gears.

The non-generating cutting process involves no relative motion between work and machine housing, as shown in the following figure. The machine housing supports a cutter rotating about axis C1, whose angular position is ac. The cutter axis cannot be tilted, and the work does not rotate. Therefore, the cutter blade is in contact with the work over its full depth.

There are two basic variants of the non-generating process, both trademarks of the Gleason Works for face milled teeth: the Formate and Helixform gear cutting processes.

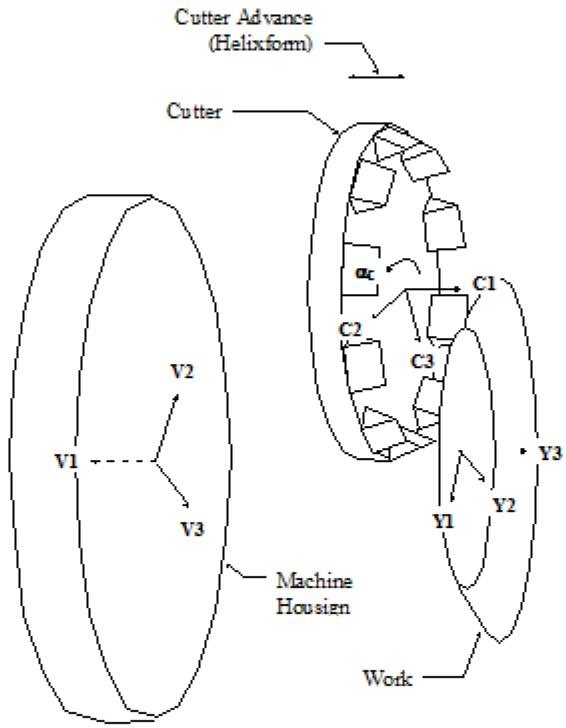
Non-generated gear teeth can also be cut using the face Hobbing process.

In the Formate process, the cutter is parallel to the root angle of the tooth, and cutting proceeds directly. The blade depth and width increase from the first to the last cutter blade, thereby progressively cutting the tooth space. The cutter is then retracted, the work is indexed, the cutter is brought back in place and another tooth space is cut, until all tooth spaces have been cut.

The Helixform process was developed to improve the pinion to gear tooth meshing conditions. Since, in the Gleason Face Milling process, the pinion and gear tooth root angles are not parallel because of the non-constant depth teeth, the teeth are not conjugate and the meshing conditions are those of pseudo-conjugate teeth which result in large Transmission Error that must be compensated by appropriate profile corrections.

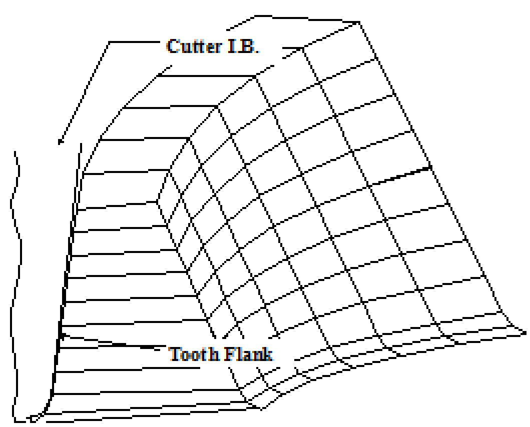
In the Helixform process, the cutter is essentially parallel to the root angle of the pinion (or face angle of the gear), and cutting proceeds while the cutter advances in a direction parallel to its axis of rotation such as to leave a tooth space parallel to the work root angle, but with the gear cutter axis parallel to the pinion cutter axis.

Of course, this is not entirely true when the pinion cutter is tilted. The blade depth and width also increase from the first to the last blade, thereby progressively cutting the tooth space. The cutter is then retracted, work is indexed, the cutter is brought back in place and another tooth space is cut, a sequence repeated until all tooth spaces have been cut.



Helixform gears are normally roughed using a process similar to the non-generated (or Formate) process, where a cutter is plunge fed while rotating.

The following figure shows a non-generated gear tooth. Note the flat tooth profiles produced by the non-generating cutting process. It is clear that the blade shown in the figure below comes in contact with the tooth flank over its full depth.



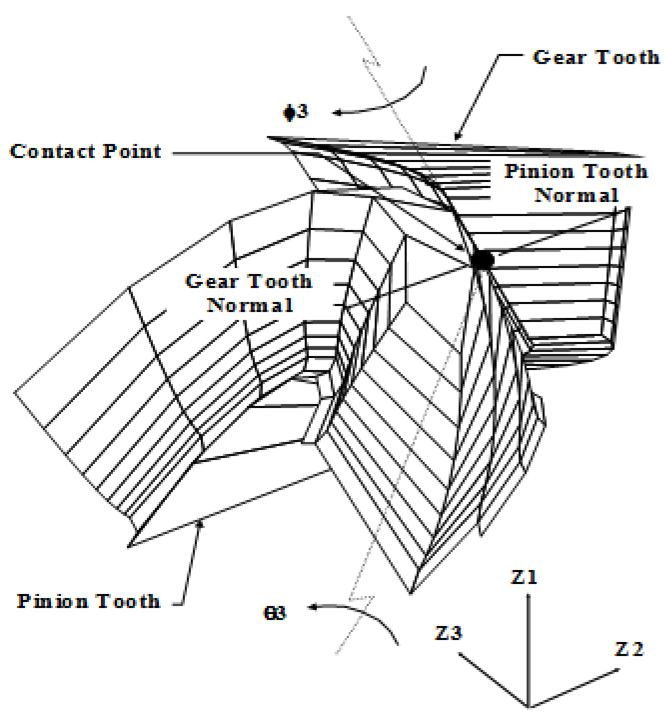
3.3 Tooth Contact Analysis

The simulation of the pinion and gear cutting processes is the basis of Tooth Contact Analysis or TCA, in which the kinematical (or unloaded motion) performance of the tooth surfaces is calculated as a consequence of the machine setups.

Spiral-bevel and hypoid gears are theoretically point-contact surfaces which means that numerically speaking, they make contact in one point only. Of course, as load is applied, the tooth surfaces deform and the theoretical contact point is spread over a much wider area in the form of an ellipse.

Spur, helical and straight bevel gears are rather line-contact surfaces, which means that they make contact along a line extending facewise on the tooth. Any contact line will normally reach each tooth end, but cutting modifications such as lengthwise crowning can be applied and then, the contact line is limited to the central part of the tooth and is therefore less sensitive to alignment and positional errors.

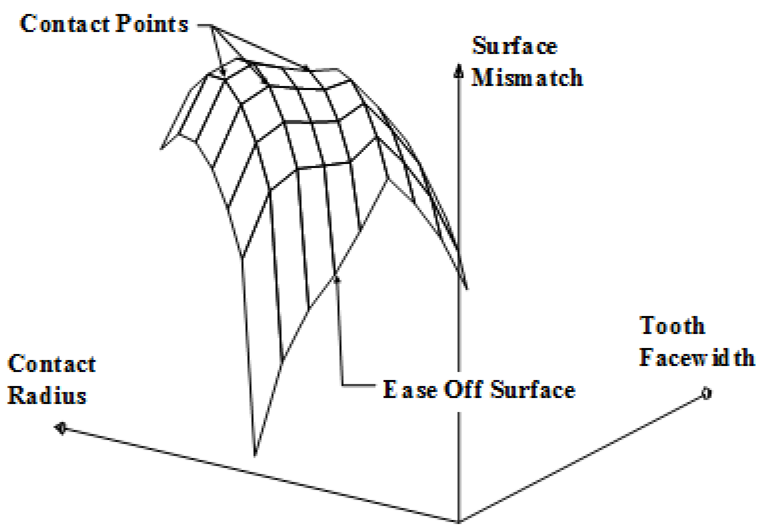
As for any surface, the basic condition for tooth surface contact is that in a general reference frame, such as Z1Z2Z3, a common contact point between the pinion and gear tooth surfaces has the same coordinates and surface normals. This double conditions yields five independent equations which, when solved, give the tooth surface parameters of the contact point and the angular position of the pinion and gear teeth, respectively Θ3 and φ3.



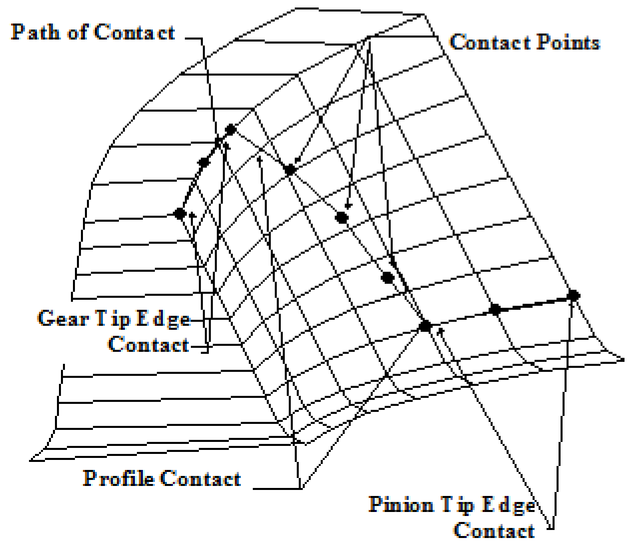
Given the highly non-linear equations needed to simulate the tooth surface cutting processes, the above five equations are solved using a Newton-Raphson based algorithm in which first order derivatives are calculated to produce convergence of the solution.

To enhance the reliability and stability of the numerical solution, the *Ease Off Surface* is calculated, in which the pinion and gear tooth surfaces are scanned to calculate a series of contact points. Each time a contact point is calculated, the separation between the pinion and gear tooth surfaces is also calculated in relation to a given reference point. The theoretical contact point is then the position where tooth to tooth mismatch separation is minimum, which also corresponds to the point where contact normals in the general reference frame are equal.

A series of such theoretical contact points gives the Path of Contact (PoC), litterally the line along which all contact points will lie during the meshing cycle of one tooth pair.



In HyGEARS, the PoC is made of the same number of profilewise points as the teeth on which it is calculated. The number of profilewise points is an editable feature in HyGEARS and while increasing the number of points increases computing time, it also increases the resolution of the PoC and, as will be shown later, the resolution of the Contact Pattern.



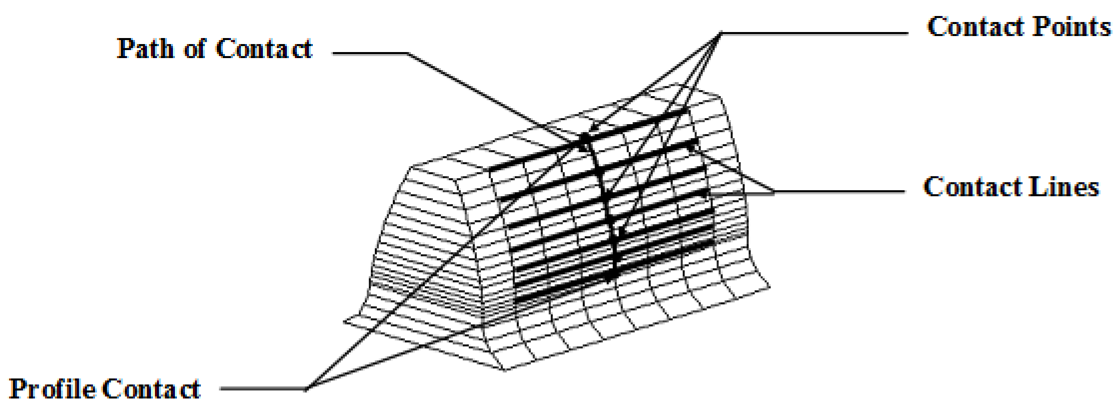
In Zerol, spiral-bevel and hypoid gears, because of the overlapping nature of the teeth caused by the spiral angle, the PoC may be made of up to three parts:

Gear Tip Edge Contact — contact normally starts at the root of the pinion tooth and ends at the root of the gear tooth, along the profile section of the PoC. Gear Tip Edge Contact occurs when the tip of the gear tooth comes in contact with the root of the pinion tooth. Adverse contact conditions are to be expected in this part of the PoC if full load is applied, as the elliptical contact area will be truncated.

Profile Contact — this is the normal area of the tooth where contact should take place under usual operating conditions. Favorable contact conditions are normally found in this part of the PoC.

Pinion Tip Edge Contact — contact normally ends at the tip of the pinion tooth along the profile section of the PoC. Pinion Tip Edge Contact occurs when the tip of the pinion tooth comes in contact with the root of the gear tooth. Adverse contact conditions are also to be expected in this part of the PoC.

In spur, helical and straight bevel gears, the PoC is all profile; however, pinion and gear tip edge contact can still occur, as shown below for a spur gear. Although contact is made along facewise lines on the tooth flank, by convention the PoC is shown at the center of such lines of contact, as shown is the figure below.



The conditions determining whether edge contact will occur or not are best understood using a Transmission Error graph.

Transmission Error is the expression of the difference in the actual, or calculated, and theoretical angular positions of the gear as it is going through mesh, as shown by the following equation:

$$\delta\phi_3 = \phi_3 - \theta_3 m_g$$

in which:

$\delta\varphi 3$	is the gear angular position error, or Transmission Error value,
$\varphi 3$	is the gear calculated angular position error,
$\Theta 3\ m_g$	is the gear theoretical angular position, equal to the product of the pinion angular position times the speed ratio.

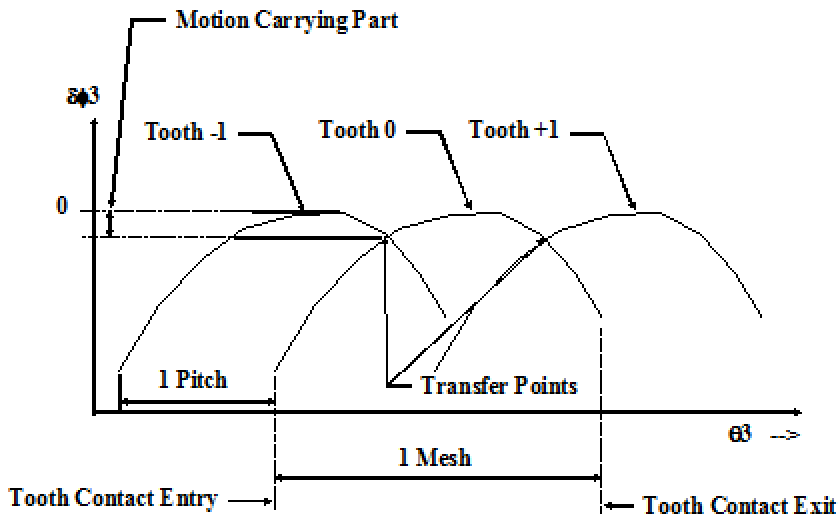
Thus, a negative result for the above equation means that the gear is late relative to the pinion, and therefore will not come into contact prematurely, which is the ideal situation.

In HyGEARS, Transmission Error can be given either in arc-seconds ("), which is 1/3600 , in uRad, in mm or uIn; the latter two are the product of the Transmission Error in uRad by the base radius for cylindrical gears and by the pitch radius of bevel gears.

Transmission Error is usually present in all types of gears, either by the very non-conjugate nature of face milled spiral-bevel and hypoid gears, or by design such as in spur and helical gears where tip edge contact is not desirable either because of the resulting large contact stresses.

Transmission Error is best understood with a Transmission Error graph such as the one below.

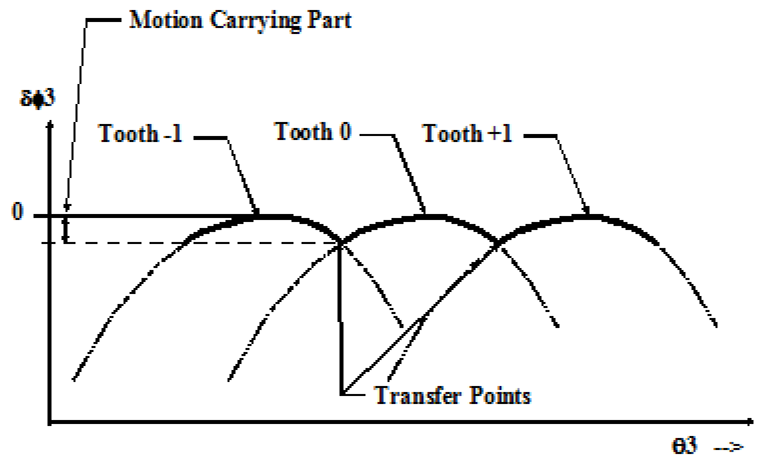
A Transmission Error graph shows the Transmission Error value df3 on the vertical axis and the pinion angular position q3 on the horizontal axis for one meshing tooth pair cycle. The graph below shows the Transmission Error curves of three consecutive meshing tooth pairs, respectively tooth pairs -1, 0 and +1, each separated by one circular pitch.



As shown by the "-->" symbol in the lower right part of the graph, in this graph motion proceeds from left to right, such that tooth pair -1 is leaving contact, tooth pair 0 is the main tooth pair in contact and tooth pair +1 is coming into contact. Therefore, contact starts at the left of a Transmission Error curve, which is the root of a pinion tooth, and ends at the right of the same Transmission Error curve, the root of the gear tooth.

The above Transmission Error curves show a convex shape, with both tooth contact entry and exit approximately at the same Transmission Error level. As contact proceeds on tooth pair -1, it can be seen that the Transmission Error level at contact entry of tooth pair 0 is less than that of tooth pair -1 for the same angular position, which means that tooth pair 0 is late relative to tooth pair -1: therefore, tooth pair -1 is carrying motion.

Motion will thus proceed until the motion transfer point where tooth pair -1 becomes late relative to tooth pair 0, and tooth pair 0 thus becomes the motion carrying tooth pair until the next motion transfer point, where tooth pair +1 will start carrying motion, and so on. The graph below shows the motion transmission envelope resulting from the Transmission Error curves presented above, where it is now clear that each tooth pair carries motion only part of the time.



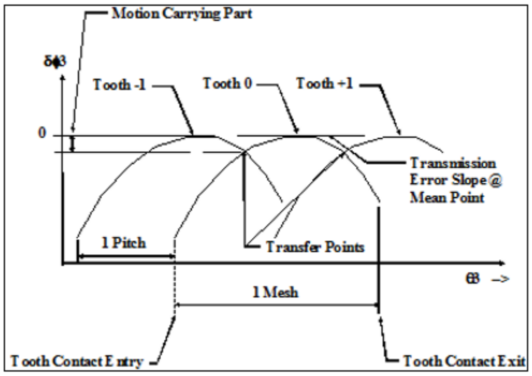
Of course, in the above scheme, it is assumed that all tooth pairs are identical, that there is no out of round or wobbling of either gear set member and that no load is applied to the gear set. In HyGEARS, it is possible to interactively modify the pinion machine settings until the Transmission Error curve is satisfactory.

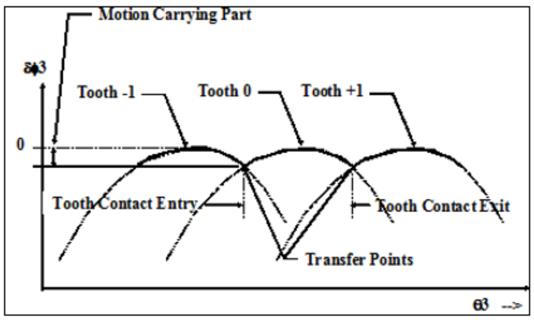
Obviously, the above example is also the goal to reach in the profile synthesis of any gear set as motion is transferred smoothly from one tooth pair to the next, without ever reaching either pinion or gear tooth tip as the motion carrying part of the Transmission Error curves above the transfer points clearly indicates. The next section will introduce various Transmission Error curve types, and the Contact Patterns they produce.

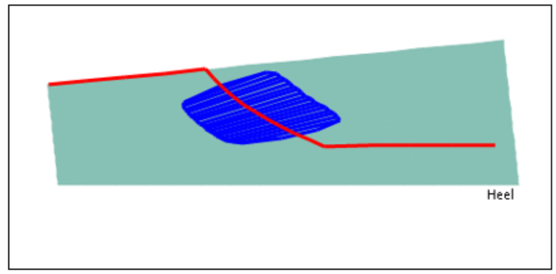
3.3.1 Well Centered Contact Pattern

Because any tooth pair carries motion only over the center part of the Transmission Error curves shown below, where the slope of the curve is nearly horizontal, the resulting Contact Pattern is well centered profilewise on the tooth flank. The Transmission Error level at which the transfer points should be located is highly dependent on the behavior of the gear set under load, as the kinematic Transmission Error curves shown here will change substantially under load.

Contact Patterns are best observed on the gear teeth as they are less curved than pinion teeth.





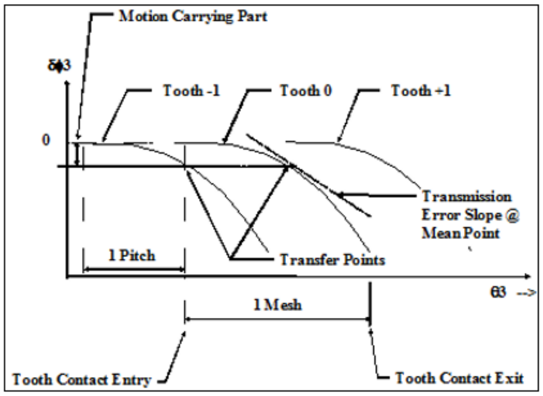


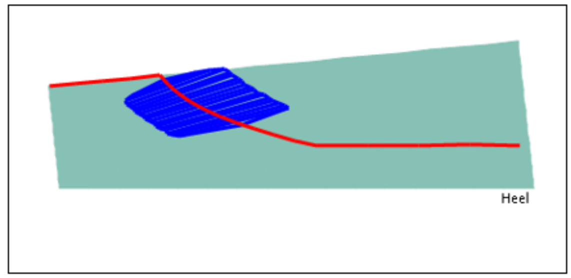
3.3.2 High Tooth Flank Contact Pattern

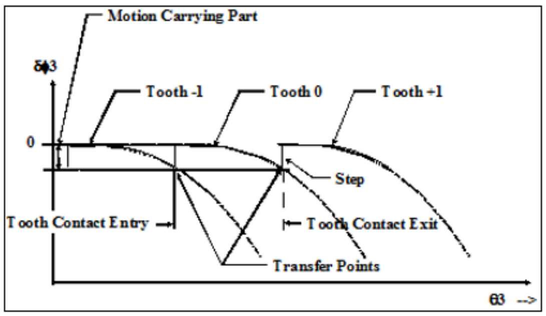
The slope of the following Transmission Error curves at the mean point is negative, such that each tooth pair starts carrying motion from contact entry at the pinion tooth root until the next tooth pair is faster than the carrying tooth pair, when motion is transferred abruptly in stepwise fashion.

Clearly, this Contact Pattern type is to be avoided since the gear tooth tip will be highly loaded at contact entry, the abrupt motion transfer from one tooth pair to the next may induce dynamic loads, and since pinion tooth root contact stresses are usually the largest over the tooth meshing cycle, a high Contact Pattern on the gear tooth flank indicates that most motion carrying is occurring at the pinion tooth root where contact stresses will be higher than necessary.

Under load, gear tip edge contact is more likely to occur than if the Contact Pattern is well centered, as shown in the first example.





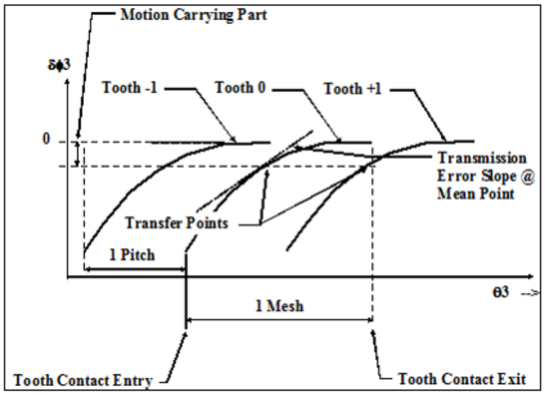


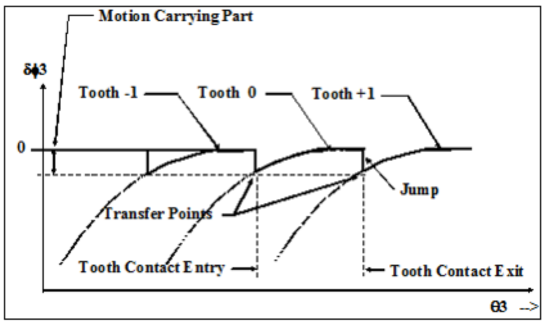
3.3.3 Low Tooth Flank Contact Pattern

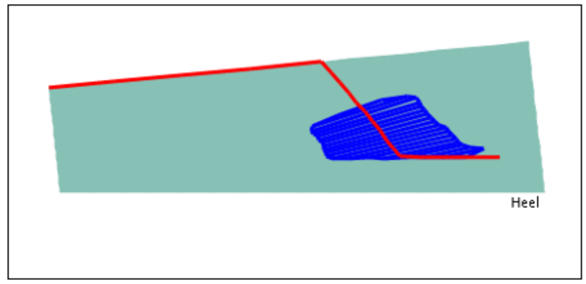
The slope of the following Transmission Error curves at the mean point is positive, such that each tooth pair starts carrying motion from about mid-mesh, until contact exit at the pinion toot tip, when the next tooth pair is faster than the carrying tooth pair. Motion is then transferred in a jump-wise fashion.

This type of Contact Pattern is also to be avoided since the pinion tooth tip will be highly loaded and the jump-wise motion transfer from one tooth pair to the next may induce dynamic loads.

Under load, pinion tip edge contact is more likely to occur than if the Contact Pattern is well centered, as shown in the first example.



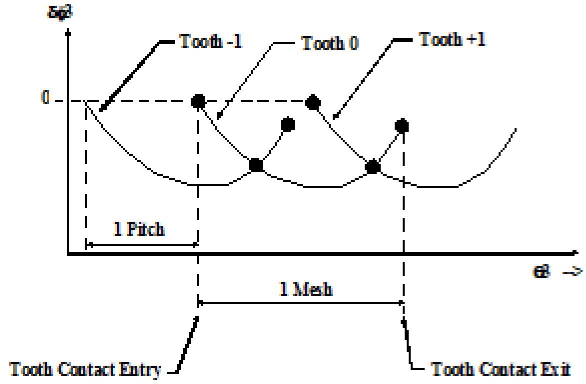


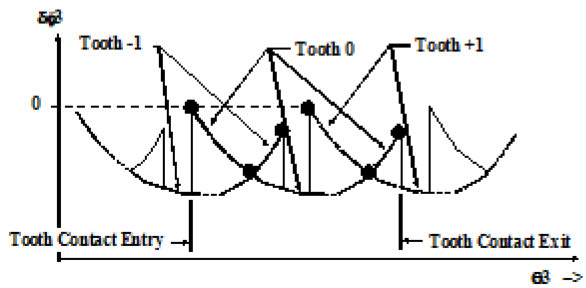


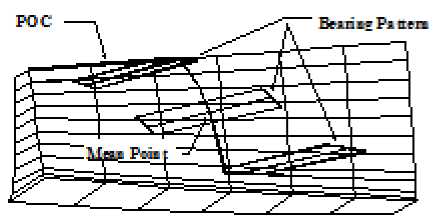
3.3.4 Bridged Contact Pattern

Bridged Contact Patterns occur when the Transmission Error curve presents a concave shape instead of a convex shape. Under such conditions, as is shown by the black dots representing the motion transfer points in the Transmission Error figure below, suppose motion is carried by tooth pair 0; it is then transferred to tooth pair -1 as it is faster than tooth pair 0; then, tooth pair 0 again carries motion until tooth pair +1 becomes faster than tooth pair 0, and the process is repeated. The Contact Pattern will therefore be made of three distinct parts, as shown in the bottom figure below.

This Contact Pattern type is also to be avoided since motion is shuttling back and forth from one tooth pair to another, contact starts at the root of the pinion tooth and ends at the root of the gear tooth, and pinion and gear tip edge contact are likely to occur under load.







3.4 Loaded Tooth Contact Analysis

The Transmission Error curves and Contact Patterns are used to evaluate the behavior of the gear set under no load or a very light load. For example, making Contact Pattern tests under a very light load is customary in the development and production control of Spiral-Bevel and Hypoid gears.

In HyGEARS, it is also possible to evaluate the behavior of a gear set under load, such as the loaded Transmission Error and the loaded Contact Pattern which will give the extent of the tooth flank that will come in contact under a given load. Such an analysis is called the Loaded Tooth Contact Analysis, or LTCA.

In the LTCA, the meshing tooth pairs are analyzed to calculate how the applied torque is shared between them. As a consequence, it is possible to estimate what the Contact Pattern will be once the actual load carried by a given tooth pair is known.

Knowing the tooth load carried by each tooth pair as it is going through mesh, the contact deformation and the minor and major axes of the contact ellipse are easily calculated using Hertz' theory. Then, the algorithm used to calculate the Contact Pattern under a very light load, with a constant separation equal to that of a marking compound, is used except that the pinion and gear tooth surfaces separation is now based on the contact deformation calculated from Hertz' theory.

This yields an estimate of what the Contact Pattern is likely to be under a given load. Note that in this calculation, no provision is made for the bearing and gearbox housing stiffnesses, and while tooth bending stiffness is calculated and used to estimate how the load is shared between consecutive tooth pairs, there is no provision at this point whether bending deformation is large enough to change the position of a contact point.

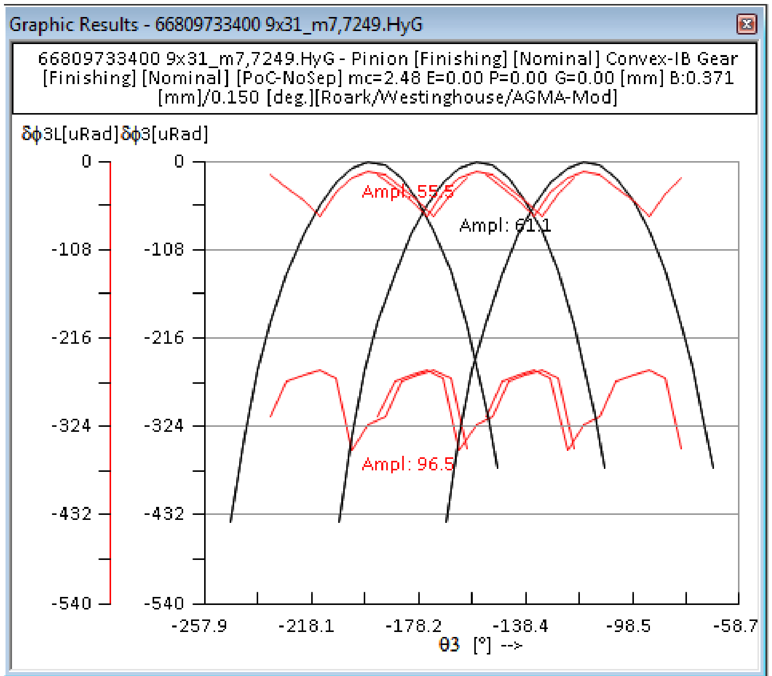
Tooth bending stiffness is calculated from the actual tooth dimensions applied to the Westinghouse or Nakada formulae or using the Finite Strips.

The figure below illustrates the shape of LTCA Transmission Error curves relative to the kinematic, or TCA, Transmission Error curve.

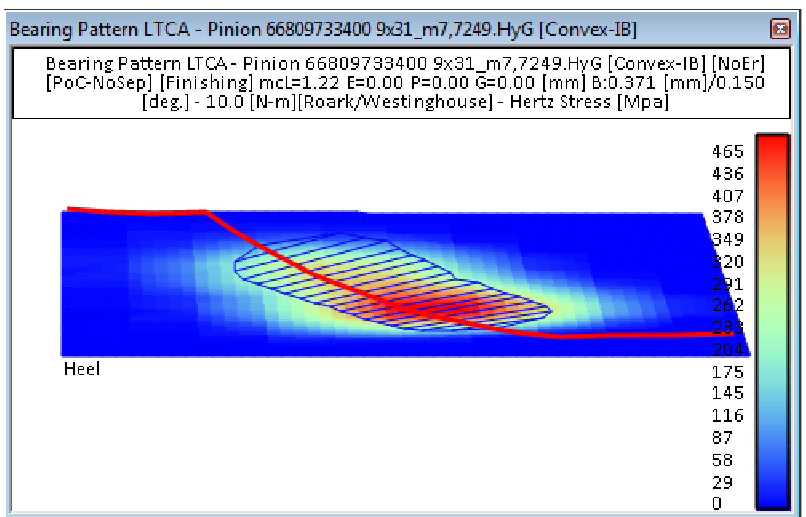
Basically, as load is applied, teeth bend and deform such that an increased pinion rotation is obtained. Therefore, the result of the Transmission Error formula presented in the TCA sections will tend to increase negatively.

As load increases, a larger portion of the tooth comes in contact since the tooth separation shown as Transmission Error is progressively taken up by tooth bending and contact deformation.

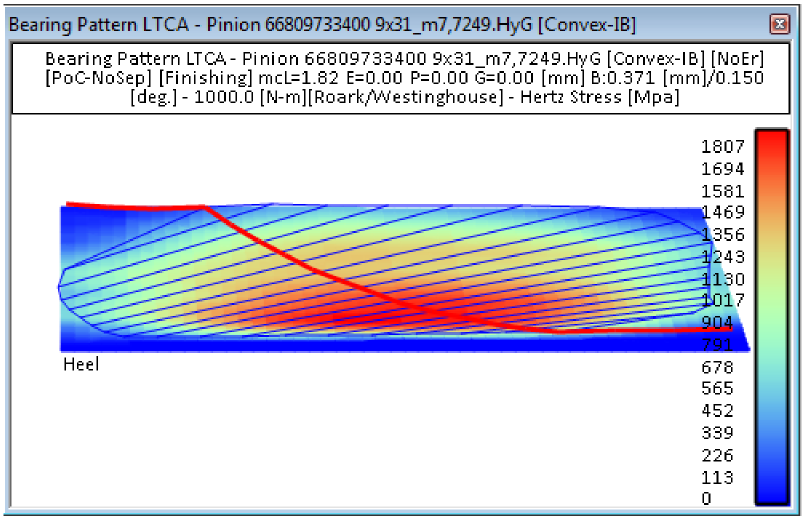
The two LTCA curves shown below have been calculated for a gear set carrying respectively 10 [N-m] (upper red curve) and 1000 [N-m] (lower red curve).



The 10 [N-m] LTCA TE curve is well above the TCA TE end values (at the pinion tooth root and tip), which means that some parts of the tooth are not in contact. This is reflected in a Contact Pattern which covers only part of the tooth flank as shown below.



When torque is increased to 1000 [N-m], the LTCA TE curve is barely above the TCA TE end values (at the pinion tooth root and tip), which means that most of the tooth flank is in contact. Increasing the load spreads the Contact Pattern over the tooth flank. This is reflected in the Contact Pattern which fully covers the PoC on the tooth flank as shown below, and a Contact Pattern which is wider than that for a 10 [N-m] torque.



From the above data, the following observations can be made:

- as torque increases, the LTCA Transmission Error curve flattens in certain areas while it curves deeper in other areas, which is caused by the combination of unloaded Transmission Error curve shape and amplitude, and tooth mesh stiffness;
- the LTCA Transmission Error curve of a gear set can be almost completely flattened out at a given torque, which would result in very smooth operation; however, the flattening of the LTCA Transmission Error curve is likely to occur at only one torque level. Therefore, at design time, one should aim for this torque level to be as close as possible to the torque at which the gear set will be submitted most of the time, while checking that at the other torque levels, behavior is acceptable;
- it is well recognized that the dynamic behavior of gear sets is strongly linked to the Transmission Error curve at any applied load; it is therefore desirable to try to minimize loaded Transmission Error as much as possible, although this is not possible over the full torque range;
- the progressive downward translation of the LTCA curve as torque is increased has no influence on the motion transmission quality of the gear set, but is rather an indication of the overall rotation the gear is submitted to because of the applied torque;
- contact entry and exit loads should be as small as possible in order to avoid large contact stresses in the area of the tooth profiles where the contacting surfaces relative curvature is highest at pinion and gear tooth root;
- bending and contact stresses should be considered at the highest torque levels to ensure that the teeth will have sufficient capacity.

3.5 General Design Guidelines

What makes the difference between a good gear set and a bad one ? Many factors indeed, but the two main ones are:

- quietness of operation,
- reliability and long life,

both of which are linked to Transmission Error and Contact Pattern.

Globally, the following goals should be kept in mind when designing a Spiral-Bevel or Hypoid gear set:

- the Contact Pattern should cover about 30 to 40% of the gear tooth facewidth in order to properly spread out the applied torque;

- the Contact Pattern should be well centered profilewise, which implies that the TCA Transmission Error curve is convex and that there is sufficient contact ratio;

- the TCA curve should provide adequate relief at the transfer points to accommodate tooth profile, thickness and spacing errors;

- the Contact Pattern should remain within tooth boundaries under the expected gear set V and H positional errors;

- pinion and gear TCA (unloaded) tip edge contact is to be avoided under normal operation, e.g. under the expected gear set V and H positional errors;

- the LTCA Transmission Error curve should be as flat as possible at the torque level where the gear set is expected to operate most of the time, thereby ensuring low noise levels;

- under load, contact entry and exit contact stresses should be as low as possible in order to limit wear and scoring in those highly solicited tooth flank areas;

- tooth contact and bending strength should be adequate under the highest operating torque, including adequate application factors;

- ensure that the PoC along the fillet portion of the tooth, on the pinion and gear, has sufficient clearance.

4 Corrective Machine Settings (Closed Loop) and The HyGEARS Surface Matching Algorithm

One of the more important applications of a simulation software such as HyGEARS is the calculation of Corrective Machine Settings (Closed Loop), used to bring the machined tooth surface as close as possible to the design, or simulated, target tooth surface.

In order to reach this goal, HyGEARS uses a Surface Matching algorithm where the simulated tooth surface is matched to the measured tooth surface. The changes in machine settings needed to match the surfaces can either be added to the original machine settings, which is called Surface Matching where the simulated tooth surface corresponds to the closest simulation estimate of the actual tooth surface, or subtracted from the original machine settings, what is called Corrective Machine Settings (Closed Loop) where the machined tooth surface is modified to match the simulated tooth surface.

The following sections explain briefly the way such calculations are performed in HyGEARS.

Error Surface Sensitivity to Machine Setting Changes

Traditionally in the gearing industry, changes to tooth surface Geometry have relied on proportional changes coefficients that may be found at the end of a gear set Summary, from The Gleason Works for example, which are based on the differential tooth surface Geometry at the mean point and on the blank Geometry. Such changes are normally applied to the pinion finishing process, as it is usually cut in Fixed Setting mode and the convex and concave tooth flanks may be treated separately.

Proportional changes may be used in the Contact Pattern development process, where the pinion finishing machine settings are progressively modified until a satisfactory Contact Pattern is obtained, by converting the V-H test values into equivalent changes on the pinion tooth surface.

The Surface Matching method presented here relies on the global response of the Error Surface, that is the difference between the simulated and measured tooth surfaces, to changes in machine settings. Therefore, this section will show how an Error Surface may respond to such changes, and global trends will be established.

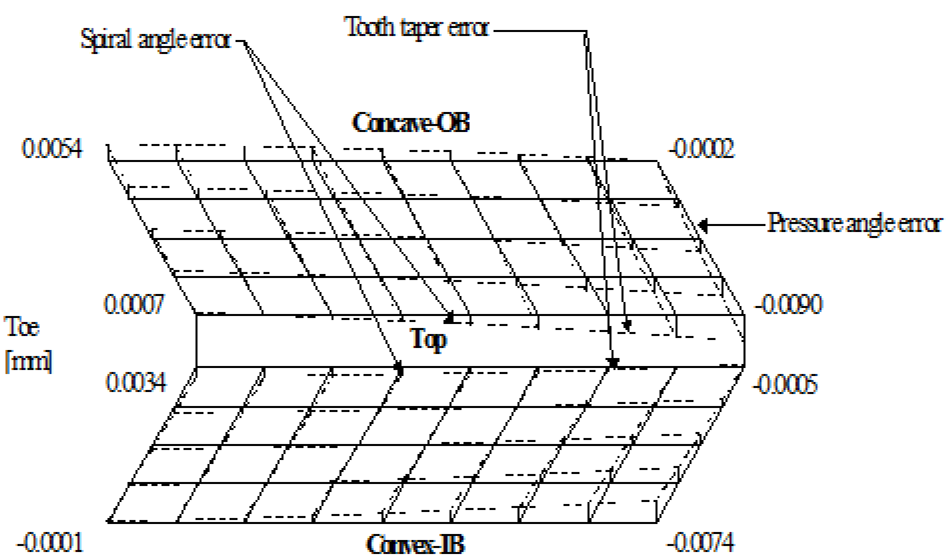
In order to demonstrate the sensitivity of the Error Surface to changes in machine settings, a theoretical measurement datafile is created, which contains a 5x9 grid of the pinion convex and concave tooth flank coordinates. When compared to the theoretical tooth flank without machine setting changes, the Error Surface shows no error, as on the convex tooth flank of the following figures.

The following figures use the same basic measurement datafile, except that the concave tooth flank data is changed to reflect tooth flank topography modifications due to changes in machine settings. The seven following machine settings are modified separately to show how the tooth flank is affected: Machine Root Angle, Spiral Angle, Cutter Tilt, Cutter Point Diameter, Work Offset, Machine center to back and Decimal Ratio. For each machine setting change, the Error Surface is recalculated and the global trends are identified.

The three following figures show what are called 1st order changes, e.g. with minimal curvature or surface twist changes.

Machine Root Angle

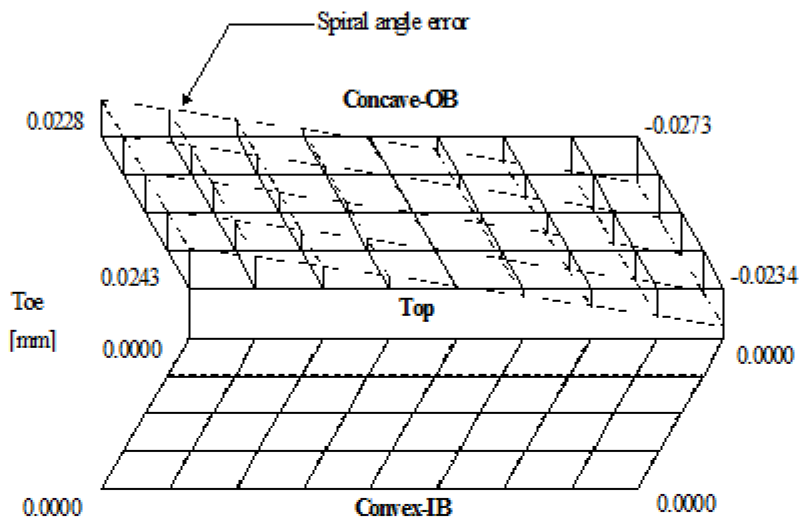
In the figure below, the machine root angle of the concave and convex tooth flanks is changed by 5'; the resulting Error Surface is a combination of spiral angle error on both tooth flanks, tooth taper error which is a difference in spiral angle error between the IB and OB tooth flanks, spiral and pressure angle errors and slight surface twist or bias. Therefore, the machine root angle could be used very effectively to control tooth taper or pressure angle errors in Spread Blade, Formate and Helixform cutting processes, at the expense of other surface changes. In the Helixform cutting process, changing cutter lead produces similar results.



5' Machine root angle change

Spiral Angle

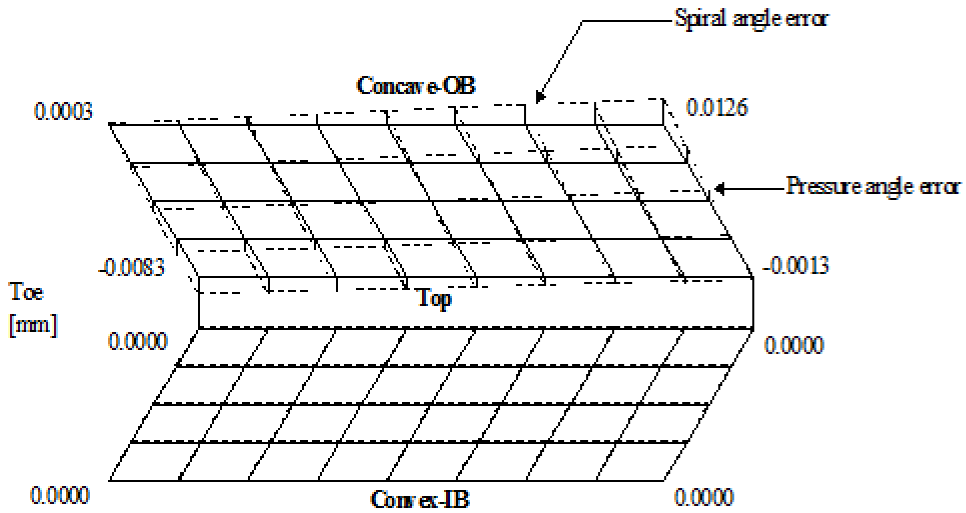
In the following figure, a 5’ spiral angle change is seen to simply produce a spiral angle error; thus the spiral angle will be the chosen parameter to control spiral angle errors. Since in classical generators the spiral angle is controlled by an eccentric mechanism, a change in spiral angle will result in changes in eccentric, cradle and swivel angles. In Hypoid pinions meshing with non-generated gear members, however, a change in spiral angle must be compensated by changes in machine root angle to maintain tooth rootline parallelism, and sliding base for tooth depth.



5’ Spiral angle change

Cutter Tilt

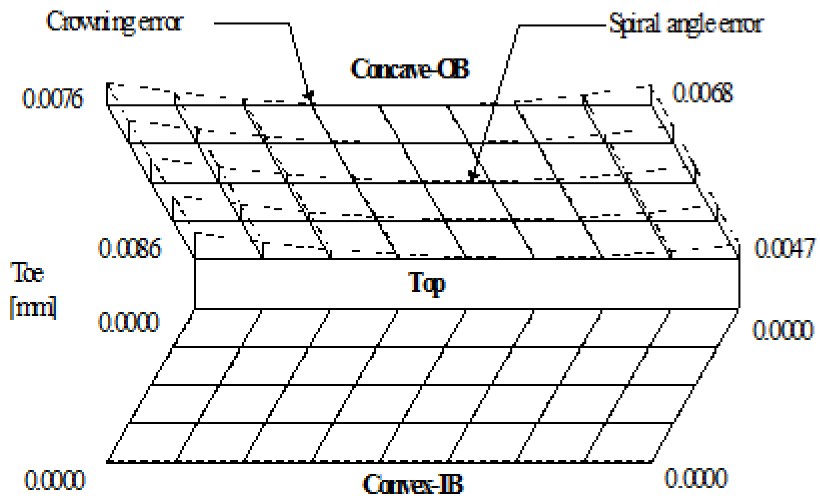
A 5’ cutter tilt change, next figure, produces a combination of spiral and pressure angle errors. In classical generators, cutter tilt is produced by the cutter spindle, a tilted plane which, when rotated, increases or decreases the cutter tilt. Cutter spindle rotation must be compensated by cutter swivel to maintain the orientation of the cutter tilt axis relative to the tooth mean point, while sliding base is used to maintain tooth depth.



5' Cutter tilt angle change

Cutter Diameter

A 0.010 [in] cutter point diameter change, below, produces a lengthwise crowning error combined to a slight spiral angle error. While cutter diameter change produces both crowning and slight spiral angle errors, broadly speaking it can be thought of as a 1st order change since the change in curvature is proportionnal to the change in cutter diameter. If the cutter is tilted, as is usually the case for pinions, the change in cutter tilt requires a change in sliding base to maintain tooth depth. However, cutter diameter change is not usually a parameter of choice to control the tooth lengthwise crowning error as cutter diameter adjustment is a lengthy process. Therefore, another parameter or combination of parameters is needed.

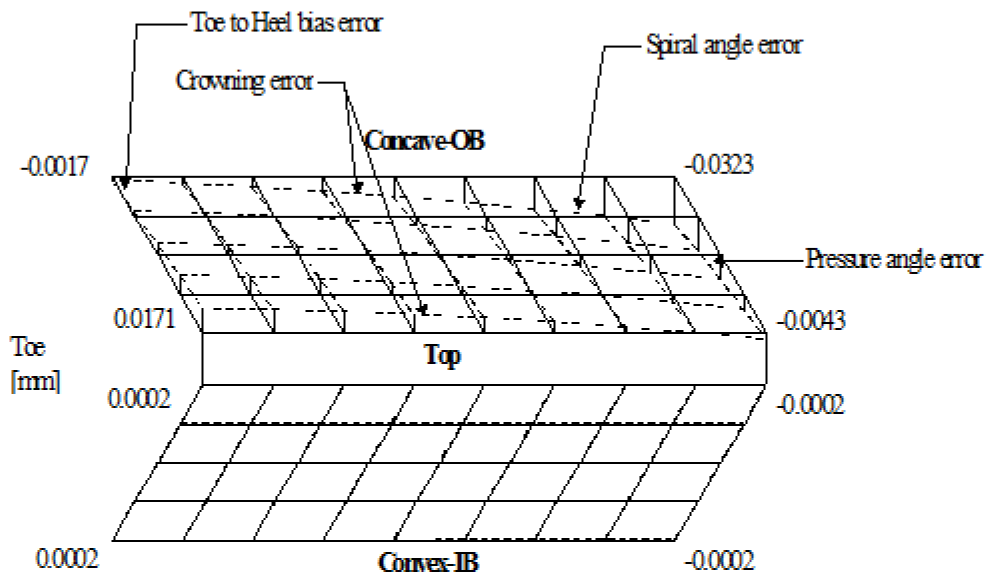


0.010 [in] Cutter diameter change

The next three figures show 2nd order changes, which usually include a combination of lengthwise crowning, surface twist or bias, spiral angle and pressure angle errors.

Work Offset

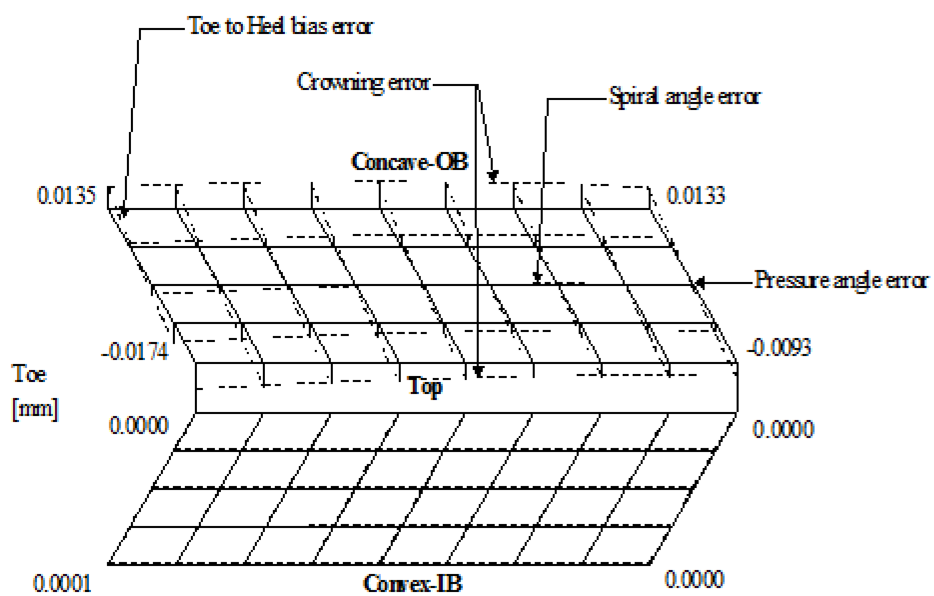
For example, a 0.200 [mm] work Offset change, in the following figure, produces a combination of tooth surface bias, spiral angle, lengthwise crowning and pressure angle errors.



0.200 [mm] Offset change

Machine Center to Back

Similarly, 0.200 [mm] work Machine center to back change, below, results in a combination of tooth surface bias, spiral angle, lengthwise crowning and pressure angle errors, but opposed to those produced by work Offset of the same sign.

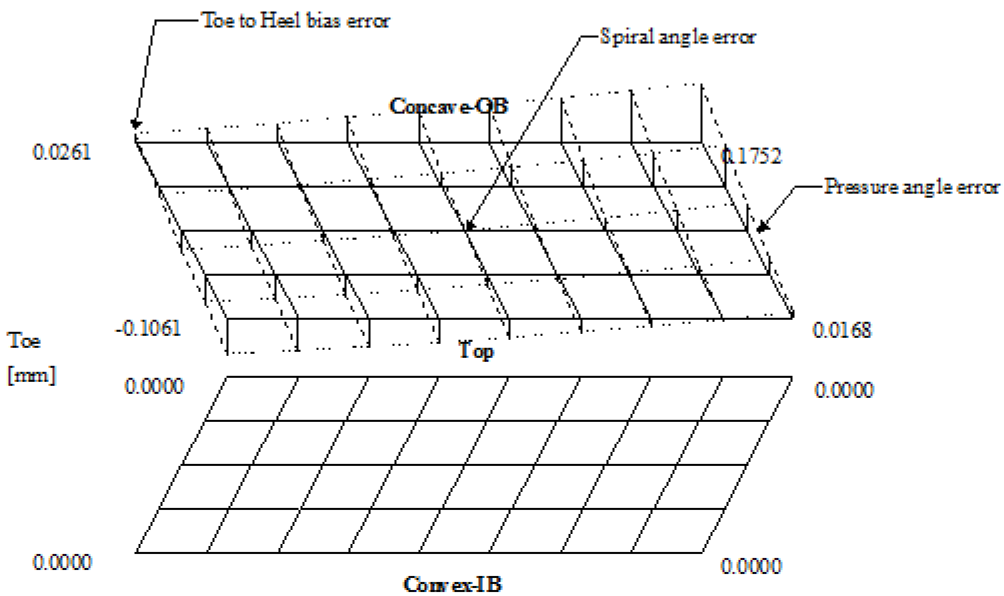


0.200 [mm] Machine center to back change

When work Machine center to back or Offset is changed, the spiral and pressure angles at the mean point are also changed and must be compensated properly by modifications of the machine settings controlling spiral and pressure angle errors.

Decimal Ratio (or Ratio of Roll)

Finally, the effect of a 1% change in Decimal Ratio is shown in the figure below where bias, pressure and spiral angle errors were induced. The amplitude of both the pressure and spiral angle errors is to be noted, while induced bias is slight when compared to a change in Offset.



1% Decimal Ratio change

Summary

From the above, the following conclusions are drawn:

- spiral angle errors are effectively controlled by a change in spiral angle;
- pressure angle errors are effectively controlled by a change in cutter tilt for generated gear pairs, or a change in swivel angle for Formate and Helixform gear pairs, with a spiral angle error side effect;
- lengthwise crowning errors are best corrected by a change in cutter point diameter, but since this is difficult to apply in practice, Offset or Machine center

to back changes can be used at the expense of induced pressure angle, spiral angle and tooth bias errors;

- tooth surface bias errors can be compensated by either Offset, Machine center to back or Decimal Ratio, an Offset change being the most effective.

Therefore, depending whether 1st or 2nd order changes are desired, a combination of the above parameters will be used. Obviously, while 1st order changes appear quite predictable, 2nd order changes include such surface error combinations and side effects that the result can hardly be predicted without using a general computer based numerical solution.

In order to quantify the quality of a tooth surface, the following values are defined:

- average pressure angle error:

$$\Phi = \frac{\sum_{col=1}^{j} \frac{\left[\sum_{row=1}^{i} \frac{\varepsilon_{i,j} - \varepsilon_{1,j}}{y_{i,j} - y_{1,j}} \right]}{i}}{j} \tag{1 a}$$

- average spiral angle error:

$$\Psi = \frac{\sum_{row=1}^{i} \frac{\left[\sum_{col=1}^{j} \frac{\varepsilon_{i,j} - \varepsilon_{i,1}}{x_{i,j} - x_{i,1}} \right]}{j}}{i} \tag{1 b}$$

- average crowning error:

$$\Xi = \frac{\sum_{row=1}^{i} \frac{(2\varepsilon_{i,mid} - (\varepsilon_{i,1} + \varepsilon_{i,j}))}{2}}{i} \tag{1 c}$$

- average profile curvature error:

$$\xi = \frac{\sum_{col=1}^{j} \frac{(2\varepsilon_{mid,j} - (\varepsilon_{1,j} + \varepsilon_{i,j}))}{2}}{j} \tag{1 d}$$

- bias error:

$$\zeta = \Phi_1 - \Phi_j \tag{1 e}$$

where:

i is the index of row measurement data, along the tooth flank;

j is the index of column measurement data, across the tooth flank;
mid is the index of the mid-column or mid-row measurement data;
$e_{i,j}$ is the error value at point ij of the measurement grid;
$x_{i,j}$ is the distance between measurement points along the tooth flank;
$y_{i,j}$ is the distance between measurement points across the tooth flank.

Equations 1 a) to e) are used to quantify the precision of a measured surface in relation to a theoretical reference. Whenever the theoretical reference is changed, the Error Surface is altered and the above defined quantities are modified accordingly.

Numerical Solution

The objective of this section is to find a combination of machine settings that will match the theoretical tooth surface to the measured surface, such that the theoretical tooth surface is technologically equivalent to the measured surface.

As shown in the preceding section, the basic structure of the solution lies in the global interpretation of the Error Surface response in terms of tooth taper, pressure angle, spiral angle, lengthwise crowning and tooth bias errors, to changes in machine settings while maintaining tooth rootline parallelism and depth.

Therefore, the sought algorithm must meet the following objective functions for 1st order errors on pinion members cut by the Fixed Setting method using cutter tilt:

$$\Phi(\tau,\ \kappa,\ SlBase) - T_1 \le L_1 \qquad (2)$$

$$\Psi(\kappa,\ \psi,\ SlBase) - T_2 \le L_2 \qquad (3)$$

where F and Y are the averaged pressure and spiral angle errors, T1 and T2 are the target surface deviations, L1 and L2 are the tolerance ranges within which the objective functions can be considered satisfied, and where the y spiral angle parameter includes the eccentric and cradle angles in a classical generator.

In practice, gear manufacturers can often determine preferred target values Ti representing the deviation between the theoretical and desired tooth surfaces. The target values are therefore included in the general formulation of the objective functions, for example to compensate for heat treatment distortion.

For 2nd order errors on pinion members cut by the Fixed Setting or Modified Roll methods, the following functions must also be satisfied if the tooth lengthwise crowning and bias errors are respectively controlled by work Offset and Machine center to back:

$$\Xi(\tau,\ \kappa,\ \psi,\ SlBase,\ Offset) - T_3 \le L_3 \qquad (4)$$

$$\zeta(\tau, \kappa, \psi, SlBase, Mctb) - T_4 \leq L_4 \tag{5}$$

where X and V are the lengthwise crowing and bias error values.

In practice, Decimal Ratio can also be used for bias errors; thus the following functions could be used instead if the tooth lengthwise crowning and bias errors are respectively controlled by work Machine center to back and Decimal Ratio:

$$\Xi(\tau, \kappa, \psi, SlBase, Mctb) - T_3 \leq L_3 \tag{6}$$

$$\zeta(\tau, \kappa, \psi, SlBase, DRatio) - T_4 \leq L_4 \tag{7}$$

A Newton-Raphson based numerical solution is used to solve the above objective functions. In this solution, the partial derivatives of the objective functions are calculated in relation to the machine setting changes t, k for 1st order errors, plus Mctb and DRatio for 2nd order errors, to produce a Jacobian matrix which, in combination with the sought machine setting changes Dt, Dk for 1st order errors, DMctb and DDRatio for 2nd errors and objective functions (2) and (3) for 1st order errors, plus (6) and (7) for 2nd errors, form the following systems, easily solved using Gaussian elimination:

$$\begin{Bmatrix} \dfrac{\partial\Phi}{\partial\tau} & \dfrac{\partial\Phi}{\partial\kappa} \\ \dfrac{\partial\Psi}{\partial\tau} & \dfrac{\partial\Psi}{\partial\kappa} \end{Bmatrix} \begin{Bmatrix} \Delta\tau \\ \Delta\kappa \end{Bmatrix} = \begin{Bmatrix} -\Phi \\ -\Psi \end{Bmatrix} \tag{8 a}$$

$$\begin{Bmatrix} \frac{\partial\Phi}{\partial\tau} & \frac{\partial\Phi}{\partial\kappa} & \frac{\partial\Phi}{\partial Mctb} & \frac{\partial\Phi}{\partial DRatio} \\ \frac{\partial\Psi}{\partial\tau} & \frac{\partial\Psi}{\partial\kappa} & \frac{\partial\Psi}{\partial Mctb} & \frac{\partial\Psi}{\partial DRatio} \\ \frac{\partial\Xi}{\partial\tau} & \frac{\partial\Xi}{\partial\kappa} & \frac{\partial\Xi}{\partial Mctb} & \frac{\partial\Xi}{\partial DRatio} \\ \frac{\partial\zeta}{\partial\tau} & \frac{\partial\zeta}{\partial\kappa} & \frac{\partial\zeta}{\partial Mctb} & \frac{\partial\zeta}{\partial DRatio} \end{Bmatrix} \begin{Bmatrix} \Delta\tau \\ \Delta\kappa \\ \Delta Mctb \\ \partial DRatio \end{Bmatrix} = \begin{Bmatrix} -\Phi \\ -\Psi \\ -\Xi \\ -\zeta \end{Bmatrix} \quad (8\ b)$$

Equation 8 a) is used for 1st order error correction, while equation 8 b) is used for 2nd order correction. Solution to equation 8 a) is usually obtained in 2 to 3 iterations for 1st order correction while 2nd order equation 8 b), with large lengthwise crowning or bias errors, may take several iterations since the numerical system must be dampened to prevent numerical divergence.

Application to the calculation of Corraective Machine Settings

The Surface Matching algorithm presented above will now be used to define a theoretical pinion member from measurement data, and use this new theoretical as a reference to calculate Corrective Machine Settings (Closed Loop). This is a typical situation which arises when Contact Pattern development is completed, and one needs to define the theoretical tooth flanks in order to be able to apply Corrective Machine Settings (Closed Loop), thus to be able to effectively and efficiently reproduce a master pinion. While only the pinion member is mentioned here, the same approach can be applied to the gear member.

In order to do so, the target tooth flanks of the master pinion are first measured. The Surface Matching algorithm is then applied to find the theoretical machine settings producing a theoretical tooth surface closest to the measured surface.

Next, a pinion is cut from the new theoretical machine settings; it is then measured and from the measurement data, Corrective Machine Settings (Closed Loop) are calculated using the Surface matching algorithm except that the machine setting changes needed to match the theoretical and measured surfaces are subtracted from the original machine settings, assuming that the changes are proportional.

Therefore, it can be expected that the Contact Pattern obtained with the master gear pair can be reproduced rather accurately. However, the following remarks should be kept in mind when applying the above, as manufacturing quality is highly based on the state of the machine and cutter blades:

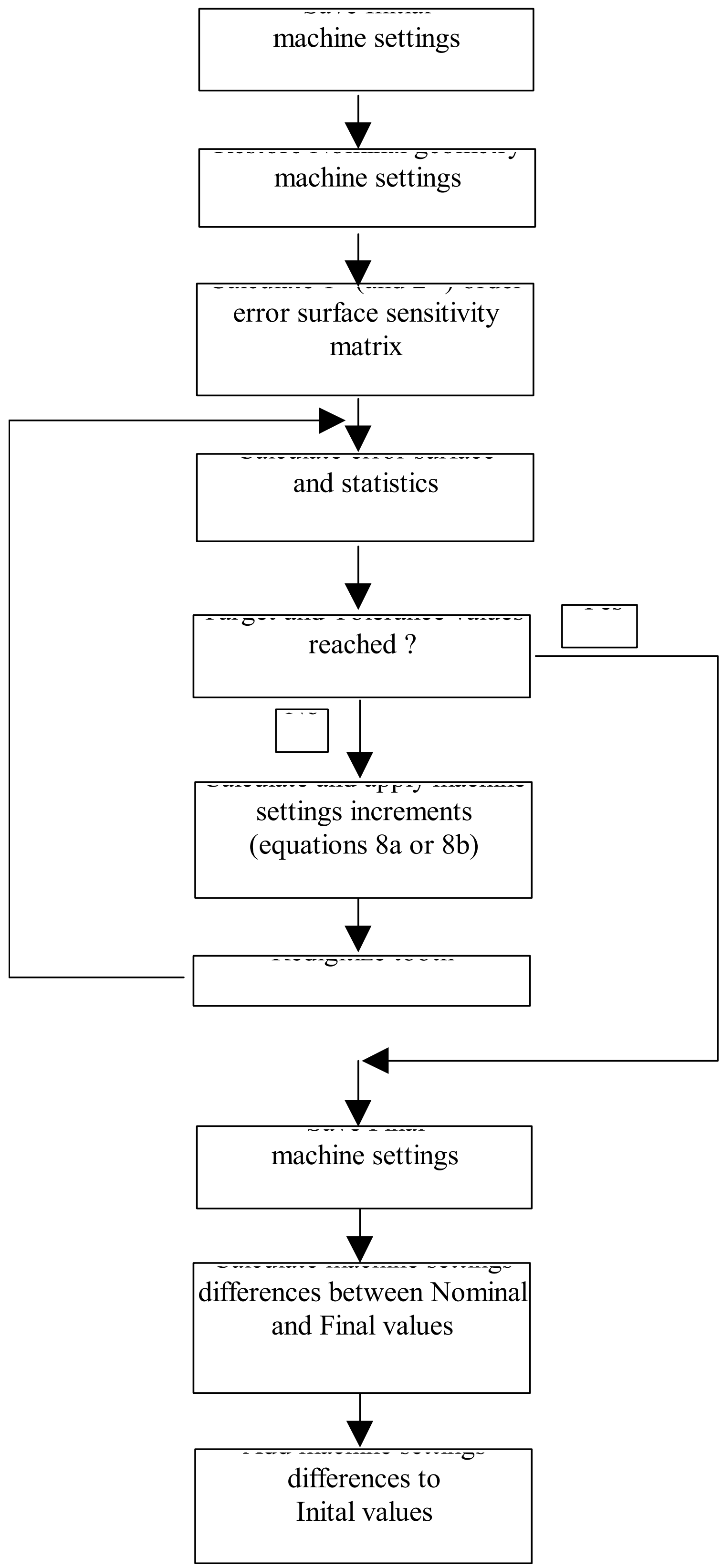
1) the cutter used to cut the reproduced pinion can be different from that used for the master pinion, especially so in the TopRem area of the blade, such that the Contact Pattern will be different;

2) the measurement area used for Surface matching, and then for Corrective Machine Settings (Closed Loop), may not include the TopRem area of the pinion tooth, such that tooth topography in this area may be different which can result in bottom-heavy or top-heavy Contact Patterns, as is the case here;

3) if the TopRem area of the tooth is included in the measurement data, it may produce errors in calculating the Corrective Machine Settings (Closed Loop) if the pressure angle in the TopRem area of the machined tooth is different from that of the simulation; therefore, it is usually preferable to avoid the TopRem area when calculating Corrective Machine Settings (Closed Loop);

4) a tooth flank can show surface waviness which alters the Contact Pattern;

The following figure shows the logic used in calculating Corrective Machine Settings (Closed Loop):


machine settings
machine settings
error surface sensitivity
matrix
and statistics
reached ?
settings increments
(equations 8a or 8b)
machine settings
differences between Nominal
and Final values
differences to
Inital values

5 HyGEARS Graphic User Interface (GUI)

The GUI is the means through which the user and the computer program interact. It provides the user with graphically oriented information at all times, and offers easy access to functions.

This section deals with 5 major topics:

Opening screens upon starting HyGEARS

The Parent Window

The Child Windows

Keyboard combinations in Child Windows

The Text Results Windows

5.1 Opening Screens

When HyGEARS is started, a number of internal verifications and opening steps are performed:

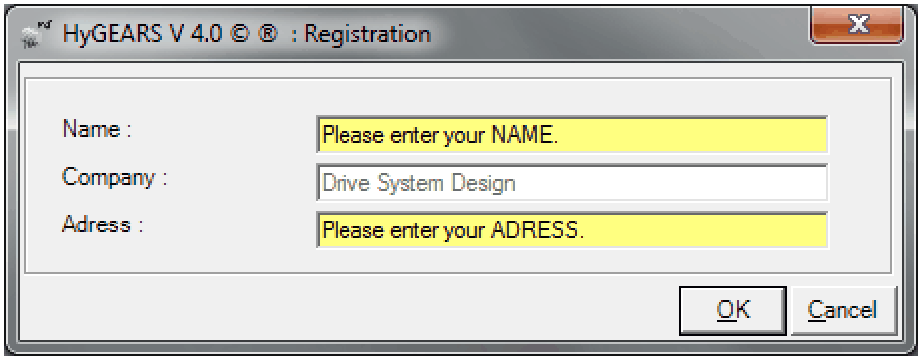
Hardware lock

The very first verification is to make sure that the parallel port hardware security lock has been installed without which HyGEARS will not operate. This security lock is a protection against unauthorized use of HyGEARS.

If this security lock is not present or is the wrong one, a warning message will notify of impending program termination. If at any time during execution of the software the security lock is removed, the same message will appear and HyGEARS will terminate at once.

User Registration

The second verification is to make sure that the user has registered in HyGEARS. This user registration is needed for printed output where the user name, address and company are printed for proper identification. Therefore, the following screen will appear for registration, if not already done. Input fields in yellow must be filled, otherwise HyGEARS *will refuse to run*.

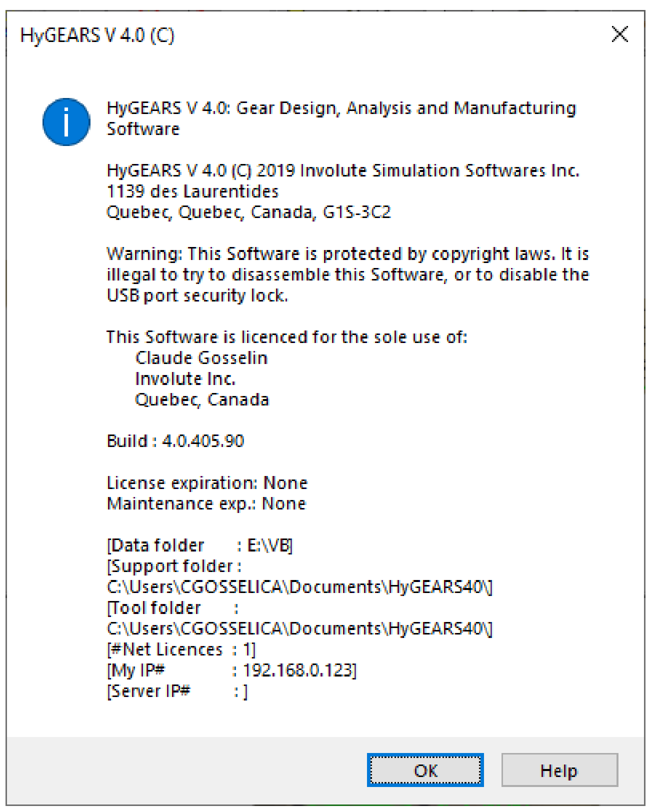


Copyright Notice

The third step is to display the copyright notice. This notice states that HyGEARS is protected by Copyright laws, that it is illegal to copy it, try to disassemble it or attempt to disable the hardware security lock needed to operate HyGEARS and provided at the time of purchase.

To view the copyright notice at any time, simply call the Help->About HyGEARS … menu sequence from the Main Menu window.

To continue with HyGEARS, click on the OK button, or press the keyboard Return key. HyGEARS is now running, and its many features and advantages may be used and enjoyed.



Opening Screen

Each time HyGEARS is started, the following opening screen is shown while HyGEARS sets up its internal registers. Depending on the speed of your computer, the opening screen may be shown from 1 to 3 seconds. Once the internal setup is completed, the opening screen is erased and the Main Menu window is shown.

5.2 Parent Window

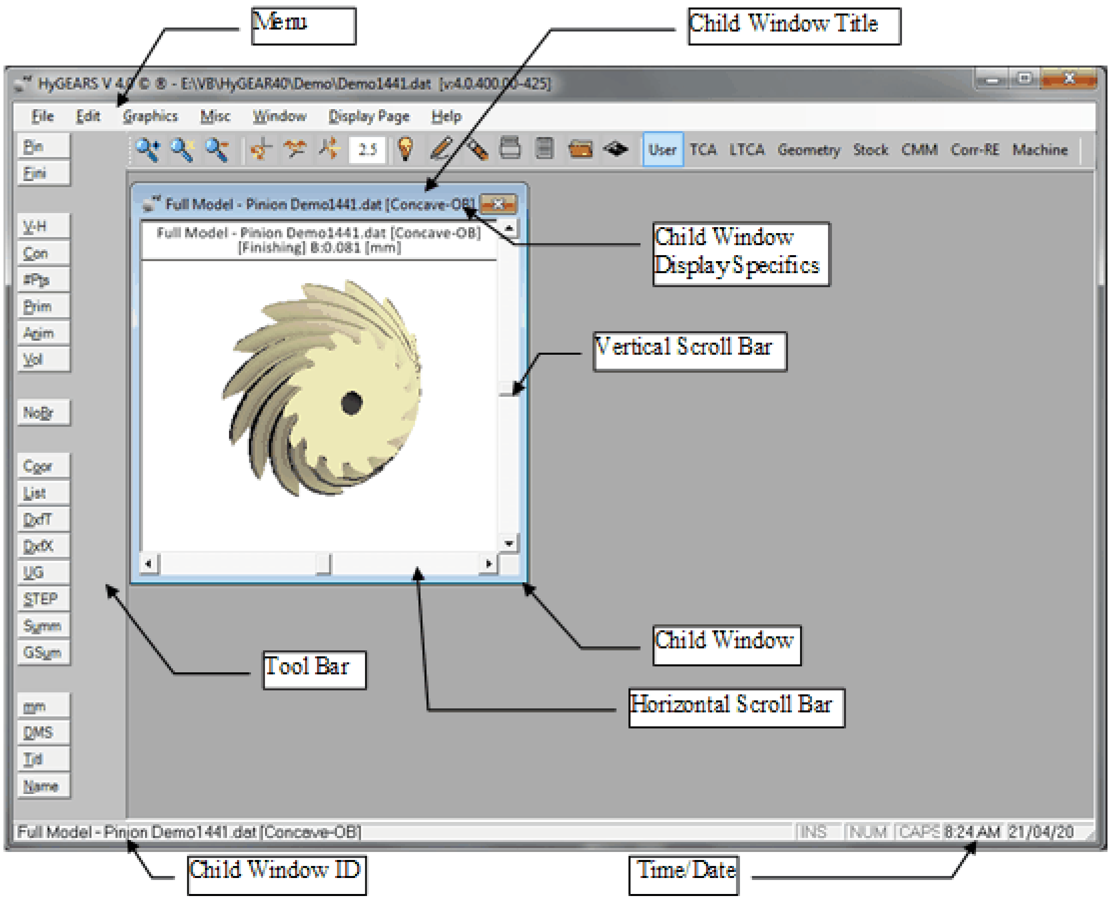
The Parent window is a container for smaller Child Windows, and is automatically created from the moment HyGEARS is started.

- The Child Windows, where the actual graphic display takes place.
- The Tool Bar, where tools specific to each Child Window are offered as push buttons.
- The Menu Area, where menus offer different Child Windows.

When initially created, the Parent window is centered on the screen. It may be moved anywhere on the screen by clicking on its title bar and holding the left mouse button down while dragging the Parent window where desired.

The Parent window size can also be increased in the same way, but by clicking and dragging on any Parent window border.

The following figure illustrates the various Parent window specifics.



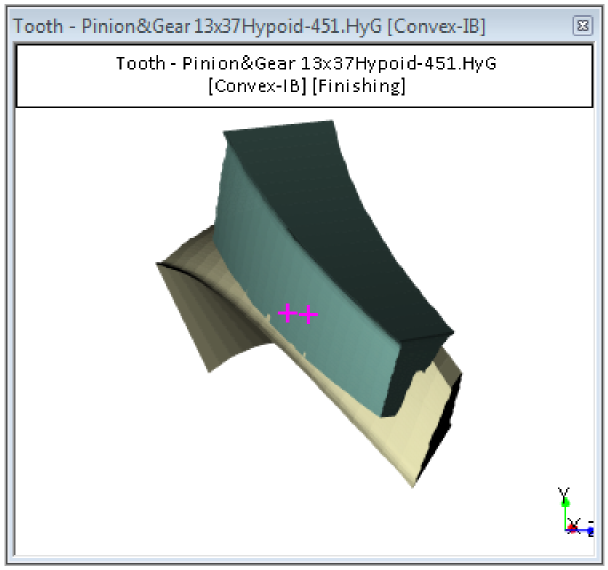
5.3 Child Windows

HyGEARS creates different Child Windows based on the user selected function from the Parent Window pull down menu, or based on the selected Pre-Defined mode. Basically, there are two different Child Window families:

3D where data is displayed in three dimensional form. In this Child Window type, it is possible to look at the display from different viewing angles, change the way lines are hidden or surfaces are drawn, zoom at different levels, etc. The 3D Child Windows include:

Tooth
Blank
Diameter over Balls
Caliper Measurement
Full Model
Cutting Machine
Path of Contact

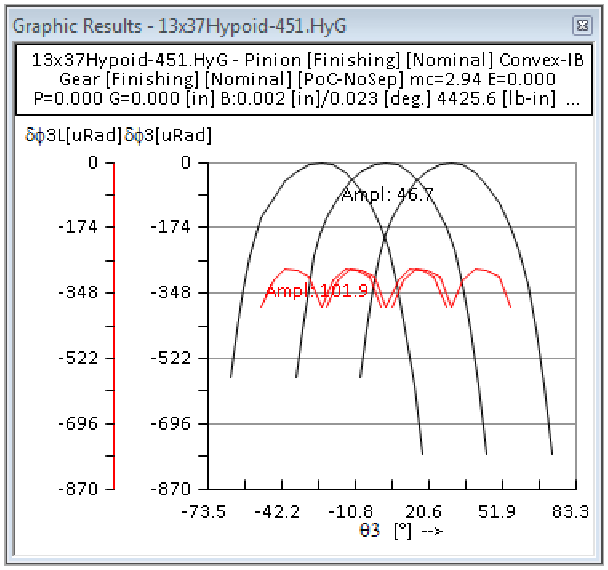
Contact Pattern
Ease Off
FEA Model
Finite Strips
Measured Surfaces
CMM Nominal Data



The 3D Child Window title bar identifies the displayed information (tooth, etc.), whether the Pinion or Gear are displayed, the Geometry data file name and the currently active tooth flank. The 3D Child Window also displays a title at the top of the graphic area reproducing the same (and some additional) information as the Child Window title bar, for easy identification when it is printed.

2D where data is displayed in two dimensional form, although this data is normally of three dimensional nature. The 2D Child Windows include:

Tooth Errors (thickness and pitch)
Comparison of Measured and Simulated Surfaces
Corrective Machine Settings (Closed Loop)
Stock Distribution
Reverse Engineering
Cutter Blade
2D Graphs
Transmission Error-Peak to Valley



The 2D Child Window title bar identifies the displayed information (Graphic Results, etc.), and the Geometry data file name.

The 2D Child Window also displays a title at the top of the graphic area where the information may be more complete than that in the title bar. For example, in the above figure, the 2D Graph title identifies Geometry file name (Demo1441.HyG), the pinion driving tooth flank (Concave-OB), the manufacturing state (Roughing or Finishing) of the pinion and gear, the E-P-G settings of the gear pair, and the pinion RPM (more about this in Chapter 6).

When created, a new Child Window is always presented in a predefined size, which may be increased by stretching the Child Window borders using the mouse, or minimized to an icon. A minimized Child Window is restored to its previous size by a left mouse button click on its maximize button.

The number of simultaneously opened Child Windows is limited either to 20. If any attempt is made to exceed one this limit, a warning message is displayed by HyGEARS and at least one Child Window must be closed in order to allow for the creation of a new one. . A Child Window is closed by a click on the "**X**" button in the Child Window upper right corner, or through the Parent window menu function Window->Close.

Each Child Window may command different actions. For example, a 3D Child Window may be rotated, shaded, or else; therefore, most of the Parent window Tool Bar graphic controls will be visible. On the other hand, a 2D Child Window is static in space, thus the Parent window 3D manipulating Tool Bar graphic controls will be invisible.

Upon creation, a Child Window is linked to the currently active Geometry data file, whose name appears in the Parent Window. Therefore, it is theoretically possible to have 20 Child Windows linked to 20 different Geometry data files if a new Geometry data file is opened before the creation of each Child Window. Since only one Child Window is active at any time, only the data of the active Child Window is in memory.

An automatic disk swapping system is built into HyGEARS to transfer to a temporary disk file the Geometry of inactive Child Windows in order to save their status and make space for the active Child Window data. The active Child Window data is loaded into memory only when needed, which is done either by attempting an action from the Parent window Tool Bar (see next section) or by double clicking on the desired Child Window. The current data will then be swapped to disk, the requested data will be loaded from disk to memory and the Main Menu title bar will reflect the name of the new currently active Geometry data. Different Child Windows linked to the same Geometry data file do not swap, since they share the same memory data. Thus, the Geometry file name attached to each Child Window dictates whether disk swapping will occur or not.

An “*” shown in a Child Window title bar indicates that some of the Geometry data has been modified in another Child Window linked to the same Geometry data file, and that the current Child Window display may not be up to date. A simple redraw command will automatically update the display and erase the “*” from the title bar.

5.4 Keyboard Combinations in Child Windows

To speed some operations, the following keyboard combinations may be used. In the following, the ^ (caret) stands for the “Control” keystroke.

^C copies the display of the current Child Window to the Windows Clipboard,
Shift^C copies the current Child Window to the Windows Clipboard (includes window borders and title bar),
^D for Beveloid gears, Shapers and Skiving tools: toggles the Blank display between the Side and Front views,
^E toggles the current Child Window in and out of the Auto Erase mode,
^F toggles the current tooth flank from Concave to Convex for spiral-bevel and hypoid gears, or from Left to Right for straight-bevel, spur and helical gears,
^G in 5Axis, toggles the "Detect Gouging" option On and Off,
^H cycles through the various possible Hide levels (no, partial, total and rendering) for the current Child Window,
^I, ^+ Zooms In the display by 15%,
^J cycles through the various possible display projections for the current Child Window,
^L toggles On and Off the "Lock on Tool" switch for 5Axis in Machine mode,
^M cycles through the various possible Marker levels for the current Child Window,

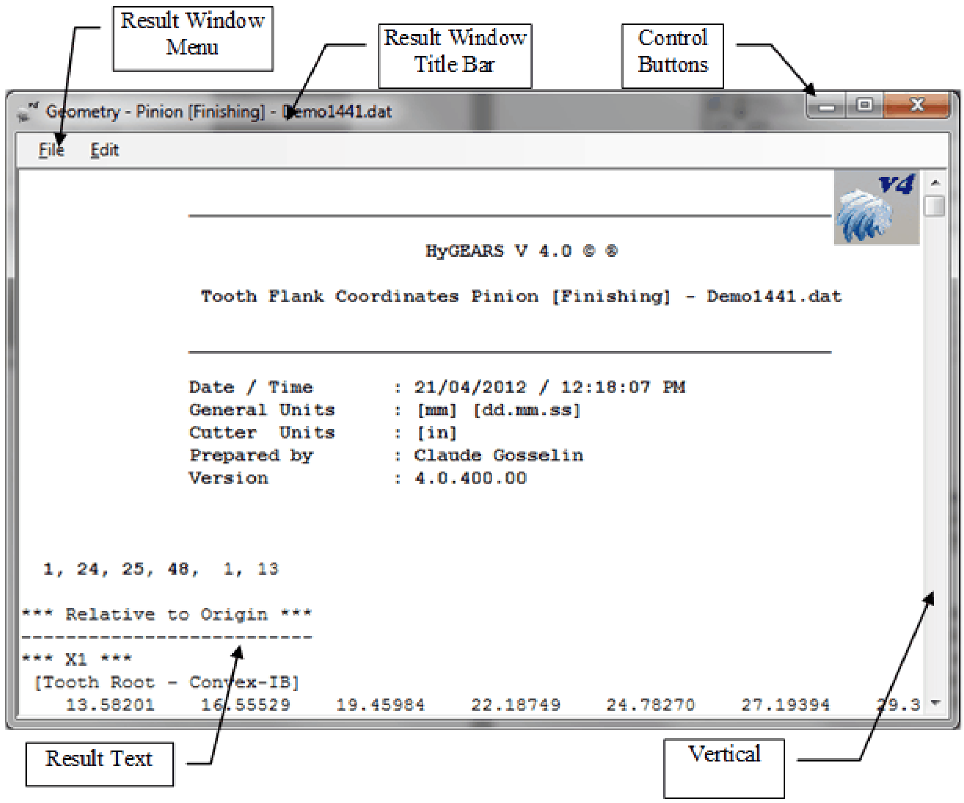
^N	toggles the current Child Window to use either the coincidence of tooth flank normals (NoSep) or the tooth to tooth separation (Sep) to establish a contact point along the PoC; it is enabled only on those PoC related Child Windows such as the PoC, Contact Pattern and 2D Graphs,
^O	to open an existing geometry data file,
^P	sends the content of the current Child Window to the Printer,
^R	toggles on and off the display of the Reference Frames,
^S	saves the current geometry data file,
^T	causes the current display to recalculate and send the calculation trace to a Text Results window,
^U, ^-	Zooms Out the display one level,
^Z	toggles the current Child Window in and out of the AutoZoom mode.

5.5 Text Results Window

Besides Child Windows used to display graphic results, HyGEARS uses Text Results windows to display text or numerical results. The Text Results window is like a mini-word processor containing results in text form. This text may be printed or saved in a disk file. The Text Results window also offers search, copy, and cut and paste capabilities like those found on a word-processor.

Note however that the user *cannot directly write into the Text Results window*.

Up to 20 Text Results windows can co-exist at the same time. If an attempt to exceed this limit is made, a warning message will be issued, and one or more Text Results window must be closed before another one is opened. Only one Text Results window can be active at any given time. To activate a Text Results window, simply click on it or its icon.



Like all other HyGEARS windows, the Text Results window can be moved by dragging it anywhere on the screen, minimized or maximized by clicking on the minimize or maximize buttons in the window upper right corner, and its size can be increased or decreased by stretching the Text Results window borders. Additionally, two vertical and horizontal scroll bars are available to scroll through the Text Results window contents.

File	Edit
Save	Copy
Print	Cut
Exit	Paste
	Find
	Font

The following table summarizes the Text Results window pull down menus and functions:

File menu

The File menu of a Text Results window is used to control file input and output and Text Results window life.

Save Saves the contents of the active Text Results window to a data file. The File Dialog Box prompts the user to enter a file name, and the contents of the active Text Results window is saved to the desired file provided the filename is valid. By default, the sub-directory structure of the currently active Geometry data file is provided as a file name pattern.

Print Prints the contents of the active Text Results window. The user is prompted to make sure that the printer is ready and on line, after which the contents of the active Text Results window is printed.

If only a part of the Text Results window is to be printed, select the text to print by pressing on the left mouse button and moving the mouse to encompass all the desired text while keeping the left mouse button pressed (the selected text will be highlighted), and invoke the Print function: HyGEARS will then print only the selected portion of the Text Results window.

Exit Closes the active Text Results window and the contents of the window is lost. Double-clicking on the control box in the upper left corner of the Text Results window achieves the same result.

Edit menu

The Edit menu of the Text Results window is used for certain cut and paste operations similar to those found on a word processor, and to control character font and size.

Copy Copies the selected text from the active Text Results window to the Clipboard, such that it can be retrieved and used by other applications. The Clipboard contents is automatically cleared prior to the Copy operation.

Cut Cuts the selected text from the active Text Results window and copies it to the Clipboard. The Clipboard contents is automatically cleared prior to the Cut operation.

Paste Pastes the contents of the Clipboard to the cursor location within the active Text Results window, provided the contents of the Clipboard is text and the cumulative dimension of the Clipboard and the Text Results window does not exceed 32 kilobytes, which is the limit in text size of a Text Results window.

Find Searches for a specific text string within the active Text Results window. The user is prompted to enter the text string to search for, and the Text Results window is scanned until a match is found. If part of the Text Results window text is selected, the selected text string is proposed as the search string by default. Upper and lower case have no effect on the search results. Pressing F3 continues the search from the current cursor location. When the end of the Text Results window is reached, the search starts anew from the beginning.

Font Displayed text in any Text Results window is assigned a font type. Depending on the Windows installed fonts available, the Font: function enables the user to change the font used to display characters in a Text Results window. A default value for the Font: function may be entered and kept in the HyGEARS Configuration (Edit->Configuration) editor window. Valid values depend on installed fonts. Consult your Windows user guide for more information.

6 HyGEARS Display Modes

HyGEARS offers 2 different ways to display graphical information:

- User mode, where desired displays are individually chosen and configured by the user;
- Pre-Defined mode, where selected information is organized and displayed in a fixed way.

In day to day use, the *Pre-Defined* mode should satisfy just about every user need, such that *User* mode is very rarely used.

6.1 User Defined Mode

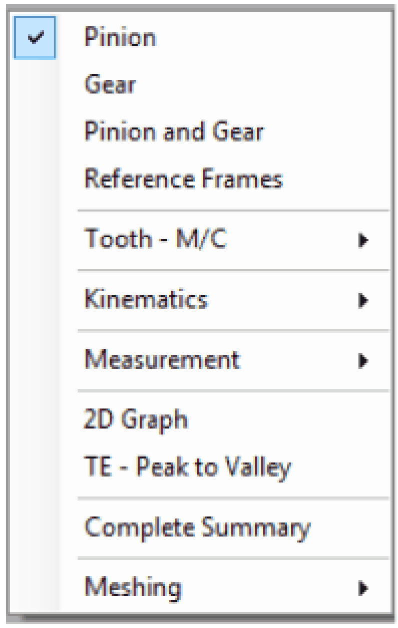
In User mode, the Graphics pull down menu is inactive until either a geometry data file has been opened, or a New Geometry has been created.

As soon as a geometry datafile has been read, or a new geometry has been created, the Parent Window is filled, and the Graphics pull down menu becomes active.

Once the Graphics pull down menu becomes active, clicking on the Parent Window Graphics function opens the Graphics pull down menu.

The Graphics pull down menu can also be opened by using the “Alt”+”G” keyboard combination, or by clicking the right mouse button above an empty space of the Parent window. When the “Alt”+”G” keyboard combination is used on the Parent window, the Graphics pull down menu will be opened at the right of the cursor.

This section is divided in 7 major topics, each giving access to a series of Graphics functions.



The Displayed Geometry

Teeth and Machines

Kinematics and Contact Pattern

Tooth Surface Measurement and Corrective Machine Settings (Closed Loop)

Kinematic results in 2D Graphs

Complete Summary macro function

Meshing Finite Element Meshing
Finite Strips Model

When a Graphics function is requested by a click of the mouse, the Parent window is shown if it is not already, and a Child Window is created to display the requested function results.

Each Graphics function conditions the command buttons of the Parent Window Tool Bar.

Note: pressing the left or right mouse button while the mouse pointer rests over an empty area of the Parent window immediately displays respectively the File or Graphics pull down menus.

6.2 Pre-Defined Mode

To alleviate the task in every day work, the *Pre-Defined* display mode is offered where specific information about the current gear set is displayed in a defined way.

The outside of the Parent Window may be re-sized to fit one's desires, and the contained Child Windows will be re-sized accordingly, while maintaining their location. The Parent Window can also be minimized, but cannot be maximized.

Nine (9) geometry dependent Pre-Defined displays allow the user to access the most current functions and displays from a simple mouse click:

TCA:	the Contact Patterns are displayed on the Gear tooth flanks, along with the Transmission Error curves, the Ease Off surfaces, a close up of the meshing Pinion and Gear teeth, and the Path of Contact, in 2D projection, where the pinion and gear teeth can be seen interacting; this allows a visual verification of the root clearance.
LTCA	[*optional*] the Loaded Tooth Contact Analysis is calculated, and contact stresses (Hertz) are displayed in colors on the tooth flanks of the Gear along with the Transmission Error curves, TCA and LTCA.
Geometry	display of the pinion and gear blanks, along with several key dimensions on the teeth such as topland and root gap width.
Loads	display of three pinion and gear teeth and blanks, along with the Transverse, Axial and Radial loads obtained from the applied torque and shown at the mean point on the middle tooth.
Modifications	[*for Spur, Helical and Straight bevel gears only*]; display of the pinion and gear profile and crowning modifications as imposed by the cutter definition and movement.
Stock	a comparison of the Finishing and Roughing tooth thickness distribution is displayed, along with the Finished and Roughed teeth superimposed in 3D; a tool allows the optimization of the stock distribution.
CMM	2D and 3D displays of the CMM target grid are presented; the user can select where the target grid is to be on the tooth flank, and can visually check for interference between the probe sphere and the opposite tooth flank.
Corr-RE	tools to calculate either Corrective Machine Settings (Closed Loop) or Reverse Engineering, once a CMM file is available.

Machine	the cutting machines are displayed and can be animated; gives access to 5Axis CnC manufacturing; the trace of the cutter blade tips can be plotted at start of roll, center roll and end of roll to visually verify for interference with the work holding part.

6.2.1 TCA

In the *TCA* Pre-Defined display, one can see:

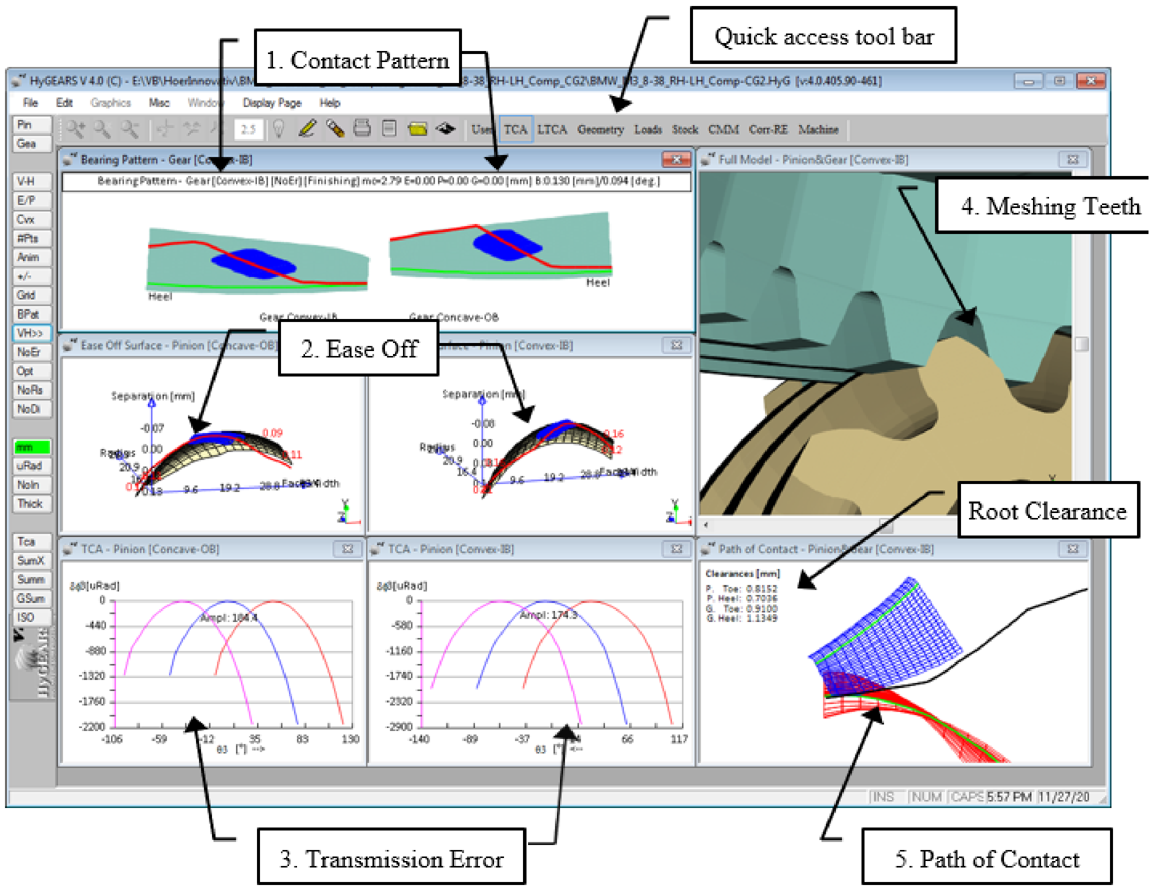
1. the Contact Patterns for both Gear tooth flanks; the Contact Patterns are calculated without load and are identified Convex-IB and Concave-OB;

2. the Ease Off surfaces, these are displayed immediately below the Contact Patterns, and correspond to the identified gear tooth flanks above;

3. the Transmission Error curves; these are displayed immediately below the Ease Off surfaces, and correspond to the identified gear tooth flanks;

4. a close up of the meshing Pinion and Gear teeth;

5. the Path of Contact, in 2D projection, where the pinion and gear teeth can be seen interacting, which allows a visual verification of the root clearance; root clearances values are displayed at Toe and Heel, for Pinion and Gear.



Function Buttons

In the *TCA* pre-defined mode, a limited number of function buttons are displayed; they offer access to the most commonly used functions.

Geometry function button group

Pin Gea

Actions function button group

V-H E/P

Cvx-Con Left-Right

#Pts Anim

+/- Grid

BPat VH>>

>>IB	>>OB
ErrS-NoEr	Opt
Res-NoRs	Dims-NoDi

Units function button group

mm-in	DMS-Dec
Sec-uRad-um-uIn	NoIn - Intr
Thick	

Output function button group

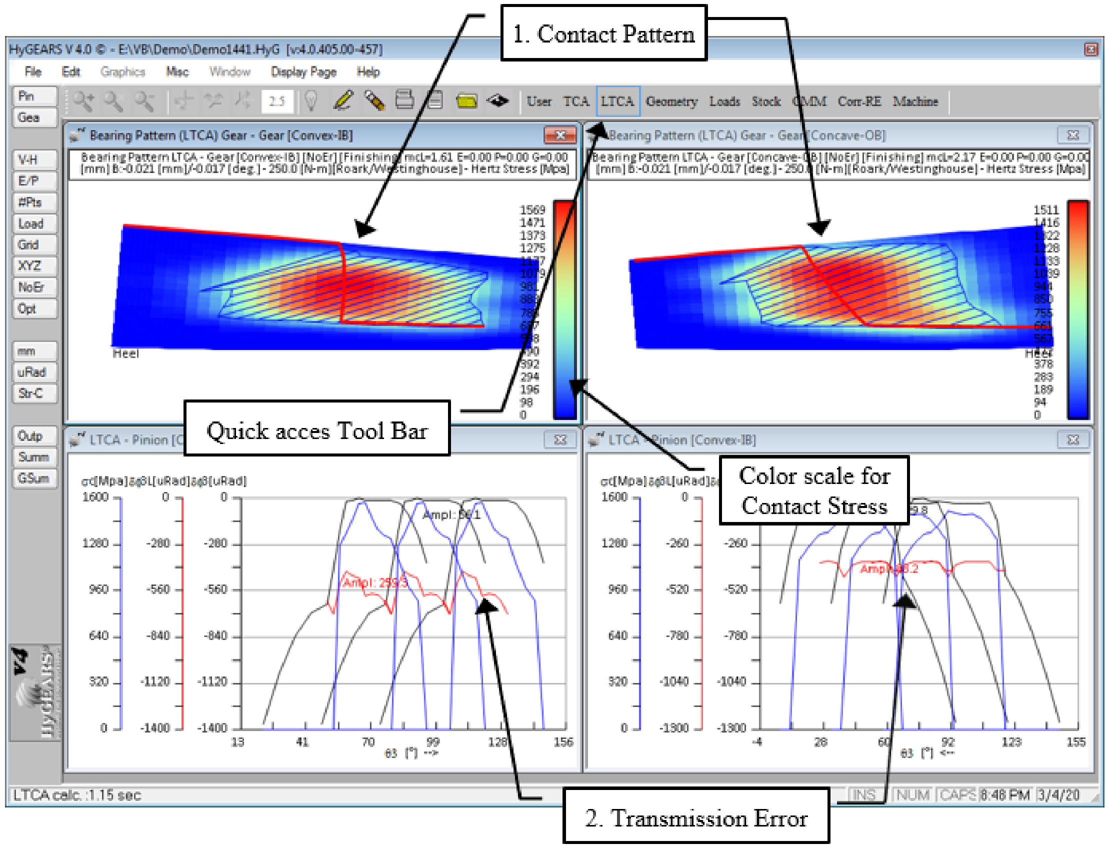
Tca	SumX
Summ	GSum
ISO	

6.2.2 LTCA

In the *LTCA* Pre-Defined display, one can see:

1. the Contact Patterns under load for both Gear tooth flanks; the Contact Patterns are displayed in separate Child Windows; the same torque is applied to each tooth flank; the contact stresses are displayed in color gradient, red being the highest stress, and blue the lowest; the color scale to the right of the Child Window gives the maximum value;

2. the Transmission Error curves, Unloaded (δf3) and Loaded (δf3L) and the contact stresses (σc); these are displayed immediately below the Contact Patterns and correspond to the teeth displayed above; the "Str-C" function button allows to switch the display from Contact Stress to Bending Stress and then to Efficiency.



Function Buttons

In the "LTCA" pre-defined mode, a limited number of function buttons are displayed; they simplify the design and analysis tasks while offering access to the most common functions.

Geometry function button group

Pin   Gea

Actions function button group

V-H   E/P

#Pts   Load

Grid

Units function button group

mm-in   DMS-Dec

Sec-uRad-um-uin   Str-C Str-B Effic

Output function button group

Outp SumX

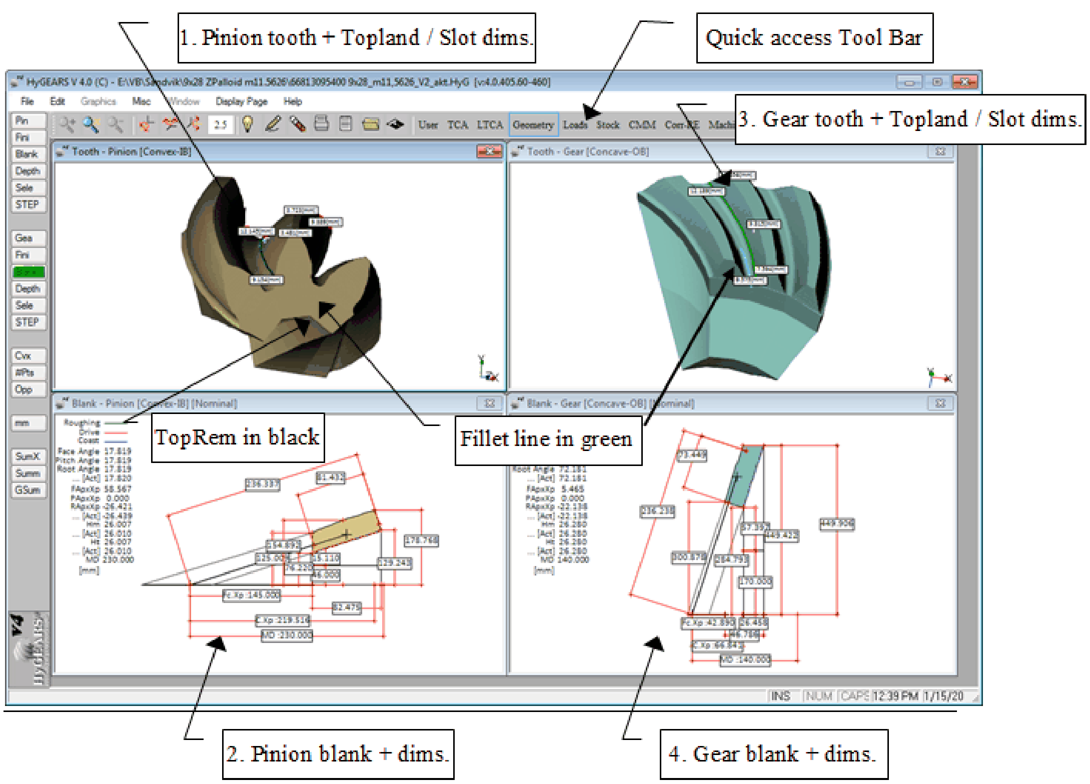
Summ GSum

ISO

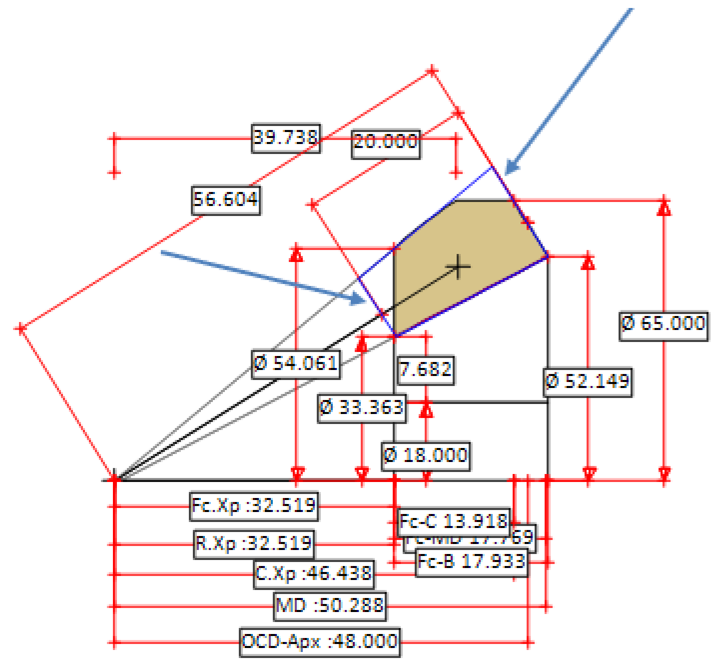
6.2.3 Geometry

In the Tooth Geometry Pre-Defined display, one can see:

1. the Pinion tooth, with the Topland and Slot dimensions, at Toe and Heel; fillet line appears in green, and the TopRem limit, if entered, is in red.
2. the Pinion Blank contour; key dimensions are displayed;
3. the Gear tooth, with the Topland and Slot dimensions, at Toe and Heel;
4. the Gear Blank contour; key dimensions are displayed.



For bevel gears, the tooth theoretical contour is also displayed in blue (blue arrows in the figure below). This allows assessing the differences between the theoretical and actual teeth which, of course, affect the tooth bending strength model.



The tooth theoretical contour is defined by:

- the Ref. Face Width value;
- the FApxXp value, i.e. the Face Apex to Crossing Point;
- the RApxXp value, i.e. the Root Apex to Crossing Point;
- the Root Angle value.

where Xp denotes the Crossing Point, i.e. where the pinion and gear axes cross.

Function Buttons

In the Geometry pre-defined mode, a limited number of function buttons are displayed; they offer access to the most commonly used functions.

Pinion function button group

Pin	Fini-Roug
Blank	Depth
Sele	STEP
DXF	RemT

Gear function button group

Gea | Fini-Roug
Blank | Depth
Sele | STEP
DXF | RemT

Actions function button group

Cvx-Con | #Pts
Opp

Units function button group

mm-In | DMS-Dec

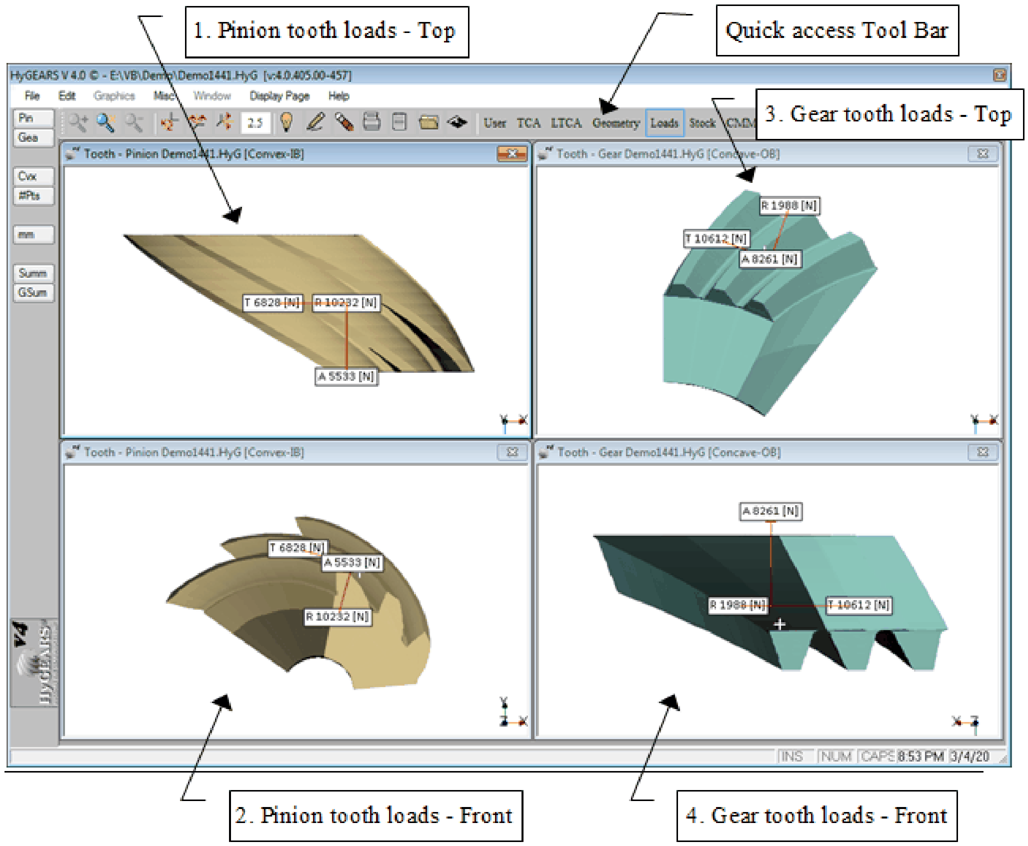
Output function button group

SumX | Summ
GSum

6.2.4 Loads

In the *Loads* Pre-Defined display, one can see:

1. the axial, radial and tangential loads on the Pinion tooth, in Top view
2. the axial, radial and tangential loads on the Pinion tooth, in Front view
3. the axial, radial and tangential loads on the Gear tooth, in Top view
4. the axial, radial and tangential loads on the Gear tooth, in Front view



Function Buttons

In the Loads pre-defined mode, a limited number of function buttons are displayed; they offer access to the most commonly used functions.

Pinion and Gear function button group

Pin Gea

Actions function button group

Cvx-Con #Pts

Units function button group

mm-In DMS-Dec

Output function button group

SumX Summ

GSum

6.2.5 Stock

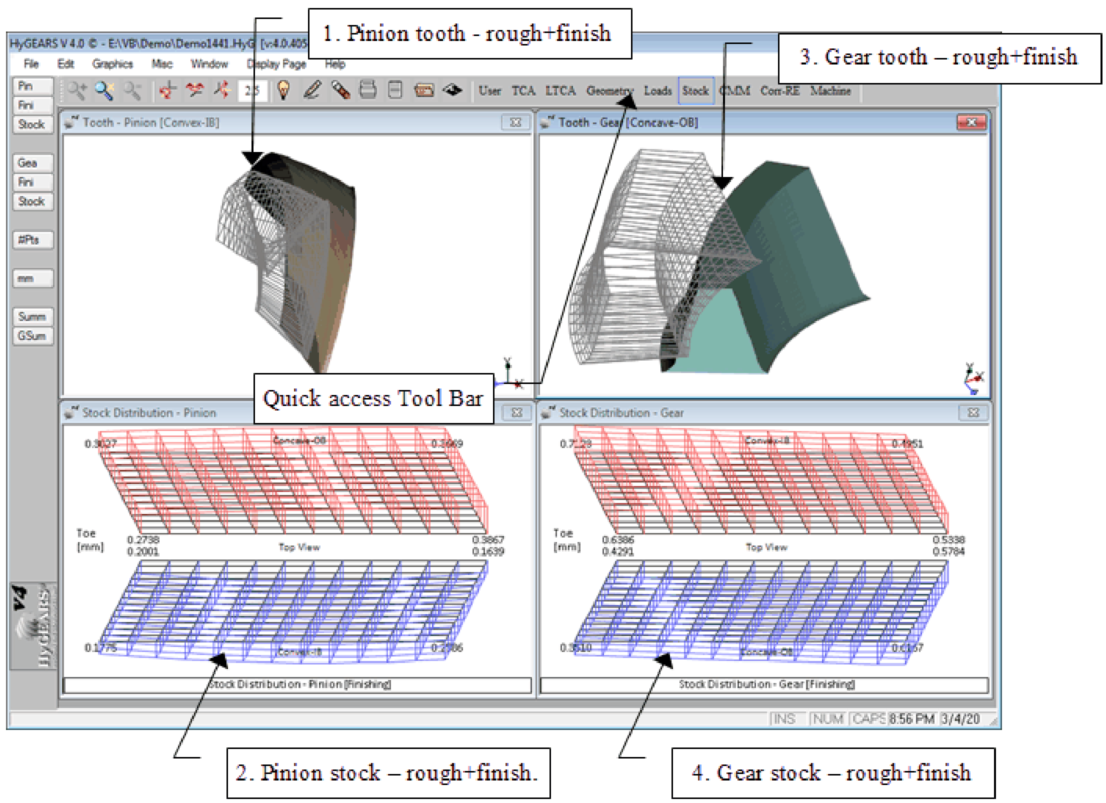
In the Stock Distribution Pre-Defined display, one can see:

1. the Pinion tooth, with the Finish and Rough states superimposed; the roughing state appears in grey lines;

2. the Pinion stock distribution between roughing and finishing; roughing appears in red and blue, for the OB and IB respectively;

3. the Gear tooth, with the Finish and Rough states superimposed; the roughing state appears in grey lines;

4. the Gear stock distribution between roughing and finishing; roughing appears in red and blue, for the IB and OB respectively.



Function Buttons

In the Stock Distribution pre-defined mode, a limited number of function buttons are displayed; they offer access to the most commonly used functions.

Pinion function button group

Pin | Fini-Roug
Stock

Gear function button group

Gea | Fini-Roug
Stock

Actions function button group

#Pts

Units function button group

mm-In | DMS-Dec

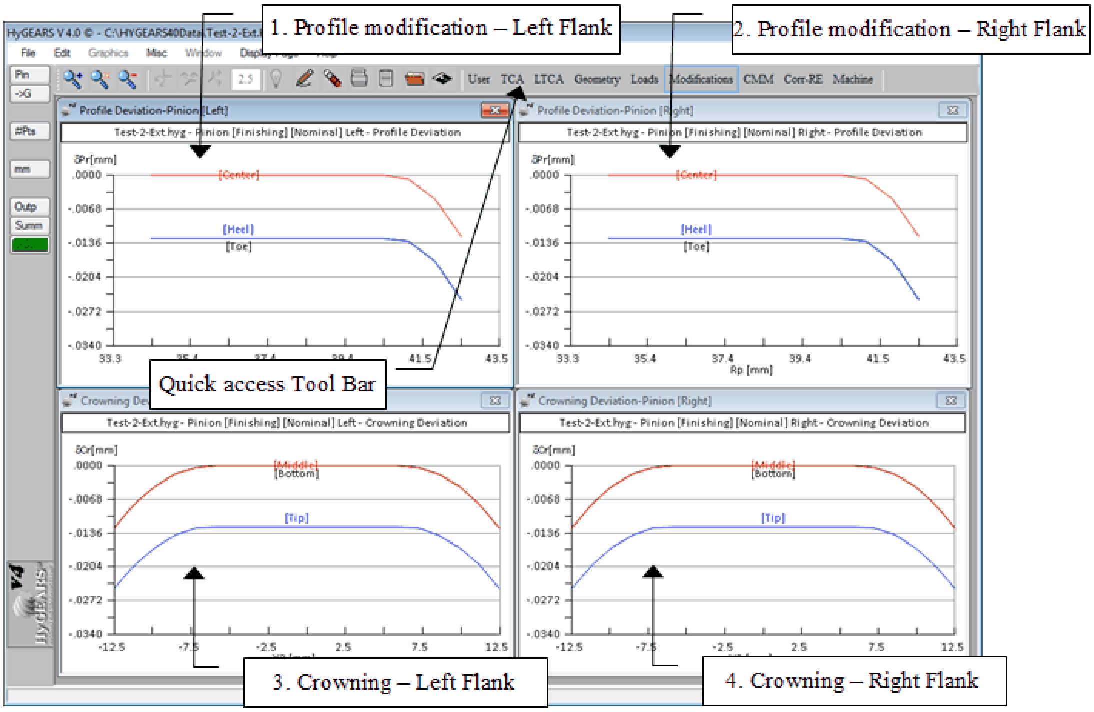
Output function button group

SumX | Summ
GSum

6.2.6 Modifications

In the *Modifications* Pre-Defined display, one can see:

1. the Pinion profile modifications on the Left tooth flank, at tooth Toe, tooth Center and tooth Heel;
2. the Pinion profile modifications on the Right tooth flank, at tooth Toe, tooth Center and tooth Heel;
3. the Pinion crowning modifications on the Left tooth flank, at tooth Bottom, tooth Middle and tooth Tip;
4. the Pinion crowning modifications on the Right tooth flank, at tooth Bottom, tooth Middle and tooth Tip.



Clicking on the "->G" function button toggles the display into Gear mode.

Function Buttons

In the Geometry pre-defined mode, a limited number of function buttons are displayed; they offer access to the most commonly used functions.

Pinion function button group

Pin

->G Toggles the display to Gear

Gear function button group

Gea

->P Toggles the display to Pinion

Actions function button group

#Pts

Units function button group

mm-In DMS-Dec

Output function button group

SumX Summ

GSum

6.2.7 CMM

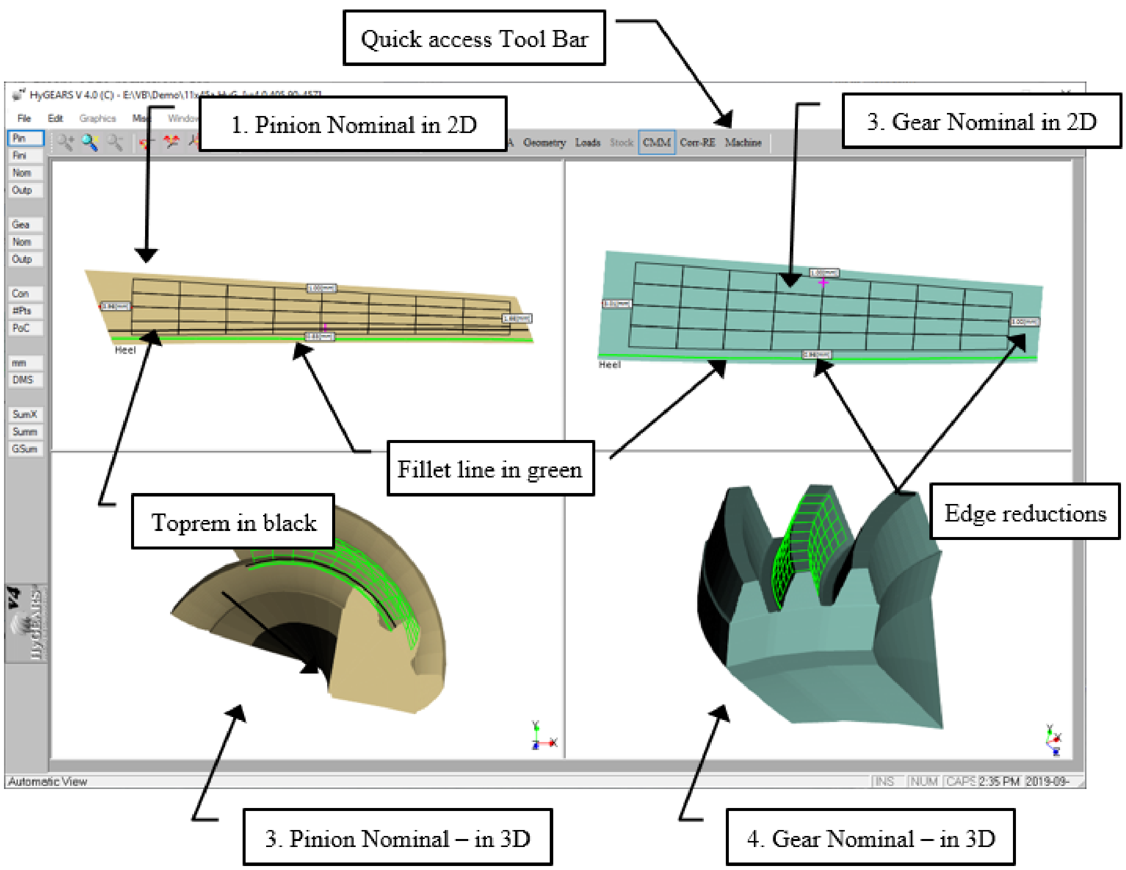
In the *CMM* Pre-Defined mode, one can see:

1. the Pinion tooth, in 2D, with the CMM target grid superimposed in black; edge reductions are also displayed; fillet line is in green, while TopRem limit, if entered, is in red; edge reductions for the CMM data are displayed – note that root and tip edge reductions are *along* the tooth profile;

2. three Pinion teeth in 3D, with the CMM target grid superimposed, in green;

3. the Gear tooth, , in 2D, with the CMM target grid superimposed in black; edge reductions are also displayed; fillet line is in green; edge reductions for the CMM data are displayed;

4. three Gear teeth in 3D, with the CMM target grid superimposed, in green.



Function Buttons

In the CMM pre-defined mode, a limited number of function buttons are displayed; they offer access to the most commonly used functions.

Pinion function button group

Pin	Fini-Roug
Nom	Outp
Save	

Gear function button group

Gea	Fini-Roug
Nom	Outp
Save	

Actions function button group

Cvx-Con	Left-Right
#Pts	PoC

Units function button group

mm-In	DMS-Dec

Output function button group

SumX	Summ
GSum	

6.2.8 Corr-RE

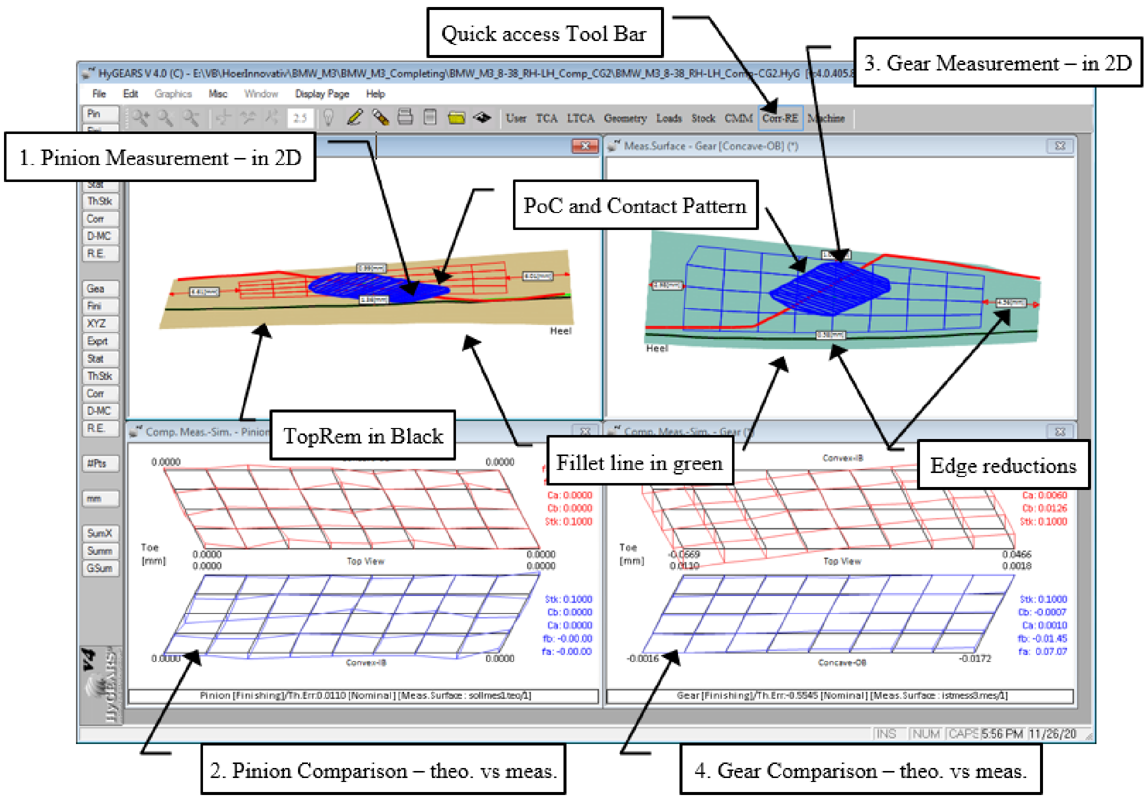
In the *Corr-RE* Pre-Defined display, one can see:

1. the Pinion tooth, in 2D, with the CMM measurement grid superimposed; the fillet line appears in green and the TopRem limit, if TopRem has been entered, appears in red; the PoC and Contact Pattern are also displayed; actual edge reductions from the CMM data are displayed;

2. the comparison between theoretical (or simulated) and actual measurement for the Pinion;

3. the Gear tooth, in 2D, with the CMM measurement grid superimposed;the fillet line appears in green; the PoC and Contact Pattern are also displayed; actual edge reductions from the CMM data are displayed;

4. the comparison between theoretical (or simulated) and actual measurement for the Gear.



Function Buttons

In the Correction – R.E. pre-defined mode, a limited number of function buttons are displayed; they offer access to the most commonly used functions.

Pinion function button group

Pin	Fini-Roug
XYZ	Exprt
Stat	ThStk
Corr	D-MC

R.E.

Gear function button group

Gea	Fini-Roug
XYZ	Exprt
Stat	ThStk
Corr	D-MC
R.E.	

Actions function button group

#Pts

Units function button group

mm-In	DMS-Dec

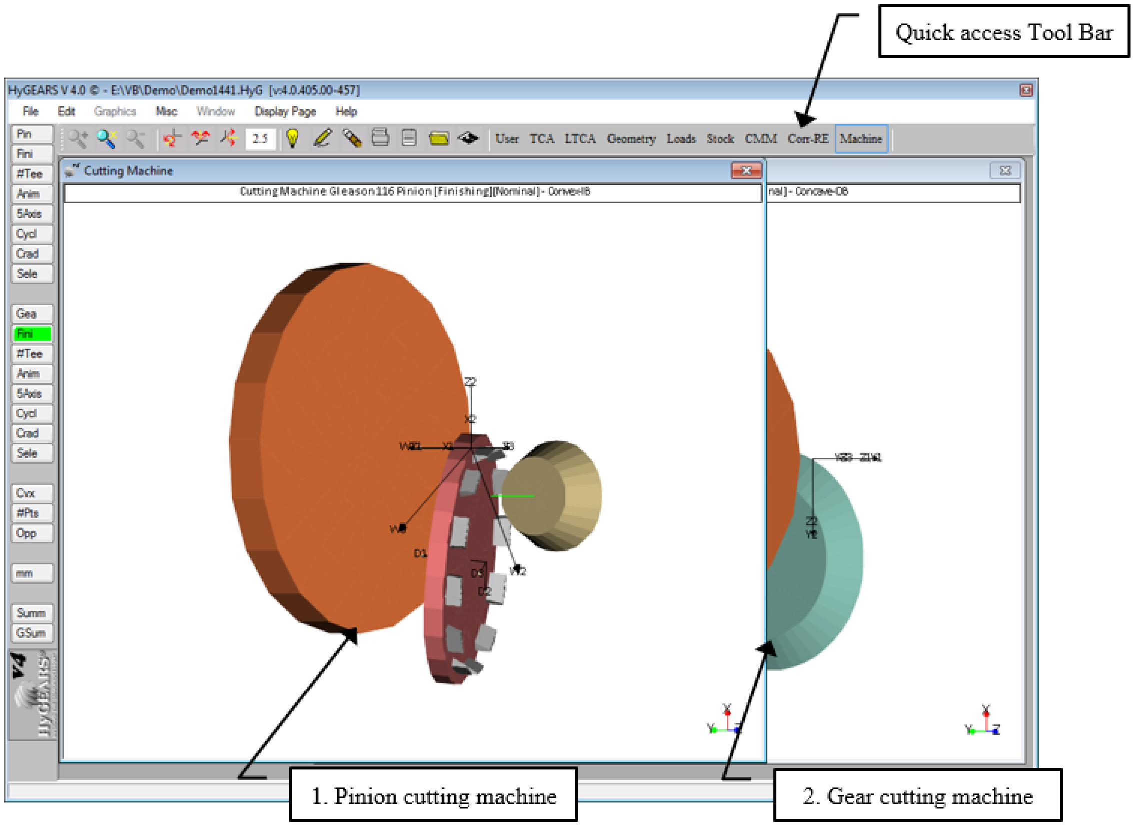
Output function button group

SumX	Summ
GSum	

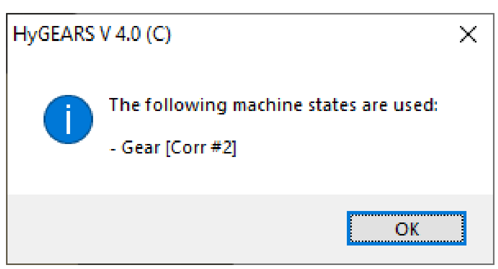
6.2.9 Machine

In the *Machine* Pre-Defined display, one can see:

1. the Pinion cutting machine;
2. the Gear cutting machine.



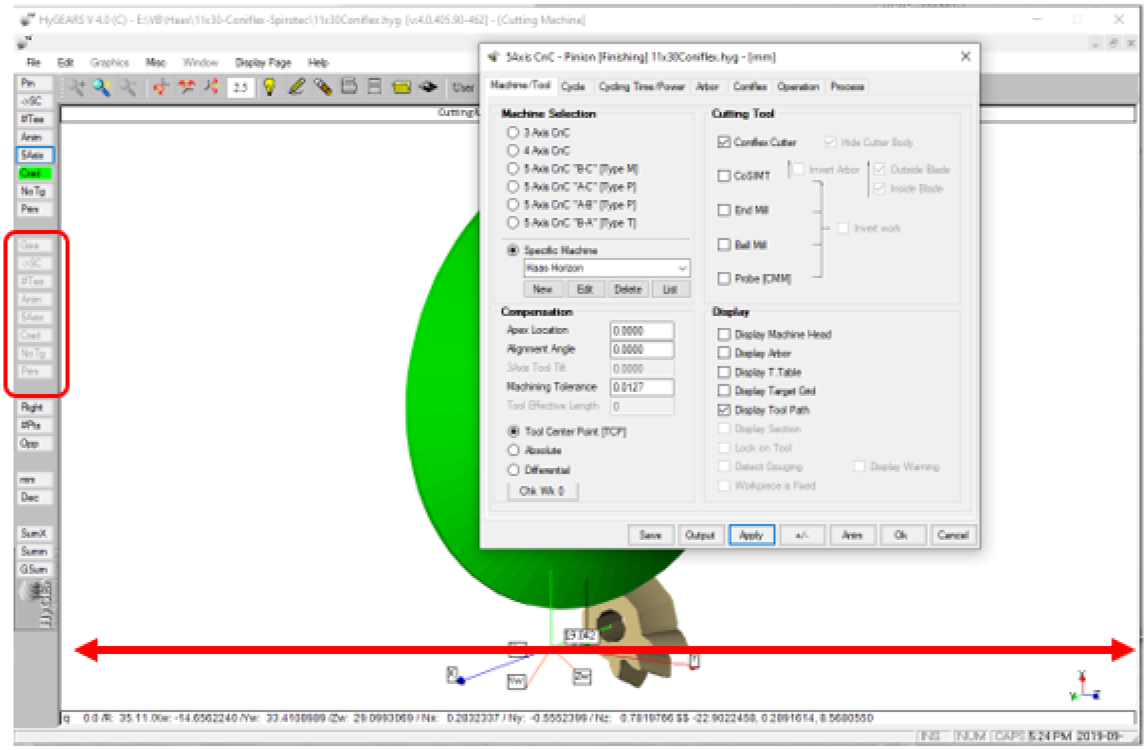
When accessing the Machine mode, HyGEARS checks to see if any Closed Loop (Corrective Machine Settings) is present in the pinion and the gear geometry data if so, then HyGEARS automatically chooses the last Closed Loop data, and informs the user of this selection. For example, figure below, the gear member has 2 Closed Loop sequences present, and therefore HyGEARS defaults to the last correction, i.e. [Corr #2].



When clicking on the [5Axis] button, HyGEARS:

- maximizes the display Child Window for the selected member, pinion or gear, and
- disables the function buttons for the non-selected member, gear or pinion,

such as to give more display area and avoid clicking on a wrong button or in the non-selected member's display area whence HyGEARS will exit the current 5Axis session. When the 5Axis window is exited, the Child Window returns to its normal 2 Child Window state.



Function Buttons

In Cutting Machine pre-defined mode, a limited number of function buttons are displayed; they offer access to the most common functions.

Pinion function button group

Pin	Fini-Roug
->SC	#Tee
Anim	5Axis
Cycl	Crad-NoCr
Sele	DxfS

Gear function button group

Gea	Fini-Roug

->SC	#Tee
Anim	5Axis
Cycl	Crad-NoCr
Sele	DxfS

Actions function button group

Cvx-Con	Left-Right
#Pts	Opp

Units function button group

mm-In	DMS-Dec

Output function button group

SumX	Summ
GSum	

7 File Input and Output

This section covers the HyGEARS file input and output, and new Geometry creation. It is therefore the starting point of any HyGEARS work session, whether work is being continued on a previously created Geometry, or a new Geometry is created from scratch.

This section is divided in 7 major subjects:

Opening an existing file on disk, and understanding the directory structure

Saving the currently active Geometry on disk

Saving an existing file on disk, under a new name or in a different directory

Creating a new Geometry

Inputting an Existing Summary

Exiting HyGEARS

Direct opening of a previously accessed Geometry data file

7.1 File Names, Directories and their Structure

File Names

File names are made of two parts: a *name* comprising 1 to 255 characters, and an *extension* comprising 1 or more characters (usually 3).

Both parts must be separated by a period "." character. The maximum length of any name is 255 characters, including path, extension and the period. By default, the following file extensions are used in HyGEARS:

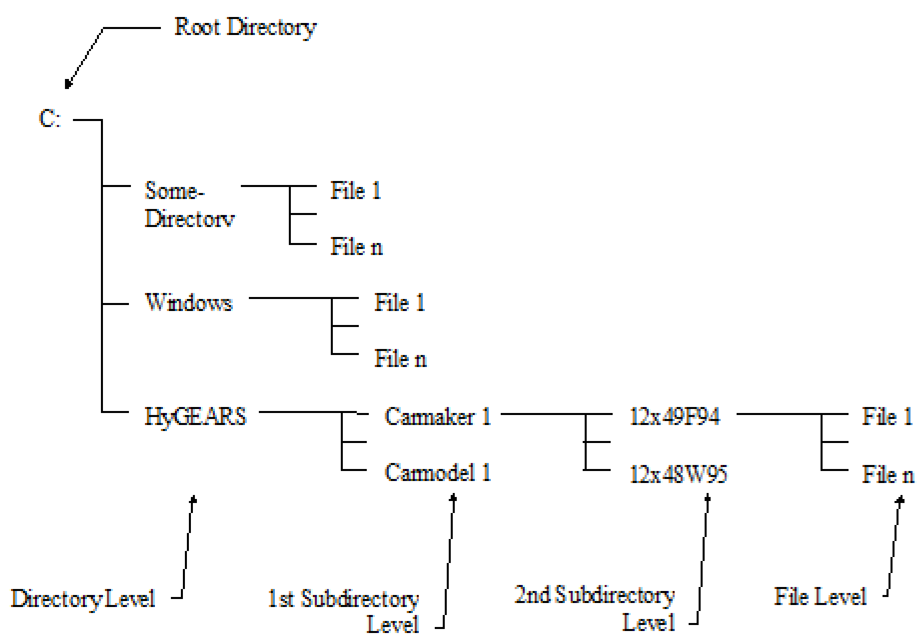
.hyg	HyGEARS Geometry data files;
.ram	Zeiss CMM nominal files;
.rfd	Zeiss CMM measurement data files;
.mes	HyGEARS measurement files, obtained either by conversion of .Ram and .Rfd files, or by other means.
.teo	HyGEARS theoretical (nominal) measurement data files.
.spa	Gleason Special Analysis files, which contain the definition of hypoid and spiral-bevel gears.

While directory and sub-directory names can include an extension, for ease of management they should be limited to 32 characters, thus without extension and the period "." character separating the name from the extension.

For example, the sub-directory name *12x49* could indicate a *12x49* gear set, but it may not be the only one on the hard disk. Therefore, it could be preferable to create a first sub-directory level using the name of the company, car model, etc. for which the gear set was created, and then create a second sub-directory indicating the actual gear set by its tooth numbers for example, or its version.

As an example, figure below, the HyGEARS directory includes two sub-directories named by the car maker or car model (only generic names were used here; please use actual names).

The *Carmaker 1* sub-directory includes two sub-directories for a 12x49 gear set, one which was completed during fall of 1994 (F94) and the other one during winter of 1995 (W95). Each sub-directory will then include its own specific files such as Geometry, Ram and measurement data files.



Directories and their Structure

The hard disks located on any modern personal computer (PC) are used to save the operating system, data and program files. The hard disks can be seen as large containers in which a number of items reside. The hard disks are usually recognized by letters "C", "D", etc. followed by a colon ":", while the floppy disks carry the "A" or "B" letters, and are also followed by a colon ":".

Thus, hard disk C: is the first hard disk on the system, and D: the second, etc. if there is more than one hard disk.

CD drives normally take letters following those of the hard disks. For example, if you have 2 hard disks respectively called C: and D:, then the CD drive letter would normally be E: and is allocated automatically by the operating system (Windows).

In order to simplify the management of all the hard disk files, which can easily number in the hundreds and thousands, they may be grouped in some form of clusters which we call directories and sub-directories. In essence, directories and sub-directories are files containing other directories and files.

The root directory is usually the top-most level in the structure, while sub-directories are subsets or subdivisions of a given directory. This directory subdivision process is performed by the operating system and is completely transparent to the user, but its underlying logic must be well understood.

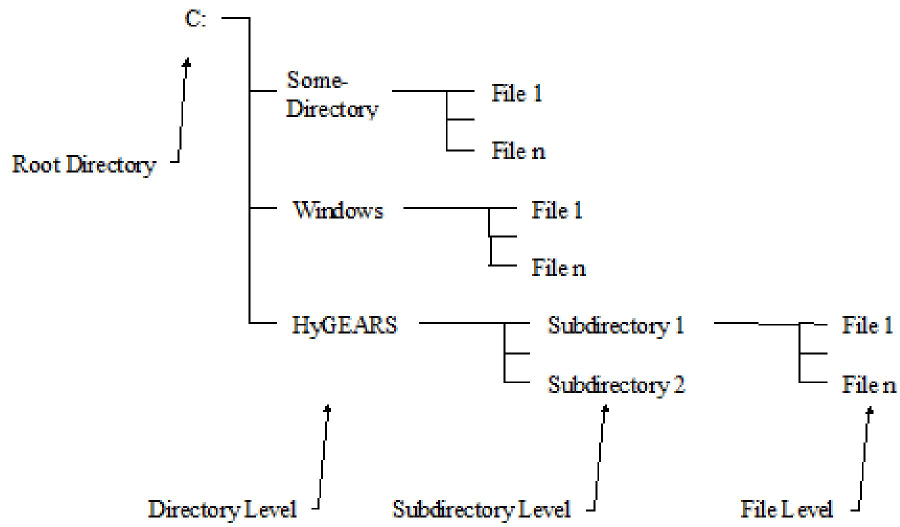
For HyGEARS to run, a number of directories must already exist on the hard disk:

- the Windows directory (which may be named otherwise depending on user preferences when Windows was installed), where all the necessary Windows program files and sub-directories are located; this directory and its sub-directories are automatically created by the Windows installation program;

- the HyGEARS directory, where all the necessary HyGEARS program files are located. The name for this directory is proposed to the user at installation time, and a default value is offered which can be overrun by the user. This directory is automatically created by the HyGEARS installation program;

- the HyGEARS sub-directories, in which the Geometry data and measurement files should be located; these directories are created by the user, and their names should reflect the contained data; this aspect will be further detailed in the following subsection “Directory and File Names”.

The following figure illustrates the basic directory, sub-directory and file structure used in the Windows Operating System. In this figure, Windows and HyGEARS are the names of top-most directory levels contained within the disk root directory. In the Windows directory, a number of files are present, and they carry names usually associated with their use or function.



The HyGEARS directory first includes sub-directories, each of which contains data files and which should carry names associated with their use or function. The choice of the data file names is decided by the user, and it is strongly recommended to use mnemonic names, e.g. names which are self explanatory and easy to remember.

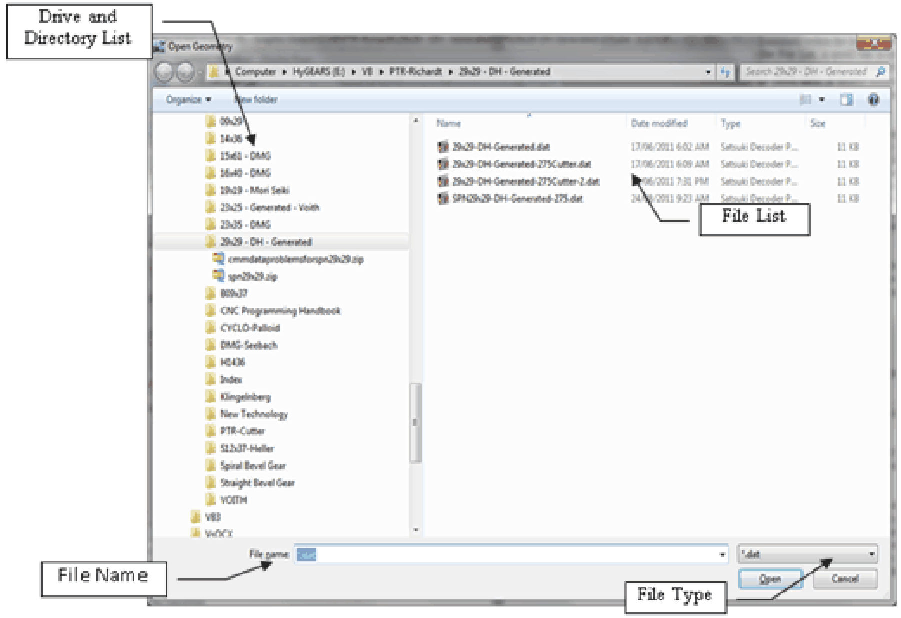
The sub-directories can be manually created using the Windows Explorer provided with the Windows Operating System (see the Windows User Guide), or automatically by HyGEARS itself when saving a datafile to a non-existing sub-directory.

7.2 File Dialog Box

Since HyGEARS operates within the Windows Operating System, it uses some of its features to help user choices. One such feature is the File Dialog Box. In short, the File Dialog Window is a window used to select one file in a given directory or sub-directory. Therefore, the File Dialog Window shows all the necessary information for the user to select the desired file.

The *File Name* field shows the file to search for. For example, since HyGEARS geometry data files use the ".HyG" extension by default, the File Name field will show this default extension when the *File -> Open* function is selected.

In the following example, the File Name field actually shows "*.HyG", where the "*" stands for "all filenames with the HyG extension", which is why the File List shows only files whose extension is ".HyG". One could actually type the desired file name in the File Name field.



Pressing the Enter Key (Return Key) at any time or clicking on the Open button tells the File Dialog Window that the selection is made; pressing the Esc (Escape) Key or the Cancel button cancels the File Dialog Box. If the requested file does not exist, an error message will be issued, the File Dialog Window will be removed and the pending operation will be canceled.

As just mentioned, the File List shows all files matching the File Name. If there are more files than there is space in the File List, a scroll bar is displayed on the bottom of the File List and the listing can be scrolled left or right using either the mouse or the Page Up / Page Down keys. A double mouse click on a file name selects it and tells the File Dialog Window that the selection is made. The same provisions as above apply in case of errors.

The Files of Type List offers a choice to the user, when this choice makes sense. For example, in the File -> Open function, since the default geometry data file type extension is "*.dat", this choice is offered along with the "*.*", or all files, choice. On the other hand, as will be seen later, when measurement data files are searched, several different file type extensions are proposed, and therefore the Files of Type List will contain the offered choices. To select an entry from the Files of Type List, click on the arrow at the right end of the Files of Type List and select the desired file type by clicking on it. Selecting a choice from the Files of Type List automatically replaces the File Name entry to reflect the user selection.

The full directory and sub-directory structure of the selected disk is found in the Drive and Directory List. To change directory, double click with the mouse on the desired sub-directory level and the File and Directory List will be updated automatically to reflect the File Pattern.

7.3 Opening an Existing Geometry File

To open and load into memory an existing Geometry data file, one can:

- give the full name and path "disk:\directory\subdirectory1\....\filename.ext" structure in the File Pattern field of the File Dialog Box, and press the Enter key or click on the OK button to complete;

- select the appropriate File Type and Disk from the provided lists of the File Dialog Box, and then select the desired directory and file name by double clicking on the available names from the Directory and File Lists.

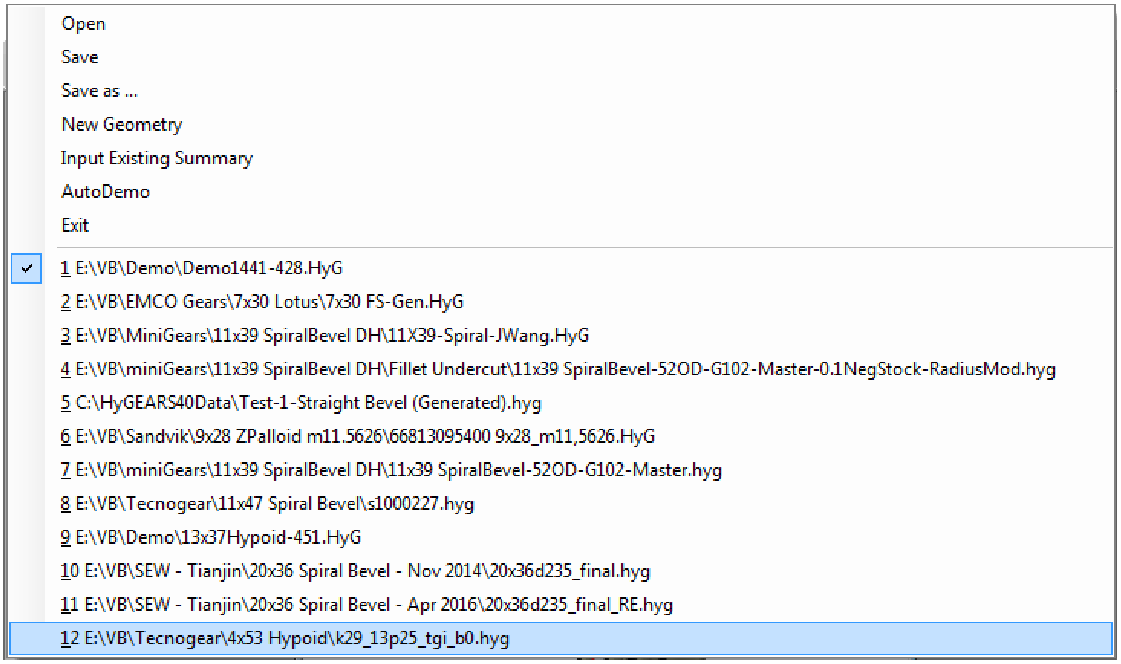
Once a selection has been made, all previous data in memory is lost and replaced by that of the selected Geometry data file, unless the current Geometry, whose name appears on the title bar of the Parent Window window, is attached to a Child Window (see The HyGEARS GUI). In such a case, the current Geometry is first saved to a temporary disk data file which has the same name as the current Geometry except that its file extension is changed to ".tmp", and then the selected Geometry data file is loaded into memory.

A double-click on a Child Window automatically reactivates the Geometry attached to it. If the currently active Geometry has not been attached to a Child Window, any modification made since it was last saved to disk is lost.

7.4 Direct Opening of a Geometry File

HyGEARS remembers the last 12 opened Geometry data files and offers a quick and convenient way to open one of the existing Geometry data files that have been accessed previously.

At the bottom of the File pull down menu, entries will be filled in the order Geometry are accessed. Once the desired data file name is shown, simply pressing the number identifying the desired data file, or clicking on it with the left mouse button, automatically loads the Geometry data file into memory.



The same rules as in the above section “Opening an existing file on disk” apply.

7.5 Saving the Currently Active Geometry

Whenever a Geometry has either been created from scratch (File->New Geometry) or loaded from an existing Geometry data file (File->Open), or created from an existing Summary, and modified, it is normally desirable to save it onto disk, such as to be able to continue working on it at a later time. If a modified Geometry is not saved to disk, the modifications made to it are lost when the work session ends or when another data file is loaded in memory.

The File->Save function is used to save the currently active Geometry to a disk Geometry data file. It uses the name and directory structure of the currently active data displayed in the Parent Window title bar to know where on disk the Geometry data file should be saved. Alternately, the *File Save* icon of the Tool Bar may be used.

If the Geometry data file already exists, a prompt to confirm the overwriting of the existing data file is issued. If confirmation is not given, the File->Save function aborts.

If the directory does not already exist, as will occur after creating a new Geometry (File->New Geometry function), a prompt to confirm the creation of the requested directory is issued. If confirmation is given, the File->Save function will proceed, creating the requested sub-directory if necessary. Otherwise, the File Dialog Box will be shown, from which the directory where the Geometry data file is to be saved can be chosen.

Care must be exerted in using the File->Save function, as will be explained later in the File->New Geometry function, since each Geometry data file should possess its own sub-directory, where all relevant data files are stored. Doing otherwise will soon become confusing, especially in a large production operation.

7.6 Saving Under a New Name

As shown in the Saving the Currently Active Geometry on Disk section, it is possible to save directly the currently active Geometry under its current file and directory names. Using the *File->Save As* function, it is possible to change the file name, the directory name, or both. This function can be useful to make a copy of an existing Geometry data file, on which development trials are made without altering the original Geometry.

When the *File->Save As* function is called, the File Dialog Box is presented, with the name of the currently active Geometry in the File Pattern field, and the directory of the currently active Geometry as the selection in the Directory List.

As a protection, a change in the Geometry file name should be accompanied by a new sub-directory name in order to keep the original and modified Geometry in separate areas of the disk

To change the name of the Geometry, simply type in the new desired name. In HyGEARS, the default Geometry file name extension is ".HyG" and it is strongly recommended to stick to it. Clicking on the OK button, or pressing the Return key will initiate the file save.

To select a different directory in which the Geometry data file is to be stored, simply navigate in the Directory List using mouse clicks.

To create a new directory in which to store the Geometry data file, simply type in the complete structure of the new sub-directory with the file name in the File Pattern field, and clicking on the OK button or pressing the Return key will initiate the saving.

If the requested sub-directory is not found, HyGEARS will ask for a confirmation to create the new sub-directory. If confirmation is given, sub-directory creation and file saving will proceed; otherwise, file saving will abort

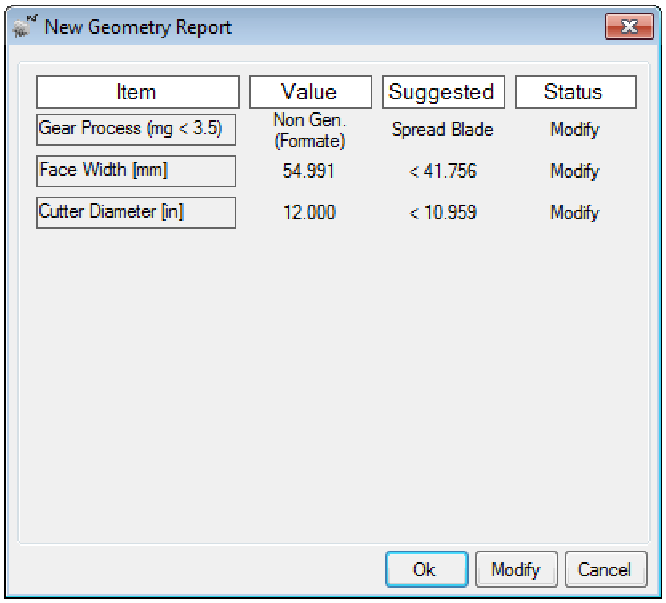
When a Geometry is saved under a new name or in a different directory, the name appearing in the Main Window title area is changed to reflect the new name, but the currently active Child Window remains linked to the old datafile. Thus, to display results based on the new Geometry datafile, a new Child Window must be created, which will then be linked to the new Geometry datafile.

7.7 Creating a New Geometry

HyGEARS offers a simple, efficient and quick way to create new geometries. The *File->New Geometry* function calls the *New Geometry Definition* input window shown below.

One simply fills in the required data,i.e. the yellow fields where data is compulsory, click on the OK button or press the Return key in any input field and the new Geometry will be created.

However, before proceeding in creating the *New Geometry*, HyGEARS will test if the starting values entered by the user are within the normal range. If not, HyGEARS will display a New Geometry Report to alert the user.



HyGEARS "remembers" the last values used to create a new geometry, and will automatically provide these values upon calling the File->New Geometry function.

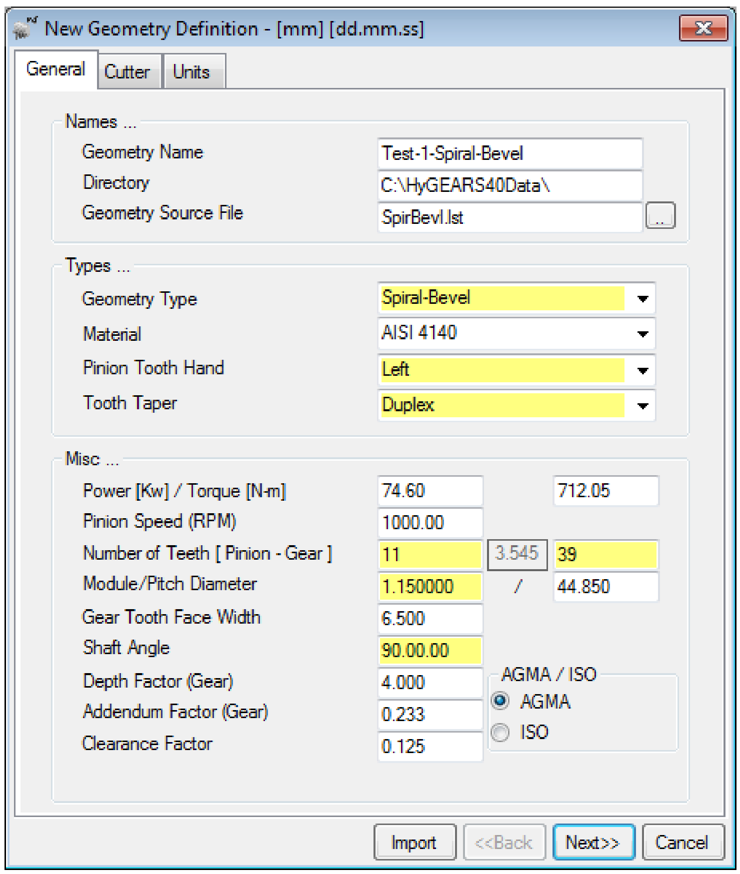
A note of caution however: as said earlier, computer programs are GIGO, or ***Garbage In Garbage Out***, which means that the output can never be better than the input. Inadequate input parameters will likely result in inadequate geometries.

Therefore, the user should respect and follow the established practice in selecting the spiral angle, pinion offset, cutter diameters, cutter blade angles, cutter blade edge radii and point width, etc. However, whenever possible, HyGEARS will issue warnings if input parameters exceed recommended practice and it is then possible to return to the New Geometry Definition window to modify input values according to the recommendations.

The New Geometry Definition window is organized in Data Pages, where the tab title indicates the data contained in the corresponding page. Data input is divided in three parts, accessed by clicking on the proper tab. An active page is indicated by its tab which sits in the foreground.

General data page	The first data page (below) deals with general blank data;
Cutter data page	The second input page covers cutter and cutting process specifications;
Blank/Units data page	The third data page covers the units in use and the dimensions of exisitng blanks.

The above referenced sections detail the different input fields for each data input page.



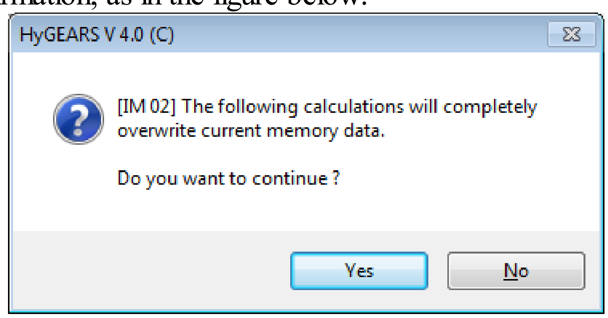
To activate an input data page, click on its tab with the left mouse button. To access to an input field, click on the desired field using the left mouse button, or successively press the Tab key until the input cursor has reached the desired field.

> **Important Note:**
>
> Many input fields must be filled before proceeding is allowed. The mandatory input fields will be identified by an * in the following paragraphs, and are in yellow.
>
> If one of these input fields is not properly filled, a warning message will be issued, the calculation of the initial machine settings will abort and HyGEARS will return to the New Geometry Definition window.

7.7.1 New Geometry Report

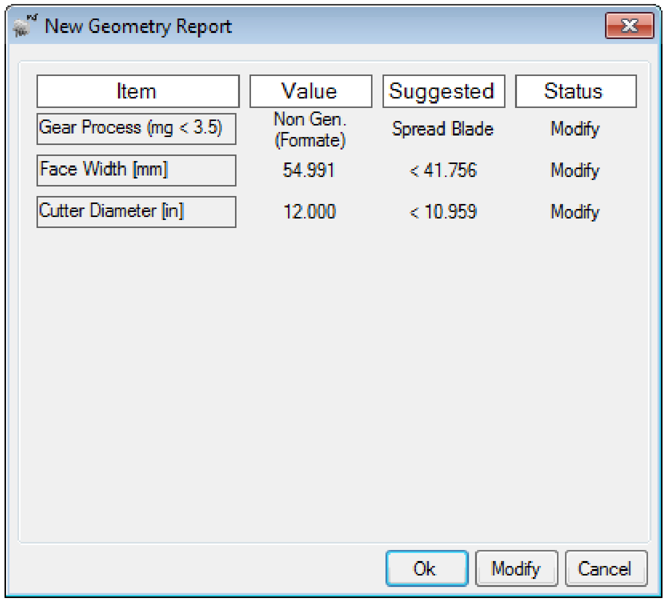
Whenever a new geometry is created, HyGEARS checks several input dimensions to establish if they are within, or outside, of the usually recommended range.

If within the recommended range, HyGEARS proceeds directly with geometry creation after requesting user confirmation, as in the figure below.



If any inputted dimension is outside the usually recommended range, HyGEARS displays a *New Geometry Report*, figure below, where the *Item* out of range is identified, its current V*alue* is displayed, the *Suggested* value is given, and the *Status* indicates "Modify" as a recommendation.

Of course, any recommendation can be ignored.



Command Buttons

Ok tells HyGEARS to use the entered data and proceed in creating the *New Geometry*;

Modify tells HyGEARS to return to the *New Geometry* input window in order to implement some of the suggestions;

Cancel cancels creating a *New Geometry*.

7.7.2 General Data Page

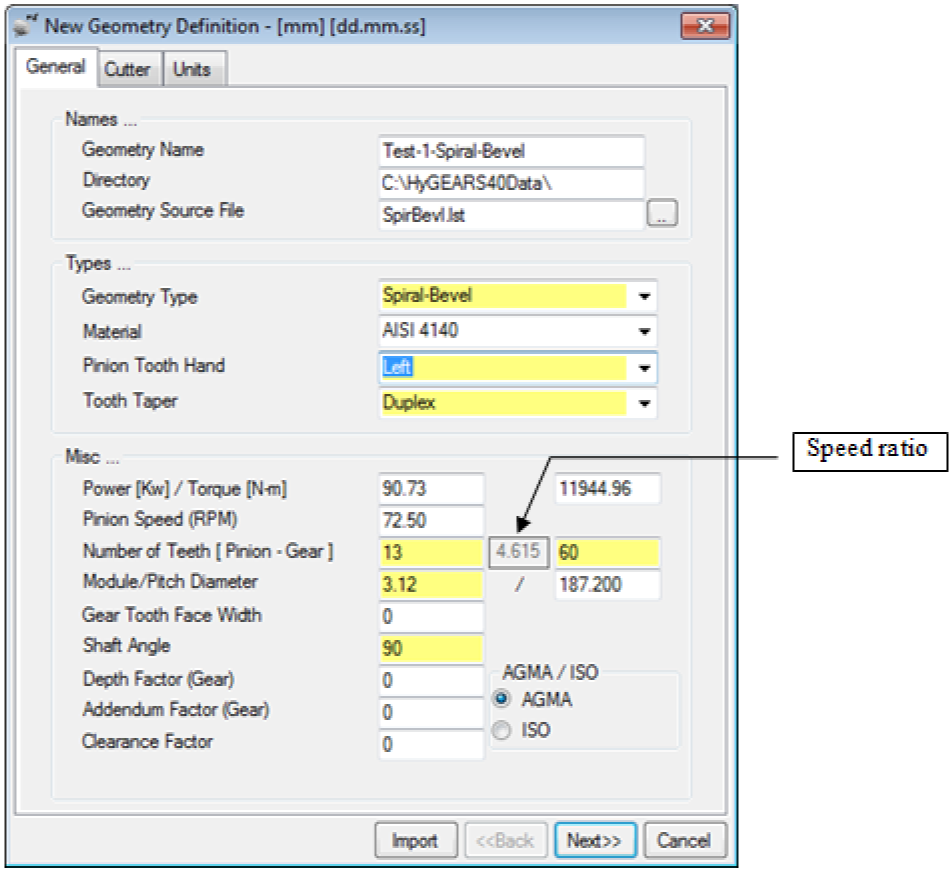
The *General* data page covers data related to the gear set blank dimensions, hand of pinion tooth, operating power and speed:

Zerol, Spiral Bevel and Hypoid Gears

Straight Bevel and Coniflex Gears

Coniflex Gears

Spur, Helical and Beveloid Gears



Geometry Name * An easy to remember name for the new Geometry data file must be entered. A good habit is to try to include the tooth numbers in the name, as well as a version number or letter. For example, “14x41A”, is a 14 tooth pinion with a 41 tooth gear, version A. If the extension is not given or is different from “.dat”, it will either be added or changed to “.dat”. If desired, this extension can then be changed at the time of saving the Geometry to disk by using the File -> Save As function.

A Geometry file name can be up to 255 characters long, including path and extension; therefore, it should be limited to 32 charaters. Its extension should be no more than 3 characters long. The following characters are not acceptable:
.,:;^’”/?!~#$%&•()<>[]{}

Directory * The full directory name must be entered, including disk name, of the location where the geometry data file is to be stored. The default directory name is “C:\hygear30data”. When the New Geometry Definition window is first shown, the Directory field is filled with the default directory name.

An error message will be issued if the HyGEARS installation directory name is given, as HyGEARS does not allow creating geometries in the installation directory. Each sub-directory segment should not be more than 10 to 15 characters long, and must not include any of the following characters: .,:;^'''/?!~#$%&•()<>[]{}

Upon saving the new geometry, HyGEARS will issue a prompting message to confirm for the creation of the requested sub-directory, if it does not exist.

Geo.Source File Whenever a Geometry is created, HyGEARS stores in two files the parameters that were inputted in the New Geometry Definition window. When another Geometry is to be created, HyGEARS will automatically load the input parameters last saved in the 1st file, depending on the Geometry type.

For Hypoid gears, the 1st file name is “Hypoid.lst”, while for Spiral bevel gears, it is “spirbevl.lst”.

The 2nd file name is based on the name given to the Geometry, to which the “.lst” extension is added. Therefore, if the name of a new Hypoid Geometry is “14x41”, the input data will be saved in the “Hypoid.lst” and “14x41.lst” files.

Now, suppose you want to create a new Geometry based on the input parameters of a previous Geometry. If the previous Geometry was the last one created, the parameters contained in “Hypoid.lst”, provided by default, can be used; otherwise, the input parameters of the 2nd file should be used.

To do so, double click on the “Geometry Source File” input field or click on the […] command button to the right of the input field to show the File Dialog Box, and select the desired “.lst” file to load its content.

Geometry Type * This entry offers several choices, which may depend on user options:

Straight-bevel
Coniflex
Spiral-bevel
Ext. Spur-Helical (external gears)
Hypoid
Int. Spur-Helical (internal gears)
Beveloid
Face

Face Clutch
Splines

Material * — This input field offers a choice of materials for both pinion and gear members. The material list is provided in an ASCII file named "material.fil", and provided with HyGEARS. It can be edited and expanded to include whichever material is desired, following the information given in the file.

The file may contain comment lines, which are preceded by a semi-colon ";" character.

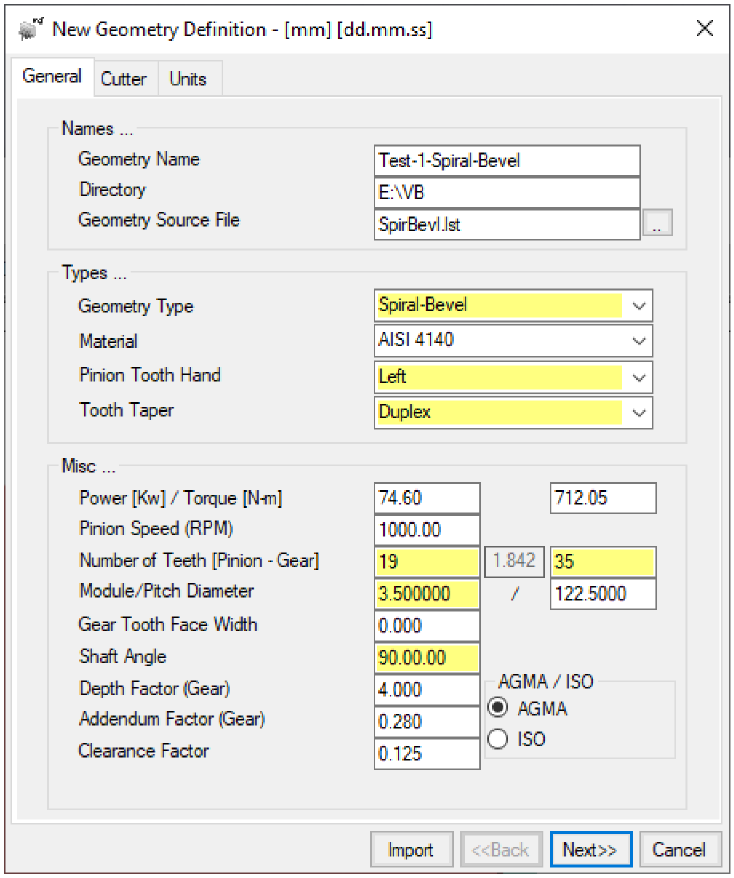
Material data is to be given in the following sequence, using the same spacing as that provided in the reference material file:

- Material Name,
- Bending Strength,
- Compressive Strength,
- Strength units; only the following unit symbols are recognized: PA, KPA, MPA, GPA, PSI, KSI
- Young's Modulus
- Poisson's ratio
- Young's Modulus units; only the following unit symbols are recognized: PA, KPA, MPA, GPA, PSI, KSI
- Hardness value
- Hardness units; the hardness units are not used for the moment; however, it is recommend to use hardness values in the following scales: BHN, HRC, HRB, HV
- Relative density (relative to water)
- Bending Strength ISO (always in MPa; used in the optional ISO-10300)
- Compressive Strength ISO (always in MPa; used in the optional ISO-10300)

Tooth Hand * — This input field refers to the pinion tooth hand, and offers a selection of either left or right hand pinion.

> **Important Note:**
>
> All preceding input fields are common to all supported gear types.
>
> Fields specific to each gear type are explained in the following sections.

7.7.2.1 Zerol, Spiral Bevel and Hypoid gears



Tooth Taper * This input field offers a selection of four tooth tapers:

i) Standard
ii) Duplex
iii) Tilted Root Line
iv) Uniform

For a complete description of the Spiral-Bevel and Hypoid geometries and taper definition, references given at the end of this document should be consulted.

Power (HP, Kw) Pinion input power (in HP or Kw).

Speed (RPM) * Pinion speed, in RPM. If left blank, a default value of 1000 RPM will be provided.

Number of Teeth * Pinion and gear tooth numbers. The value displayed between the pinion and gear tooth numbers is the speed ratio, which is updated as the tooth numbers change. When the gear tooth number is changed, the Gear Pitch Diameter (below) is updated.

Diametral Pitch * Gear diametral pitch, if the linear units are in inches [1/in].

Module * Gear module, if the linear units are in millimeters [mm].

Pitch Diameter Gear pitch diameter, in the current units ([mm], [in]); when the pitch diameter is modified, the Gear Diametral pitch or Module is recalculated based on the current gear number of teeth.

Gear Face Width Gear tooth face width (linear units). In Helixform gear sets, the tooth facewidth affects the angular face of the gear member and since the F45 Helixform cutting machine standard angular face angle is 30, a warning message will be issued if the facewidth produces a face angle larger than the standard value.

In all cases, the gear tooth facewidth should not exceed 30% of the gear outer cone distance, which is the value HyGEARS will default to if the field is left blank.

Shaft Angle * Angle between pinion and gear shafts (angular units). For the current version of HyGEARS, Hypoid gears are limited to 90° shaft angle, and spiral bevel gears may have 80° to 100° shaft angles.

Spiral bevel gears may have 20 to ~110 shaft angles; if the pitch angle of the gear member exceeds 85°, the shaft angle will be reduced until the pitch angle is equal or less than 85°.

However, it is not possible to have less than an 80 shaft angle for non generated spiral-bevel gear sets, as the pinion machine root angle will be less than -12, the limit on many existing generators.

Depth Factor Gear depth factor, at mid-face. HyGEARS will default to the following suggested depth factors as a function of the pinion tooth number if the field is left blank. Generally speaking, a depth factor of 4 is adequate, but other values may be used, as dictated by experience.

Type of Gear	Pinion Tooth Number	Depth Factor
Spiral Bevel	12 and + 11	4.000 3.990

	10	3.950
	9	3.880
	8	3.790
	7	3.670
	6	3.530
Hypoid	11 and +	4.000
	10	3.900
	9	3.800
	8	3.700
	7	3.600
	6	3.500

Addendum Factor Gear addendum factor, at mid-face, to apportion the working depth between the pinion and gear addendums. HyGEARS will default to the following suggested addendum factors as a function of the pinion tooth number if the field is left blank.

For gear pairs where the gear member is not generated:

Pinion Tooth Number	Addendum Factor
9 and +	0.170
8	0.150
7	0.130
6	0.110

For gear pairs where the gear member is generated, and the pinion has less than 21 teeth:

Pinion Tooth Number	Addendum Factor
12 and +	$0.210 + 0.290/m^2_{90}$
11	$0.210 + 0.280/m^2_{90}$
10	$0.175 + 0.260/m^2_{90}$
9	$0.145 + 0.235/m^2_{90}$
8	$0.130 + 0.195/m^2_{90}$
7	$0.110 + 0.160/m^2_{90}$

6	$0.100 + 0.115/m^2_{90}$

where m^2_{90} is the equivalent 90° speed ratio.

For gear pairs where the gear member is generated, and the pinion has 21 teeth or more:

Speed Ratio	Addendum Factor
3.333 + : 1	0.300
2.500 : 1	0.325
2.000 : 1	0.350
1.667 : 1	0.375
1.429 : 1	0.400
1.250 : 1	0.425
1.111 : 1	0.450
1.000 : 1	0.500

Clearance Factor Gear clearance factor, at mid-face, between the tooth root and the tip of the mating member; HyGEARS will then adjust the mating member's Face Apex beyond the Crossing Point to satisfy the requested clearance factor value.

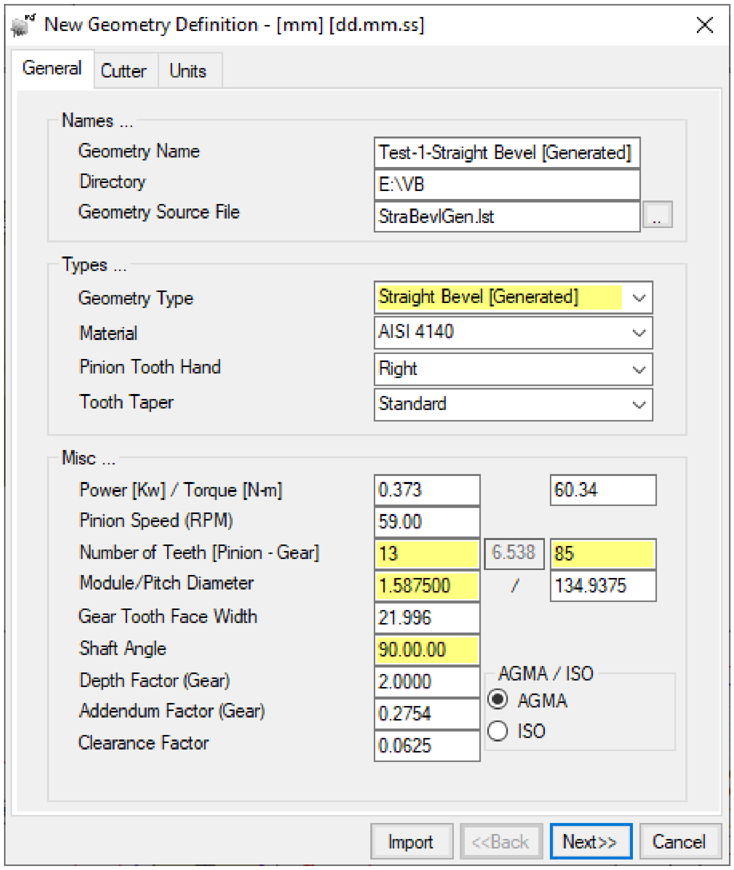
HyGEARS will default to 0.125 when the field is left blank, or a value less than 0.025 is entered.

Offset Pinion design offset (linear units) for Hypoid gears. The offset will be below center for a left hand pinion and above center for a right hand pinion. A plus or minus sign has no effect since HyGEARS will automatically default to this convention.

The recommended values for this field range from 10% to 20% of the gear pitch diameter. If this field is left blank, HyGEARS will default to 10% of the gear pitch diameter.

7.7.2.2 Straight Bevel gears

In HyGEARS, just about any type of modification can be imposed to the pinion or gear, such as modified roll to control and improve transmission error, or crowning to localize the contact.



Pinion Tooth Hand — The teeth can be straight or have an helix angle (given in the Cutter data page)

Tooth Taper — Can be *Standard* or *Uniform*

Power (HP, Kw) — Pinion input power (in HP or Kw – Units depend on the choice of the Units data page).

Speed (RPM) — Pinion RPM. If left blank, a default value of 1000 RPM will be provided.

Number of Teeth * — Pinion and gear tooth numbers.

Diametral Pitch * — Gear diametral pitch, if the linear units are in inches [1/in]; when the Gear diametral pitch is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth.

Module * — Gear module, if the linear units are in millimeters [mm]; when the Module is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth.

Pitch Diameter

Gear pitch diameter, in the current units ([mm], [in]); when the pitch diameter is modified, the Gear Diametral pitch or Module is recalculated based on the current gear number of teeth.

Gear Face Width

Gear tooth face width (linear units). Normally, to avoid undercutting, the gear tooth facewidth should not exceed 30% of the gear outer cone distance, which is the value HyGEARS will default to if the field is left blank.

Shaft Angle *

Angle between pinion and gear shafts (angular units). Any shaft angle may be used, but angles less than 10 are not allowed since they may not produce reliable results; 90 is usual; angles in the neighborhood of 135 to 150 effectively create an internal straight-bevel gearset.

Depth Factor

Gear depth factor, at mid-face. HyGEARS will default to the following suggested depth factors as a function of the pinion tooth number if the field is left blank. Generally speaking, a depth factor of 2.000 is adequate, but other values may be used, as dictated by experience.

Pinion Tooth Number	Depth Factor
12 and +	2.000
11	1.995
10	1.975
9	1.940
8	1.900
7	1.835
6	1.752

HyGEARS will default to 0.210 when the field is left blank, or a value less then 0.025 is entered.

Addendum Factor

Gear addendum factor, at mid-face, to apportion the working depth between the gear addendum. HyGEARS will default to the following suggested addendum factors as a function of the pinion tooth number if the field is left blank.

Pinion Tooth Number	Addendum Factor
12 and +	0.220
11	0.210
10	0.175

9	0.145
8	0.130
7	0.110
6	0.100

HyGEARS will default to 0.210 when the field is left blank, or a value less then 0.025 is entered.

Clearance Factor

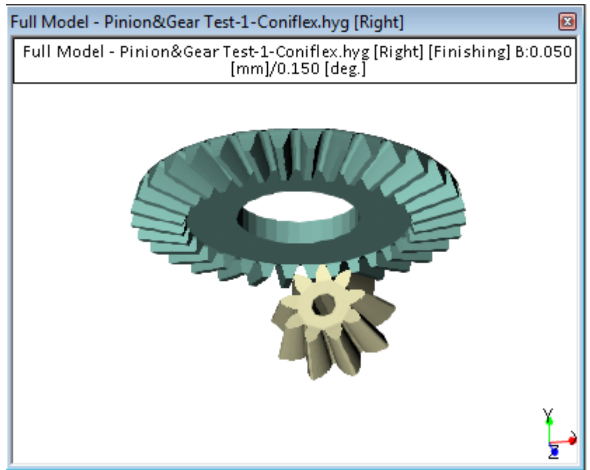
Gear set clearance factor, at mid-face, between the tooth root and the tip of the mating member; HyGEARS will then adjust the mating member's Face Apex beyond the Crossing Point to satisfy the requested clearance factor value.

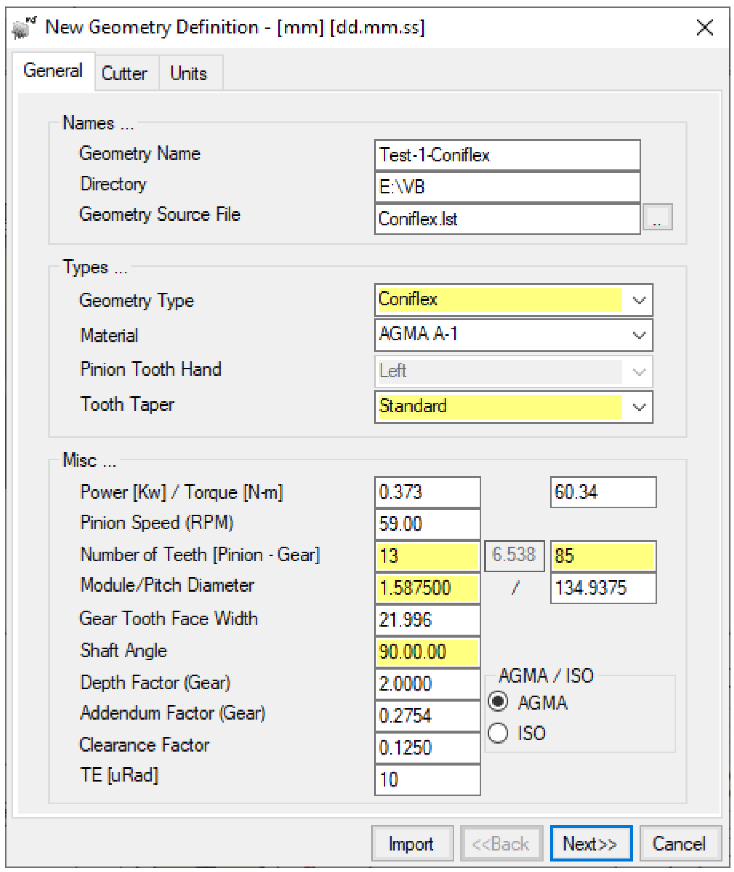
HyGEARS will default to 0.125 when the field is left blank, or a value less then 0.025 is entered.

7.7.2.3 Coniflex gears

HyGEARS can calculate *Coniflex* straight bevel gears of module ~1 up to ~9 mm. Gleason machines #102, #104, #114 and #134 are supported.

The Contact Pattern will be centered on the tooth flank, and the Transmission Error will be in the order of 50 µRad.





Number of Teeth * Pinion and gear tooth numbers.

Diametral Pitch * Gear diametral pitch, if the linear units are in inches [1/in]; when the Gear diametral pitch is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth.

Module *	Gear module, if the linear units are in millimeters [mm]; when the Module is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth.
Pitch Diameter	Gear pitch diameter, in the current units ([mm], [in]); when the pitch diameter is modified, the Gear Diametral pitch or Module is recalculated based on the current gear number of teeth.
Gear Face Width	Gear tooth face width (linear units). Normally, to avoid undercutting, the gear tooth face width should not exceed 30% of the gear outer cone distance, which is the value HyGEARS will default to if the field is left blank.
Shaft Angle *	Angle between pinion and gear shafts (angular units). Any shaft angle may be used, but angles less than 15° are not recommended since they may produce unreliable results; 90° is usual; angles above 90° do not produce acceptable results, especially when the gear pitch angle is above 80°.
Depth Factor	Gear depth factor, at mid-face. HyGEARS will default to the following suggested depth factors as a function of the pinion tooth number if the field is left blank. Generally speaking, a depth factor of 2.000 is adequate, but other values may be used, as dictated by experience.

Pinion Tooth Number	Depth Factor
12 and +	2.000
11	1.995
10	1.975
9	1.940
8	1.900
7	1.835
6	1.752

HyGEARS will default to 2.000 when the field is left blank, or a value less than 0.025 is entered.

Addendum Factor	Gear addendum factor, at mid-face, to apportion the working depth between the gear addendum. HyGEARS will default to the following suggested addendum factors as a function of the pinion tooth number if the field is left blank.

Pinion Tooth Number	Addendum Factor
12 and +	0.220

11	0.210
10	0.175
9	0.145
8	0.130
7	0.110
6	0.100

HyGEARS will default to 0.210 when the field is left blank, or a value less than 0.025 is entered.

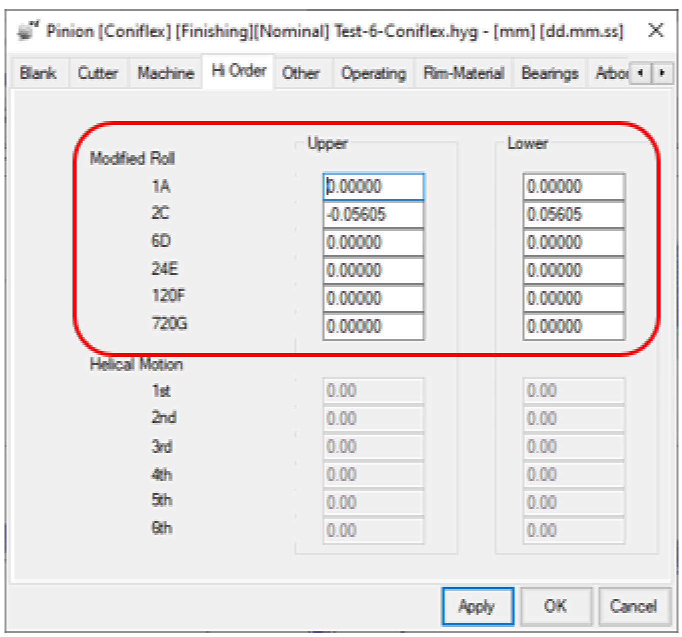
Clearance Factor

Gear clearance factor, at mid-face, between the tooth root and the tip of the mating member; HyGEARS will then adjust the mating member's Face Apex beyond the Crossing Point to satisfy the requested clearance factor value.

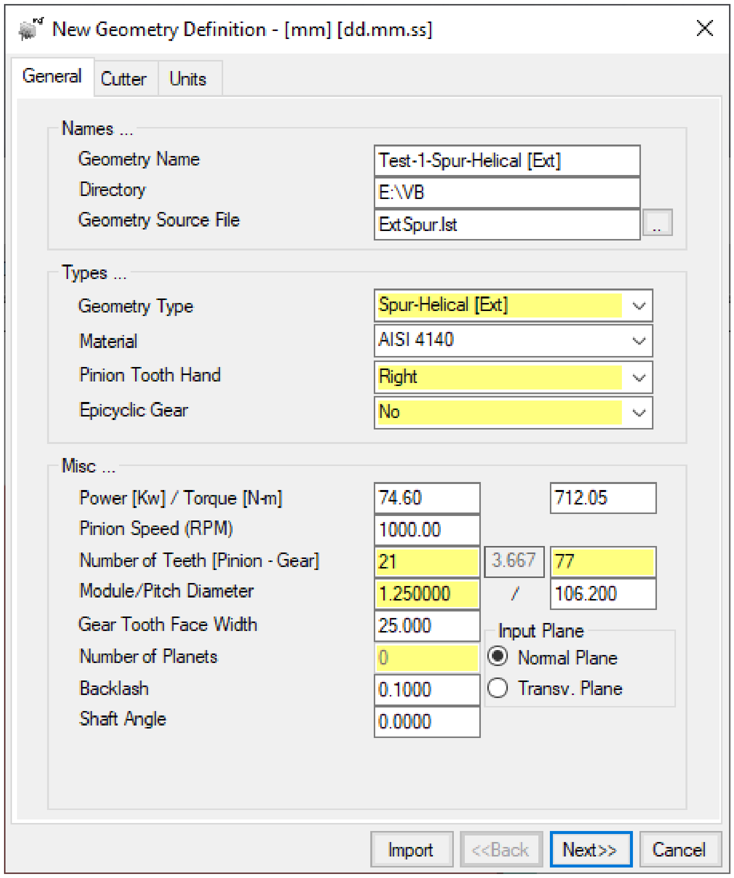
HyGEARS will default to 0.125 when the field is left blank, or a value less than 0.025 is entered.

TE [uRad]

Desired level of Transmission Error, in mRad. If 0, then TE is ignored. TE is controlled by modified roll; therefore, the Higher Order changes for Modified Roll are then accessible in the Summary editor, as is shown below.



7.7.2.4 Spur and Helical gears



Pinion Tooth Hand — Left or right hand, as per the drop down box. A left handed pinion has teeth that go toward left when seen from the toe end. A left handed pinion mates with a right handed gear.

Epicyclic Gear Train — Yes or No; HyGEARS has the built in ability to simulate either the sun to planet mesh with external gears, or the planet to ring gear mesh with internal gears. In both cases, all applied torques and RPMs are assumed on the pinion, and at load application time, torque will be divided by the number of planets. At display time, for the sun to planet mesh the ring gear is displayed as a toothless ring, and for the planet to ring gear mesh the pinion is displayed as a toothless cylinder.

Power (HP, Kw) — Pinion input power (in HP or Kw – Units depend on the choice of the Units data page).

*Speed (RPM) ** — Pinion speed, in RPM. If left blank, a default value of 1000 RPM will be provided. For epicyclic gear trains, this entry corresponds to the sun (pinion) RPM.

Number of Teeth * Pinion and gear tooth numbers.

Diametral Pitch * Gear diametral pitch, if the linear units are in inches [1/in]; when the Gear diametral pitch is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth. May be given either in the Normal or Transverse plane as selected from the Input Plane window.

Module * Gear module, if the linear units are in millimeters [mm]; when the Module is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth. May be given either in the Normal or Transverse plane as selected from the Input Plane window.

Pitch Diameter Gear pitch diameter, in the current units ([mm], [in]); when the pitch diameter is modified, the Gear Diametral pitch or Module is recalculated based on the current gear number of teeth.

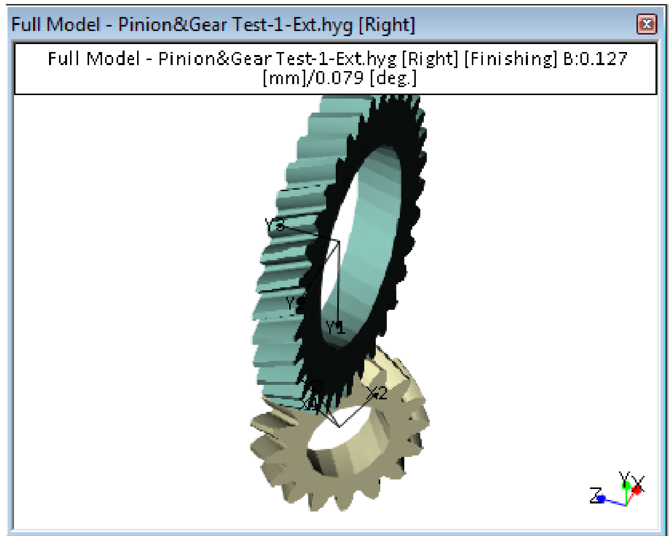
Gear Face Width * Gear tooth face width (linear units).

Number of Planets * For non-planetary gear trains, this amounts to zero; for planetary gear trains, this value must be larger than zero; no verification is made as to the possibility of interference between neighboring planets.

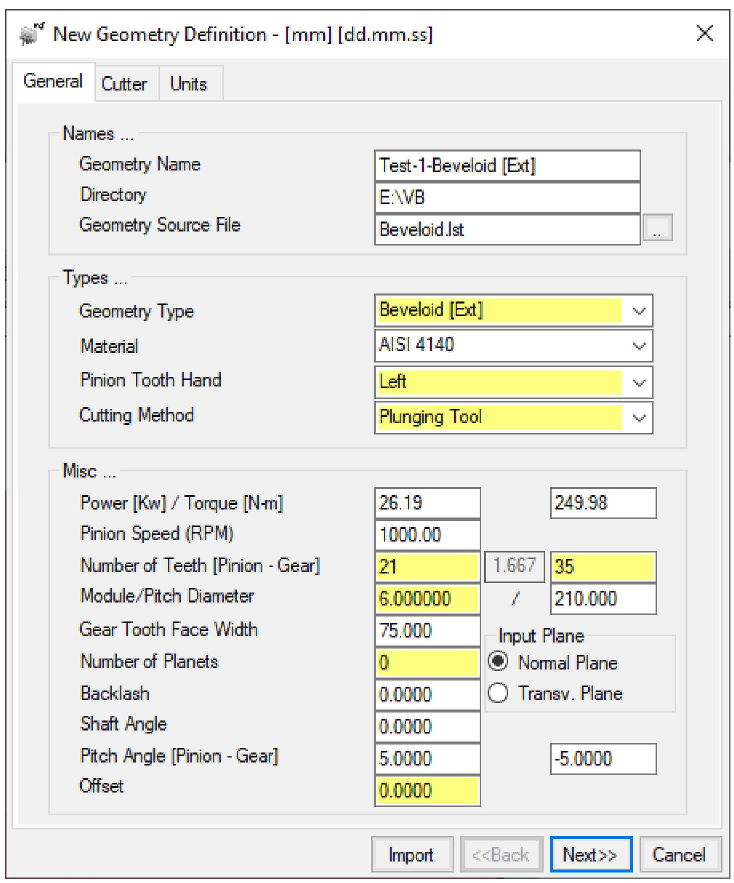
Shaft Angle Angle between pinion and gear shafts (angular units). Applies only to external gears. Maximum value is 60 º.

For *Spur and Helical* gears, any shaft angle non equal to zero results in crossed axis helical gears, the pinion having an helix angle equal to that of the entry in the Cutter data page, the gear having an helix angle equal to the complement between that of the pinion and the shaft angle.

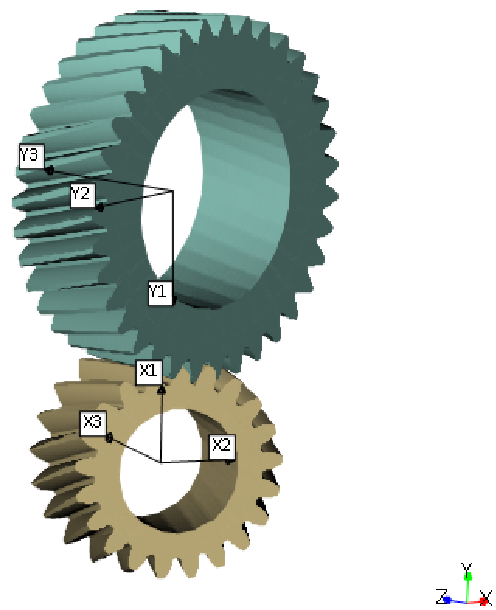
If the shaft angle is non-zero, then the pinion helix angle should also be non-zero, and preferably, close to half the value of the shaft angle.



7.7.2.5 Beveloid gears



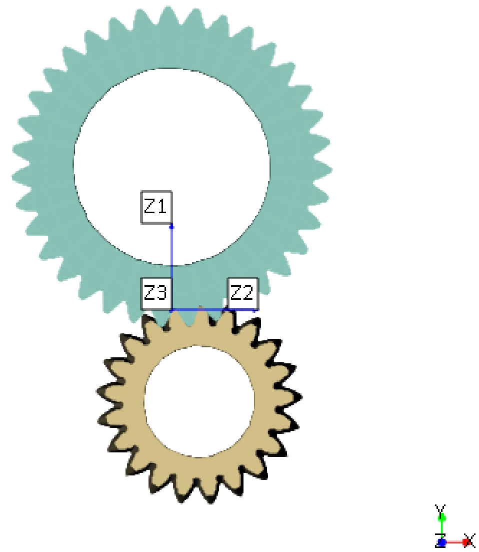
Pinion Tooth Hand	Left or right hand, as per the drop down box. A left handed pinion has teeth that go toward left when seen from the toe end. A left handed pinion mates with a right handed gear.
Cutting Method	Plunging Tool or Pivoted Work. For Plunging Tool, the tool moves radially as a function of its position along the face width; in practice, the Profile Shift changes. For Pivoted Work, the work piece is pivoted by the Pitch Angle and the tool moves in a straight line.
Power (HP, Kw)	Pinion input power (in HP or Kw – Units depend on the choice of the Units data page).
Speed (RPM) *	Pinion speed, in RPM. If left blank, a default value of 1000 RPM will be provided. For epicyclic gear trains, this entry corresponds to the sun (pinion) RPM.
Number of Teeth *	Pinion and gear tooth numbers.
Diametral Pitch *	Gear diametral pitch, if the linear units are in inches [1/in]; when the Gear diametral pitch is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth. May be given either in the Normal or Transverse plane as selected from the Input Plane window.
Module *	Gear module, if the linear units are in millimeters [mm]; when the Module is modified, the Gear Pitch Diameter is recalculated based on the current gear number of teeth. May be given either in the Normal or Transverse plane as selected from the Input Plane window.
Pitch Diameter	Gear pitch diameter, in the current units ([mm], [in]); when the pitch diameter is modified, the Gear Diametral pitch or Module is recalculated based on the current gear number of teeth.
Gear Face Width *	Gear tooth face width (linear units).
Number of Planets *	Should be 0.
Backlash	Desired operating backlash (linear units).
Shaft Angle	Angle between pinion and gear shafts (angular units). Applies only to external gears. Maximum value is 60 º. The shaft angle is applied to the gear member such that both the pinion and gear axes are in the same plane and intersect at their apex.

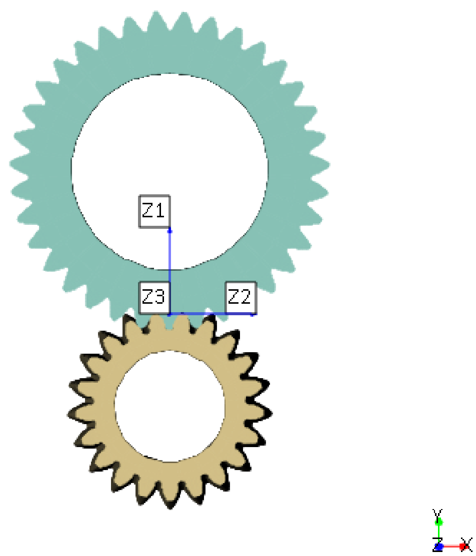


Pitch Angle Pitch cone angle for the Pinion and Gear; when the same value is used with opposite signs, the axes or rotation are parallel. Otherwise, they are concurrent.

Offset The pinion may be offset (left below) relative to its normally centered position (right below).

With offset **No offset**





7.7.3 Cutter Data Page

When creating a *New Geometry*, data required to define the Cutter and Machining processes vary according to the geometry to be created.

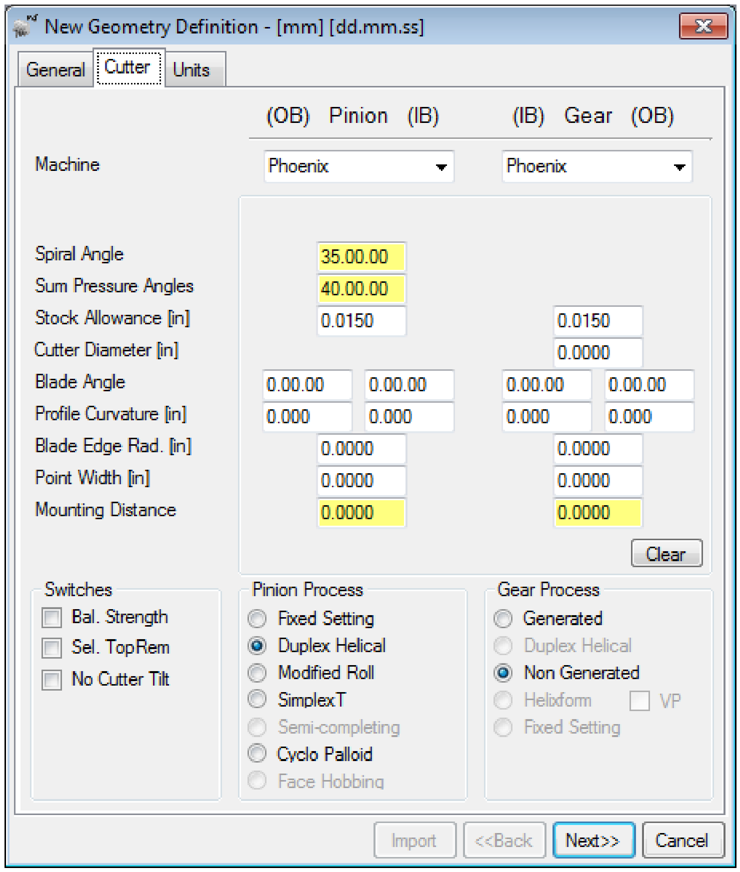
In particular, *Cutter* data is specific to geometry type, as follows:

Zerol, Spiral-Bevel and Hypoid Gears

[Straight-Bevel Gears](#)

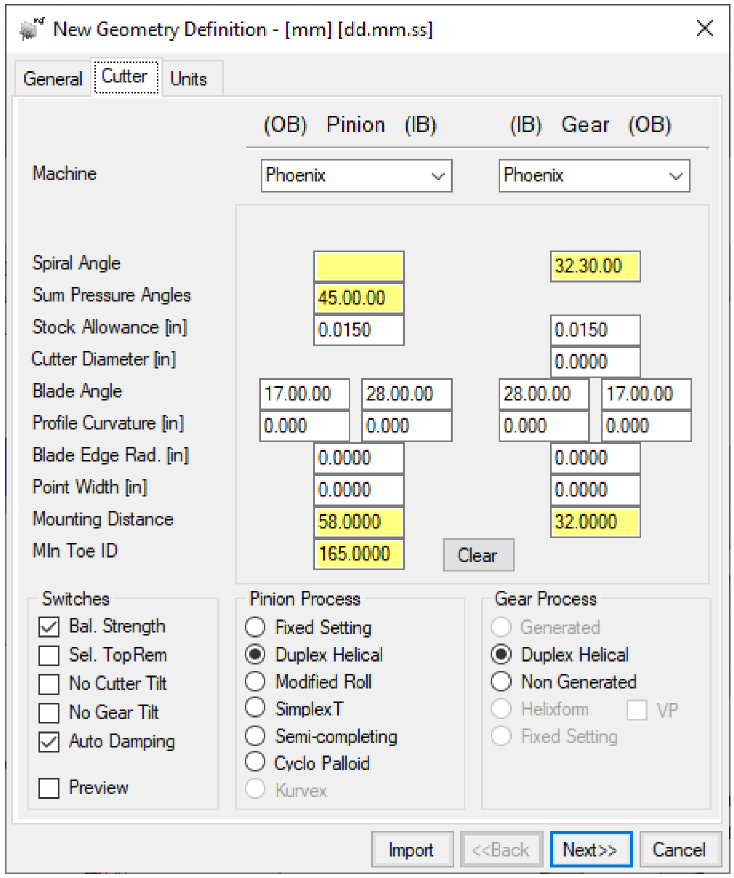
[Coniflex Gears](#)

[Spur, Helical and Beveloid Gears](#)



7.7.3.1 Zerol, Spiral Bevel and Hypoid gears

The Cutter data page shown below covers data related to the selected machine, spiral angle, pressure angle, cutter dimensions and blade angles. Selections and input fields are offered for both the pinion and the gear.



Machine

In HyGEARS, the machine names are based on the model number. The Machine input field considers only the finishing machine, the roughing machine being either the same as the finishing machine, or a close parent usually associated. A Completing Cycle does both roughing and finishing on the same machine.

Finishing Process	Roughing Process
Fixed Setting	Spread Blade
Duplex Helical	Completing Cycle
Modified Roll	Spread Blade
Face Hobbing	Completing Cycle
Semi-Completing	Completing Cycle
Spread Blade	Spread Blade
Formate	Formate/ Completing Cycle
Helixform	Non-Generated Plunge
Simplex-T	Completing Cycle

> **Important Note:**
>
> At this time, it **is not possible to create a Face Hobbed** geometry directly; it must either be imported through Gleason ".spa" files, Klingelnberg neutral data files or entered manually (see Existing Geometry).

Gleason Machine Number
16
22
26
102
106
108
116
Phoenix
607
613
631
641
Basic 999

Klinglenberg Machine Number
K-ND (neutral data)
Other Machine Number
YH 603 (no cutter tilt)

> **Important Note:**
>
> Machine #603 is a chinese 4 Axis CnC generator that cannot accommodate cutter tilt. It can be used solely as the cutting machine for a gear member without cutter tilt.
>
> However, for generated Duplex Helical spiral-bevel gears, this machine may be chosen for either the pinion or gear and then the gearset is cut *without cutter tilt* which means a possible degradation in the behavior of the gearset. This is best applied to small module gearsets, with a speed ratio above 3.5.

The pinion and gear process inputs, at the bottom of the Cutter Data section, determine which machine is offered in the Machine field.

Conversion to other machines can later be done when editing either the pinion or the gear summaries.

Gear Convex Press. This input field, available only for Hypoid gears with non-constant depth teeth, offers the possibility to specify the desired pressure angle, in the root cone of the driving tooth flank of the gear member, e.g. gear convex. If this field is left blank, HyGEARS will calculate its own pressure angle value. The minimum pressure angle value is 8. To change the pressure angle, HyGEARS modifies the gear member root angle.

Spiral Angle Pinion or gear spiral angle at mid-face (angular units).

When creating a new Hypoid gear set, it is possible to impose the spiral angle on the gear rather than on the pinion. If the Spiral Angle field for the pinion is left blank and that of the gear is filled, HyGEARS will take the gear's value as the target and find the pinion spiral angle that matches the desired gear value for the given set of parameters.

If both entries are left blank, the pinion spiral angle will be calculated using the following formula (for Hypoid gears):

$$\psi = 25 + 5\sqrt{\frac{Ng}{Np}} + 90\frac{E}{D}$$

where:	Ng	is the gear tooth number
	Np	is the pinion tooth number
	E	is the pinion offset
	D	is the gear pitch diameter

For Spiral Bevel gears, the standard spiral angle is usually 35° and is the same for pinion and gear. If using the Fixed Setting or the Modified Roll processes for the Pinion, this angle can be reduced to 1°; if less, HyGEARS will default to 1°. For Completing cycles, such as Duplex Helical, at this time, spiral angles less than 20° do not yield predictable results and a warning message will be issued.

Sum Press. Angles On Hypoid gear sets, the pressure angles are different on the convex and concave sides because of the pinion offset. For this reason, the sum of the pressure angles is normally specified (angular units). The following values are recommended:

36 and 40	light drives

45 and 50	heavy duty drives

To avoid undercut, a sum of pressure angles of 40 or more should be used on gear sets with pinions of 12 teeth or less. A default value of 45 will be used if this input field is left blank.

For spiral bevel gears, the pressure angles are normally the same on both tooth flanks, and the Mean Pressure Angle will thus be half the value given in this field.

Stock Allowance

The pinion and gear material removal allowance between roughing and finishing cuts. The roughing cutter and machine settings data will be calculated from the finish machine settings to leave enough material to remove at the finishing pass such as to completely cover the tooth flank. A default value of 0.015 " (0.381 mm) is used when this field is left blank.

Cutter Diameter

The pinion point cutter diameter for either or both the convex (I.B.) and concave (O.B.) tooth sides may be given for Fixed Setting or Modified Roll pinions, if it is desired to use an existing cutter; the average diameter is to be provided for Duplex Helical pinions. If the cutter diameter is not specified, it is calculated from the gear cutter diameter and point width, pinion and gear blade angles, and 25 to 30% tooth flank Contact Pattern coverage. The Contact Pattern coverage can later be modified using the Graphics->Contact Pattern Development function.

The gear average cutter diameter can be inputted in the specified units. Since cutters come in standard dimensions, standard practice should be followed in selecting an appropriate gear cutter diameter.

Gear cutter diameters are normally based on the gear mean cone distance; and they should be kept within the following limits:

$$2.2A_{mG}\sin(\Psi)\leq C_d\leq 2A_{mG}$$

where: AmG is the gear mean cone distance;

Cd is the gear cutter diameter;

y is the mean gear spiral angle.

If the inputted gear cutter diameter exceeds one of these limits, a warning will be issued allowing to modify the inputted cutter diameter value before proceeding. If the warning is ignored, HyGEARS will proceed, but the results cannot be guaranteed.

It should also be noted that specifying the gear cutter diameter automatically defines the pinion cutter point or average diameters, if the fields have been left blank. On the other hand, specifying the pinion cutter point or average diameters without specifying the gear cutter diameter should be avoided.

The following table lists some standard cutter diameters as a function of gear pitch diameter.

Gear Pitch Diameter [in]	Gear Pitch Diameter [mm]	Cutter Diameter [in]
3.000 - 5.250	75 - 135	3.500
3.875 - 6.750	100 - 170	4.500
4.250 - 7.500	110 - 190	5.000
5.125 - 9.000	130 - 230	6.000
5.375 - 9.375	135 - 240	6.250
6.500 - 11.250	165 - 285	7.500
7.750 - 13.500	195 - 345	9.000
10.250 - 18.000	260 - 455	12.000
13.750 - 24.000	350 - 610	16.000
18.000 - 31.500	455 – 800	21.000

Blade Angle

In Hypoid gears, pressure angles on the convex (I.B.) and concave (O.B.) tooth flanks are different. The blade angles are normally based on the sum of pressure angles, and should be selected according to standard practice.

If the blade angles needed for a particular case are not known, it is preferable to let HyGEARS select default values, then use the standard cutter blade angle values closest to the values calculated by HyGEARS and rerun the New Geometry Definition function.

If the blade angles fields are left blank, HyGEARS will use the following default values:

Blade Edge Rad.

The cutter blade edge radius for either or both the convex (I.B.) and concave (O.B.) tooth flanks may be given in the specified units, if it is desired to use an existing cutter. If this field is left blank, best fit values will be calculated.

Point Width — The gear cutter point width may be given in the specified units, if it is desired to use an existing cutter. If this field is left blank, a best fit value will be calculated.

For Fixed Setting or Modified Roll pinions, the point width may be entered for information purposes only, but will not be used in calculations. For Duplex Helical pinions, if the point width is not provided, a default value will be calculated.

Mounting Distance — The pinion and gear mounting distances should be inputted in this field (linear units). If this field is left blank, HyGEARS will base the mounting distances on the Front Crown to Crossing point and tooth facewidth dimensions.

Pinion Process * — The pinion finishing process is the Fixed Setting by default. The selection of the Pinion process conditions the available gear cutting processes.

When the Cyclo Palloid process (optional) is selected, the Cyclo Palloid data page is displayed, and a number of input fields in the General and Cutter data pages are deactivated since they are superseded by Cyclo Palloid specific entries. Cyclo Palloid applies only to spiral bevel gears.

Gear Process * — Spiral bevel and hypoid gear members may be cut by four different processes, depending on the speed ratio and the available equipment. The four processes are: Formate, Helixform, Spread Blade, Duplex Helical (Face Hobbing is not available). The Formate process is the default setting.

When the Helixform cutting process is selected, a check box is shown to offer the choice of selecting a Variable Pitch cutter for gear members whose angular face is larger than 27.5 °

Note: Whatever the cutter choice made at this point, it can be changed later when HyGEARS calculates the initial machine settings. For example, if a Variable Pitch cutter was selected, and the gear angular face is less than 27.5 °, HyGEARS will offer the possibility to change the selection.

Switches — Several switches are offered to control specific aspects of geometry creation:

Bal. Strength: when this is checked, HyGEARS will modify the pinion and gear tooth thicknesses to balance the bending strength within 5%, therefore overriding any cutter point width that may have been entered; bending strength is calculated at mid-tooth height;

Sel. TopRem: when this is checked, HyGEARS looks at the Path of Contact (PoC) on the drive side (pinion concave-OB) and finds the 2nd contact point along the profile portion of the PoC; HyGEARS will then select the nearest TopRem value that exceeds the distance along the pinion blade edge at which the 2nd contact point occurs, thereby providing effective profile relief at contact entry; the default TopRem angle is 2.5 º. The default values may then be modified through the TopRem data page of the Summary Editor.

No Cutter Tilt: for spiral-bevels only. When this is checked (currently applicable only to generated Duplex Helical gears), HyGEARS will create a gearset in which no cutter tilt is used. This allows manufacturing on inexpensive 4 axis CnC machines such as the Chinese YH 603.

Important Note:

The machine settings produced by the New Geometry Definition function are only starting values for the development of a gear set.

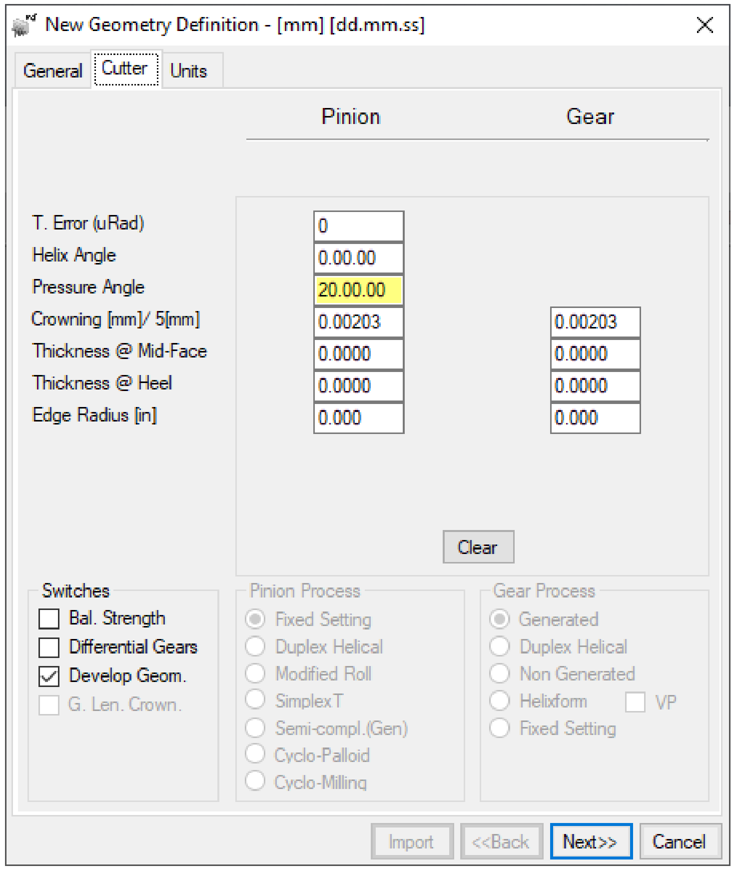
However, if the inputted values follow the recommended guidelines, HyGEARS will produce a gear set with a fairly bias-free Bearing Pattern covering 25 to 30% of the facewidth, centered at approximately 50% of the tooth facewidth.

Therefore, after using the New Geometry function, it is strongly recommended to use the Graphics->Bearing Pattern Development function to further develop machine settings and ensure the desired Bearing Pattern and operating conditions.

It is also recommended to use the Graphics->Blank function to verify the finishing and roughing tooth depths on both the pinion and gear members.

7.7.3.2 Straight Bevel gears

The Cutter data page shown below covers data related to pressure angle and tooth numbers.



T. Error (uRad)	the amount of TE in the given units; if zero, then no TE control is applied.
Helix Angle	the helix angle is imposed at zero, since this is a straight-bevel gear.
Pressure Angle *	the pressure angle corresponds to the actual blade angle that will be used to generate the gearset, and will be the gearset pressure angle at the pitch point, i.e. at mid-facewidth, on the pitch cone.
Crowning [mm] / 5[mm]	the desired amount of crowning per 5[mm] of tooth facewidth, pinion and gear;
Thickness @ Mid-Face	the desired tooth thickness at mid-facewidth; ignored if 0;
Thickness @ Heel	the desired tooth thickness at Heel; ignored if 0;
Edge Radius:	the desired cutter edge radius; ignored if 0.

Switches Several switches are offered to control specific aspects of geometry creation:

Bal. Strength: when this is checked, HyGEARS will modify the pinion and gear tooth thicknesses to balance the bending strength within 5%; bending strength is calculated at mid-tooth height;

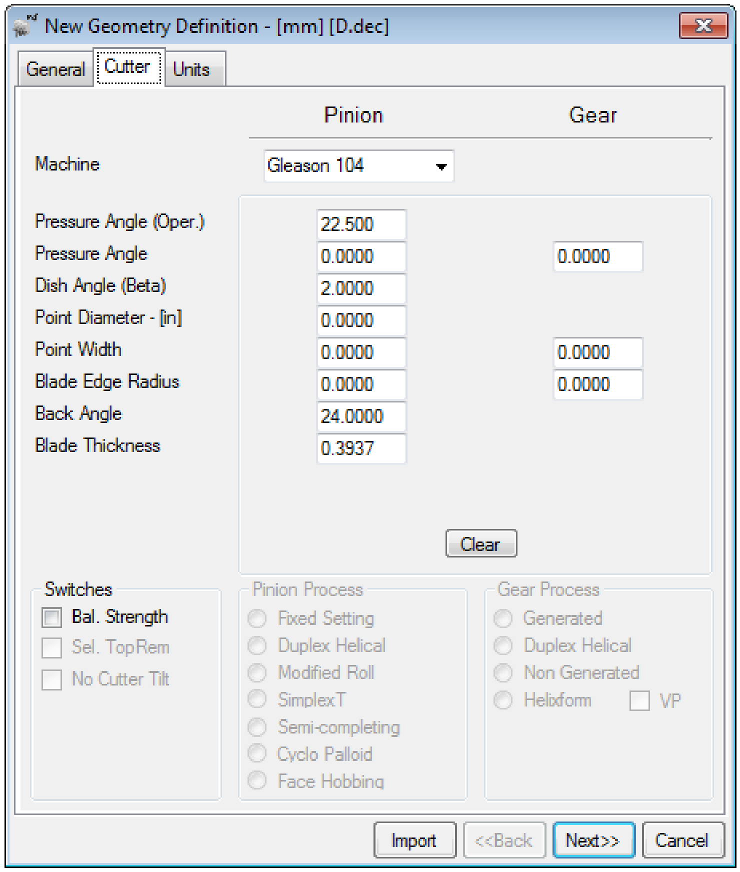
Differential Gears: when this option is selected, the usual Depth Factor (Gear), Addendum Factor (Gear) and Clearance Factor are no longer available and the default Gleason tooth proportion factors for differential gears are rather used where (units: inches):

- Mean working depth Hk = 1.600 / DP
- Mean whole depth H = 1.788 / DP + 0.002"
- Clearance C = 0.040 "
- Gear outer addendum aoG = 0.430 / DP + 0.370 / (DP *(Z2 / Z1)2)
- Pinion outer addendum aoP = H - aoG
- Gear outer dedendum boG = 1.788 / DP – aoG
- Pinion outer dedendum boP = 1.788 / DP – aoP

Develop Geom: when this is checked, which is the default, HyGEARS will modify the pinion and gear machine settings to obtain a centered contact pattern, with the required backlash and TE; otherwise, the raw machine settings are used directly.

7.7.3.3 Coniflex gears

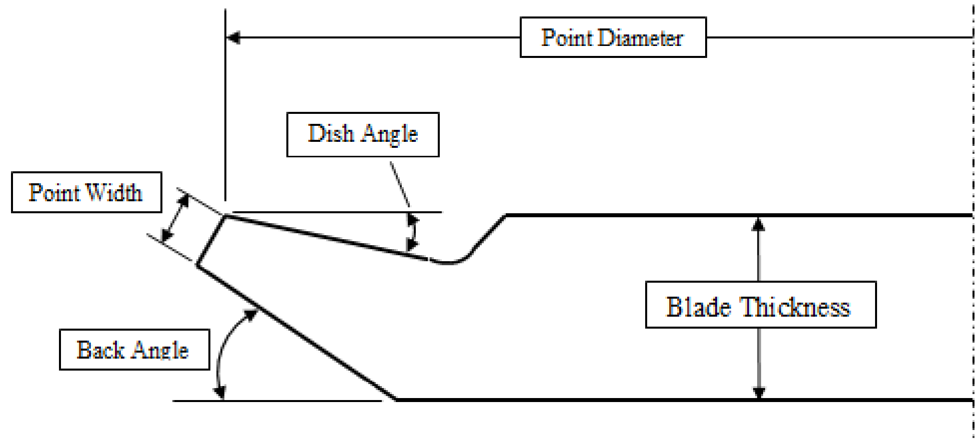
The Cutter data page shown below covers data related to pressure angle and tooth numbers.



Pressure Angle (Oper) Operating Pressure angle; this will be the pressure angle at the pitch point, mid-face width.

Pressure Angle The pressure angle corresponds to the actual blade angle that will be used to generate the gear-set, and will be the gear-set pressure angle at the pitch point, i.e. at mid-face width, on the pitch cone, unless a values has been entered for the Operating Pressure angle. If left blank, a default value will be provided.

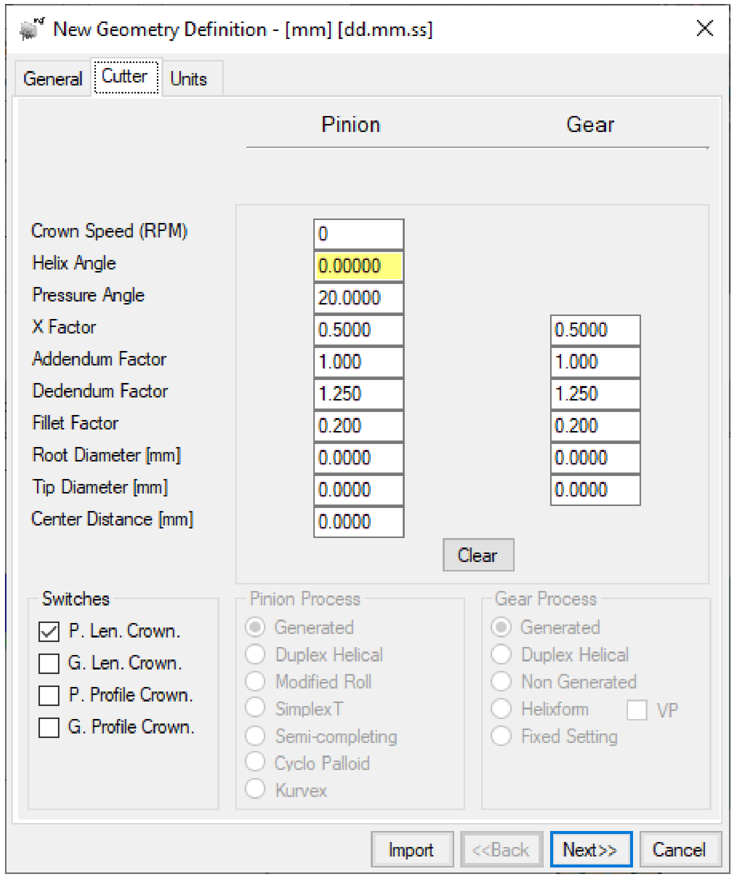
Dish Angle (Beta) The Coniflex cutter is similar to a dish; the Dish Angle is the deviation between a straight line and the actual cutting edge, as shown in the figure below. Default value varies as function of module and gear ratio.



Point Diameter	Point diameter of the Coniflex cutter. Default value is 4.25" or 107.95 mm for machine 102, 9" for machines 104 and 134, and 15" for machine 114. If left blank, the default value will be provided. Given in the current cutter units ([in] in above figure).
Point Width	Point Width of the Coniflex cutter. If left blank, a default value will be provided. Given in the current cutter units ([in] in above figure).
Blade Edge Radius	Edge radius of the Coniflex cutter. If left blank, a default value will be provided. Given in the current cutter units ([in] in above figure).
Back Angle	Back angle of the Coniflex cutter. If left blank, a default value of 24° will be provided.
Blade Thickness	Thickness of the Coniflex cutter. If left blank, a default value of 10 mm will be provided.

7.7.3.4 Spur, Helical and Beveloid gears

The Cutter data page shown below covers data related to tooth numbers and basic machining parameters.



Inputs

Crown Speed ... * — Crown gear speed, in RPM. If left blank, a default value of 0 RPM will be provided. This is used in epicyclic gear trains, and corresponds to the crown gear RPM.

Helix Angle — The hand of the helix angle depends on the tooth hand given in the General data page. If the Shaft angle is non zero, then the Pinion and Gear Helix angles will be half that of the Shaft angle. A zero shaft angle is imposed for internal gears.

Pressure Angle * — The pressure angle corresponds to the actual blade angle that will be used to generate the gearset, and will be the gearset pressure angle at the pitch point, i.e. at mid-facewidth, on the pitch circle. May be given in the Normal or Transverse plane as selected from the Input Plane window.

X Factor — Also called Profile Shift Factor. Desired amount of tool withdrawing at generation, to avoid undercutting. Actual tool shift is the product of the module time this factor, or the quotion of this factor by the diametral pitch. Often, if a positive value (withdraw from the axis of rotation) is given to the pinion, an equivalent negative (advance toward the axis of rotation) value is given to the gear member.

In all cases, a new operating center distance is calculated based on the inputted values.

*Addendum Factor **	Pinion/Gear addendum factor. This value must be positive and larger than zero.
*Dedendum Factor **	Pinion/Gear dedendum factor. This value must be positive and larger than zero.
*Fillet Factor **	Pinion/Gear fillet factor. This value must be positive and larger than zero.
Root Diameter	When this value is given, HyGEARS calculates the equivalent Dedendum Factor and uses the imposed diameter value. In the current linear units.
Outside Diameter	When this value is given, HyGEARS calculates the equivalent Addendum Factor and uses the imposed diameter value. In the current linear units.
TIF Diameter	True Involute Form diameter. When this value is given, HyGEARS will modify the Edge Radius of the cutter in order for the Involute profile to start at the specified TIF Diameter while respecting the Root Diameter, if specified.
Center Distance	Desired operating center distance. In the current linear units. When this value is imposed, HyGEARS calculates the gearset on its basic center distance, and then operates it on the given center distance. Therefore, if the given center distance is too small, tip to fillet/root interference may result, along with reduced backlash (even negative backlash); if too large, then backlash will increase, and contact ratio may become insufficient.

<u>Switches</u>

P. Len. Crown.	Pinion Lengthwise Crowning. If selected, HyGEARS will apply default lengthwise crowning to the pinion tooth.
G. Len. Crown.	Gear Lengthwise Crowning. If selected, HyGEARS will apply default lengthwise crowning to the gear tooth.

P. Profile Crown.	Pinion Profile Crowning. If selected, HyGEARS will apply default profile modifications to the pinion tooth.
G. Profile Crown.	*Gear* Profile Crowning. If selected, HyGEARS will apply default profile modifications to the gear tooth.

7.7.4 Units Data Page

The input fields of the Units data page concern the units used in the New Geometry window and can be changed at anytime, without losing the values already entered in the input fields:

In addition, it is possible to tell HyGEARS that **existing blanks** are to be used when calculating the new Geometry. To specify the existing blanks, the Outside Diameters, Face Angles and Face Apex beyond the Crossing Point of both the pinion and gear members must be specified.

Zerol, Spiral-Bevel and Hypoid Gears

Straight Bevel and Coniflex Gears

Spur, Helical and Beveloid Gears

> **Important Note:**
>
> When existing blank dimensions are specified, HyGEARS will attempt to find an acceptable solution, but there is no guarantee that the requested dimensions will be exactly provided or useable.

Units

Linear Units Desired linear units, either [in] or [mm], which apply to Diametral Pitch, Face Width, Offset and Mounting Distance. They are identified in the New Geometry Definition window title bar. The New Geometry input fields affected by a change in the selected linear units will be updated. The selected linear units will remain bound to the Geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

The following table gives the units in use when linear units are either [in] or [mm]:

	[in]	[mm]

Torque	[lb-in]	[N-m]
Force	[lb]	[N]
Stress	[Ksi]	[Mpa]
Power	[HP]	[Kw]
Stiffness	[lb/in]	[N/mm]
Volume	[in^3]	[mm^3]
Mass	[lbm]	[kgm]
Inertia	[lbm- in^2]	[kgm- mm^2]
Speed	[ft/min]	[m/min]
Misalignment	[in/in]	[mm/mm]
Surface Finish	[µin]	[µm]
Temperature	[F]	[C]
Warp	[/0.1 in]	[/10 mm]

Note that, internally, HyGEARS performs all its calculations in imperial units. The units are converted only when input or output is required.

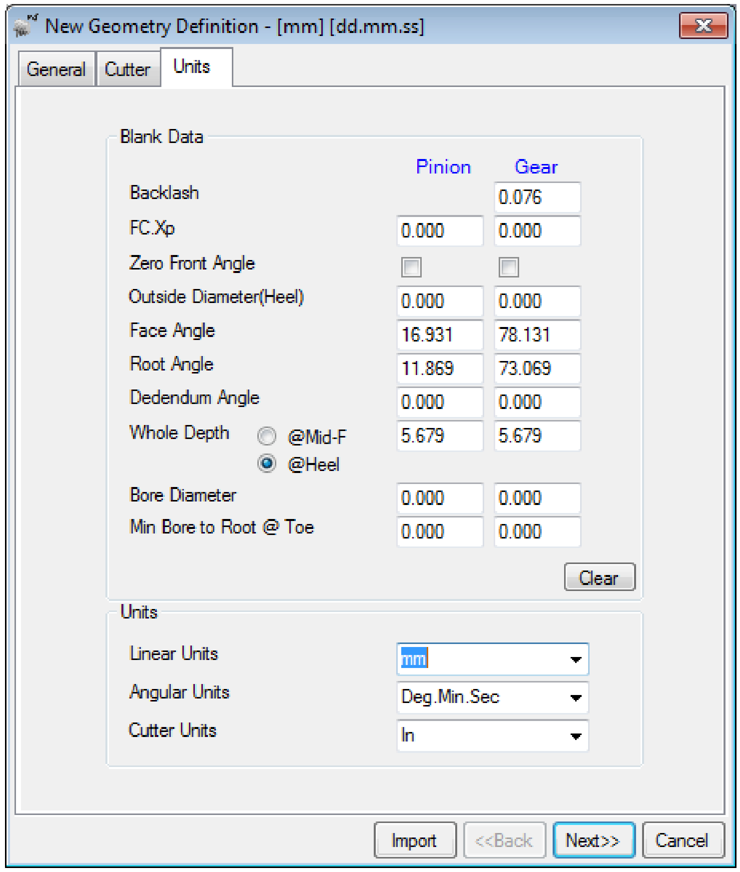
Angular Units Desired angular units, which apply to Spiral Angle, Pressure Angle and Blade Angles, and may either be in decimal format or Degree.Minute.Second format (dd.mm.ss). They are identified in the New Geometry Definition window title bar. The New Geometry input fields affected by a change in the selected angular units will be updated. The selected angular units will remain bound to the Geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

Cutter Units Desired cutter units, either [in] or [mm], which apply to Cutter Diameter, Stock Allowance, Blade Edge Radius and Point Width, and are specifically identified next to the input field titles. The New Geometry input fields affected by a change in the selected cutter units will be updated. The selected cutter units will remain bound to the Geometry until they are changed from the HyGEARS configuration window (Edit->Configuration).

7.7.4.1 Zerol, Spiral Bevel and Hypoid gears

Blank Data

HyGEARS allows the user to impose several Blank dimensions, as follows.



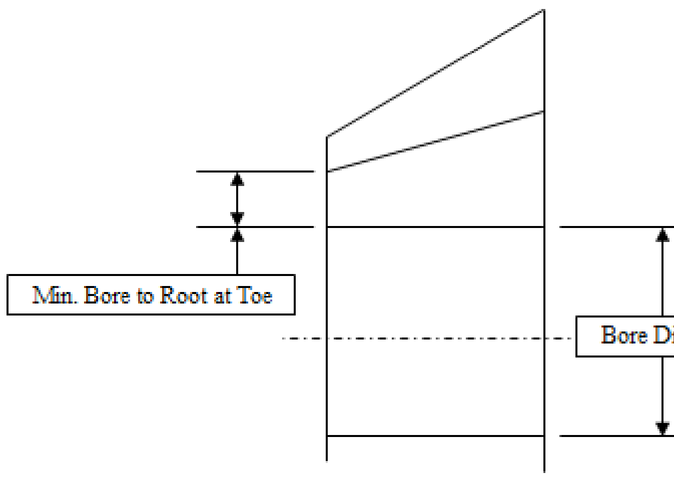
Backlash	Desired operating backlash; if the cutter blade Point Width is imposed, imposing backlash may cause too deep or too shallow teeth. If left blank, a default value will be provided.
FC.Xp	Desired Front Crown to Crossing Point; if left empty, then the calculated value is used.
Zero Front Angle	When checked, the Front Angle of the blank is zero; otherwise, the Front Angle equals the Pitch Angle.
Outside Diameter	Desired OD, for the pinion and gear members; this value is interpreted as a *tip diameter* rather than a *turned diameter*. If left blank the calculated value will be used.
Face Angle	Desired Face Angle, for the pinion and gear members; if left blank the calculated value will be used.
Root Angle	Desired Root Angle, for the pinion and gear members; if left blank the calculated value will be used.

Dedendum Angle Dedendum angle on the pinion and gear members; if left blank the calculated value will be used. The Root Angle is given priority over the Dedendum Angle if not zero.

Whole Depth Tooth whole depth at mid-face or Heel. If left blank, the whole depth will be based on the addendum and dedendum factors.

Bore Diameter Desired diameter of the bore of the blank. If left blank, a default value will be provided.

Min. Bore to Root This value works in conjunction with the Bore Diameter above. If a value is entered, HyGEARS will attempt to adjust tooth depth such that the requested value is satisfied at Toe.



Important Note:

When existing blank dimensions are specified, HyGEARS will attempt to find an acceptable solution, but there is no guarantee that the requested dimensions will be exactly provided or useable.

Units

Linear Units Desired linear units, either [in] or [mm], which apply to Diametral Pitch, Face Width, Offset and Mounting Distance. They are identified in the New Geometry Definition window title bar. The New Geometry input fields affected by a change in the selected linear units will be updated. The selected linear units will remain bound to the Geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

The following table gives the units in use when linear units are either [in] or [mm]:

	[in]	[mm]
Torque	[lb-in]	[N-m]
Force	[lb]	[N]
Stress	[Ksi]	[Mpa]
Power	[HP]	[Kw]
Stiffness	[lb/in]	[N/mm]
Volume	[in^3]	[mm^3]
Mass	[lbm]	[kgm]
Inertia	[lbm- in^2]	[kgm- mm^2]
Speed	[ft/min]	[m/min]
Misalignment	[in/in]	[mm/mm]
Surface Finish	[µin]	[µm]
Temperature	[F]	[C]
Warp	[/0.1 in]	[/10 mm]

Note that, internally, HyGEARS performs all its calculations in imperial units. The units are converted only when input or output is required.

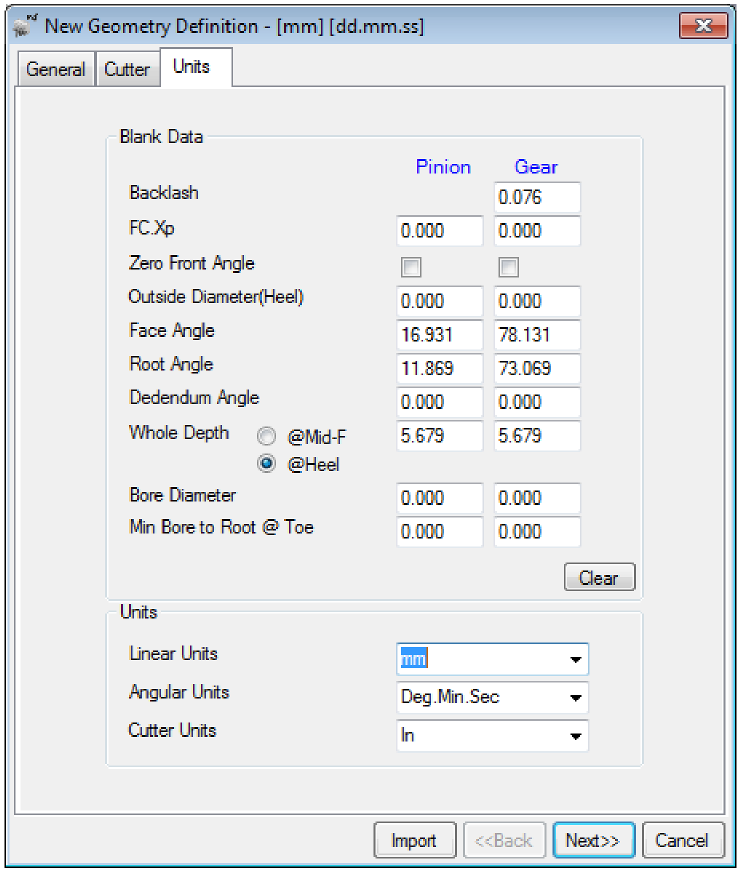
Angular Units Desired angular units, which apply to Spiral Angle, Pressure Angle and Blade Angles, and may either be in decimal format or Degree.Minute.Second format (dd.mm.ss). They are identified in the New Geometry Definition window title bar. The New Geometry input fields affected by a change in the selected angular units will be updated. The selected angular units will remain bound to the Geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

Cutter Units Desired cutter units, either [in] or [mm], which apply to Cutter Diameter, Stock Allowance, Blade Edge Radius and Point Width, and are specifically identified next to the input field titles. The New Geometry input fields affected by a change in the selected cutter units will be updated. The selected cutter units will remain bound to the Geometry until they are changed from the HyGEARS configuration window (Edit->Configuration).

7.7.4.2 Straight Bevel and Coniflex gears

Blank Data

HyGEARS allows the user to impose several Blank dimensions, as follows.



Backlash	Desired operating backlash; if the cutter blade Point Width is imposed, imposing backlash may cause too deep or too shallow teeth. If left blank, a default value will be provided.
FC.Xp	Desired Front Crown to Crossing Point; if left empty, then the calculated value is used.
Zero Front Angle	When checked, the Front Angle of the blank is zero; otherwise, the Front Angle equals the Pitch Angle.
Outside Diameter	Desired OD, for the pinion and gear members; this value is interpreted as a *tip diameter* rather than a *turned diameter*. If left blank the calculated value will be used.

Face Angle Desired Face Angle, for the pinion and gear members; if left blank the calculated value will be used.

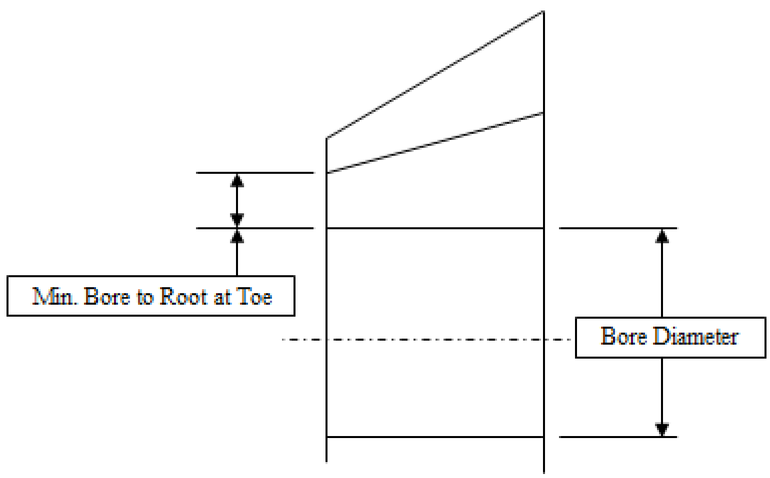
Root Angle Desired Root Angle, for the pinion and gear members; if left blank the calculated value will be used.

Dedendum Angle Dedendum angle on the pinion and gear members; if left blank the calculated value will be used. The Root Angle is given priority over the Dedendum Angle if not zero.

Whole Depth Tooth whole depth at mid-face or Heel. If left blank, the whole depth will be based on the addendum and dedendum factors.

Bore Diameter Desired diameter of the bore of the blank. If left blank, a default value will be provided.

Min. Bore to Root This value works in conjunction with the Bore Diameter above. If a value is entered, HyGEARS will attempt to adjust tooth depth such that the requested value is satisfied at Toe.



> **Important Note:**
>
> When existing blank dimensions are specified, HyGEARS will attempt to find an acceptable solution, but there is no guarantee that the requested dimensions will be exactly provided or useable.

Units

Linear Units Desired linear units, either [in] or [mm], which apply to Diametral Pitch, Face Width, Offset and Mounting Distance. They are identified in the New Geometry Definition window title bar. The New Geometry input fields affected by a change in the selected linear units will be updated. The selected linear units will remain bound to the Geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

The following table gives the units in use when linear units are either [in] or [mm]:

	[in]	[mm]
Torque	[lb-in]	[N-m]
Force	[lb]	[N]
Stress	[Ksi]	[Mpa]
Power	[HP]	[Kw]
Stiffness	[lb/in]	[N/mm]
Volume	[in^3]	[mm^3]
Mass	[lbm]	[kgm]
Inertia	[lbm- in^2]	[kgm- mm^2]
Speed	[ft/min]	[m/min]
Misalignment	[in/in]	[mm/mm]
Surface Finish	[µin]	[µm]
Temperature	[F]	[C]
Warp	[/0.1 in]	[/10 mm]

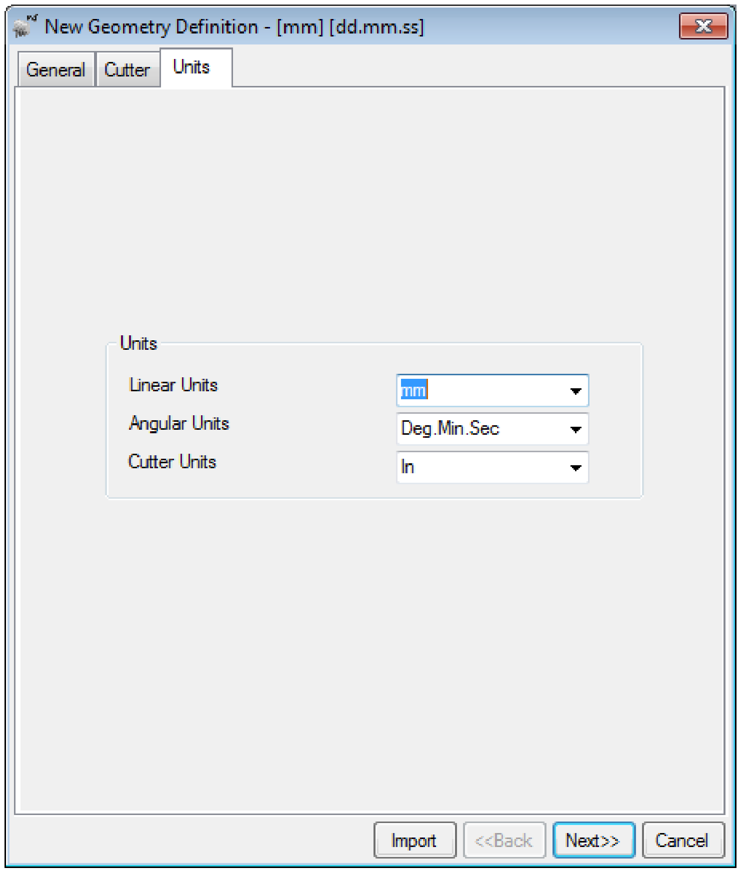
Note that, internally, HyGEARS performs all its calculations in imperial units. The units are converted only when input or output is required.

Angular Units Desired angular units, which apply to Spiral Angle, Pressure Angle and Blade Angles, and may either be in decimal format or Degree.Minute.Second format (dd.mm.ss). They are identified in the New Geometry Definition window title bar. The New Geometry input fields affected by a change in the selected angular units will be updated. The selected angular units will remain bound to the Geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

Cutter Units Desired cutter units, either [in] or [mm], which apply to Cutter Diameter, Stock Allowance, Blade Edge Radius and Point Width, and are specifically identified next to the input field titles. The New Geometry input fields affected by a change in the selected cutter units will be updated. The selected cutter units will remain bound to the Geometry until they are changed from the HyGEARS configuration window (Edit->Configuration).

7.7.4.3 Spur, Helical and Beveloid gears

The input fields of the Units data page concern the units used in the New Geometry window and can be changed at anytime, without losing the values already entered in the input fields.



Linear Units

Desired linear units, either [in] or [mm], which apply to Diametral Pitch, Face Width, Root and Outside Diameters, and Center Distance. They are identified in the New Geometry Definition window title bar. The New Geometry input fields affected by a change in the selected linear units will be updated. The selected linear units will remain bound to the geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

The following table gives the units in use when linear units are either [in] or [mm]:

	[in]	[mm]

Torque	[lb-in]	[N-m]
Force	[lb]	[N]
Stress	[Ksi]	[Mpa]
Power	[HP]	[Kw]
Stiffness	[lb/in]	[N/mm]
Volume	[in^3]	[mm^3]
Mass	[lbm]	[kgm]
Inertia	[lbm- in^2]	[kgm- mm^2]
Speed	[ft/min]	[m/min]
Misalignment	[in/in]	[mm/mm]
Surface Finish	[µin]	[µm]
Temperature	[F]	[C]
Warp	[/0.1 in]	[/10 mm]

Note that, internally, HyGEARS performs all its calculations in imperial units. The units are converted only when input or output is required.

Angular Units

Desired angular units, which apply to Helix Angle, Pressure Angle and Blade Angles, and may either be in decimal format (xx.yy) or Degree.Minute.Second format (dd.mm.ss). They are identified in the New Geometry Definition window title bar.

The New Geometry input fields affected by a change in the selected angular units will be updated. The selected angular units will remain bound to the geometry until they are changed from the HyGEARS Configuration window (Edit->Configuration).

Note that when entering angular units, whatever the configuration, using the xx.yy format tells HyGEARS to interpret the angles in decimal format, whereas using the DD.MM.SS format (thus three sets of data separated by periods) informs HyGEARS to interpret the input in degree.minute.second format.

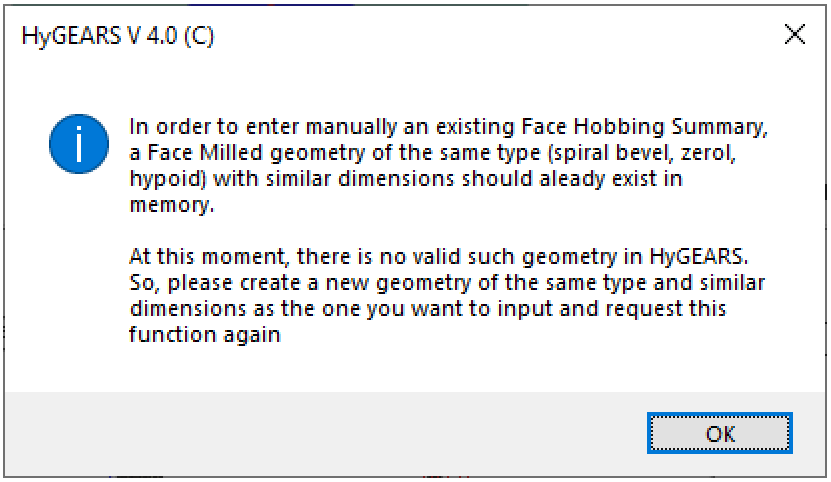
Cutter Units

Desired cutter units, either [in] or [mm], which apply to Blade Edge Radius and Point Width. No New Geometry cutter entry is affected by these values.

7.8 Inputting an Existing Geometry

HyGEARS offers a way to input an *existing* Face Hobbed Geometry Summary by simply editing-in the printed Summary. This normally takes about 5 to 10 minutes and allows you to work directly with the inputted data.

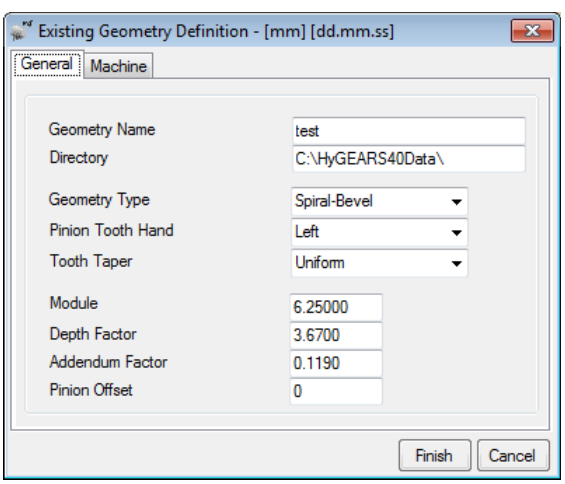
This procedure applies to Face Hobbed gear sets only. It is accessible only when a geometry is already present in memory. If not, then the following message is displayed:



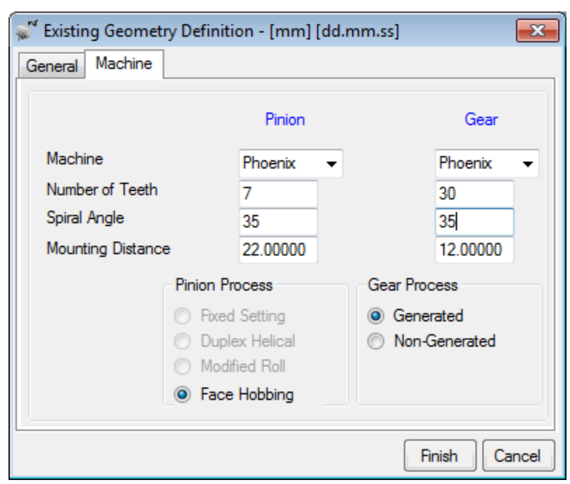
The *Existing Geometry* Input window, shown below, is arranged in up to 3 Data Pages:

General data page
Machine data page

To do so, call the File->Define Existing Geometry from the [Parent Window](#) pull down menu. HyGEARS then presents the following Existing Geometry Definition window, in which several fields must be filled before proceeding.



General data page



Machine data page

Essentially, the definition is done in 4 steps:

Step 1 the input fields of the Existing Geometry Definition window must be filled in the

General data page
Machine data page

Step 2 the *Finish* button is clicked and HyGEARS displays a Summary Editor for the **Pinion Finishing Data**, where all relevant data must be provided; the Summary Editor is populated with the data from the pinion already loaded in memory;

Step 3 the *Finish* button is clicked again, and HyGEARS displays a Summary Editor for the **Gear Finishing Data**, where all relevant data must be provided; the Summary Editor is populated with the data from the gear already loaded in memory;

Step 4 when the *Ok* button of the *gear Summary Editor* (of *Step 3* above) is clicked, the geometry is created and displayed.

Note: The Geometry Summary Editor section should be consulted before proceeding, as the understanding of its operation is needed when filling the required fields.

3 Data Pages are to be filled in the **Geometry Summary Editor**:

Summary Blank data page
Summary Cutter data page
Summary Machine data page

Default values will be provided for all other values, which can be edited at a later stage.

Important Note:

If a geometry already exists in memory when calling the Existing Geometry Definition window, HyGEARS will use the data in memory as default values in all fields. It can thus be quite a time saver to load a geometry similar to the one to be created, prior to calling the Existing Geometry Definition window. But, note that HyGEARS expects that *at least one value is changed* at each editing step.

This can also lead to confusion and care must be exerted to make sure all data is checked before proceeding as very little verification is performed at this step.

7.9 Exiting HyGEARS

The File->Exit function calls the “end of session” function, and is functionally equivalent to a click on the “X” control in the upper right corner of the Main Menu window.

Upon calling the File->Exit function, HyGEARS will scan the currently active Geometry and all the geometries attached to Child Windows, determine if they have been modified, and ask if the Geometry is to be saved if it has been modified or if it is saved in a temporary file (when attached to a Child Window).

A Geometry is modified whenever one of its Geometry parameters, operating conditions or units in use is altered. The following procedure is followed:

- HyGEARS first asks to confirm that Exit is desired, where two answers are possible:

  Yes continues with the File->Exit process;
  No aborts the File->Exit process.

- Then, the very first Geometry to be scanned is the currently active Geometry, and HyGEARS offers three choices if the currently active Geometry has been modified or altered in any way since it was last saved:

  Yes saves the modified Geometry
  No bypasses saving
  Cancel aborts the File->Exit function.

  Thus, it is still possible to abort exiting HyGEARS at this point.

- Finally, all the Geometry files attached to existing Child Windows are scanned to determine if they have been modified since they were last saved and HyGEARS again offers two choices if so (however, from this point on, it is not possible to avoid exiting HyGEARS):

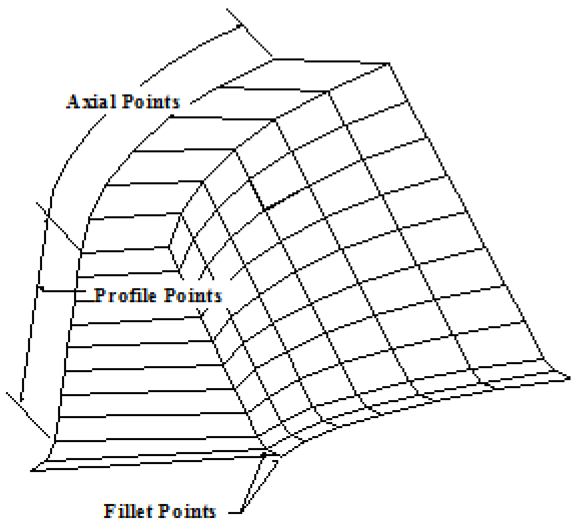
  Yes saves the modified Geometry
  No bypasses saving

8 Digitization Process

In HyGEARS, the pinion and gear teeth are known by their 3 dimensional boundaries. The digitization process is the sequence of operations needed to obtain the 3 dimensional boundaries of a tooth, and a user defined number of points within these boundaries. By default, each tooth flank is represented by a grid of:

- 11 *axial* points ;
- 19 *profilewise* points;
- 5 *fillet* points.

The digitization process involves finding the coordinates of all these points, and storing them into memory for later use. When an input field value is modified, the tooth is redigitized to reflect the modified input data.



The digitization process can take a few milliseconds, depending on the computer used, the number of points calculated and the cutting process. The larger the number of points, the longer the required digitization time.

The number of points also has a direct influence in the resolution of the calculated Path of Contact, Contact Pattern and Loaded Tooth Contact Analysis. The above default values are generally acceptable, and may be changed through the use of specific functions.

If the input data such as machine settings is wrong in any way, the digitization process may fail, and a warning message will be issued. It will therefore be necessary to review the Summary Editor input values and correct the faulty data.

One must keep in mind that the digitization process is equivalent to cutting the actual tooth, therefore a failure in the digitization process generally means that the actual tooth could not have been cut properly. A cutting machine setup preview is available to visually verify that the input data is adequate.

The digitization process may also be traced to identify the cause of an error. Involute Inc. will be glad to help if this happens.

9 Editing Functions

Some functions contained in the Edit pull down menu of the Parent Window are inactive until either a Geometry data file has been opened, or a New Geometry has been created (see File Input and Output). It is assumed here that a Geometry is present in memory.

The following *editing functions* are offered throughout HyGEARS:

- *Editing* the pinion or gear Geometry Summary
- *Editing* the pinion and gear Tooth Number of Points
- *Editing* the pinion and gear V-H Settings
- Resetting the Corrective Machine Setting history
- Resetting the Contact Pattern Development History
- *Editing* the HyGEARS Configuration
- *Editing* the User Registration

9.1 Geometry Summary

HyGEARS offers an integrated *Geometry Summary* Editor in which geometric data and machine settings can be directly modified.

The Summary editor must be used with caution, in order not to improperly modify sensitive machine settings. Input fields which are not editable appear in dimmed contrast.

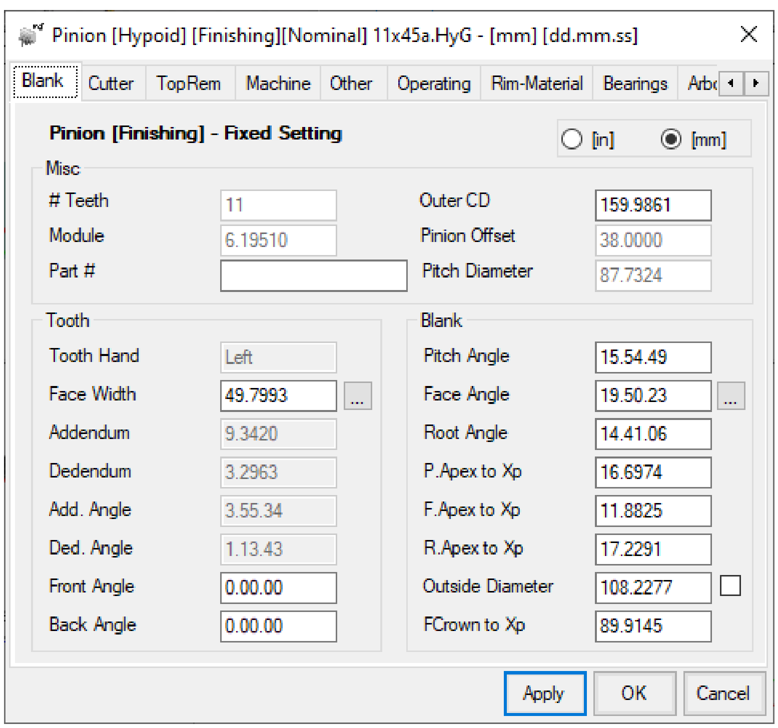
The *Geometry Summary* Editor is organized in Data Pages, where the tab title indicates the data contained in the corresponding page. Data input is divided in eleven Data Pages, accessed by clicking on the proper tab.

The following sections detail the different input fields for each data page. Input fields are accessed by a left mouse button click on the desired field, or by successively pressing the Tab key until the input cursor has reached the desired field.

The figure below presents a typical Pinion Summary editor window. The *Gear Summary* editor window is essentially the same. Some of the available input fields and field titles will vary depending on the machine used. However, most fields remain identical.

The *Geometry Summary* Editor is organized in the following Data Pages:

- *Blank Data*
- *Cutter Data*
- *Blade Edge Data*
    - *Spur/Helical/Beveloid gears*
    - *Straight Bevel gears*
- *TopRem Data*
- *Machine Data*
- *Higher Order Data*
- *Other Data*
- *Operating Data*
- *Rim and Material Data*
- *Bearing Data*
- *Links Data*



The *Geometry Summary* Editor title bar identifies the edited gear set member, either the Finishing or Roughing Summary data, and the general linear and angular units used.

Cutter and TopRem units are identified on the Cutter data page tab. The linear, angular and cutter units may be permanently modified through the HyGEARS configuration window (Edit -> Configuration), but the Geometry *Summary Editor* must be closed before access to the configuration window is possible.

Units

cutter units	may be changed on the fly by clicking on the desired units in the upper-right corner of the Cutter data page;
linear units	may be changed on the fly from any data page by clicking on the desired units in the upper-right corner of the data page;
angular units	can be entered as DD.MM.SS or Deg.Dec in any angle input field.

Command Buttons

OK ends the Summary editor, and if any input field value has been modified, the digitization process will take place.

Apply causes HyGEARS to update the current state of the Geometry in memory, redisplay the Child Window if applicable, and remain in the Geometry Summary editor.

Cancel returns the Geometry to its state prior to loading the Geometry Summary editor, no matter how many changes were performed.

9.1.1 Blank Data

The Blank data page of Geometry Summary editor covers the main Blank dimensions.

Summary fields involving a fundamental geometry redefinition cannot be edited, such as the tooth number, diametral pitch or module, or tooth hand, or if they are calculated results from other values, such as the addendum and which depend on the addendum and dedendum factors.

Zerol, Spiral-bevel and Hypoid Gears

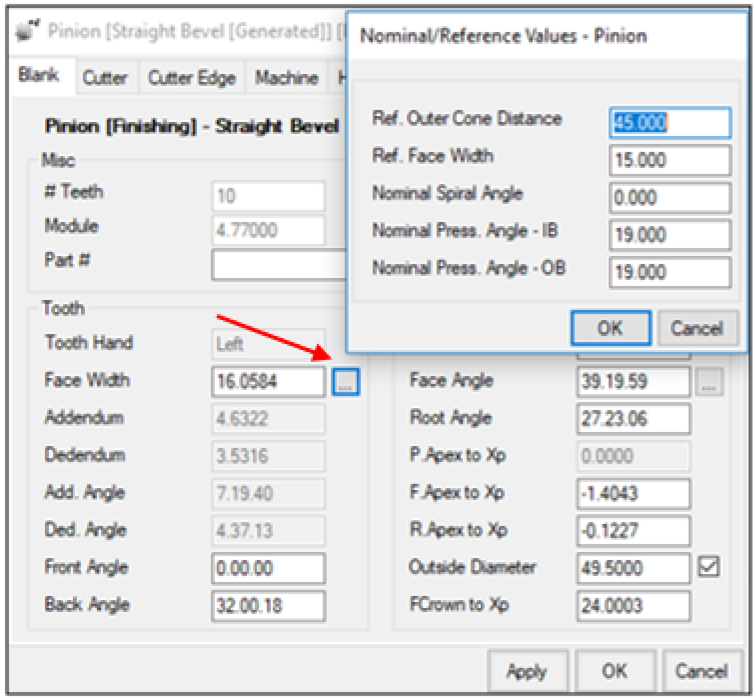
Coniflex bevel Gears

Straight-bevel Gears

Spur, Helical and Beveloid Gears

9.1.1.1 Nominal Reference Values

In the Summary editor, for all bevel gears, the “Ref. Vals” button to allow entering / editing the Reference Outer Cone Distance, Pressure and Spiral angles.



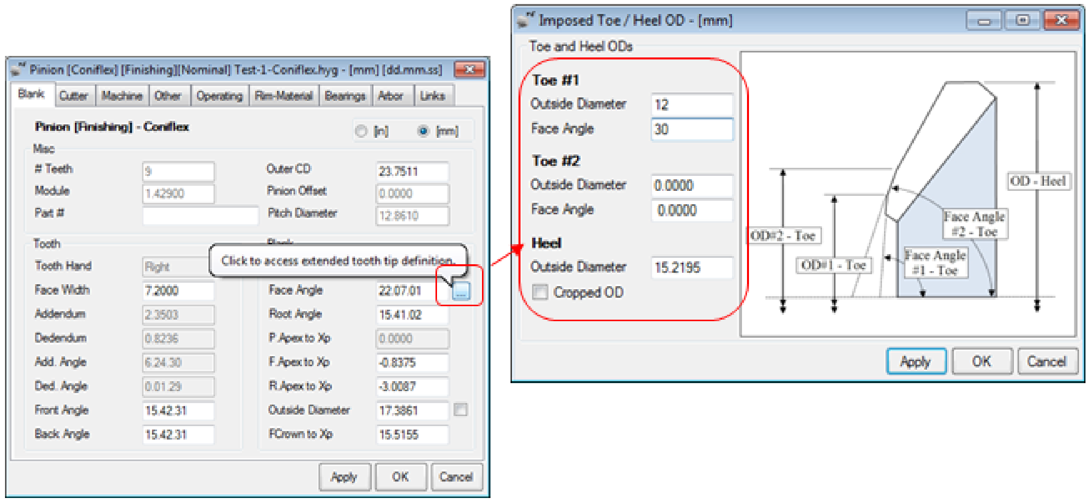
When the [...] button is clicked, the Nominal/Reference Values window is displayed where the default values can be edited. These include:

- Outer Cone Distance,
- Face Width
- Spiral Angle
- Pressure Angle IB
- Pressure Angle OB

The Nominal Spiral and Pressure angles are used in the Graphic Summary ([GSum] function button) to calculate the Transverse, Radial and Axial loads. They are also used to calculate the Mean Normal Module, and in the ISO-10300 output.

9.1.1.2 Imposed Toe/Heel OD

For Bevel gears, the *Imposed Toe/Heel OD* window, displayed below, allows imposing different Face Angles along tooth tip at Toe such as the replicate exactly the actual tooth blank.



Tapered Toe Tip OD can be done in 2 steps;

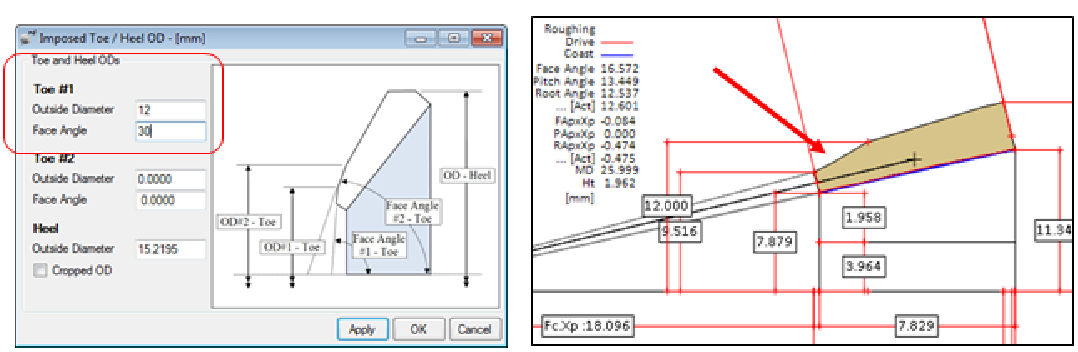
- if 1 step, either the *Toe #1* or *Toe #2* can be used, but the OD must be null for either *Toe #1* or *Toe #2;*
- if 2 steps are needed, then *Toe #1* is closest to Toe, while *Toe #2* is between Heel and *Toe #1*.

The following rules apply:

- The Face Angle of each step must be larger than the design Face Angle of the part;
- The OD of each step must be larger than the tip OD at Toe, but smaller than the tip OD at Heel.

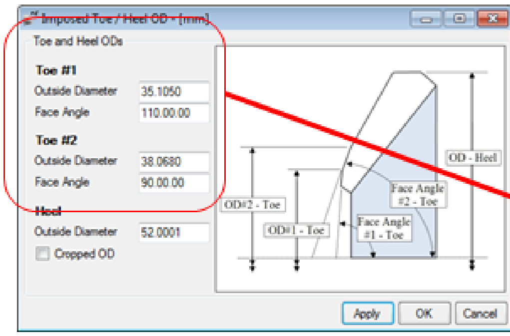
One-Step Tapered Toe OD

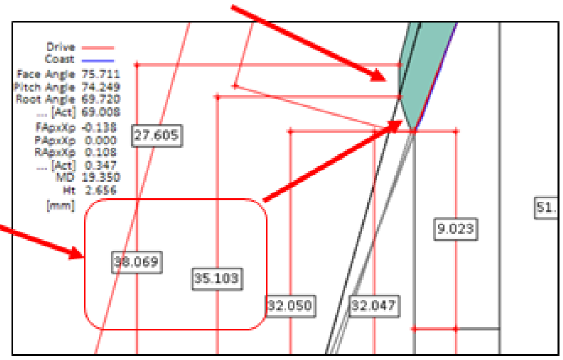
The figures below show a 1 Step Tapered Toe Tip, with its definition.



Two-Step Tapered Toe OD

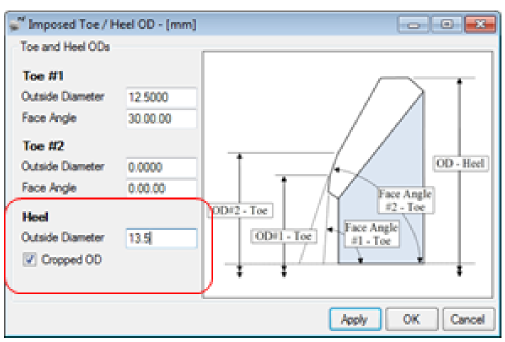
By contrast, the two figures below show a 2 Step Tapered Toe Tip, with its definition. It is clear that Toe #2 lies between Toe #1 and Heel.

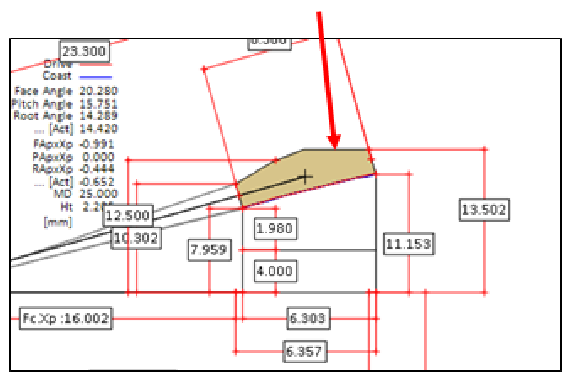




Turned/Cropped Heel OD

A *turned, or cropped, OD* is defined by clicking on the "Cropped OD" check box, left figure below, entering the desired OD and clicking on the "Apply" button.



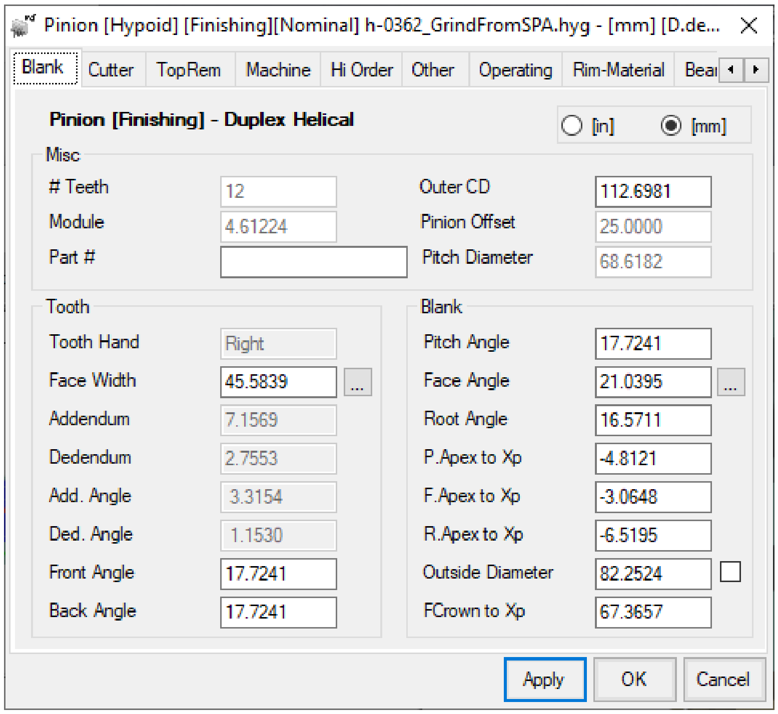


9.1.1.3 Zerol, Spiral-Bevel, Hypoid

The Summary editor Blank data page covers the overall spiral-bevel and hypoid pinion or gear blank definition. Summary fields involving a fundamental Geometry redefinition cannot be edited, such as the tooth number, diametral pitch or module, tooth hand or cutting process, or if they are calculated results from other values, such as the addendum, dedendum and addenddum and dedendum angles which depend on the face, pitch and root angles.

The Blank Data section groups data fields by type, and the linear and angular units in use are those identified on the Summary title bar ([in] - [dd.mm.ss] in this example) which can be changed by calling the Edit->Configuration function from the Main Menu, or using the "in-mm" and "DMS-Dec" Function buttons.

The Blank Data section includes the following fields, which refer to the figures below:



The Blank Data section includes the following fields, which refer to the figures below:

# Teeth	Number of teeth; not editable.
Module	Gear set module; not editable; this field becomes the Diam.P. when the linear units in use are [in].
Part #	Drawing number; used only in printed output;
Outer CD	Outer cone distance; editable. Care must be exerted when modifying this field since the cone distance is a calculated value.
Pinion Offset	Pinion offset, in linear units. For a left hand pinion, the offset will be below center, and above center for a right hand pinion. Not editable.
Tooth Hand	Tooth hand, either left or right; not editable.
Face Width	Facewidth; editable. Care must be used when modifying this field since the tooth facewidth is a calculated value from the gear tooth facewidth and the pinion operating offset.
Addendum	Addendum at tooth heel, calculated from the addendum angle; not editable.

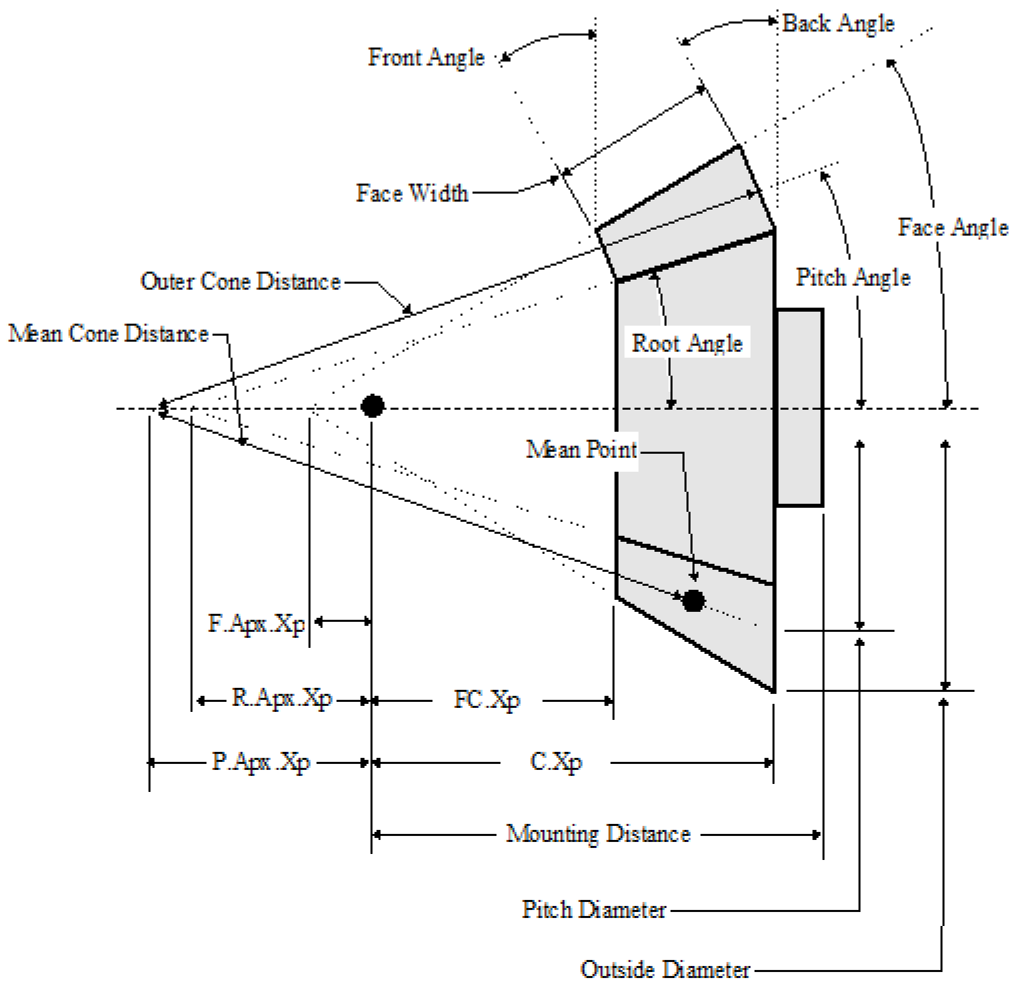
Dedendum	Dedendum at tooth heel, calculated from the dedendum angle; not editable.
Add. Angle	Addendum angle, calculated from the difference between the face and pitch angles; not editable.
Ded. Angle	Dedendum angle, calculated from the difference between the pitch and root angles; not editable.
Front.Angle	Blank front angle, generally zero for pinion members, and equal to the pitch angle for gear members; editable.
Back Angle	Blank back angle, sometimes zero for pinion members, and equal to the pitch angle for gear members; editable. If 90°, HyGEARS will default to 89.95° and any value entered for the OD will be interpreted as a *turned OD*; HyGEARS will then modify both the Outer CD and Face Width such that the requested OD is matched, and the Toe OD is not affected.
Pitch Angle	Pitch angle; editable. Care must be exerted when modifying this field since the pitch angle is a calculated value.
Face Angle	Face angle; editable. Care must be exerted when modifying this field since the face angle is a calculated value. The check box to the right of the Face Angle gives access to the Imposed Toe/Heel OD window.
Root Angle	Root angle; editable. Care must be exerted when modifying this field since the root angle is a calculated value.
P.Apex Xp.	Pitch apex beyond the crossing point; editable. Care must be exerted when modifying this field since the pitch apex beyond the crossing point is a calculated value.
F.Apex Xp.	Face apex beyond the crossing point; editable. Care must be exerted when modifying this field since the face apex beyond the crossing point is a calculated value.
R.Apex Xp.	Root apex beyond the crossing point; editable. Care must be exerted when modifying this field since the root apex beyond the crossing point is a calculated value.
Outside Diameter	calculated value for the OD; the *check box* besides the OD value, when checked, imposes the OD value which must then be equal, or less, than the calculated value. If the entered value is less, and the *check box* is checked, then the entered OD will create a *turned OD* at the desired OD value; if not checked, then the *FApxXp* will be adjusted to match the entered OD.

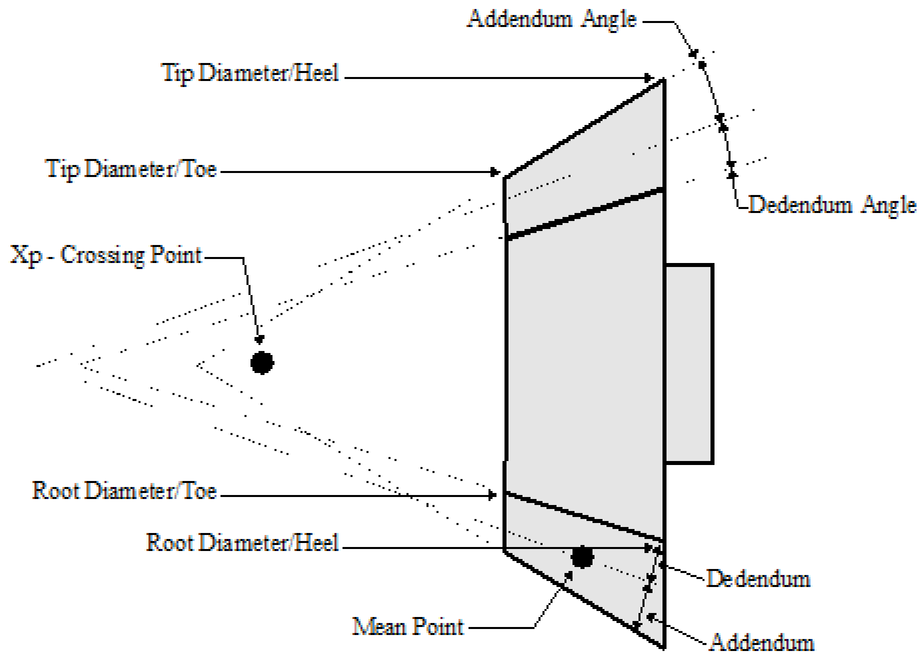
For Hypoid Gears:

FCrown. Xp.	Front crown to crossing point; editable. Care must be exerted when modifying this field since the front crown to crossing point is a calculated value. This value is usually zero for gear members.

For Zerol and Spiral-bevel Gears:

Crown Xp. Crown to crossing point; editable. Care must be exerted when modifying this field since the crown to crossing point is a calculated value.



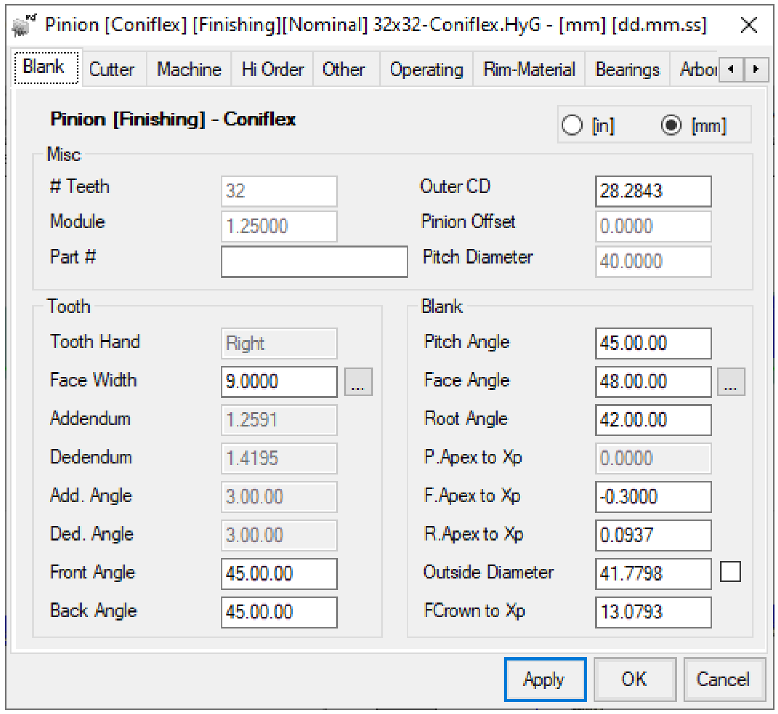


9.1.1.4 Coniflex

The Blank data page of the Geometry Summary editor covers the overall Coniflex bevel gear pinion or gear blank definition.

Summary fields involving a fundamental geometry redefinition cannot be edited, such as the tooth number, diametral pitch or module, or tooth hand, or if they are calculated results from other values, such as the addendum and which depend on the addendum and dedendum factors.

The Blank Data section groups data fields by type, and the linear and angular units in use are those identified on the Summary title bar ([in] - [dd.mm.ss] in this example) which can be changed by calling the Edit->Configuration function from the Main Menu, or using the “in-mm” and “DMS-Dec” function buttons.

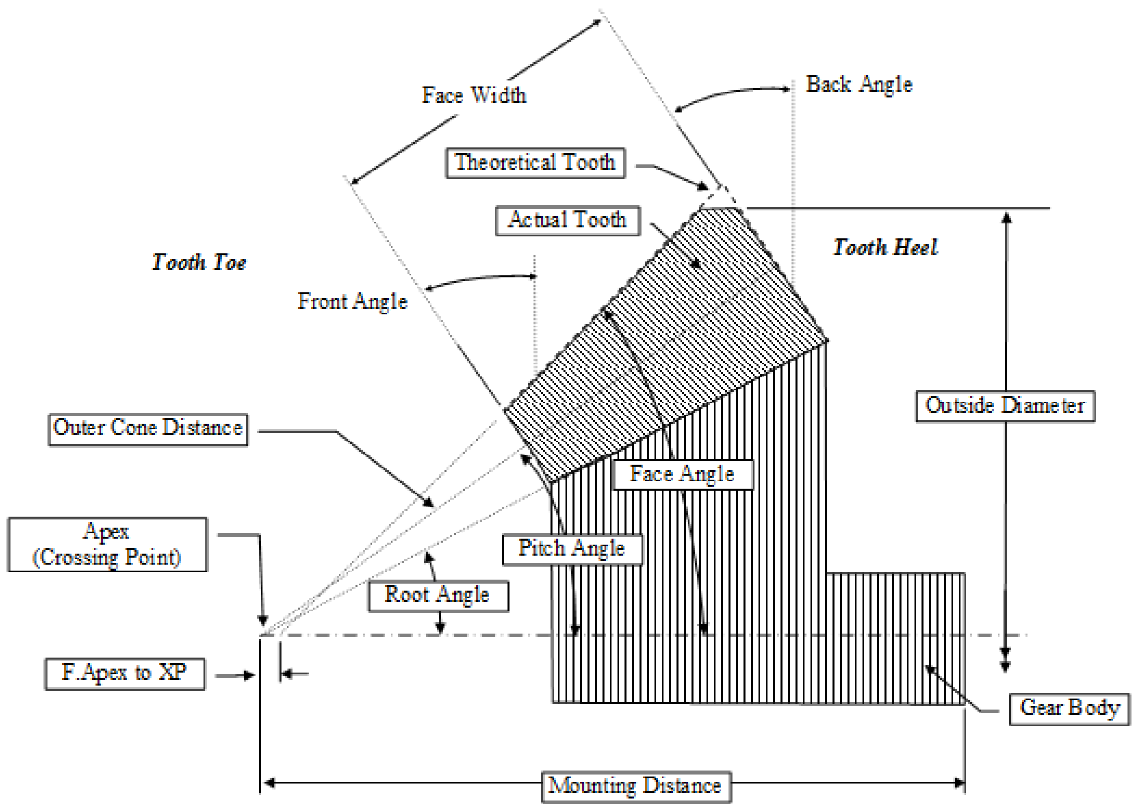


The Blank Data section includes the following fields, which refer to the figure below:

# Teeth	Number of teeth; not editable.
Module.	Gear set module; not editable; this field becomes the Diam.P. when the linear units in use are [in].
Part #	Drawing number; used only in printed output;
Outer CD	Outer cone distance; editable. Care must be exerted when modifying this field since the cone distance is a calculated value.
Tooth Hand	Tooth hand. Right only for the Pinion by convention; not editable.
Face Width	Face width; editable. Care must be used when modifying this field since the tooth face width is a calculated value and too large a face width may result in undercutting at toe.
Addendum	Addendum at tooth heel, calculated from the addendum angle; not editable.
Dedendum	Dedendum at tooth heel, calculated from the dedendum angle; not editable.
Add.Angle	Addendum angle, calculated from the difference between the face and pitch angles.
Ded.Angle	Dedendum angle, calculated from the difference between the pitch and root angles; not editable.
Front Angle	Blank front angle, often zero for pinion members, and equal to the pitch angle for gear members; editable.
Back Angle	Blank back angle, sometimes zero for pinion members, and equal to the pitch angle for gear members; editable. If 90°, HyGEARS will default to 89.95° and any value entered for the OD will be interpreted as a *turned*

OD; HyGEARS will then modify both the Outer CD and Face Width such that the requested OD is matched, and the Toe OD is not affected.

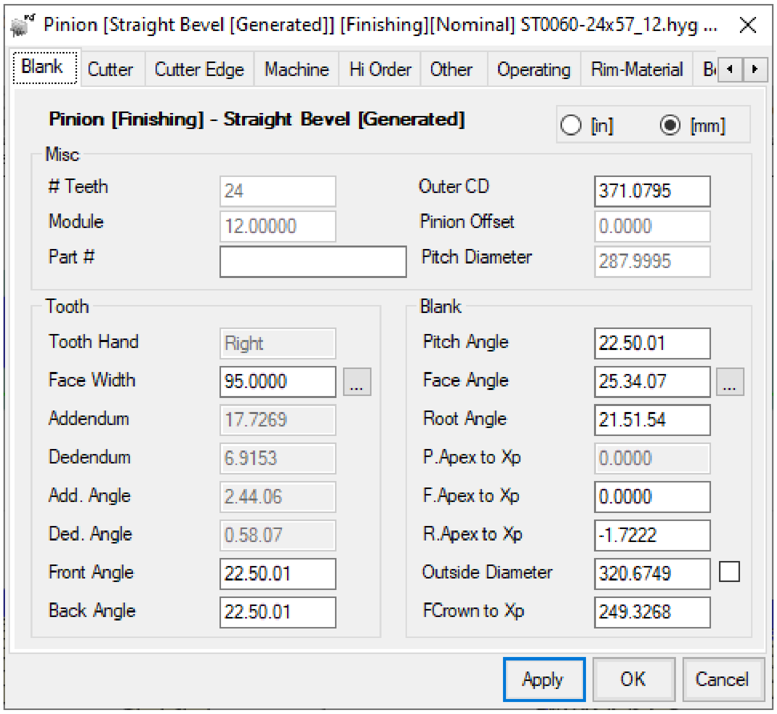
Pitch Angle	Pitch angle; editable. Care must be exerted when modifying this field since the pitch angle is a calculated value.
Face Angle	Face angle; editable. Care must be exerted when modifying this field since the face angle is a calculated value. The check box to the right of the Face Angle gives access to the Imposed Toe/Heel OD window.
Root Angle	Root angle; editable. Care must be exerted when modifying this field since the root angle is a calculated value.
P.Apex Xp.	Pitch apex beyond the crossing point; not editable.
F.Apex Xp.	Face apex beyond the crossing point; editable. Care must be exerted when modifying this field since the face apex beyond the crossing point is a calculated value.
R.Apex Xp.	Root apex beyond the crossing point; not editable.
Outside Diameter	calculated value for the OD; the *check box* besides the OD value, when checked, imposes the OD value which must then be equal, or less, than the calculated value. If the entered value is less, and the *check box* is checked, then the entered OD will create a *turned OD* at the desired OD value; if not checked, then the FApxXp will be adjusted to match the entered OD.
FCrown. Xp.	Front crown to crossing point; editable.



9.1.1.5 Straight-Bevel

The Geometry Summary editor Blank data page covers the overall straight-bevel gear pinion or gear blank definition. Summary fields involving a fundamental geometry redefinition cannot be edited, such as the tooth number, diametral pitch or module, or tooth hand, or if they are calculated results from other values, such as the addendum and which depend on the addendum and dedendum factors.

The Blank Data section groups data fields by type, and the linear and angular units in use are those identified on the Summary title bar ([in] - [deg.min.sec] in this example) which can be changed by calling the Edit->Configuration function from the Main Menu, or using the “in-mm” and “DMS-Dec” function buttons.



The Blank Data section includes the following fields, which refer to the figures below:

# Teeth	Number of teeth; not editable.
Module.	Gear set module; not editable; this field becomes the Diam.P. when the linear units in use are [in].
Part #	Drawing number; used only in printed output;
Outer CD	Outer cone distance; editable. Care must be exerted when modifying this field since the cone distance is a calculated value.
Tooth Hand	Tooth hand. Right only for the Pinion by convention; not editable.
Face Width	Face width; editable. Care must be used when modifying this field since the tooth face width is a calculated value and too large a face width may result in undercutting at toe.
Addendum	Addendum at tooth heel, calculated from the addendum angle; not editable.
Dedendum	Dedendum at tooth heel, calculated from the dedendum angle; not editable.
Add.Angle	Addendum angle, calculated from the difference between the face and pitch angles.
Ded.Angle	Dedendum angle, calculated from the difference between the pitch and root angles; not editable.
Front Angle	Blank front angle, often zero for pinion members, and equal to the pitch angle for gear members; editable.
Back Angle	Blank back angle, sometimes zero for pinion members, and equal to the pitch angle for gear members; editable. If 90°, HyGEARS will default to 89.95° and any value entered for the OD will be interpreted as a *turned*

OD; HyGEARS will then modify both the Outer CD and Face Width such that the requested OD is matched, and the Toe OD is not affected.

Pitch Angle Pitch angle; editable. Care must be exerted when modifying this field since the pitch angle is a calculated value.

Face Angle Face angle; editable. Care must be exerted when modifying this field since the face angle is a calculated value. The check box to the right of the Face Angle gives access to the Imposed Toe/Heel OD window.

Root Angle Root angle; editable. Care must be exerted when modifying this field since the root angle is a calculated value.

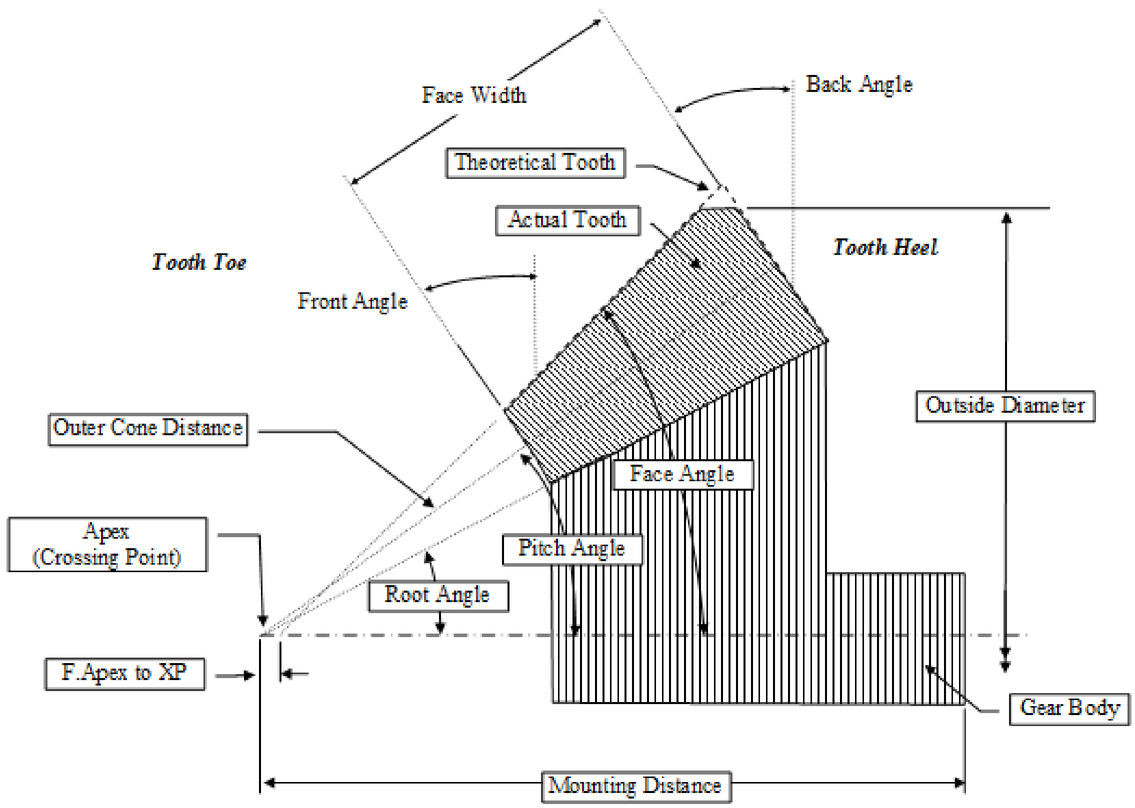
P.Apex Xp. Pitch apex beyond the crossing point; not editable.

F.Apex Xp. Face apex beyond the crossing point; editable. Care must be exerted when modifying this field since the face apex beyond the crossing point is a calculated value.

R.Apex Xp. Root apex beyond the crossing point; not editable.

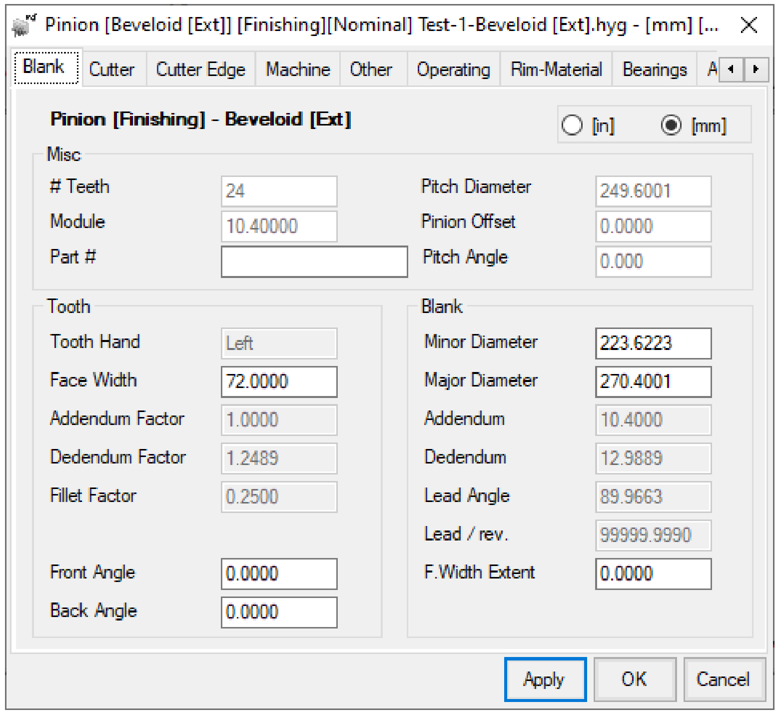
Outside Diameter calculated value for the OD; the *check box* besides the OD value, when checked, imposes the OD value which must then be equal, or less, than the calculated value. If the entered value is less, and the *check box* is checked, then the entered OD will create a *turned OD* at the desired OD value; if not checked, then the FApxXp will be adjusted to match the entered OD.

FCrown. Xp. Front crown to crossing point; editable.



9.1.1.6 Spur, Helical, Beveloid

The Geometry Summary editor Blank data page covers the overall Spur and Helical pinion and gear blank definition. Summary fields involving a fundamental geometry redefinition cannot be edited, such as the tooth number, diametral pitch or module, or tooth hand, or if they are calculated results from other values, such as the addendum and which depend on the addendum and dedendum factors.

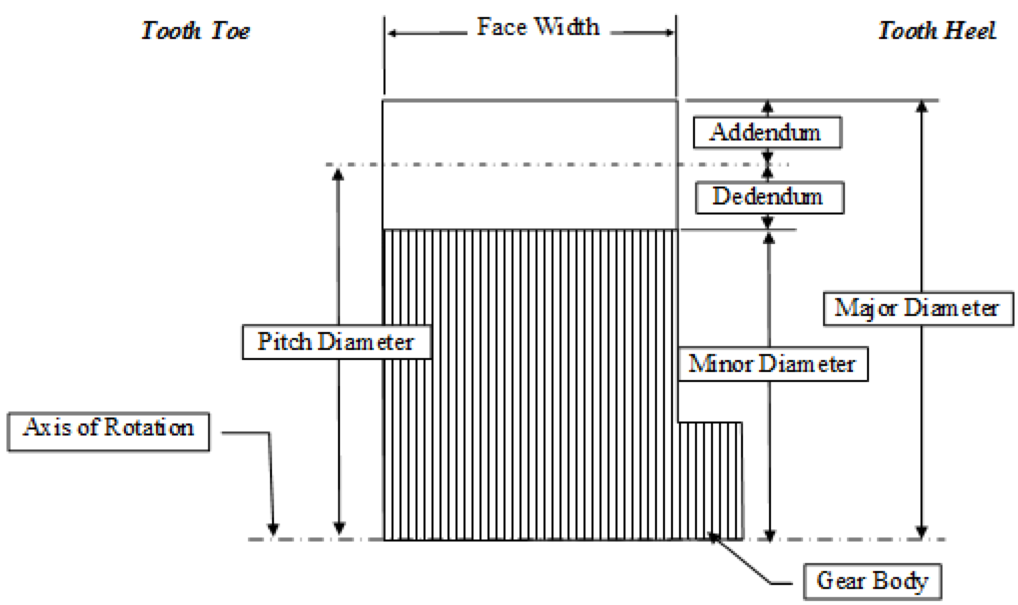


The Blank Data section groups data fields by type, and the linear and angular units in use are those identified on the Summary title bar which can be changed by calling the Edit->Configuration function from the Main Menu, or using the “in-mm” and “DMS-Dec” function buttons.

The Blank Data section includes the following fields, which refer to the figure below:

# Teeth	Number of teeth; not editable.
Module	Gear set module; not editable; this field becomes the Diametral Pitch when the linear units in use are [in].
Part #	Drawing number; used only in printed output;
Pitch Diameter	Pinion or gear Pitch Circle Diameter. Not editalbe since it depends on the data at creation time.
Tooth Hand	Tooth hand, either left or right; not editable.
Face Width	Facewidth; editable. Care must be used when modifying this field since this field affects only the edited member, i.e. either the pinion or the gear.
Addendum	Addendum at tooth heel, calculated from the addendum angle; not editable.
Dedendum	Dedendum at tooth heel, calculated from the dedendum angle; not editable.
Addendum Factor	Addendum factor specified at creation time. It defines the Major Diameter in reference to the Pitch Diameter. Not editable
Dedendum Factor	Dedendum factor specified at creation time. It defines the Minor Diameter in reference to the Pitch Diameter. Not editable.

Fillet Factor	Fillet factor specified at creation time. It defines the Blade Edge Radius and therefore the Minor Diameter. Not editable.
Front Angle	Blank front angle, generally zero; editable.
Back Angle	Blank back angle, generally zero; editable.
Minor Diameter	Desired Minor Diameter (Root Diameter); if a value is entered different form the one displayed, HyGEARS will adjust the Dedendum Factor accordingly.
Major Diameter	Desired Major Diameter (Outside Diameter); if a value is entered different form the one displayed, HyGEARS will adjust the Addendum Factor accordingly.
Addendum	Calculated tooth addendum.
Dedendum	Calculated tooth dedendum.
Lead Angle	Lead angle of the tooth; in fact equal to 90 - Helix angle;
Lead / rev.	Tooth advance per revolution.
F.Width Extent	For Beveloid gears only: the tooth can be extended by the entered amount at the Heel end, such as to replicate a normal tooth for most calculation purposes such as bending stress, but yet extend the tooth beyond the entered face width.



9.1.2 Cutter Data

The Cutter data page contains the dimensions related to cutter blade, blade angle, point width, edge radius, and others.

All fields are editable, but care must be used when changing values such as the cutter point diameter, since a change in cutter diameter (in Spiral-Bevel and Hypoid Gears) must be compensated by a change in sliding base and machine center to back when cutter tilt is used, what is sometimes called proportional changes.

Cutter units are identified in the Cutter data page tab, and can be changed by calling the Edit->Configuration function from the Main Menu, or by modifying the Cutter Units at the top right of the Cutter data page.

Zerol, Spiral-bevel and Hypoid Gears

Coniflex bevel Gears

Straight-bevel Gears

Spur, Helical and Beveloid Gears

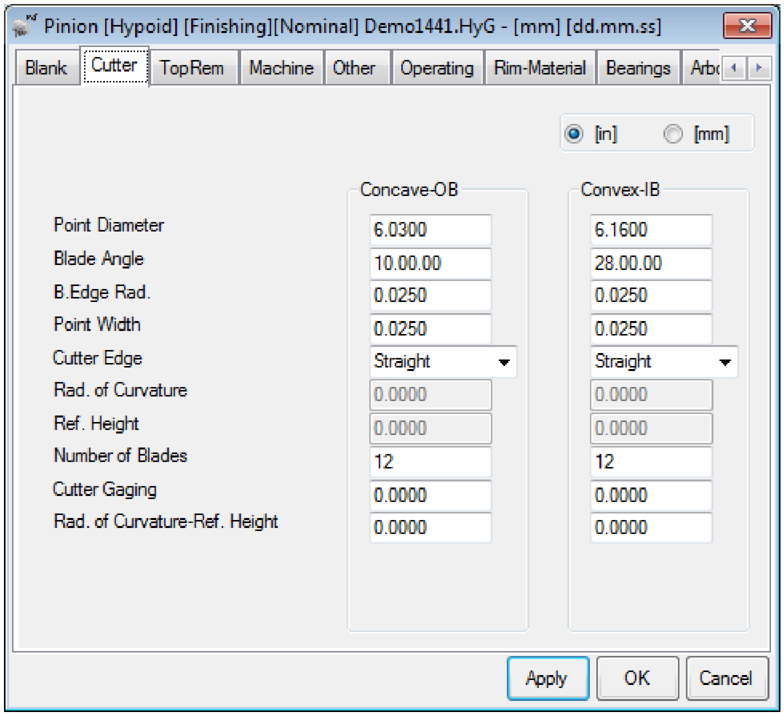
9.1.2.1 Zerol, Spiral-Bevel, Hypoid

The Cutter data page of the Summary editor covers data related to the cutter definition. All fields are editable, but care must be used when changing values such as the cutter point diameter, since a change in cutter diameter must be compensated by a change in sliding base and machine center to back when cutter tilt is used, what is sometimes called proportionnal changes. This is done automatically by HyGEARS in the Graphics->Contact Pattern Development function.

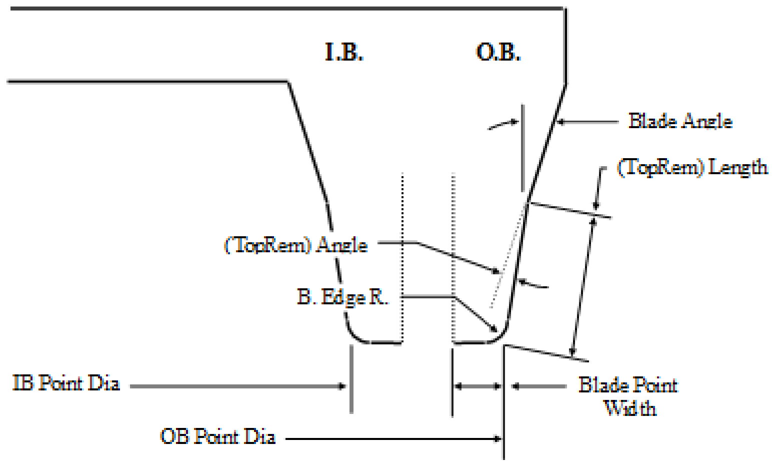
Cutter units are identified in the Cutter data page tab, and can be changed by calling the Edit->Configuration function from the Main Menu, or by modifying the Cutter Units at the top right of the Cutter data page.

Fixed Setting and Modified Roll Cutter Data

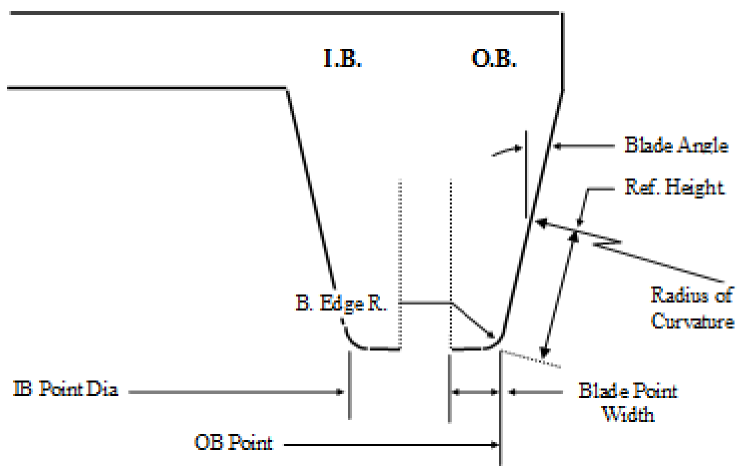
The Cutter Data fields shown and described below are for Fixed Setting or Modified Roll pinion cutters.



Cutter Data includes the following fields, for both the O.B. (concave) and I.B. (convex) tooth flanks, and refers to the following figures for understanding:

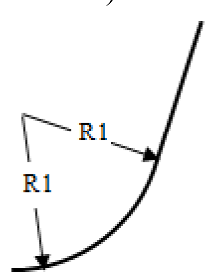


Straight Edge Cutter

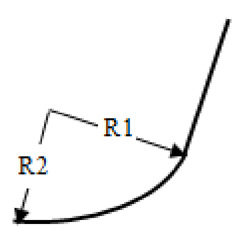


Circular Edge Cutter

Point Diameter	Cutter point diameter.
Blade Angle	Blade angle. Both I.B. and O.B. are positive values.
B.Edge Rad	Blade edge radius. It can be entered either as “R1” for circular edge radius, or “R1/R2” for an elliptic edge radius (see below).



Circular B. Edge R

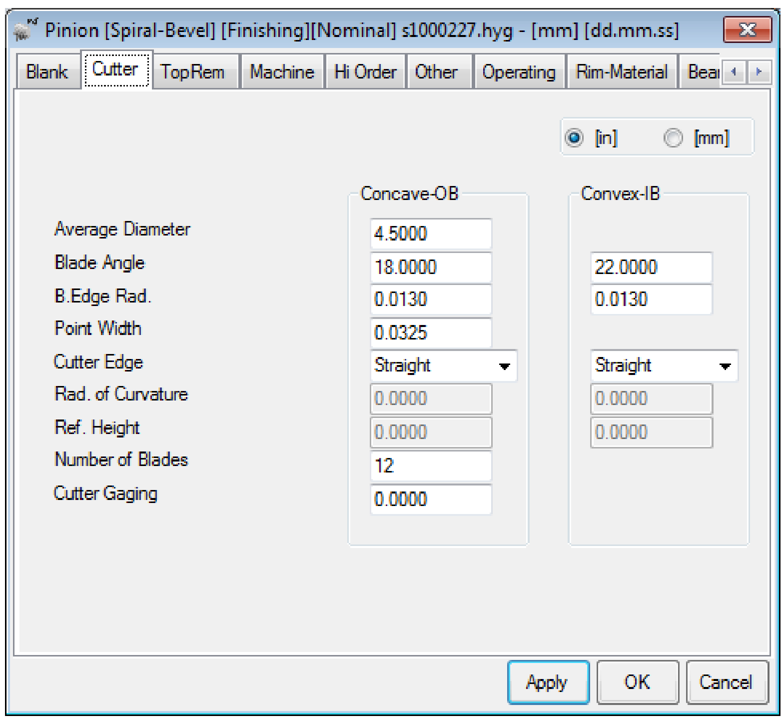


Elliptic B. Edge R.

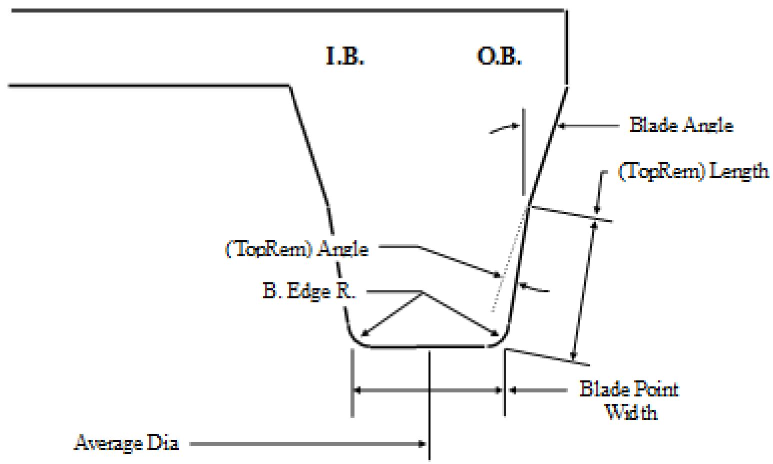
Point Width	Blade point; not used in calculations.
Cutter Edge	Straight or Circular.
Radius of Curvature	Radius of curvature of Circular edged cutter.
Reference Height	Height at which the Blade Angle is defined for Circular edged cutter.
Number of Blades	Number of cutter blades, for Face Milling processes.
Cutter Gaging	Cutter gaging position on the machine. Machine settings are adjusted when Cutter Gaging is changed.
Rad of Curv-Ref Height	Unused for face Milling.

Completing Cycles Cutter Data

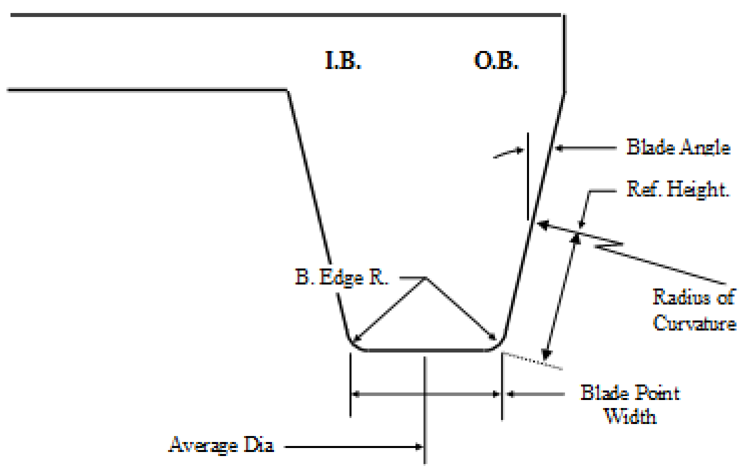
The Spread Blade, Duplex Helical, Formate and Helixform cutting processes use the same cutter definition fields.



The following figures are used to understand the input fields descriptions, and refer to the field titles of the above figure:

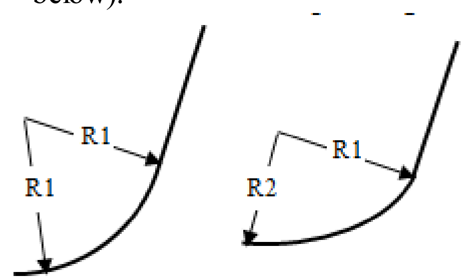


Straight Edge Cutter



Circular Edge Cutter

Average Diameter	Cutter average diameter.
Blade Angle	Blade angle. Both I.B. and O.B. are positive values.
Blade Edge Rad	Blade edge radius. It can be entered either as "R1" for circular edge radius, or "R1/R2" for an elliptic edge radius (see below).

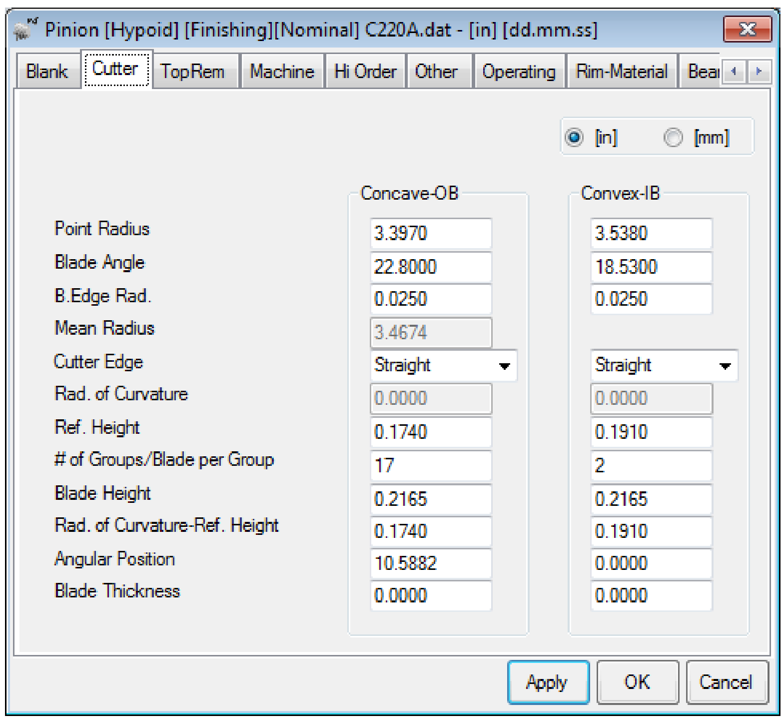


Circular B. Edge R   Elliptic B. Edge R.

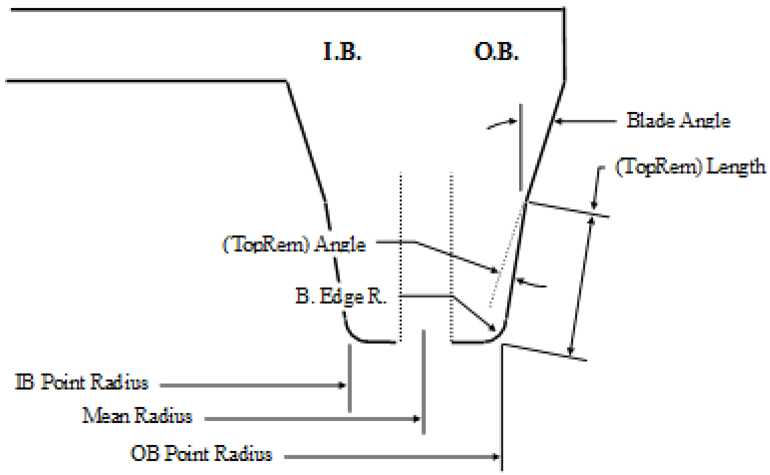
Point Width	Blade point width.
Cutter Edge	Straight or Circular.
Radius of Curvature	Radius of curvature of Circular edged cutter.
Reference Height	Height at which the Blade Angle is defined for Circular edged cutter.
Number of Blades	Number of cutter blades, for Face Milling processes.
Number of Groups	Number of cutter blade groups, for Face Hobbing processes.
Cutter Gaging	Cutter gging position (Depth of cut for Face Hobbing).
Rad of Curv-Ref Height	Unused for face Milling.

Face Hobbing Cutter Data

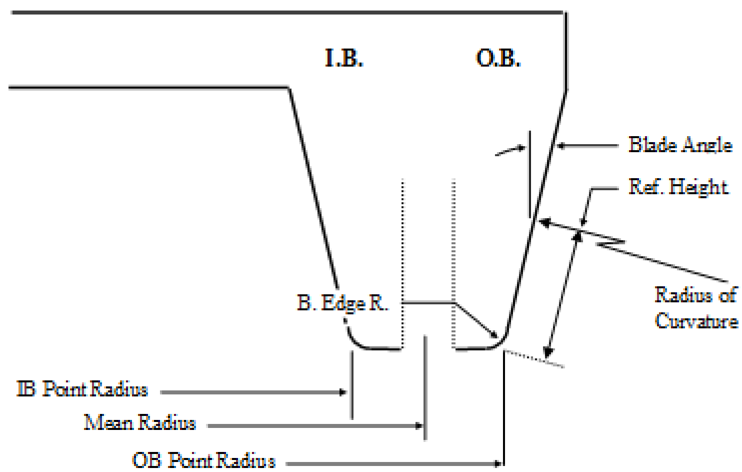
The Cutter Data fields shown and described below are for Face Hobbing pinion and gear cutters.



Cutter Data includes the following fields, for both the O.B. (concave) and I.B. (convex) tooth flanks, and refers to the following figures for understanding:

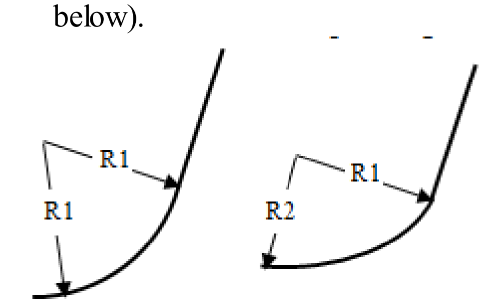


Face Hobbing Straight Edge Cutter



Face Hobbing Circular Edge Cutter

Point Radius	Cutter point radius.
Blade Angle	Blade angle. Both I.B. and O.B. are positive values.
Blade Edge Rad	Blade edge radius. It can be entered either as "R1" for circular edge radius, or "R1/R2" for an elliptic edge radius (see below).

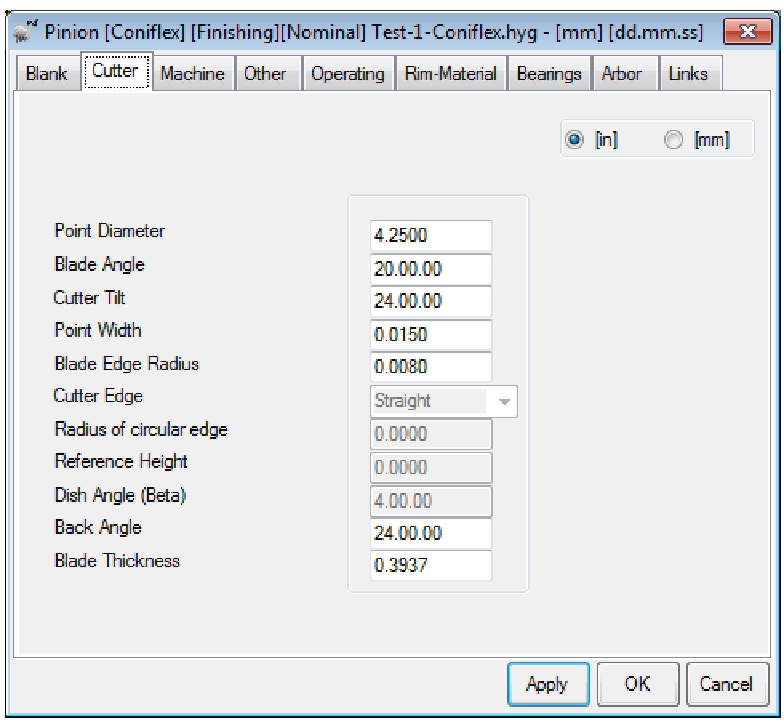


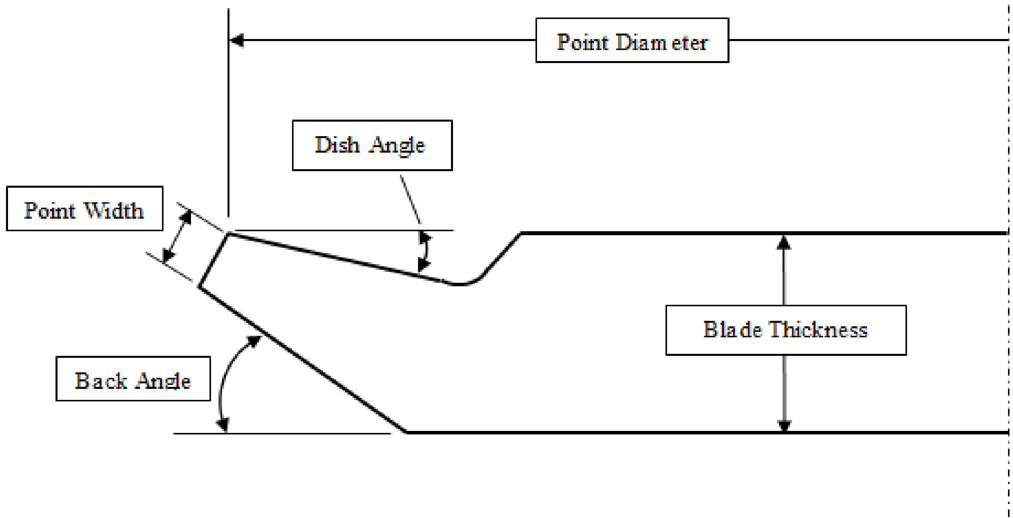
Circular B. Edge R **Elliptic B. Edge R.**

Cutter Edge	Straight or Circular.
Radius of Curvature	Radius of curvature of Circular edged cutter.
Reference Height	Height at which the Reference Radius is defined.
# of Groups	Number of Face Hobbing cutter blade groups.
Blade per Group	Number of Face Hobbing cutter blades per group.
Blade Height	Overall blade height.
Rad of Curv-Ref Height	Height at which the Blade Angle is defined for Circular edged cutter.
Angular Position	Angle made between consecutive IB and OB blades; nominally equal to 360 divided by the product of the "# of Groups" times "Blade per Group".
Blade Thickness	This value is not necessary for simulation per se, but useful when checking of interference between say the IB blade and the OB tooth flank and v ice-versa. This value corresponds to the length of the blade in the cutting direction.

9.1.2.2 Coniflex

The Cutter data page of the Geometry Summary editor covers data related to the cutter definition. All fields are editable, but care must be used when changing values such as the cutter point diameter, since a change in cutter diameter must be compensated by a change in sliding base to maintain tooth depth.

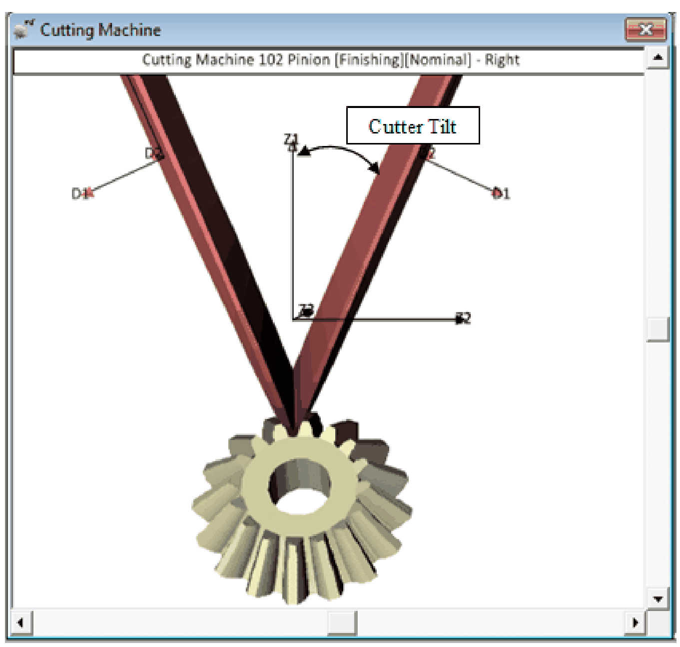




Point Diameter Point diameter of the Coniflex cutter. Default value is 4.25” or 107.95 mm for machine #102, 9” for machines #104 and #134, and 15” for machine #114.

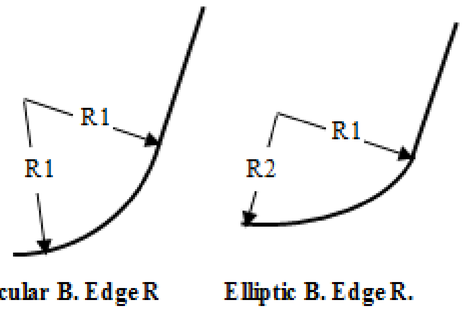
Blade Angle The blade angle corresponds to the theoretical blade angle that is used to generate the gear-set, and is be the gear-set pressure angle at the pitch point, i.e. at mid-face width, on the pitch cone.

Cutter Tilt The Coniflex cutter is similar to a dish; it is tilted by a pre-set value in conventional machines. This value should not be modified.



Point Width Point Width of the Coniflex cutter.

Blade Edge Radius Blade edge radius. It can be entered either as “R1” for circular edge radius, or “R1/R2” for an elliptic edge radius (see below).



Cutter Edge Straight only at this time.

Rad. of Curvature Radius of curvature of Circular edged cutter. Unused at this time

Ref. Height Height at which the Blade Angle is defined for Circular edged cutter. Unused at this time

Dish Angle (Beta) The Coniflex cutter is similar to a dish; the Dish Angle is the deviation between a straight line and the actual cutting edge, as shown in the figure above. This value cannot be edited as it is a consequence of the Blade Angle and the Cutter Tilt.

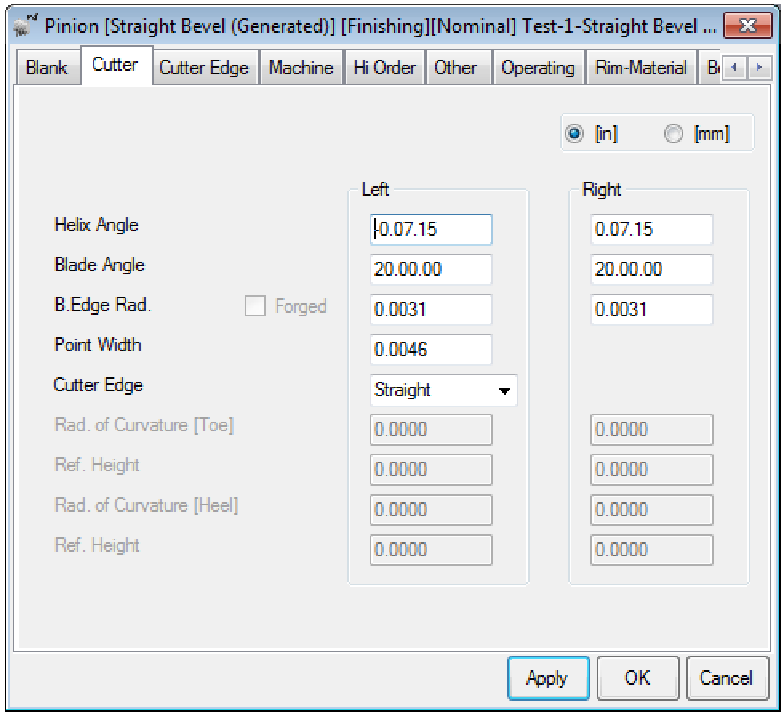
Back Angle Back angle of the Coniflex cutter.

Blade Thickness: Thickness of the Coniflex cutter

9.1.2.3 Straight-Bevel

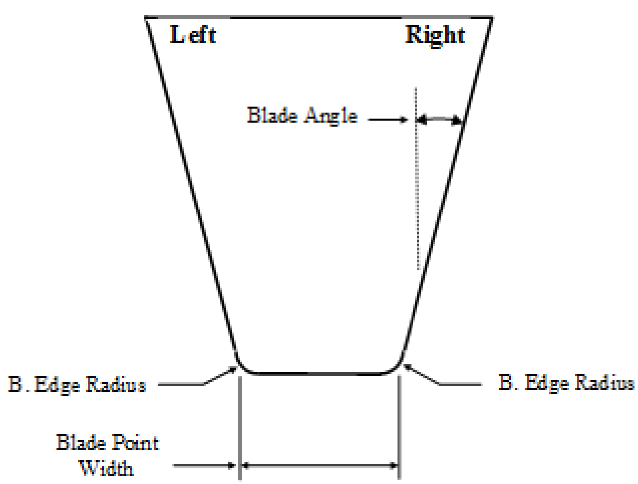
The Cutter data page of the Geometry Summary editor covers data related to the cutter definition. All fields are editable, but care must be used when changing values such as the cutter point diameter, since a change in cutter diameter must be compensated by a change in sliding base and machine center to back when cutter tilt is used, what is sometimes called proportional changes. This is done automatically by HyGEARS in the Graphics->Contact Pattern Development function.

Cutter units are identified in the Cutter data page tab ([in] here), and can be changed by calling the Edit->Configuration function from the Main Menu, or by modifying the Cutter Units at the top right of the Cutter data page.



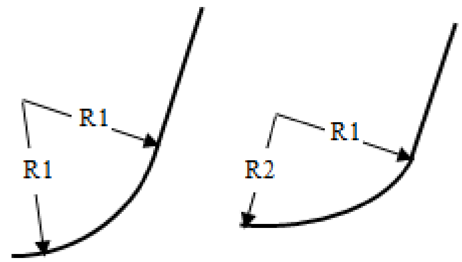
In straight-bevel gears, the cutter blades may be modified in a way similar to TopRem for spiral-bevel and hypoid gears. Deviations from the nominal blade angle, called Relief Angles, may be specified for the Addendum portion of the tooth, corresponding to the lower part of the cutter blade, and the Dedendum portion of the tooth, and which corresponds to the upper part of the blade. These deviations are specified in the Cutter Edge data page.

Cutter Data includes the following fields, for both tooth flanks, and refers to the following figures for understanding:



Straight-Bevel Gear Cutter Blade

Helix Angle	Helix angle of the tooth.
Blade Angle	Blade angle. Both Left and Right blade angles are positive values.
B.Edge Rad	Blade edge radius. If the "Forged" check box is checked, then the Left Blade Edge Radius corresponds to the Toe value and the Right Blade Edge Radius corresponds to the Heel value; intermediate values between Toe and Heel are interpolated as a function of facewidth position. It can be entered either as "R1" for circular edge radius, or "R1/R2" for an elliptic edge radius (see below).



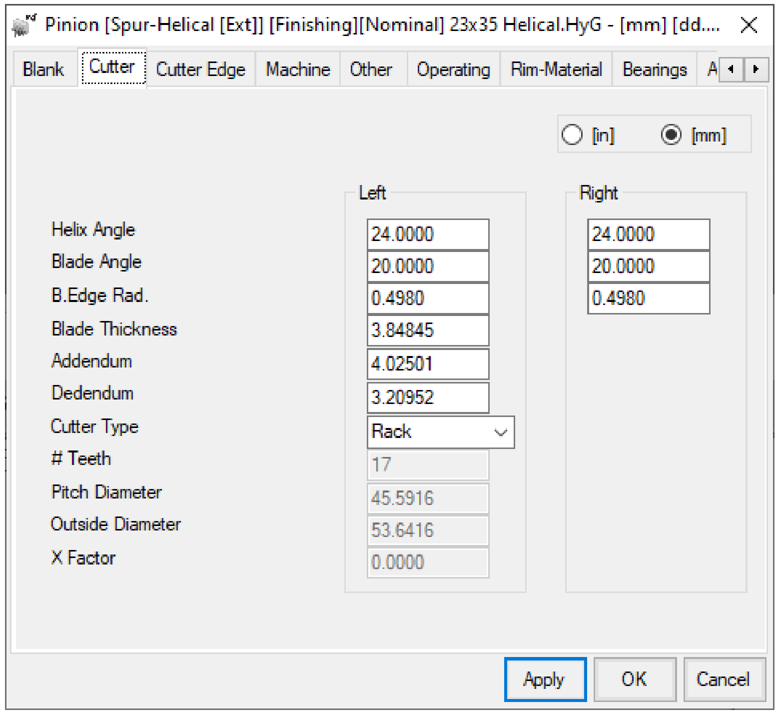
Circular B. Edge R **Elliptic B. Edge R.**

Point Width	Blade point width. It is used in calculations since it determines the tooth thickness
Cutter Edge	Straight only at this time.
Rad. of Curvature [Toe]	Radius of curvature of Circular edged cutter at Toe. Unused at this time
Ref. Height	Height at which the Blade Angle is defined at Toe for Circular edged cutter.
Rad. of Curvature [Heel]	Radius of curvature of Circular edged cutter at Heel. Unused at this time
Ref. Height	Height at which the Blade Angle is defined at Heel for Circular edged cutter.

9.1.2.4 Spur, Helical, Beveloid

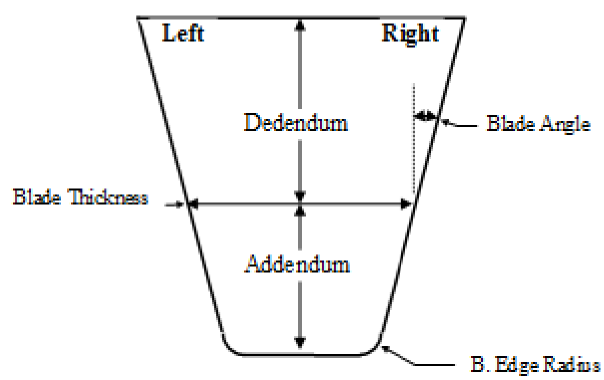
The Cutter data page of the Geometry Summary editor covers data related to the cutter definition. All fields are editable, but care must be used when changing.

Cutter units are identified in the Cutter data page tab ([in] here), and can be changed by calling the Edit->Configuration function from the Main Menu, or by modifying the Cutter Units at the top of the Cutter data page.



In spur and helical gears, the cutter blades may be modified in a way similar to TopRem for spiral-bevel and hypoid gears. Deviations from the nominal blade angle, called Relief Angles, may be specified for the Addendum portion of the tooth, corresponding to the lower part of the cutter blade, and the Dedendum portion of the tooth, and which corresponds to the upper part of the blade. These deviations are specified in the Cutter Edge data page.

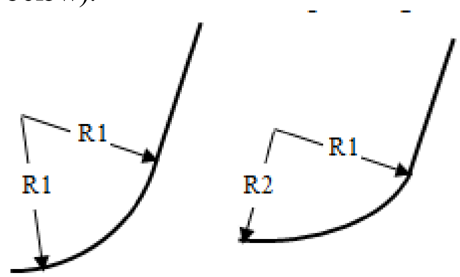
The Cutter data page is used to specify the cutting blade geometry. It includes the following fields, for both tooth flanks, and refers to the following figures for understanding:



Spur and Helical Gear Cutter Blade

Helix Angle	Helix angle of the gear set. Editable.
Blade Angle	Blade angle. Both Left and Right blade angles are positive values.

B.Edge Rad	Blade edge radius. It can be entered either as “R1” for circular edge radius, or “R1/R2” for an elliptic edge radius (see below).



Circular B. Edge R   Elliptic B. Edge R.

Blade Thickness	Blade thickness at the specified Addendum. It is used in calculations since it determines the tooth thickness.
Addendum	Cutter Blade Addendum.
Dedendum	Cutter Blade Dedendum.
Cutter Type	Either *Rack* or *Shaper*, which means that the tooth dimensions are defined in the plane normal to the tool.
# Teeth	Number of teeth for a *Shaper*; editable only when the selected tool is a *Shaper*;
Pitch Diameter	Pitch Diameter for a *Shaper*; editable only when the selected tool is a *Shaper*;.
Outside Diameter	Outside Diameter for a *Shaper*; editable only when the selected tool is a *Shaper*.

9.1.3 Cutter Edge Data

The Cutter Edge data page of Geometry Summary editor covers the modifications given to the cutting edge in order to impose profile modifications to the tooth profile.

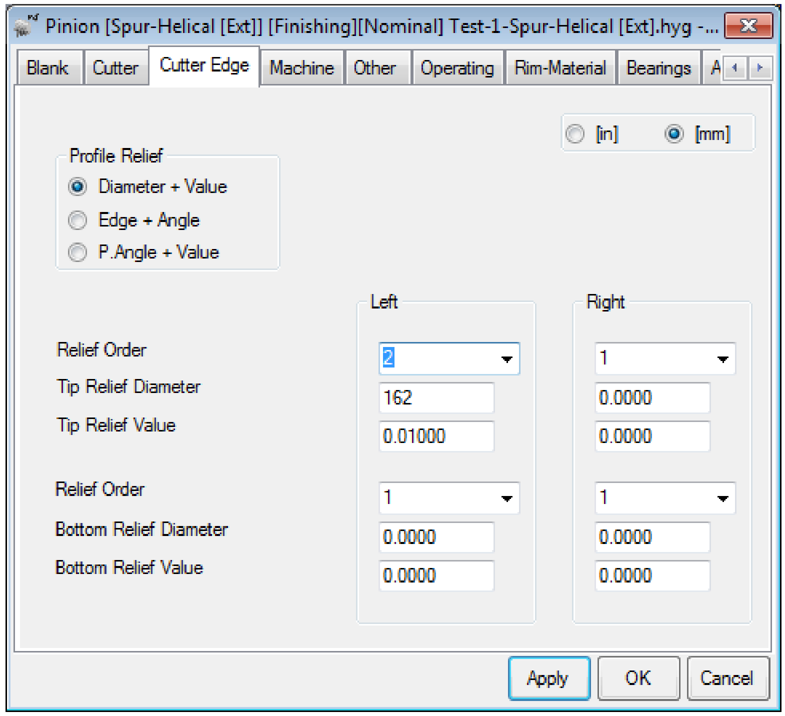
Straight-bevel Gears

Spur, Helical and Beveloid Gears

9.1.3.1 Spur, Helical, Beveloid

The Cutter Edge data page of the Geometry Summary editor covers data related to cutter edge relief.

Diameter + Value
Edge + Value
P.Angle + Value



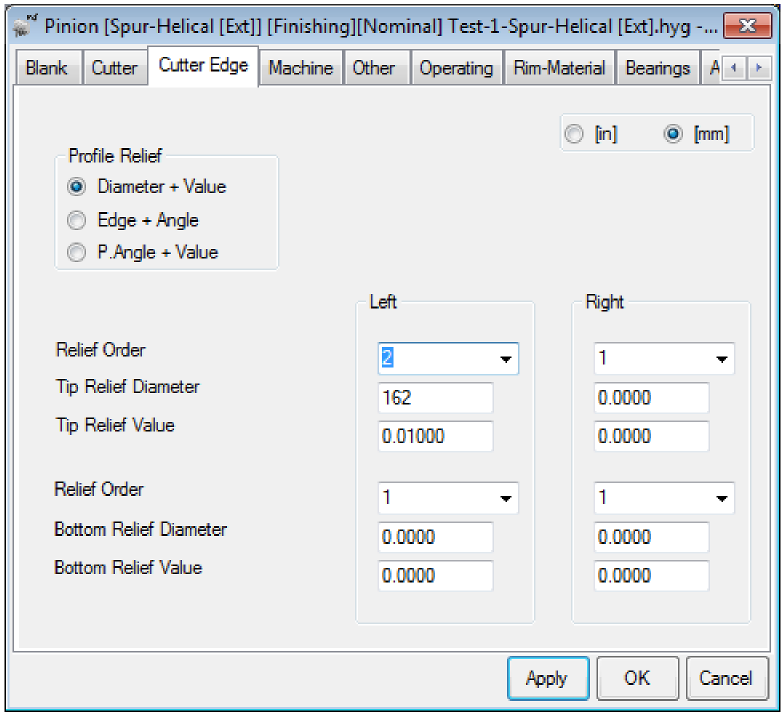
In spur and helical gears, the cutter blades may be modified in a way similar to TopRem for spiral-bevel and hypoid gears. Deviations from the nominal blade angle, called Relief Angles, may be specified for the Addendum portion of the tooth, corresponding to the lower part of the cutter blade, and the Dedendum portion of the tooth, and which corresponds to the upper part of the blade.

The cutter blades may be modified in three different ways:

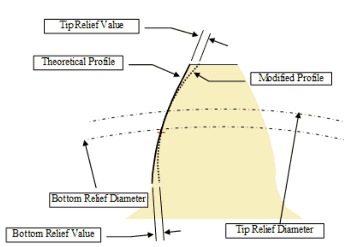
Diameter + Value

In this method, one specifies the diameter at which deviation is to start, and a specified deviation value.

For example, in the figure below, deviation on the left tooth is to start at a diameter of 162 mm, and reach a value of 0.010 [mm] at tip.



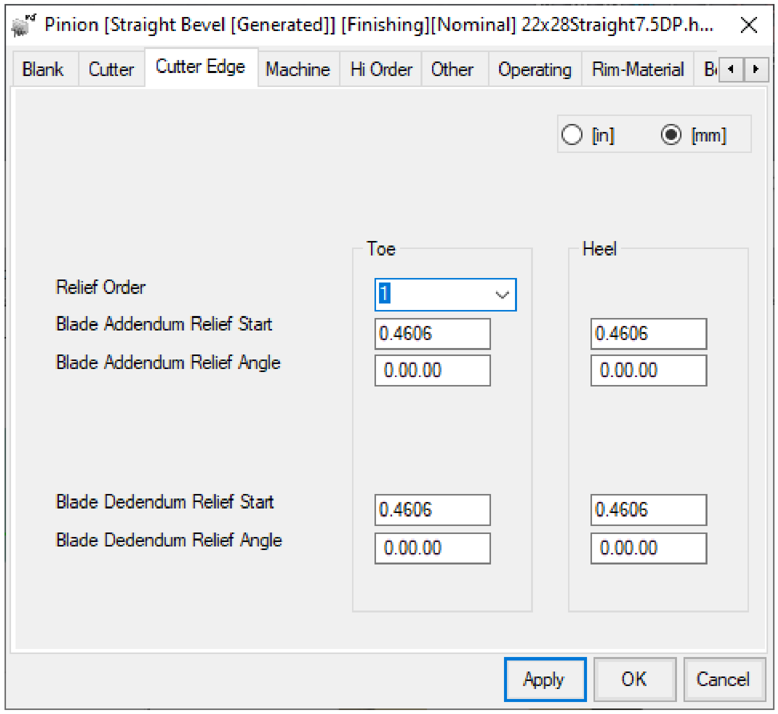
Relief Order	Order with which the deviation evolves; TopRem are typically first order (straight) deviations; higher orders are possible in HyGEARS.
Tip Relief Diameter	Diameter at which Tip Relief is to start.
Tip Relief Value	Amount of deviation normal to the tooth profile at the Tip Diameter, i.e. at the end of the Relief curve.
Bottom Relief Diameter	Diameter at which Bottom Relief is to start.
Bottom Relief Value	Amount of deviation normal to the tooth profile at the Fillet Diameter, i.e. at the end of the Relief curve.

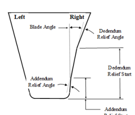


Spur and Helical Gear Tooth

Edge + Angle

This is similar to TopRem for spiral-bevel and hypoid gears. Deviations from the nominal blade angle, called Relief Angles, may be specified for the Addendum portion of the tooth, corresponding to the lower part of the cutter blade, and the Dedendum portion of the tooth, and which corresponds to the upper part of the blade;



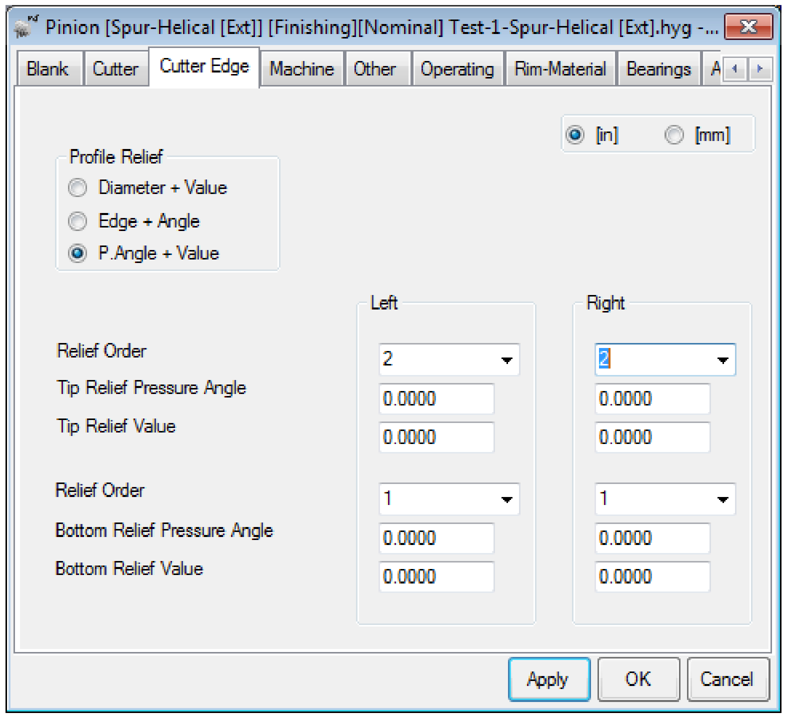


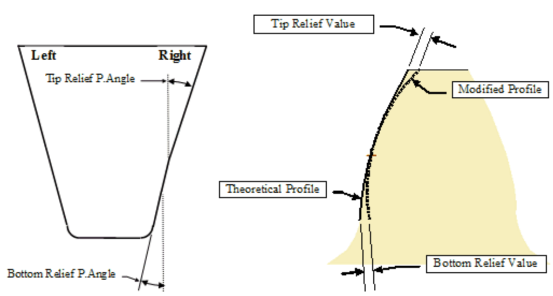
Straight-Bevel Gear Cutter Blade Edge Relief

Relief Order	Order with which the deviation evolves; TopRem are typicall first order (straight) deviations; higher orders are possible in HyGEARS.
Addendum Relief Start	Vertical position, i.e. *not* along the blade edge, where Addendum Relief begins. If this value is null, then relief is ignored.
Addendum Relief Angle	Amount of deviation from the given Blade Angle. A positive value is as shown in the figure above. If this value is null, then relief is ignored.
Dedendum Relief Start	Vertical position, i.e. *not* along the blade edge, where Dedendum Relief begins. If this value is null, then relief is ignored.
Dedendum Relief Angle	Amount of deviation from the given Blade Angle. A positive value is as shown in the figure above. If this value is null, then relief is ignored.

P. Angle + Value

Specification the Pressure Angle and actual deviation value desired at the end of the deviation; HyGEARS will determine where on the Cutter Blade deviation is to begin.





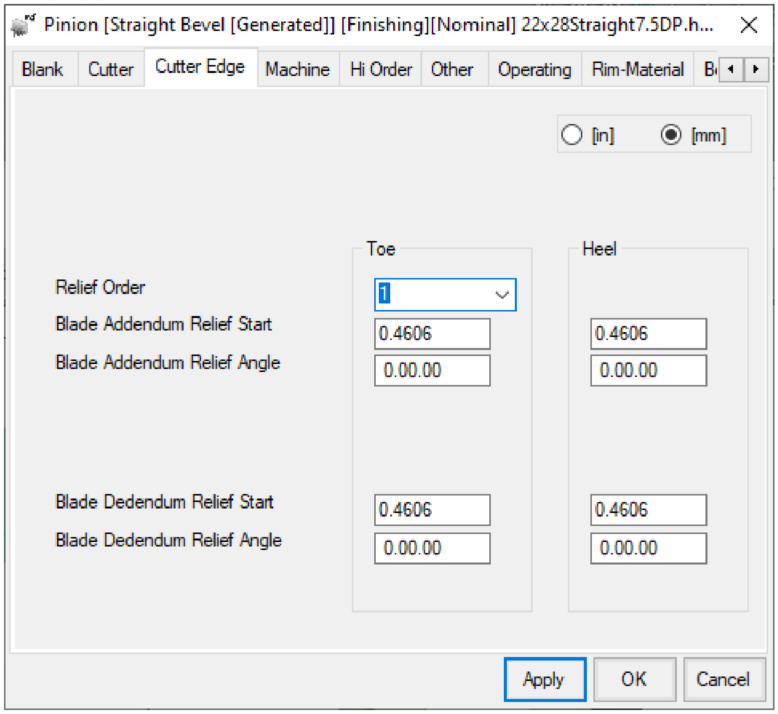
Relief Order	Order with which the deviation evolves; TopRem are typically first order (straight) deviations; higher orders are possible in HyGEARS.
Tip Relief P. Angle	Desired Blade Angle for Tip Relief.
Tip Relief Value	Amount of deviation normal to the tooth profile at the Tip Diameter, i.e. at the end of the Relief curve.
Bottom Relief P. Angle	Desired Blade Angle for Bottom Relief.

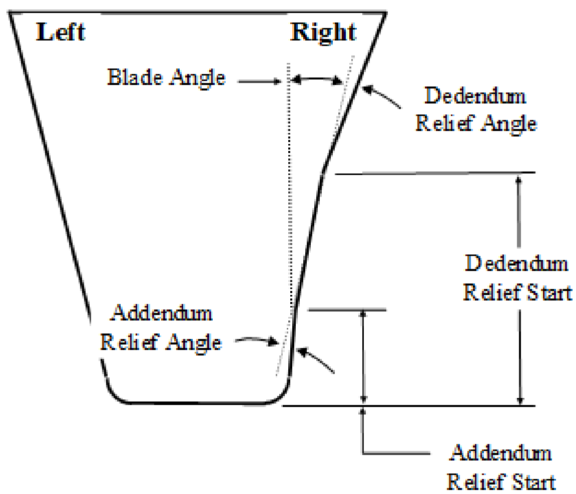
Bottom Relief Value	Amount of deviation normal to the tooth profile at the Fillet Diameter, i.e. at the end of the Relief curve.

9.1.3.2 Straight-Bevel

This is similar to TopRem for spiral-bevel and hypoid gears. Linear deviations from the nominal blade angle, called Relief Angles, may be specified for the Addendum portion of the tooth, corresponding to the lower part of the cutter blade, and the Dedendum portion of the tooth, and which corresponds to the upper part of the blade;

Values are given at Toe and Heel, which are linearly interpolated along the tooth flank. In this manner, it is possible to obtain a variable profile modification along the tooth (for Forged gears of course). The same values are used for the Left and Right tooth flanks.





Straight-Bevel Gear Cutter Blade Edge Relief

Relief Order	Order with which the deviation evolves; TopRem are typicall first order (straight) deviations; higher orders are possible in HyGEARS.
Addendum Relief Start	Vertical position, i.e. *not* along the blade edge, where Addendum Relief begins. If this value is null, then relief is ignored.

Addendum Relief Angle	Amount of deviation from the given Blade Angle. A positive value is as shown in the figure above. If this value is null, then relief is ignored.
Dedendum Relief Start	Vertical position, i.e. *not* along the blade edge, where Dedendum Relief begins. If this value is null, then relief is ignored.
Dedendum Relief Angle	Amount of deviation from the given Blade Angle. A positive value is as shown in the figure above. If this value is null, then relief is ignored.

9.1.3.3 Spiral-Bevel TopRem/Tip Relief Data

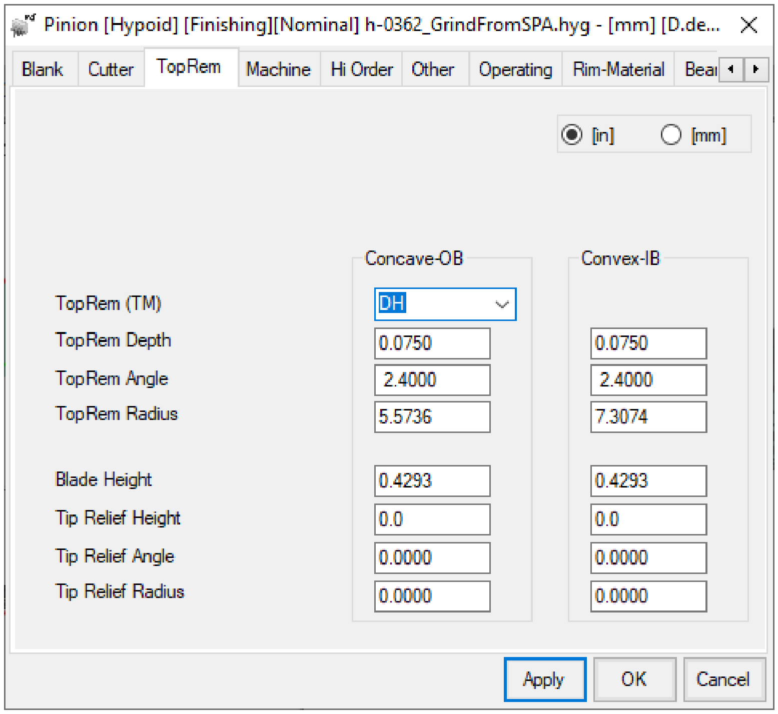
The TopRem data page of the Geometry Summary editor covers data related to the cutter edge modification by TopRem and Tip Relief. Although, strictly speaking, it is not normally used on gear members, it is nevertheless offered in HyGEARS for the sake of flexibility.

TopRem is offered in two flavors:

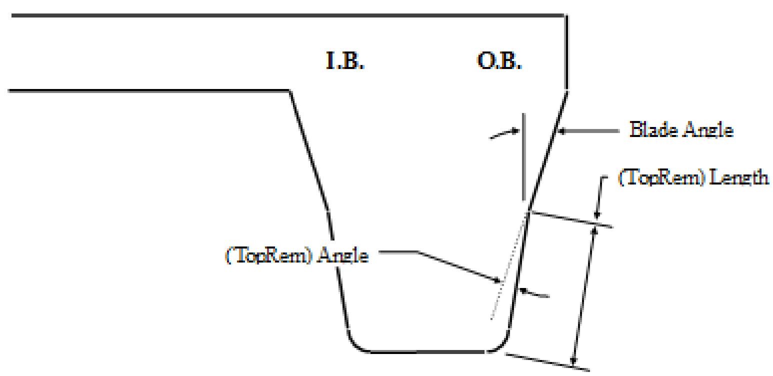
Linear	for use on straight edged cutters; it is defined by the TopRem Depth and the TopRem Angle;
Circular	for use on straight edged and circular edged cutters; it is defined by the TopRem Depth and the TopRem Radius.

Both TopRem Angle and Radius can be entered at the same time, and both will be saved within the HyG file. When both Angle and Radius values are given, the Radius value is given preference.

The TopRem (TM) field offers are list of predefined Linear TopRem values corresponding to different TopRem letters.

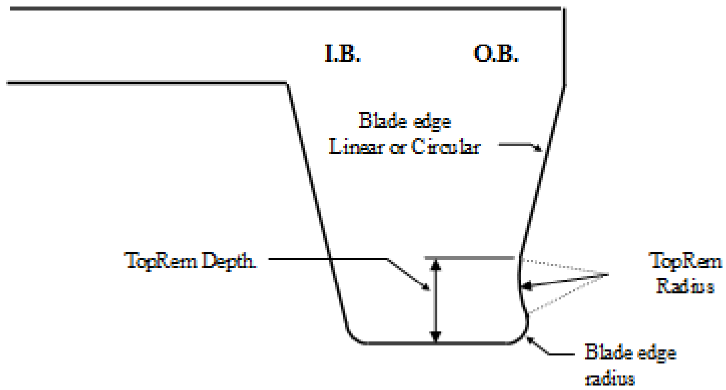


Linear TopRem



Linear TopRem

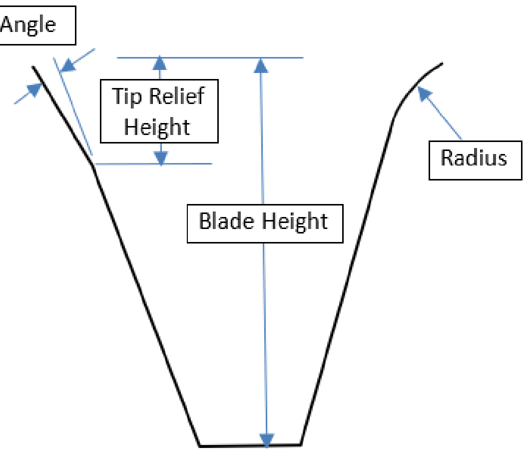
Circular TopRem

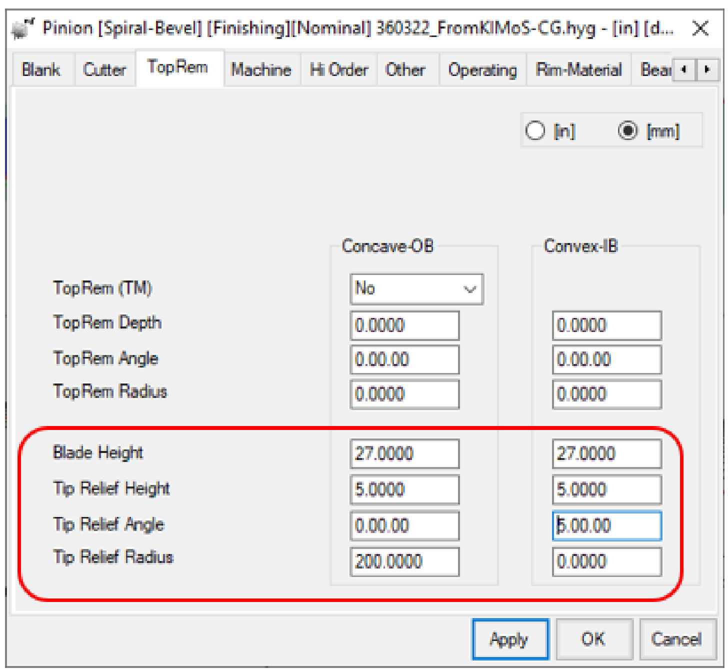


Circular TopRem

Tip Relief

The Tip Relief variables appear as defined below. When non-zero values for Tip Relief Angle and Radius are entered, preference is given to Circular Tip Relief, i.e. the Tip Relief Radius is considered.





9.1.4 Machine Data

The Machine Settings data page of the Summary editor covers all data related to the machine setup.

All fields are editable but care must be used when changing values since, for example in a Spiral-Bevel or Hypoid gear, if cutter Tilt is present, a change in Eccentric Angle must be compensated by a change in Sliding Base and Machine Center to Back.

Linear and angular units are identified in the Summary Editor title bar and can be changed on the fly from the Machine Settings data page or by calling the Edit->Configuration function from the Main Menu.

- Spiral-Bevel and Hypoid Gears
- Coniflex Bevel Gears
- Straight-Bevel Gears
- Spur and Helical Gears

9.1.4.1 Zerol, Spiral-Bevel, Hypoid

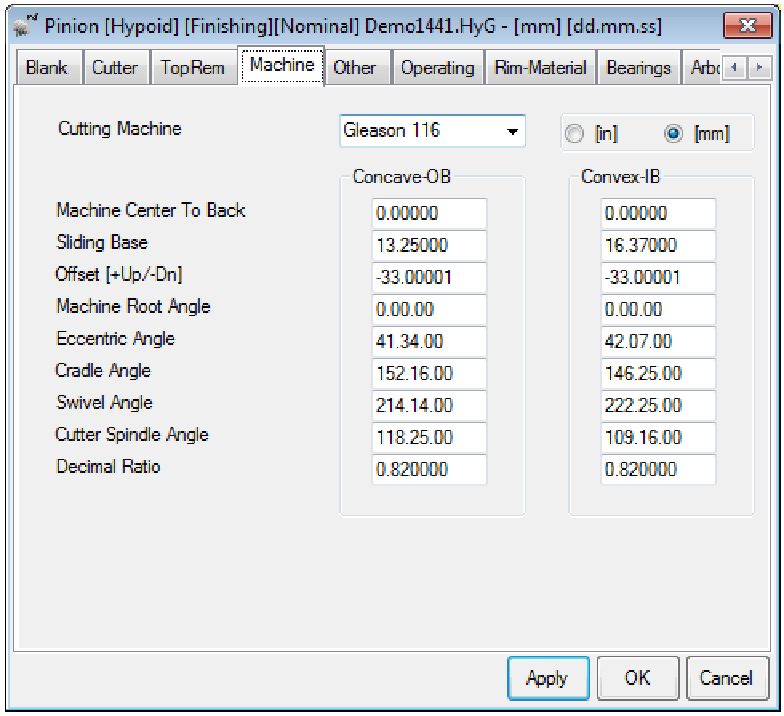
The Machine Settings data page of the Summary editor covers all data related to the machine setup. All fields are editable but care must be used when changing values since, for example, a change in eccentric angle must be compensated by a change in sliding base and machine center to back, what is also called proportional changes. This is done automatically by HyGEARS in the Graphics->Contact Pattern Development function.

Linear and angular units are identified in the Summary Editor title bar and can be changed by calling the Edit->Configuration function from the Main Menu.

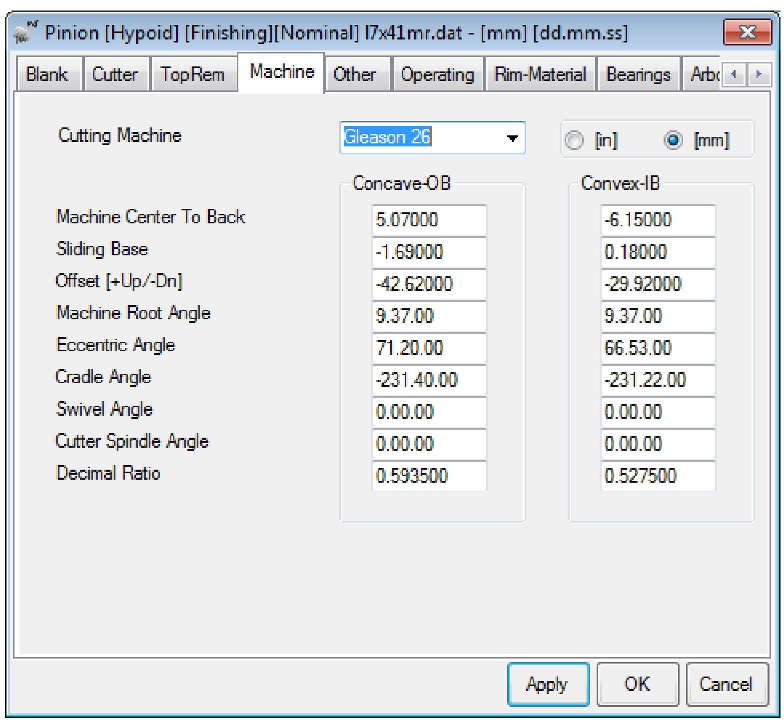
Mechanical Machine Settings

The main difference here is that the Fixed Setting and Modified Roll Machine Settings data page shows different editable input fields for the concave (O.B.) and convex (I.B.) tooth flanks, while the Spread Blade and Duplex Helical Machine Settings data page shows editable input fields for both the concave (O.B.) and convex (I.B.) tooth flanks at the same time.

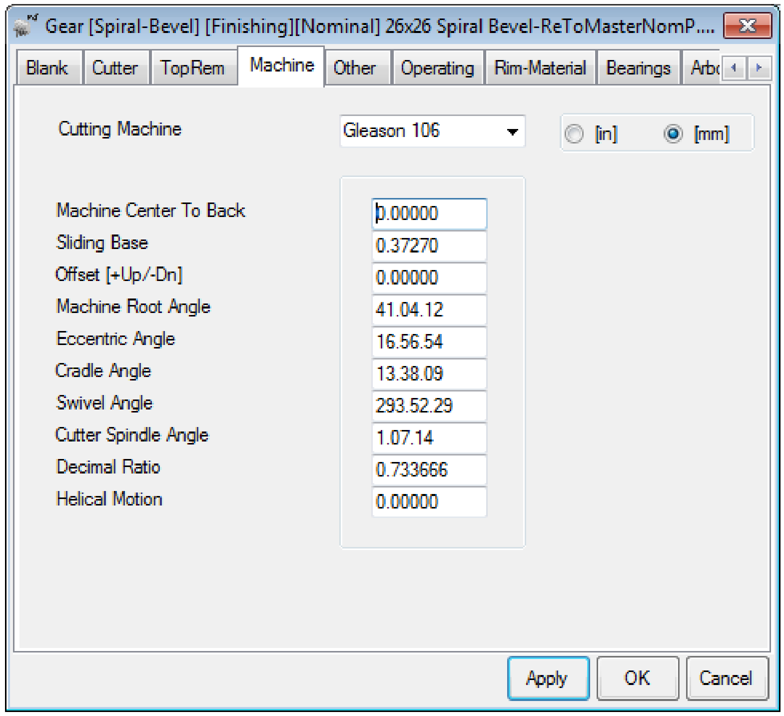
Fixed Setting



Modified Roll



Spread Blade and Duplex Helical



The Machine Settings data page includes the following fields:

Machine — Cutting machine. By default, when using the New Geometry Definition function to create a new gear set, the pinion cutting machine is set to Phoenix.

Note 1 — Angular machine settings for Gleason generators are always in the [Deg.Min.Sec] format. However, both formats may be used provided one remembers that the Deg.Dec format has only 2 sets of digits separated by a period, whereas the Deg.Min.Sec format has three sets of digits separated by two periods.

Note 2 — Angular machine settings for Phoenix machines are always in the [Deg.Dec] format. However, both formats may be used provided one remembers that the Deg.Dec format has only 2 sets of digits separated by a period, whereas the Deg.Min.Sec format has three sets of digits separated by two periods.

Note 3 — The Gleason #26 generator does not support cutter tilt; an error message will be displayed if it is selected for conversion when cutter tilt is present.

It is possible to convert the summary to that of other generating machines such as Gleason generators 26, 106 and 116, the Formate and Helixform 607 machine or the Phoenix free form machines by selecting the desired machine from the Cutting Machine input field list.

All machine settings are automatically updated, and will become the current machine settings unless the Esc (escape key) or the Cancel button is pressed. In such a case, the geometry is returned to its previous machine and the Summary editor is terminated.

The following machines are supported, for the specified cutting processes:

Gleason Machine Number
16 22 26 (*) 102 106 108 116 Phoenix 607 613 631 641 Basic 999
Klinglenberg Machine Number
K-ND (neutral data)
Other Machine Number
YH 603 (*)

(*) Gleason machine #26 and Chinese machine YH 603 do not support cutter tilt.

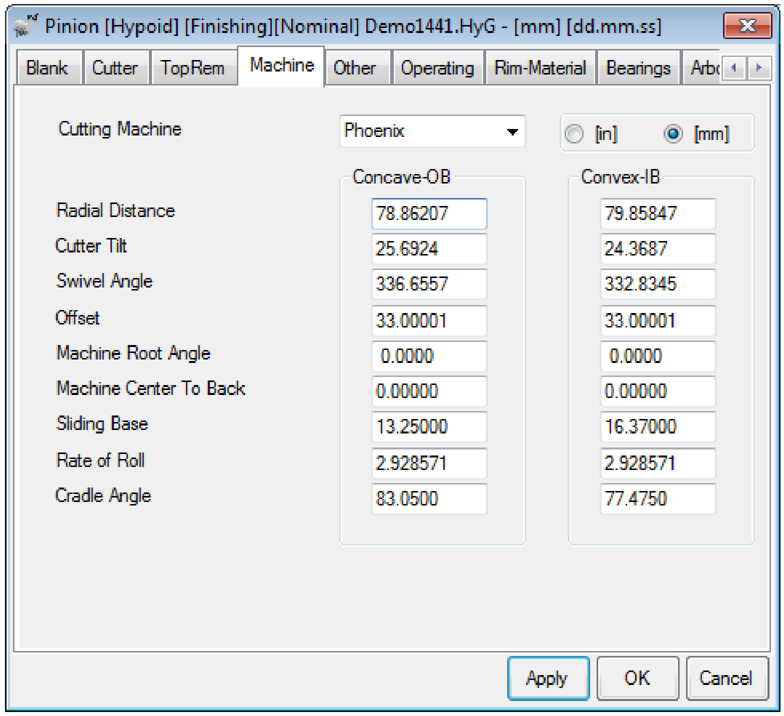
Radial Distance	Distance between the cutter center and the machine center (Phoenix only).
Cutter Tilt	Cutter tilt angle (Phoenix and K-ND only).

Machine Center to Back	Machine center to the back of the workpiece. Usually only a change in the nominal position. A positive value means withdraw (with); a negative value means advance (adv).
Sliding Base	Sliding base. A positive value means withdraw (with); a negative value means advance (adv).
Offset	Offset. A positive value means up; a negative value means down.
Machine Root Angle	Machine root angle.
Eccentric Angle	Eccentric angle.
Cradle Angle	Cradle angle.
Swivel Angle	Swivel angle.
Swash Angle	Swash angle (Cutter spindle rotation angle on Gleason machines).
Decimal Ratio	Decimal ratio on Gleason machines.
Rate of Roll	Workpiece to cradle ratio of roll. On Phoenix and K-ND machines.
Helical Motion	Workpiece advance [in/20 cutter rotation; mm/20 cutter rotation].
Eccentric	Value of the Modified Roll eccentric.
Roll Ratio	Ratio of roll for the Modified Roll eccentric.
Gaging Angle	Gaging angle of the Modified Roll eccentric.

Phoenix Machine Settings

The figure below shows how the Machine data page look for Gleason's Phoenix cutting machine in the Fixed Setting mode..

Fixed Setting



Modified Roll

The Phoenix uses the higher order change parameters 2C, 6D, 24E, 120F and 720G which are used to modify the position of the cradle as generation proceeds.

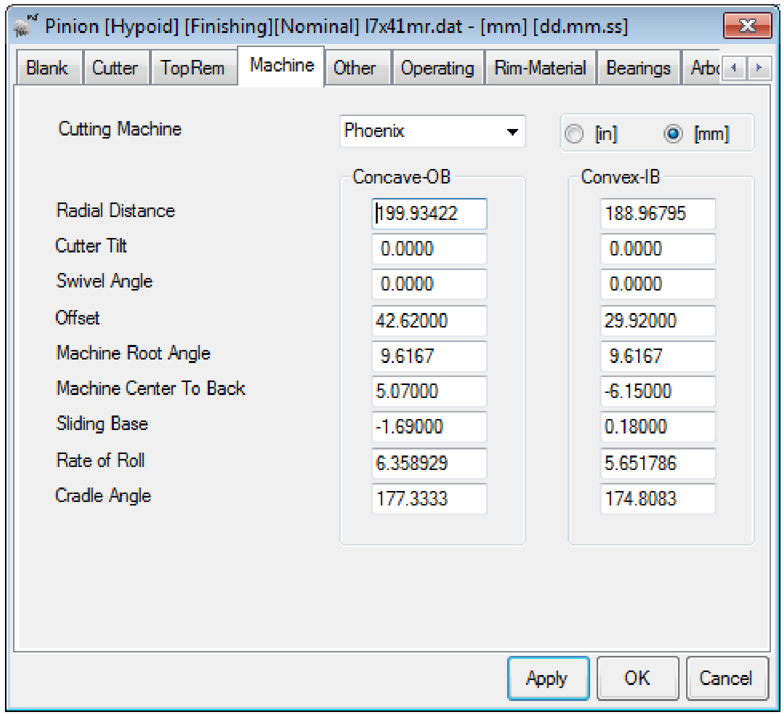
When converting a conventional Modified Roll machine such as the #26 to a CNC machine such as the Phoenix, HyGEARS converts all machine settings, including the higher order change coefficients 2C and 6D. The same procedure applies for the Chinese YH 603 and Klingelnberg ND machine (#888)

On the Phoenix machine, modifications to the ratio of roll are controlled by a 6^{th} order polynomial whose 2^{nd} , 3^{rd}, 4^{th}, 5^{th} and 6^{th} order coefficients (as per the Gleason nomenclature) are 2C, 6D, 24E, 120 F and 720G

The modified cradle angle is therefore:

$$L_{1m} = \alpha_3 R_r + \frac{2C}{2}(C_r - \alpha_3 R_r)^2 - \frac{6D}{6}(C_r - \alpha_3 R_r)^3 + \frac{24E}{24}(C_r - \alpha_3 R_r)^4 - \frac{120F}{120}(C_r - \alpha_3 R_r)^5 + \frac{720G}{720}(C_r - \alpha_3 R_r)^6$$

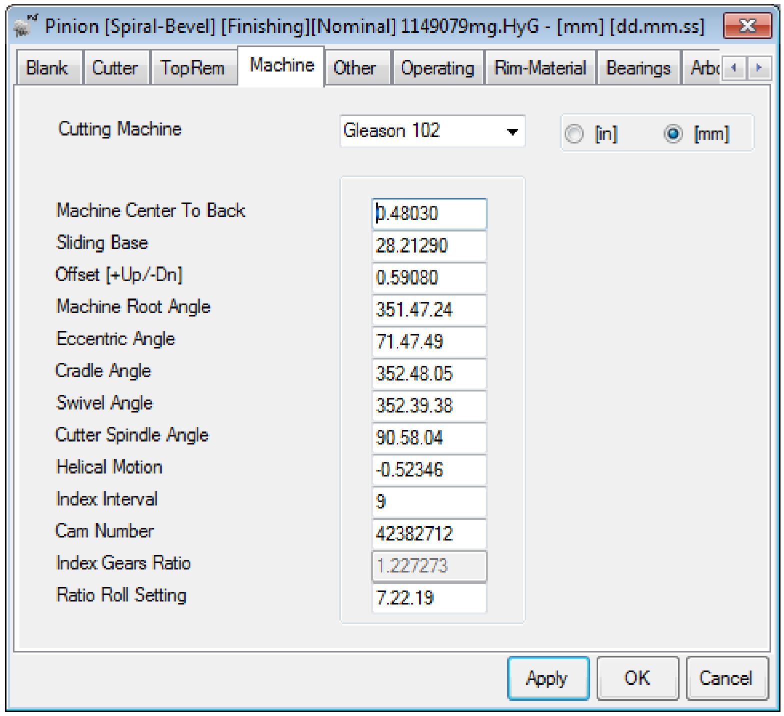
where: α_3 is the roll angle of the workpiece
R_r is the ratio of roll of the workpiece to the cradle
C_r is the cradle angle given in the machine settings



Higher order change parameters 2C, 6D, 24E, 120F and 720G are displayed, and can be edited, in the Higher Order data page.

Gleason #102 Machine Settings

The figure below shows how the Machine data page look for Gleason's #102, which is capable of Duplex Helical motion. Its cradle rotation may also be disabled such that the #102 can also cut non-generated (formate only) gear members.



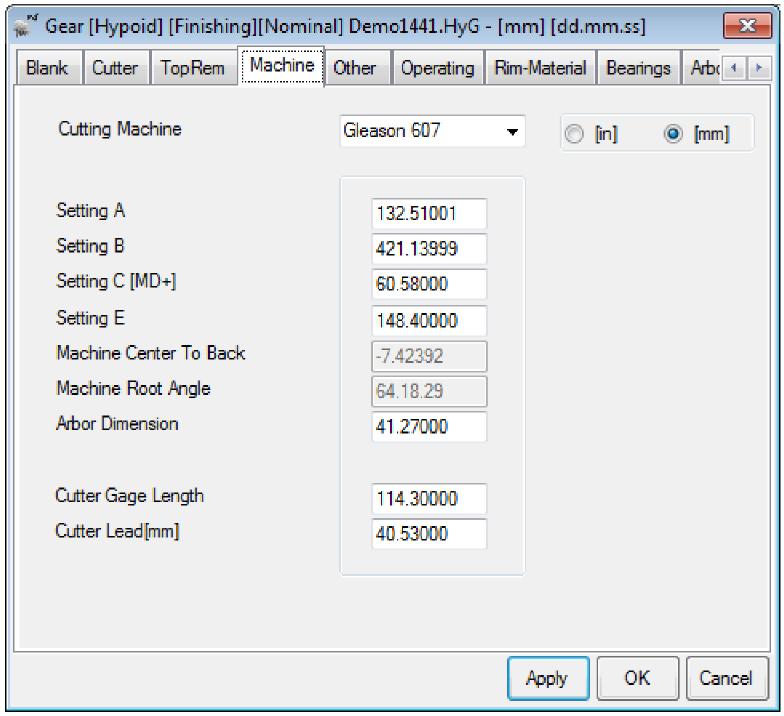
On the #102, a combination of Index Interval, Cam Number, Index Gear Ratio and Ratio of Roll Setting is given in lieu of the Decimal ratio, usual on machines such as the #116.

The Index Interval and Cam Number are the only 2 values that can be edited; when modified, both the Index Gears Ratio and Ratio-Roll Setting are recalculated and redisplayed.

The Index Interval and Cam Number must comply with Gleason's actual hardware, which is described in publications such as SGDH, the Calculating Instructions for Generated Spiral-Bevel Gears cut by the Duplex Helical Method.

Gleason 607 Formate and Helixform Machine Settings

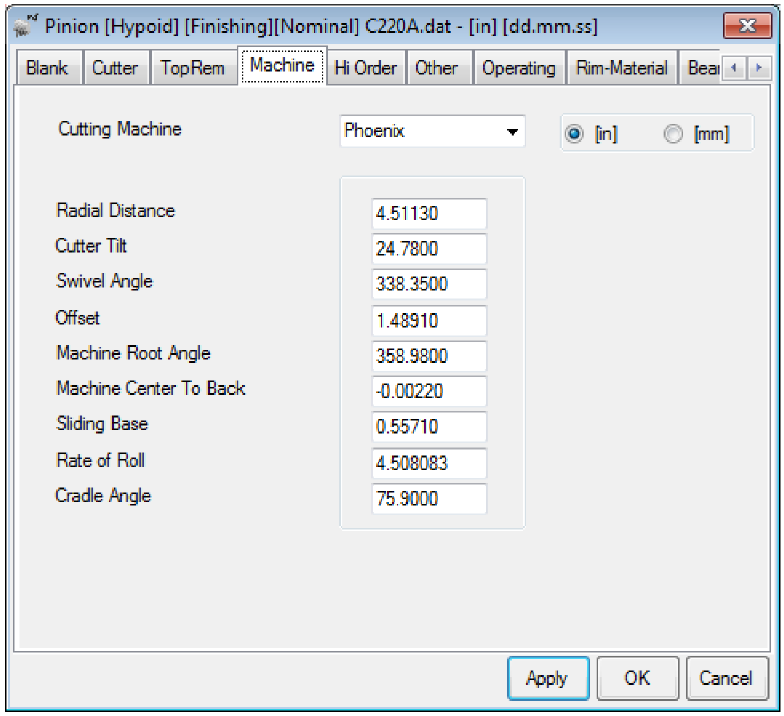
Two versions of the Gleason 607 cutting machine may be used for the Formate and Helixform gear cutting processes. In both cases, the machine settings use the same fields and names.



The Machine Settings data page includes the following fields:

Cutting Machine	Desired cutting machine; the table above lists the available machines for non-generated cutting processes.
Setting A	Machine A gage bar length, in the current linear units.
Setting B	Machine B gage bar length, in the current linear units.
Setting C [MD+]	Machine C gage bar length, in the current linear units.
Setting D, E	Machine D or E, depending on the tooth hand, gage bar length, in the current linear units.
Machine Center to Back	Machine center to back, in the current linear units. This is a basic machine settings reference value, and is not used. A positive value means withdraw (with); a negative value means advance (adv).
Machine Root Angle	Machine root angle, in the current angular units. This value is calculated from the above D or E gage bar lengths values.
Arbor Dimension	Arbor length, in the current linear units. If modified, the machine settings are updated for the new value.
Cutter Gage Length	Cutter gage length, in the current linear units. If modified, the machine settings are updated for the new value.
Cutter Lead	Gear cutter lead, for Helixform process only, in the given units/revolution (for example, [mm/revolution] in the above figure).

Phoenix Face Hobbing Machine Settings



The Machine Settings data page includes the following fields:

Machine Cutting machine.

Note Angular machine settings for Phoenix machines are always in the [Deg.Dec] format. However, both formats may be used provided one remembers that the Deg.Dec format has only 2 sets of digits separated by a period, whereas the Deg.Min.Sec format has three sets of digits separated by two periods.

The following machines are supported, for the specified cutting process:

Gleason Machine Number
Phoenix Basic 999
Klinglenberg Machine Number
K-ND (neutral data)

Radial Distance Distance between the cutter center and the machine center (Phoenix only).

Cutter Tilt	Cutter tilt angle (Phoenix and K-ND only).
Swivel Angle	Cutter swivel angle.
Offset	Offset. A positive value means up; a negative value means down.
Machine Root Angle	Machine root angle.
Machine Center to Back	Machine center to the back of the workpiece. Usually only a change in the nominal position. A positive value means withdraw (with); a negative value means advance (adv).
Sliding Base	Sliding base. A positive value means withdraw (with); a negative value means advance (adv).
Rate of Roll	Workpiece to cradle ratio of roll. On Phoenix and K-ND machines.

Higher order changes, such as Modified Roll and Helical Motion, are detailed in the Higher Order data page.

9.1.4.2 Coniflex

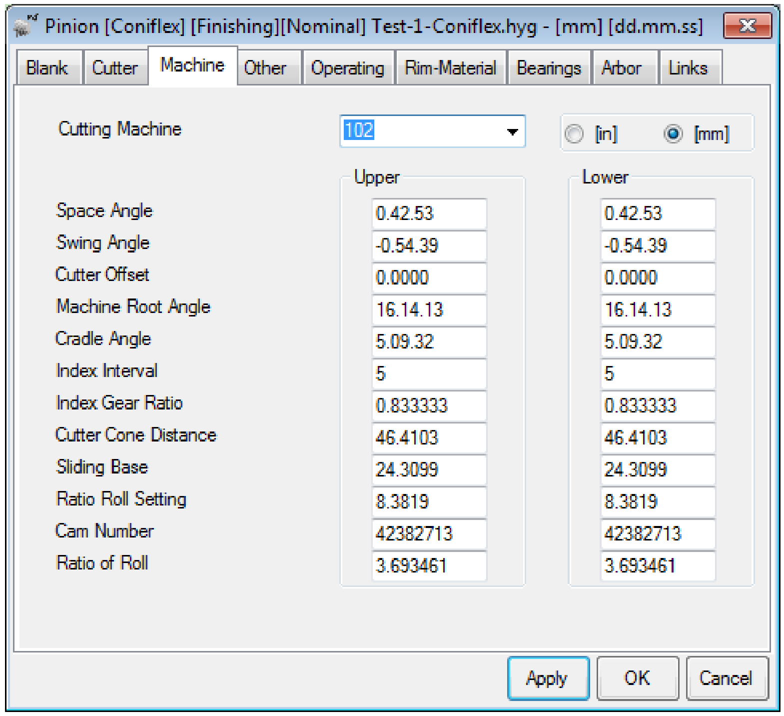
The Machine Settings data page of the Summary editor covers all data related to the machine setup. All fields are editable but care must be used when changing values.

The two figures below display the Machine data page for Gleason's #102, 104, 114 and 134 Coniflex machines.

Gleason #102 machine

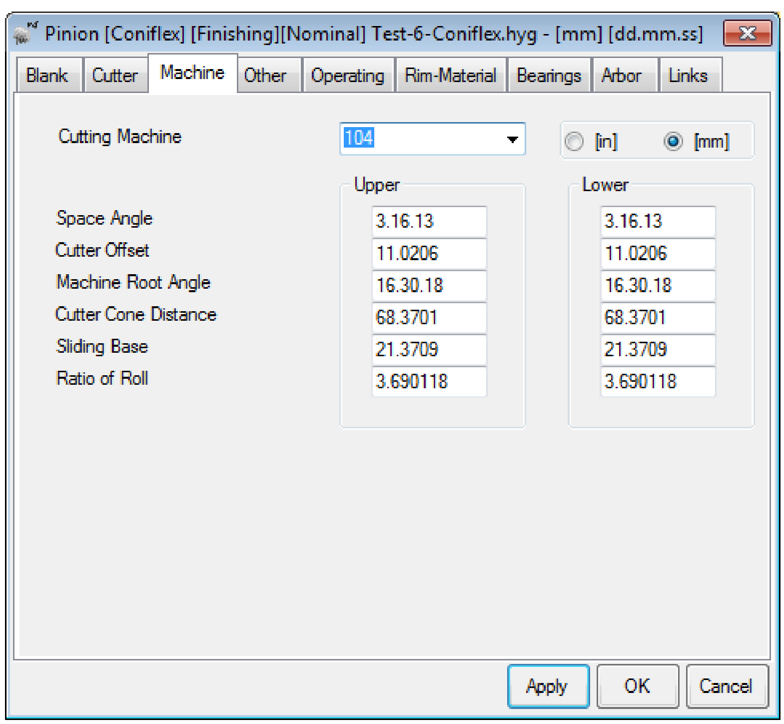
A combination of Index Interval, Cam Number, Index Gear Ratio and Ratio of Roll Setting is given in lieu of the Decimal ratio, usual on machines such as the #116.

The Index Interval and Cam Number can be edited; when modified, both the Index Gears Ratio and Ratio-Roll Setting are recalculated and redisplayed.



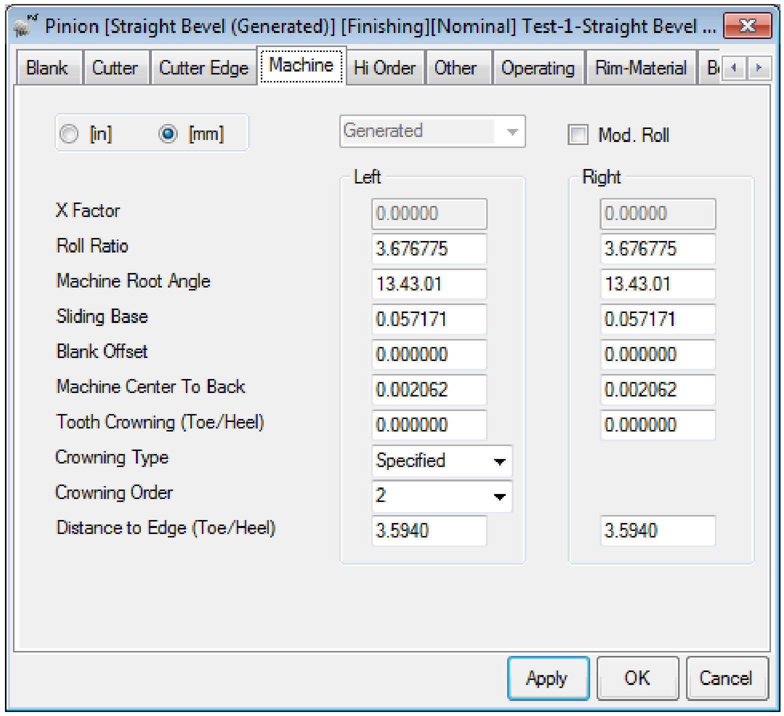
Gleason machines #104, 114 and 134

The Ratio of Roll between the cradle and the work piece is given rather than the Decimal Ratio. Ratio of Roll can easily be converted to Decimal Ratio.



9.1.4.3 Straight-Bevel

The Machine Settings data page of the Summary editor covers all data related to the machine setup. All fields are editable but care must be used when changing values.



In HyGEARS, the Straight Bevel gear machine is apparented to Gleason's two-tool generator. That is to say that cutters have a rectilinear motion along the facewidth. The cutters replicate rectilinear teeth of a theoretical crown gear mating with the workpiece. Since the teeth are tapered lengthwise, the cutter blades follow the topland of the crown gear teeth and thus, the pinion and gear are not conjugate and Transmission Error will be apparent; the closer the speed ratio is to 1, the further from conjugacy since the pinion and gear addendum angles tend to increase; the larger the speed ratio, the lower the resulting Transmission Error.

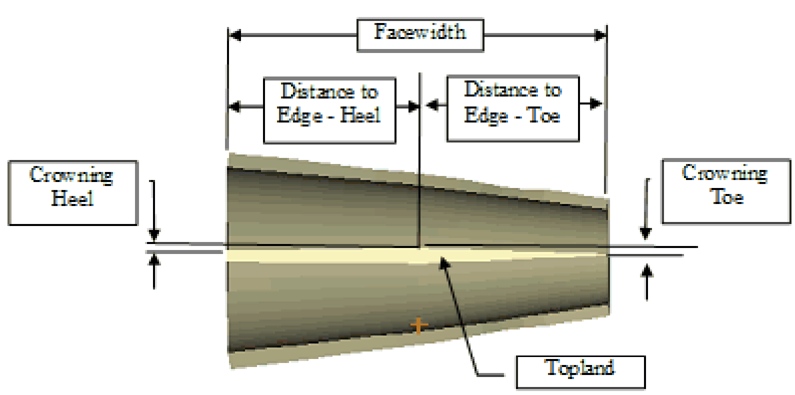
To this rectilinear motion, crowning may be added by slightly curving the linear motion of the cutter blades along the teeth. This allows for localized contact on the tooth flank and thus decreases the sensitivity of the gearset to position and alignment errors resulting from manufacturing tolerances and gearbox deformation.

Linear and angular units are identified in the Summary Editor title bar ([in] - [deg.min.sec] in this example) and can be on the fly.

The Machine Settings data page includes the following fields:

X Factor — Tool shift factor; a positive value withdraws the tool from the axis of rotation of the workpiece; actual tool shift is the product

	of the Module times the X Factor, for metric units, or the quotient of the X Factor by the Diametral Pitch for imperial units.
Roll Ratio	Ratio of roll between the workpiece and the theoretical crown gear. The ratio of roll depends on the pinion and gear tooth numbers and the shaft angle.
Machine Root Angle	Machine root angle. The machine root angle is a function of the Roll Ratio.
Sliding Base	Sliding base, i.e withdraw or advance of the workpiece relative to the tool. A positive value means withdraw (with); a negative value means advance (adv).
Blank Offset	Blank offset; positive Up, negative Down;
Tooth Crowning	Desired amount lengthwise tooth crowning to localize the Contact Pattern at the center of the tooth flank. If crowning is insufficient, the Contact Pattern may shift because of manufacturing tolerances and deformations under load; if too large, then contact stresses are likely to increase because of the reduced contact area. Separate values are given at Toe and Heel.
Crowning Type	Only “Specified” available at this time. In this case, the tool is allowed to deviate only in the plane containing rectilinear motion.
Crowning Order	Order at which crowning is to evolve from the edge; normally, second order crowning is acceptable; first order should be avoided unless one simply desires a break-edge at toe and heel, and which case the Distance to Edge should be short.
Distance to Edge	Distance from tooth edges, Toe and Heel, where crowning starts. If second or third order crowning is used, this may be equal to half the facewidth; if first order is used, this should be close to the edge in order to avoid singular contact at mid-facewidth. Separate values are given at Toe and Heel.



Mod. Roll:	Modified Roll has been introduced in HyGEARS to allow control of the Transmission Error. Whenever a new Straight Bevel gear geometry is created, Modified Roll values are

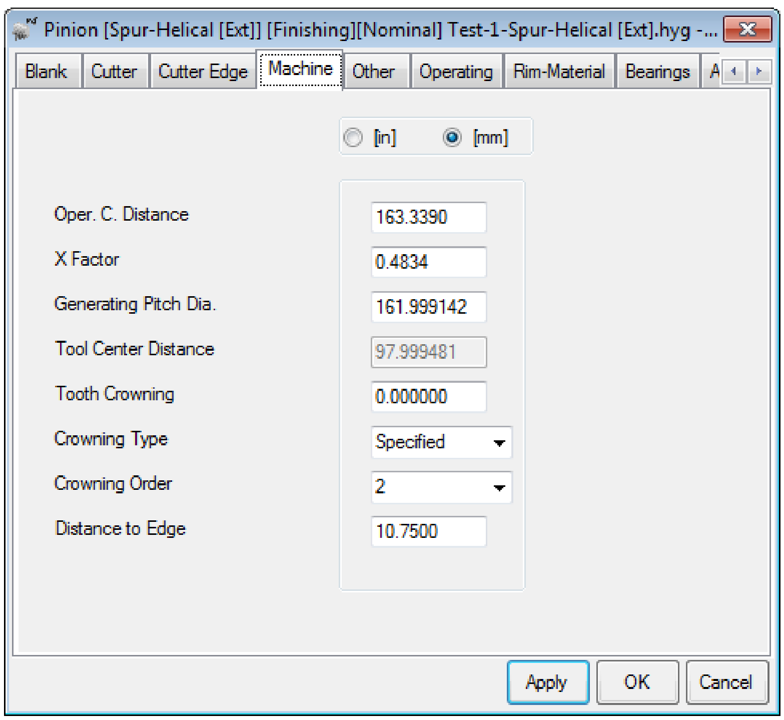
calculated to limit Transmission Error to a user defined value. Modified Roll does not exist on traditional straight-bevel machines, and can therefore be used only when the gearset is forged, or cut on a 5 Axis CnC machine.

Note: The Mod.Roll *check box* activates and de-activates Modified Roll.

Higher order changes, such as Modified Roll and Helical Motion, are detailed in the Higher Order data page.

9.1.4.4 Spur, Helical, Beveloid

The Machine Settings data page of the Summary editor covers all data related to the machine setup. All fields are editable but care must be used when changing values.

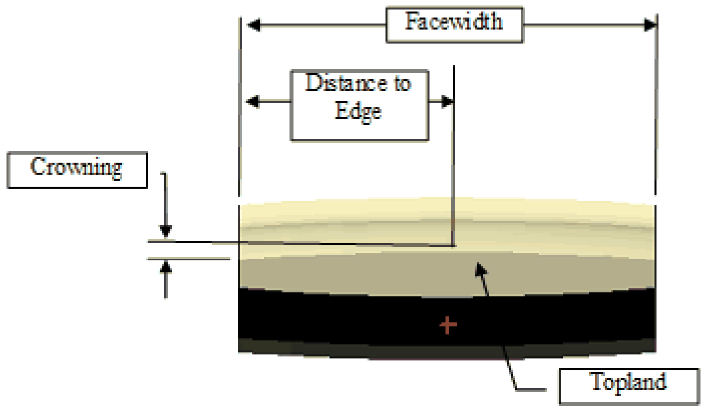


In HyGEARS, the spur and helical gear machine, for both the external and internal gears, is basically a rack. Additionally, shaper cutters may be used, which make more sense for internal gears. Of course, the generated profiles are identical using either tool.

Linear and angular units are identified in the Summary Editor title bar ([in] - [deg.min.sec] in this example) and can be changed on the fly.

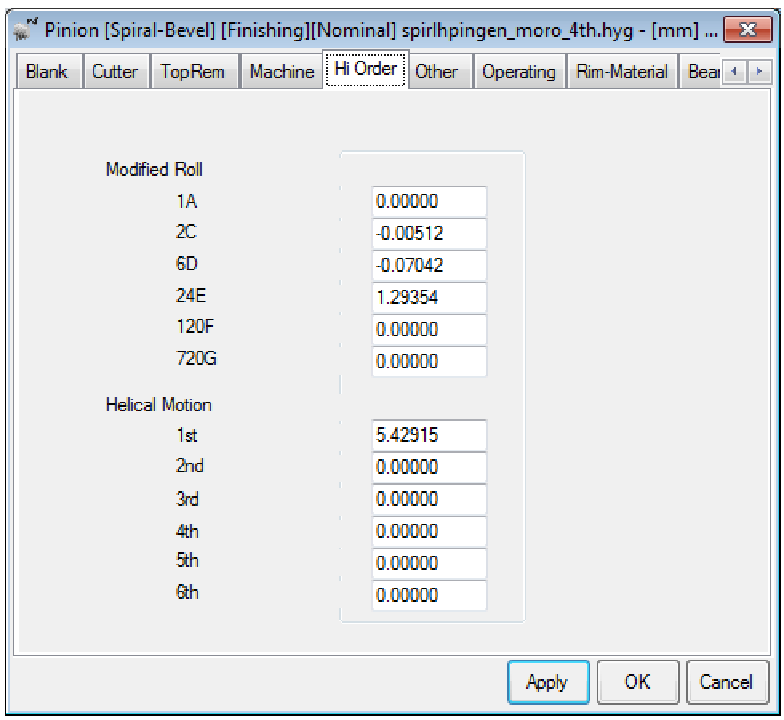
The Machine Settings data page includes the following fields:

Operating C. Distance	Gear set operating center distance, in the current linear units. This value is calculated when the gear set is initially created; it can be changed to accommodate different situations.
X Factor	Profile shift factor; a positive value withdraws the tool away from the axis of rotation of the workpiece; actual tool shift is the product of the Module times the X Factor, for metric units, or the quotient of the X Factor by the Diametral Pitch for imperial units. This value is given when the geometry is created; it can changed afterwards in order to adjust tooth thickness. When doing so, the OD does not change, but of course the ID is likely to change since the position of the tool changes.
Generating Pitch Dia.	The diameter on which the generating rack rolls without slip. This can be changed, but with caution since it determines the ratio of roll.
Tool Center Distance	Distance between the axes of rotation of the workpiece and shaper cutter, when a shaper cutter is selected. Increasing this center distance means changing the Generating Pitch Dia. in order to maintain the proper speed ratio between tool and workpiece.
Tooth Crowning	Desired amount lengthwise tooth crowning to localize the Contact Pattern at the center of the tooth flank. If crowning is insufficient, the Contact Pattern may shift because of manufacturing tolerances and deformations under load; if too large, then contact stresses are likely to increase because of the reduced contact area.
Crowning Type	"Specified" or "Machine Vertical". With the "Machine Vertical" setting, the tool – normally a shaper cutter - is moved radially relative to the workpiece in order to produce the requested crowning. With "Specified", the tool – normally a rack - is allowed to deviate only in the plane containing the rectilinear motion of the rack.
Crowning Order	Order at which crowning is to evolve from the edge; normally, second order crowning is acceptable; first order should be avoided unless one simply desires a break-edge at toe and heel, and which case the Distance to Edge should be short.
Distance to Edge	Distance from tooth edges, Toe and Heel, where crowning starts. If second or third order crowning is used, this may be equal to half the facewidth; if first order is used, this should be close to the edge in order to avoid singular contact at mid-facewidth.



9.1.5 Higher Order Data

The Higher Order data page covers the coefficients of 6^{th} order Taylor Series used to modify:



Modified Roll

Controls the position of the cradle in reference to the work piece: the modified cradle angle L_{1m} is:

$$L_{1m} = \alpha_3 R_r + \frac{2C}{2}(C_r - \alpha_3 R_r)^2 - \frac{6D}{6}(C_r - \alpha_3 R_r)^3 + \frac{24E}{24}(C_r - \alpha_3 R_r)^4 - \frac{120F}{120}(C_r - \alpha_3 R_r)^5 + \frac{720G}{720}(C_r - \alpha_3 R_r)^6$$

where:

α_3	is the roll angle of the work piece
R_r	is the ratio of roll of the work piece to the cradle
C_r	is the cradle angle given in the machine settings
2C	is the 2nd order coefficient of the Taylor series
6D	is the 3rd order coefficient
24E	is the 4th order coefficient
120F	is the 5th order coefficient
720G	is the 6th order coefficient

Helical Motion

Controls the Sliding base position X_{bm} of the work piece in reference to the machine plane and roll angle:

$$X_{bm} = X_b + 1_{st}(C_r - \alpha_3 R_r) + 2_{nd}(C_r - \alpha_3 R_r)^2 + 3_{rd}(C_r - \alpha_3 R_r)^3 + 4_{th}(C_r - \alpha_3 R_r)^4 + 5_{th}(C_r - \alpha_3 R_r)^5 + 6_{th}(C_r - \alpha_3 R_r)^6$$

where:

α_3	is the roll angle of the work piece
R_r	is the ratio of roll of the work piece to the cradle
C_r	is the cradle angle given in the machine settings
1_{st}	is the 1st order coefficient of the Taylor series (typically called Helical Motion parameter)
2_{nd}	is the 2nd order coefficient
3_{rd}	is the 3rd order coefficient
4_{th}	is the 4th order coefficient
5_{th}	is the 5th order coefficient
6_{th}	is the 6th order coefficient

9.1.6 Other Data

The Other data page covers other data related to the pinion or gear and general calculation handling.

Linear and angular units are identified in the Summary Editor title bar and can be changed on the fly in the Other data page or by calling the Edit->Configuration function from the Parent Window menu.

Zerol, Spiral-Bevel and Hypoid Gears

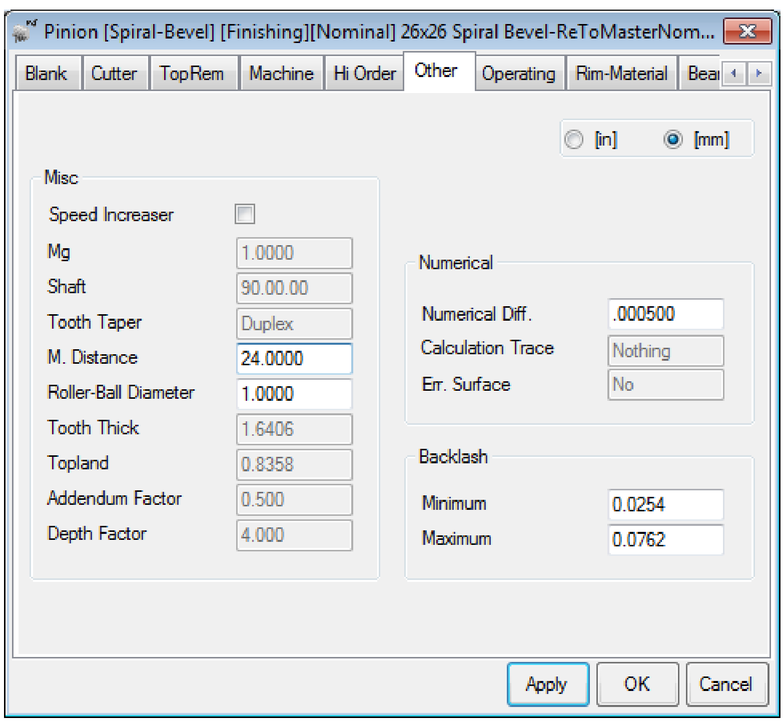
Straight-Bevel and Coniflex Gears

Spur, Helical and Beveloid Gears

9.1.6.1 Zerol, Spiral-Bevel, Hypoid

The Summary editor Other data page covers other data related to the pinion or gear and general calculation handling. Linear and angular units are identified in the Summary editor title bar.

The Other data page includes the following editing fields:



Speed Increaser	When this option is On, e.g. with a checkmark, the pinion is driven by the gear member.
Mg	Gear set speed ratio.
Shaft	Gear set shaft angle.
Tooth Taper	Selected tooth taper at creation time.
M. Distance	Mounting distance.
Roller-Ball Diameter	Diameter of the Roller/Ball used for Dia. Over Ball Child Window.
Tooth Thick	Tooth normal thickness at mid-face. This is a calculated value from the New Geometry initial machine settings, and must be modified with care since it will directly affect the tooth proportions and the backlash. It is an editable field only for Fixed Setting and Modified Roll pinions.
Topland	Tooth normal topland at mid face. This value is a direct consequence of the tooth thickness and cutting process.
Addendum Factor	Gear addendum factor, as selected at creation time.
Depth Factor	Gear depth factor, as selected at creation time.
Numerical Diff	In HyGEARS, because of the highly non-linear equations involved, most calculations are performed using iterative schemes such as Newton-Raphson, where first and second order derivatives are needed. Such derivatives are calculated numerically, and the Numerical Diff. input field is the increment used to calculate the numerical derivatives. The default value of 0,0005 has been tested and found to be adequate for most situations; this value is applicable to both angular and linear derivatives. Higher values may slow the convergence rate of numerical solutions, while lesser values may produce inconsistencies since the increment may produce derivatives within the precision range of the computer. Therefore, it is strongly recommended not to change this value without proper subsequent testing.
Calculation Trace	HyGEARS supports tracing of the evolution of some calculations, such as the digitization process of the tooth, through the “Ctrl T” keyboard combination. Although numerical divergence rarely occurs, tracing can be useful in identifying the cause of non-converging calculations. Thus field cannot be modified through the Geometry Editor.

Tracing results are sent to a Text Results window where they can be viewed, printed or saved to a file. Three tracing levels are supported, which are set from the Properties Window:

No	no tracing occurs
Partial	only the main calculation results are shown.
Total	all calculation results are shown.

Appendix C describes tracing interpretation.

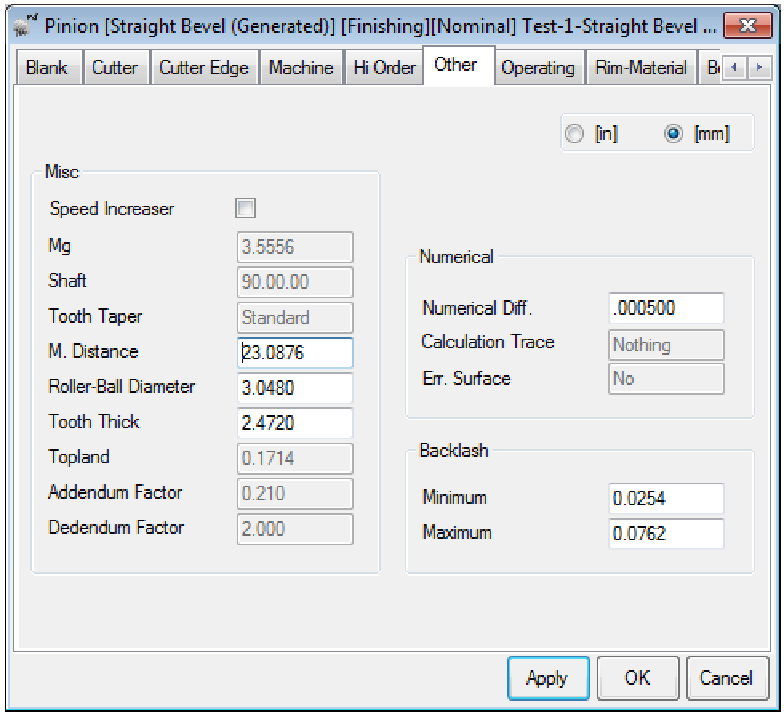
Err. Surface — Given measurement results availability, it is possible in HyGEARS to calculate an error surface between the measured and theoretical results, and use this error surface for Path of Contact, Contact Pattern and Loaded Tooth Contact Analysis calculations, thereby simulating the operation of the actual tooth surface. Error surface is either On (Yes) or Off (No), and is set from the Parent window button bar.

Backlash — The minimum and maximum reference values for backlash may be modified in this field; they have no effect on the behavior of the gearset. However, the actual gear set backlash is modified only through the Contact Pattern Development and Proportional Changes windows.

9.1.6.2 Coniflex, Straight-Bevel

The Other data page covers other data related to the pinion or gear and general calculation handling. Linear and angular units are identified in the Summary editor title bar.

The Other data page includes the following editing fields:



Speed Increaser	When this option is On, e.g. with a checkmark, the pinion is driven by the gear member.
Mg	Gear set speed ratio.
Shaft	Gear set shaft angle.
Tooth Taper	Selected tooth taper at creation time.
M. Distance	Mounting distance.
Roller-Ball Diameter	Diameter of the Roller/Ball used for Dia. Over Ball Child Window.
Tooth Thick	Normal tooth thickness at mid-face on the Pitch Cone.
Addendum Factor	Gear addendum factor, as selected at creation time.
Depth Factor	Gear depth factor, as selected at creation time.

Numerical Diff

In HyGEARS, because of the highly non-linear equations involved, most calculations are performed using iterative schemes such as Newton-Raphson, where first and second order derivatives are needed.

Such derivatives are calculated numerically, and the Numerical Diff. input field is the increment used to calculate the numerical derivatives. The default value of 0,0005 has been tested and found to be adequate for most situations; this value is applicable to both angular and linear derivatives. Higher values may slow the convergence rate of numerical solutions, while lesser values may produce inconsistencies since the increment may produce derivatives within the precision range of the computer. Therefore, it is strongly recommended not to change this value without proper subsequent testing.

Calculation Trace

HyGEARS supports tracing of the evolution of some calculations, such as the digitization process of the tooth, through the "Ctrl T" keyboard combination. Although numerical divergence rarely occurs, tracing can be useful in identifying the cause of non-converging calculations. Thus field cannot be modified through the Geometry Editor.

Tracing results are sent to a Text Results window where they can be viewed, printed or saved to a file. Three tracing levels are supported, which are set from the Properties Window:

No	no tracing occurs
Partial	only the main calculation results are shown.
Total	all calculation results are shown.

Appendix C describes tracing interpretation.

Err. Surface

Given measurement results availability, it is possible in HyGEARS to calculate an error surface between the measured and theoretical results, and use this error surface for Path of Contact, Contact Pattern and Loaded Tooth Contact Analysis calculations, thereby simulating the operation of the actual tooth surface. Error surface is either On (Yes) or Off (No), and is set from the Parent window button bar.

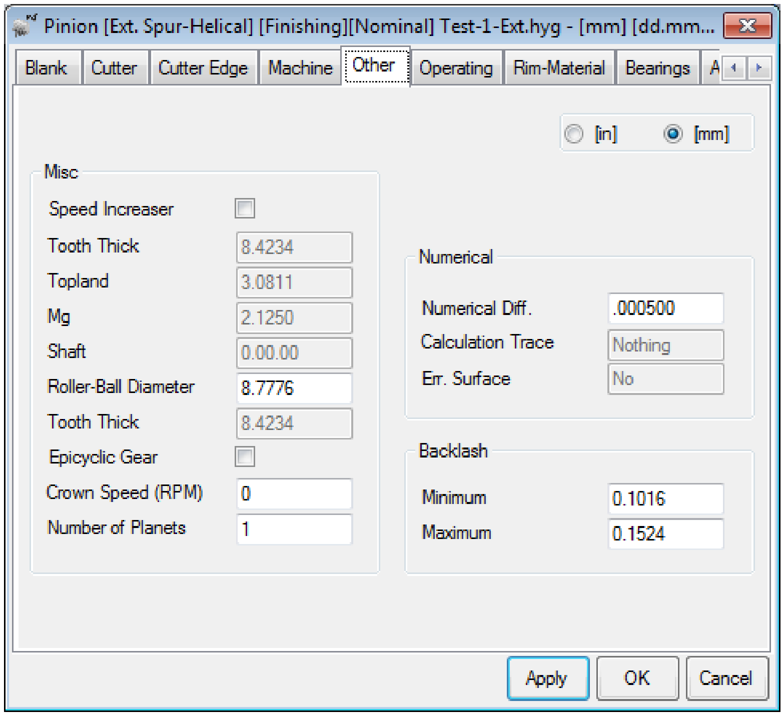
Backlash

The minimum and maximum reference values for backlash may be modified in this field; these values have *no effect* on the behavior of the gearset.

9.1.6.3 Spur, Helical, Beveloid

The Other data page covers other data related to the pinion or gear and general calculation handling. Linear and angular units are identified in the Summary editor title bar.

The Other data page includes the following editing fields:



Speed Increaser	When this option is On, e.g. with a checkmark, the pinion is driven by the gear member.
Tooth Thick	Tooth normal thickness on the Pitch Circle. Not editable since it depends on the Cutter Blade Thickness.
Topland	Tooth normal Topland on the Outside Diameter. Not editable since it depends on the Cutter Blade Thickness.
Mg	Gear set speed ratio.
Shaft	Gear set shaft angle.
Roller-Ball Diameter	Diameter of the Roller/Ball used for Dia. Over Ball Child Window.
Epicyclic Gear Train	Check this box to convert to a Planetary gear train. The “Crown Gear Speed (RPM)” and “Number of Planets” then become a`ctive for edition.
Crown Speed (RPM)	Crown gear RPM in an Epicyclic Gear Train. With the Sun (Pinion) mand Crown RPM known, the Planet RPM can be easily calculated, and relative speeds can be obtained for lubricant film thickness.
Number of Planets	Number of planets in an Epicyclic Gear Train.

Numerical Diff	In HyGEARS, because of the highly non-linear equations involved, most calculations are performed using iterative schemes such as Newton-Raphson, where first and second order derivatives are needed.

Such derivatives are calculated numerically, and the Numerical Diff. input field is the increment used to calculate the numerical derivatives. The default value of 0,0005 has been tested and found to be adequate for most situations; this value is applicable to both angular and linear derivatives. Higher values may slow the convergence rate of numerical solutions, while lesser values may produce incosistencies since the increment may produce derivatives within the precision range of the computer. Therefore, it is strongly recommended not to change this value without proper subsequent testing.

Calculation Trace

HyGEARS supports tracing of the evolution of some calculations, such as the digitization process of the tooth, through the "Ctrl T" keyboard combination. Although numerical divergence rarely occurs, tracing can be useful in identifying the cause of non-converging calculations. Thus field cannot be modified through the Geometry Editor.

Tracing results are sent to a Text Results window where they can be viewed, printed or saved to a file. Three tracing levels are supported, which are set from the Properties Window:

No	no tracing occurs
Partial	only the main calculation results are shown.
Total	all calculation results are shown.

Appendix C describes tracing interpretation.

Err. Surface

Given measurement results availability, it is possible in HyGEARS to calculate an error surface between the measured and theoretical results, and use this error surface for Path of Contact, Contact Pattern and Loaded Tooth Contact Analysis calculations, thereby simulating the operation of the actual tooth surface. Error surface is either On (Yes) or Off (No), and is set from the Parent window button bar.

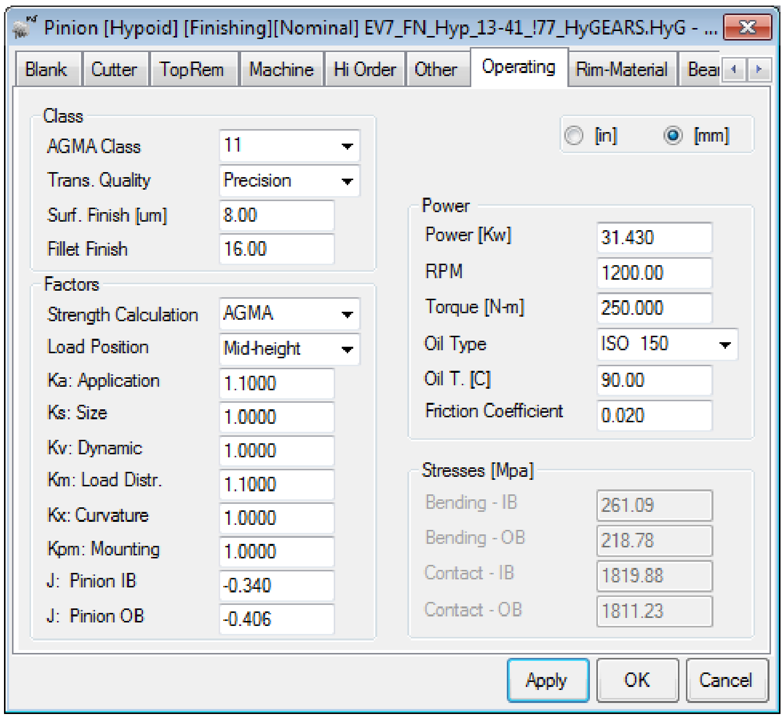
Backlash

The minimum and maximum reference values for backlash may be modified in this field; they have no effect on the behavior of the gearset. The actual backlash is modified through the Operating Center Distance.

9.1.7 Operating Data

The Operating data page or the Geometry Summary Editor covers data such as power and speed, and the way the Geometry factor J and application factors are calculated for the evaluation of the pinion and gear tooth bending strengths.

Class Data
Factors Data
Power Data
Stress Data



The Operating Data section includes the following fields, which are common to both the pinion and the gear:

Class Data

AGMA Class — AGMA gear set class. Class 5 is a basic low quality gear set, while AGMA class 13 is considered aviation quality. Quality class influences the dynamic factor Kv, when calculated by HyGEARS. The default value is 11.

Trans. Quality — Transmission quality, which can be:
Open lowest quality
Closed

Precision
High precision — highest quality

Surf. Finish — Tooth surface finish, in [uin] when linear units are [in], and [um] when linear units are [mm]. This value is used when calculating the Λ factor in the LTCA, i.e. the ratio of the oil film thickness to surface roughness.

Fillet Finish — Fillet surface finish, in [uin] when linear units are [in], and [um] when linear units are [mm]. This value is used in the ISO 10300 calculations.

Factors Data

Strength Calc: HyGEARS offers three ways to asses the tooth bending strength:

AGMA: traditional way,

$$\sigma_b = \frac{2T_p\,P_d\,K_a\,K_s\,K_m}{D\,F\,J\,K_v\,K_x}$$

AGMA-Mod: variant of AGMA

$$\sigma_b = \frac{2T_p\,P_d\,K_a\,K_s\,K_m}{D\,{}^{F}\!/_{2}\,J\,K_v\,K_x}$$

Aida+Terauchi: Spur gears

$$\sigma_{A+Tb} = \frac{2T_p}{D\,F}\left\{1+\frac{0.08\,T}{r_f}\right\}\left(0.66\,S_b + 0.4\sqrt{S_b{}^2 + 36\tau^2} + 1.15\,S_c\right)\frac{K_a\,K_s\,K_m}{K_v\,K_x}$$

AGMA: this is the traditional way.

Tp	is the torque on the pinion member,
Pd	is diametral pitch,
D	is the pitch diameter,
F	is the facewidth in the axial plane,
J	is the tooth geometry factor,
K	are the application factors.

In the formula, the Contact Pattern is assumed to *cover the full tooth facewidth* in the axial plane, which is often the case when gears are heavily loaded, and the lesser of the pinion and gear facewidths is used.

AGMA-Mod: this is a variant of the *AGMA* formula:

Tp is the torque on the pinion member,
Pd is diametral pitch,
D is the pitch diameter,
F/2 is 1/2 the facewidth in the axial plane,
J is the tooth geometry factor,
K are the application factors.

In the formula, the Contact Pattern is assumed to *cover only half the tooth*, which is often the case when gears are not too heavily loaded.

Aida+Terauchi: this equation was developed by *Aida and Terauchi for spur gears*, but may also be used for Spiral Bevel gears, although with caution:

Tp is the torque on the pinion member,
Pd is diametral pitch,
D is the pitch diameter,
F is the facewidth,
K are the application factors,
T is the tooth thickness at the fillet critical section,
r_f is the fillet radius at the critical section,
X is half the tooth thickness at the point of loading,
H is the tooth height at the point of loading,
L is the pressure angle at the point of loading,

$$S_b = 6H\frac{\sin(\varphi_L)}{T^2}$$

$$S_c = \left\{1 + 6\frac{X}{T}\right\}\frac{\cos(\varphi_L)}{T}$$

$$\tau = \frac{\sin(\varphi_L)}{T}$$

If the K factors are equal to unity, an equivalent Geometry Factor J_{eq} is then obtained by the following equation:

$$J_{eq} = \frac{2 T_c P_d}{D F \sigma_{A+Tb}}$$

In the above, the stress concentration factor k_t at the root of the tooth is given by:

$$k_t = \left\{1 + \frac{0.08T}{r_f}\right\}$$

Load Position

HyGEARS offers to calculate the J Factor, for the AGMA and AGMA-Mod strength models, in several positions:

Tip	tooth tip at mid-tooth facewidth;
HPSTC	Highest point of single tooth contact; thus the PoC is first calculated;
Mid-height	mid tooth-height, at mid-tooth facewidth;
Free	at tooth Tip if AGMA Class < 9; at HPSTC if AGMA Class > 8

Ka Application

Also called Overload Factor, Ka represents the way the load is transmitted from source to work. Ka is equal to 1.0 by default, or can be taken from the following table.

Load on Driven Mach. / **Prime Mover**	**Uniform**	**Light Shock**	**Medium Shock**	**Heavy Shock**
Uniform	1.00	1.25	1.50	1.75 +
Light Shock	1.10	1.35	1.60	1.85 +
Medium Shock	1.25	1.50	1.75	2.00 +
Heavy Shock	1.50	1.75	2.00	2.25 +

Ks Size

The size factor Ks is a function of the strength of the material in use, and represents the non-uniformity of the material properties, which depend mainly on tooth size, diameter of the part, the ratio of the tooth size to the diameter of the part, the face width, the area of stress pattern and the material characteristics. If the input field is left blank, the size factor Ks will be calculated based on the following equations:

For gears where 16 > Pd > 1: $Ks = 0.5 + \frac{0.2032}{Pd}$

For gears where Pd > 16: Ks = 0.5

For gears where Pd < 1: Ks = 0.7

where Pd is the diametral pitch.

Kv Dynamic

The dynamic factor Kv makes allowance for the effects of gear tooth quality as related to load and speed. If the input field is left blank, the dynamic factor Kv will be calculated based on the following equations:

$$Kv = \left[\frac{A}{A + \sqrt{Vt}}\right]^{B}$$

$$A = 50 + 56(1.0 - B)$$

$$B = 0.25(12 - Qv)^{2/3}$$

$$5 \le Qv \le 11$$

$$Vt = 0.262dn$$

where Qv is the AGMA quality class, d is the pinion pitch diameter at the heel and n is the pinion number of teeth.

Km Alignment

The alignment factor, or load distribution factor Km modifies the load rating formulas to reflect the non-uniform distribution of the load along the tooth length. The following table provides Km guideline values as a function of design and transmission quality, provided the Contact Pattern is well positionned along the tooth. A default value of 1.0 is assumed if this field is left blank. For non-crowned gear teeth, use 2.0 times the values listed in the table.

	Both Members Straddle Mounted	**One Member Straddle Mounted**	**Neither Member Straddle Mounded**
Very Accurate Automotive	1.00	1.10	1.25
Automotive	1.00	1.10	1.25
High Quality Commercial	1.00	1.10	1.25
General Commercial	1.20	1.32	1.50

Kx Curvature

The lengthwise curvature factor for bending strength Kx depends on the spiral angle and the lengthwise tooth curvature. If the input field is left blank, the lengthwise curvature factor for bending strength Kx will be calculated based on the following equations:

$$Kx = 0.211\left(\frac{Rc}{A}\right)^q$$

$$q = \frac{0.279}{\log 10(\sin\,\psi)}$$

where Rc is the cutter radius, A is the mean cone distance, and y is the mean spiral angle.

Kpm Mounting The Pinion mounting factor; used in the ISO 10300 calculations.

J : Pinion Pinion geometry J factor, used to calculate the pinion tooth bending strength. If this fields is left blank or is negative, the pinion J factor will be calculated by HyGEARS as per the selected Load Position. Of course, the absolute value will then be used in strength calculations.

J : Gear Gear geometry J factor, used to calculate the gear tooth bending strength. If this fields is left blank or is negative, the gear J factor will be calculated by HyGEARS as per the selected Load Position. Of course, the absolute value will then be used in strength calculations.

Power Data

Power Pinion input power, in [HP] when linear units are [in], and [Kw] when linear units are [mm]. For epicyclic gearsets, pinion (or sun gear) torque is obtained at the pitch diameter, and then divided by the number of planets.

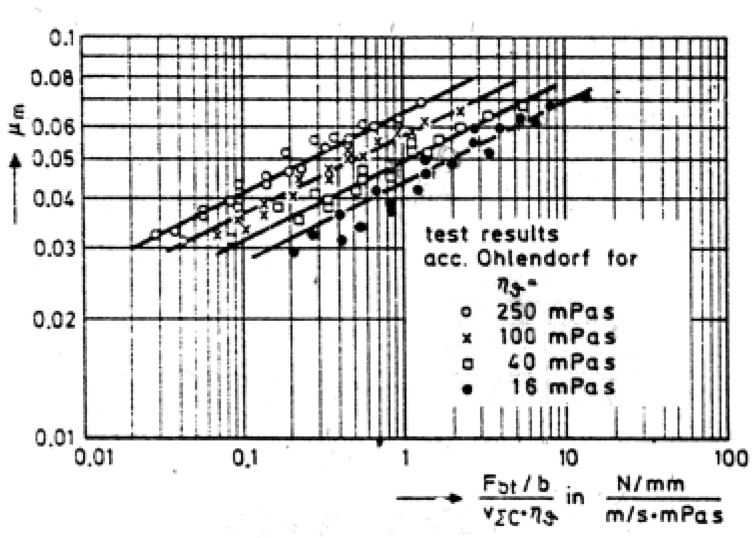
RPM Pinion input speed, in revolutions per minute, whether in speed reducer or speed increaser mode.

Oil Type Oil type, in ISO class 46 to 1500. Oil kinematic and dynamic viscosities, as a function of oil temperature, are contained in the “oil.fil” file, copied in the HyGEARS directory at installation time. The oil kinematic and dynamic viscosity are used in the calculation of the oil film thickness in the LTCA functions.

Oil T Oil temperature, in [F] when linear units are [in], and [C] when linear units are [mm]. This value is used to calculate the oil film thickness.

Friction Coeff. The friction coefficient is used in the evaluation of the work lost due to friction, and thus of the mesh efficiency. The work lost is then converted in temperature increase of the oil film to calculate the oil viscosity and evaluate the oil film thickness.

The input value can be either positive or negative; a positive value is imposed all throughout the meshing cycle. A negative value tells HyGEARS to interpolate in a lookup table, which was compiled from Prof. Hans Winter's work in Munich Technical University ("Scoring Load Capacity of Gears Lubricated with E-P Oils", AGMA Technical Paper P219.17, AGMA FTM 1983, Montreal, Canada); HyGEARS then calculates several factors involved in creating Prof. Winter's data, and logarithmic interpolation is applied. The coefficient of friction then varies as a function of load and sliding speed, therefore as a function of contact position.



Stress Data

Bending — Bending stress, at the given calculation point (HPSTC, Mid-Height, etc.), in the given units, for IB and OB or Left and Right tooth flanks..

Contact — Contact stress, at the given calculation point (normally LPSTC), in the given units, for IB and OB or Left and Right tooth flanks..

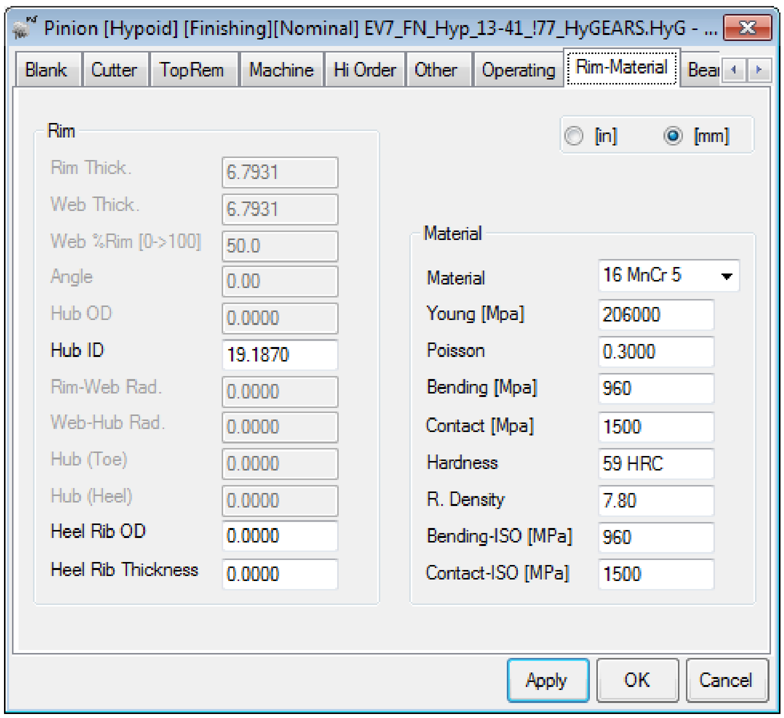
9.1.8 Rim and Material Data

The Rim-Material data page covers data related to the pinion or gear hub dimensions and material selection. Linear and angular units are identified in the Summary editor title bar.

HyGEARS offers the possibility of simulating thin rimmed hubs in case the tooth number is sufficiently large to provide space for the thinned hub portion. The following figures describe the thin rimmed hub shape variables.

If any of the rim values are zero or negative, the rim is assumed solid and only the Hub I.D. becomes significant. For the gear member of gear sets of speed ratio 3.5:1 and above or when the gear member is not generated (crown gear), only the Hub I.D. and Rim Thickness are significant.

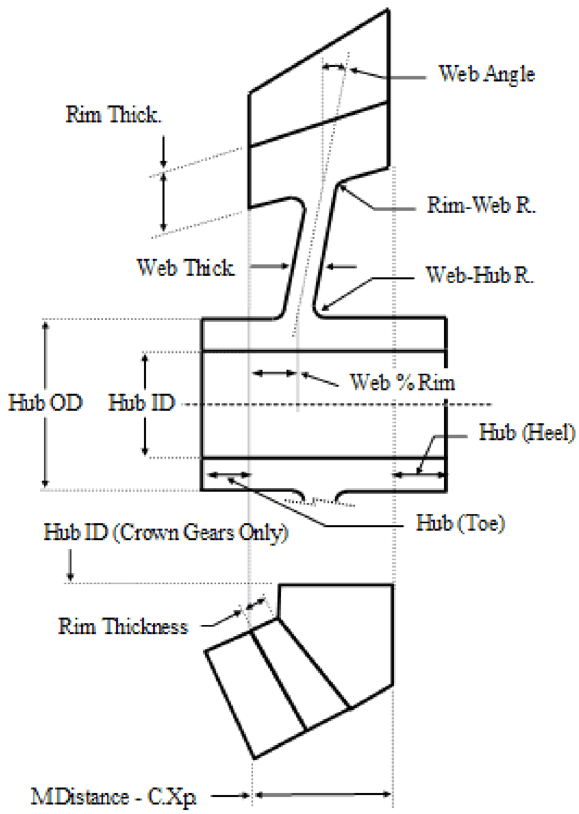
The Rim-Material data page includes the following fields which refer to the figures below for interpretation:

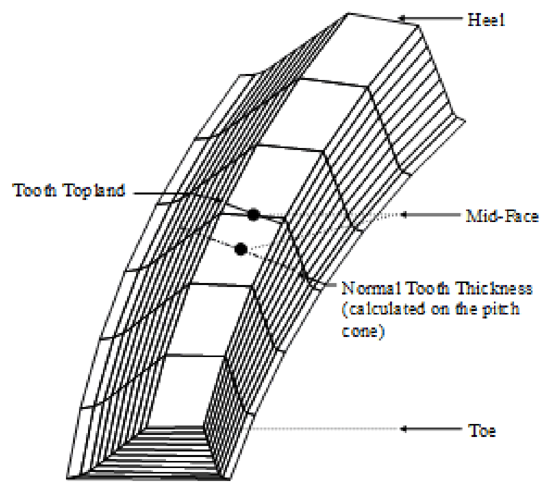


Rim Data

Rim Thick. Rim thickness. If zero, a solid rim is assumed. Refer to the above figure for proper interpretation.
Web Thick. Web thickness. If zero, a solid rim is assumed.
Web % Rim Axial position of the root of the web, in % of facewidth.
Angle Angle of web, relative to radial line.
Hub OD Hub outside diameter. If zero, a solid rim is assumed.
Hub ID. Hub inside diameter.
Rim-Web R. Rim to web radius. If zero, a solid rim is assumed.
Web-Hub R. Web to hub radius. If zero, a solid rim is assumed.

Hub (Toe)	Length of hub protruding ahead of the tooth (this is used to represent a shaft beginning ahead of the tooth itself).
Hub (Heel)	Length of hub protruding after the tooth (this is used to represent a shaft finishing after the tooth itself).





Material Data

Material:	This drop down list box offers all the materials listed in the “material.fil” file provided with HyGEARS which can be edited and expanded to include whichever material desired, following the information given in the file.

The file may contain comment lines, which are preceded by a semi-colon “;” character.

Material data is to be given in the following sequence, using the same spacing as that provided in the reference material file:

- Material Name,
- Bending Strength,

- Compressive Strength,
- Strength units; only the following unit symbols are recognized: PA, KPA, MPA, GPA, PSI, KSI
- Young Modulus
- Poisson ratio
- Young Modulus units; only the following unit symbols are recognized: PA, KPA, MPA, GPA, PSI, KSI
- Hardness value
- Hardness units; the hardness units are not used for the moment; however, it is recommend to use hardness values in the following scales: BHN, HRC, HRB, HV
- Relative density (relative to water)
- Bending Strength ISO (always in MPa; used in optional ISO-10300)
- Compressive Strength ISO (always in MPa; used in optional ISO-10300)

Young Material Young's modulus, either in Ksi if the linear units are [in], or Mpa if the linear units are [mm]. This value is extracted from the information provided in the "material.fil" file, and can be overwritten if desired. Used in the Hertz contact stress and deformation and the Westinghouse, Nakada and Finite Strips bending deflection calculations.

Poisson Material Poisson's ratio. This value is extracted from the information provided in the "material.fil" file, and can be overwritten if desired. Used in the Hertz contact stress and deformation and the Westinghouse, Nakada and Finite Strips bending deflection calculations.

Bending Bending strength of the selected material, either in Ksi if the linear units are [in], or Mpa if the linear units are [mm]. This value is extracted from the information provided in the "material.fil" file, and can be overwritten if desired.

Contact Contact strength of the selected material, either in Ksi if the linear units are [in], or Mpa if the linear units are [mm]. This value is extracted from the information provided in the "material.fil" file, and can be overwritten if desired.

Hardness Hardness of the selected material, either in BHN (Brinnell), HRB (Rockwell B), HRC (Rockwell C), HV (Vickers). This value is extracted from the information provided in the "material.fil" file, and can be overwritten if desired.

R. Density Material density relative to that of water. This value is extracted from the information provided in the “material.fil” file, and can be overwritten if desired. Used in the weight and inertia calculations.

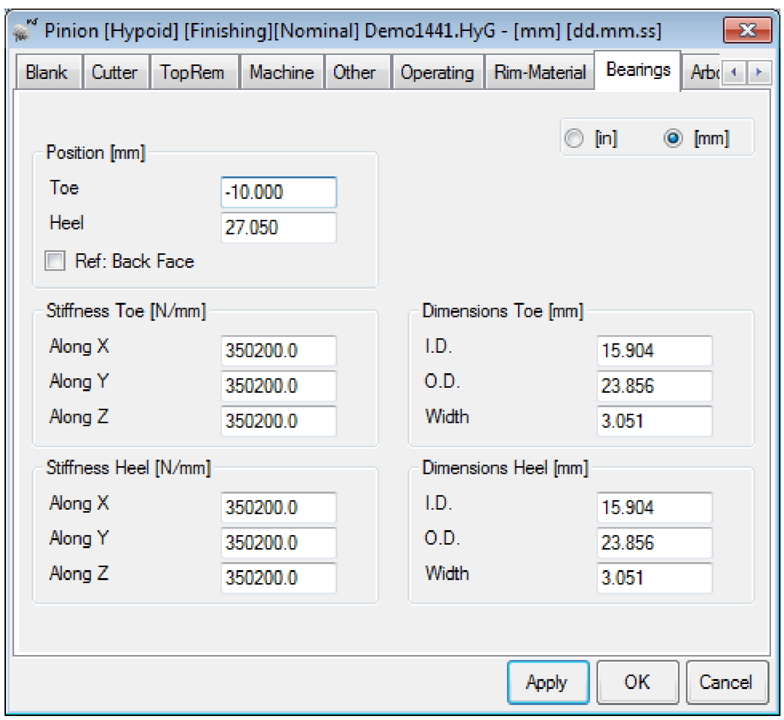
Bending (ISO) Bending strength of the selected material, used in the optional ISO-10300 calculations of tooth bending resistance. Always in [MPa].

Contact (ISO) Contact strength of the selected material, used in the optional ISO-10300 calculations of tooth contact resistance. Always in [MPa].

9.1.9 Bearing Data

The Bearings data page provides the dimensions, location and stiffness of the supporting bearings.

The Bearings may be displayed by clicking on the “*NoBr*” function button which toggles bearing display On and Off.



Bearing reactions may be displayed by accessing the Gearing Primitives window through the “Prim” function button and then selecting the “Bearing Reactions” option. If the “Display Values” option is selected, the bearing reactions will be calculated and displayed.

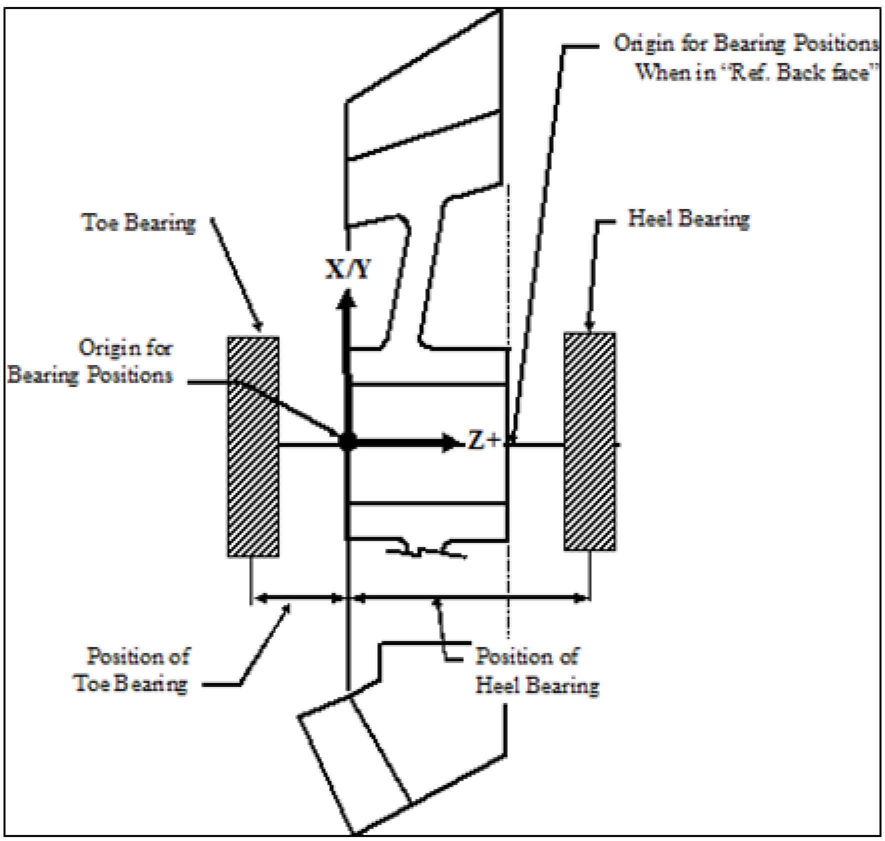
By convention, the Heel Bearing is considered to restrain axial loads (Z direction); to impose one bearing, its stiffness is simply non-zero. Otherwise, the Heel Bearing is used.

Position

Toe Axial position of the Toe Bearing. The origin is at the Toe end of the hub. A negative value displaces the Bearing away from the front of the hub.

Heel Axial position of the Heel Bearing. The origin is at the Toe end of the hub. A negative value displaces the Bearing away from the front of the hub.

Ref. Back Face When this check box is checked, the reference is no more the Front face of the gear, as above, but rather the Back face.



Stiffness

Bearing stiffness may be edited along 3 directions for the Toe and Heel Bearing, e.g. in two orthogonal X and Y directions in the transverse plane, and along the axis of rotation for the axial stiffness. If one value is null, then the other value is used; if both values are non-null, then the Heel Bearing Stiffness is used.

Bearing stiffness is used in the LTCA functions to determine how the gear supports move under load; the calculated displacements are then used to recalculate the position of the Path of Contact and the Contact Pattern.

Dimensions

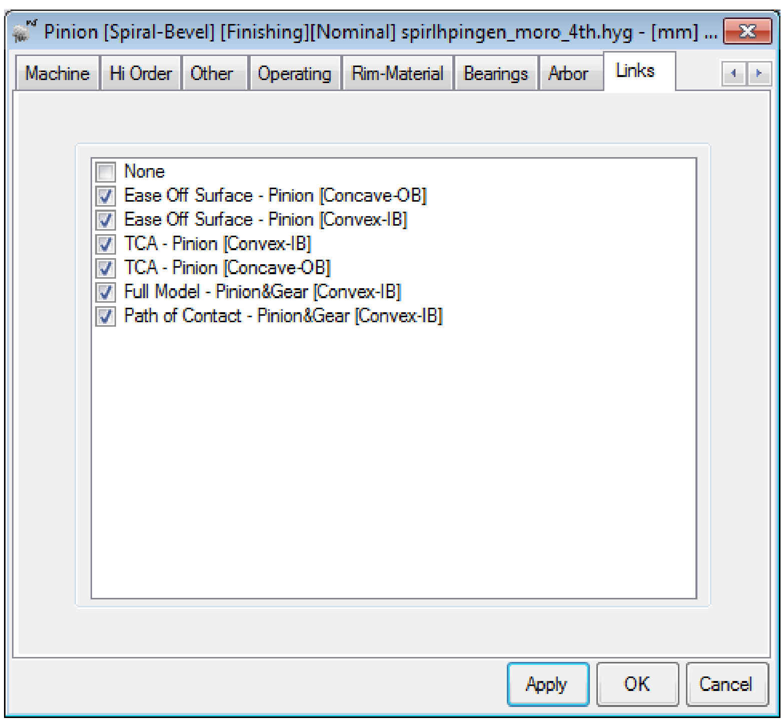
Bearing dimensions may be defined, and are used only for display purposes.

9.1.10 Links Data

The Links data page is used to tell HyGEARS which of the Child Windows associated to the currently loaded geometry are to be redisplayed when a change is made.

Normally, all Child Windows will be redisplayed, but one may desire to restrict this redisplay to selected windows in order to show what changes are taking place, for example on a LTCA result, or for some Contact Pattern or Kinematic result.

Only checked Child Windows are redisplayed. If '*None*' is selected, then no associated Child Window display is updated.



9.2 Tooth Number of Points

In HyGEARS, the pinion and gear teeth are known by their 3 dimensional boundaries which are made of a preset number of points.

Each set of four points constitutes a facet, or surface patch; a series of such surface patches is used to display the tooth envelope as shown below. Therefore, the number of patches in any tooth direction is equal to the number of points in this direction, minus 1.

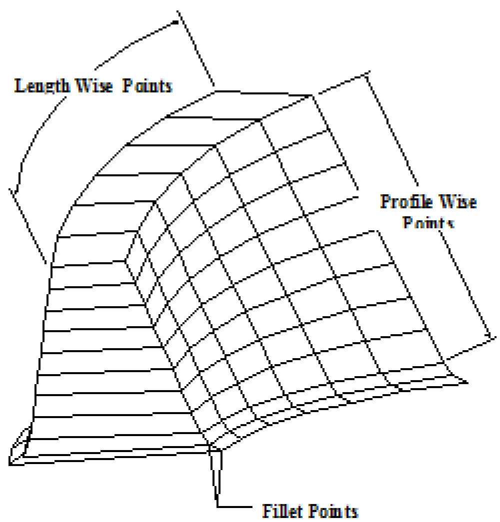
The number of points can be changed in order to improve the visual effect of the displayed tooth, or to increase the resolution with which calculations such as the Path of Contact, the Contact Pattern and the Loaded Tooth Contact Analysis are performed.

Increasing the number of points generally improves the resolution of such calculations, but it also increases the computation times proportionally. Therefore, the number of points should be kept to the initial values, unless higher resolution is essential, as the software performance will decrease.

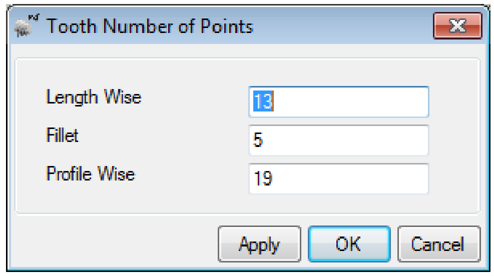
The figure below shows how the tooth number of points are defined. Both the pinion and gear tooth numbers are always the same, and they are the same on the convex and concave tooth flanks as well.

The default values for the tooth number of points are:

- 11 *length wise* points;
- 19 *profile wise* points;
- 5 *fillet* points.



The *Tooth Number of Points editor* shown below presents three input fields for which the following minima and maxima apply:



Length wise number of points:	from 3 to 59;
Fillet number of points:	from 1 to X;
Profile wise number of points:	from 3 to Y (the sum of the X and Y points cannot exceed 125).

The *Profile wise* number of points applies to each tooth flank; therefore, for the complete tooth, twice the inputted number of points will be calculated.

As for other input windows, to access to any input field, simply click on the desired field using the left mouse button, or successively press the Tab key until the desired field is reached.

Command Buttons

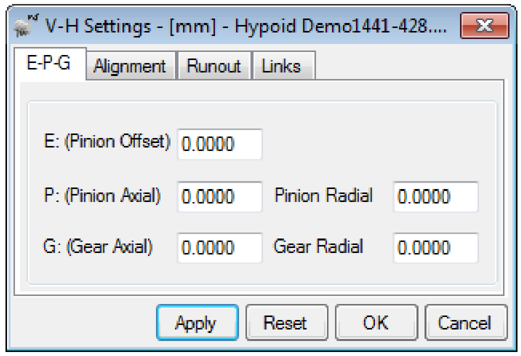
Apply	tells HyGEARS to use the entered data, recalculate the display, and remain in the input window;
OK	completes the input.
Cancel	cancels any input that was done;

Note: If any modification was made to the original number of points, both the pinion and gear teeth are redigitized (see The Digitization Process).

9.3 VH Settings

When designing a new gear set, or when developing the Contact Pattern for a production gear set, it is necessary to evaluate how the Contact Pattern responds to the gear set operating position.

For example, the necessary change in the pinion vertical position to properly locate the Contact Pattern along the tooth can be translated in a change in pinion offset. The V-H test is therefore extremely useful in the development and verification of a gear set.



- Bevel Gears
- Cylindrical Gears

In HyGEARS, it is possible to simulate the V-H test by modifying the operating positions of the pinion or the gear in the same way this would be achieved on an actual V-H tester. However, because it is software, the HyGEARS V-H tester is much faster.

In addition, it is possible to simulate the effects of shaft angle error, misalignment and eccentricity, all of which are inputted through the V-H Settings window.

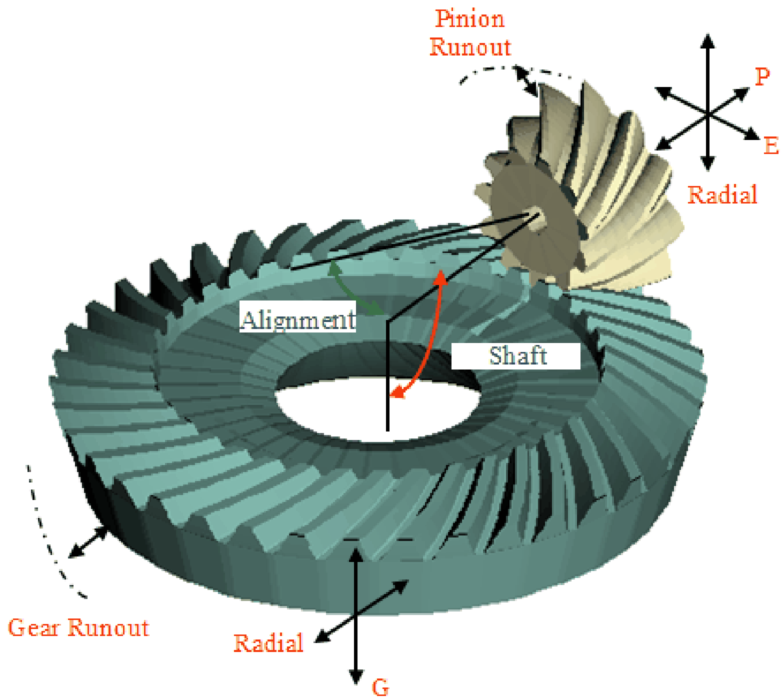
The V-H Settings window presents input data fields for the current pinion tooth driving side, relating to the pinion and gear operating positions. The units in use are identified on the V-H Settings window title bar ([mm] in the example below). The Reset button sets all values to zero for the current pinion driving tooth flank, while the Apply button tells HyGEARS to use the entered data, recalculate the display, and remain in the V-H Settings window.

Command Buttons

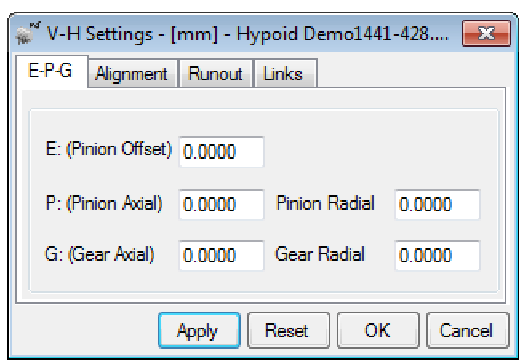
Apply	tells HyGEARS to use the entered data, recalculate the display, and remain in the input window;
Reset	tells HyGEARS to restore the original values;
OK	completes the input.
Cancel	cancels any input that was done.

9.3.1 Bevel Gears

The HyGEARS V-H Settings window offers the possibility to modify the following operating data (refer to the figure below for interpretation):



E-P-G Data



E (Pinion Offset) Pinion vertical position on the VH tester, in the current linear units. A negative value draws the pinion axis closer to that of the gear.

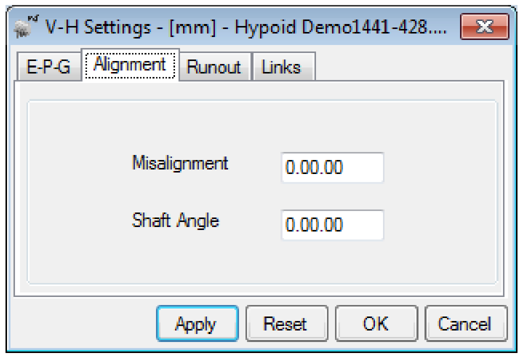
P (Pinion Axial) Pinion horizontal position on the VH tester, in the current linear units. A positive value moves the pinion away from the crossing point.

G (Gear Axial) Gear horizontal position on the VH tester, in the current linear units. A positive value moves the gear away from the crossing point.

Pinion Radial Produces the same effect as G, with the same sign (a positive value moves the pinion away from the gear) but allows to superimpose two things: a gear axial movement, G, and a pinion radial movement..

Gear Radial Produces the same effect as P, with the same sign (a positive value moves the gear away from the pinion) but allows to superimpose two things: a pinion axial movement, P, and a gear radial movement..

Alignment Data

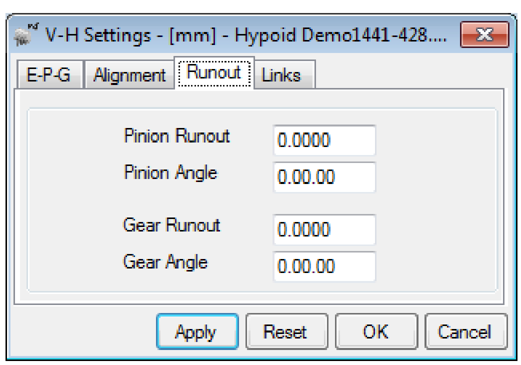


Misalignment Alignment error between the pinion and gear shafts. A positive value rotates the pinion axis of rotation in a clockwise direction about the Z1 axis of the General reference frame.

Shaft Angle Shaft angle error. A positive value increases the shaft angle.

Runout Data

Runout is ever present in geared systems, and the ability to estimate its impact on motion performance is important. HyGEARS supports runout for both the pinion and gear members.



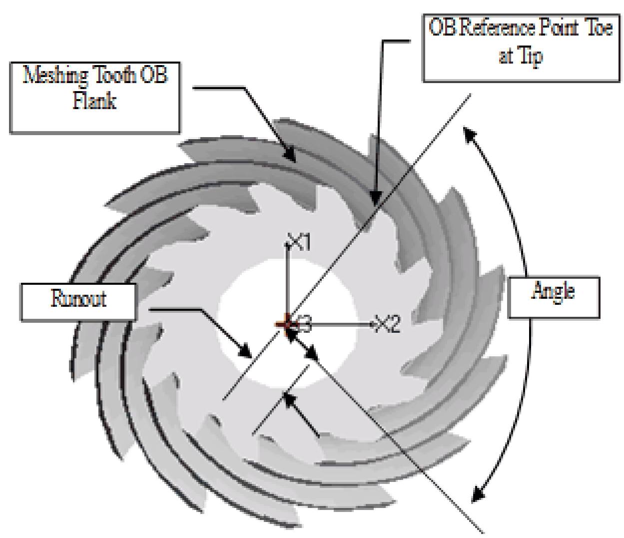
Pinion Runout Pinion runout. Runout value is absolute. Its direction is provided by the Pinion Angle relative to the reference point.

Pinion Angle	Direction in which the runout is maximum, relative to the reference point at tooth tip, toe end, on the current tooth flank. A positive value is a clockwise angle when viewed from the front end of the pinion.
Gear Runout	Gear runout. Runout value is absolute. Its direction is provided by the Gear Angle relative to the reference point.
Gear Angle	Direction in which the runout is maximum, relative to the reference point at tooth tip, toe end, on the current tooth flank. A positive value is a clockwise angle when viewed from the front end of the gear.

To understand the references, the figure below is to be used: in this case, the current pinion tooth flank is the OB; thus, the reference point is at the pinion tip, Toe end, on the OB tooth flank.

Next, the runout is 100 deg. in a clockwise direction from the reference point, such that the Pinion angle is + 100 deg.

Thus, it is possible to simulate different runout positions simply by changing the value of the Pinion or Gear Angle.

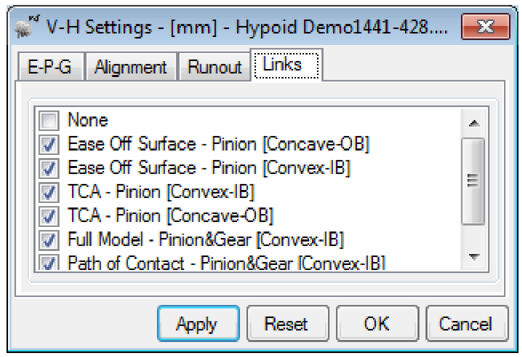


Links Data

The Links data page is used to tell HyGEARS which of the Child Windows associated to the currently loaded geometry are to be redisplayed when a change is made.

Normally, all Child Windows will be redisplayed, but one may desire to restrict this redisplay to selected windows in order to show what changes are taking place, for example on a LTCA result, or for some Contact Pattern or Kinematical result.

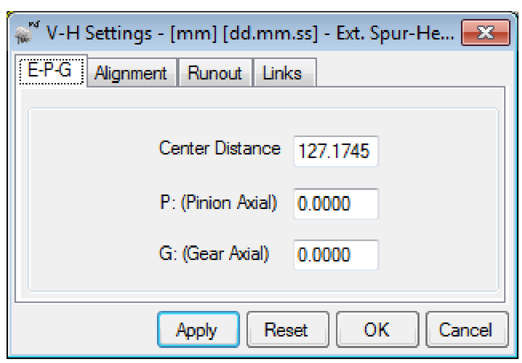
Only checked Child Windows are redisplayed. If 'None' is selected, then no associated Child Window display is updated.



9.3.2 Cylindrical Gears

The HyGEARS V-H Settings window offers the possibility to modify the following operating data :

Center Distance and Axial Data

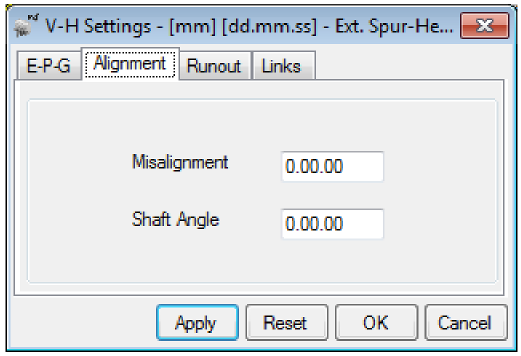


Center Distance Enter the new Operating Center Distance.

P (Pinion Axial) Enter the Pinion change in axial position, in the current linear units. A positive value moves the pinion away from the front face.

G (Gear Axial) Enter the Gear change in axial position, in the current linear units. A positive value moves the gear away from the front face.

Alignment Data

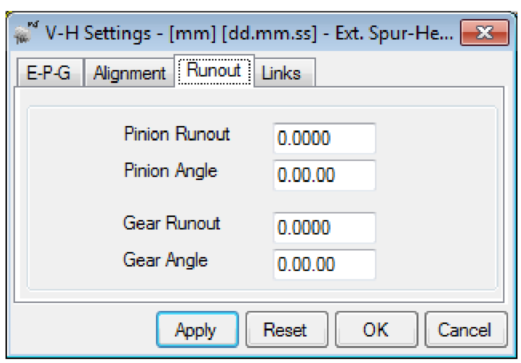


Misalignment Alignment error between the pinion and gear shafts. A positive value rotates the pinion axis of rotation in a clockwise direction about the Z1 axis of the General reference frame.

Shaft Angle Shaft angle error. A positive value increases the shaft angle.

Runout Data

Runout is ever present in geared systems, and the ability to estimate its impact on motion performance is important. HyGEARS supports runout for both the pinion and gear members.



Pinion Runout Runout value is absolute. Its direction is provided by the Pinion Angle relative to the reference point.

Pinion Angle Direction in which the runout is maximum, relative to the reference point at tooth tip on the current tooth flank. A positive value is a clockwise angle when viewed from the front end of the pinion.

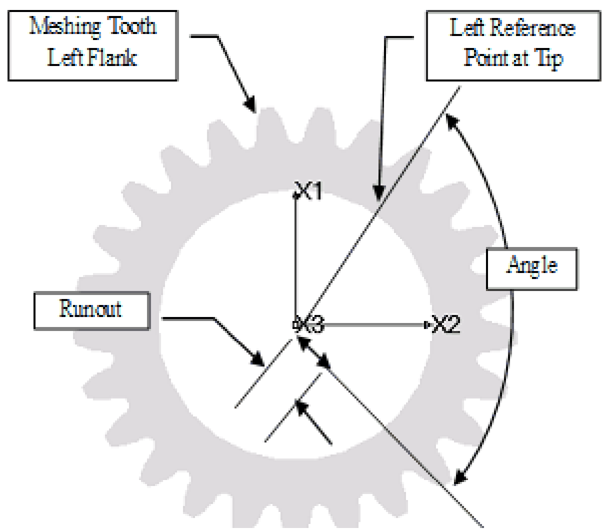
Gear Runout Runout value is absolute. Its direction is provided by the Gear Angle relative to the reference point.

Gear Angle Direction in which the runout is maximum, relative to the reference point at tooth tip on the current tooth flank. A positive value is a clockwise angle when viewed from the front end of the gear.

To understand the references, the figure below is to be used: in this case, the current pinion tooth flank is the left; thus, the reference point is at the pinion tip on the left tooth flank.

Next, the runout is 100 deg. in a clockwise direction from the reference point, such that the Pinion angle is + 100 deg.

Thus, it is possible to simulate different runout positions simply by changing the value of the Pinion or Gear Angle.

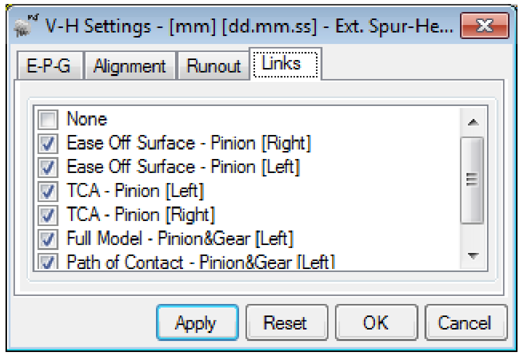


Links Data

The Links data page is used to tell HyGEARS which of the Child Windows associated to the currently loaded geometry are to be redisplayed when a change is made.

Normally, all Child Windows will be redisplayed, but one may desire to restrict this redisplay to selected windows in order to show what changes are taking place, for example on a LTCA result, or for some Contact Pattern or Kinematic result.

Only checked Child Windows are redisplayed. If 'None' is selected, then no associated Child Window display is updated.



9.4 Resetting the Corrective Machine Settings History

When developing a gear set or controlling the production, it is usual to make changes to the machine settings of either the pinion or the gear, or both.

These machine settings changes can be calculated by the specialized HyGEARS Corrective Machine Settings (Closed Loop) module, which compares a measured surface to a simulated surface, and identifies which machine settings must be changed and the amount of modification needed to properly correct the measured surface errors.

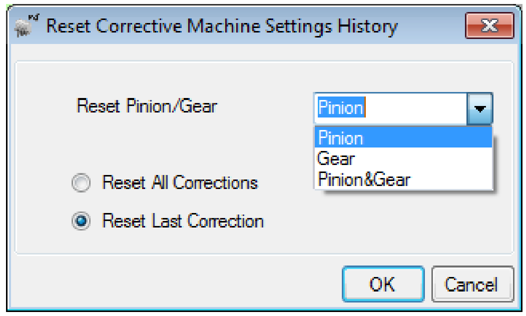
Each time a modification is made using the HyGEARS Corrective Machine Settings (Closed Loop) module, the modifications are added to a table, a kind of history database stored in the Geometry datafile.

If, for example, a copy of an existing Geometry datafile is made using the *File->Save As* function, the complete Corrective Machine Setting history of the original Geometry datafile will be copied with the Geometry itself. If, now, it is desired to start anew the Corrective Machine Setting process on a different series of cutting machines and with new measured data, it will be necessary to erase the Corrective Machine Setting history that came with the original Geometry when it was saved under a new name.

The *Edit->Reset History* function is used to either erase the last entry or erase completely the Corrective Machine Setting history for either the pinion or the gear, or both at the same time.

The figure below shows the Reset Corrective Machine Settings (Closed Loop) History window, where the drop-down list box offers three choices: Pinion, Gear and Pinion-Gear.

The Reset Corrective Machine Settings (Closed Loop) History window also offers the choice to erase either the last entry to the history of the selected member (*Reset Last Correction*), or the entire history (*Reset All Corrections*).



Picking any choice followed by a press of the Return key or the OK button will start the reset process. HyGEARS will then ask the user to confirm the resetting.

Note: while the reset is effective from the moment it has been confirmed by the user, the disk Geometry datafile is not affected until the Geometry has been saved on disk.

9.5 Resetting the Bearing Pattern Development History

When developing a gear set using the VH>> function, it is usual to make changes to the machine settings of the pinion based on the results of V-H test during Contact Pattern Development..

These machine settings changes to properly locate the Contact Pattern can be calculated by the specialized HyGEARS VH>> function, which compares the theoretical and actual Contact Patterns and identifies which machine settings must be changed and the amount of modification needed to properly match the location of the actual Contact Pattern to that of the theoretical bearing pasttern.

Each time a modification is made using the HyGEARS VH>> function, the modifications are added to a table, a kind of history database stored in the Geometry datafile itself.

If, for example, a copy of an existing Geometry datafile is made using the File->Save As function, the complete VH>> machine settings changes history of the original Geometry datafile will be copied with the Geometry itself. If, now, it is desired to start anew the VH>> process on a different series of cutting machines and with new V-H test data, it will be necessary to erase the VH>> machine settings changes history that came with the original Geometry when it was saved under a new name.

The Edit->Reset Contact Pattern Development History function is used to erase completely the Corrective Machine Setting history for the pinion HyGEARS will then ask the user to confirm the resetting.

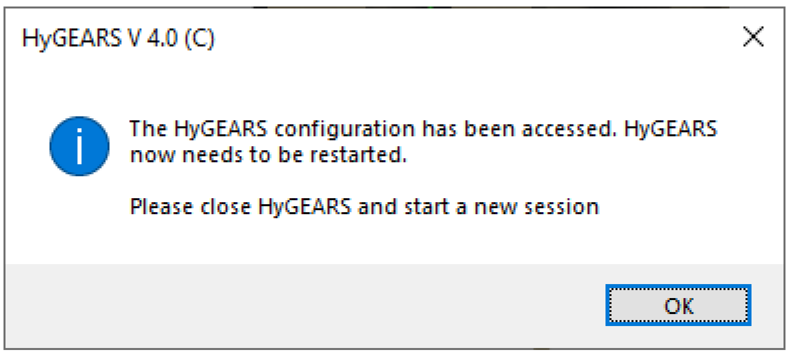
Note: while the reset is effective from the moment it has been confirmed by the user, the disk Geometry datafile is not affected until the Geometry has been saved on disk.

9.6 HyGEARS Configuration

HyGEARS offers a *Configuration Editor* where user preferences, such as language, units, display orientation and fonts may be kept permanently for HyGEARS to reuse every time it is run.

The HyGEARS *Configuration Editor* is organized in data pages, where the tab title indicates the data contained in the corresponding page.

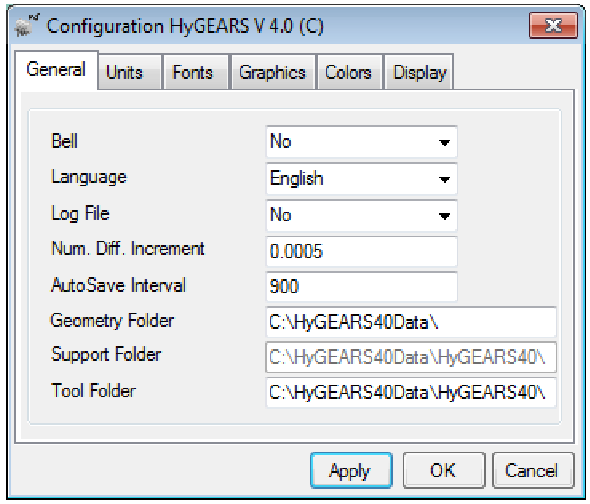
Note: whenever the Configuration Editor is accessed, HyGEARS must be restarted whatever changes may have been done. The following message will be displayed to that effect:



Data input is divided in six pages, accessed by clicking on the proper tab.

- General data page
- Units data page
- Fonts data page
- Graphics data page
- Colors data page
- Display data page

Input fields are accessed by a left mouse button click on the desired field, or by successively pressing the Tab key until the input cursor has reached the desired field. Some fields may offer multiple choices through drop down list boxes.



Command Buttons

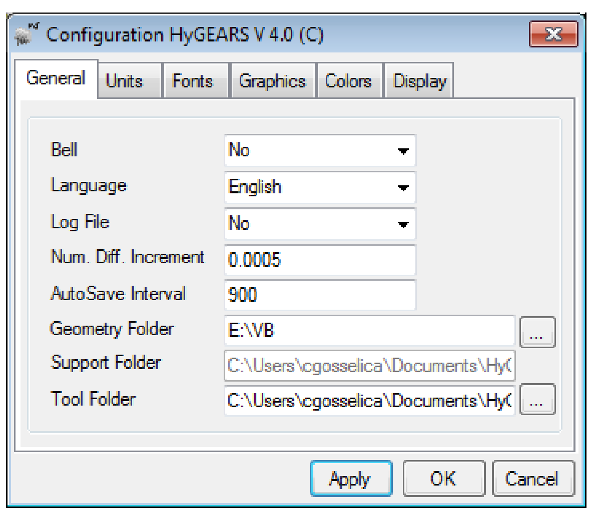
Apply reads the changes, re-displays the current windows, and stays in the *Configuration Editor*;

OK completes the input, ends the *Configuration Editor*, and HyGEARS records the changes made;

Cancel cancels any input that was done, HyGEARS ignores all changes made and ends the *Configuration Editor*.

9.6.1 General Data Page

The General data page offers control over the general behavior of HyGEARS.



Bell Whenever a message is displayed on the screen requiring user confirmation, HyGEARS can sound a bell, such as to attract user attention. The bell can be either on (Yes) or off (No).

Language HyGEARS can be used in different languages provided the appropriate language files have been installed with the software. The default language is English. If no language file is found in the operating sub-directory, HyGEARS will not run.

The HyGEARS Configuration window offers only the installed language files, such that the Language drop-down list box can only contain valid entry fields. If the user attempts to type-in an unknown language file name, HyGEARS will ignore the typed entry and default to the currently installed language.

Making a language selection different from that already in use will automatically initiate the update of the currently displayed HyGEARS windows, which may take a few seconds.

Note that since the default font used in the HyGEARS windows is MS Serif, some languages, such as Japanese, may need a modification to the Input Field Font entry below in order to select an appropriate font.

Log File All user actions may be kept in a session log file, such that unpexpected result causes may be identified later by examining the log file. When the Log File is on, all user actions are recorded in the log file and all the messages sent to the Action Trace file of the Parent Window are also written to the log file. The log file name is "Hygears.log."

If at HyGEARS startup, the "Hygears.log" file already exists and the log file is on, the "Hygears.log" file is renamed "Hygears.bck", and a new "Hygears.log" log file is started. The old "Hygears.bck" file is always deleted before the "Hygears.log" file is renamed to "Hygears.bck".

The first entry line in the log file is the date and time it was created. Then, all user and HyGEARS internal actions are recorded. However, given the large number of HyGEARS internal actions, it is recommended to use the log file only when it is desired to trace a specific operating problem as a log file may rapidly become very large and thus slow down the software performance.

The two following values are valid for the log file:

No log file is off.
Yes log file is on.

Num.Diff Incr.

In HyGEARS, because of the highly non-linear equations involved, most calculations are performed using iterative schemes such as Newton-Raphson, were first order derivatives are needed. Such derivatives are calculated numerically, and the Num.Diff input field is the increment used to calculate the numerical derivatives.

The default value of 0,0005 has been tested and found to be adequate for most situations; this value is applicable to both angular and linear derivatives. Higher values may slow the numerical solution convergence rate, while lesser values may produce inconsistencies since the increment may produce derivatives within the precision range of the computer. Therefore, it is strongly recommended not to change this value without proper subsequent testing.

The Num. Diff. Increment of the Configuration window is the same as the one found when editing the Pinion or Gear Geometry Summaries.

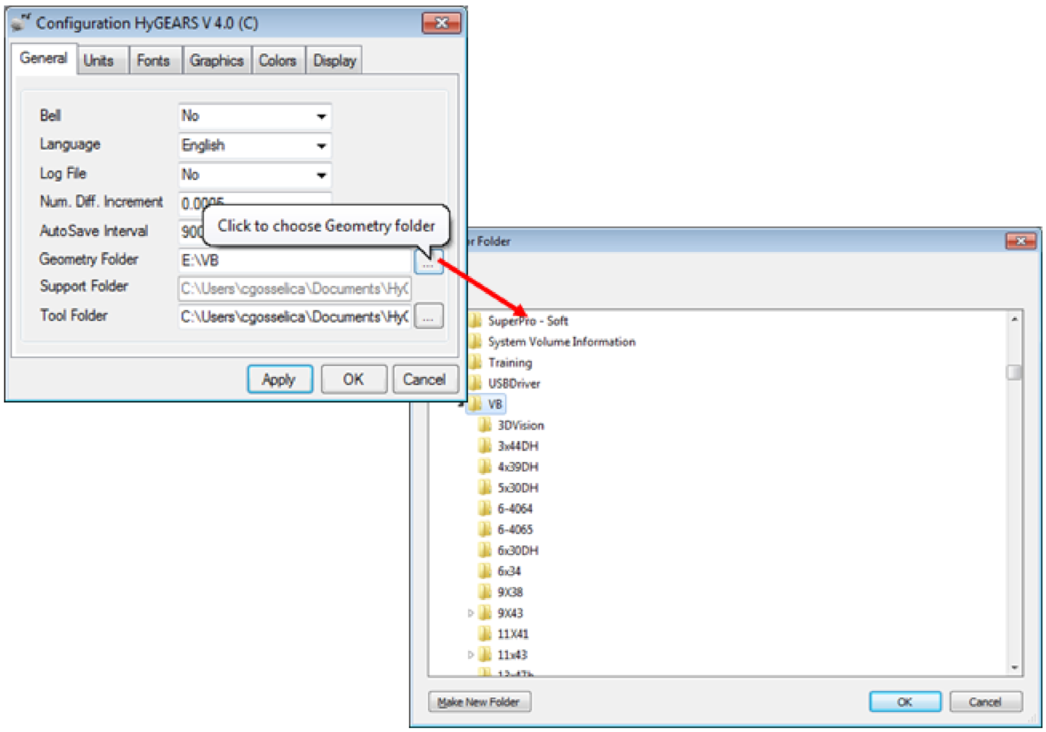
AutoSave ...

HyGEARS can be told to perform an autosaving of the Geometry currently loaded in memory whose name appears on the Main Menu window title bar. The autosaving feature simply makes a backup copy of the memory data at fixed intervals.

In case of a computer crash due to a power failure or else, when run again HyGEARS will automatically detect that such an inorderly HyGEARS end has occurred, and will propose to reload the autosave file, if it exists. Doing so simply restores the working session to the state it was when the last autosaving was performed.

The autosave interval is given in minutes, and is set at 15 minutes by default. Since autosaving takes only 2 to 3 seconds, it is not a problem to reduce the autosaving interval to 10 or even 5 minutes. However, too frequent an autosave will soon prove annoying, while too long an interval means that more work may be lost in case of a system crash. To effectively disable the Autosaving, simply enter a value of 200 or 300 minutes.

Geometry Folder Default root directory where files are to be stored when created. The [...] button displays a navigator to browse to the desired Geometry folder, which can be useful in a network environment where folder names can be quite long.

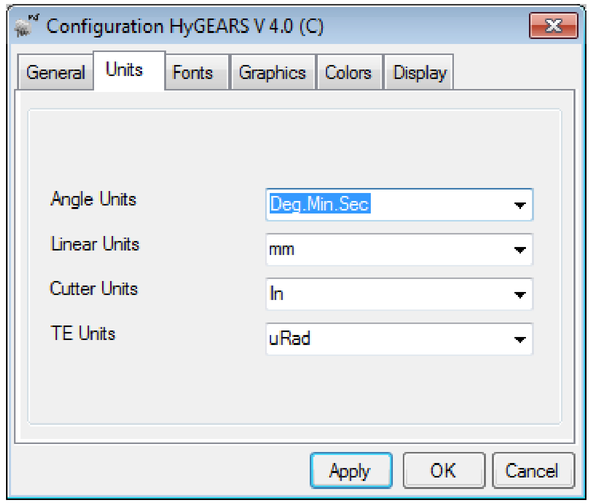


Support Folder Folder where all HyGEARS support files such as Material.fil, Oil.fil, Configur.Inv, et. are stored. Cannot be modified as it depends on where HyGEARS was installed.

Tool Folder Folder where tool files such as CoSIMT.fil, EndMill.fil, etc. are stored. Can be anywhere on a network such as to be available to everybody. The [...] button displays a navigator to browse to the desired Tool folder, which can be useful in a network environment where folder names can be quite long.

9.6.2 Units Data Page

The Units data page offers control over the units used by HyGEARS in the various edit windows and reports. The selected units will be permanently kept in the configuration file, and used at HyGEARS startup. However, the units definition are also kept in the Geometry data files, and when a Geometry data file is loaded into memory, the latter will take precedence over those established in the Configuration window.



Angle Units: HyGEARS input and output can be made in user selected units. In particular, angular units can be presented in two different modes:

Decimal the angle is formatted in the usual decimal way, e.g. "aaa.dddd", where "aaa" is the integer part of the angle value, and "dddd" is the decimal part of the angle value; for example 22 1/2 will be formatted as 22.5000.

Deg.Min.Sec the angle is formatted in Degree, Minutes, Seconds, using a period as the separator; for example 22 1/2 will be formatted as 22.30.00.

Note: HyGEARS will detect whether the "deg.dec" or "deg.min.sec" format is used by counting the number of period characters in the string; if only one, then the "deg.dec" format is assumed; otherwise, the "deg.min.sec" format is assumed.

Linear Units HyGEARS input and output can be made in user selected units. Changing the linear units from imperial to metric or vice-versa will also change all other units such as power, stress, speed, etc. Linear units can be presented either in imperial units or metric units:

In imperial units.
mm metric units.

The following table gives the units in use when linear units are either [in] or [mm]:

	[in]	[mm]
Torque	[lb-in]	[N-m]
Force	[lb]	[N]
Stress	[Ksi]	[Mpa]
Power	[HP]	[Kw]
Stiffness	[lb/in]	[N/mm]
Volume	[in^3]	[mm^3]
Mass	[lbm]	[kgm]
Inertia	[lbm- in^2]	[kgm- mm^2]
Speed	[ft/min]	[m/min]
Misalignment	[In/in]	[mm/mm]
Surface Finish	[min]	[mm]
Temperature	[F]	[C]
Warp	[/0.1 in]	[/10 mm]

Note that internally, HyGEARS performs all its calculations in imperial units. The units are converted only when input or output is required.

Cutter Units Because cutters are frequently described in imperial units while other data may be given in metric units, HyGEARS cutter input and output can be made in user selected units. Cutter units affect the cutter diameter, stock allowance, point width, blade edge radius and TopRem length only. Cutter units can be used either in imperial units or metric units:

In imperial units.
mm metric units.

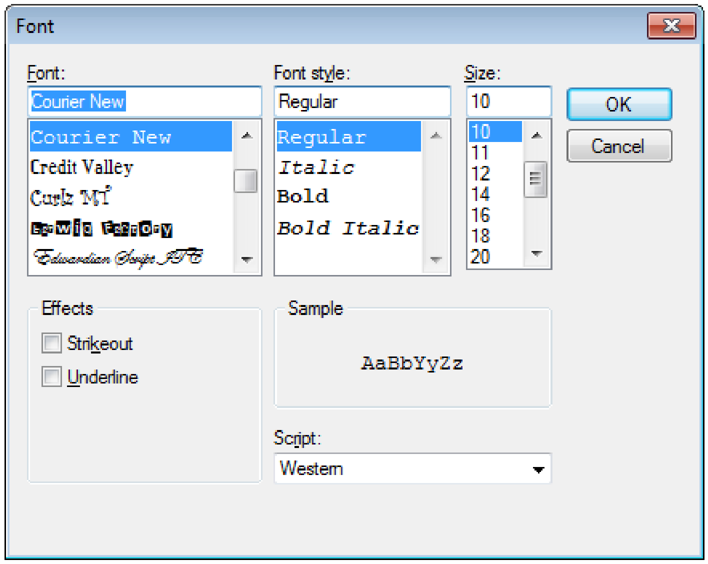
TE Units Transmission Error units can be chosen as:

Sec arc-seconds
uRad micro radians
um micro-meters
uIn micro-inches

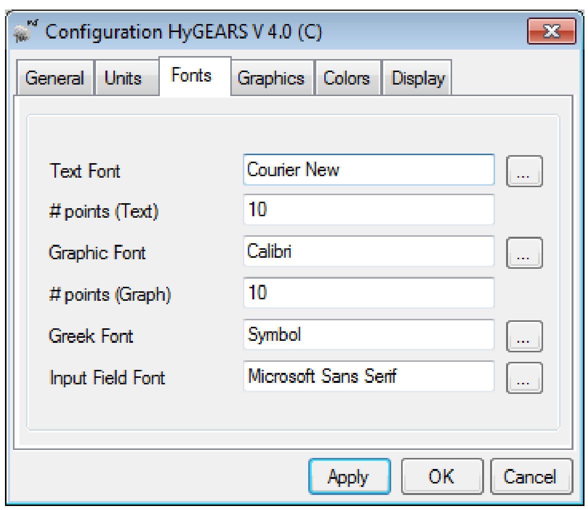
9.6.3 Fonts Data Page

The Fonts data page offers control over the way text is displayed in the graphics and text outputs produced by HyGEARS.

Fonts are extracted from the Windows Font Dialog Box. To access it, simply click on the **[...]** command button to the right of the Font descriptions.



Selecting a font using the Font Dialog Box also sets its Point size, which is why all the fields in the data page are read-only (one cannot write directly into those fields).



Text Font

All HyGEARS numerical output results are sent to Text Results windows, where such results can be viewed, saved to a file or printed. The Text Font input field controls the font used in such Text Results windows.

By default, this font is set to *Courier New*, which is fixed spacing. Selecting another font for the Text Font will affect all Text Results window output created afterward. Since most numerical output results are printed in columns, it is important to remember that the selected Text Font should be a fixed spacing font such as Courier New, otherwise output will appear in uneven columns.

#points (Text) Text Results windows character point size. Small or large values may be selected from the Font Dialog Box (when selecting the Text Font above), but beware of the results if the selected size is too large or too small.

Graphic Font Child Window displays are often accompanied by text, such as a title, or the reference frame axes identifiers, or the graph scales in 2D graphs. The Graphic Font input field selects the default character font for the Child Windows. Default is *Calibri* 10 points

#points (Graph) Character point size of the text displayed in Child Windows.

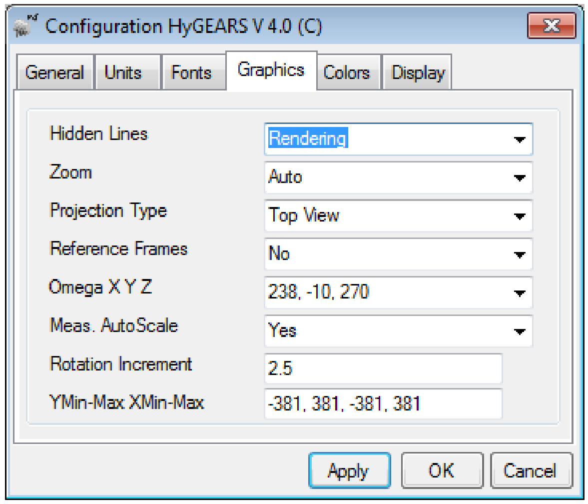
Greek Font HyGEARS 2D Graphs, which display kinematic results such as the Transmission Error and loaded tooth contact analysis, use Greek symbols to symbolically identify certain variables. The Greek Font is used by the 2D Graph module to select the appropriate font.

Input Field Font All HyGEARS input windows use the *Microsoft Sans Serif* font by default. It is possible to change the font used in HyGEARS windows by selecting a different font in the Input Field Font.

Note that for certain languages, such as Japanese, it may be necessary to change the Input Field Font in order to use a font coherent with the language file characters.

9.6.4 Graphics Data Page

The Graphics data page offers control over the way graphics are displayed by HyGEARS.



Hidden Lines Lines used to draw the 3D Child Window objects are organized in four-sided facets which represent the envelope of the displayed object, such as a tooth, the hub or the full model.

The facets looking away from the user or the ones hidden behind other objects can be removed from the display in order to enhance the rendering of the displayed objects. The process of eliminating non-visible parts of the display is called hidden-line removal. Four hidden-line removal methods are offered in HyGEARS:

No all the lines are displayed, without any concept of surface or depth;

Partial only those facets facing the user are displayed, without any concept of depthwise ordering;

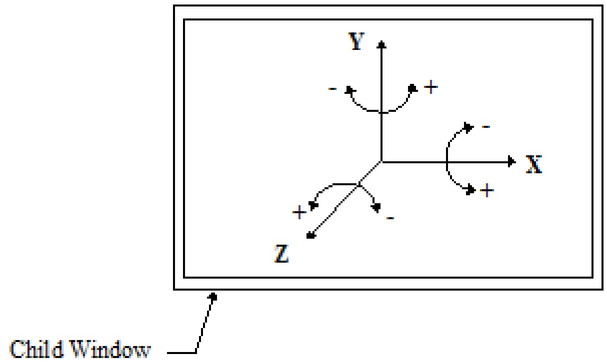
Total only those facets facing the user are ordered depthwise and displayed, such as to represent a true solid;

Rendering only those facets facing the user are ordered depthwise, shaded in a variant of the current fill color and displayed, such as to represent a true solid.

Note that the two first hidden-line removal modes imply that Zoom is in manual mode. The Total hidden-line removal mode is the fastest, followed by Rendering, Partial and No.

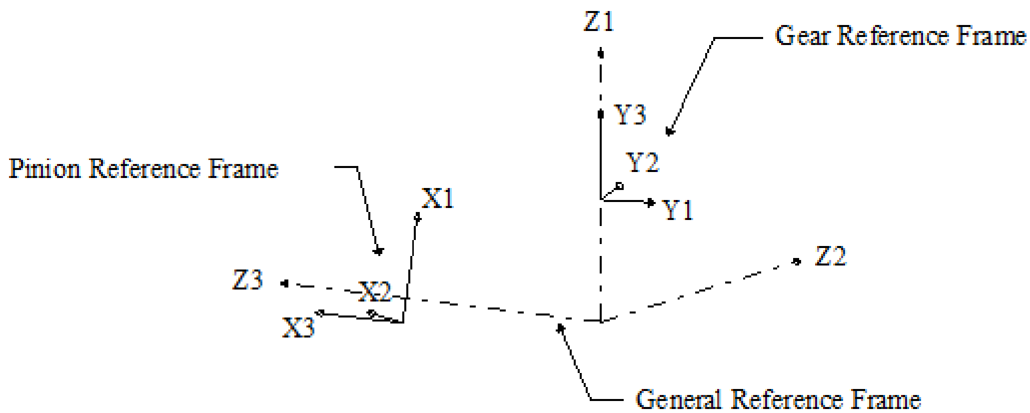
Zoom In HyGEARS 3D Child Windows, it is possible to scale the displayed objects such as to improve the visibility in some regions, which is the Manual Zooming mode, or it is possible to leave the software do the job of finding the best zooming scale such that the displayed objects completely fill the available screen space, which is the Auto Zooming mode. The Auto Zooming mode is recommended for most applications.

Projection ... HyGEARS objects displayed in 3D Child Windows can be viewed in different projections (from different directions) relative to the Child Window. Six projections are offered, and refer to the following figure for interpretation:



Top	view in the -Y direction;
Face	view in the -Z direction;
Right Side	view in the +X direction;
User Defined	view in a user defined direction about X, Y and Z; the viewing angles are defined in the Omex, Omey, Omez field below; when the Reset button of the Tool Bar is pressed, the currently displayed objeccs are repositionned at the user selected Omex, Omey, Omez viewing angles.
Left Side	view in the -X direction;
Auto	projection decided by HyGEARS to show the required tooth flank in the best viewing angle. This is valid if only either the pinion or the gear is shown.

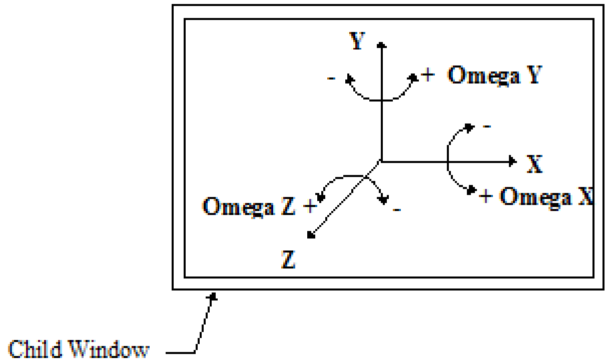
Reference ... All HyGEARS objects are calculated in their own reference frame whose position is known in a general reference frame. When a different projection is chosen as above, the general reference frame orientation is changed relative to that of the Child Window's X-Y-Z reference frame. It is possible to display or not the general reference frame and the reference frames tied to the pinion and gear. The figure below illustrates the basic reference frames in use:



Z1Z2Z3	general reference frame, in which the reference frames tied to the pinion and the gear are placed and oriented. When the Omex, Omey, Omez viewing angles are zero, the Z1Z2Z3 general reference is coincident to the Child Window XYZ reference frame.
X1X2X3	pinion reference frame. X3 is the pinion rotation axis, and is parallel to the general reference frame Z3 axis.
Y1Y2Y3	gear reference frame. Y3 is the gear rotation axis, and is parallel to the general reference frame Z1 axis when the shaft angle is 90 . Otherwise, axis Y3 lies in the Z1-Z3 plane and is pivoted by the shaft angle relative to the pinion rotation axis X3.

Omega X, Y.. when in User Defined projection, HyGEARS objects displayed in 3D Child Windows can be viewed in an user defined direction relative to the Child Window XYZ reference frame. Omega X, Omega and Omega Z are rotation angles about Child Window axes X, Y and Z, used to change the viewing angle. By default, the user defined Omega X, Omega Y and Omega Z values are respectively set to 238, -10, 270 and they provide an adequate viewing direction for most applications.

The drop down list box always offers up to three sets of values: the default values of 238, -10, 270, the previoulsy set values in the Configuration window, only if they are different from the default values, and the current values in the active Child Window also only if they are different from the default values. When the Reset button of the Tool Bar is pressed, the currently displayed objects are repositionned at the user selected Omega X, Omega and Omega Z viewing angles.



The defined Omega X, Omega and Omega Z values can be changed by directly entering the new desired values in the drop-down list box edit field, or by selecting the values from the drop-down list box.

Meas. Auto.. Some HyGEARS functions display tooth surface errors compared to tooth surface theoretical values; the surface errors, or differences between theoretical and measured values, are scaled to the Child Window dimensions such as to give an adequate perception of the results. By default, HyGEARS uses Autoscaling, where scale factor is based on the maximum error found in the graph. Through the Meas. AutoScale input field, tt is possible to override this feature and apply a fixed scaling factor to such results. When a fixed value is selected, HyGEARS will base its scaling factor on the selected value; otherwise, Autoscaling will be in effect. Valid values, based on the current linear units, are:

Yes Autoscaling, where the scale factor is based on the maximum error within the graph;
0.010 [mm] or 0.0004 [in]
... ...
0.120 [mm] or 0.0047 [in]

Rotation ... As was shown in the Button Bar section of the Parent window (see The HyGEARS GUI), it is possible to re-orient the displayed object by successive rotations about the X, Y or Z Child Window axes. The default amount of rotation performed each time a Button Bar rotation button is pressed is set through this input field. Simply enter a default value which will be assigned to each newly created Child Window. This value can later be changed through the Button Bar Rotation Increment button.

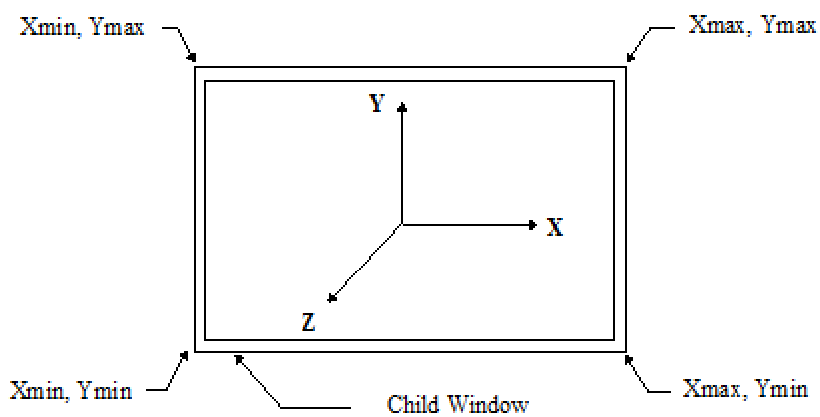
YMin ... When HyGEARS objects are displayed in the 3D Child Windows, they are mapped (scaled) to the boundaries of their Child Window hosts which means that a scale factor is applied between the real dimensions of the displayed object and those of the display window. When a Child Window is in Auto

Zoom mode, the X and Y scale factors are calculated automatically by HyGEARS.

Basically, the Child Window dimensions Ymin, Ymax, Xmin and Xmax represent the space within which the object will be displayed. By default, the dimensions are set to 30 in by 30 in (762 mm x 762 mm), such that most gears will easily fit in.

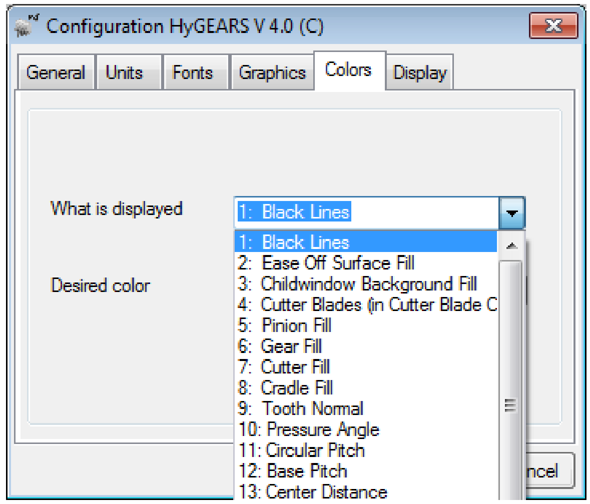
When Ymin is equal to Ymax, and Xmin is equal to Xmax, the Child Window origin is centered. If they are different, the Child Window origin will move to a point at mid distance between the Min and Max values in each direction.

The values must be inputted in the order shown, (Ymin, Ymax, Xmin, Xmax) and be separated by a comma.

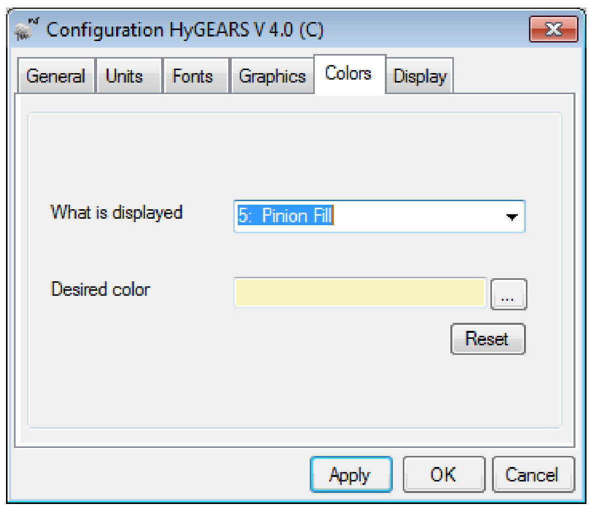


9.6.5 Colors Data Page

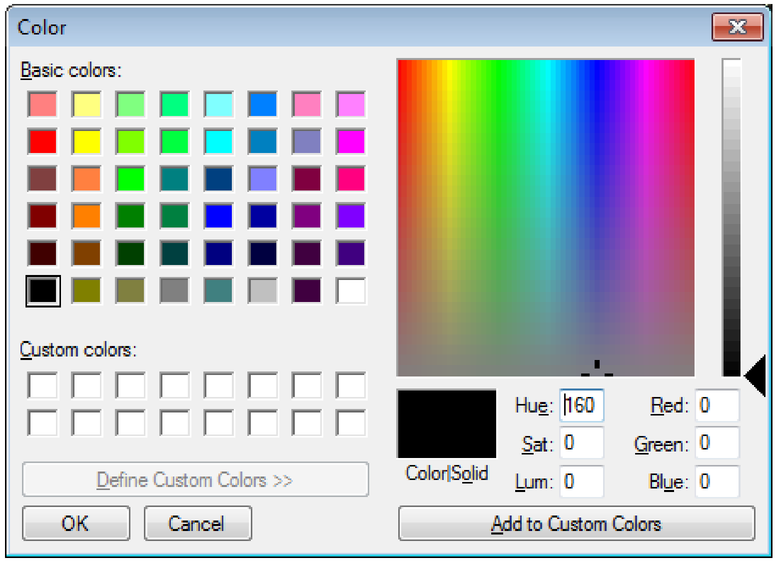
The Colors data page allows the selection, and conservation, of preferred colors in HyGEARS graphics displays. For ease of referencing, the identifiers of the colors are numbered. A list of the available numbered color fields appears below, with a more detailed description.



Basically, the “What is displayed” drop-down box offers some 60+ selections; when a selection is made, its current color is displayed in the “Desired color” field, as shown below.



By clicking on the […] button to the right of the colored “Desired color” field, the user is presented with a Windows color selection form from which the desired color may be defined:



Command Buttons

Once the desired modifications have been done, clicking on:

Apply	redisplays all current Child Windows to allow appreciation of the color changes;
OK	redisplays all current Child Windows, exits the Configuration Editor, and keeps the changes that were made;
Cancel	exits the Configuration Editor, and abandons the changes made to the Colors (only).

List of Editable Colors and Short Explanation

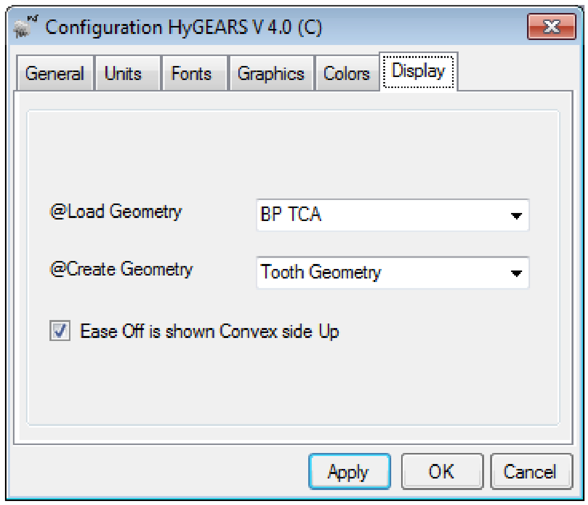
1: Black Lines	All black lines drawn in any Child Window
2: Ease Off Surface Fill	Filling color of Ease Off Surface
3: Childwindow Background Fill	Background color of all Child Windows
4: Cutter Blades (in Cutter Blade ChildWindow)	Filling color of Cutter Blades
5: Pinion Fill	Pinion filling color, teeth and body
6: Gear Fill	Gear filling color, teeth and body
7: Cutter Fill	Cutter body fill (Machine Child Window)
8: Cradle Fill	Cradle body fill (Machine Child Window)

9: Tooth Normal	Tooth flank Normal (Gearing Primitives)
10: Pressure Angle	Pressure Angle (Gearing Primitives)
11: Circular Pitch	Circular Pitch (Gearing Primitives)
12: Base Pitch	Base Pitch (Gearing Primitives)
13: Center Distance	Center Distance (Gearing Primitives)
14: Tip Circle-Cone	Face Cone (Gearing Primitives)
15: Pitch Circle-Cone	Pitch Cone (Gearing Primitives)
16: Form Circle-Cone	Start of active Profile Cone (Gearing Primitives)
17: Root Circle-Cone	Tooth Root Cone (Gearing Primitives)
18: Base Circle-Cone	Base Cone (Gearing Primitives)
19: Tooth Section	“Sect-NoSc” function button and Gearing Primitives
20: Pitch Plane	Pitch Surface (Gearing Primitives)
21: Meshing Plane	Meshing Surface (Gearing Primitives)
22: PoC in General Ref. Frame	Path of Contact (Gearing Primitives)
23: PoC on Tooth Flank	Path of Contact
24: Contact Pattern	Contact Pattern
25: LPSTC	Lowest point of single tooth contact / Lower transfer point
26: HPSTC	Highest point of single tooth contact / Higher transfer point
27: Sliding Speeds	Sliding speed vectors
28: Loads – LTCA-FStips-FEA Mesh	Applied loads in LTCA, Finite Strips, Finite Element Mesh
29: Bearings	Pinion and Gear bearings
30: Machine Base	Base of the machine (Machine Child Window)
31: Finite Strips	Finite Strip, when displayed in the finite Strips Child Window
32: Projected 2D Pinion Tooth	Tooth Child Window - used in combination with Gear tooth to assess root clearance
33: Projected 2D Gear Tooth	Tooth Child Window - used in combination with Gear/Pinion tooth to assess root clearance
34: Cutter Path Trace	Machine Child Window - "Anim" function button

35: Probe – CMM or Dia Over Balls	Probe sphere in CMM Nominal and Dia Over Balls Child Windows
36: Cutter Blade – IB	IB Cutter Blade for Face Hobbed gears (“NoBl-Blad” function button)
37: Cutter Blade – OB	OB Cutter Blade for Face Hobbed gears (“NoBl-Blad” function button)
38: Feed Marks	Feed marks color
40: Dimension Lines	All extension lines for dimensioning
39: Text	All text
41: Measured Surface and Tooth Root IB.Pinion-OB.Gear	Coast tooth flank color
42: Measured Surface and Tooth Root OB.Pinion-IB.Gear	Drive tooth flank color
43: Reference Frames	All reference frames (^ R keyboard combination)
44: Ease Off Reference Grid	Bottom (reference) grid of Ease Off Surface
45: Princ. Curvatures – Normal	Tooth normal for Principal Curvatures
46: Princ. Curvatures – Major	Major curvature direction vector
47: Princ. Curvatures – Minor	Minor curvature direction vector
48: CMM Nominal Grid	CMM Nominal ChildWindow
49: Undercut Limit	Undercut line (“NoUn-Undr” function button)
50: Fillet Limit	Fillet line (“NoUn-Undr” function button)
51: TopRem Limit	TopRem line (“NoUn-Undr” function button)
52: Mean Point	Mean Point on tooth flank; shown as a cross
53: STOP Button (animations and calculations)	STOP button when calculation/animation is underway
54: Active Function Button on Tool Bar	Normally, a function button is GREEN when active
55: Inactive Function Button on Tool Bar	Normally, a function button is RED when inactive
56:	
57:	
58:	
59:	
60:	
61: Contact Element – Separation Grid	Separation Grid color for Contact Elements (LTCA)

62: Contact Element – Projected Grid	Projected Grid color for Contact Elements (LTCA)
63: Contact Element – Grid	Actual Grid color for Contact Elements (LTCA)

9.6.6 Display Data Page



@Load Geometry
@Create Geometry

The Display data page allows the user to decide how HyGEARS will graphically present results for two events:

- When a geometry is *loaded from a saved file* on disk;
- When a *New Geometry* is created.

The default value for both Load Geometry and Create Geometry is "BP TCA" as it immediately reveals most of the dimensions of a gearset.

At any time after either Load Geometry or Create Geometry, one can select a specific display different from the default.

Eight choices are offered:

User Defined:	in this case, nothing will be displayed on screen; the Graphics and Window pull down menus will be enabled and the user can decide what to display and where on the screen.

[BP TCA]: the Contact Pattern on the Gear tooth flanks is displayed, along with the Transmission Error curves, the Ease Off surfaces, a close up of the meshing Pinion and Gear teeth, and the Path of Contact, in 2D projection, where the pinion and gear teeth can be seen interacting.

[BP LTCA]: the Loaded Tooth Contact Analysis is calculated, and contact stresses (Hertz) are displayed in colors on the tooth flanks of the Gear along with the Transmission Error curves, TCA and LTCA.

[Tooth Geometry]: display of the pinion and gear blanks, along with several key dimensions on the teeth.

[Stock Distribution]: a comparison of the Finishing and Roughing tooth thickness distributions is displayed, along with the Finished and Roughed teeth superimposed in 3D.

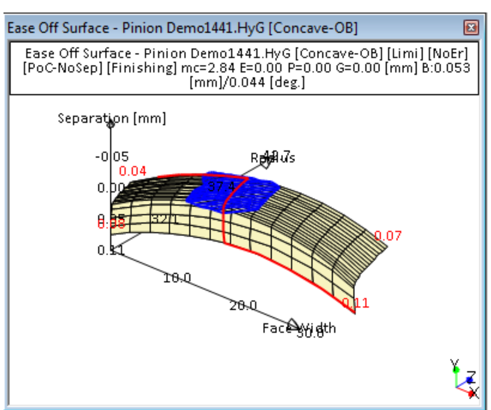
[CMM Nominal]: 2D and 3D displays of the CMM target grid are presented; the user can select where the target grid is to be on the tooth flank, and can visually check for interference between the probe sphere and the opposite tooth flank.

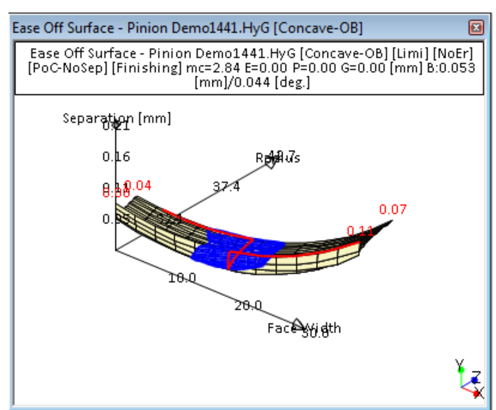
[Correction-R.E.]: tools to calculate either Corrective Machine Settings (Closed Loop) or Reverse Engineering, once a CMM file is available.

[Cutting Machine]: the cutting machines are displayed and can be animated.

Ease Off is shown Convex side-Up:

The Ease Off surface may be displayed in one of 2 modes: *Convex* or *Concave* side-Up. When checked, this option imposes the left display below.

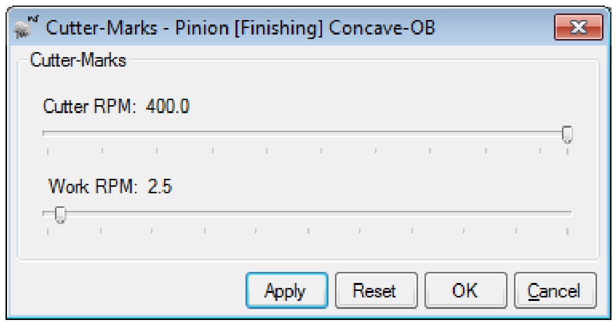




Convex side-Up **Concave side Up**

9.7 Work and Tool Speed

HyGEARS can display, in the relevant Child Windows, the traces left by the cutting tool on the tooth flank, what is call Feed Marks in HyGEARS. Of course, these feedmarks depend on the relative work and tool speeds, which may be set using the Work and Tool Speed editor presented in the figure below.

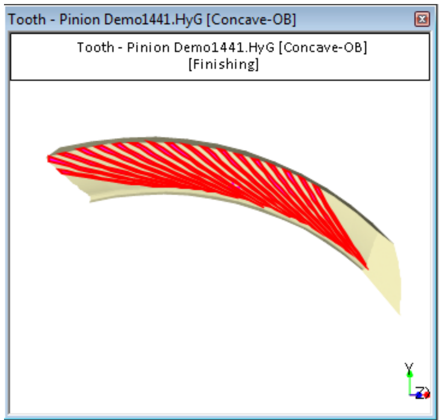


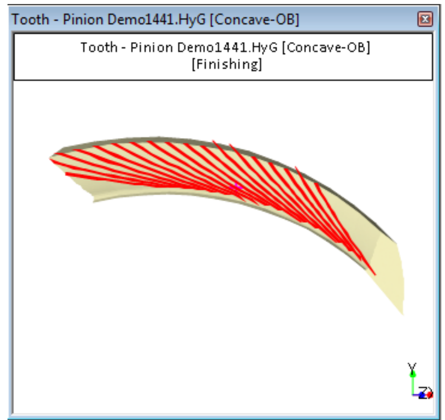
Sliders are used to control the speeds of the Cutter and Work. As the sliders are moved left or right, the speed values are updated.

Command Buttons

Apply	tells HyGEARS to use the entered data, e.g. the Horizontal and Vertical Positions, recalculate the display, and remain in the input window;
Reset	tells HyGEARS to restore the original values;
OK	completes the input.
Cancel	cancels any change done.

The figures below show the cutting marks left on the pinion tooth flank for two Cutter RPMs: 75 and 250, while the Work RPM is maintained at 2.5. Obviously, in the second picture where the Cutter speed is higher, FeedMarks are thinner, which should lead to a better surface finish, and also to a shorter tool life because of the higher speeds.



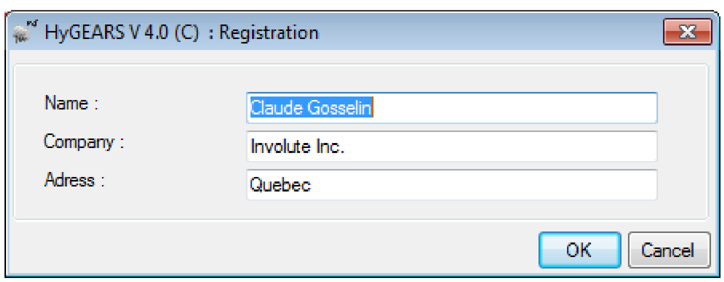


75 RPM **250 RPM**

9.8 User Registration

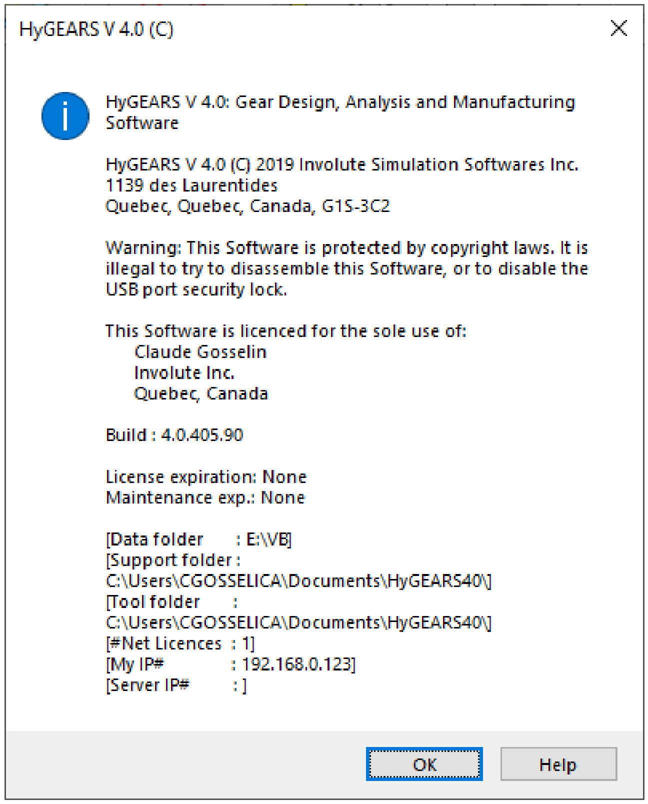
In actual use, many HyGEARS printed outputs are necessary. These outputs are identified to the registered user name, company and address.

Upon the initial installation of HyGEARS, the user *Registration Editor* is displayed to be filled appropriately, as explained in the Opening Screens. It is possible to change the default user identification through the *Registration Editor* shown below:



Note that since the Company name is embedded within HyGEARS as an additional protection against unauthorized copy, it is not editable.

Pressing the Esc key or the Cancel button at any time will cancel the changes made; pressing the Return key or the OK button permanently stores the inputted user registration information, and displays the Copyright notice.


HyGEARS V 4.0 (C)
HyGEARS V 4.0: Gear Design, Analysis and Manufacturing Software
HyGEARS V 4.0 (C) 2019 Involute Simulation Softwares Inc.
1139 des Laurentides
Quebec, Quebec, Canada, G1S-3C2
Warning: This Software is protected by copyright laws. It is illegal to try to disassemble this Software, or to disable the USB port security lock.
This Software is licenced for the sole use of:
Claude Gosselin
Involute Inc.
Quebec, Canada
Build : 4.0.405.90
License expiration: None
Maintenance exp.: None
[Data folder : E:\VB]
[Support folder : C:\Users\CGOSSELICA\Documents\HyGEARS40\]
[Tool folder : C:\Users\CGOSSELICA\Documents\HyGEARS40\]
[#Net Licences : 1]
[My IP# : 192.168.0.123]
[Server IP# :]
OK
Help

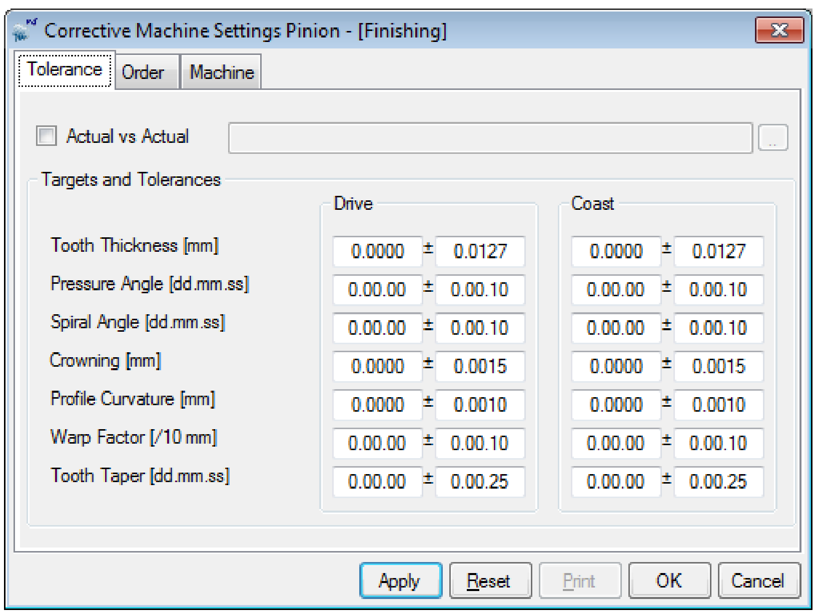
10 Closed Loop and Reverse Engineering

HyGEARS offers sophisticated algorithms to either:

- *match a simulated tooth surface to measurement data*, what is called Reverse Engineering or RE (which is also used in the Stock Distribution optimization),
- *match a measured tooth surface to the simulation data*, what is called Corrective Machine Settings (Closed Loop).

For more details, please refer to The HyGEARS Simulation, section Corrective Machine Settings (Closed Loop) and The HyGEARS Surface Matching Algorithm.

In both cases, it is possible to tell HyGEARS user preferences through the Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection Window shown below.



The Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection Window is organized in up to six Data Pages, respectively containing options and information on:

Tolerance	options on target values and tolerances;
Order	options on what is to be corrected;
Machine	options on control parameters constraints;
Correction	the calculated changes in machine settings;

Expected Stats	what HyGEARS hopes to achieve after correction;
Errors	what remains after correction or RE
Trace	calculation trace, in which numerical problems may be traced.

Initially, only the first 3 Data Pages are displayed. Once data is available, the other 3 Data Pages are shown.

Straight-bevel and spur/helical/Beveloid gears may be corrected in:

1st order	mode where pressure and spiral angle errors are corrected;
2nd order	mode, control over lengthwise curvature and tooth surface bias is offered;

Fixed Setting, Modified Roll, Semi-Completing spiral-bevel gears may be corrected in:

1st order	mode where pressure and spiral angle errors are corrected;
2nd order	mode, control over lengthwise curvature and tooth surface bias is offered;

Spread Blade, *Duplex Helical,* generated *Face Hob* and *Cyclo-Palloid spiral-bevel gears* can be corrected either in:

0rd mode	where only tooth thickness is controlled (only for Corrective Machine Settings (Closed Loop))
1st order	mode, where mode where pressure and spiral angle errors are corrected.
2nd order	mode, control over lengthwise curvature and tooth surface bias is offered;

Formate and *Helixform spiral-bevel* can be corrected either in:

0rd mode	where only tooth thickness is controlled (only for Corrective Machine Settings (Closed Loop))
1st order	mode, where mode where pressure and spiral angle errors are corrected.

Command Buttons

The following Command buttons appear at the bottom of the Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection Window and become active as results are available:

Apply Tells HyGEARS to start calculating either Reverse Engineering or Corrective Machine Settings (Closed Loop) using the currently selected correction modes.

The “Apply” button caption is then changed to “Stop” which, when clicked with the left mouse button, tells HyGEARS to stop the iteration process.

When the Corrective Machine Settings (Closed Loop) algorithm is accessed the first time for either the pinion or the gear, HyGEARS defines the Nominal Summary, which is equivalent to copy the current Machine Settings as the first entry in the pinion or gear Correction History. The so-called Nominal Summary will then be used as the reference to calculate Corrective Machine Settings (Closed Loop).

In Reverse Engineering mode, HyGEARS proceeds directly, as the calculated machine settings will be kept to define the new current Summary. Reverse Engineering cannot be applied after Corrective Machine Settings (Closed Loop) have been applied.

Note that as long as the Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection Window is not exited, pressing the “Apply” button tells HyGEARS to reset the Geometry to its original state and then proceed with the new selection. Thus, successive "Apply" actions are not additive.

To calculate Reverse Engineering or Corrective Machine Settings (Closed Loop), HyGEARS matches the theoretical and measured surfaces to evaluate which machine settings must be changed and by how much; while doing so, HyGEARS periodically redraws the comparison between the measured and simulated surfaces for the user to follow the evolution.

When the error tolerance or Maximum # of iterations has been reached, HyGEARS calculates the machine setting modifications as the difference between the machine settings before and after the application of the Surface Matching algorithm.

For Reverse Engineering, the machine settings differences are added to the original Summary settings before the algorithm was initiated; for Corrective Machine Settings (Closed Loop), they are subtracted.

Results are sent to the Correction and Expected Stats Data Pages (see further in this section for details) where they can be viewed and printed before a decision is made.

Reset Tells HyGEARS that the Geometry is to be returned to its original state, without exiting the Selection window.

Print Tells HyGEARS to print the current Corrective Machine Settings (Closed Loop) or Reverse Engineering results.

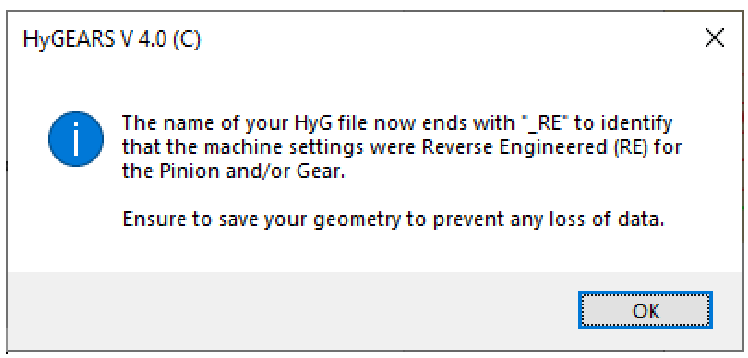
OK Tells HyGEARS that the results obtained are satisfactory and that they are to be kept as is. The Selection window is closed and HyGEARS returns control to the Parent window.

For Reverse Engineering, the tooth surface is kept as calculated, but is not conserved definitely as long as the Geometry has not been saved on disk. While it is possible to reset the Corrective Machine Settings (Closed Loop) History, and thus to revert to the original Geometry Summary, Reverse Engineering machine settings changes are permanent.

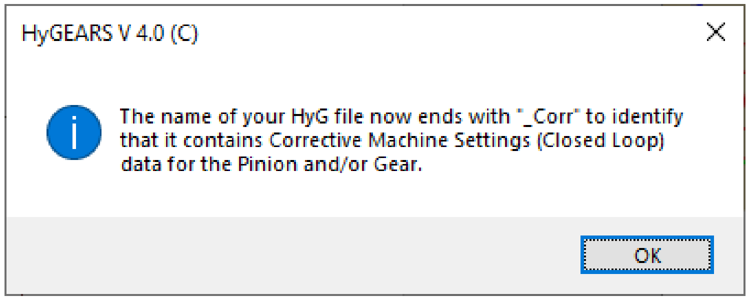
HyGEARS automatically appends "_CORR" or "_RE" at the end of the HyG file name such as to force a "clean" use of file names. In addition, for Closed Loop (i.e. [Corr] function button), the renamed HyG file is automatically saved in the source folder such as to avoid "forgetting" to save the file after Correction is completed.

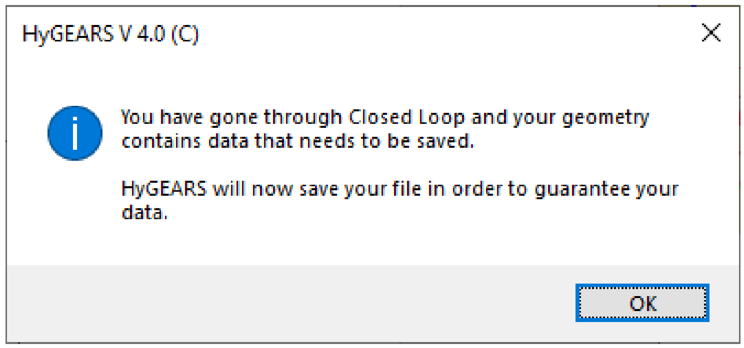
A message is then displayed on screen to inform the user of what happened.

Reverse Engineering (RE):



Closed Loop (Corr):





Cancel Tells HyGEARS that the results obtained are not satisfactory and that the Geometry is to be returned to its original state. The Selection window is closed and HyGEARS returns control to the Parent window.

10.1 Measurement Data Conversion

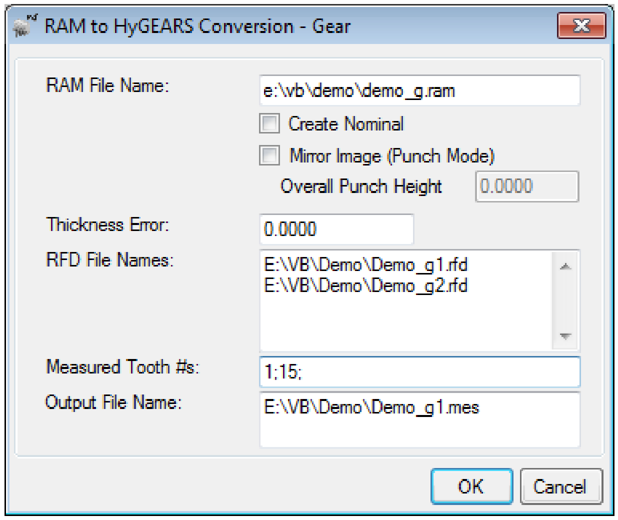
HyGEARS offers a function to automatically convert Zeiss "Ram" and "Rfd", Hoeffler, MdM, GAGE and Leitz measurement data files into HyGEARS measurement data files.

Many Child Windows require a measurement data file. When the name of a measurement data file is given, the following tests are performed:

1. test if the data file is of "Ram" type;
2. test if the data file is of "Rfd" type;
3. test if the data file is of "Gleason-Zeiss" type;
4. test if the data file is of "Hoeffler" type;
5. test if the data file is of "Klingelnberg P" type;
6. test if the data file is of "MdM" type;
7. test if the data file is of "CDS" type;
8. test if the data file is of "GAGE" type;
9. test if the data file is of "Leitz" type;
10. test if the data file header is of HYGEARS type.

In each case, the appropriate HyGEARS measurement data conversion function is called.

All the above conversion utilities share a common interface, where only the inputted files may change. In the last case above, the measurement data file is of the HyGEARS type and need not be converted. If none of the above applies, HyGEARS will assume that the provided data file is not of a known type, and the function will abort.



Command Buttons

OK	completes the input and initiates the file conversion.
Cancel	cancels any input that was done and exits.

Behavior

The CMM to HyGEARS measurement data conversion utility is called whenever the selected measurement datafile is not of HyGEARS format; a window similar to the Ram to HyGEARS Measurement Selection Window, above, is displayed, where different possibilities are offered to the user, depending on the above-selected file.

RAM File Name	the RAM, or any other, file name, as long as it contains either CMM target data, such as the RAM file, or CMM measurement data, such as the Hoeffler files;
Create Nominal	the inputted file, whatever the type, is converted to a theoretical file, i.e. without any error value; useful to compare the simulation of different software;
Thickness Error	some file formats, such as RAM, do not include the tooth thickness error; this can be inputted in the Thickness Error field;
RFD File Names	for RAM type files, the error files are expected in there; if none is provided, HyGEARS will assume a theoretical file is to be created;

	for CMM files that return the actual coordinates of the contact point, such as Hoeffler, up to three other datafiles may be provided; these files should be in the same sequential order as their physical position on the measured member; double click in the field to call the File Dialog Box;
Measured Tooth #s	Input the number of the teeth as they were measured;
Output File Name	The output name is based on that of the RAM file, or on that of the first RFD file if provided; for theoretical files, the extension is ".teo"; when measurement data is provided, the extension is ".mes".

When the CMM to HyGEARS measurement data conversion has been completed, the output HyGEARS measurement data file name becomes part of the gear set geometry data and will be stored in the geometry data file, such as to be available by default each time it is needed.

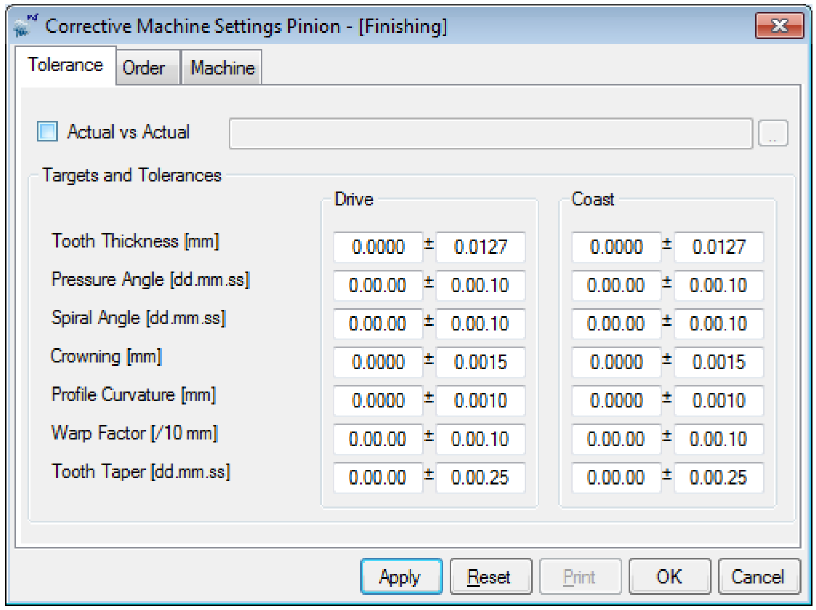
The measurement data file name can easily be changed at anytime, to see the effects of machine settings changes for example.

10.2 Tolerance Data Page

The Tolerance data page enables the user to specify by how much the Corrected or Matched surface is to deviate from the reference surface, what is called the target [deviation] value, and within what tolerance a result is considered acceptable. Only those tolerance and target values consistent with the cutting process and selected correction order are enabled.

Target and tolerance values are offered for either or both the IB and OB tooth flanks, depending whether a Fixed Setting, Modified Roll, Spread Blade, Formate, Helixform, Duplex Helical or Face Hobbing cutting process is used.

When a Geometry is initially created, default tolerance values are set while target deviation values are zero. Tolerance and target values are saved with the Geometry datafile such as to be conserved for future reference.



Actual vs Actual

The first option offered in the Tolerance Data page is the “Actual vs Actual” check box. By default, this option is not activated. When activated by a left mouse button click, HyGEARS expects that the input field to the right of the check box will contain the name of the HyGEARS Actual, or measurement, data file to be used as a reference or target.

The Actual Measurement data filename may be entered manually in the field; alternately, a double-click on the input field, or a single-click on the **[…]** button to the right of the field, will call the File Dialog Box which can be used to navigate in the directory structure and select the appropriate file.

When provided with a valid Actual Measurement file, HyGEARS will calculate the Corrective Machine Settings (Closed Loop) or Reverse Engineering in relation to the above provided Actual Measurement data file instead of the current theoretical tooth surface. All the Target and Tolerance values described below are then calculated in relation to the provided Actual Measurement data file.

When a valid Actual Measurement data file name is provided, the following verifications are made:

- the provided Actual Measurement data file must be of HyGEARS type;
- the provided Actual Measurement data file must be of the same type as the current Measurement data file used to calculate the Corrective Machine Settings (Closed Loop) or Reverse Engineering;

- the Actual and current Measurement data files must origin from the same RAM file.

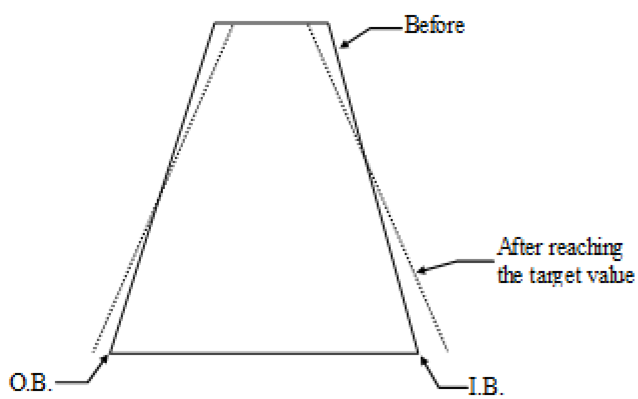
Targets and Tolerances

As illustrated above, targets and tolerances input fields are listed as [Target] +/- [Tolerance], for the currently selected tooth flank. For Spread Blade, Formate, Helixform, Duplex Helical and Face Hobbing cutting processes, only one input window is offered, which is valid for both tooth flanks. The following targets and tolerances are offered:

Tooth Thickness given in the current linear units, tooth thickness target and tolerance is offered only for Spread Blade, Formate, Helixform, Duplex Helical and Face Hobbing cutting processes, and is controlled through cutting depth. A positive target value increases the tooth thickness. Tooth thickness is controlled only in Corrective Machine Settings (Closed Loop); it is ignored by Reverse Engineering which will rather maintain tooth depth while machine settings are changed.

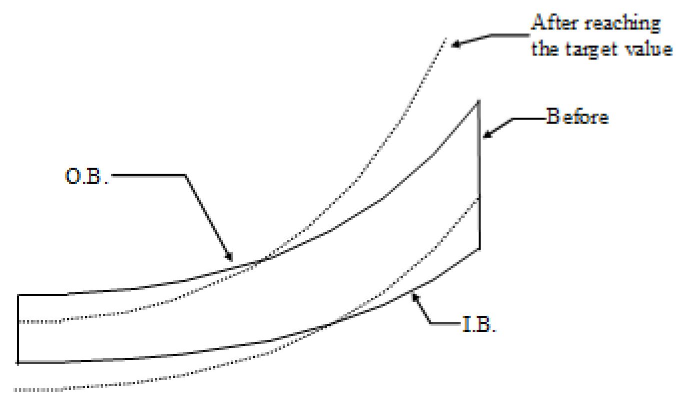
Pressure Angle pressure angle target and tolerance input fields are offered for all correction order modes, e.g. 1st and 2nd, except for order 0 when only tooth thickness is controlled.

When a Spread Blade, Formate, Helixform, Duplex Helical or Face Hobbing cutting process is used, the pressure angle target can be calculated from either the Drive, Coast or average Drive and Coast tooth flanks, as explained in the Machine data page section below. A positive pressure angle target value will increase the pressure angle, as shown below.



Spiral Angle spiral angle target and tolerance input fields are offered for all correction order modes, e.g. 1st and 2nd, except for order 0 when only tooth thickness is controlled.

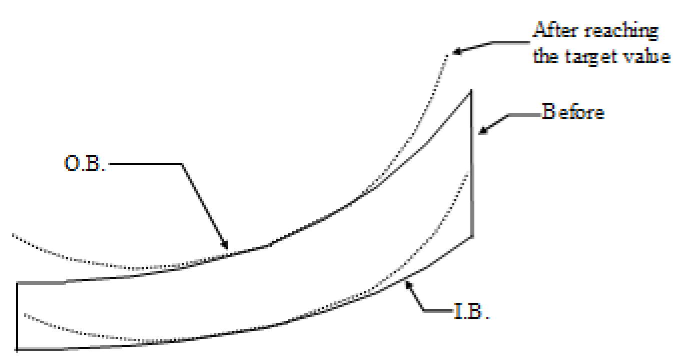
When a Spread Blade, Formate, Helixform, Duplex Helical or Face Hobbing cutting process is used, the spiral angle target can be calculated from either the Drive, Coast or average Drive and Coast tooth flanks, as explained in the Machine data page section below. A positive spiral angle target value will increase the spiral angle, as shown below.



Crowning

crowning, or lengthwise curvature, target and tolerance input fields are offered only in 2nd and 2nd+ correction order modes, solely for Fixed Setting and Modified Roll pinions. Crowning may be controlled either by a change in Cutter diameter, Machine center to back, work Offset Fixed Setting, plus Modified Roll or Cam Eccentric in Modified Roll pinions.

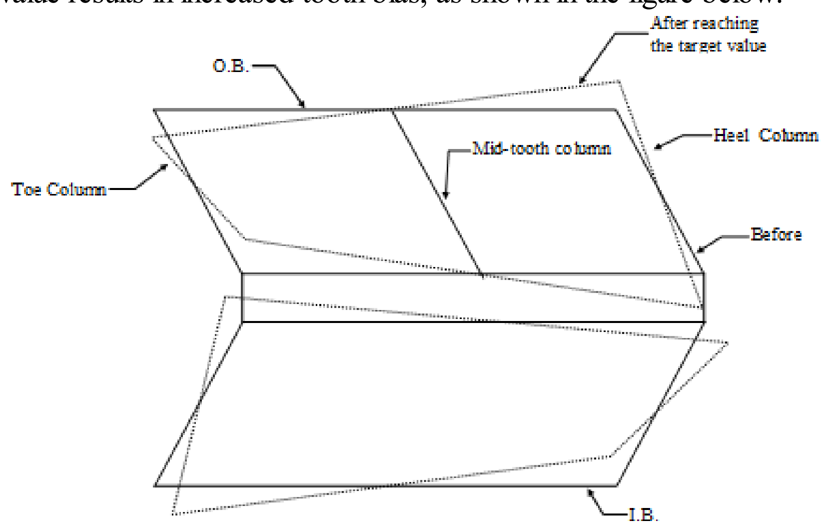
The default crowning control parameter, in 2nd order mode, is the Machine center to back, while in 2nd+ correction mode, the default control parameter becomes the Cutter point diameter. A positive target value results in increased lengthwise curvature, as shown in the figure below.



Tooth Bias

tooth bias target and tolerance input fields are offered only in 2nd and 2nd+ correction order modes, solely for Fixed Setting and Modified Roll pinions. Tooth bias may be controlled either by a change in Decimal Ratio, Machine center to back, work Offset for Fixed Setting pinions, plus Modified Roll or Cam Eccentric in Modified Roll pinions.

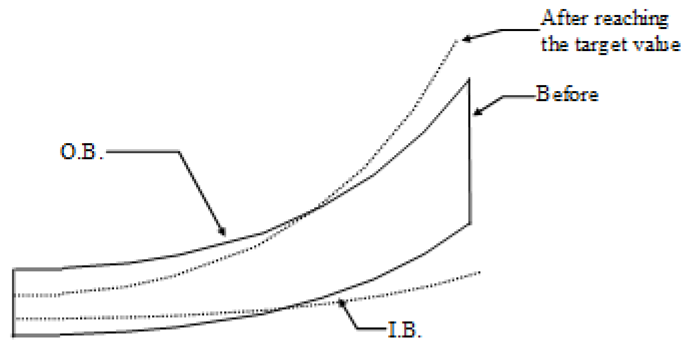
The default tooth bias control parameter, in 2nd order mode, is the Decimal Ratio, while in 2nd+ correction mode, the default control parameter becomes the Machine center to back. A positive target value results in increased tooth bias, as shown in the figure below.



Tooth Taper

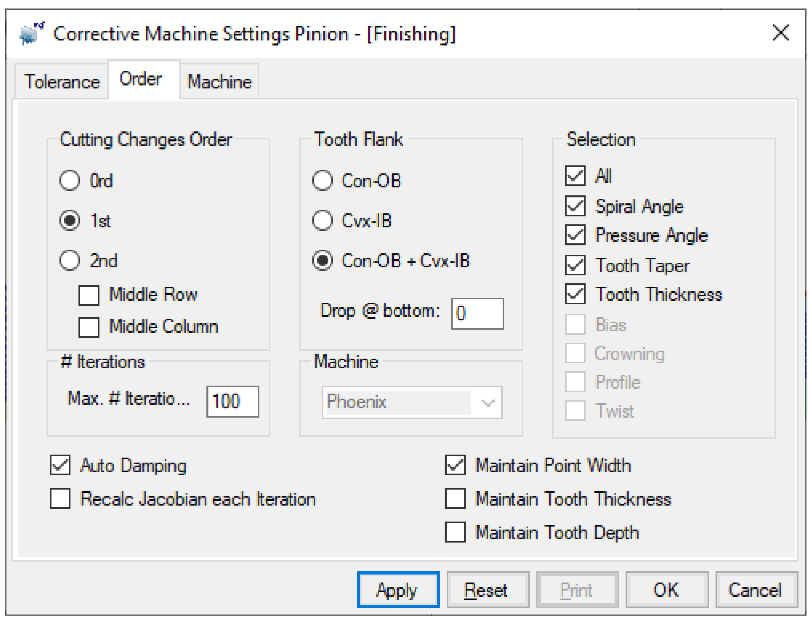
tooth taper target and tolerance input fields are offered in 1st order correction mode, for Spread Blade, Formate, Helixform, Duplex Helical or Face Hobbing cutting processes.

Tooth taper is defined as the difference in spiral angle error between the IB and OB tooth flanks. Tooth taper is controlled by work horizontal position for non-generated gear members, and by work Offset for generated pinion and gear members. A positive tooth taper target value will increase the toe to heel tooth taper, as shown below.



10.3 Order Data Page

The *Order* data page enables the user to specify in which way the surface is to be Corrected or Matched. Basically, tooth surfaces may be corrected as follows:



Cutting Changes Order

The Cutting Changes Order selection window, shown above, offers only those correction modes that are valid for the currently considered member. Cutting Changes Order selections are not mutually exclusive.

The "*Middle Row*" and "*Middle Column*" entries, available for correction orders 1 and 2, allow selecting a subset of the measurement datafile, if desired;

0rd order for tooth thickness control only, for Spread Blade, Formate, Helixform, Duplex Helical or Face Hobbing cutting processes in Corrective Machine Settings (Closed Loop) mode;

1st order pressure and spiral angle errors, for all cutting processes, either in Reverse Engineering or Corrective Machine Settings (Closed Loop) mode; tooth taper is added for Spread Blade, Formate, Helixform, Duplex Helical or Face Hobbing cutting processes;

2nd order pressure and spiral angle errors, lengthwise curvature and tooth surface bias, only for generated members, either in Reverse Engineering or Corrective Machine Settings (Closed Loop) mode;

Tooth Flank

In Completing cycle cutting processes, where both tooth flanks are cut simultaneously, the controlling tooth flank may be set for optimal results to either the Drive, Coast or Drive + Coast tooth flanks, where in the latter the averaged tooth errors are used.

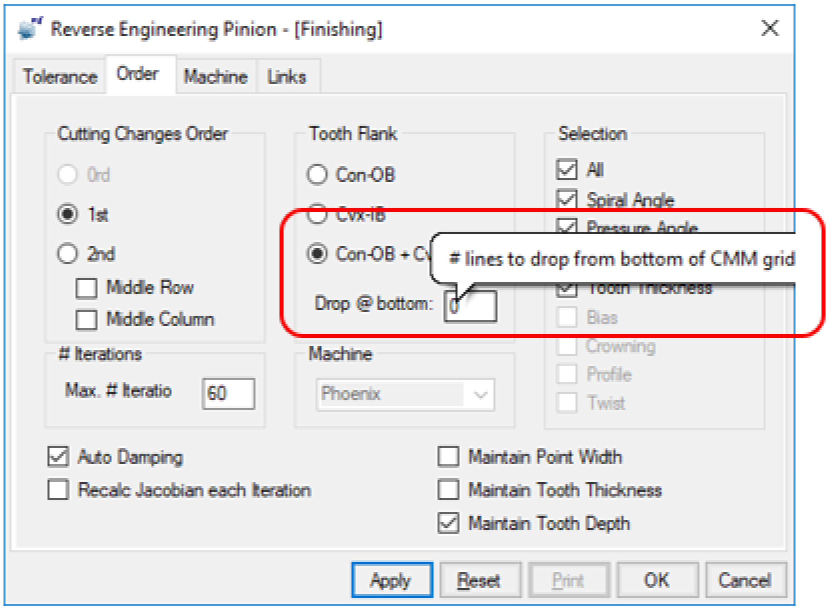
In Fixed Setting and Modified Roll Cutting processes, the tooth flanks can be corrected separately or at the same time, using the same switch.

For Spur/Helical/Beveloid, Straight-bevel and Coniflex gears, the tooth flanks are labeled "Right" and "Left" rather than "Concave" and "Convex".

The behavior of the RE and Closed Loop algorithm is as follows when either the *Left-Concave* or *Right-Convex* tooth flank is selected:

- When the *Right* flank is selected, the modified machine settings of the *Right* flank are copied to the *Left* flank;
- When the *Left* flank is selected, the modified machine settings of the *Left* flank are copied to the *Right* flank;
- When the *Right + Left* flanks are selected, each flank is treated individually, which usually results in different machine settings for each flank.

The "Drop @ bottom" entry is tell HyGEARS to drop some measurement lines nearest the fillet. By default, this entry is 0. However, when the bottom lines are very near the fillet limit, there is always the chance that Undercutting happens which hampers the numerical solution. It is therefore useful to drop 1 or 2 lines such as to avoid the Undercut area, and the solution will remain stable.



Machine

The current machine is displayed. Corrections are outputted for the displayed machine.

Iterations

The # Iterations window offers the possibility to modify the number of correction "passes" made by HyGEARS. Usually, 5 to 10 iterations are sufficient for 1st order correction, 20 to 30 iterations are sufficient for moderately off surfaces in 2nd order correction mode. The maximum number of iterations is limited at 99.

Auto-Damping

This option, normally On, forces HyGEARS to set to 1.0 the damping factor of the numerical solution. If divergence is detected, HyGEARS will automatically adjust the damping factor to ensure convergence. In Auto-damping mode, results are usually obtained in 1 to 2 iterations rather than 20 to 30.

It is possible to deselect this feature, and HyGEARS will proceed as before, i.e. in HyGEARS V 2.5 and before where.the Damping factor was fixed.

Recalculate Jacobian Every Iteration

This option, normally Off, forces HyGEARS to recalculate a new Jacobian matrix of the 1st order derivatives of the objective functions used in the Surface Matching Algorithm. This may be useful when convergence is not obtained (extremely rare). See "Tracing the Surface Matching Algorithm", for further details.

Maintain Point Width

For Completing cycles only. If checked, Sliding base will be used to control tooth thickness.

Maintain Point Thickness

No modification allowed in tooth thickness; therefore, either cutter Point Width or Sliding Base will be used to maintain tooth thickness constant.

Maintain Tooth Depth

When correcting Tooth Thickness, tooth depth is not allowed to change. Therefore, the tool Point Width must change.

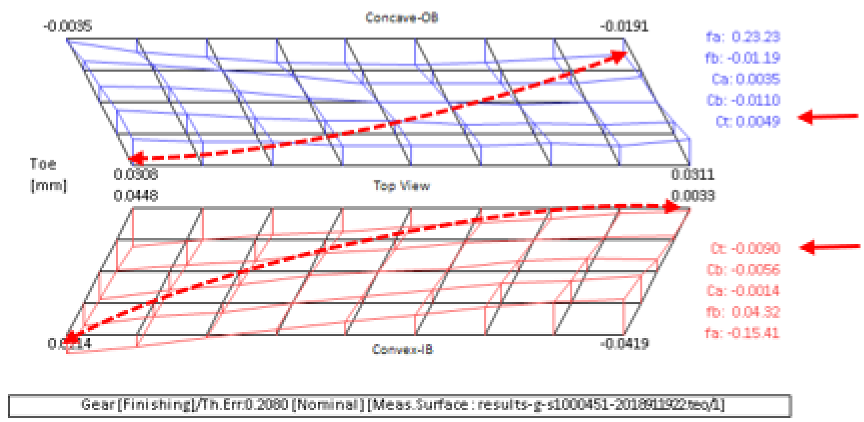
Selection

Selection offers to either apply the corrections to all or selected items.

The "*All*" selection is the default value, but other selections may be made if desired. Note though that a Pressure Angle selection, alone, may well cause tooth surface bias or spiral angle errors. Therefore, the "All" selection is usually the best bet.

Offered selections depend on the Change Order and cutting process.

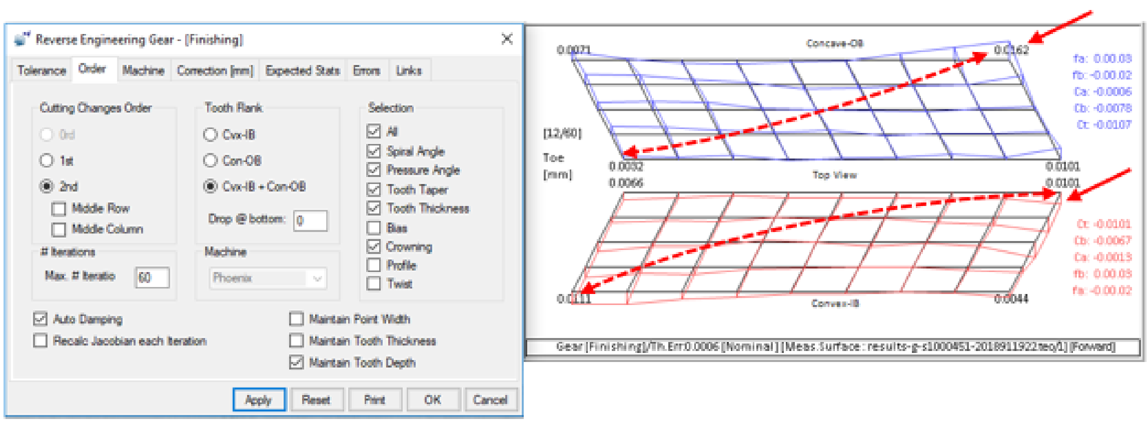
One selection may need a bit of description however: Twist. Twist is defined as the curvature along the diagonal from (figure below):



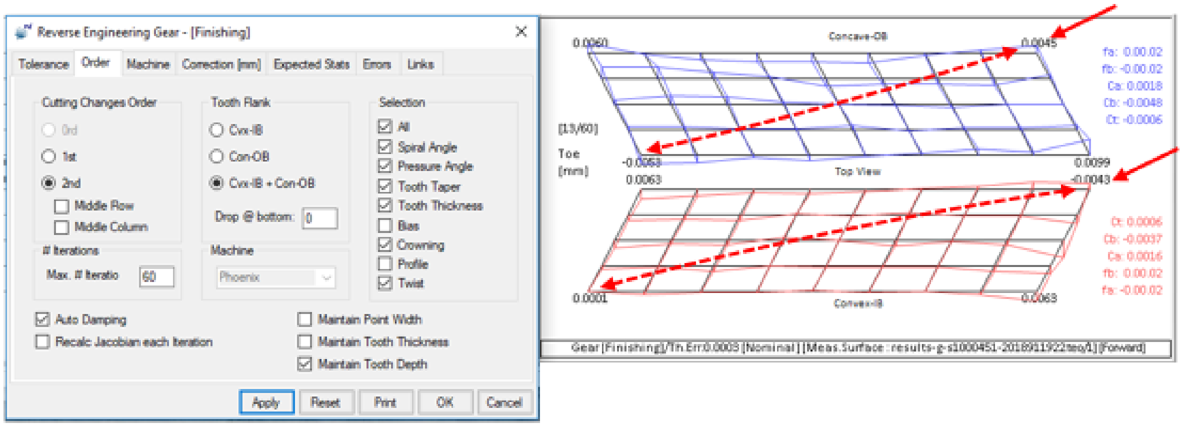
1. Concave Flank: Toe Tip to Heel Bottom
2. Convex Flank: Toe Bottom to Heel Tip

The Ct value in the figure above gives the calculated amount of Twist

For example, figure below, selecting 2nd Order with Crowning, the following result is obtained for RE; one can see that along the diagonals, some significant curvature remains.



By contrast, adding Twist to the selection yields the following result where it is clear that the curvature along the diagonals has been almost entirely eliminated.



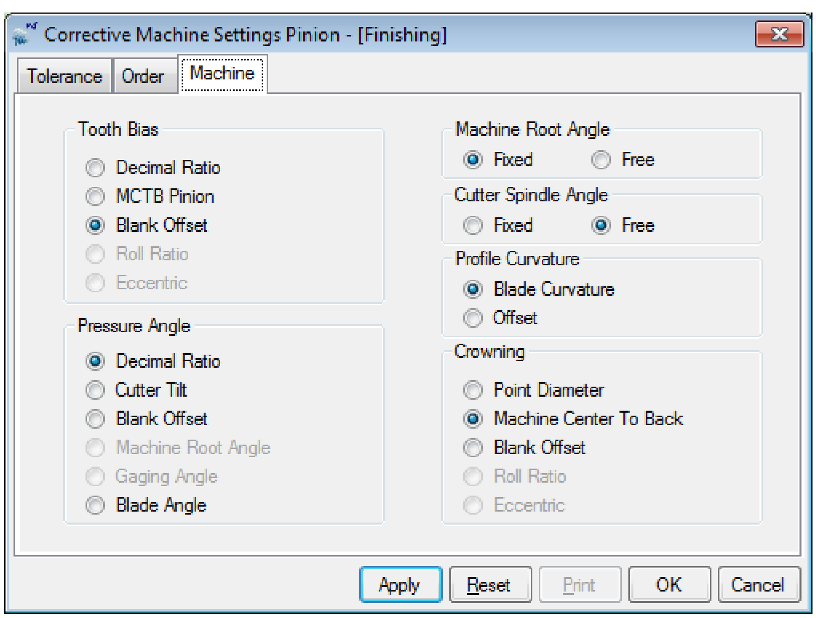
Twist is available only if the reference machine is a Phoenix.

10.4 Machine Data Page

The Machine data page enables the user to specify in which control parameters are to be used to control the way the surface is to be Corrected or Matched.

Fixed Setting and Modified Roll spiral-bevel pinions

The figure below shows the Machine data page for Fixed Setting and Modified Roll pinions. Five selection windows offer the following choices:



Tooth Bias control parameter for tooth bias correction; Machine Center to Back is the default parameter, but Decimal Ratio or Offset, Modified Roll or Cam Eccentric may be chosen; since Offset affects the profile curvature, some change in profile curvature is to be expected in 2nd order mode.

Note 1: since Machine center to back, Blank Offset, Modified Roll and Cam Eccentric appear in both the Tooth Bias and Crowning selection windows, they are mutually exclusive.

Note 2: in 2nd order mode, the combination of Decimal Ratio to control Tooth Bias and Offset to control Crowning usually does not yield reliable results and is not recommended. When such a selection is made, HyGEARS will issue a warning message.

Crowning control parameter for lengthwise curvature correction; Cutter Diameter is the default parameter, but Machine Center to Back or Blank Offset may be chosen; since Machine Center to Back affects the profile curvature, some change in profile curvature is to be expected in 2nd order mode.

Note 1: since Machine Center to Back and Blank Offset appear in both the Tooth Bias and Crowning selection windows, they are mutually exclusive.

Note 2: in 2nd order mode, the combination of Decimal Ratio to control Tooth Bias and Offset to control Crowning usually does not yield reliable results and is not recommended. When such a selection is made, HyGEARS will issue a warning message.

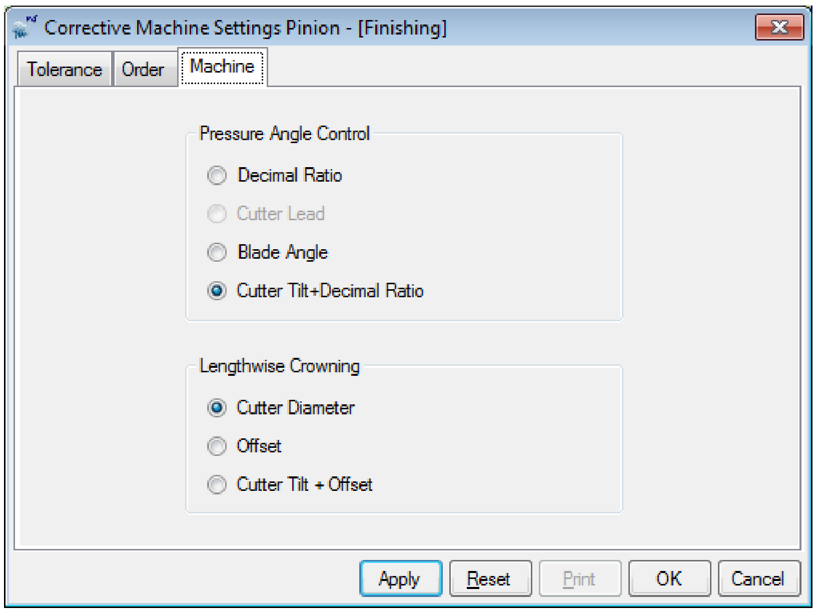
Machine Root Angle Machine root angle may either be kept fixed, what is normally the case, or set free. By default, Machine root angle is fixed.

Cutter Spindle Angle the Cutter Spindle Angle is free by default, in order to maintain tooth rootline parallelism when pressure angle errors are corrected; however, it may be kept fixed when tooth surface errors are small, such that the operator has one adjustment less to make on the cutting machine, thereby reducing the risks of setup errors.

Note: if the Cutter Spindle Angle is kept fixed when tooth surface errors are large, the tooth rootline will not remain parallel and it is possible that HyGEARS does not find a solution to the requested tooth surface correction.

Pressure Angle — control parameter for tooth pressure angle correction; Cutter Tilt is the default parameter, for Fixed Setting, and Gaging Angle for Modified Roll; Decimal Ratio, Blank Offset or Blade Angle may be chosen; since Decimal Ratio affects the profile curvature, some change in profile curvature is to be expected in 2nd order mode.

Spread Blade and Duplex Helical spiral-bevels



The figure above shows the Machine data page for Spread Blade and Duplex Helical members. The choices are for Pressure Angle and Lengthwise Crowning control.

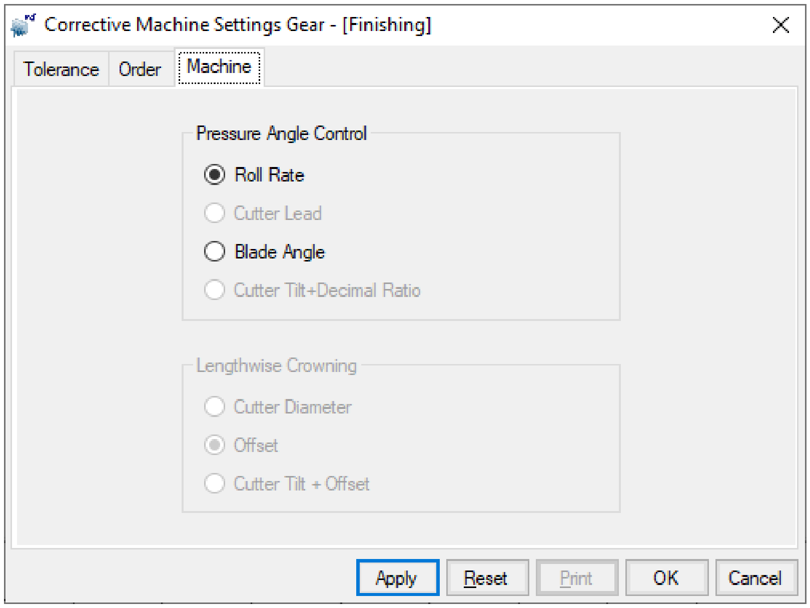
Tooth Bias — controlled by a combination of Machine Center to Back and Helical Motion.

Crowning — choice of cutter Diameter., blank Offset or cutter Tilt + blank Offset;

Tooth Thickness — controlled by the cutter Point Width or Sliding base;

Pressure Angle — choice of the control parameter for tooth pressure angle correction; Cutter Tilt combined with Decimal Ratio is the default parameter, Blade Angle or Decimal Ratio can also be selected; if Decimal Ratio is selected alone, then the *average pressure angle error* is corrected.

Formate and Helixform spiral-bevel gears

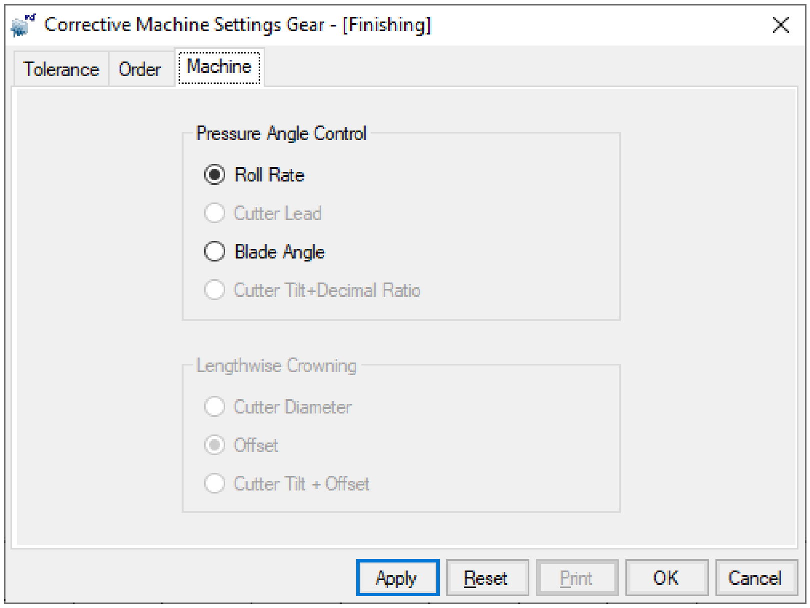


The figure above shows the Machine data page for a Helixform gear member. Two selection windows offer the following choices:

Pressure Angle Control in completing cycles such as Formate and Helixform, pressure angle correction is obtained by changing the Machine Root Angle, Cutter Lead (for Helixform – very ineffective and not recommended) or Blade Angle. Machine Root Angle is the default parameter.

EndRem in Helixform gear members, it is usual to remove excess material at the toe of the IB tooth flank, to avoid end contact. However, when correcting tooth flanks, it may be desirable to avoid accounting for this tooth area in the measurement since spiral angle errors will appear larger. Therefore, by setting EndRem Off, HyGEARS will drop the measurement data of the 1st column on the gear IB tooth flank.

Straight-bevel gears

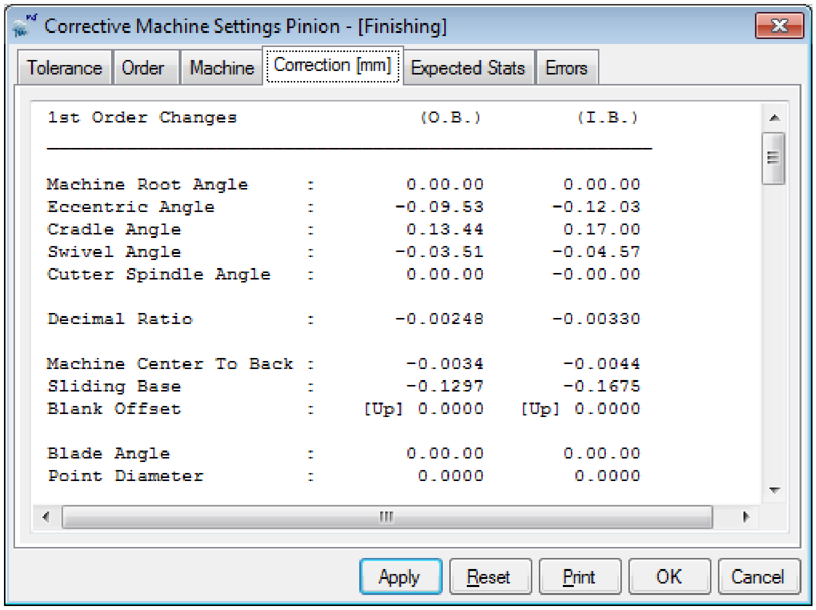


The figure above shows the Machine data page for a Straight-bevel gear.

Pressure Angle Control Roll Rate (i.e. Ratio of Roll) is the default parameter; this should be used for Closed Loop (Corrective Machine Settings); alternately, Blade Angle may also be used, but it is better suited to Reverse Engineering.

10.5 Correction Data Page

The Correction data page provides the changes in machine setting for the current selection. When the “Print” command button is pressed, the contents of the Correction data page is printed.

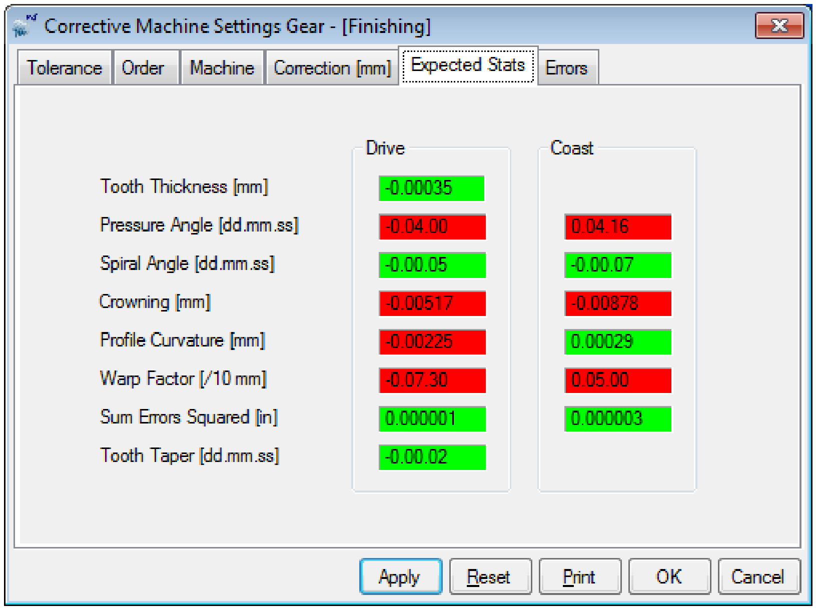


The contents of the Correction data page may be selected using the mouse and pressing the Ctrl-C keyboard combination which will copy the selected text to the Windows Clipboard from which it may be retrieved to be inserted in a report.

10.6 Expected Stats Data Page

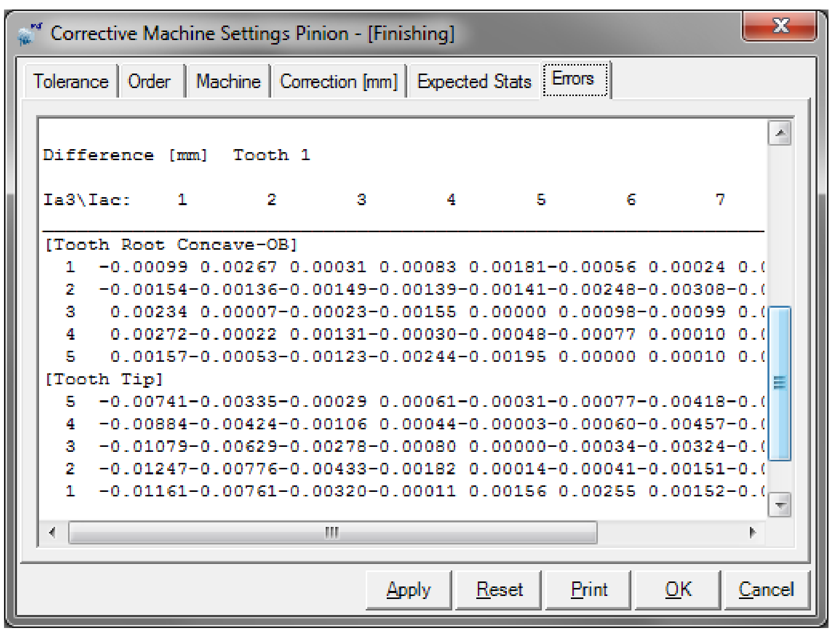
The Expected Stats data page displays what the surface statistics would be if the machine setting changes were applied exactly on a perfect machine.

The Expected Stats which are within the tolerances specified on the Tolerance data page are written on a green background; those outside are on a red background.



10.7 Errors Data Page

The Errors Data Page lists the actual errors that remain after RE or are to be expected after Corrective Machine Settings (Closed Loop), on a point to point correspondence.

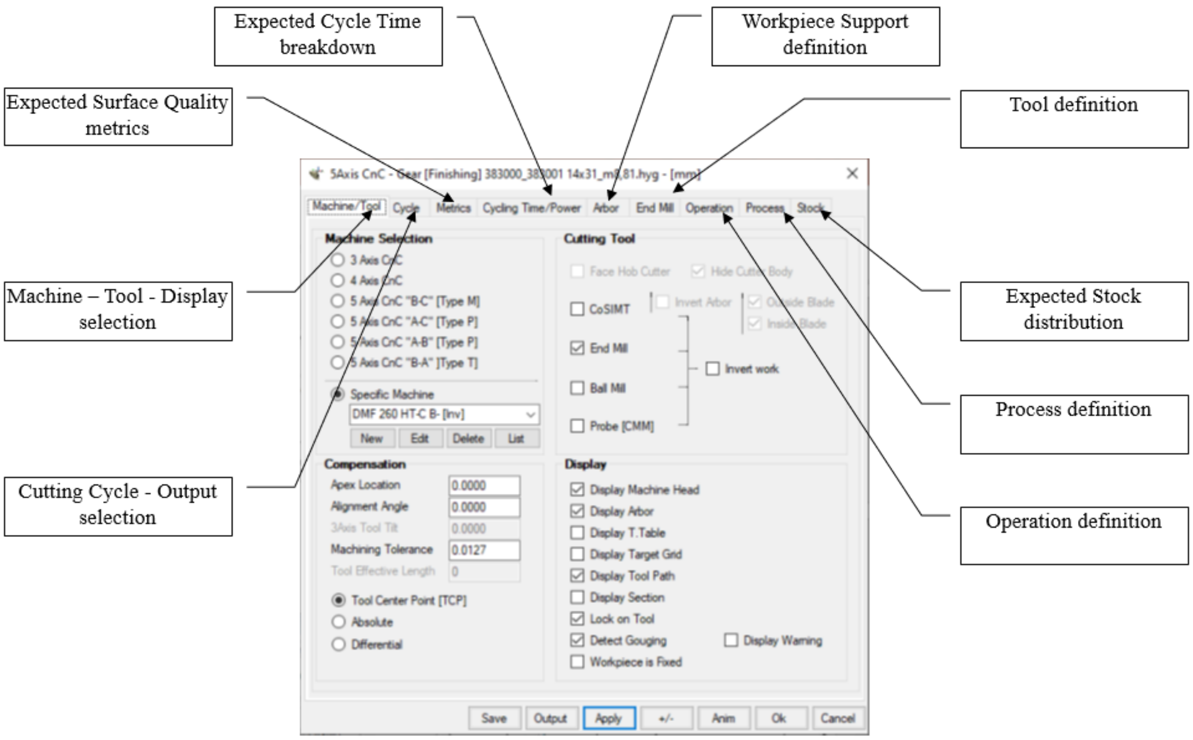


11 5Axis CnC Manufacturing

One advanced feature of HyGEARS is its capacity to generate on the fly machine-ready part-programs for 3, 4 and 5 Axis CnC Machines of any manufacturer and using tools such as Conical Side Milling Tool (i.e. CoSIMT, similar to Sandvik's InvoMill and UpGear tools), Face Mill cutter, Coniflex dish type cutter (for Coniflex gears), End Mill and Ball Mill.

- Machine/Tool
- Cutting Cycle
- Metrics
- Cycling Time
- Arbor
- Face Mill cutter
- CoSIMT tool
- End Mill tool
- Ball Mill tool
- Probe (CMM) tool
- Operation management
- Process management

In addition, part-programs can be generated to use a Probe tool such as Renishaw's in order to measure the tooth flank.



- Supported Controllers
- Supported Tools
- Graphic Display
- Command Buttons

Machines are better defined with the help of Involute Inc. once the specific kinematics of the machine, as built by the manufacturer, are known.

For example, the positive direction of the X, Y and Z axes may differ from one machine to another; the labels of the axes also often vary; and there are different architectures to CnC machines.

HyGEARS can account for all these variants in defining any multi-axis CnC machine on the market.

Controllers

HyGEARS currently supports 6 controllers, i.e.

- GCodes
- Heidenhaim
- Siemens
- Okuma

- Fanuc
- Mazak

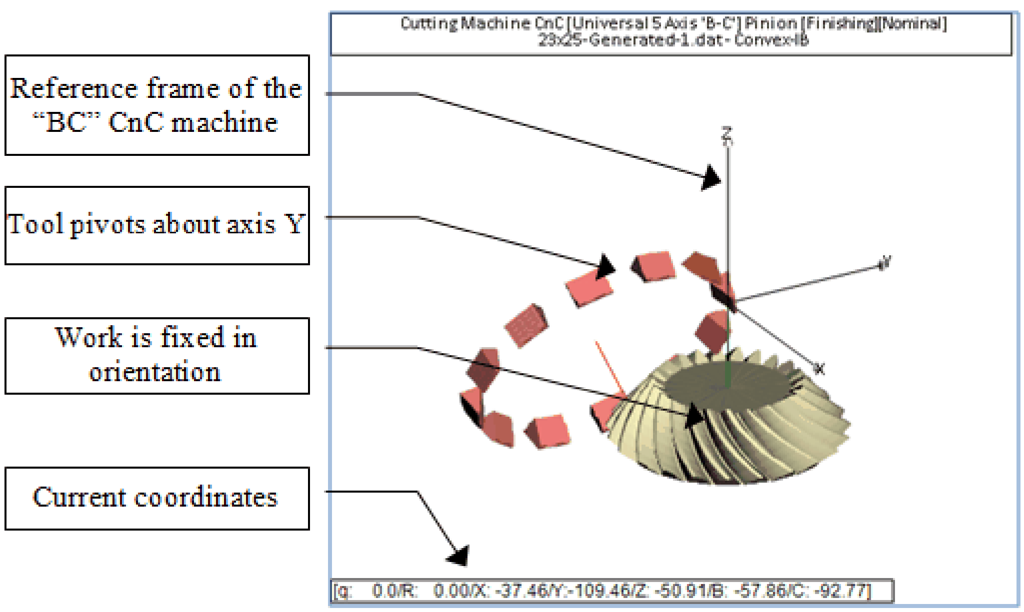
Graphic Display

The 5 Axis CnC Interface displays the axes of the selected machine, the selected tool and the work piece, with or without teeth.

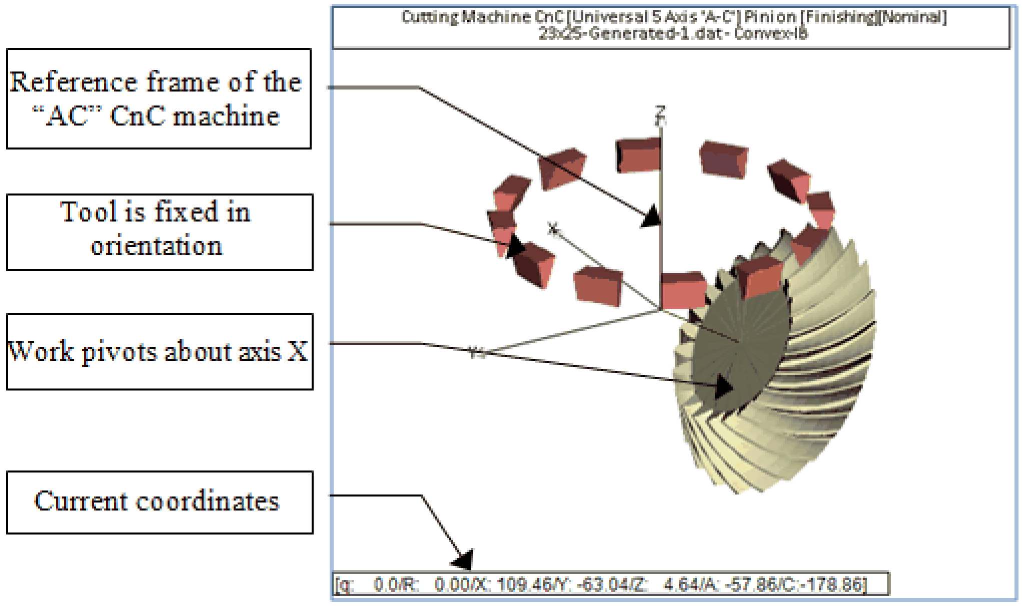
For example, the figure below displays a work piece installed in a 5 Axis CnC "BC" type machine with a Face Mill cutter; therefore, the work piece is installed along, and rotates about, the Z axis, and the cutter pivots about axis Y.

The bottom of the display shows the current coordinates and angles:

q:	is the current cradle angle
R:	is the current roll angle;
X, Y Z	are the coordinates of the tool – either the tool center point (TCP) or the tool Tip point - in machine or work piece coordinates;
B:	is pivot angle of the cutter about axis Y;
C:	is the rotation angle of the work piece.



The figure below displays the same work piece installed in a 5 Axis CnC AC type machine with a Face Mill cutter (body hidden for better visibility); the work is tilted about axis A and rotates about its axis of rotation; the cutter axis is parallel to axis Z.

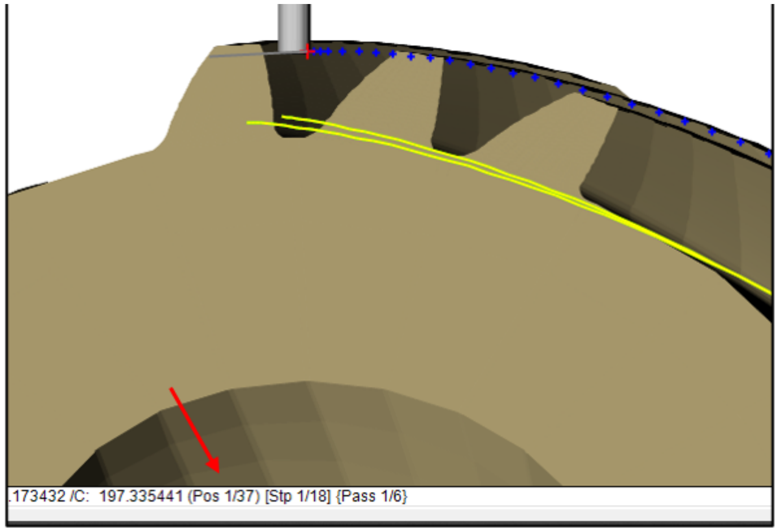


The bottom of the display shows the current coordinates and angles:

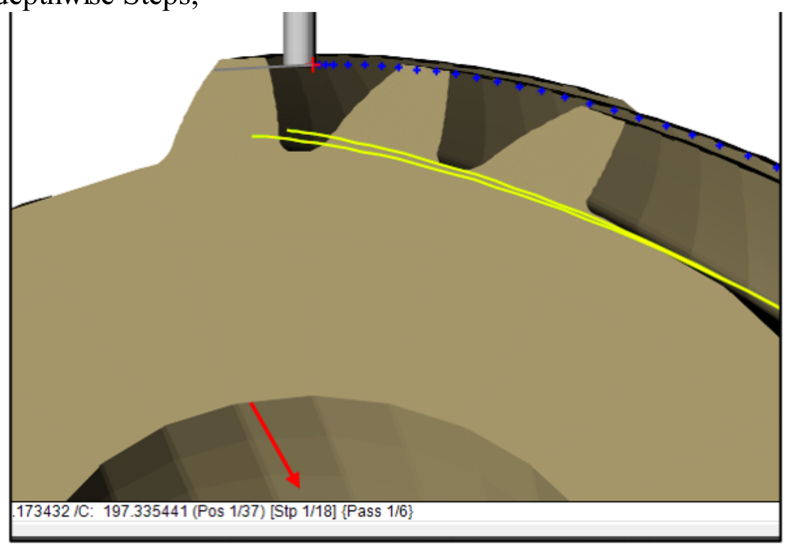
q:	is the current cradle angle
R:	is the current roll angle;
X, Y Z	are the coordinates of the tool – either the tool center point (TCP) or the tool Tip point - in machine or work piece coordinates;
A:	is the pivot angle of the work piece about axis X;
C:	is the rotation angle of the work piece.

Depending on the tool used, other info can be displayed after the tool coordinates:

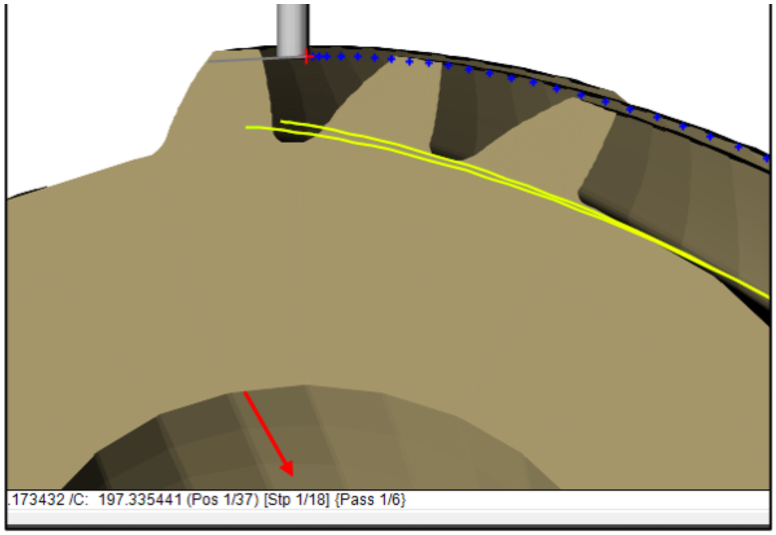
(Pos x/y): **x** is the current lengthwise position number and **y** is the total number of *Face Width Pts* required, as shown below. This position corresponds to the position of the red dot indicating the current point in the milling cycle;



[Stp x/y]: **x** is the current depthwise Step, and **y** is the requested number of depthwise Steps;



{Pass x/y}: for the MultiPass cycle; **x** is the current pass across the tooth gap, and **y** is the calculated number of passes for the current Step; the calculated number of passes is based on the maximum width of the tooth gap and the tool diameter;



All graphic controls and function buttons of the Parent Window are accessible while the 5 Axis CnC Interface window is displayed. Therefore, one can consult the Summary Editor ("Pin" or "Gear" function buttons), change the number of teeth displayed on the work piece to enhance viewing, rotate the display to get a better viewpoint, even change the location of the light to better see details.

All gear types offered in HyGEARS, including spiral-bevel gears cut by the Face Milling and Face Hobbing cutting processes, are supported.

Supported Tools

Six (6) tools are supported for CnC programming:

Face Mill	conventional cutter for spiral-bevel gears, Face Hobbed gears cannot be cut on a 5 Axis CnC machine using a Face Hob cutter – a 6 Axis CnC machine is required; a CoSIMT, End Mill or Ball Mill tool must be used instead (below);
Coniflex	dish type face mill cutter for Coniflex gears;
CoSIMT	or Conical side milling tool (i.e. Sandvik's InvoMill and UpGear tools), for all gear types;
End Mill	for all gear types;
Ball Mill	for all gear types;
Probe (CMM)	for measurement of all gear types.

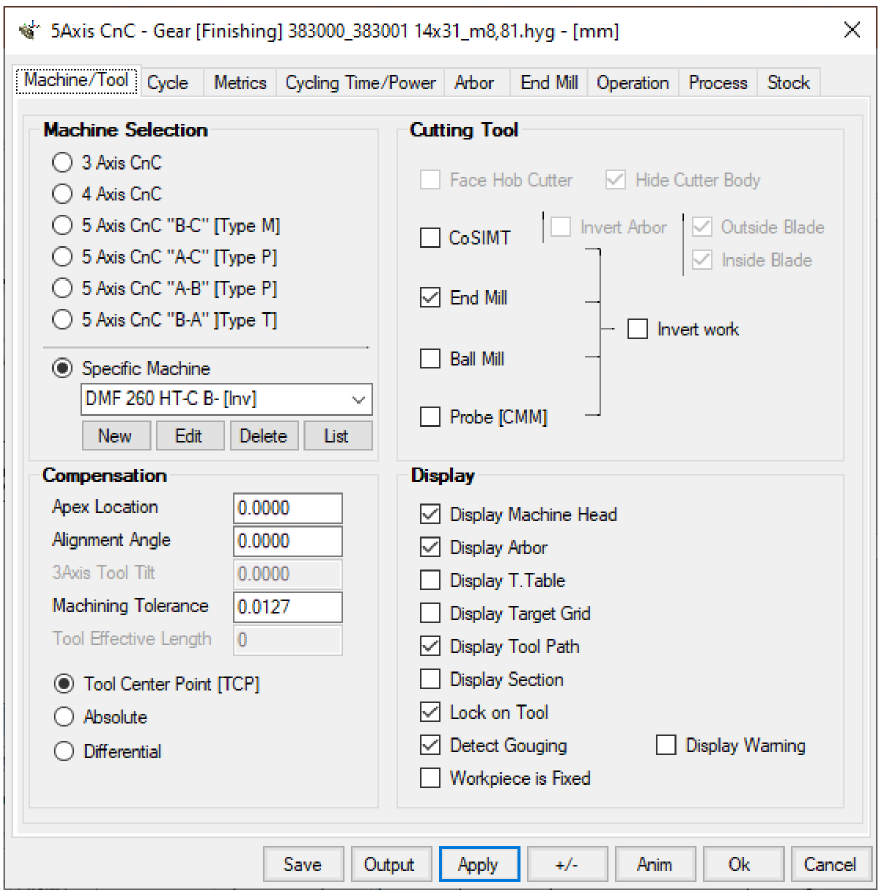
For spiral-bevel gears, the conventional Face Mill cutter offers the best performance in terms of cutting times, and should be used for medium sized batches

The CoSIMT offers excellent versatility to cut different geometries from a given tool, but is really best adapted to small batches, prototyping and large gears that would otherwise require large, and therefore quite expensive, generators.

The same comments apply to End Mill and Ball Mill cutters, but they are notably slower than CoSIMT.

Command Buttons

The figure below shows the basic interface to CnC pre-processing (called through the "5Axis" function button).



Save: saves the current Operation definition to the Operations.fil file; same effect as when the Save button of the Operation tab is used;

Output: generates the CnC part-program as per the selected tools and options in the various data pages;

Apply: reads the selected options and updates the display accordingly;

+/-: single steps through the cutting cycle; "+" is given with a left mouse click; "-" is given with a right mouse click;

Anim: starts an animation of the cycle; the cutter will cut one flank, retract, cut the other flank, retract, and start all over again;

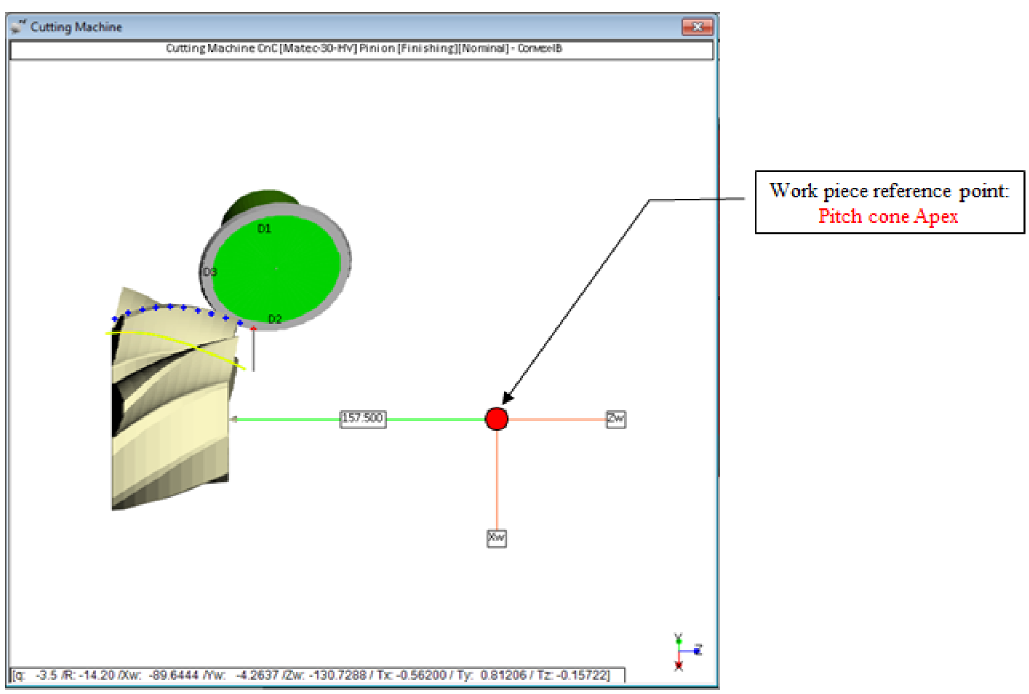
Ok: accepts the current selections, exits the *5Axis* window and returns to the Parent Window;

Cancel: drops the selections, exits the *5Axis* window and returns to the Parent Window.

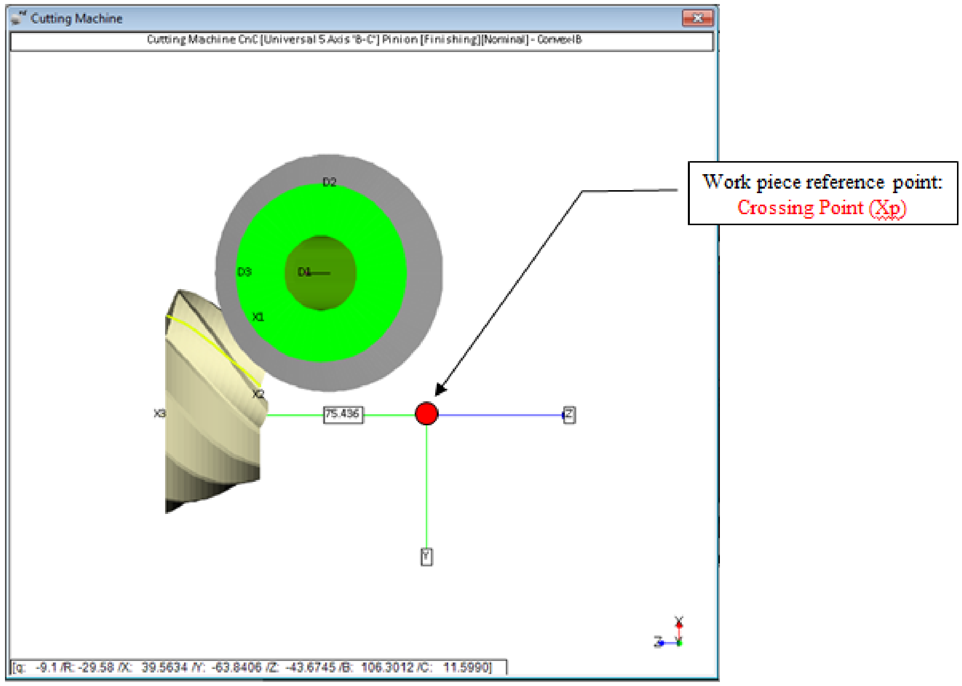
11.1 Work Piece Reference

When preparing a part program, the location of the work piece is fundamental. HyGEARS uses the following as reference for the different supported gear types.

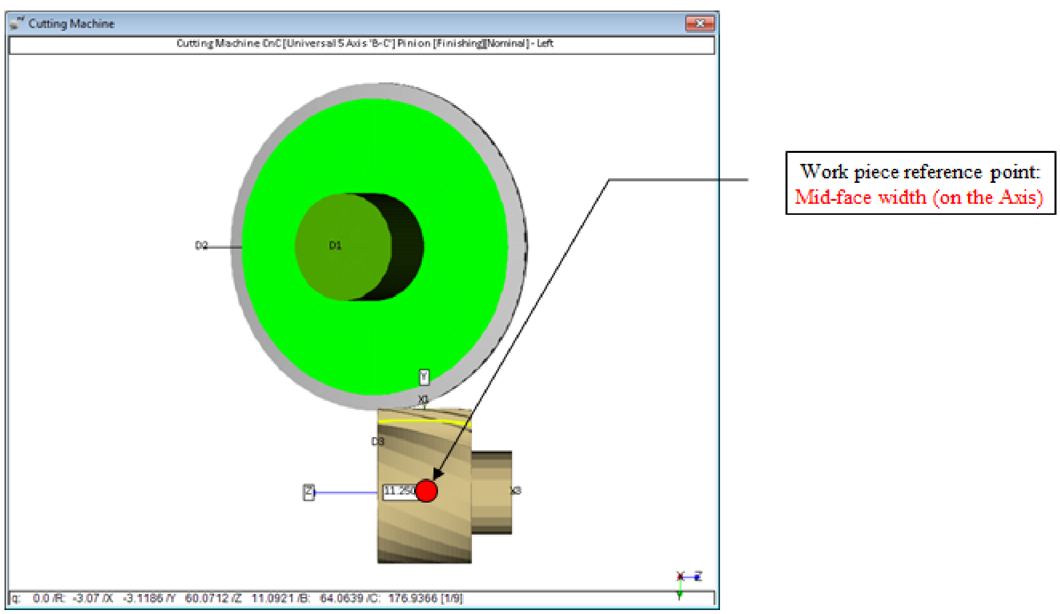
Straight Bevel / Coniflex / Spiral Bevel / Zerol gears



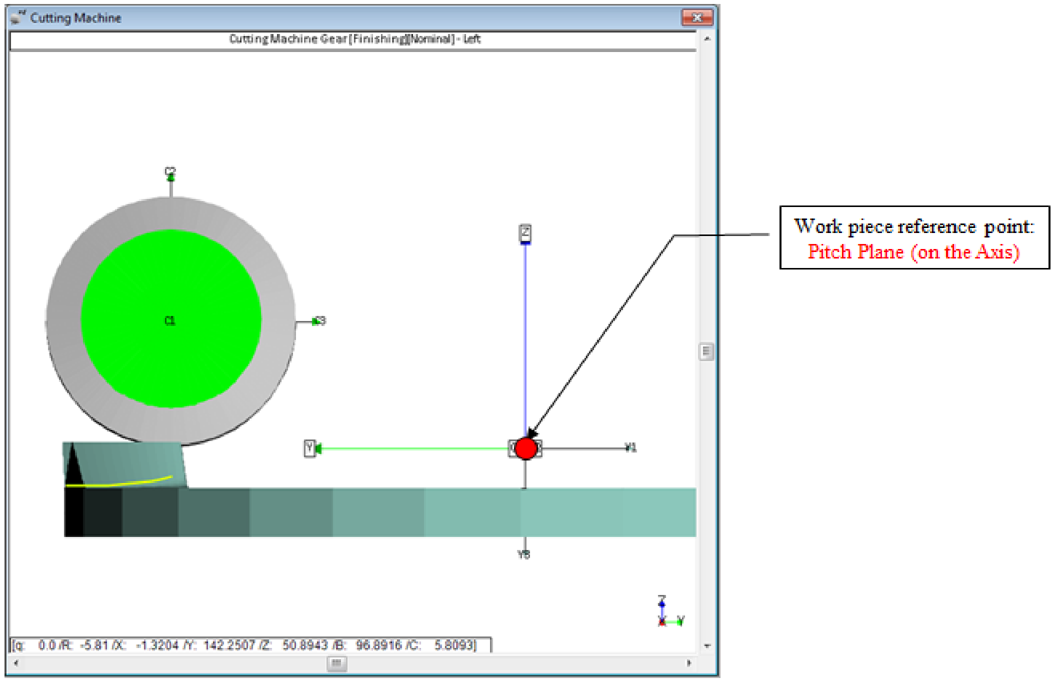
Hypoid gears



Spur / Helical / Herringbone / Beveloid gears



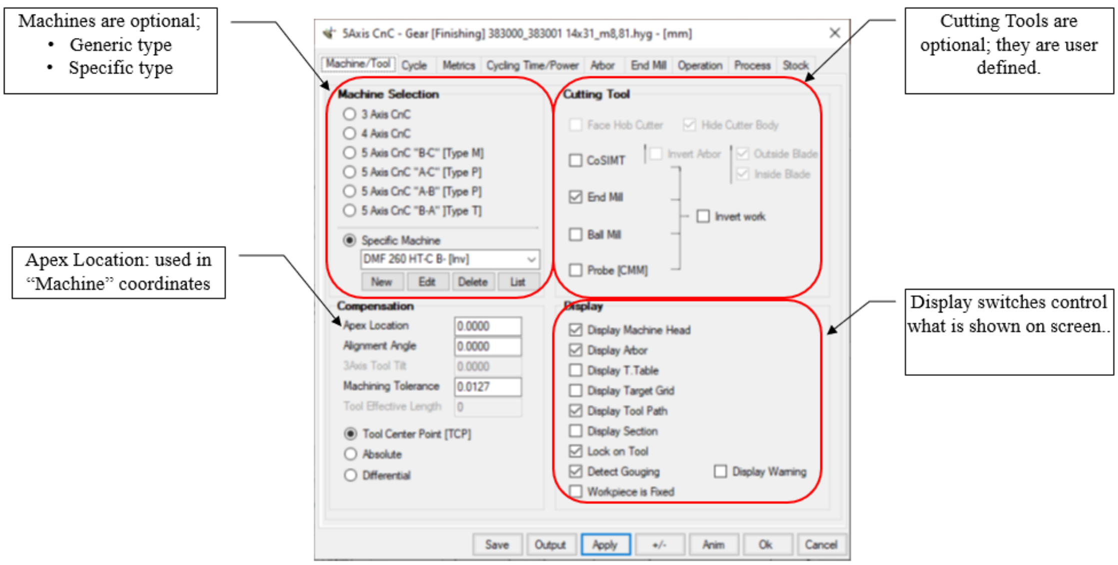
Face gears



11.2 Machine/Tool

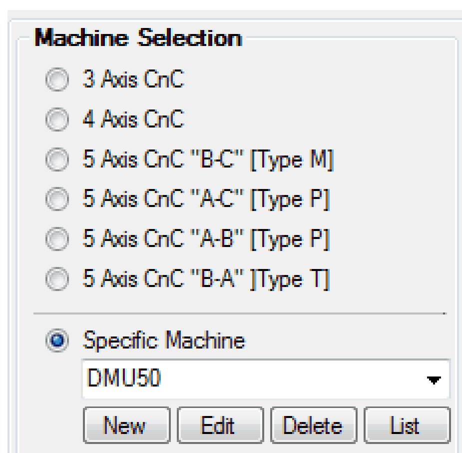
In the "Machine/Tool" data page, the user can select the desired machine, the tool, how compensation is calculated, and display features.

- Machine Selection
- Compensation
- Cutting Tool
- Display



Machine Selection

- Basic Universal CnC machines
- Specific Machine



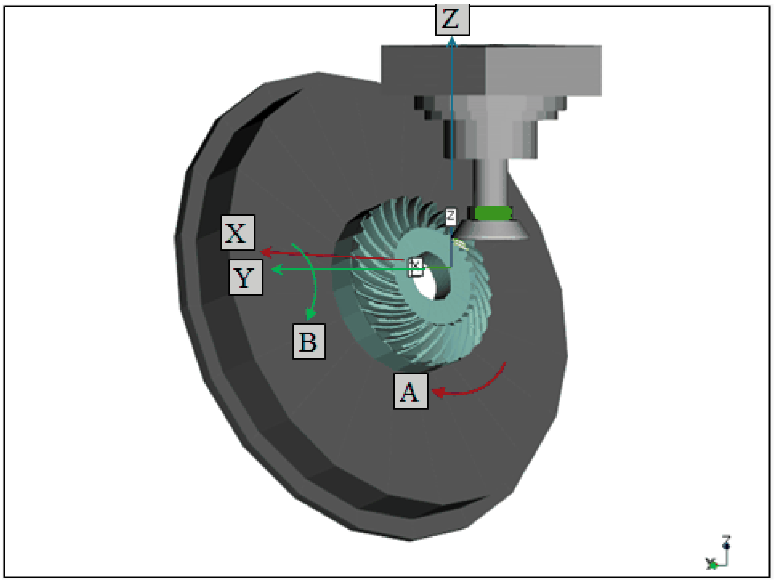
Basic Universal CnC machines: the Basic machines offered depend on user options; they implement the default definition within HyGEARS and therefore axis names and signs are imposed. They include:

- *3 Axis CnC* machines; they can allow indexation which means that only X, Y and Z coordinates are used to move the tool, but turntable rotation is used to index from tooth gap to tooth gap.

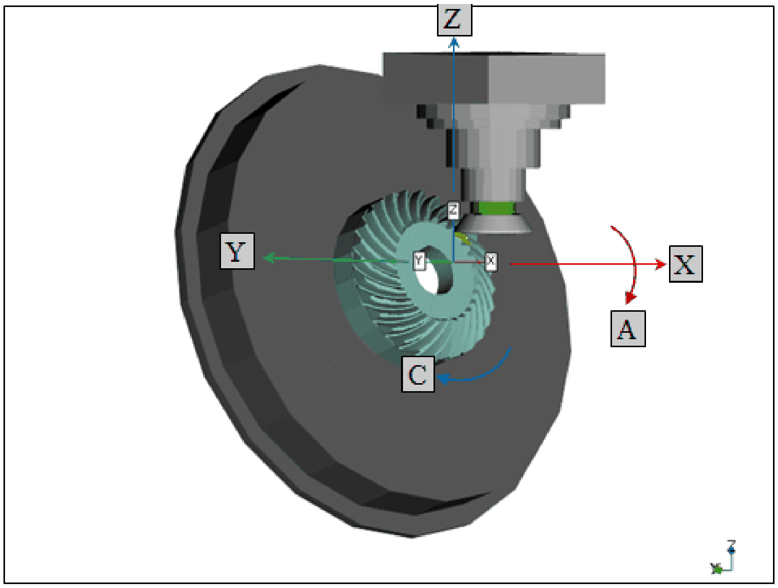
- *4 Axis CnC* machines; they behave like 5Axis "BC" type machines, and can have 1 axis which is not synchronized;

o *5 Axis CnC* machines; they can be of:

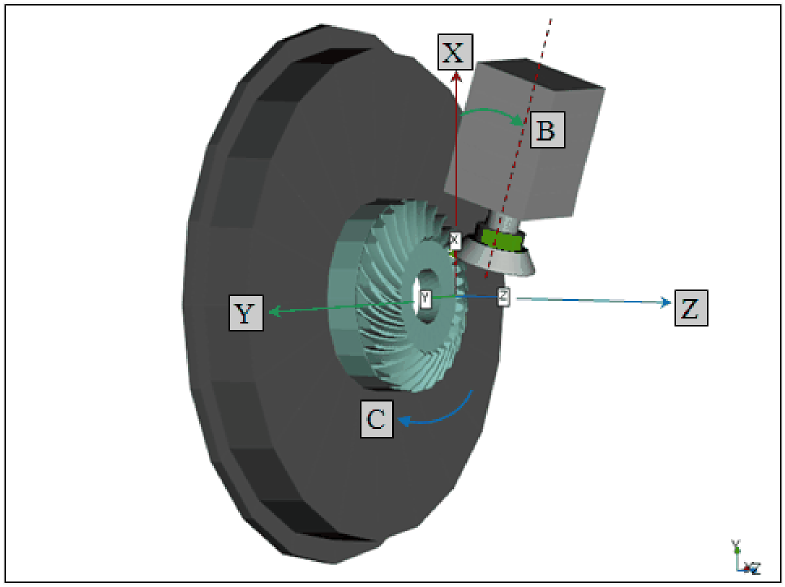
"AB" [type P]: X, Y Z linear coordinates, Turntable tilt B about axis Y and workpiece rotation A:



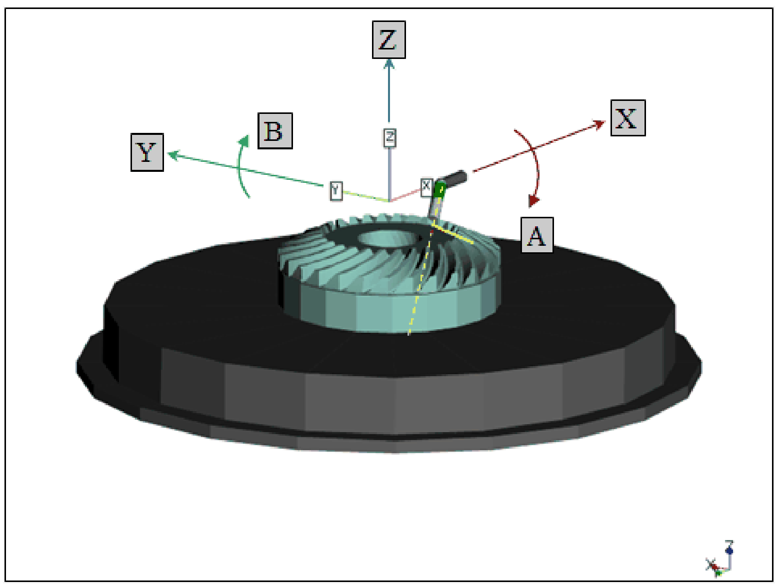
"AC" [type P]: X, Y Z linear coordinates, Turntable tilt A about axis X and workpiece rotation C:



"BC" [type M]: X, Y Z linear coordinates, Tool tilt B about axis Y and workpiece rotation C:



"BA" [type T]: X, Y Z linear coordinates, Tool swivel A about axis X and Tool tilt B about axis Y:



Specific Machine: a list of all the currently defined machines in HyGEARS is presented; the list is filtered by user options. For example, if a user purchased the 5 Axis "B-C" architecture, then only the "B-C" type machines already defined in HyGEARS will be displayed.

New

A user can create a "New" machine by selecting a reference machine from the "Specific Machine" list, and then click on the "New" button.

The CnC 5Axis Machine Definition window will then be displayed. A name for the new machine MUST be provided.

Edit

A user can modify an existing machine by selecting the desired machine from the "Specific Machine" list, and then click on the "Edit" button.

The CnC 5Axis Machine Definition window will then be displayed. Note that the "Mach. Definition" data page is disabled when the machine has been created by Involute Inc. in order to prevent data loss. However, the "Mach. Preamble" and "Controller-Machine Head" can be accessed and the data contained within can be modified.

Please notify Involute Inc. of any change made in those sections such that they can be added to the master "Machine.fil" file distributed with HyGEARS at each installation.

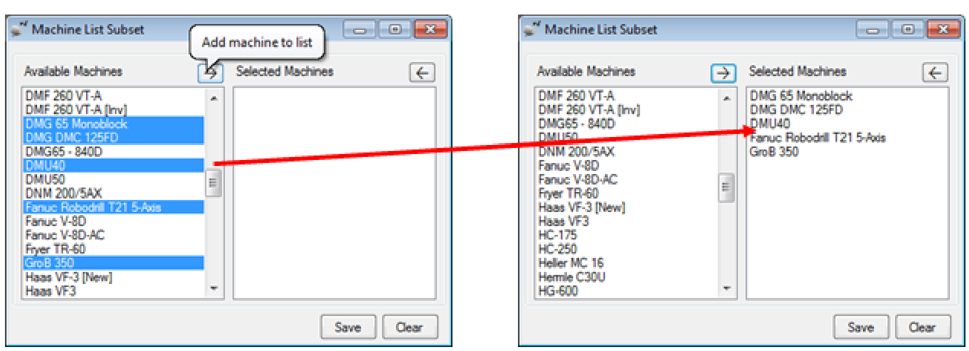
Delete

A user can delete an existing user-defined machine by selecting the desired machine from the "Specific Machine" list, and then click on the "Delete" button. Confirmation for machine deletion is required.

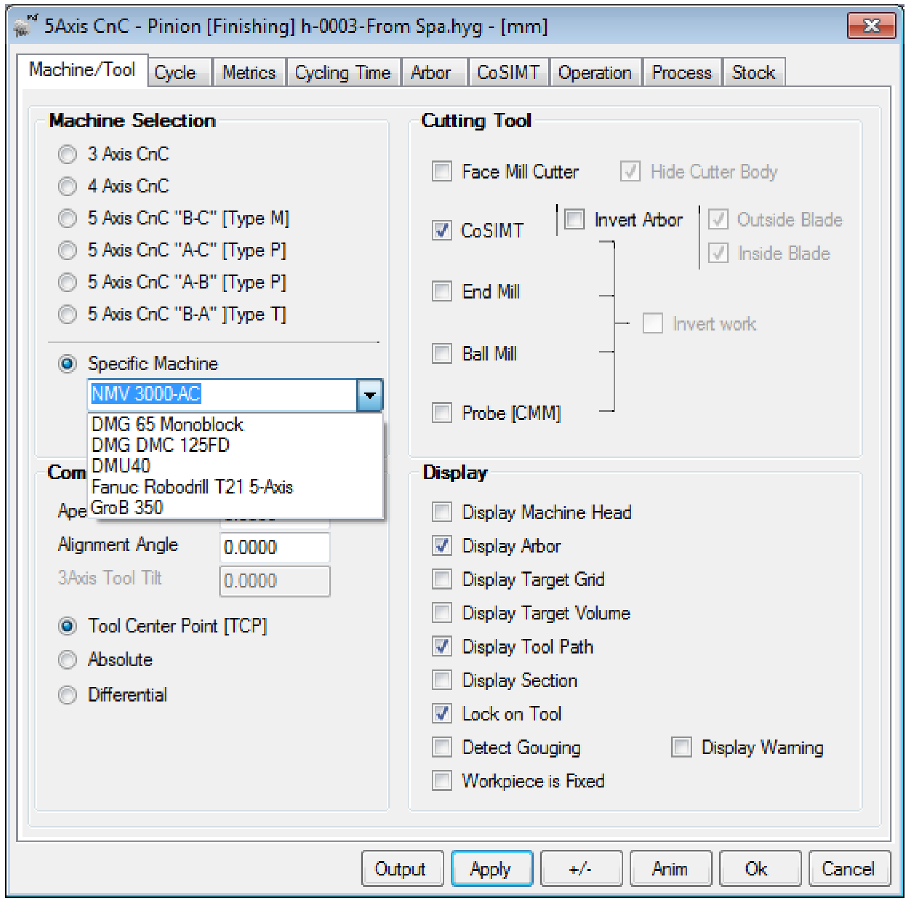
List

The *List* button allows defining a subset of the machines available in HyGEARS, thereby easing machine selection as the number of HyGEARS machines grows.

The desired machines are selected from the *Available Machines* list and transferred to the *Selected Machines* list using the [->] button. The [<-] button is used to remove machines from the *Selected Machines* list. Multi-selection is available. The *Clear* button empties the *Selected Machines* list.

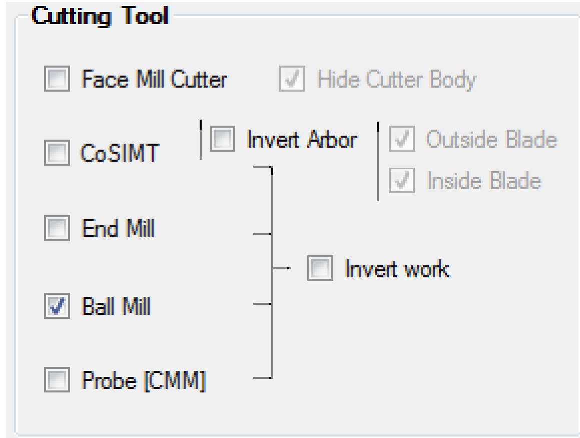


When the *Save* button is clicked, a file called *MachineList.fil* is created that contains only the selected machines. The *Specific Machine* list then shows only the selected machines (figure below). If the *Selected Machines* list is empty, then the full machine list is displayed as usual.



Cutting Tool

- Face Mill Cutter
- CoSIMT
- End Mill
- Ball Mill
- Probe (CMM)

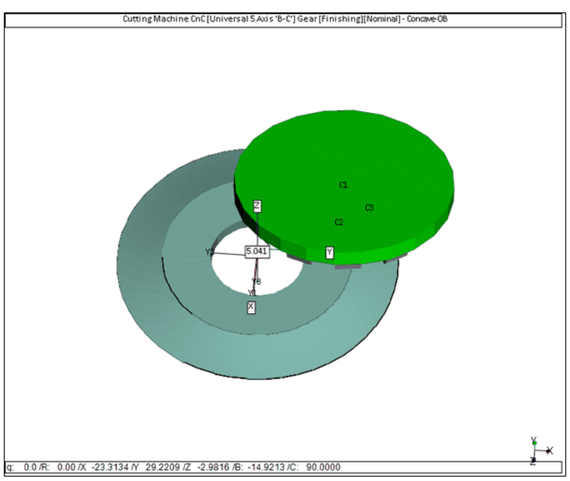


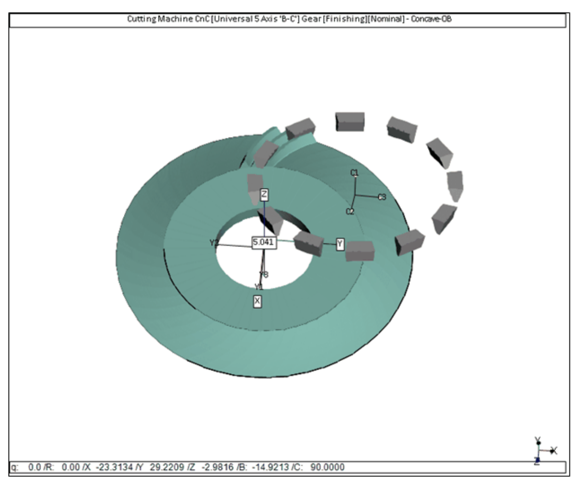
Several tools are available, depending on the geometry type. For example, for Spiral Bevel gears, the Face Mill Cutter, CoSIMT, End Mill, Ball Mill and Probe tools are available; for Coniflex gears, the Dish type cutter, CoSIMT, End Mill, Ball Mill and Probe tools are available; for all other gear geometries, only the CoSIMT, End Mill, Ball Mill and Probe tools are offered.

Face Mill Cutter

The figures below show a Face Mill cutter with a workpiece; several tool manufacturers offer Face Mill cutters; for Roughing purposes, some manufacturers also offer Face Mill cutters with replaceable inserts..

When selecting "*Hide cutter body*", the backing plate supporting the cutter blades is removed, allowing to better follow the blades when the display is animated, as shown in the figures below:





The figure below displays such a typical cutter head. These cutters can be sharpened in CnC cutter grinders.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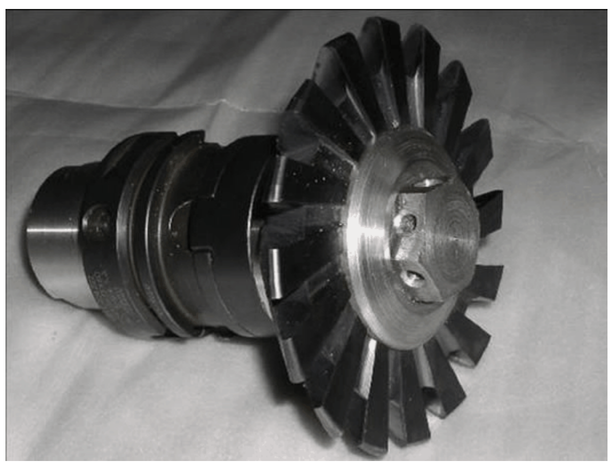
CoSIMT (i.e. Conical Side Milling Tool)

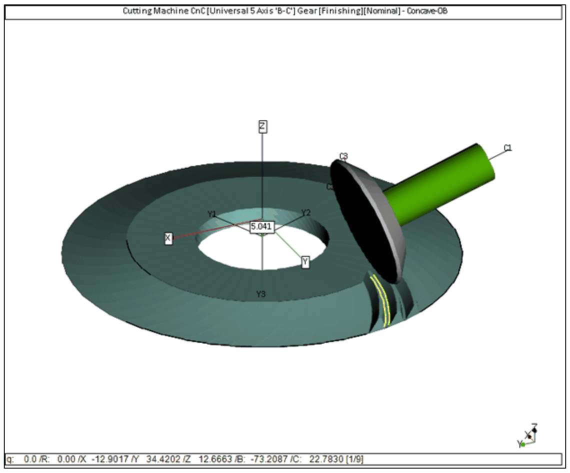
The CoSIMT is a Conical Side Milling Tool (for example, Sandvik, Ingersoll Rand, etc.), as shown below. CoSIMT are user defined, and the definition of each tool remains proprietary to the user.

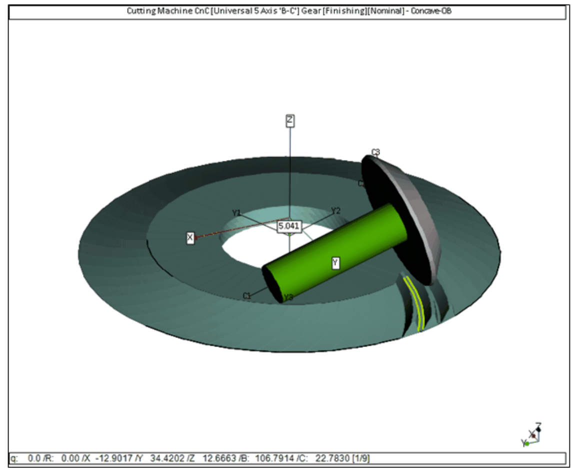


This tool can be made to order in various sizes, or purchased to be used with replaceable inserts such as made by Sandvik. Given the usually small size, such tools easily fit in the tool holder of 5 Axis CnC machines. CoSIMT with integral blades must be sharpened using a CnC cutter grinder.

One can elect to *Invert Work* if the maximum tilt angle of the tool in a "BC" type machine is exceeded, which is easily detected when the CnC program is generated.

Alternately, one can elect to "*Invert Arbor*" where the tool arbor is switched the side opposite the default side, as shown below. The left figure has the arbor on the "conventional" side, whereas the arbor in the right figure is inverted, resulting in a B angle which is the 180º complement to that on the left figure.

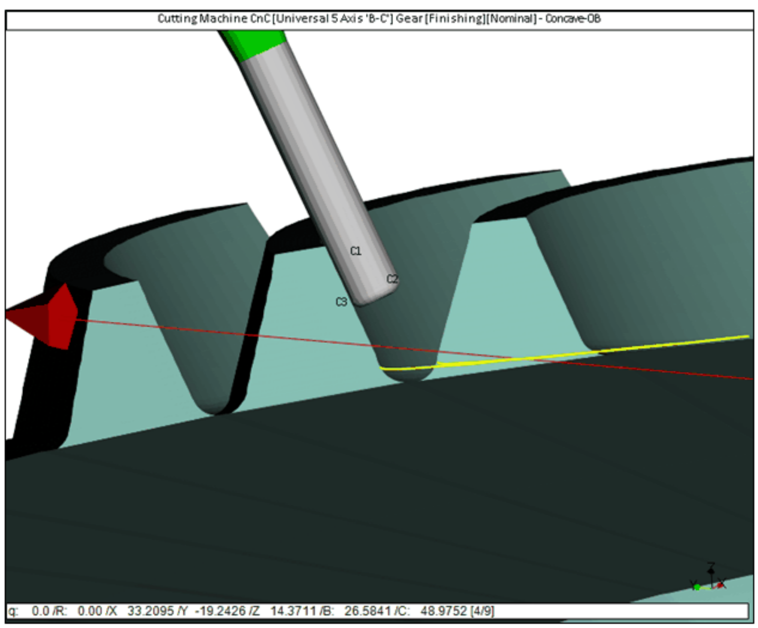




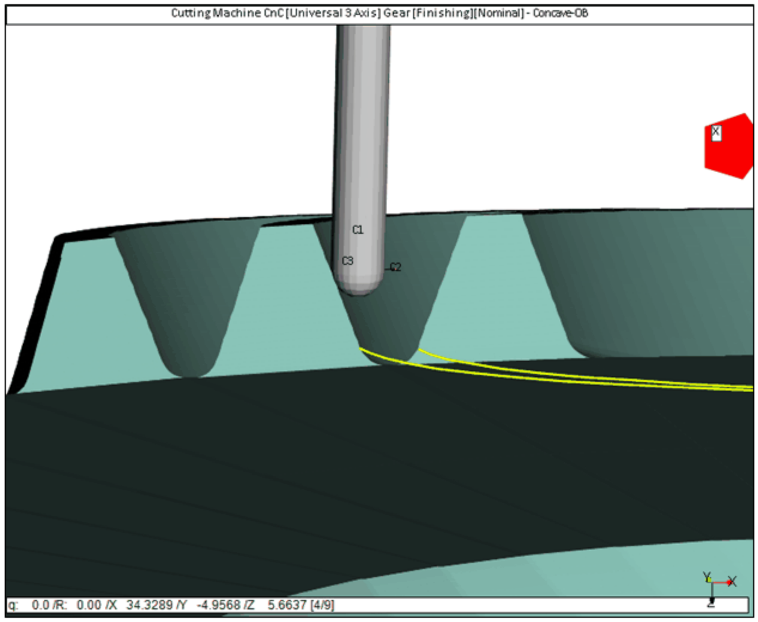
End Mill

The End Mill is a tool widely available in the industry, and is extensively used on CnC machines.

When used in 5 Axis CnC machines, the End Mill cuts the tooth flank with its sides rather than its spherical end thereby distributing wear over the length of the tool.

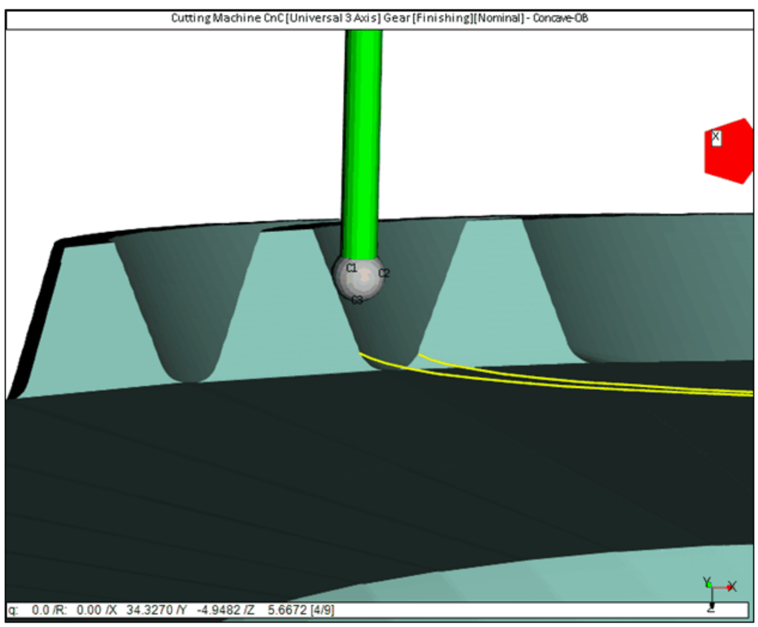


In 3 Axis machines, the End Mill will rather cut with its spherical end since the machine cannot tilt the tool or turntable.



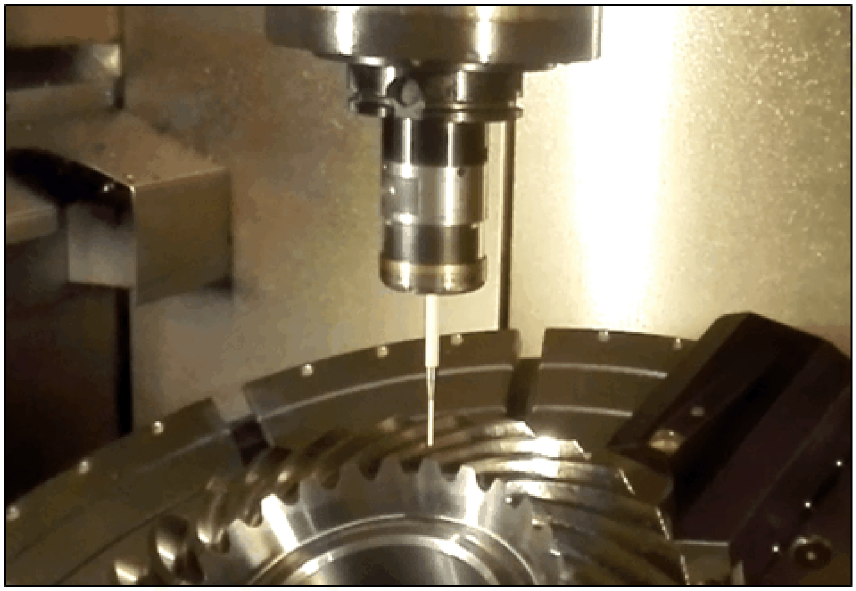
Ball Mill

The Ball Mill is also a tool widely available in the industry, and is extensively used on CnC machines. It always cuts on its spherical lower half.

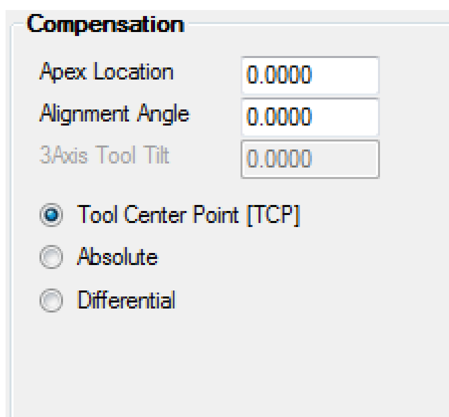


Probe (CMM)

The Probe (CMM) is a measuring head, such as those manufactured Renishaw, which can be installed in the CnC machine to measure the tooth flanks. HyGEARS offers a specialized cycle to measure the tooth flanks and return the results in a text file that is then converted by HyGEARS into a standard format.



Compensation



Compensation is the act of adjusting the coordinates of the tool to account for the fact that either the turntable supporting the workpiece tilts, or else the tool is tilted about an arm on the machine which is offset.

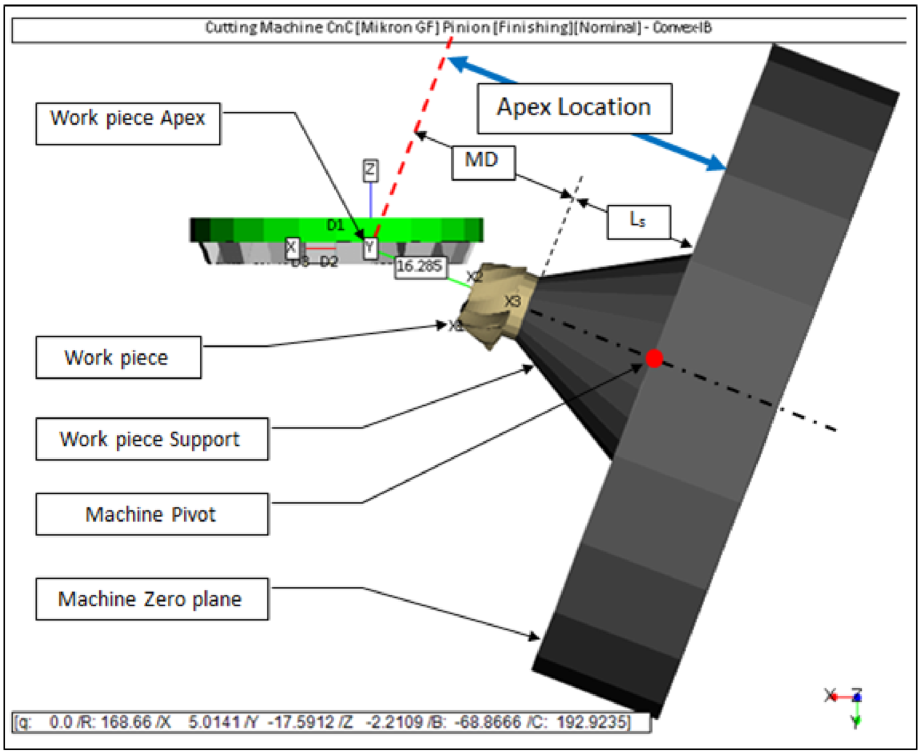
In most cases, compensation is not required since it is preferable to operate the CnC machine in *Work Coordinates*, where the controller does all the compensation.

Apex Location

Apex Location gives the distance between the apex of the bevel gear and the center of the machine;

- *Hypoid gears*: the apex is considered at the Crossing Point;
- *other bevel gears*: the apex is at the Pitch Cone apex.

For example, figure below, *Apex Location* would be equal to $MD + L_s$ i.e. Mounting Distance + Work piece Support length.



Alignment Angle

The Alignment Angle imposes a delta rotation to the workpiece, which can be useful to align the part after Heat Treatment when it is re-installed on the machine for hard finishing.

3Axis Tool Tilt

3Axis Tool Tilt is used on some 3Axis CnC machines where the tool can be angled to a fixed value.

Tool Center Point [TCP] / Absolute / Differential

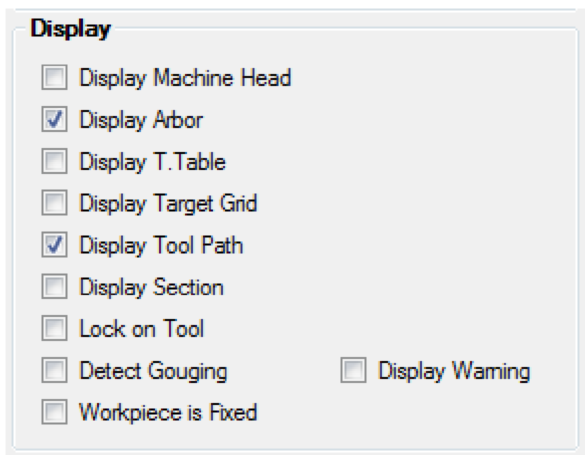
Compensation can be done in one out of 3 ways:

Tool Center Point [TCP]: nothing is done, i.e. the calculated coordinates are outputted *without compensation*;

Absolute: the coordinates are given in *reference to the machine center*;

Differential: for BC type machines; the coordinates are given at the location where the tool is inserted in the pivoting head.

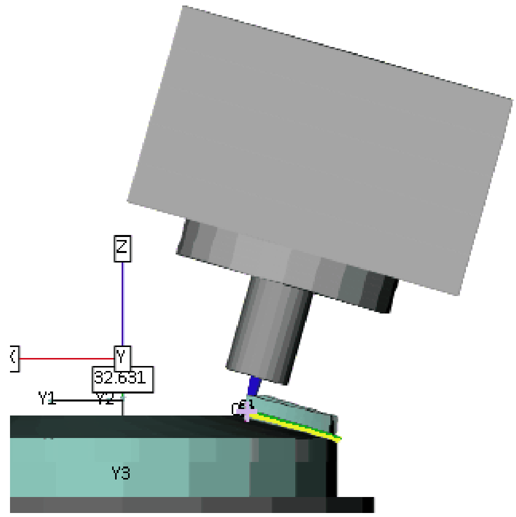
Display



Several Display options are available to enhance the rendering of results, or to ease perception and verifications.

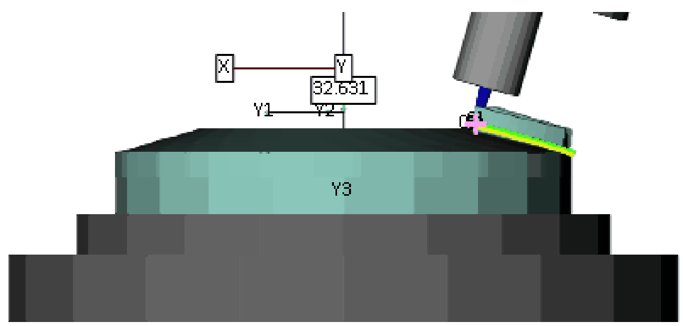
Display Machine Head

This displays the machine head as described in the "Controller-Machine Head" data page of the Machine Definition window ("Edit" function button for Specific Machine). This can be useful to check for potential collision, but will also hide or even dwarf the tool if it is small. Thus turn it On only when needed.



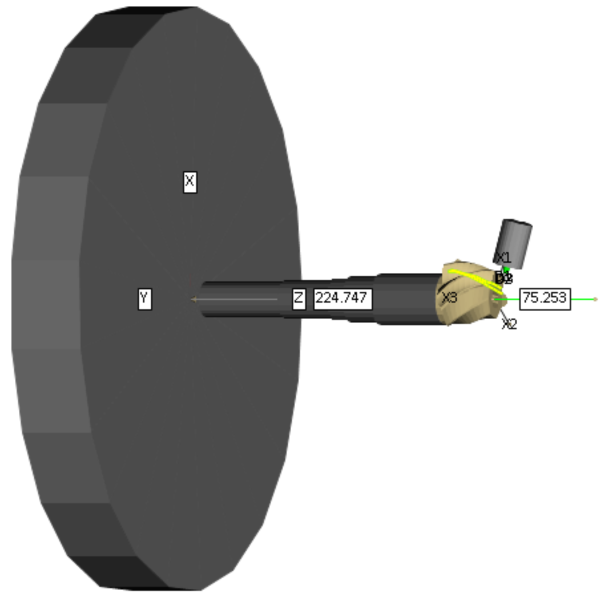
Display Arbor

This displays the machine's turntable and supporting arbor as described in the "Arbor" data page of the 5Axis window. This can be useful to check for potential collision, but may clutter somewhat the display. Thus turn it On only when needed.



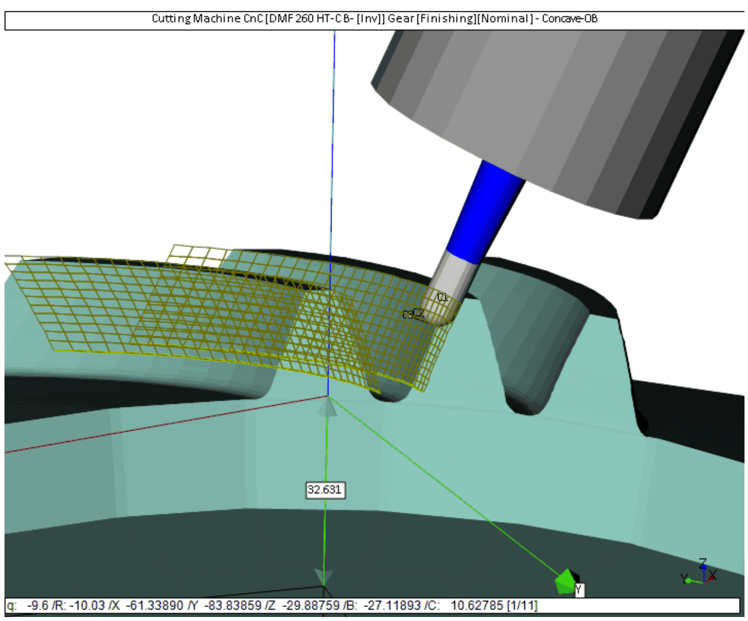
Display T.Table

Switches On/Off the display of the Turn Table (defined with the machine), such as to give a reference on the machine.



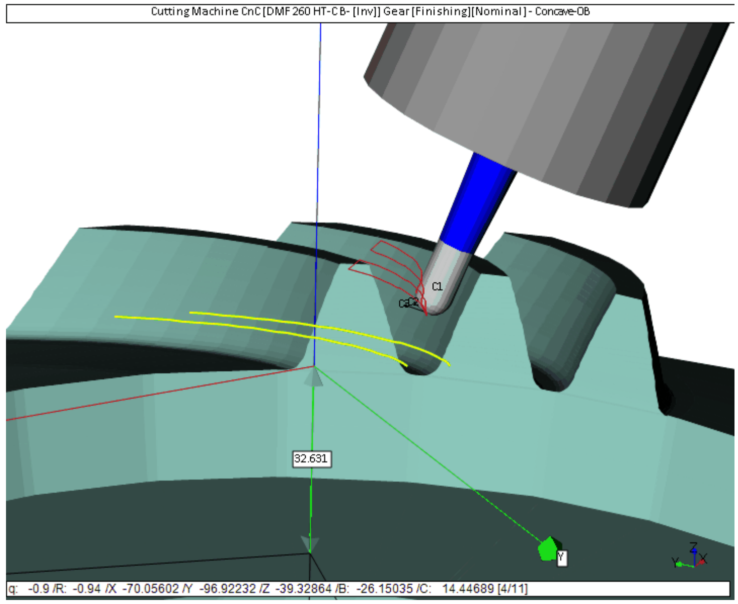
Display Target Grid

This displays in grid form the target points of the currently selected cycle. Useful to visualize how densely the cutting points are packed along the tooth flanks.



Display Tool Path

Displays a red line indicating the passage of the Tool Center Point (TCP).



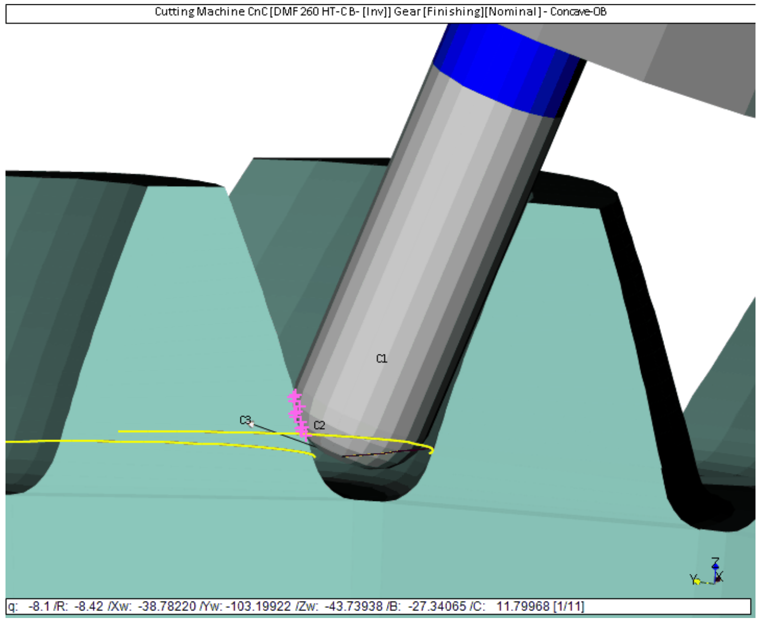
Lock on Tool

When checked, if the display is zoomed at any level (^Z, ^I keyboard combinations), the display will be centered on the current tool to work contact point. Very useful to maintain the display centered about what is going on when the tool moves in the gap.

Detect Gouging

Applies to CoSIMT, End Mill or Ball Mill tools. Instructs HyGEARS to check if the tool is contacting with the opposite tooth flank because of excessive diameter or point width; Gouging is shown as pink crosses where the tool contacts the opposite tooth flank.

Detect Gouging accounts for the imposed Stock ("Cycle" data page, "5Axis" window). When the *Display Warning* is checked, HyGEARS will display a message when Gouging occurs and will stop the animation at that point.



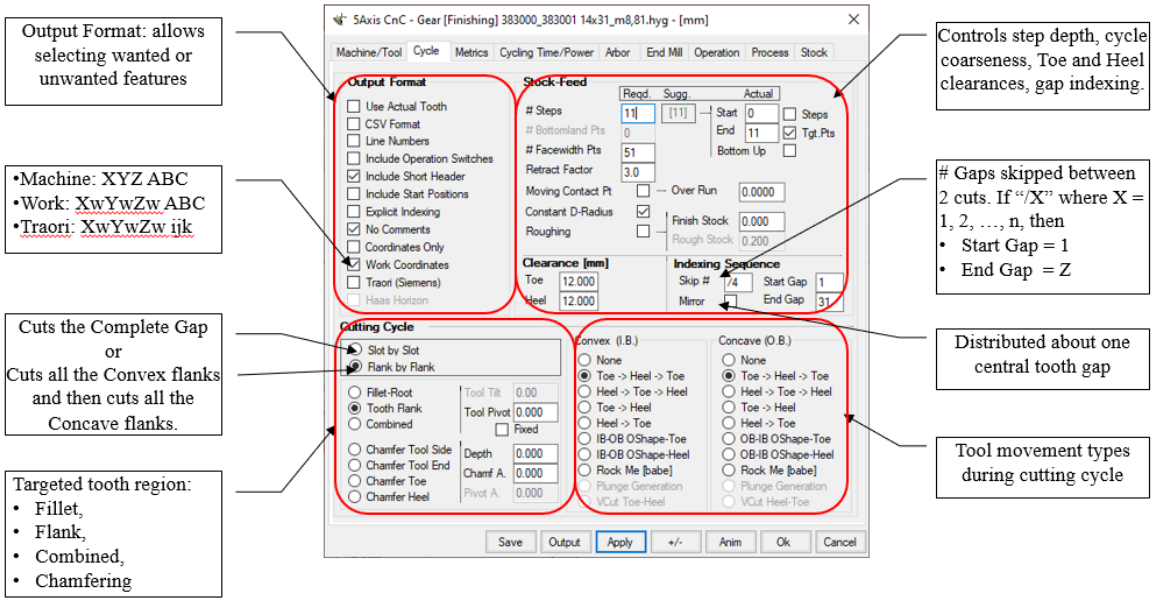
Workpiece is Fixed

Applies to CoSIMT, End Mill or Ball Mill tools. Instructs HyGEARS to prevent the workpiece from rotating, and rather tilts and swivels the tool to maintain the same tool to work angles and positions. Very useful to follow a tool in a gap and visualize if any interference can occur.

11.3 Cutting Cycle

In HyGEARS, cutting cycles can be extensively tailored to user preferences, depending on tool selection. The "Cycle" data page allows complete control of the cutting cycle; it is divided in different sections, each of which is detailed below.

- Cutting Cycles
- Stock-Feed
- Clearance
- Indexing Sequence
- Output Format



Cutting Cycles

- [CoSIMT, End Mill, Ball Mill tools]
- [Face Mill cutters]
- [Coniflex cutters]
- [Probe (CMM)]

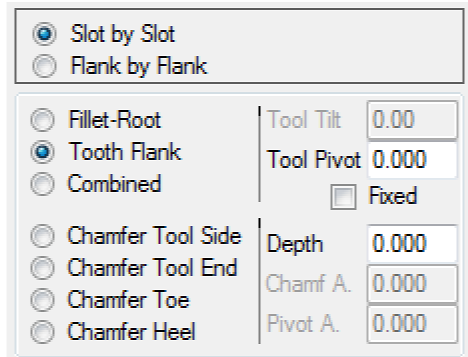
➢ ***CoSIMT, End Mill, Ball Mill* tools**

Cutting Areas of the Tooth

For the CoSIMT, End Mill and Ball Mill tools, the cut may be done:

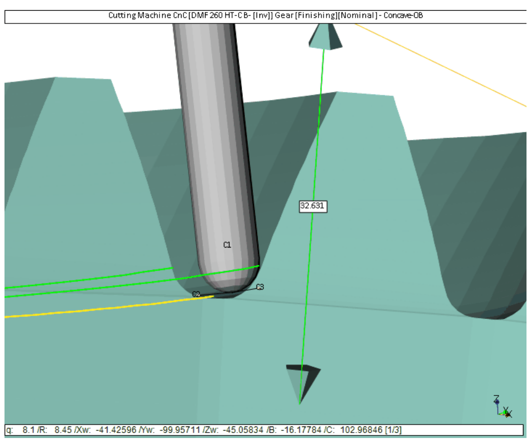
Slot by Slot — i.e. the complete gap, IB and OB, is cut before indexing to the next gap;

Flank by Flank — i.e. all the IB flanks are cut first, then all the OB flanks are cut; this implies indexing for each sequence.

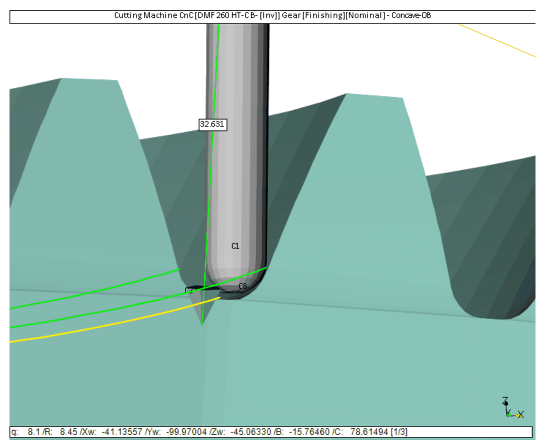


HyGEARS offers several *tooth areas* for Finishing and Roughing, as follows:

Fillet-Root i.e. the bottom part of the tooth, below the tooth flank; *Tool Tilt* becomes active, which allows pivoting the tool away from the current tooth flank to avoid any potential interference;



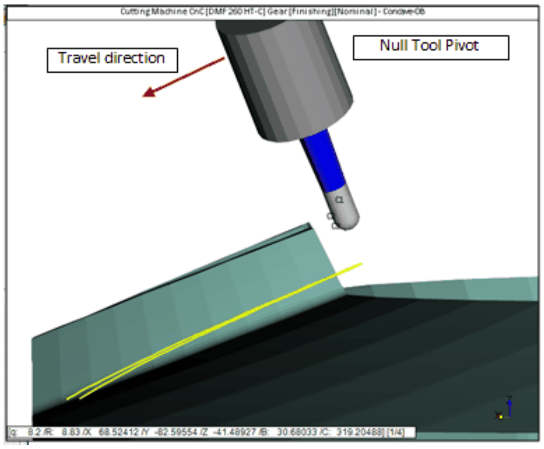
10 deg. Tool Tilt

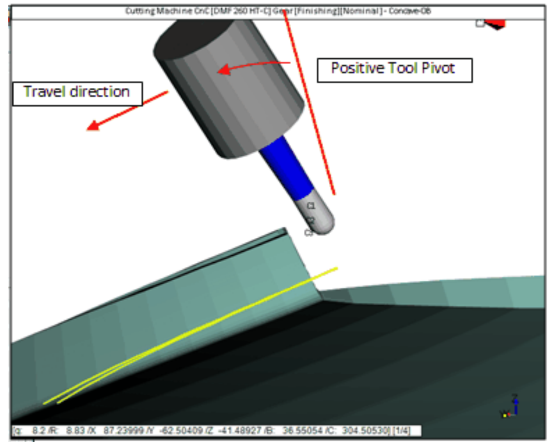


0 deg. Tool Tilt

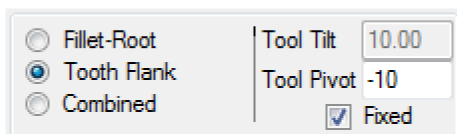
Tooth Flank i.e. the load carrying part of the tooth; for End Mill tools, *Tool Pivot* becomes active, which allows pivoting the tool about the tooth flank normal vector, thus allowing an End Mill to cut with a better angle at the bottom of the tool.

Pivot direction inverts with travel direction

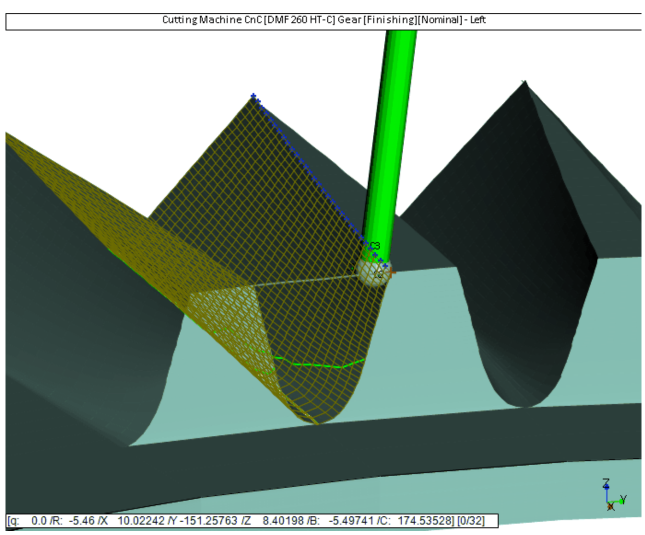




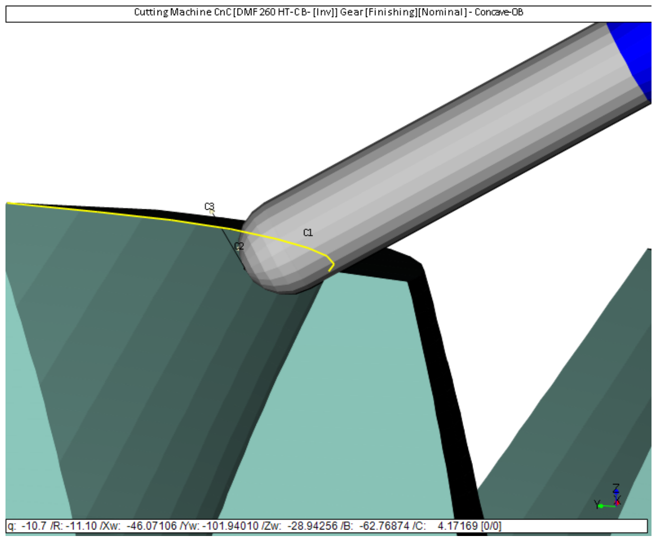
If the *Fixed* option is checked then *Tool Pivot* remains in the same direction when tool travel direction reverses.



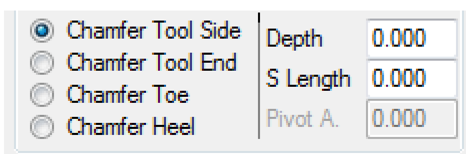
Combined combination of Flank and Fillet; best used for uniform depth teeth such as Face Gears; Target grid then covers the entire depth of the tooth, rather than only the Fillet or Flank; the same tool is expected to cut the Flank and Fillet and therefore the tool's edge radius should account for the fillet radius;

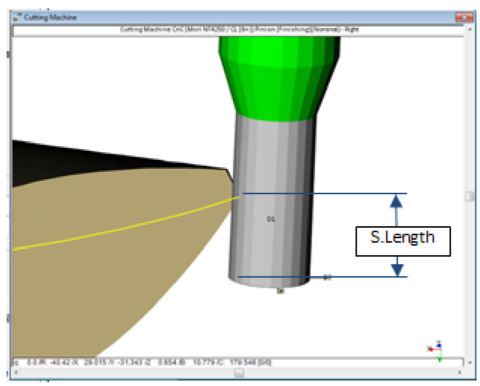


Chamfer Tool Side: use the cutting side of an End Mill to chamfer tooth tip;

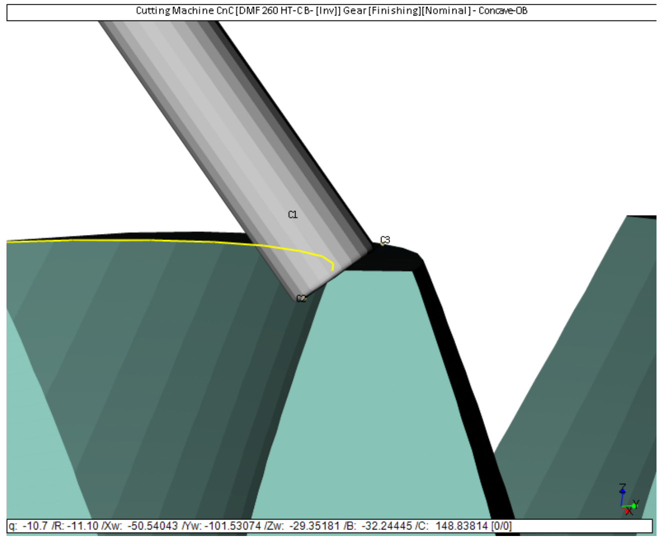


The chamfering *Depth* and *S.Length* can be specified. *S. Length* is the distance along the tool cutting edge where chamfering is concentrated.

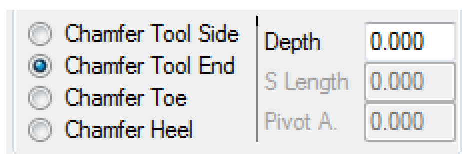




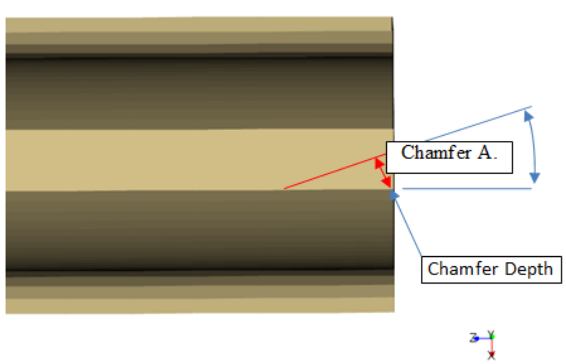
Chamfer Tool End: use the cutting tip of an End Mill to chamfer tooth tip; a flat ended End Mill is preferable to ensure a straight chamfer.

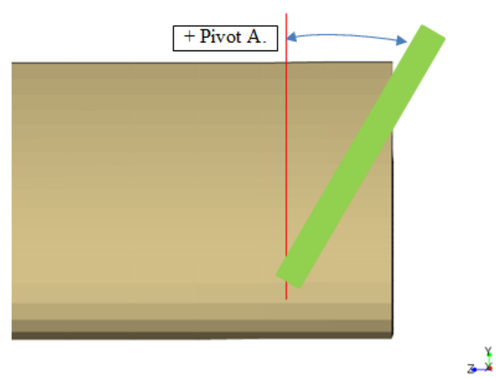


The chamfering *Depth* can be specified.



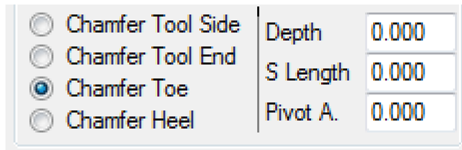
Chamfer Toe: chamfer the Toe end of the tooth along the profile and fillet; the fields "*Champf A.*" and "*Pivot A.*" then become active; *Champf A.* is the angle made between the tooth flank and the chamfer itself; *Pivot A.* is the angle the tool is pivoted *Outside of* or *Into* the tooth to prevent interference with the tooth flank itself.





Top View **Side View**

The chamfering *Depth, S.Length* and Pivot Angle can be specified. *S. Length* is the distance along the tool cutting edge where chamfering is concentrated.

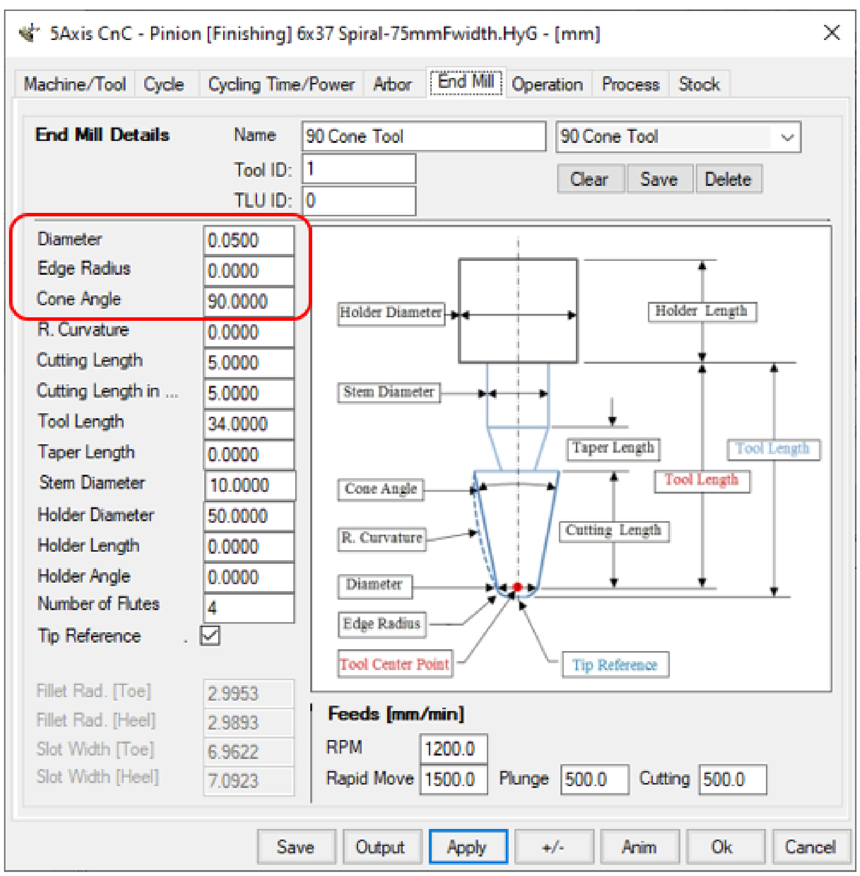


Chamfer Heel chamfer the Heel end of the tooth along the profile and fillet; behavior is identical to *Chamfer Toe.*

Chamfering with a Cone Tool (special End Mill):

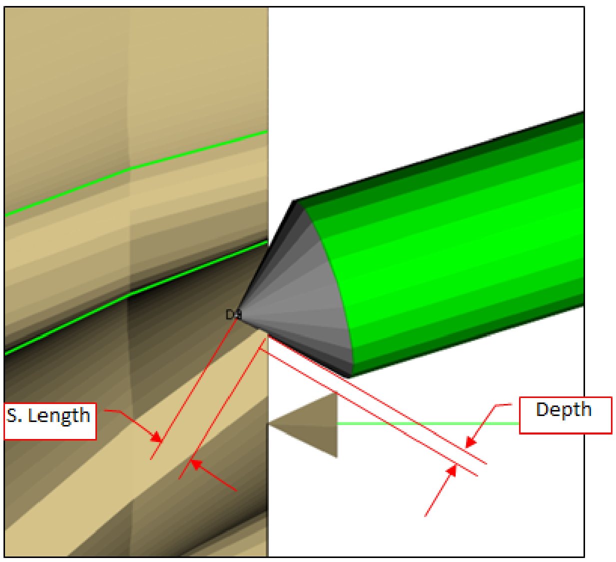
HyGEARS will recognize an End Mill defined as a Cone Tool for chamfering when:

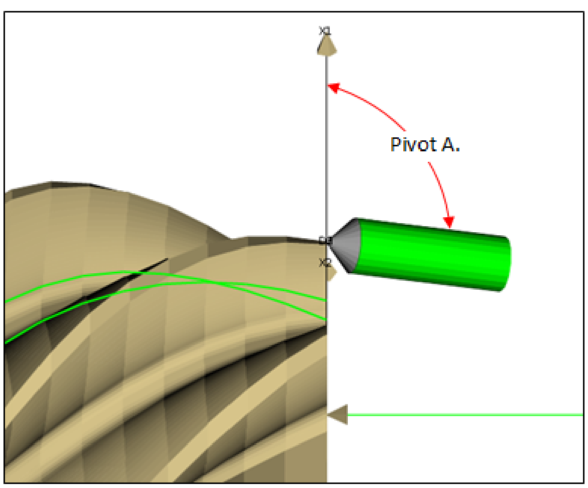
- the Cone Angle is 45 ° and above, and
- the Edge Radius is zero.

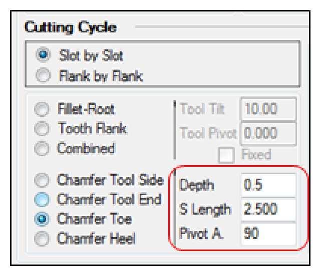


When a Cone Tool is detected, the chamfering options become *Depth*, *S.Length* and *Pivot A*.

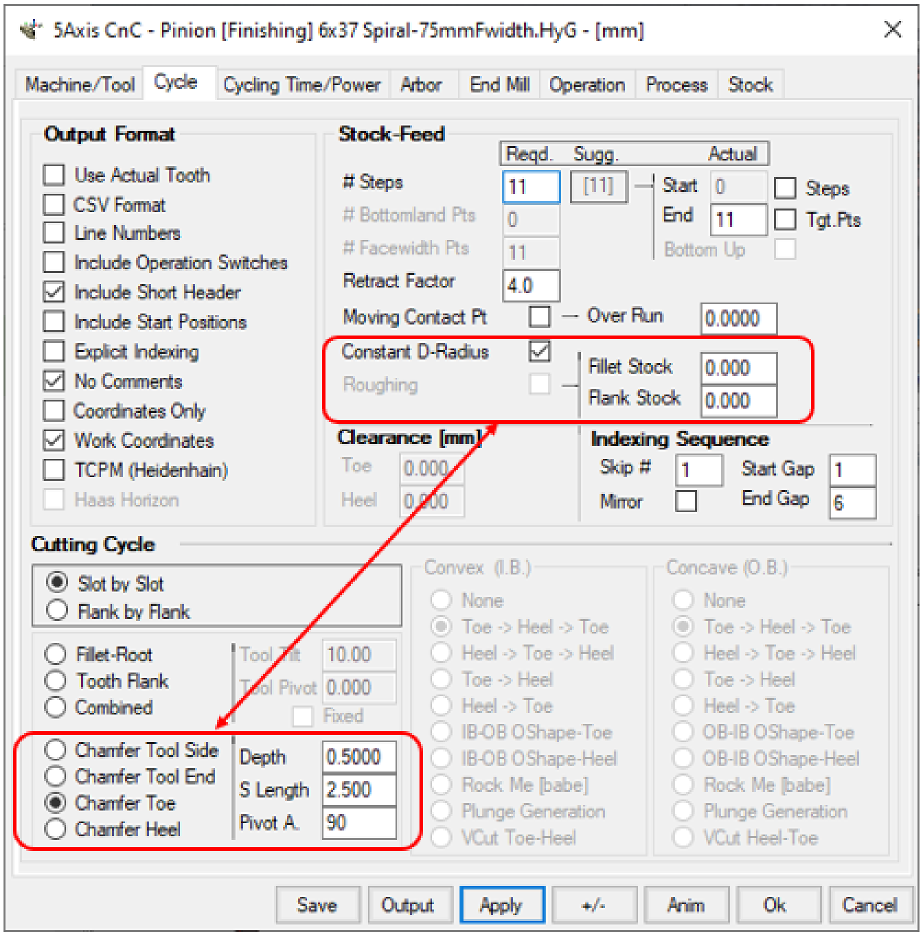
✍*Depth*: depth to which the chamfer is to be cut;
✍*S.Length*: distance along the edge of the Cone Tool; should always be larger than zero;
✍*Pivot A.*: angle to pivot the Cone Tool out of the gap (+ value) or into the gap (- value);





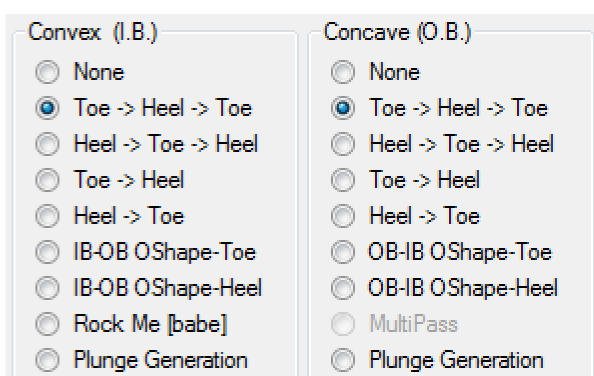


Note: when chamfering is selected, the Stock entry fields for tooth flank and fillet are available. It is therefore possible to account for the same Stock as that used to cut the tooth flank and fillet.



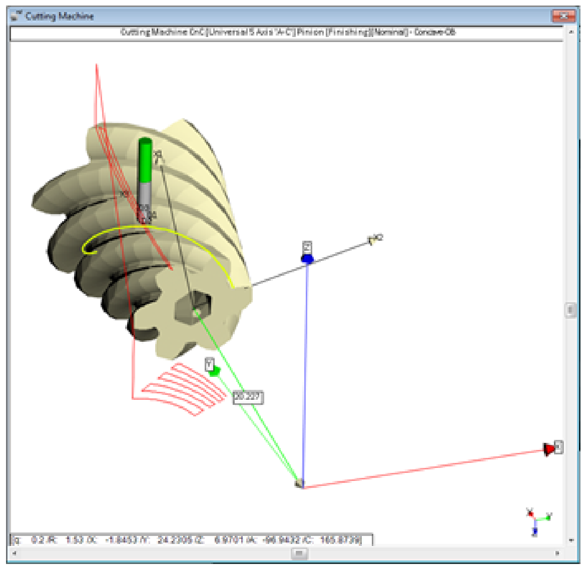
Cutting Cycles

For the CoSIMT, End Mill and Ball Mill tools, different cutting cycles may be selected for the IB and OB flanks, such as to allow cycle time optimization. For example, if cutting the IB starts at Toe and finishes at Heel, it makes sense to start cutting the OB at Heel and finish at Toe, such as to avoid the return trip from one tooth end to the other when switching tooth flanks.



None: the selected tooth flank will NOT be included in the part program; thus only one flank will be cut.

Toe->Heel->Toe: the cycle starts with the tool at tooth Toe on the selected tooth flank and at the selected Step, moves toward Heel, indexes one Step deeper, and returns to Toe, until all Steps have been cut (Steps are defined below, in the Stock-Feed section).

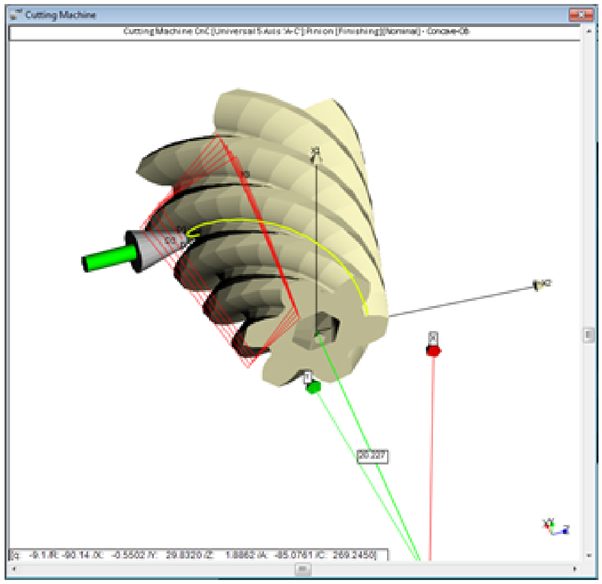


Heel->Toe->Heel: the cycle starts with the tool at tooth Heel on the selected tooth flank and at the selected Step, moves toward Toe, indexes one Step deeper, and returns to Heel, until all Steps have been cut (Steps are defined below, in the Stock-Feed section).

Toe->Heel: the cycle starts with the tool at tooth Toe on the selected tooth flank and at the selected Step, moves toward Heel, retracts above the tooth, returns to Toe to start cutting again, until all Steps have been cut (Steps are defined below, in the Stock-Feed section).

Heel->Toe: the cycle starts with the tool at tooth Heel on the selected tooth flank and at the selected Step, moves toward Toe, retracts above the tooth, returns to Heel to start cutting again, until all Steps have been cut (Steps are defined below, in the Stock-Feed section).

IB-OB OShape-Toe: the cycle starts with the tool at tooth Toe on the IB flank and at the selected Step, moves toward Heel, switches to the OB at Heel and cuts on the OB while returning to Toe where the tool indexes one Step deeper and resumes the same cycle, i.e. cuts on IB from Toe to Heel, switches to OB, cuts on OB from Heel to Toe, and so on until all Steps have been cut (Steps are defined below, in the Stock-Feed section).



IB-OB OShape-Heel:same as *IB-OB OShape-Toe*, but rather starting at Heel on the IB.

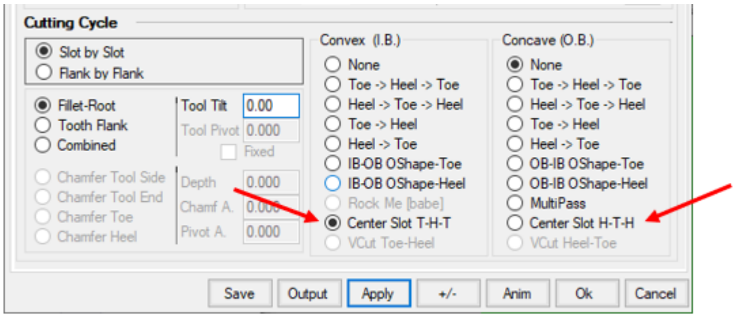
OB-IB OShape-Toe: same as *IB-OB OShape-Toe*, but rather starting at Toe on the OB.

OB-IB OShape-Heel:same as *IB-OB OShape-Heel*, but rather starting at Heel on the OB.

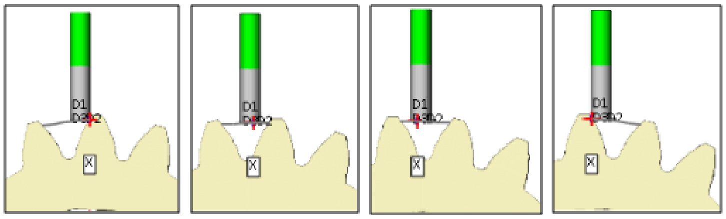
Rock Me [babe]: the cycle starts at IB Toe-Tip and cuts depth wise to the Fillet; if the OB cycle is not "None", then, the tool switches to the OB and cuts from Fillet to Tip, advances along the OB tooth flank, cuts depth wise along the OB side until the Fillet, switches to the IB and cuts untill Tip, advances along the IB face width, and starts over until Heel is reached; this process is well suited to CoSIMT and finishing in a single operation. If the opposite flank cycle is set to "None", then

Center Slot: for Roughing only; the tool simply cuts down the center of the tooth gap; may be effective with large tools, but can cause tool vibrations that result in a bad surface finish and poor tool life. Center Slot is offered n 2 flavors: T-H-T (i.e.

Toe-Heel-Toe, where movement starts at Toe) and H-T-H (i.e. Heel-Toe-Heel, where movement starts at Heel).

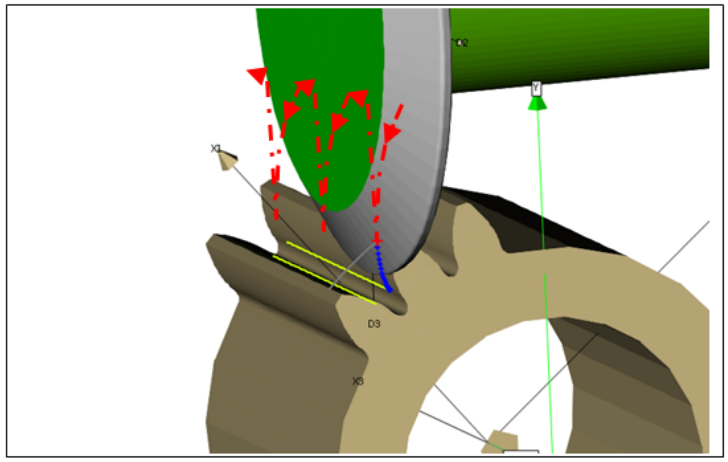


MultiPass: for Roughing only; the cycle starts at IB Toe-Tip, cuts along the IB tooth flank until Heel, then the tool moves toward the OB by one tool diameter (if End Mill or Ball Mill) or one Point Width (if CoSIMT) on the same Step and then returns to Toe; this process is repeated an even number of times until the OB flank is reached, and then the process is repeated one Step deeper. This is very effective for small tools and CoSIMT since the metal chips formed by the cutting tool always have an exit; feed rates can usually be increased. A maximum of 6 passes is allowed.

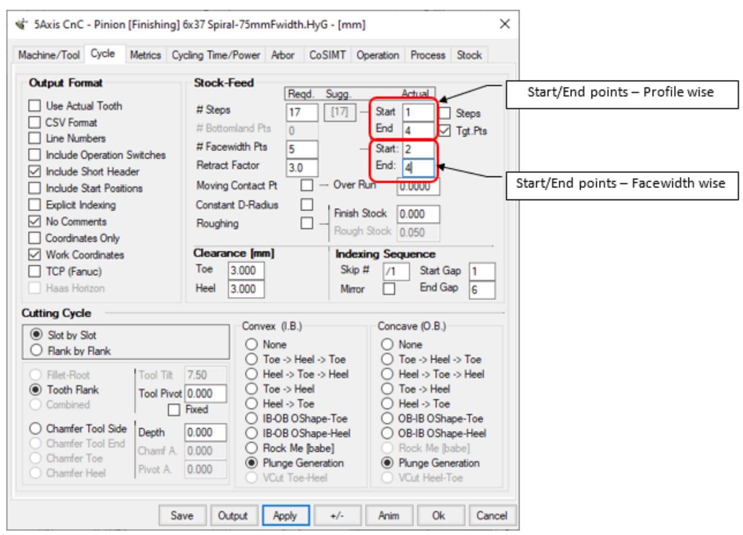


Pass #1 Pass #2 Pass #3 Pass #4

Plunge Generation: for CoSIMT only; *Plunge Generation* plunges a CoSIMT tool along the profile from the OD to the root of the workpiece (see red dotted line, figure below). When at the bottom of the flank, the CoSIMT is retracted, advanced along the face width, and the *Plunge Generation* movement runs again, until all the targeted face width positions have been cut. It applies only to the tooth flank. The minimum # *Facewidth Pts* is 3.

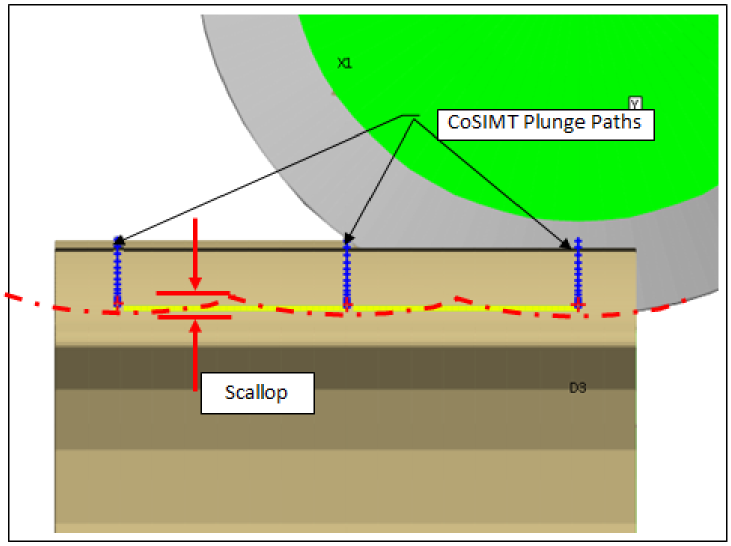


When the *Plunge Generation* cycle is selected, Start / End points along the Face width can be selected to limit the cycle to a specific part of the tooth; for example, figure below, although the # Facewidth Pts is 5, the Start and End have been limited to 2 and 4, which means that the CoSIMT will plunge in only 3 places along the Facewidth, as shown above.



The *Plunge Generation* cycle can be advantageous to rapidly cut spur and helical gears since the flat face of the CoSIMT can cover a large part of the tooth in one plunge. However, at the bottom of the tooth, a scallop will be left in the overlapping regions (figure below) and the *# Facewidth*

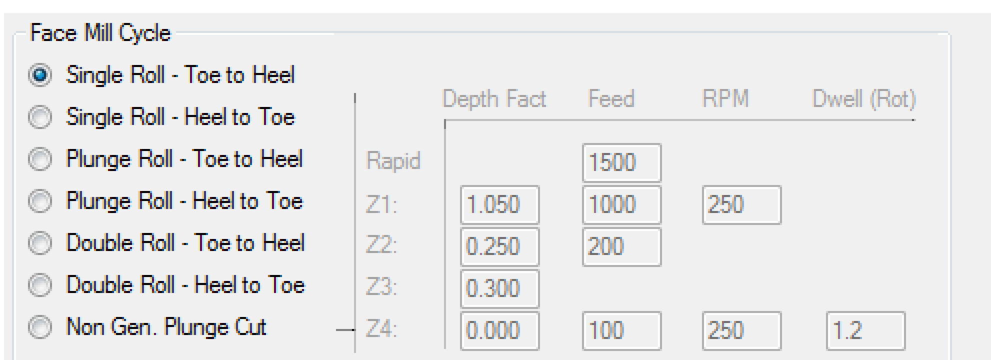
Pts may need to be increased, followed by a fillet Operation to ensure an even fillet shape.



➤ ***Face Mill Cutters***

For Face Mill cutters, the offered cutting cycles depend on the cutting process, i.e. either Completing or Fixed Setting.

Completing i.e. Duplex Helical, Spread Blade, Formate (non generated)



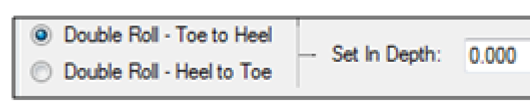
Single Roll - Toe to Heel: the cut starts at Toe and is done in one pass; the tool retracts, returns to Toe and the workpiece is indexed.

Single Roll - Heel to Toe: the cut starts at Heel and is done in one pass; the tool retracts, returns to Heel and the workpiece is indexed.

Plunge Roll - Toe to Heel: the cut starts at Toe at tooth tip; the cutter progressively digs into the tooth gap till Heel is reached at full depth; the tool then returns to Toe while cutting full depth, where it is retracted and the workpiece is indexed for the next gap;

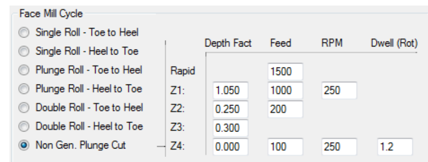
Plunge Roll - Heel to Toe: the cut starts at Heel at tooth tip; the cutter progressively digs into the tooth gap till Toe is reached at full depth; the tool then returns to Heel while cutting full depth, where it is retracted and the workpiece is indexed for the next gap.

Double Roll - Toe to Heel: the cut starts at Toe, at Set In Depth; the cutter generates till Heel is reached; the tool then plunges full depth and returns to Toe while cutting full depth, where it is retracted and the workpiece is indexed for the next gap;



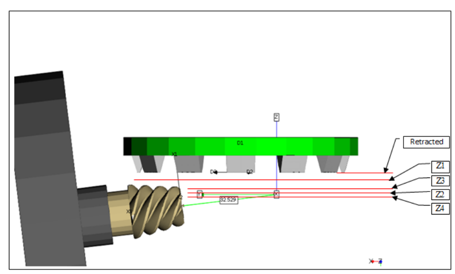
Double Roll - Heel to Toe: the cut starts at Heel, at Set In Depth; the cutter generates till Toe is reached; the tool then plunges full depth and returns to Heel while cutting full depth, where it is retracted and the workpiece is indexed for the next gap.

Non Gen. Plunge Cut: this cycle is intended for either non generated (Formate) gears or to "rough cut" generated gears. It is divided in up to 5 segments as detailed below:



- In the following, all depths Z1, Z2, etc. are given as *Depth Factors* calculated at **mid-face width**, i.e. tooth depth at mid-face width is multiplied by the *Depth Fact* value to obtain the actual tooth depth;
- The tool is initially in its retracted position; the *Rapid Move* feed is 1500 mm/min; in the current example, the *Retract Factor* is 3.0, and is calculated at *mid-face width*;
- The tool plunges to depth Z1 (i.e. 1.050 times tooth depth at mid-face width) at *Z1 feed* (1000 mm/min above); Z1 **should** be outside the tooth in order to allow a fast plunge, and therefore should always be somewhat larger than 1.0;
- The tool then cuts from depth Z1 (1.050 above) to depth Z2 (0.250 above) at the *Z2 feed* (200 mm/min above) and with the *Z1 RPM* (250 RPM above);

- The tool then retracts from depth Z2 (0.250 above) to depth Z3 (0.300 above) where RPM is changed from 250 to 150 RPM;
- The tool then cuts from depth Z3 (0.300 above) to depth Z4 (0.000 above, i.e. tooth root) at the *Z4 Feed* (100 mm/min above) with the tool rotating at *Z4 RPM* (150 RPM above); when at depth Z4, the tool dwells for *Z4 Dwell (Rot)* (i.e. 1.2 *cutter rotations* above);
- The tool then retracts at *Rapid Feed* (1500 mm/min above) to its retracted position given by the *Retract Factor* (3.0 above), the part is indexed and the cycle starts over again.



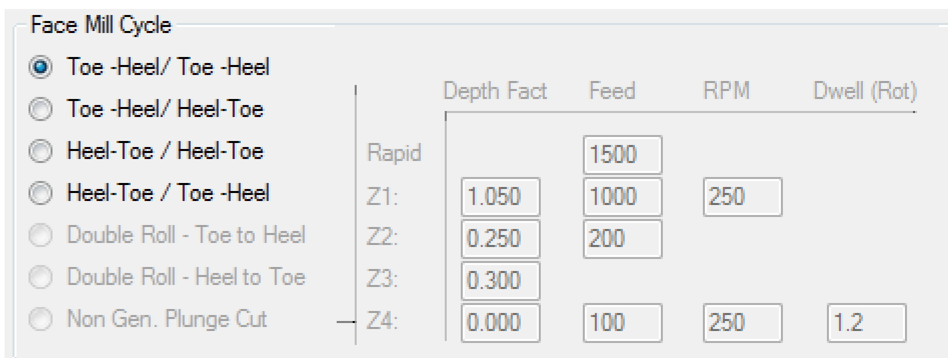
Notes:

- in the above example, Z3 (0.300) is *above* Z2 (0.250) as it is desired to retract the tool in order to change its RPM when it is not contacting the workpiece;
- any of the Z1, Z2 and Z3 *Depth Fact* values can be zero or negative; if so, then the cycle

ignores the zero or negative values and aims only for *Depth Fact* Z4, which may be larger, equal, or less than zero;

- if the Z3 *Depth Fact* value is zero or negative, no cutter *Z4 RPM* change occurs;
- Dwell time is based on the current tool RPM and the number of desired cutter rotations *Dwell (Rot)*.

Fixed Setting i.e. Fixed Setting, Modified Roll, Semi-Completing



Toe-Heel / Toe-Heel: the cut starts at Toe on the IB which is cut in one pass; when at Heel, the the tool retracts, returns to Toe and the OB is then cut.

Toe-Heel / Heel-Toe: the cut starts at Toe on the IB which is cut in one pass; when at Heel, the tool returns to Toe while cutting the OB.

Heel-Toe / Heel-Toe: the cut starts at Heel on the IB which is cut in one pass; when at Toe, the the tool retracts, returns to Heel and the OB is then cut.

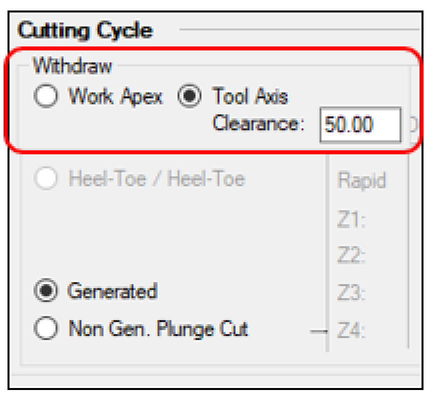
Heel-Toe / Toe-Heel: the cut starts at Heel on the IB which is cut in one pass; when at Toe, the tool returns to Heel while cutting the OB.

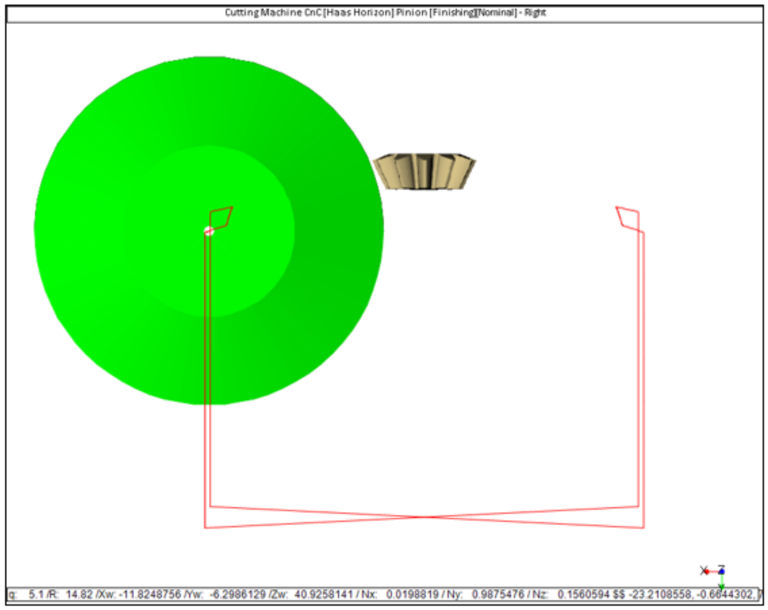
➢ ***Coniflex Dish-type Cutters***

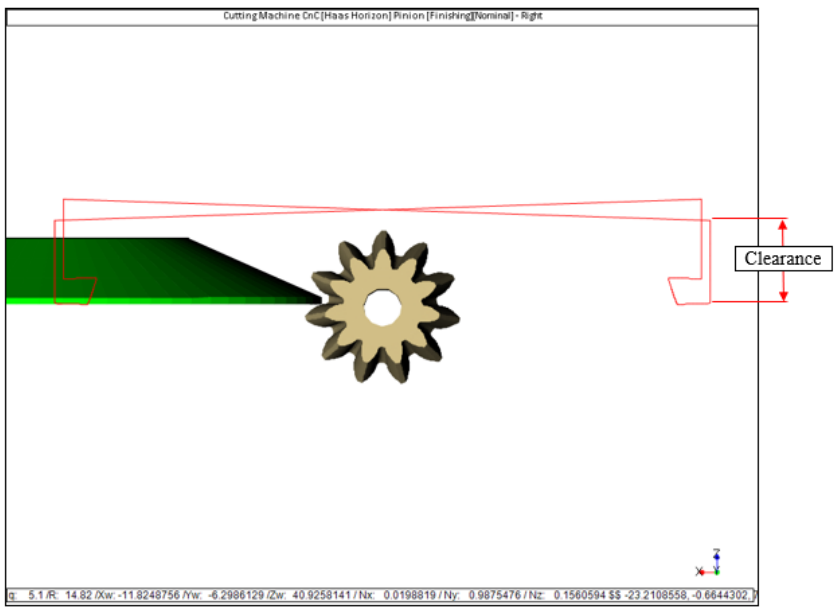
For Coniflex cutters, the cutting cycle is imposed: all the gaps of one flank are cut; then the tool is withdrawn and transferred to the opposite tooth flank where all gaps are then cut.

However, the tool can be withdrawn to either the *Work Apex* or along the *Tool Axis*. For example, in AC type machines, retracting to the Work Apex is usually not an issue because of a large volume; this is not so in a Gleason Phoenix machine where travel along the work piece is limited, and then withdrawing along the Tool Axis becomes compulsory. This has limited effect on cycle time, and is usually based on what the machine can allow.

Whenever *Tool Axis* is selected, the withdraw Clearance becomes active. This dictates by how much the tool is withdrawn along its axis





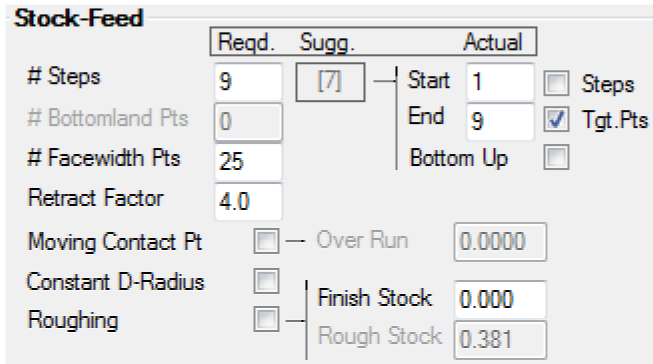


Withdraw to workpiece Apex **Withdraw along Tool Axis**

➢ ***Probe (CMM)***

For Probe (CMM) tools, the measurement cycle is imposed: it starts at Toe-Tip on the IB grid and moves towards Heel, goes down 1 Step and returns to Toe until all the IB flank has been measured; the Probe then moves to the OB flank and follows the same pattern.

Stock Feed



For the CoSIMT, End Mill and Ball Mill tools, different values define how the tool path is calculated, as follows:

 # Steps: this defines how the tooth is divided *depthwise*, and therefore the depth of cut at each pass; minimum is 3, maximum is 121; if any of these values is exceeded, HyGEARS will overwrite in red as a reminder.

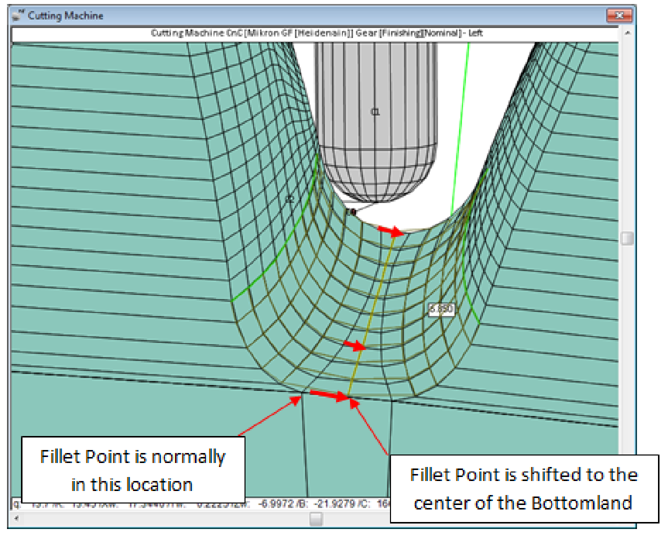
[7]: this would be the suggested (i.e. "*Sugg,*" above *[7]*) End Step, based on tooth gap width and tool dimension.

Start: Step at which cutting begins; usually 1.

End: Step at which cutting ends; depends on tooth gap width at Toe and Heel, and tool dimension.

Bottom Up: when in Finishing mode (i.e. the *Roughing* checkbox is unchecked), this indicates to HyGEARS to start cutting from the End Step to the Start Step, rather than in the conventional top-down approach.

#Bottomland Pts: corresponds to the number of passes that the End Mill, Ball Mill or CoSIMT tool will do in the bottom part of the tooth gap, i.e. the Bottomland. Until now, HyGEARS generates the fillet area, and moves the bottom most points – along the facewidth – to the center of the Bottomland such as to ensure a final pass removing leftover material.

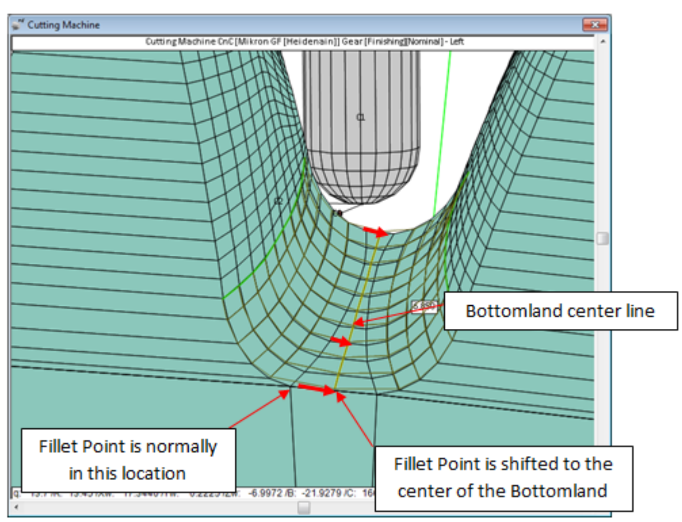


This is fine when the Bottomland is fairly constant in width, such as in Duplex Helical spiral-bevel gears. However, when the Bottomland width is not constant, such as in Straight-bevel gears cut by a 2Tool generator, above figure, one may want to impose how may points will be used across the Bottomland, hence the “#Bottomland Pts” field; valid only when the fillet is considered.

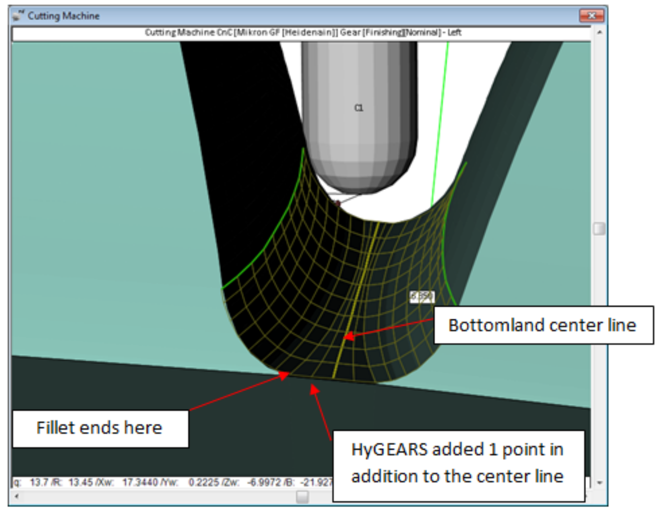
"*#Bottomland Pts*" can take several values:

0: this is the case until HyGEARS Build 405.60; the last point in the fillet is moved to the center of the Bottomland flat (figure below);

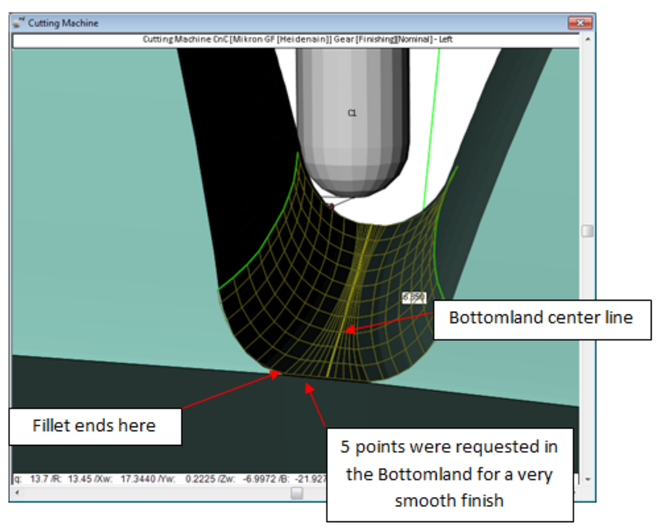
.



-1: HyGEARS calculates the "*#Bottomland Pts"* based on point spacing in the fillet: HyGEARS searches for the place where fillet point-to-point spacing is maximum (in the depth-wise direction) and uses this to establish how many points there should be;



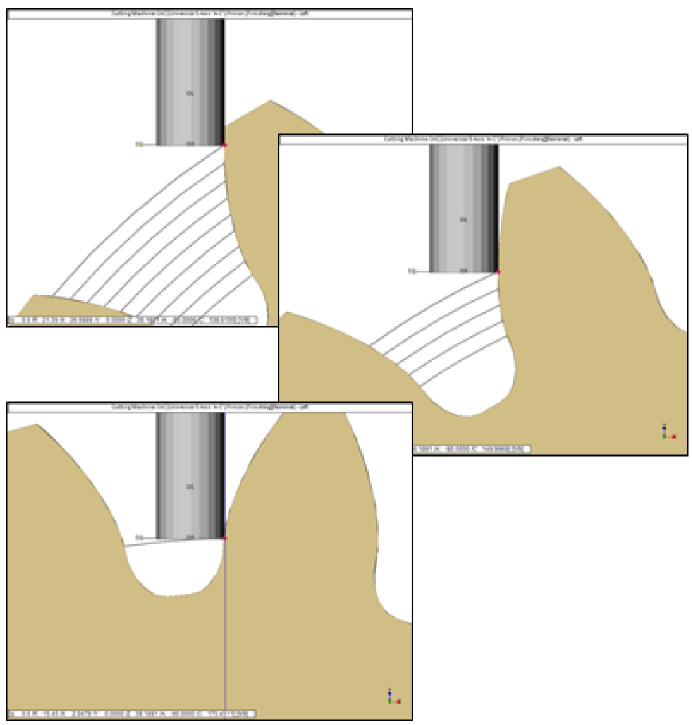
1, 2, …: user imposed "#Bottomland Pts" - can be anything to user's choice, the maximum being the limit of the storage array; HyGEARS then inserts the requested "#Bottomland Pts" between the end of the fillet and the centerline running along the bottomland.



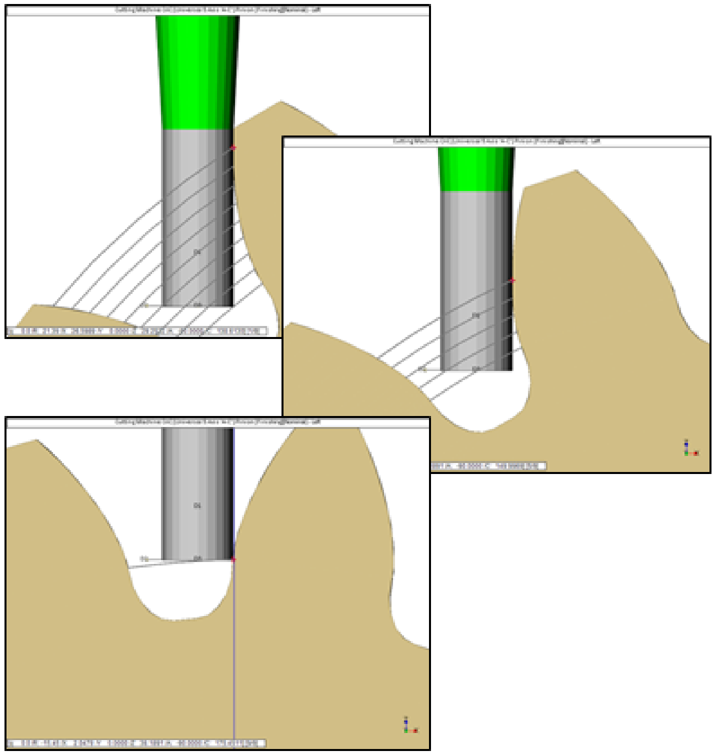
 # Facewidth Pts: number of points in which the tooth flank is subdivided; each of these points will become a target aimed by the cutting tool. Minimum is 7; maximum is 121.

Retract Factor: when the requested cycle is completed, the tool is retracted for indexation to the next gap; the distance by which the tool is retracted is the tooth depth at Heel multiplied by the *Retract Factor*. If HyGEARS finds that the *Retract Factor* is too small, a warning sign will be displayed beside the *Retract Factor* field.

Moving Contact Pt: when unchecked, this tells HyGEARS that the tool will always cut at the same position along its cutting edge, i.e. at tip; when checked, HyGEARS will move the work to tool contact point along the tool such as to distribute tool heat and wear evenly.



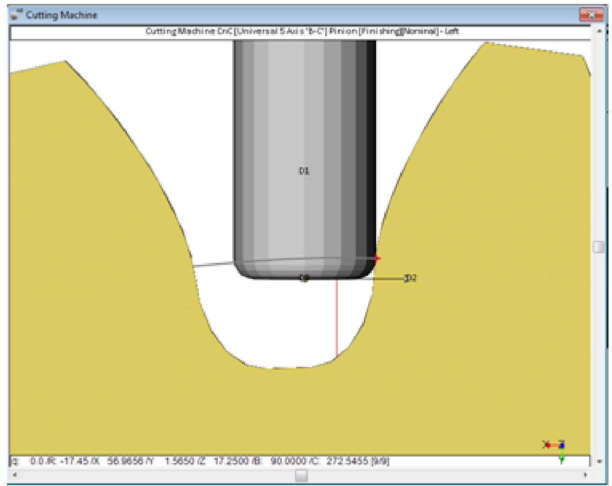
Fixed Contact Pt



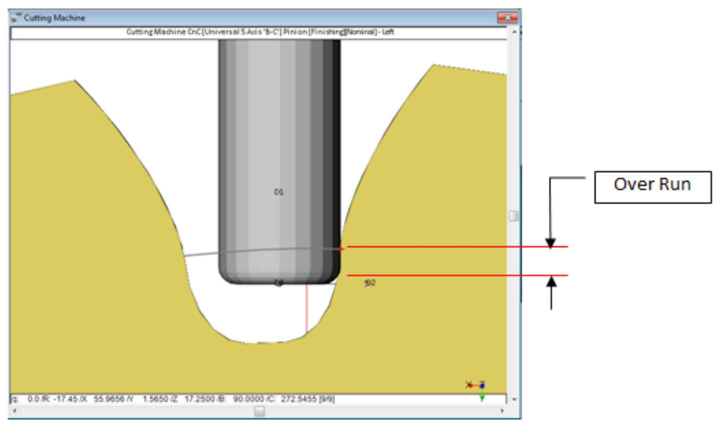
Moving Contact Pt

Over Run: allows specifying by how much an End Mill or CoSIMT tool may exceed the fillet limit when cutting the tooth flank in Finishing mode (i.e. Roughing unchecked) and Moving Contact Pt, such as to avoid leaving a lip between fillet and flank if the *tooth flank is finished with negative stock*.

This implies that the fillet was cut with *some* negative stock such as to leave a bit of room to allow for negative stock on the tooth flank.

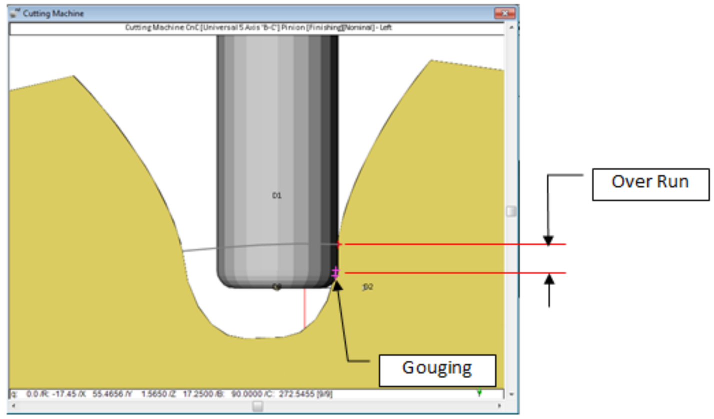


Over Run nil



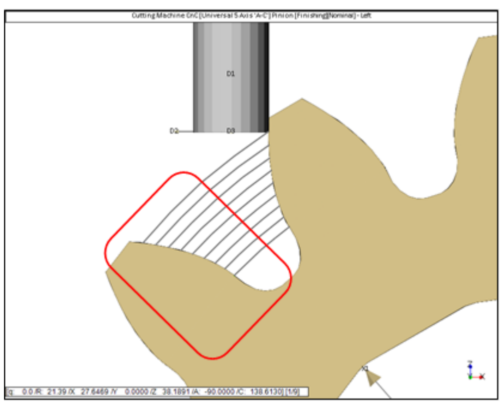
Over Run 1 [mm]

If *Over Run* is large enough, the End Mill extends *below* the fillet line, and now Gouging (pink crosses, figure below) is seen to occur between the bottom of the End Mill and the fillet.

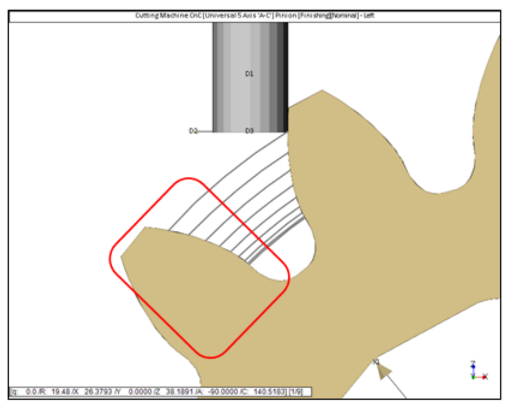


Over Run with Fillet Gouging

Constant D-Radius: this tells HyGEARS whether Step separation is based on equal tooth depth separation (i.e. *Constant D-Radius* is checked), or equal roll angle separation (i.e. *Constant D-Radius* is unchecked); Constant D-Roll (i.e. *Constant D-Radius* is unchecked) significantly improves surface finish near the fillet for parts will less than 20 teeth.

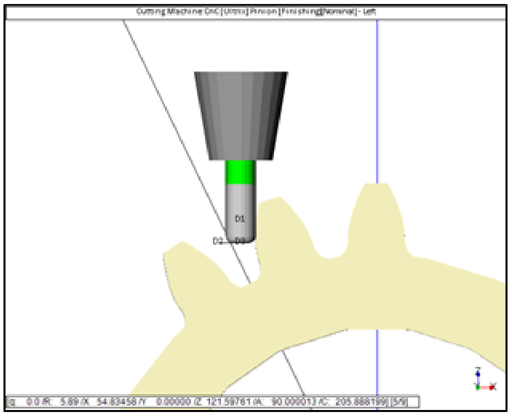


Constant D-Radius

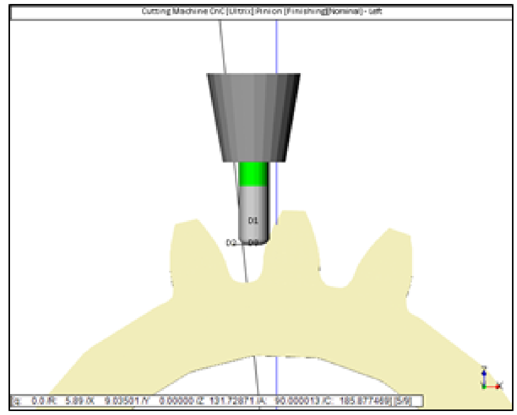


Constant D-Roll

Roughing: when unchecked, cutting is in Finishing mode where most of the cutting cycles are available; when checked, cutting will be in Roughing mode, and cutting cycles such as Center Slot and MultiPass are available. In Roughing mode, the End Mill sits radially to the blank, whereas in Finishing mode, the tool will rest tangentially to the tooth flank.



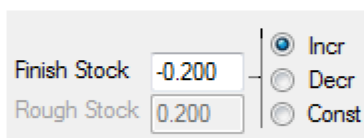
Finishing End Mill



Roughing End Mill

Stock: Stock, i.e. how much material is to be left in reference to the target tooth flank; Stock may be positive, which is expected at the soft cut before Heat Treatment; Stock may also be negative such as to allow correcting errors on a hardened part.

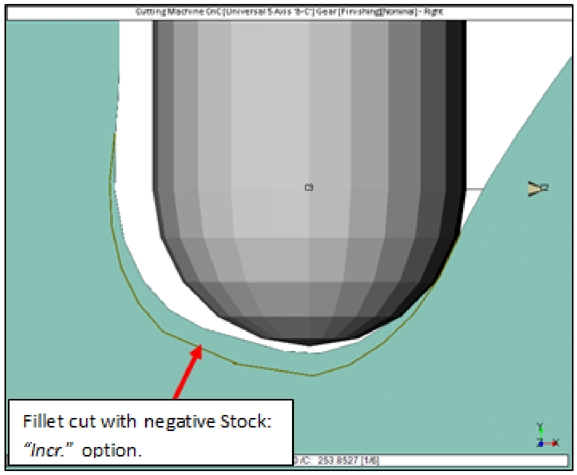
When cutting in the *Fillet-Root* area of the tooth, for a negative stock value, 3 options are displayed:

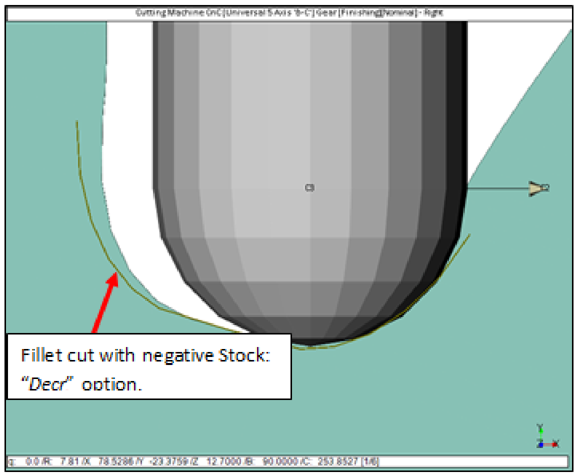


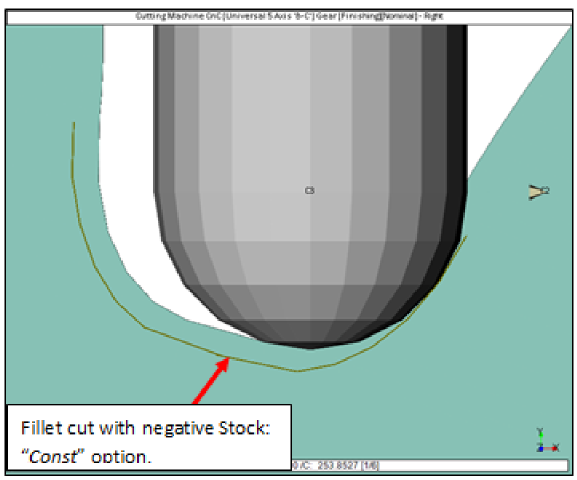
Incr Stock is zero at the Fillet to Flank junction line and progressively increases to its maximum value at the root;

Decr Stock is maximum at the Fillet to Flank junction line and progressively decreases to zero at the root;

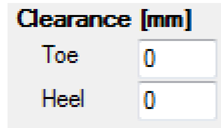
Const Stock is constant everywhere in the Fillet.


Fillet cut with negative Stock:
"Incr." option.


Fillet cut with negative Stock:
"Decr" option.


Fillet cut with negative Stock:
"Const" option.

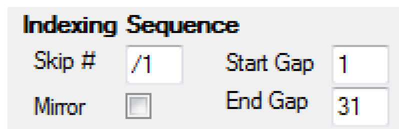
Clearances



Clearances, at Toe and Heel, are required to allow changes to the roll angle and depthwise position of the tool without damage; clearances are also very much needed to allow plunging the tool at a high feed rate, thereby decreasing cycle times.

Clearances are specified in the current linear units (here [mm]), and should always be positive. As a general rule, for End Mill and Ball Mill tools, and unless otherwise instructed,1 to 1.5 diameters are adequate.

Indexing Sequence



The Indexing Sequence instructs HyGEARS as to how tooth gap to tooth gap indexing is to be performed.

Skip #: this field tells HyGEARS how many gaps are to be skipped between two consecutive cuts. Skipping gaps allows distributing thermal load and tool wear more evenly on the workpiece; it also allows distributing pitch to pitch errors more randomly.

Default value is 1. If entered as above, i.e. "/##", the "/" instructs HyGEARS that the Start Gap will be 1, and the End Gap will be the tooth number Z of the current workpiece; the "##" value is the number of tooth gaps to skip when indexing.

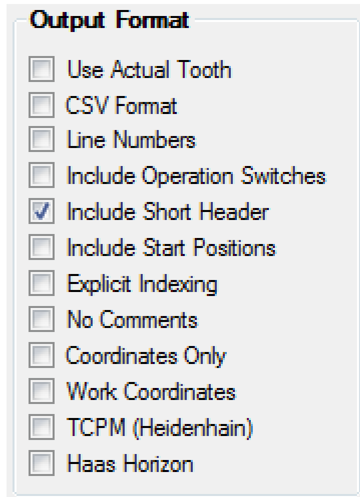
If the Skip # is negative, i.e. such as "/-1", then the direction of the indexing angle from tooth gap to tooth gap is inverted, which can allow for shorter cycles depending on how much travel is required at indexing time.

Start Gap: desired gap where cutting is to start.

End Gap: desired gap where cutting is to end.

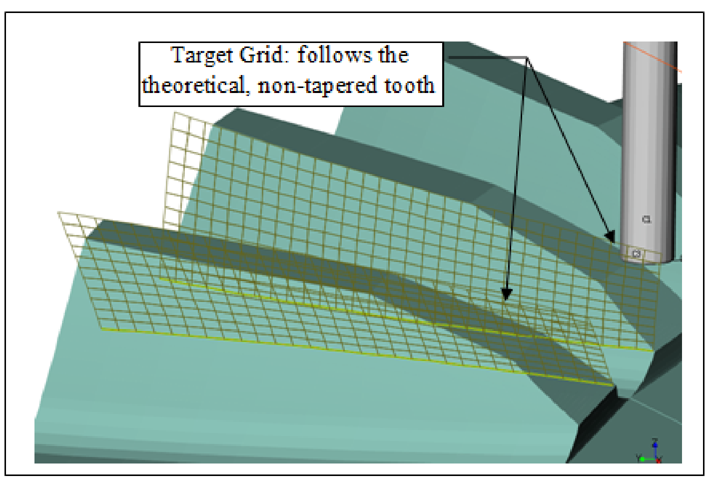
Mirror: when checked, indexing will be spread on each side of a center tooth.

Output Format

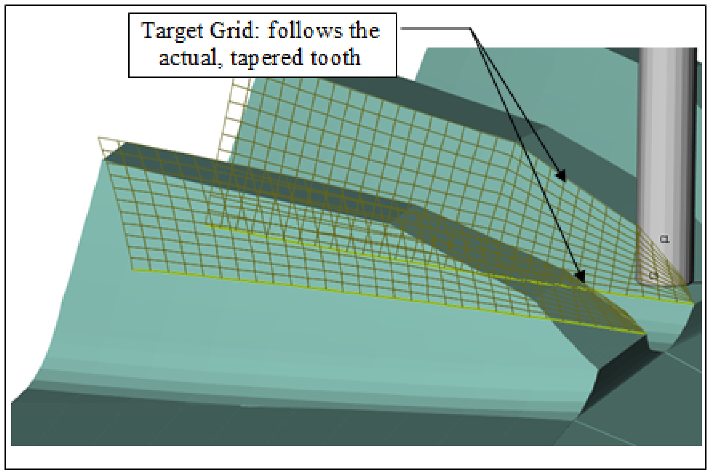


Output Format allows tailoring the way the part-programs are outputted as desired by the user. The following options are available:

Use Actual Tooth: By default, HyGEARS generates the *target grid*, i.e. the grid of points where the tool contacts the work piece, using Front and Back angles equal to the pitch angle, and eliminating any taper on the face cone. Such a *target grid* appears in the figure below, where it is clear that the grid does not follow the actual tooth shape at Toe.



When *Use Actual Tooth* is checked, HyGEARS generates the *target grid* following the actual tooth shape, and the resulting grid appears in the figure below. Clearly, the target grid follows the tooth shape at Toe where the actual tooth shows a double taper along the topland.



CSV Format:	the part program is outputted in comma separated values (CSV) format such that the coordinates and angles can be imported in an Excel sheet directly.
Line Numbers:	add / remove *line number* at beginning of each line; normally NOT required as the controllers allow toggling On and Off line numbering display.
Include Operation Switches	*Operation Switches* are a series of commands given at the beginning of a part-program to configure the machine; these include Coolant On/Off code, Tool # and tool select, Spindle RPM and CW or CCW rotation. More often than not, the switches are NOT required as all the desired code can be put in the Program Preamble (see Machine Definition, "Mach. Preamble" data page).
Include Short Header	The *Short Header* is a series of several comments at the very beginning of a part-program. These comments summarize very briefly what is included in the part-program. They are thus a good reminder when reading a part-program created

months or years before. A typical *Short Header* appears below.

```
(*************************************)
(PROGRAM NAME       : 3/32" FINISH FILLET)
(PROGRAM DATE       : 07-18-2015)
(SUMMARY VERSION    : [Nominal])
(TOOL ID            : 1 21011 29)
(TOOL DIAMETER      : 2.39[mm])
(TOOL LENGTH        : 12.00 [mm])
(APEX LOCATION      : 50.00 [mm])
(*************************************)
```

Include Start Positions

Start Positions are the coordinates from which the part-program begins. Some machine manufacturers (such as Breton in Italy) offer an integrated gear cutting cycle that uses the *Start Positions*; they are normally NOT required.

Explicit Indexing

The default HyGEARS part-programs have 1 general subprogram where all tool movements are described by coordinates and angles; a *control loop* repeatedly calls this subprogram after indexing the turntable supporting the workpiece such that all tooth gaps can be cut. This approach makes for a compact part-program, saves memory in the controller, and is usually very easy to debug should a problem occur. *Explicit Indexing* means that each tooth gap will have its own subprogram; thus the part-program will be much larger, and tracking any issue in the part-program can become difficult. Normally NOT used.

No Comments

Toggles Off the comments that allow understanding how the part-program is built. Most controllers do not mind the comments, but some machine manufacturers do not want them, so they can be removed with this switch.

Coordinates Only

When this option is checked, only the G commands will be outputted; this means no control loop, nor comments. To be used by machines where the manufacturer offers a gear cycle.

Work Coordinates

and

Traori (Siemens) / TCPM / TCP / TCPC

Part-programs can be produced in 3 different modes:

Machine Coordinates, where tool coordinates are given in reference to the machine center;

```
G1 X12.92481 Y-10.64030 Z-4.34083
B34.87732 C=DC(42.30285)
```

Work Coordinates, where tool coordinates are given in reference to the workpiece;

```
G1 X-2.39771 Y16.56857 Z-4.34083
B34.87732 C=DC(42.30285)
```

Traori/TCPM/TCP/TCPC (Siemens/Fanuc/Heidenhain/Okuma controllers), where tool coordinates and unit vector are given in reference to the workpiece.

```
G1 X-2.39771 Y16.56857 Z-4.34083
A3=-0.42292 B3=0.38486 C3=0.82038
```

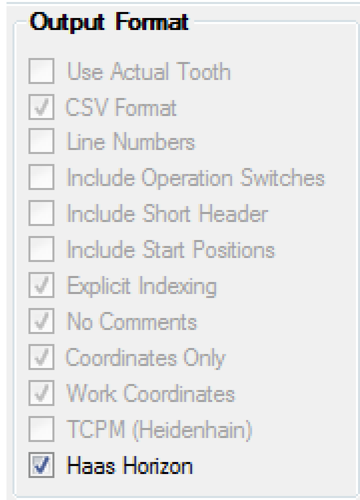
Therefore,

1. When *Work Coordinates* and *Traori/TCPM/TCP/TCPC* are unchecked, part-programs are outputted in *Machine Coordinates.*

2. When *Work Coordinates* is checked, it excludes *Traori/TCPM/TCP/TCPC* and part-programs are outputted in *Work Coordinates,* i.e in reference to the workpiece, even as it rotates.

3. When *Traori/TCPM/TCP/TCPC* (which depends on the machine's controller) is checked, it excludes *Work Coordinates* and part-programs coordinates are outputted in reference to the workpiece, while the tool unit vector gives the orientation of the tool axis in the workpiece reference frame as it rotates.

Haas Horizon When this switch is checked, all the other options become inactive and the part program output is given in a format specific to the Haas Horizon interface for the Haas CB Grinders family. *Haas Horizon* comes as an option.

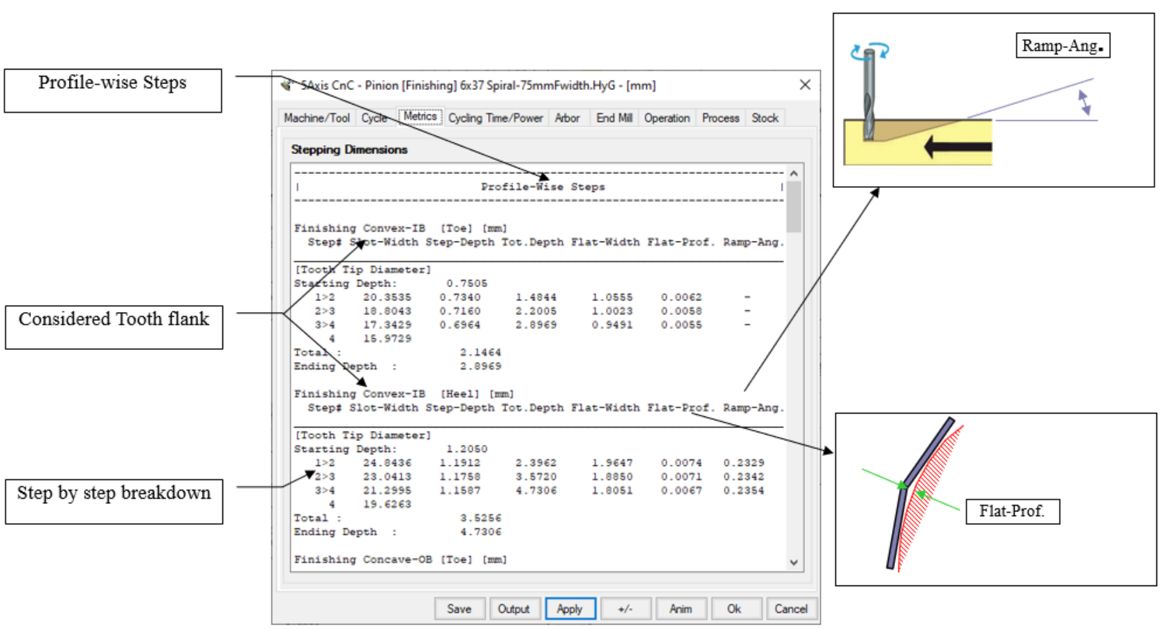


11.4 Metrics

The Metrics data page provides information as to the Slot width, Step Depth, Length of Flats. and expected cutting quality of the surface. This applies to CoSIMT, End Mill and Ball Mill tools, either in Roughing or Finishing mode.

The following information is given in consecutive tables, which can be scrolled up and down.

```
-----------------------------------------------------------------
|                     Profile-Wise Steps                        |
-----------------------------------------------------------------
```



Step#: 1>2, 2>3, 3>4 ... /Max requested

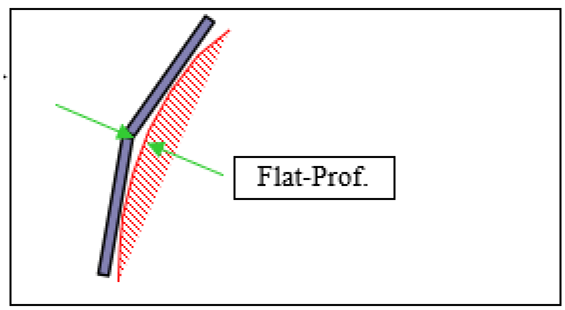
Slot Width : at the given Step, in the normal direction;

Step depth : @ mid slot; the Total and Ending Depth are given at the bottom of the column, while the Starting Depth is given at the top of the column;

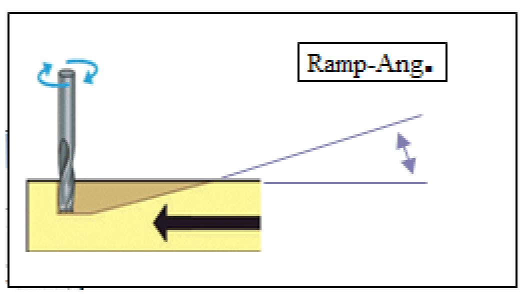
Tot.Depth: current depth at which the tool is;

Flat Width: distance along the profile between 2 consecutive target points;

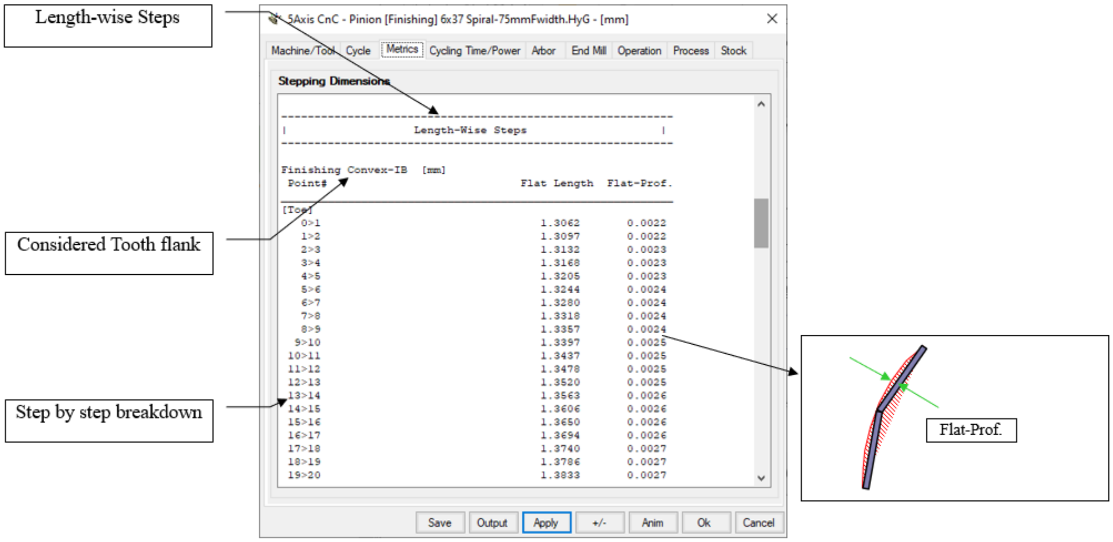
Flat-Prof: distance along the tooth flank normal between the lines joining 2 points along the profile and the actual profile; this gives a measure of the "scalloping" of the profile with decreasing #Steps; 2 to 4 mm normally give an excellent surface finish; increase the #Steps to improve surface finish;



Ramp-Ang.: the angle caused by the difference in Step Depth at Toe and Heel in tapered teeth. It is usual in tool makers' data to quote the cutting feed rate as a function of the Ramp Angle.




```
-----------------------------------------------------------------
|                     Length-Wise Steps                         |
-----------------------------------------------------------------
```



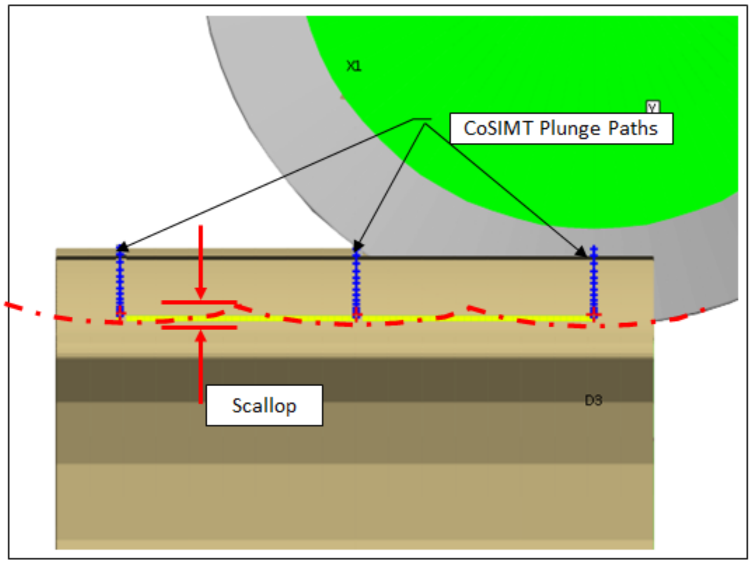
Point#: 1>2, 2>3, 3>4 ... /Max requested

Flat Length: distance along the tooth face between 2 points which are based on the # Points requested; the Total is given at the bottom of the column;

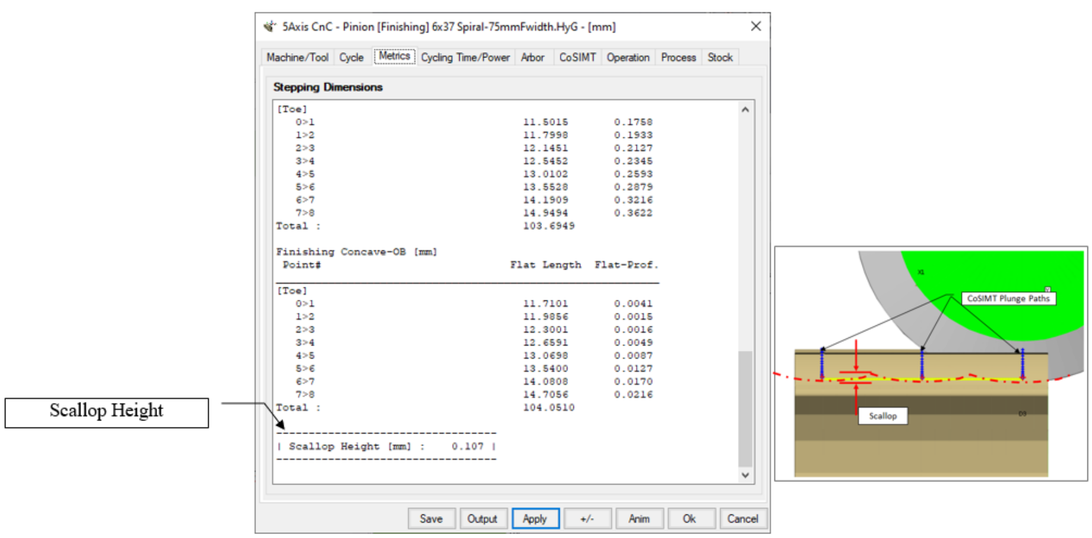
Flat-Prof: distance along the tooth flank normal vector between the line joining 2 consecutive points along the face width and the actual profile; this gives a measure of the "flattening" of the face width with decreasing #Facewidth Points.

```
---------------------------------------------------------
|                  Root Scalloping                      |
---------------------------------------------------------
```

The *Plunge Generation* cycle can be advantageous to rapidly cut spur and helical gears since the flat face of the CoSIMT can cover a large part of the tooth in one plunge. However, at the bottom of the tooth, a scallop will be left in the regions where the CoSIMT overlaps (figure below) and the # *Facewidth Pts* may need to be increased, followed by a fillet Operation, to ensure an even fillet shape.



For the *Plunge Generation* cycle, the Metrics tab displays the expected scallop height based on the Toe and Heel clearances, the *#Facewidth Pts* (which reflect the # of CoSIMT Plunge Paths and Start / End points), and the CoSIMT OD (figure below).



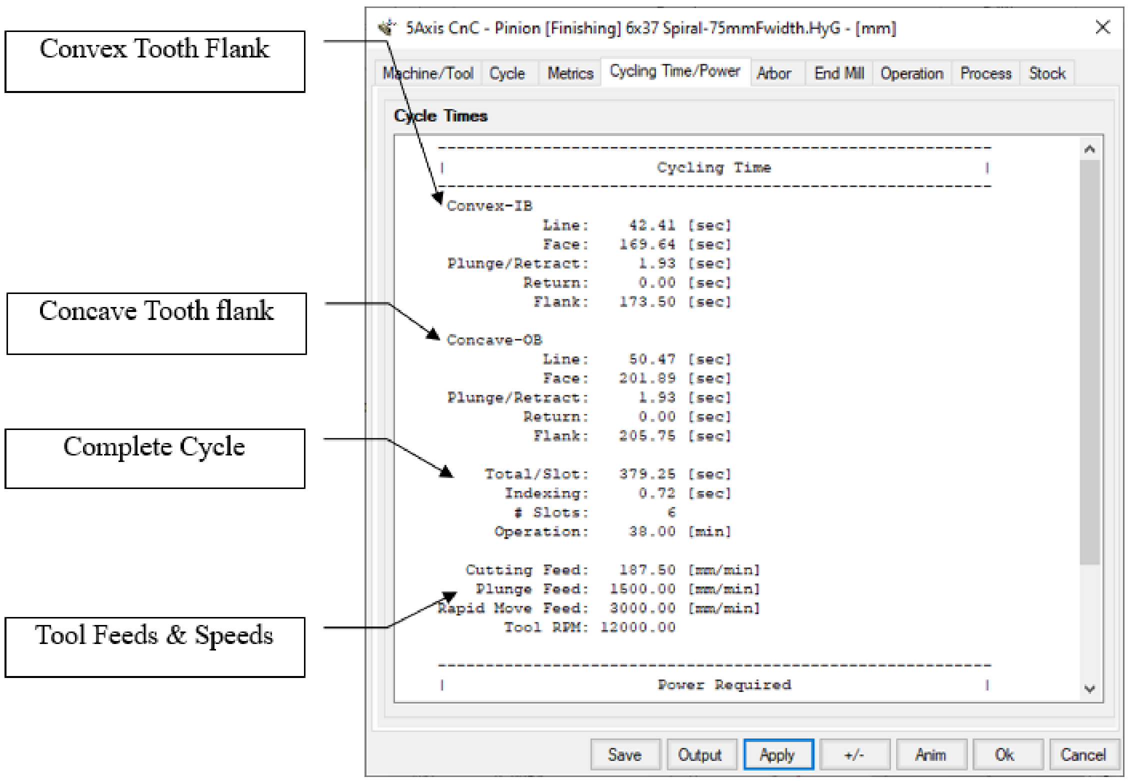
11.5 Cycling Time/Power

The display is given in 2 tables:

- Cycling Time
- Power Required

Cycling Time

The Cycling Time is the estimated duration of the cutting cycle based on the tool used, feeds and cycle selection. Note that the values displayed can vary substantially depending on how the controller treats the combination of linear and angular motions.



Cycling time includes values for each tooth flank as follows:

Line:	time needed to do one Toe to Heel or Heel to Toe pass;
Face:	time needed to complete one tooth flank;
Plunge/Retract:	time needed to either plunge or retract the tool;
Return:	time needed for the Return Trip, i.e. after retracting to the next plunge.

The times needed per slot (Total/Slot), Indexing and Operation are given, along with the Feeds used in the calculations.

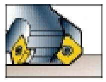
```
----------------------------------------------------------------
|                      Cycling Time                            |
----------------------------------------------------------------
 Left
            Line:     38.10 [sec]
```

```
           Face:   190.50 [sec]
 Plunge/Retract:   136.36 [sec]
         Return:    12.70 [sec]
          Flank:   475.91 [sec]

 Right
           Line:    38.10 [sec]
           Face:   190.50 [sec]
 Plunge/Retract:   136.36 [sec]
         Return:    12.70 [sec]
          Flank:   475.91 [sec]

     Total/Slot:   951.82 [sec]
       Indexing:     1.59 [sec]
        # Slots:       21
      Operation:   333.69 [min]

   Cutting Feed:   500.00 [mm/min]
    Plunge Feed:    50.00 [mm/min]
Rapid Move Feed:  1500.00 [mm/min]
```

Power Required

The Power Required is an *estimate* of the *average cutting torque* imposed on the tool, and the consequent *average power* when tool RPM is considered. Cutting torque and power are based on the relations provided by Sandvik (figure below):

Formulas



$$v_c = \frac{D_{cap} \times \pi \times n}{1000}$$

Cutting speed (v_c)
(m/min)

$$n = \frac{v_c \times 1000}{\pi \times D_{cap}}$$

Spindle speed (n)
(rpm)

$$f_z = \frac{v_f}{n \times z_c}$$

Feed per tooth (f_z)
(mm)

$$Q = \frac{a_p \times a_e \times v_f}{1000}$$

Metal removal rate (Q)
(cm^3/min)

$$v_f = f_z \times n \times z_c$$

Table feed or feed speed (v_f)
(mm/min)

$$M_c = \frac{P_c \times 30 \times 10^3}{\pi \times n}$$

Torque (M_c)
(Nm)

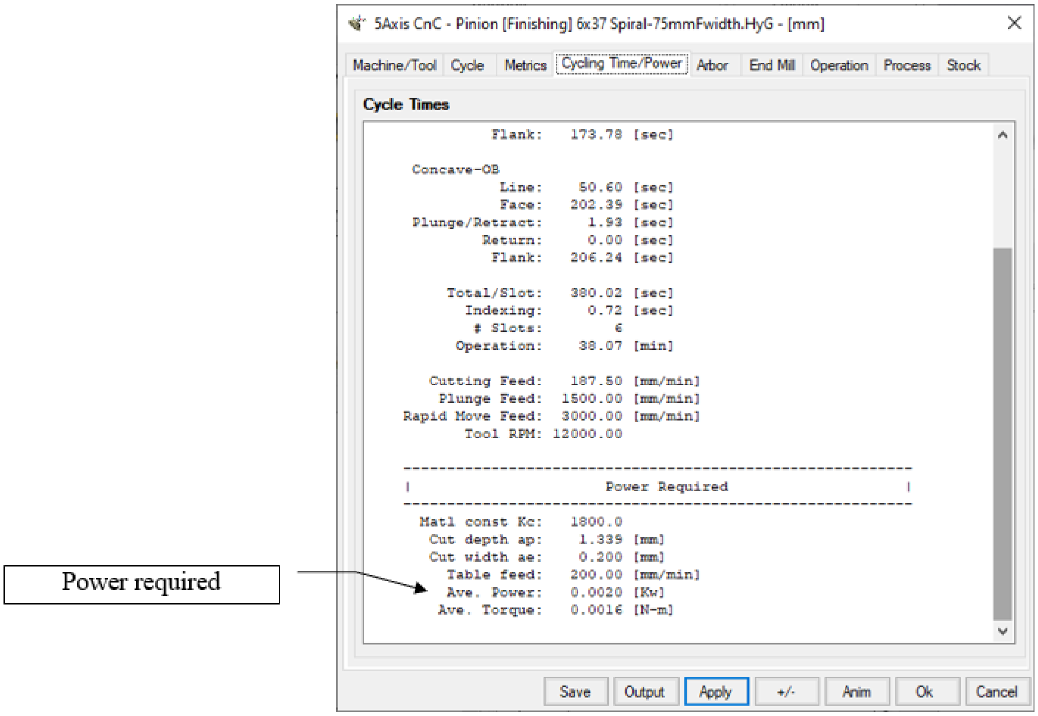
$$P_c = \frac{a_p \times a_e \times v_f \times k_c}{60 \times 10^6}$$

Net power requirement
(P_c) (kW)

The results are displayed below the Cycling Time, as shown in the following figure.

When Face Milling tools are used, such as a Face Mill cutter for spiral bevel gears, or a Coniflex dish type cutter for Coniflex bevel gears, HyGEARS calculates the volume of material to be removed from the gap and the time required to remove this volume in order to obtain the Ave. Torque and Ave. Power values.

When a CoSIMT, End Mill or Ball Mill tool is used, depending on the type of cutting cycle selected, HyGEARS will calculate the *ae* value, which is the size of the cut / tool blade or *flute*, in order to estimate torque and power.



Matl const Kc depends on material type and hardness. Sandvik provides reference values for various materials, as shown below (https://www.sandvik.coromant.com/en-us/knowledge/milling/formulas_and_definitions/formulas). Value *ae* and material const. *Kc* can be found and modified on the Operations data page.

ISO Material Classification

ISO	CMC No.	MATERIAL		SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
				N/MM²	HB
P Steel	01.1	UNALLOYED STEEL	C=0.1-0.25%	2000	125
	01.2		C=0.25-0.55%	2100	150
	01.3		C=0.55-0.80%	2200	170
	02.1	LOW-ALLOY STEEL (alloying elements≤5%)	Non-hardened	2150	180
	02.12		Ball bearing steel	2300	210
	02.2		Hardened and tempered	2550	275
	02.2		Hardened and tempered	2850	350
	03.11	HIGH-ALLOY STEEL (alloying elements>5%)	Annealed	2500	200
	03.21		Hardened tool steel	3900	325
	06.1	STEEL CASTING	Unalloyed	2000	180
	06.2		Low-alloy (alloying elements≤5%)	2100	200
	06.3		High-alloy (alloying elements>5%)	2650	225

ISO	CMC No.	MATERIAL			SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
M Stainless steel					N/MM^2	HB
	05.11	STAINLESS STEEL	Non-hardened		2300	200
	05.12	-Bars/forged	PH-hardened		3550	330
	05.13	Ferritic/martensitic	Hardened		2850	330
	05.21	STAINLESS STEEL	Austenitic		2300	180
	05.22	-Bars/forged	PH-hardened		3550	330
	05.23	Austenitic	Super austenitic		2950	200
	05.51	STAINLESS STEEL	Non-weldable	≥0.05%C	2550	230
	05.52	-Bars/forged	Weldable	<0.05%C	3050	260
		Austenitic-ferritic				
		(Duplex)				
	15.11	Stainless steel - Cast	Non-hardened		2100	200
	15.12	Ferritic/martensitic	PH-hardened		3150	330
	15.13		Hardened		2650	330
	15.21	Stainless steel - Cast	Austenitic		2200	180
	15.22	Austenitic	PH-hardened		3150	330
	15.23		Super austenitic		2700	200
	15.51	Stainless steel - Cast	Non-weldable	≥0.05%C	2250	230
	15.52	Austenitic-ferritic	Weldable	<0.05%C	2750	260
		(Duplex)				

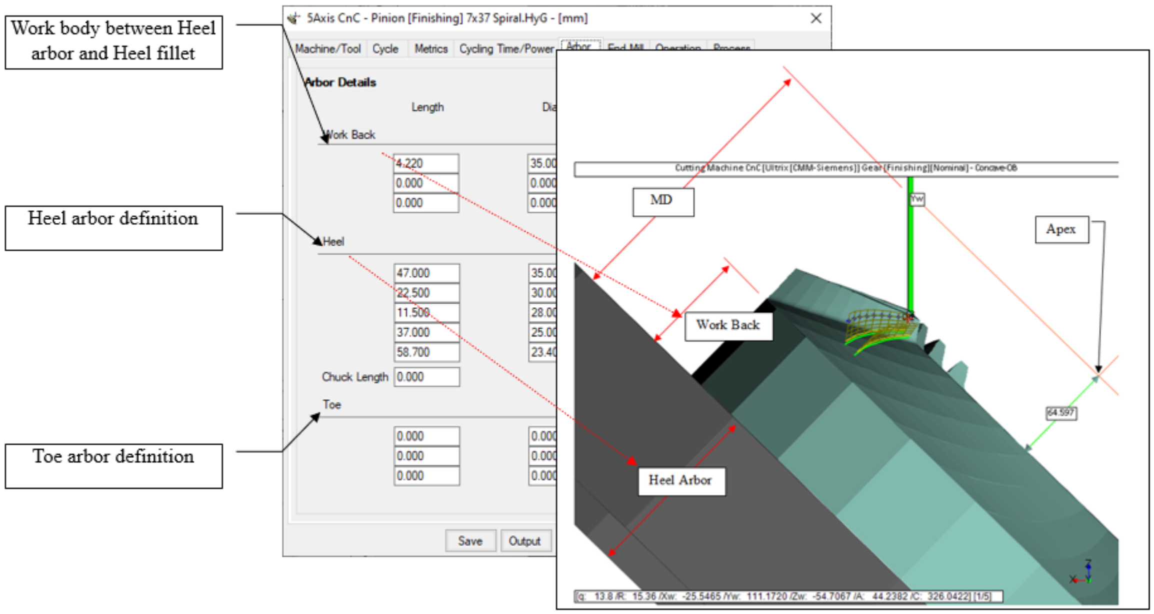
ISO	CMC No.	MATERIAL		SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
K Cast iron				N/MM^2	HB
	07.1	MALLEABLE CAST IRON	Ferritic (short chipping)	940	130
	07.2		Pearlitic (long chipping)	1100	230
	08.1	GREY CAST IRON	Low tensile strength	1100	180
	08.2		High tensile strength	1150	220
	09.1	NODULAR SG IRON	Ferritic	1050	160
	09.2		Pearlitic	1750	250
	09.3		Martensitic	2700	380

ISO	CMC No.	MATERIAL		SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
H Hardened material				N/MM^2	HB
	04.1	HARD STEEL	Hardened and tempered	3250	45 HRC
		Extra hard steel	Hardened and tempered	5550	60 HRC
	10,1	CHILLED CAST IRON	Cast or cast and aged	2800	400

11.6 Work Arbor

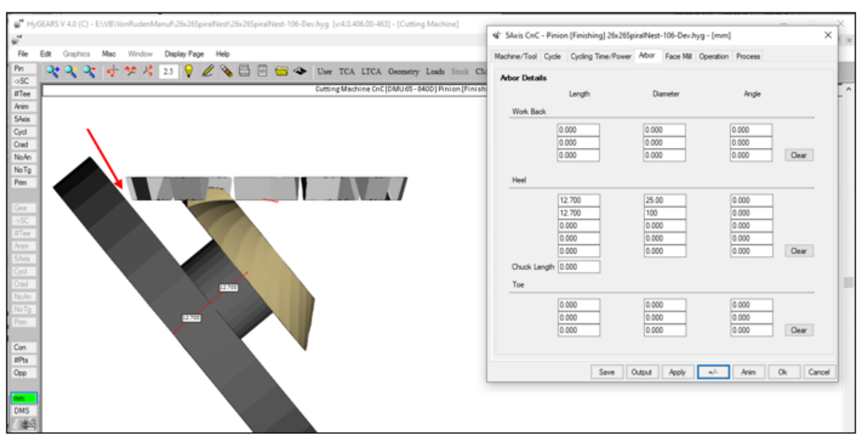
HyGEARS allows the definition of three environment components on the workpiece:

Work Back space between tooth root at Heel and the back face of the part from where the Mounting Distance is calculated;
Heel Arbor work support at Heel;
Toe Arbor work support at Toe.

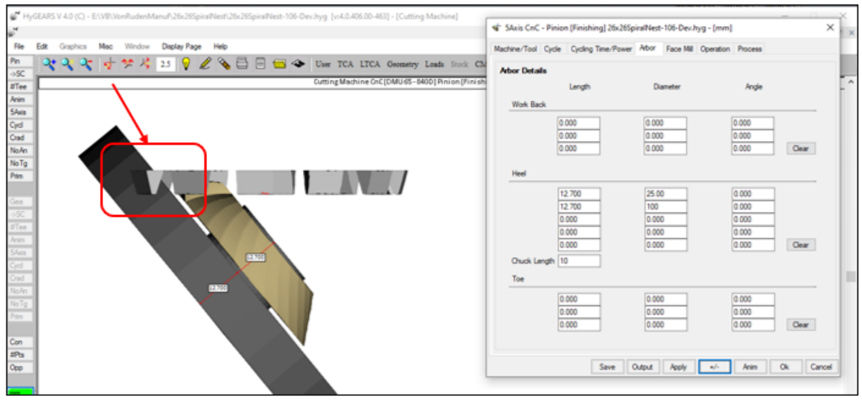


Chuck Length moves the workpiece relative to the defined arbor without having to modify the arbor. This way, one can assess what change in Chuck Length is required to avoid the tool hitting the support arbor behind the workpiece.

For example, figure below, the Face Mill cutter is seen quite close to the support arbor behind the part. The Chuck Length is null in this setup.

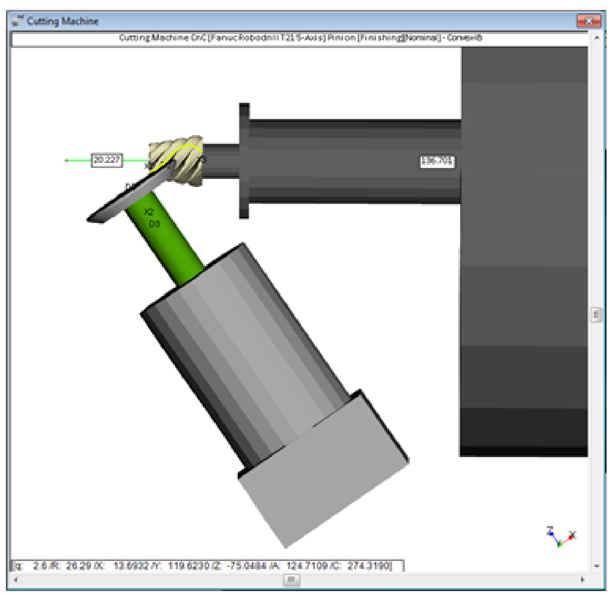


Because of the configuration of the installation, the Chuck Length must be increased by 10 mm to have better holding support. In this condition, we can see (figure below) that the Face Mill cutter will hit the support and an alternative approach must be found.



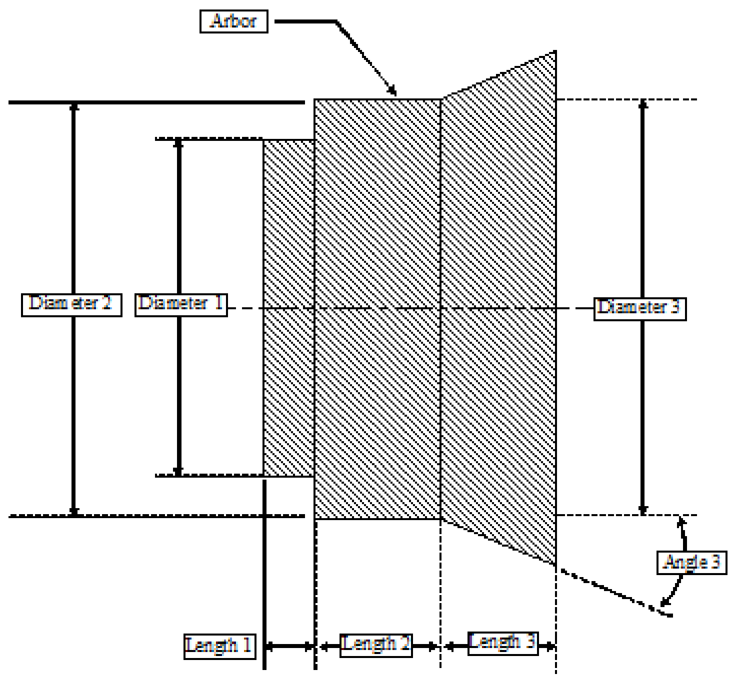
Defining these components then allows visualization (see Display Options in the Machine/Tool data page) and prevent collisions should clearances become too small, as is shown in the figure below where the Machine Head, holding a CoSIMT tool, and the work Heel Arbor are displayed.

Arbors are normally specific to each part, and must therefore be defined individually.



Up to 8 arbor segments may be defined, 5 of which are at *Heel*, and 3 at *Toe*. *Work Back* is that portion between the end of the teeth and the MD and can also be displayed by 3 segments in the same manner.

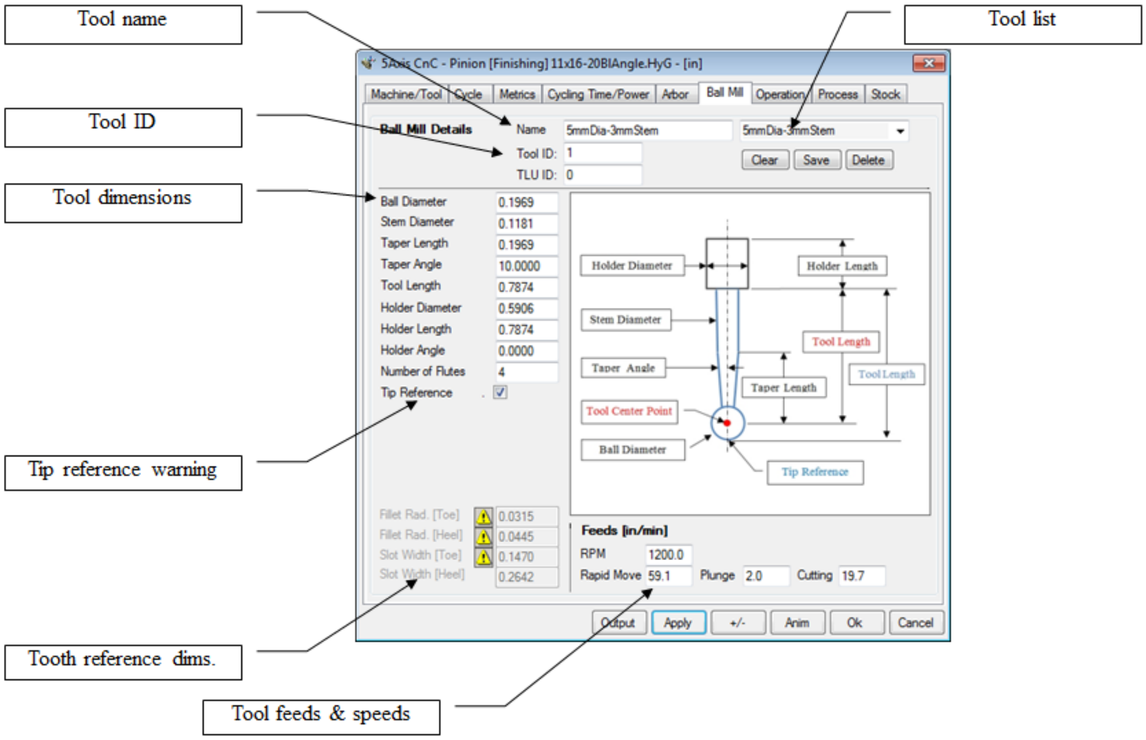
Each component is defined by a series of cylinders of a given Length and Diameter; if an Angle is also given, the cylinder becomes a frustum of cone of the given Diameter at its smaller end - see figure below.



11.7 Ball Mill tool

Ball Mill tools are conserved in a special file called "BallMill.fil". Users define their own tools which are added to the "BallMill.fil" file; thus, tools are proprietary to users.

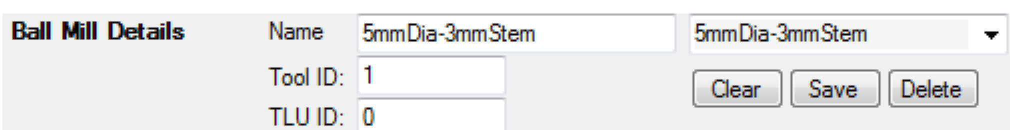
- Ball Mill Details
- Tool Definition
- Part Limits
- Feeds
- Reference Points



Ball Mill tools are frequently used tools in milling machines. While being rather inexpensive tools, quality is and tolerances are fundamental to ensure tooth flank topography: a diameter error of only 20 mm will directly result in a tooth thickness error of ~20 mm, i.e. ~10 mm per flank, and will induce spiral angle error.

Typical diameter tolerances on Ball Mill tools are in the 20 to 30 mm range and therefore are very influential on part quality.

Ball Mill Details



Ball Mill tools are identified by their name, which can be up to 30 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the Ball Mill list contains the names of all the Ball Mill tools already defined.

The *Tool ID*, by default 1, is used to identify the tool position in the tool changer.

The *TLU ID* stands for *Tool Lookup ID* and is required by some Fanuc controllers to obtain tool dimensions.

The 3 following buttons allow control over Ball Mill tools:

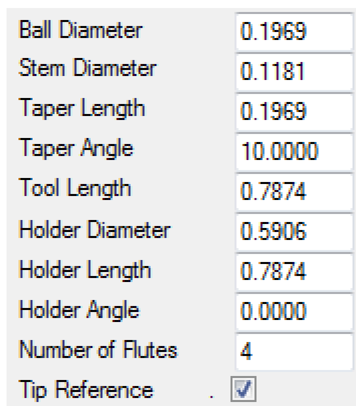
Clear: clears all input fields described below;

Save: saves the current definition of the Ball Mill tool named in the *Name* field; if the Ball Mill tool exists, confirmation is required to overwrite the existing definition; if it does not exist, it is added to the Ball Mill list to the right of the *Name* field;

Delete: deletes the currently displayed tool; confirmation is required before deletion is completed.

Tool Definition

Ball Mill tools are described by the following data:



Ball Diameter: the *diameter* of the Ball Mill;

Stem Diameter: the *diameter* of the non-cutting part of the End Mill;

Taper Length: the length of the tapered part of the Stem;

Taper Angle: the angle of the tapered part of the Stem;

Tool Length: the overall *Tool Length*, from Tip (if Tip Reference is selected) to Holder;

Holder Diameter: the *diameter* of the tool holder;

Holder Length: the *length* of the tool holder;

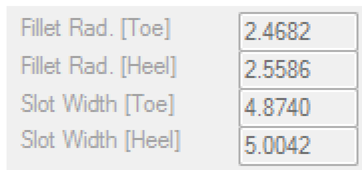
Holder Angle: the *angle* of the tool holder, if conical;

Number of Flutes: the number of *cutting edges* of the tool;

Tip Reference: if checked, the tool coordinates will be given at Tool Tip; otherwise, coordinates are given at Tool Center Point and a warning sign will be displayed, as shown above.

Part Limits

The lower left part of the Ball Mill data page lists limits specific to the part being cut. These serve as guides to tool size. If slot width at the Fillet line is smaller than Ball Mill diameter, a warning sign is displayed; likewise, if the Fillet Radius is smaller than the radius of the Ball Mill, a warning sign is displayed.



Fillet Rad [Toe]: the *minimum* calculated fillet radius at Toe;

Fillet Rad [Heel]: the *minimum* calculated fillet radius at Heel;

Slot Width [Toe]: the *minimum* calculated fillet slot width at Toe;

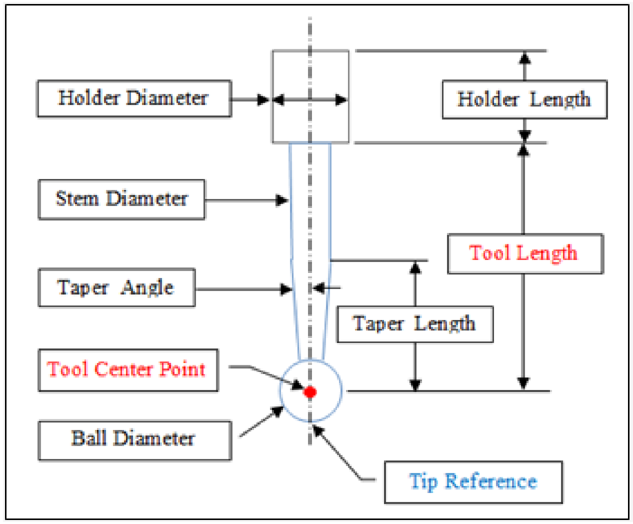
Slot Width [Heel]: the *minimum* calculated fillet slot width at Heel;

Feeds

The lower right part of the Ball Mill data page lists the feeds associated to the Ball Mill. These values are saved with the Ball Mill and are retrieved each time this tool is selected from the Ball Mill List.

Reference Points

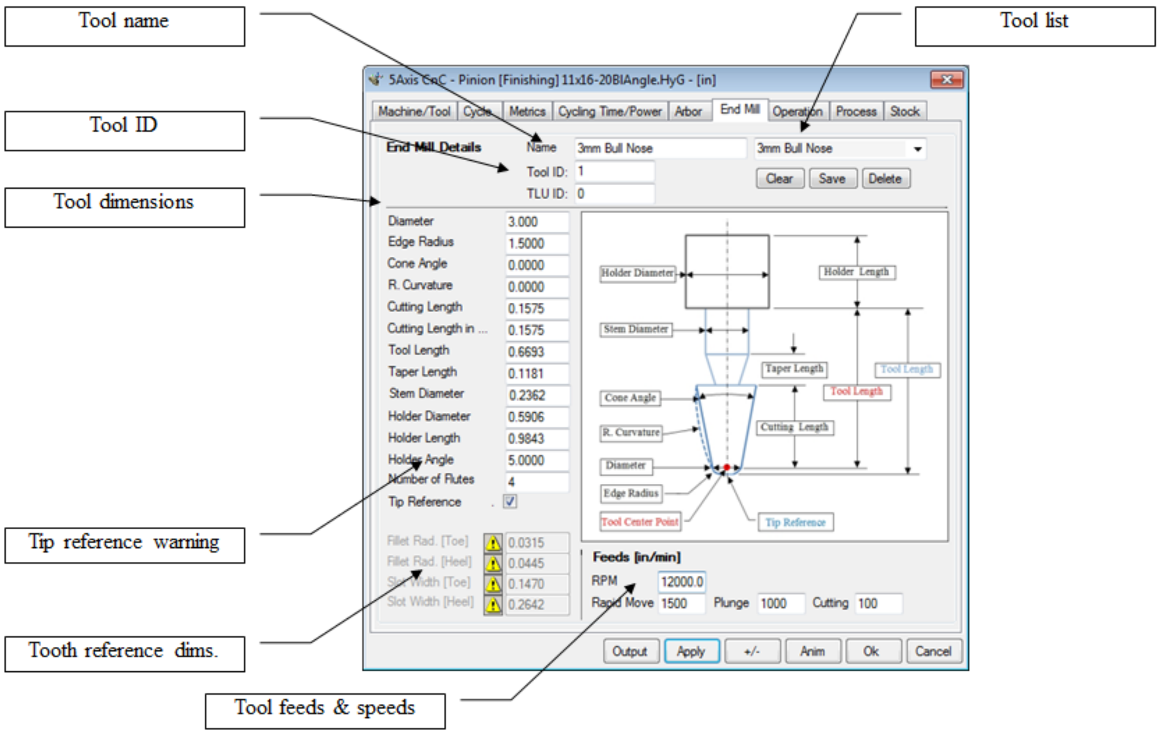
Tool reference can be given either at TCP, or Tool Center Point, or at Tip, as shown below. The calculated coordinates will depend on the choice made for reference.



11.8 End Mill tool

End Mill tools are conserved in a special file called "EndMill.fil". Users define their own tools which are added to the "EndMill.fil" file; thus, tools are proprietary to users.

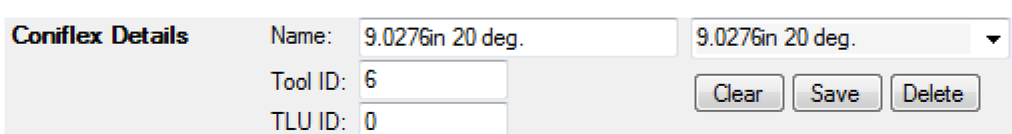
- End Mill Details
- Tool Definition
- Part Limits
- Feeds
- Reference Points



End Mill tools are amongst the most frequently used tools in milling machines. While being rather inexpensive tools, quality is and tolerances are fundamental to ensure tooth flank topography: a diameter error of only 20 µm will directly result in a tooth thickness error of ~20 µm, i.e. ~10 µm per flank, and will induce spiral angle error.

Typical diameter tolerances on End Mill tools are in the 20 to 30 µm range and therefore are very influential on part quality.

End Mill details



End Mill tools are identified by their name, which can be up to 30 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the End Mill list contains the names of all the End Mill tools already defined.

The *Tool ID*, by default 1, is used to identify the tool position in the tool changer.

The *TLU ID* stands for *Tool Lookup ID* and is required by some Fanuc controllers to obtain tool dimensions.

The 3 following buttons allow control over End Mill tools:

Clear: clears all input fields described below;

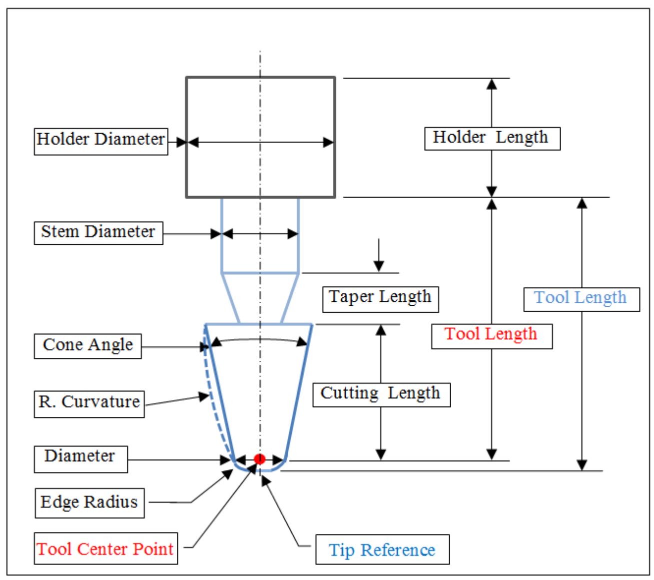
Save: saves the current definition of the End Mill tool named in the *Name* field; if the End Mill tool exists, confirmation is required to overwrite the existing definition; if it does not exist, it is added to the End Mill list to the right of the *Name* field;

Delete: deletes the currently displayed tool; confirmation is required before deletion is completed.

Tool Definition

End Mill tools are described by the following data:

Diameter	3.000
Edge Radius	1.5000
Cone Angle	0.0000
R. Curvature	0.0000
Cutting Length	0.1575
Cutting Length in ...	0.1575
Tool Length	0.6693
Taper Length	0.1181
Stem Diameter	0.2362
Holder Diameter	0.5906
Holder Length	0.9843
Holder Angle	5.0000
Number of Flutes	4
Tip Reference	☑

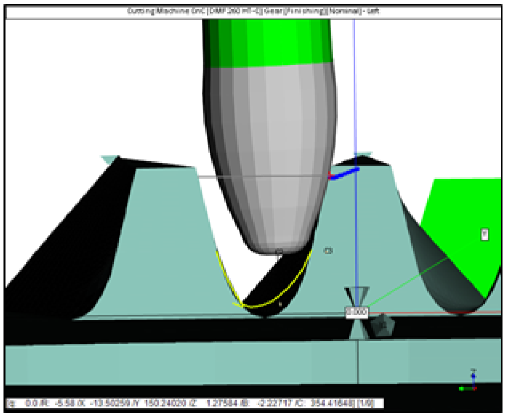


Diameter: the *diameter* of the End Mill;

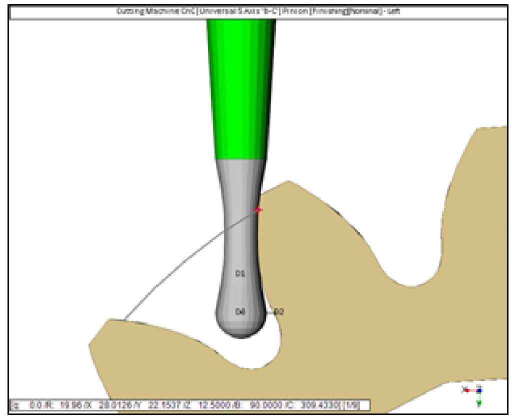
Edge Radius: the *Edge Radius* of the End Mill; can be zero;

Cone Angle: in case of a tapered End Mill, the *full* Cone Angle as per the above figure;

R. Curvature: the HyGEARS End Mill tools can have a zero, positive or negative *Radius of Curvature*; when zero, a cylindrical End Mill is obtained; when positive or negative, the shapes depicted below are obtained;



Positive R. Curvature



Negative R. Curvature

Cutting Length: the *actual length* of the cutting flukes;

Cutting Length in Use: the *maximum length* of the cutting flukes that will be used when cutting with a *Moving Contact Pt*. (see Cycle data page, Stock-Feed section); the *Cutting Length in Use* should always be smaller than the *Cutting Length* in order to provide a margin of safety; increasing the *Cutting Length in Use* increases the chances of Gouging (see Machine/Tool data page, Display Options) when using a *Moving Contact Pt*.

Tool Length: the overall *Tool Length*, from Tip (if Tip Reference is selected) to Holder;

Taper Length: the length of the tapered section between the cutting flutes and the Stem;

Stem Diameter: the *diameter* of the non-cutting part of the End Mill;

Holder Diameter: the *diameter* of the tool holder;

Holder Length: the *length* of the tool holder;

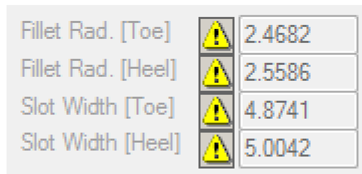
Holder Angle: the *angle* of the tool holder, if conical;

Number of Flutes: the number of *cutting edges* of the tool;

Tip Reference: if checked, the tool coordinates will be given at Tool Tip; otherwise, coordinates are given at Tool Center Point and a warning sign will be displayed.

Part Limits

The lower left part of the End Mill data page lists limits specific to the part being cut. These serve as guides to tool size. If slot width at the Fillet line is smaller than End Mill diameter, a warning sign is displayed; likewise, if the Fillet Radius is smaller than the Edge Radius of the End Mill, a warning sign is displayed, as shown below.



Fillet Rad [Toe]: the *minimum* calculated fillet radius at Toe;

Fillet Rad [Heel]: the *minimum* calculated fillet radius at Heel;

Slot Width [Toe]: the *minimum* calculated fillet slot width at Toe;

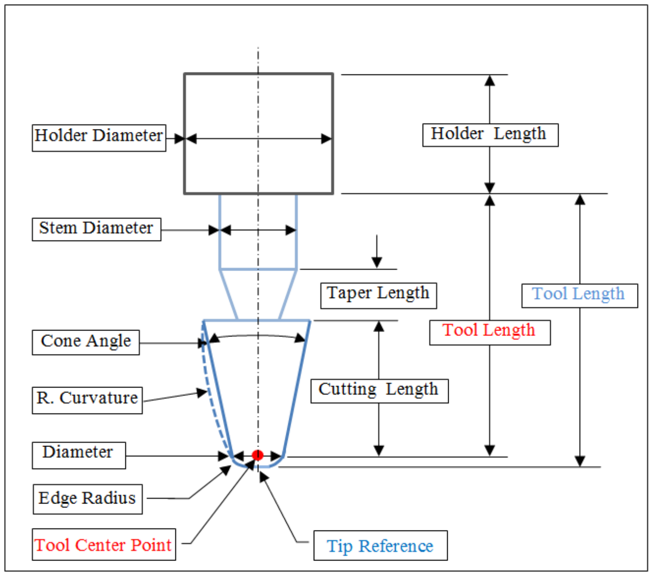
Slot Width [Heel]: the *minimum* calculated fillet slot width at Heel;

Feeds

The lower right part of the End Mill data page lists the feeds associated to the End Mill. These values are saved with the End Mill and are retrieved each time this tool is selected from the End Mill List.

Reference Points

Tool reference can be given either at TCP, or Tool Center Point, or at Tip, as shown below. The calculated coordinates will depend on the choice made for reference.



11.9 CoSIMT tool

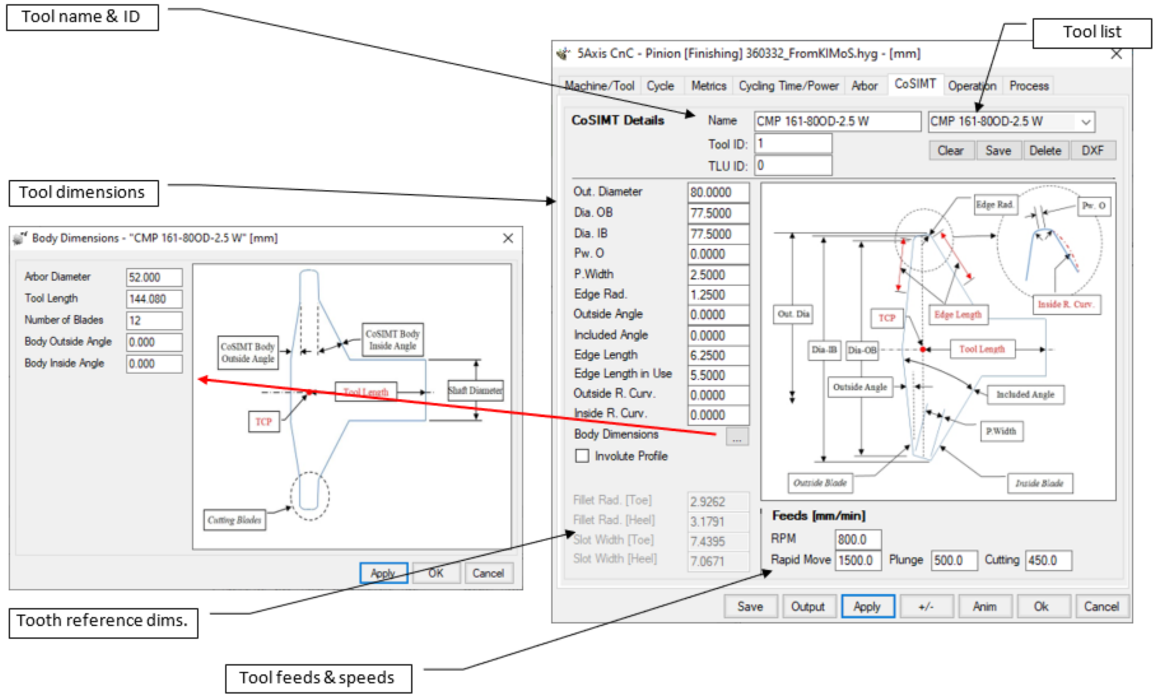
CoSIMT stands for "Conical Side Milling Tool", which is a generic name for tools such as Sandvik's InvoMill and Gleason's UpGear tools.

CoSIMTs are extremely effective tools for Roughing operations, but given they normally use inserts for cutting edges, the location of which cannot always be precisely controlled, quality Finishing operations are more difficult to achieve unless a high-end CoSIMT is used. In such a case, significant costs are associated to the tool, inserts and insert installation.

Sandvik's CoSIMTs come in 2 basic sizes, which limits the range of modules that can be covered, especially smaller modules.

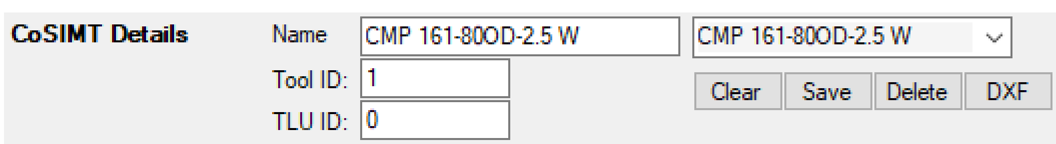
CoSIMT tools are conserved in a special file called "CoSIMT.fil". Users define their own tools which are added to the "CoSIMT.fil" file; thus, tools are proprietary to users.

- Tool Definition
- Part Limits
- Feeds
- Reference Points
- DXF Output



CoSIMT tools are frequently used tools in milling machines. While being rather inexpensive, quality and tolerances are fundamental to ensure tooth flank topography.

CoSIMT Details



CoSIMT tools are identified by their name, which can be up to 30 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the CoSIMT list contains the names of all the CoSIMT tools already defined.

The *Tool ID*, by default 1, is used to identify the tool position in the tool changer.

The *TLU ID* stands for *Tool Lookup ID* and is required by some Fanuc controllers to obtain tool dimensions.

The following buttons allow control over CoSIMT tools:

Clear: clears all input fields described below;

Save: saves the current definition of the CoSIMT tool named in the *Name* field; if the CoSIMT tool exists, confirmation is required to overwrite the existing definition; if it does not exist, it is added to the CoSIMT list to the right of the *Name* field;

Delete: deletes the currently displayed tool; confirmation is required before deletion is completed.

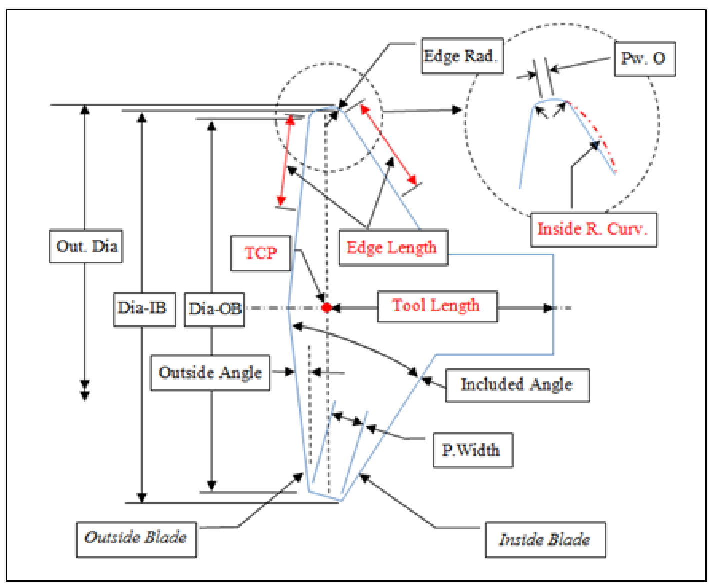
DXF: outputs in DXF format the profile of the CoSIMT blade to a text results window (the DXF option is required).

Tool definition

CoSIMT tools are described by the following data (refer to figure for details):

Main CoSIMT Dimensions

Out. Diameter	80.0000
Dia. OB	78.4000
Dia. IB	78.4000
Pw. O	0.0000
P.Width	1.6000
Edge Rad.	0.8000
Outside Angle	0.0000
Included Angle	0.0006
Edge Length	5.2500
Edge Length in Use	3.0000
Outside R. Curv.	0.0000
Inside R. Curv.	0.0000



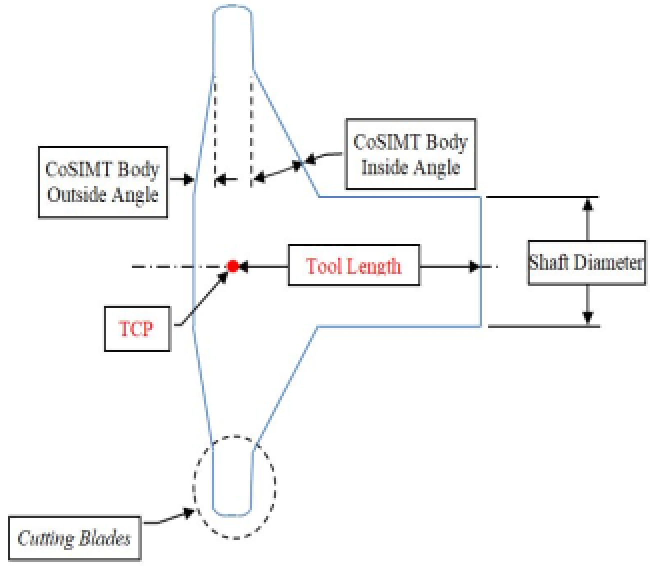
Out. Diameter: the overall *outside diameter* of the CoSIMT;

Dia. OB: the *diameter* at the tip of the cutting edge on the *outside blade* of the CoSIMT, which is opposite the arbor;

Dia. IB: the *diameter* at the tip of the cutting edge on the in*side blade* of the CoSIMT, which is on the same side as the arbor;

Pw.O.:	the length of the flat part between the Edge Radii of the OB and IB;
P.Width:	the *Point Width* between the tips of the cutting edges of the IB and OB blades;
Edge Rad.:	the *Edge Radius* at the end of the cutting edges of the IB and OB blades;
Outside Angle:	the *angle of the cutting edge* of the outside blade; if positive, the cone is convex; if negative, the cone is concave, such as in UpGear tools; if null, the cutting face is flat such as InvoMill tools;
Included Angle:	the angle between the *IB and OB cutting edges*;
Edge Length:	the *length,* along the blade, of the cutting edges;
Edge Length in Use:	the *actual length,* along the blade, of the cutting edges to be used for Moving Contact Pt. (see Cycle data page, Stock-Feed section);
Outside R. Curv:	the *radius of curvature* of the OB blade; can be negative (concave blade), positive (convex blade) or null (flat blade);
Inside R. Curv:	the *radius of curvature* of the IB blade; can be negative (concave blade), positive (convex blade) or null (flat blade);

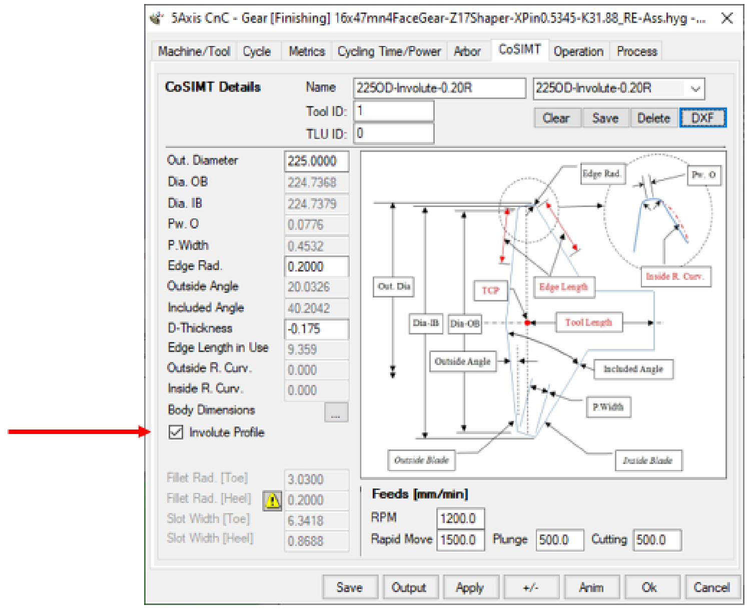
CoSIMT Body Dimensions



Arbor Diameter:	the *diameter* of the CoSIMT arbor;
Tool Length:	the *length* of the CoSIMT, from the end of the arbor to the TCP (Tool Center Point);
Number of Blades:	the number of *cutting edges* of the tool;
Body Outside Angle:	cone angle of the CoSIMT body on the side opposite the arbor;
Body Inside Angle:	cone angle of the CoSIMT body on the side of the arbor.

Involute Profile

When the reference tool is a Shaper (for Face Gears for example), CoSIMT tools can be defined with an Involute profile by clicking on the Involute Profile switch.



When doing so, the same Involute profile as defined for the Shaper is used on the CoSIMT, but it is shifted radially such as to satisfy the entered OD. The only variables for this CoSIMT become:

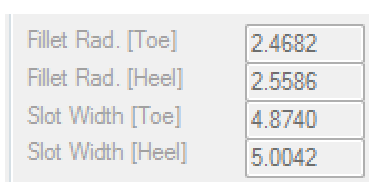
Out. Diameter: outside diameter of the CoSIMT;

Edge Rad.: Edge radius;

D-Thickness: change in thickness at the pitch circle; this can be used to ensure the CoSIMT does not simultaneously touch both tooth flanks when grinding such as not to suffer side movements.

Part Limits

The lower left part of the CoSIMT data page lists limits specific to the part being cut. These serve as guides to tool size. If slot width at the Fillet line is smaller than CoSIMT P. Width, a warning sign is displayed; likewise, if the Fillet Radius is smaller than the edge radius of the CoSIMT, a warning sign is displayed.



Fillet Rad [Toe]: the *minimum* calculated fillet radius at Toe;

Fillet Rad [Heel]: the *minimum* calculated fillet radius at Heel;

Slot Width [Toe]: the *minimum* calculated fillet slot width at Toe;

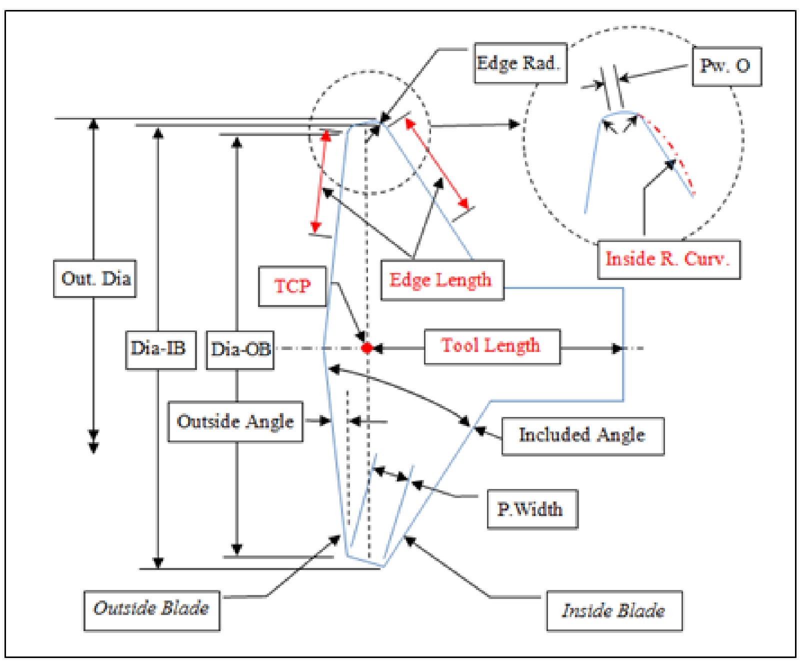
Slot Width [Heel]: the *minimum* calculated fillet slot width at Heel;

Feeds

The lower right part of the CoSIMT data page lists the feeds associated to the CoSIMT. These values are saved with the CoSIMT and are retrieved each time this tool is selected from the CoSIMT List.

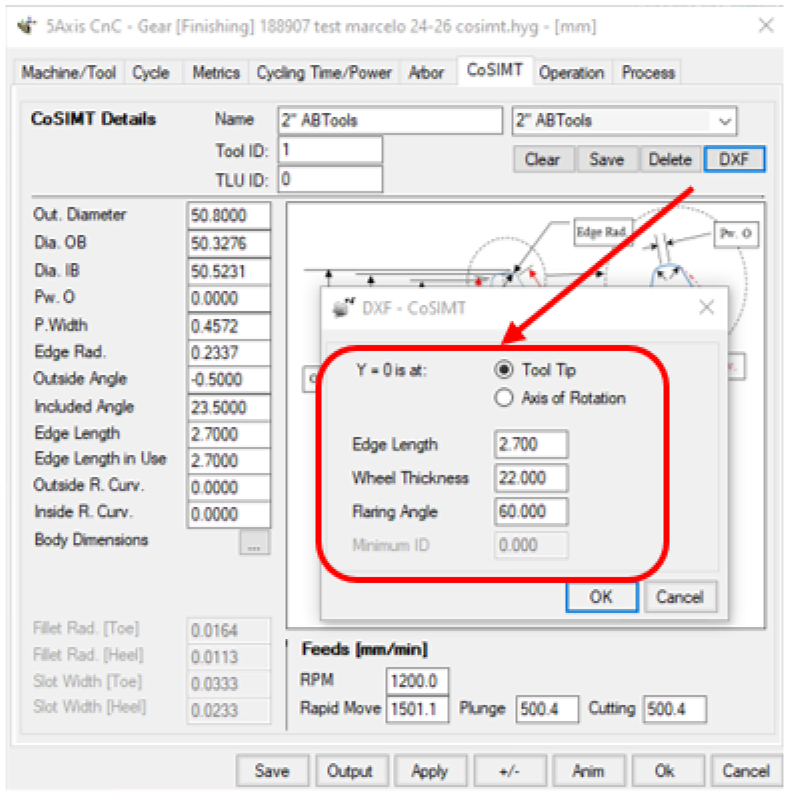
Reference Point

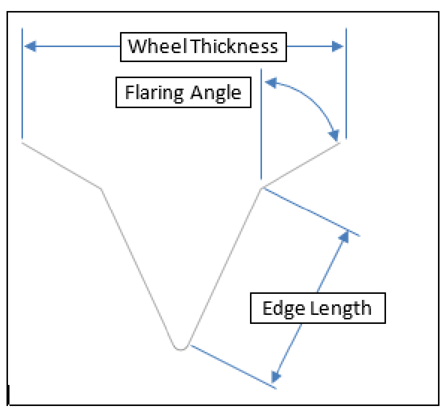
Tool reference is given at TCP, or Tool Center Point, which is calculated value from the tool dimensions, and cannot usually be measured on the CnC machine. The calculated coordinates will depend on the choice made for reference.



DXF Output

For the CoSIMT DXF output (optional), the following inputs allow defining the tool such that on a grinder, the dressing software can account for the desired shape outside of the actual grinding area.





In particular, the following can be defined:

Y = 0 is at: where is the radial 0 value; can be at Tool Tip or Axis of Rotation;

Edge Length; default is that in the CoSIMT definition; same value for both sides;

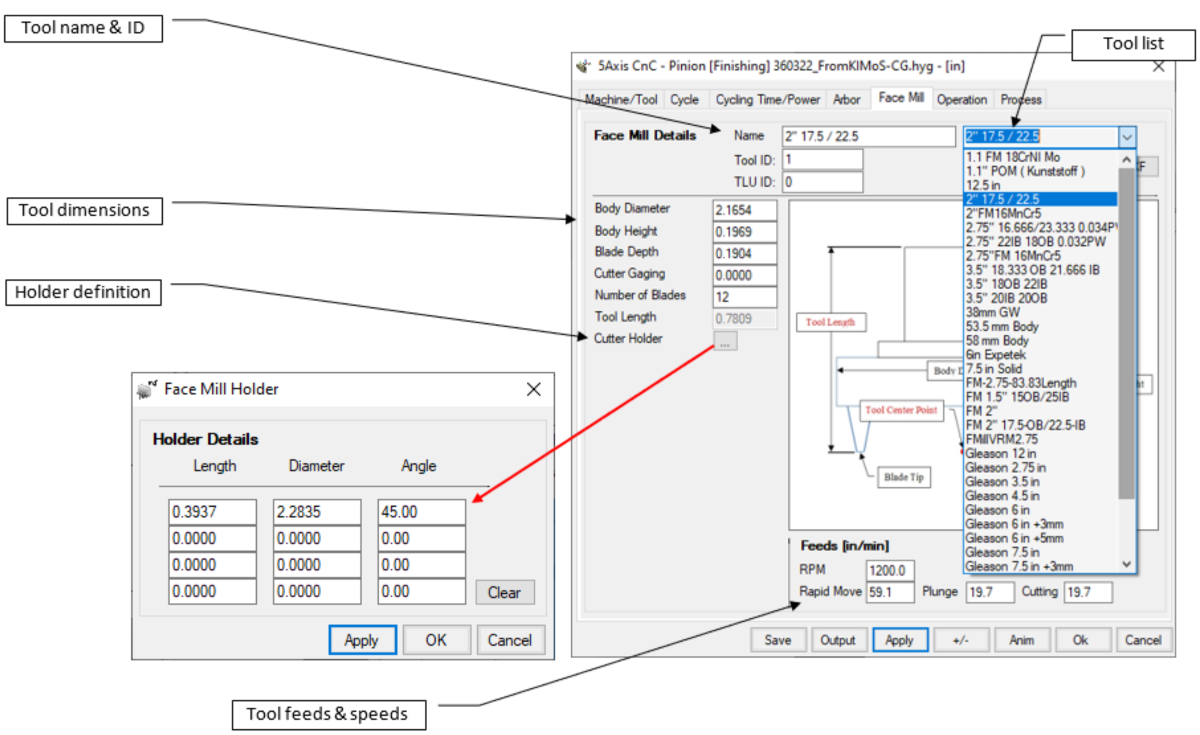
Wheel Thickness: thickness of the grinding wheel disk; default is 22 mm;

Flaring Angle: from the grinding edge, the angle at which the dresser must travel to reach the ends of the grinding wheel disk. Same value for both sides.

11.10 Face Mill cutter

Face Mill tools are conserved in a special file called "FaceMill.fil". Users define their own tools which are added to the "FaceMill.fil" file; thus, tools are proprietary to users.

- Face Mill Details
- Tool Definition
- Feeds
- Reference Point
- DXF Output



Face Mill tools are the most productive tools to cut spiral bevel gears. However, they are costly and their size makes it often impractical to use on 5 Axis CnC machines because of the required torque.

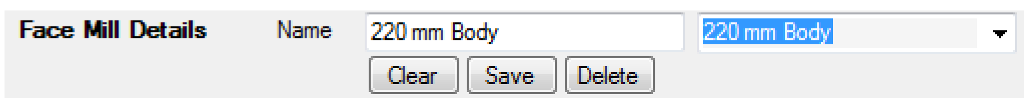
Face Mill cutters can be found in 3 basic configurations, none of which influence calculation of the CnC machine coordinates:

Solid: cutter body and blades are integral; special grinding equipment and procedures are required for sharpening;

Separate blades: cutter blades are removed for sharpening and must be adjusted when reinstalled; can be very precise if the blades are well adjusted;

Insert blades: the cutter body supports inserts that are replaced when worn; precision is usually low because of insert precision in location, but is adequate for Roughing; very cost effective as a Roughing operation prior to hard finish grinding.

Face Mill Details



Face Mill tools are identified by their name, which can be up to 30 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the Face Mill list contains the names of all the Face Mill tools already defined.

The *Tool ID*, by default 1, is used to identify the tool position in the tool changer.

The *TLU ID* stands for *Tool Lookup ID* and is required by some Fanuc controllers to obtain tool dimensions.

The 3 following buttons allow control over Face Mill tools:

Clear: clears all input fields described below;

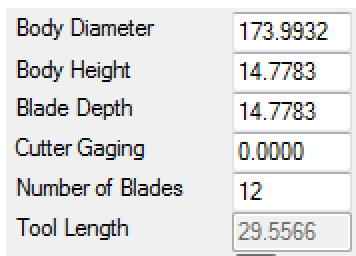
Save: saves the current definition of the Face Mill tool named in the *Name* field; if the Face Mill tool exists, confirmation is required to overwrite the existing definition; if it does not exist, it is added to the Face Mill list to the right of the *Name* field;

Delete: deletes the currently displayed tool; confirmation is required before deletion is completed.

DXF: outputs in DXF format the profile of the Face Mill blade to a text results window (the DXF option is required).

Tool Definition

Face Mill tools are described by the following data, none of which influences the actual blade data used to calculate the coordinates. In short, the data entered below is used only for graphic representation.



Body Diameter: the *diameter* of the Face Mill cutter body;

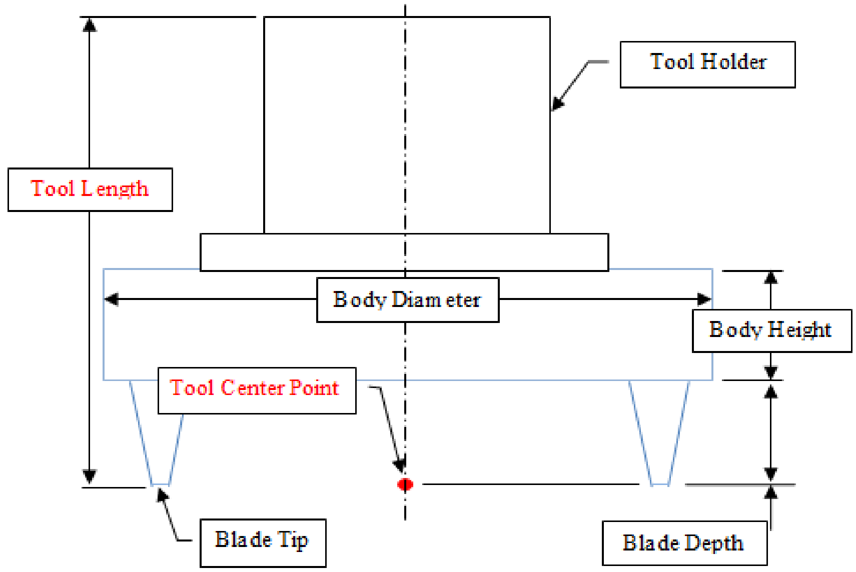
Body Height: the *height* of the Face Mill cutter body;

Blade Depth: the *depth* of the cutter blades;

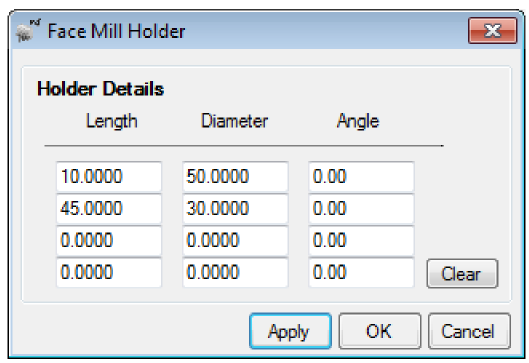
Cutter Gaging: unused at this time;

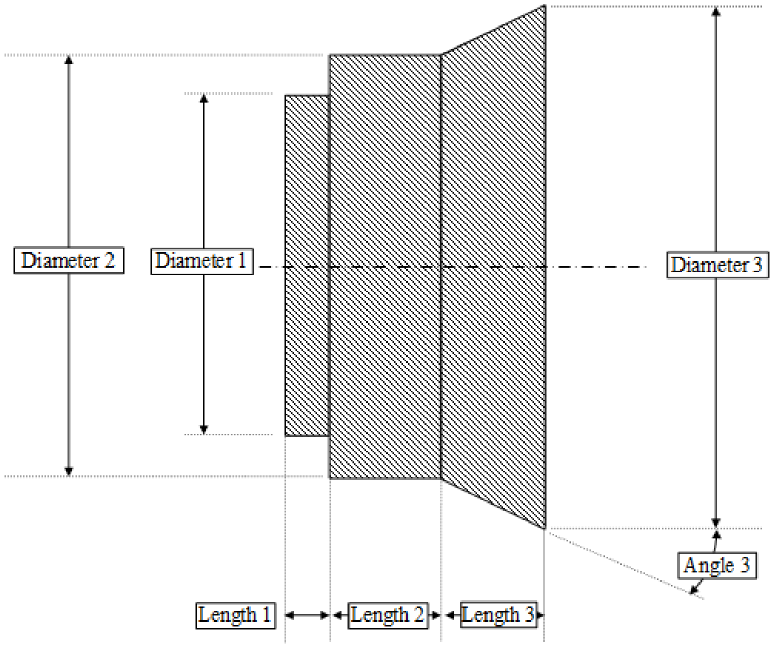
Number of Blades: the *number* of cutter blades displayed;

Tool Length: the overall *Tool Length*, from blade Tip to Holder; this is a calculated value;



Cutter Holder: the [...] button gives access to define the cutter holder as a series of up to 4 cylinders and cones, as shown below.



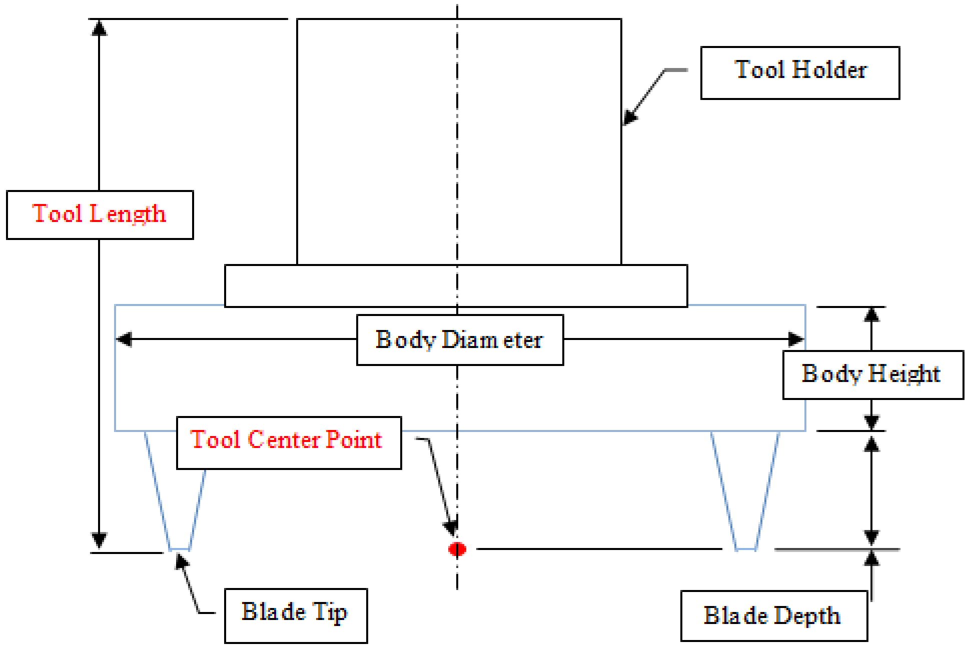


Feeds

The lower right part of the Face Mill data page lists the feeds associated to the Face Mill cutter. These values are saved with the Face Mill and are retrieved each time this tool is selected from the Face Mill List.

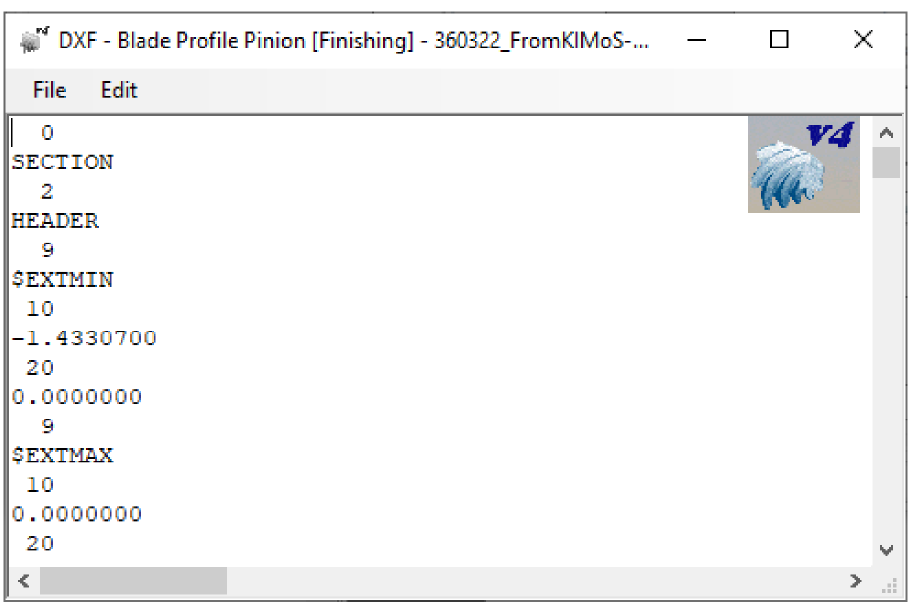
Reference Point

Tool reference is at the Tool Center Point, always in the plane of Blade tips, along the axis of the cutter, as shown in the figure below.



DXF Output

The DXF file is displayed in a Text Results window for review. It only needs be saved on disk.



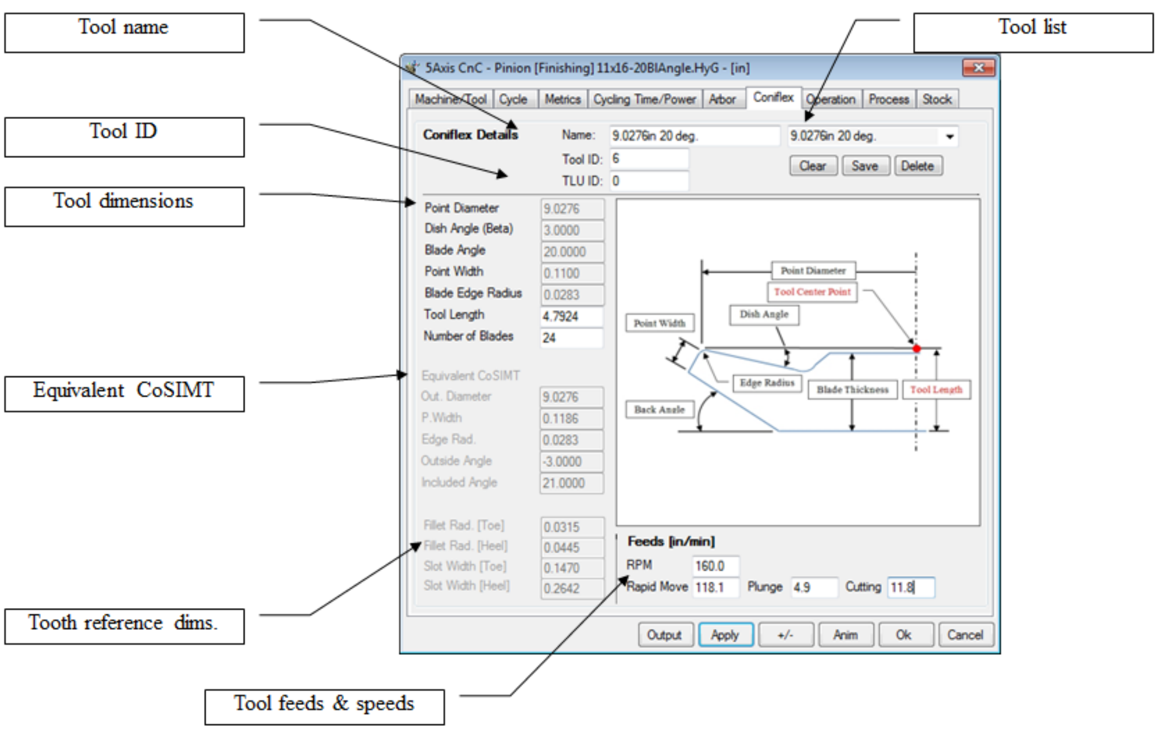
11.11 Coniflex cutter

Coniflex cutters are very specific tools, and therefore cannot be defined completely by the user.

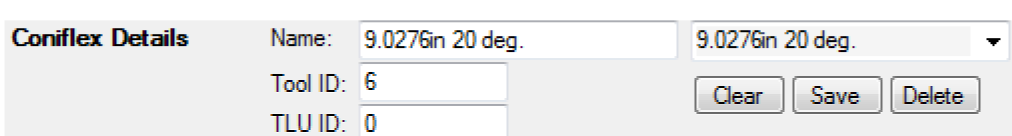
- Tool Definition
- Equivalent CoSIMT
- Part Limits
- Reference Point
- DXF Output

Given Coniflex dish type cutters are very similar to CoSIMT tools, HyGEARS provides reference values that would have to be used on a CoSIMT to be used as a Coniflex dish type cutter.

Coniflex tools are conserved in a special file called "Coniflex.fil". Users define their own tools which are added to the "Coniflex.fil" file; thus, tools are proprietary to users.



Coniflex details



Coniflex tools are identified by their name, which can be up to 30 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the End Mill list contains the names of all the End Mill tools already defined.

The *Tool ID*, by default 1, is used to identify the tool position in the tool changer.

The *TLU ID* stands for *Tool Lookup ID* and is required by some Fanuc controllers to obtain tool dimensions.

The 3 following buttons allow control over End Mill tools:

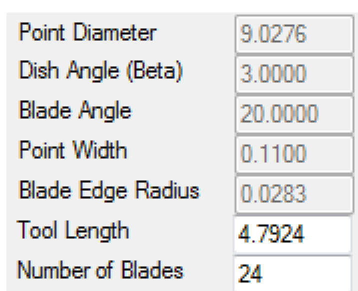
Clear: clears all input fields described below;

Save: saves the current definition of the Coniflex tool named in the *Name* field; if the Coniflex tool exists, confirmation is required to overwrite the existing definition; if it does not exist, it is saved and added to the Coniflex list to the right of the *Name* field;

Delete: deletes the currently displayed tool; confirmation is required before deletion is completed.

Tool Definition

Coniflex dish type cutters are described by the following data, which is imported from the Cutter definition in the Summary editor, and cannot be edited.



Point Diameter: the *diameter* of the Coniflex dish type cutter;

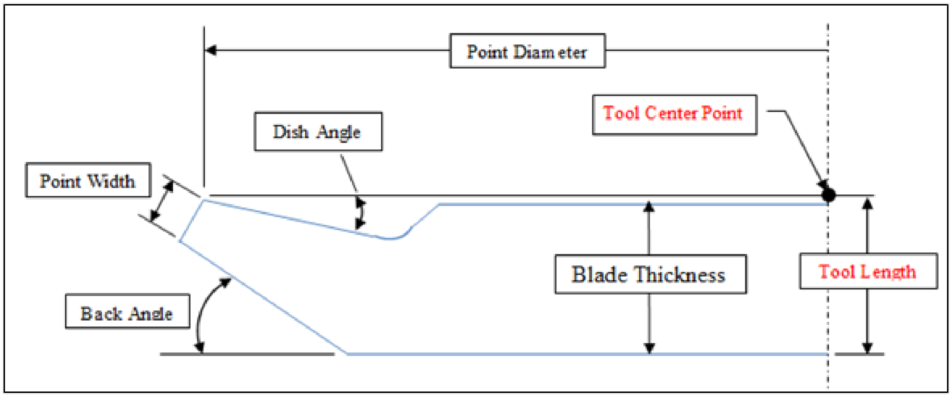
Dish Angle: the *angle* between the cutting edge of the blade and the plane of blade tips;

Blade Angle: the desired *pressure angle* of the work piece;

Point Width: the *Point Width* of the cutter blade;

Blade Edge Radius: the *radius* at the end of the cutting edge of the blade.

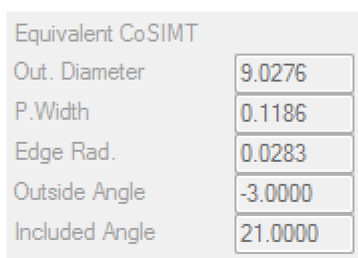
Tool Length: the *overall length* of the tool, including the support arbor.



Number of Blades: the number of *cutting edges*.

Equivalent CoSIMT

The following values are provided to define a CoSIMT equivalent to the Coniflex dish type cutter used for the current geometry.



Out. Diameter: the overall *outside diameter* of the CoSIMT;

P.Width: the *Point Width* between the tips of the cutting edges of the IB and OB blades;

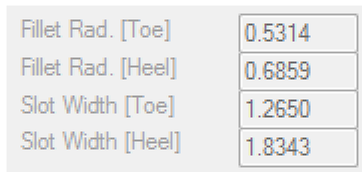
Edge Rad.: the *Edge Radius* at the end of the cutting edges of the IB and OB blades;

Outside Angle: the *angle of the cutting edge* of the outside blade; if positive, the cone is convex; if negative, the cone is concave, such as in UpGear tools; if null, the cutting face is flat such as InvoMill tools;

Included Angle: the angle between the *IB and OB cutting edges*;

Part Limits

The lower left part of the Ball Mill data page lists limits specific to the part being cut. These serve as guides to tool size. If slot width at the Fillet line is smaller than Ball Mill diameter, a warning sign is displayed; likewise, if the Fillet Radius is smaller than the radius of the Ball Mill, a warning sign is displayed.



Fillet Rad [Toe]: the *minimum* calculated fillet radius at Toe;

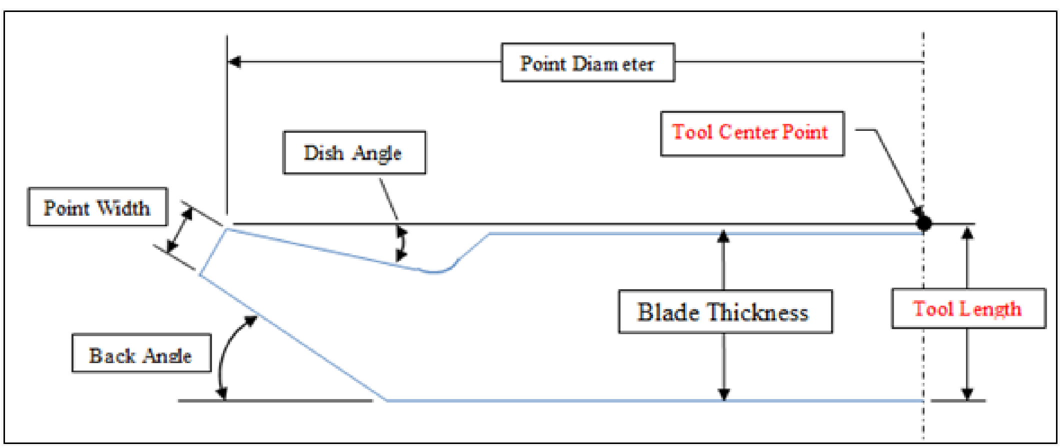
Fillet Rad [Heel]: the *minimum* calculated fillet radius at Heel;

Slot Width [Toe]: the *minimum* calculated fillet slot width at Toe;

Slot Width [Heel]: the *minimum* calculated fillet slot width at Heel;

Reference Point

Tool reference is always given at TCP, or Tool Center Point.

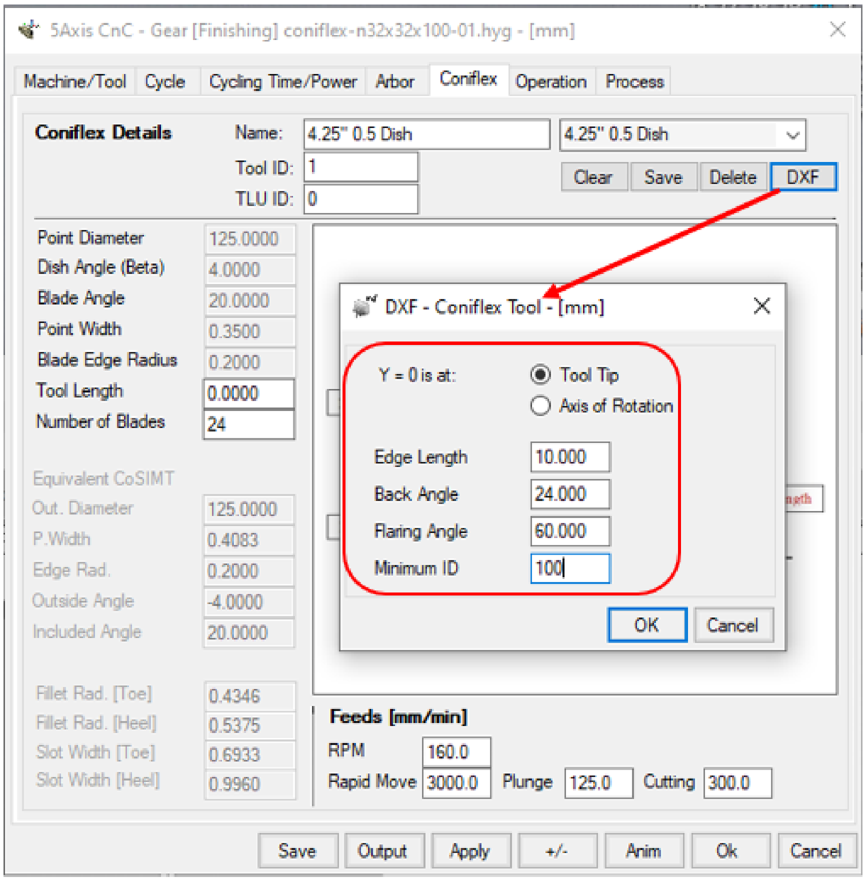


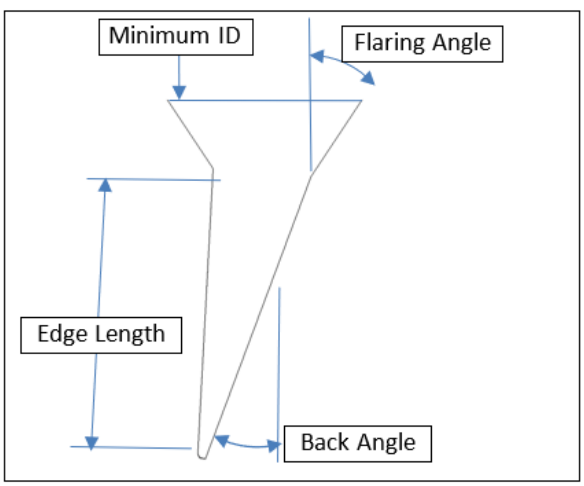
DXF Output

For the Coniflex cutter DXF output (optional), the following inputs now allow defining the tool such that on a grinder, the dressing software can account for the desired shape outside of the actual grinding area.

The following can be defined:

Y = 0 is at:	where is the radial 0 value;
Edge Length;	length of the grinding edge; default is 10 mm;
Back Angle:	back angle of the grinding wheel;
Flaring Angle:	from the grinding edge and the back side, the angle at which the dresser must travel to reach the ends of the grinding wheel disk.
Minimum ID:	where the DXF stops; if zero, then the DXF stops at the end of the grinding edge.


5Axis CnC - Gear [Finishing] coniflex-n32x32x100-01.hyg - [mm]
Machine/Tool
Cycle
Cycling Time/Power
Arbor
Coniflex
Operation
Process
Coniflex Details
Name:
4.25" 0.5 Dish
4.25" 0.5 Dish
Tool ID:
1
TLU ID:
0
Clear
Save
Delete
DXF
Point Diameter
125.0000
Dish Angle (Beta)
4.0000
Blade Angle
20.0000
Point Width
0.3500
Blade Edge Radius
0.2000
Tool Length
0.0000
Number of Blades
24
Equivalent CoSIMT
Out. Diameter
125.0000
P.Width
0.4083
Edge Rad.
0.2000
Outside Angle
-4.0000
Included Angle
20.0000
Fillet Rad. [Toe]
0.4346
Fillet Rad. [Heel]
0.5375
Slot Width [Toe]
0.6933
Slot Width [Heel]
0.9960
DXF - Coniflex Tool - [mm]
Y = 0 is at:
Tool Tip
Axis of Rotation
Edge Length
10.000
Back Angle
24.000
Flaring Angle
60.000
Minimum ID
100
OK
Cancel
Feeds [mm/min]
RPM
160.0
Rapid Move
3000.0
Plunge
125.0
Cutting
300.0
Save
Output
Apply
+/-
Anim
Ok
Cancel


Minimum ID
Flaring Angle
Edge Length
Back Angle

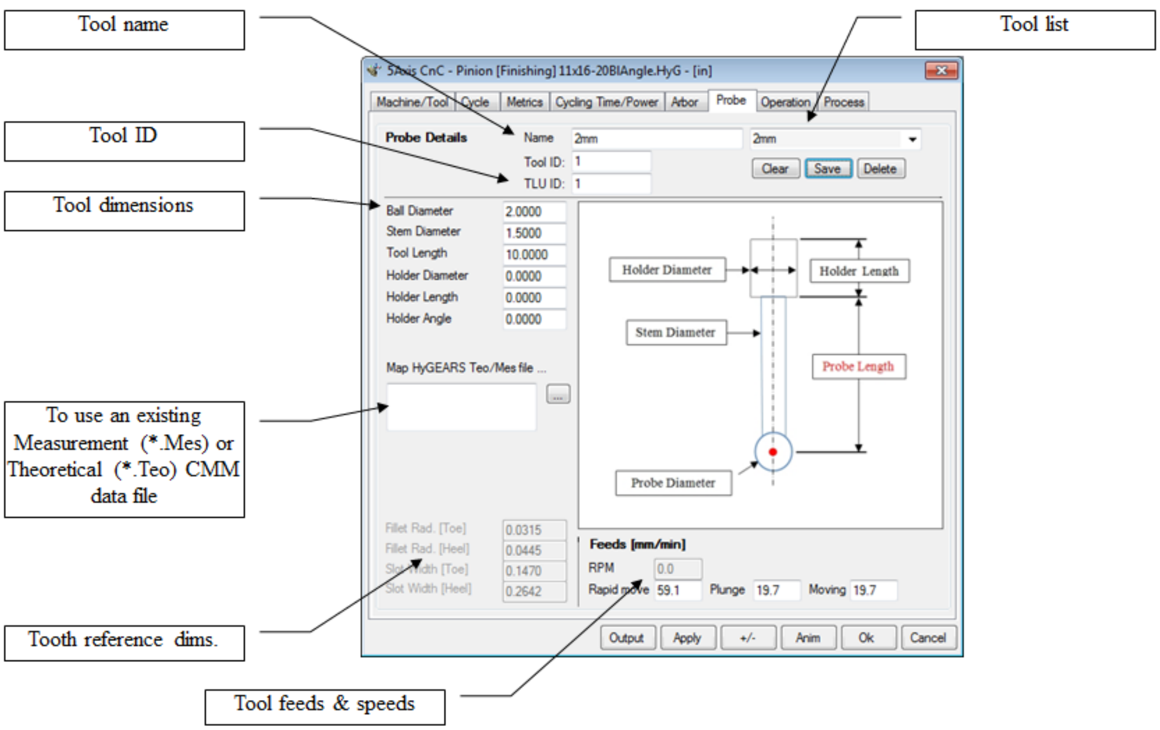
11.12 Probe (CMM) tool

Probe (CMM) tools such as Renishaw's are intended to measure *in-situ* the tooth flanks of the work piece. In essence, such tools are intended to replace a CMM to assess cutting quality and, if required, calculate and apply Corrective Machine Settings (Closed Loop).

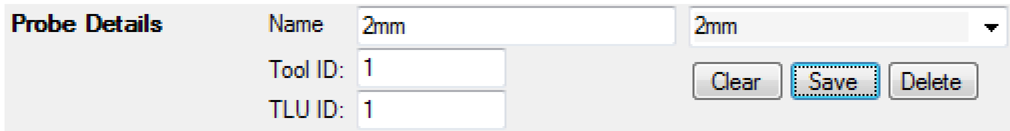
Measurement quality depends largely on machine calibration. Therefore, careful calibration of the Probe tool is essential before committing to the results obtained.

Probe tools are conserved in a special file called "Probe.fil". Users define their own tools which are added to the "Probe.fil" file; thus, tools are proprietary to users.

- Probe Details
- Tool Definition
- Part Limits
- Feeds
- Reference Point



Probe Details



Probe tools are identified by their name, which can be up to 30 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the Probe list contains the names of all the Probe tools already defined.

The *Tool ID*, by default 1, is used to identify the tool position in the tool changer.

The *TLU ID* stands for *Tool Lookup ID* and is required by some Fanuc controllers to obtain tool dimensions.

The 3 following buttons allow control over Probe tools:

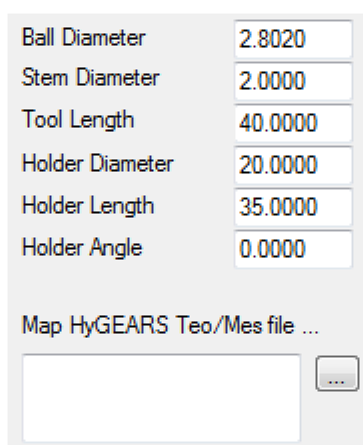
Clear: clears all input fields described below;

Save: saves the current definition of the Probe tool named in the *Name* field; if the Probe tool exists, confirmation is required to overwrite the existing definition; if it does not exist, it is added to the Probe list to the right of the *Name* field;

Delete: deletes the currently displayed tool; confirmation is required before deletion is completed.

Tool definition

Probe tools are described by the following data:



Ball Diameter: the *diameter* of the Probe measuring sphere;

Stem Diameter: the *diameter* of the stem of the Probe;

Tool Length: the overall *Tool Length*, from TCP to Holder; note that Probe tools are always referenced to TCP;

Holder Diameter: the *diameter* of the tool holder;

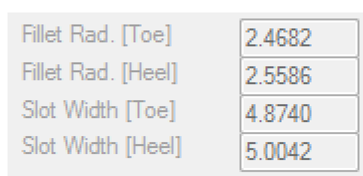
Holder Length: the *length* of the tool holder;

Holder Angle: the *angle* of the tool holder, if conical;

Map HyGEARS Teo/...: the *name* of a *CMM target* file, or *CMM output* file, after conversion to HyGEARS format (the extension of which is normally ".Teo" or ".Mes") ; HyGEARS will use the coordinates and number of points of this file to drive the Probe to measure at exactly the same location on the tooth, such that actual CMM results can be compared to CnC machine results.

Part Limits

The lower left part of the Probe data page lists limits specific to the part being cut. These serve as guides to tool size. If slot width at the Fillet line is smaller than Probe diameter, a warning sign is displayed; likewise, if the Fillet Radius is smaller than the radius of the Probe, a warning sign is displayed.



Fillet Rad [Toe]: the *minimum* calculated fillet radius at Toe;

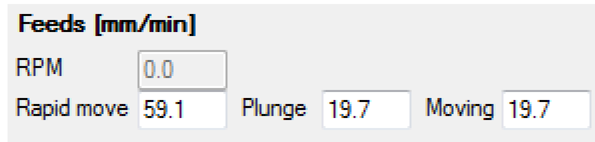
Fillet Rad [Heel]: the *minimum* calculated fillet radius at Heel;

Slot Width [Toe]: the *minimum* calculated fillet slot width at Toe;

Slot Width [Heel]: the *minimum* calculated fillet slot width at Heel;

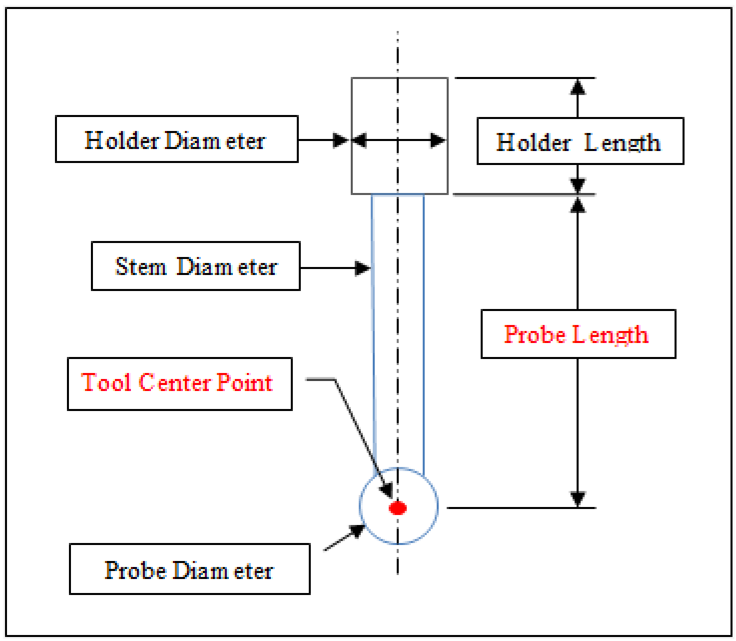
Feeds

The lower right part of the Probe data page lists the feeds associated to the Probe. These values are saved with the Probe and are retrieved each time this tool is selected from the Probe List. Note that for Probe tools, RPM does not apply and is grayed out.



Reference Point

Tool reference is always at TCP, or Tool Center Point.



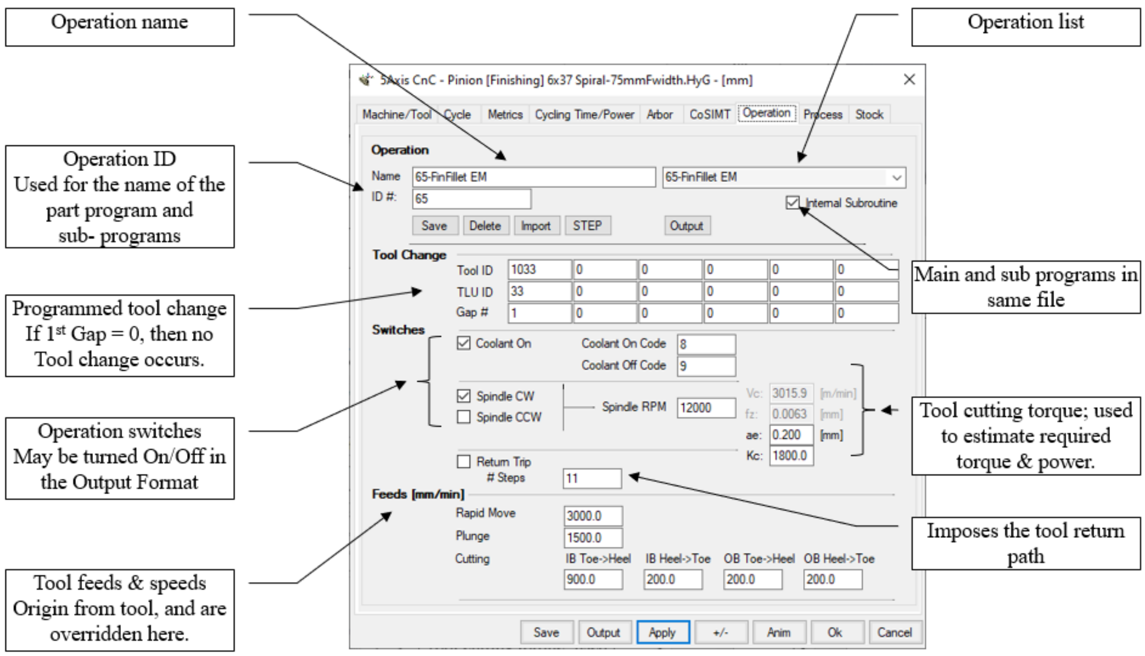
11.13 Operations

HyGEARS allows the creation of *Operations*, where every combination of Machine, Tool, Display, Compensation, Cutting Cycle and Arbor selections, for the current geometry, is saved under one identifier such as to be able to use the same combinations with different geometries, or when defining Processes.

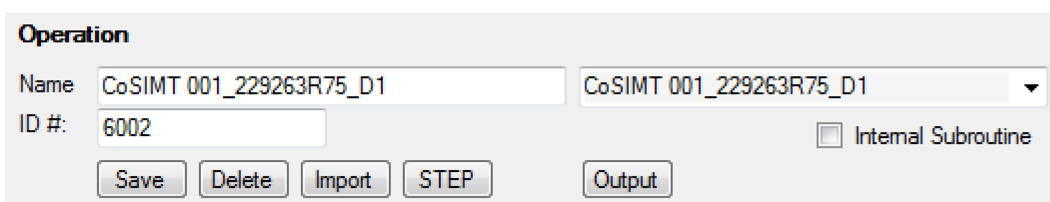
- Operation Details
- Tool Change
- Switches
- Feeds

An Operation is *specific* to a geometry, i.e. it is saved in the “Operations.fil” file stored in the *current geometry’s folder.*

The HyGEARS *Operation* is thus a very powerful and effective tool in defining and conserving the definition of a part program in a parametrized form, which is *reusable*.



Operation Details



Operations are identified by their name, which can be up to 50 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the Operations list contains the names of all the Operations already defined.

ID#: when a part-program is generated, its basic name and internal addresses will be based on the *ID#* given; numbers and alphabetical characters only;

Internal Subroutine: indicates whether the subprogram containing all the commands driving the tool are contained in the same file as the control code, or in a separate file; normally, *Internal Subroutine* should be used as it makes part program management much easier.

If the machine is defined for External Subroutines, then by default, the *Internal Subroutines* is unchecked. However, if the user checks the *Internal Subroutines* and clicks on Output without clicking on Apply, then the part program will be prepared with an Internal Subroutine.

The following buttons allow control over Operations :

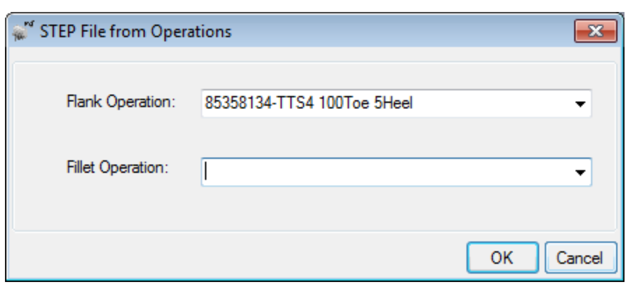
Save: saves the current Operation named in the *Name* field; if the Operation exists, confirmation is required to overwrite the existing definition; if it does not exist, it is added to the Operations list to the right of the *Name* field;

Delete: deletes the currently displayed Operation; confirmation is required before deletion is completed;

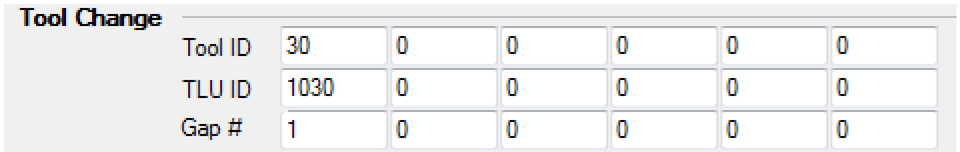
Import: allows importing Operations from other geometries such that Operations can be re-used; when the *Import* button is clicked, a Windows Explorer window is displayed to navigate to the desired folder and select the relevant *Operations.fil* file;

Output: generates and displays the part-program for the current Operation;

STEP: requires the STEP option; allows creating a STEP file made of 2 Operations: one for the tooth Flank, one for the Fillet; thus the created STEP file could be used in a FEA software to assess the effects of a protuberance in the Fillet, or else.



Tool Change



The programmed "*Tool Change*" uses a macro to specify, at set tooth gap intervals, what tool should be used. This allows bypassing the controller command which may be used to impose regular tool change.

Tool Changes may be required when large gears, with a large number of gaps, are to be hard finished; the finishing End Mill or Ball Mill tools may then wear off rapidly and may require early replacement.

For example, above figure, a 25 tooth part is cut, with tool #1 for tooth gap 1 to 8, tool #11 for tooth gap 9 to 17, and tool #29 for tooth gap 18 to 25. At the end of the cycle, the tool is returned to that of tooth gap 1, i.e. tool #1, but without loading it (thus M6 is not shown in the code below).

The control sequence of the part program then takes on the following shape:

```
           (  -----------   Start of Program   ---------- )
           (  ----------   Start of Cycle   ------------- )
           (                  Section  1                  )

 T1 M6                                                            (  Tool
Change Macro )

           (  --------   Tooth Space #  1  -------------- )
 G52 C-14.400
( Increment gap space angle )
 M98 P6002                                                        ( GoTo
Subroutine 6002 )

...
           (  --------   Tooth Space #  8  -------------- )
 G52 C-115.200
( Increment gap space angle )
 M98 P6002                                                        ( GoTo
Subroutine 6002 )

 T21011 M6                                                        (  Tool
Change Macro )

           (  --------   Tooth Space #  9  -------------- )
 G52 C-129.600
( Increment gap space angle )
 M98 P6002                                                        ( GoTo
Subroutine 6002 )

...
           (  --------   Tooth Space # 17  -------------- )
```

```
 G52 C-244.800
( Increment gap space angle )
 M98 P6002                                                    ( GoTo
Subroutine 6002 )

 T29 M6                                                       (  Tool
Change Macro )

           (  --------   Tooth Space # 18  -------------- )
 G52 C-259.200
( Increment gap space angle )
 M98 P6002                                                    ( GoTo
Subroutine 6002 )

...
           (  --------   Tooth Space # 25  -------------- )
 G52 C-0.000
( Increment gap space angle )
 M98 P6002                                                    ( GoTo
Subroutine 6002 )
           (  ----------   End of Cycle   --------------- )

 T1                                                           (  Tool
Change Macro )
```

Notes:

- The Tool Change option calls a Tool Change macro (see the Machine Definition data page), specifically defined for each machine; by default, the Tool Change macro is "T## M6" where "##" indicates the tool ID.
- It is also possible to tell the controller to prepare the next tool to be called by using the appropriate command followed by "??"; for example, on the Okuma controller, using the "G116 T## Q??" macro tells the controller to load tool "##" and prepare tool "??" which will be used next after tool "##"; the "load next tool" command ("Q??" above) must follow the "select tool command" ("T##" above);
- the Tool Change macro can be given on several lines;
- in the sample code given above, the default Tool Change macro "T## M6" is used; ## is replaced by the Tool ID value for the given gap;
- TLU ID stands for *Tool Look Up ID* and is meant to tell the machine controller where to search for tool length offset; the TLU ID given replaces the *!!* characters in the Tool Change Macro, as shown below in line *G43 H!!* for a Fanuc controller;

Tool Change Macro

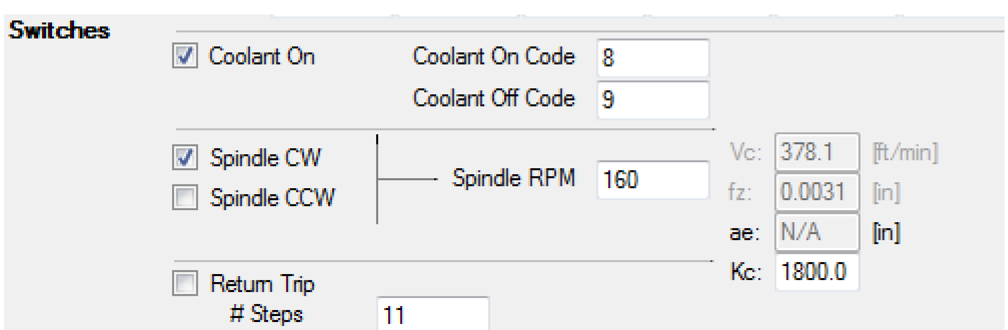
```
T##                 (Tool number)
G361 B-90.0 D0.     (Set B at -90)
G43 H!!             (Tool length offset from controller table)
G97 S#569 M13       (Constant RPM - Start Spindle)
M369                (Release BAxis brake)
```

- if no Tool Change macro is given, then nothing is displayed;
- if the first Gap# is empty or 0, then the Tool Change Macro is not used; likewise, if no tool ID is given, then no Tool Change occurs;
- Tool #1 is always given in the Operation switches, even if no Tool Changes are requested;
- If only 1 tool is given, then the Tool Change macro is called at the very beginning of the Cycle sequence;
- If more than 1 tool is given, the 1st tool is recalled at the end of the Cycle sequence;
- The Short Header lists all the tools used, i.e., for the above example:

```
(**************************************)
(PROGRAM NAME        : 3/32" FINISH FILLET)
(PROGRAM DATE        : 07-18-2015)
(SUMMARY VERSION     : [Nominal])
(TOOL ID             : 1 11 29)
(TOOL DIAMETER       : 2.39[mm])
(TOOL LENGTH         : 12.00 [mm])
(APEX LOCATION       : 50.00 [mm])
(**************************************)
```

Switches

Several *Switches* may be defined, as follows. These will be used as long as the "Include Operation Switches" option is selected in the Cycle data page, Output Format section.



Coolant On: tells HyGEARS that Coolant is to be used, or not; then appropriate Coolant codes are given for the machine;

Spindle: spindle RPM and direction, either CW or CCW, are given; note that this value is used to control spindle RPM whether the Switches output is enabled or not;

Cutting data: Next to the Spindle RPM, tool cutting data is given; when the Spindle RPM or Cutting Feed is modifed, *Vc* and *fz* are updated (*fz* is based on the largest of the enabled Cutting Feeds).

Vc:	378.1	[ft/min]
fz:	0.0031	[in]
ae:	N/A	[in]
Kc:	1800.0	

- *Vc*: cutting speed, i.e. tangential speed at the tool OD;
- *fz*: feed / tooth, i.e. size of the cutting bite / tool blade or flute;
- *ae*: working engagement, i.e. shape of the cut; may be disabled and replaced by "*N/A*" when *Not Applicable,* for example for Face Mill / Coniflex tools;
- *Kc:* material constant; see tables below (https://www.sandvik.coromant.com/en-us/knowledge/milling/formulas_and_definitions/formulas).

ISO Material Classification

ISO	CMC No.	MATERIAL		SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
P Steel				N/MM²	HB
	01.1	UNALLOYED STEEL	C=0.1-0.25%	2000	125
	01.2		C=0.25-0.55%	2100	150
	01.3		C=0.55-0.80%	2200	170
	02.1	LOW-ALLOY STEEL (alloying elements≤5%)	Non-hardened	2150	180
	02.12		Ball bearing steel	2300	210
	02.2		Hardened and tempered	2550	275
	02.2		Hardened and tempered	2850	350
	03.11	HIGH-ALLOY STEEL (alloying elements>5%)	Annealed	2500	200
	03.21		Hardened tool steel	3900	325
	06.1	STEEL CASTING	Unalloyed	2000	180
	06.2		Low-alloy (alloying elements≤5%)	2100	200
	06.3		High-alloy (alloying elements>5%)	2650	225

ISO	CMC No.	MATERIAL			SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
M Stainless steel					N/MM²	HB
	05.11	STAINLESS STEEL	Non-hardened		2300	200
	05.12	-Bars/forged	PH-hardened		3550	330
	05.13	Ferritic/martensitic	Hardened		2850	330
	05.21	STAINLESS STEEL	Austenitic		2300	180
	05.22	-Bars/forged	PH-hardened		3550	330
	05.23	Austenitic	Super austenitic		2950	200
	05.51	STAINLESS STEEL	Non-weldable	≥0.05%C	2550	230
	05.52	-Bars/forged	Weldable	<0.05%C	3050	260
		Austenitic-ferritic				
		(Duplex)				
	15.11	Stainless steel - Cast	Non-hardened		2100	200
	15.12	Ferritic/martensitic	PH-hardened		3150	330
	15.13		Hardened		2650	330
	15.21	Stainless steel - Cast	Austenitic		2200	180
	15.22	Austenitic	PH-hardened		3150	330
	15.23		Super austenitic		2700	200
	15.51	Stainless steel - Cast	Non-weldable	≥0.05%C	2250	230
	15.52	Austenitic-ferritic	Weldable	<0.05%C	2750	260
		(Duplex)				

ISO	CMC No.	MATERIAL		SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
K Cast iron				N/MM²	HB
	07.1	MALLEABLE CAST IRON	Ferritic (short chipping)	940	130
	07.2		Pearlitic (long chipping)	1100	230
	08.1	GREY CAST IRON	Low tensile strength	1100	180
	08.2		High tensile strength	1150	220
	09.1	NODULAR SG IRON	Ferritic	1050	160
	09.2		Pearlitic	1750	250
	09.3		Martensitic	2700	380

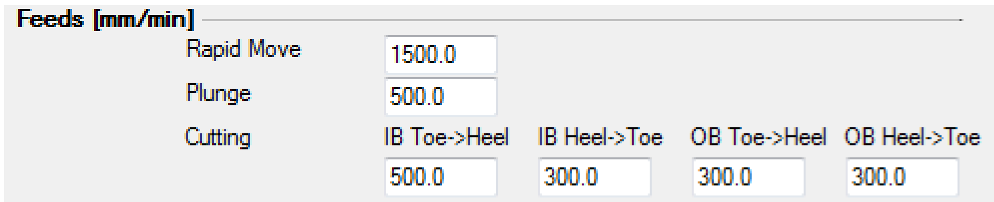
ISO	CMC No.	MATERIAL		SPECIFIC CUTTING FORCE Kc 0.4	HARDNESS BRINELL HB
H Hardened material				N/MM²	HB
	04.1	HARD STEEL	Hardened and tempered	3250	45 HRC
		Extra hard steel	Hardened and tempered	5550	60 HRC
	10,1	CHILLED CAST IRON	Cast or cast and aged	2800	400

Return Trip: the *Return Trip* is a sequence of commands at the end of the subprogram which drive the tool back to its starting position; some controllers, when left free to bring the tool back to the coordinates at the start of the subprogram, may take a "shortcut" which can result in a collision with the work piece; this is frequent when Work Coordinates are chosen; using the *Return Trip* imposes the tool path.

In order to avoid having to use the *Return Trip*, or to ensure there is no risk of collision, one can select an even number of Steps such that the tool starts and ends the cycle at Toe or Heel.

When HyGEARS detects that the Start and End of a given cycle are at either Toe or Heel, the Return Trip is unchecked automatically such as to prevent undesired tool motions.

Feeds



Tool feeds are obtained from the tool definition; when a tool (Face Mill, CoSIMT, End Mill, Ball Mill, Probe) is selected, its feeds are copied to the Operation data page; the values in the Operation data page can then be modified as desired, and will be conserved as defined if the Operation is saved.

One can thus override the tool Feed values at the Operation level.

In particular, up to four (4) Cutting Feeds can be defined for any tool, to account for the direction of rotation of the tool and the direction of travel along the tooth face. Cutting Feeds become enabled when relevant to the selected Cycle.

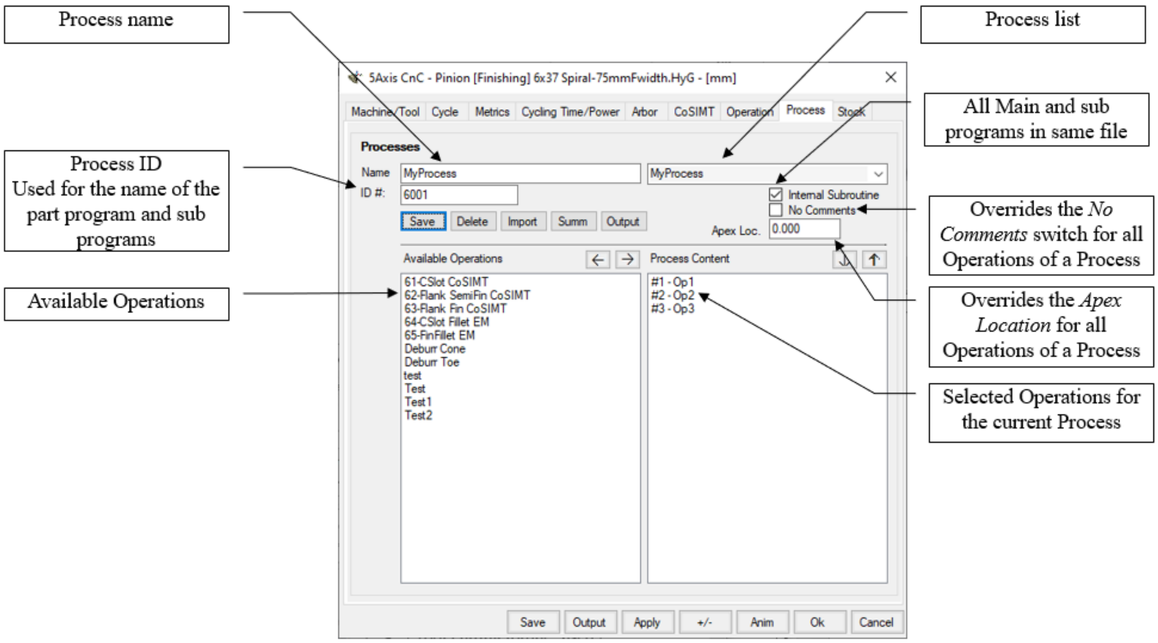
11.14 Processes

HyGEARS allows the creation of *Processes*, where selected Operations are sequenced in a specified order.

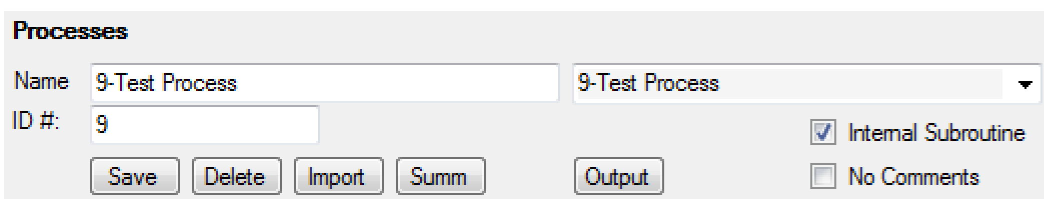
- Process Details
- Available Operations
- Process Content

A Process is *specific* to a geometry, i.e. it is saved in the “Processes.fil” file stored in the *current geometry’s folder*.

The HyGEARS *Process* is a very powerful and effective tool in defining and conserving the sequence of part programs in parametrized form, which is *reusable*.



Process Details



Processes are identified by their name, which can be up to 50 characters long, and may include any character. To the right of the *Name* input field, in light gray color, the Processes list contains the names of all the Processes already defined.

ID#: when a part-program is generated, its basic name and internal addresses will be based on the *ID#* given; numbers and alphabetical characters only;

The *ID#* is used to determine the alphanumeric character string from which the Process will be numbered, and how the Operations called from the Main program are numbered; the default value for the "ID #" is that of the "Pgm Start #" defined in the controller section of the Machine Definition.

The Process name is based on the ID #; all Operations in the sequence increase by 3; since there can be up to 2 sections in each Operation, Section #1 = Operation + 1; Section #2 = Operation + 2. Sections in an Operation can be internal or external files as well.

Thus, for a Process “ID #” = A6001, assuming the Main and Sub program Prefix is “O”, we would have the following names for each program in the Process:

```
Main:                       "OA6001"
Operation 1:                "OA60011"         (i.e. Main + "1")
        Section 1:          "OA60012"         (i.e. Main + "2")
        Section 2:          "OA60013"         (i.e. Main + "3")
Operation 2:                "OA60014"         (i.e. Main + "4")
        Section 1:          "OA60015"         (i.e. Main + "5")
        Section 2:          "OA60016"         (i.e. Main + "6")
  … etc.
```

Internal Subroutine: indicates whether the subprograms containing all the commands driving the tools are contained in the same file as the control code, or in a separate file; normally, *Internal Subroutine* should be used as it makes part program management much easier.

If the machine is defined for External Subroutines, then by default, the *Internal Subroutines* is unchecked. However, if the user checks the *Internal Subroutines* and clicks on Output without clicking on Apply, then the part program will be prepared with an Internal Subroutine.

No Comments: overrides the *No Comments* switch of all individual Operations of the selected Process. Thus, Operations can be defined and tested with comments, but when generating the complete Process, all comments can be removed such as to produce clean code.

Apex Loc.: overrides the *Apex Location* of all individual Operations of the selected Process. Thus, Operations can be defined and tested with a given Apex Location and when generating the complete Process, the *Apex Loc.* value overrides the Apex Location values already in all individual Operations of the selected Process.

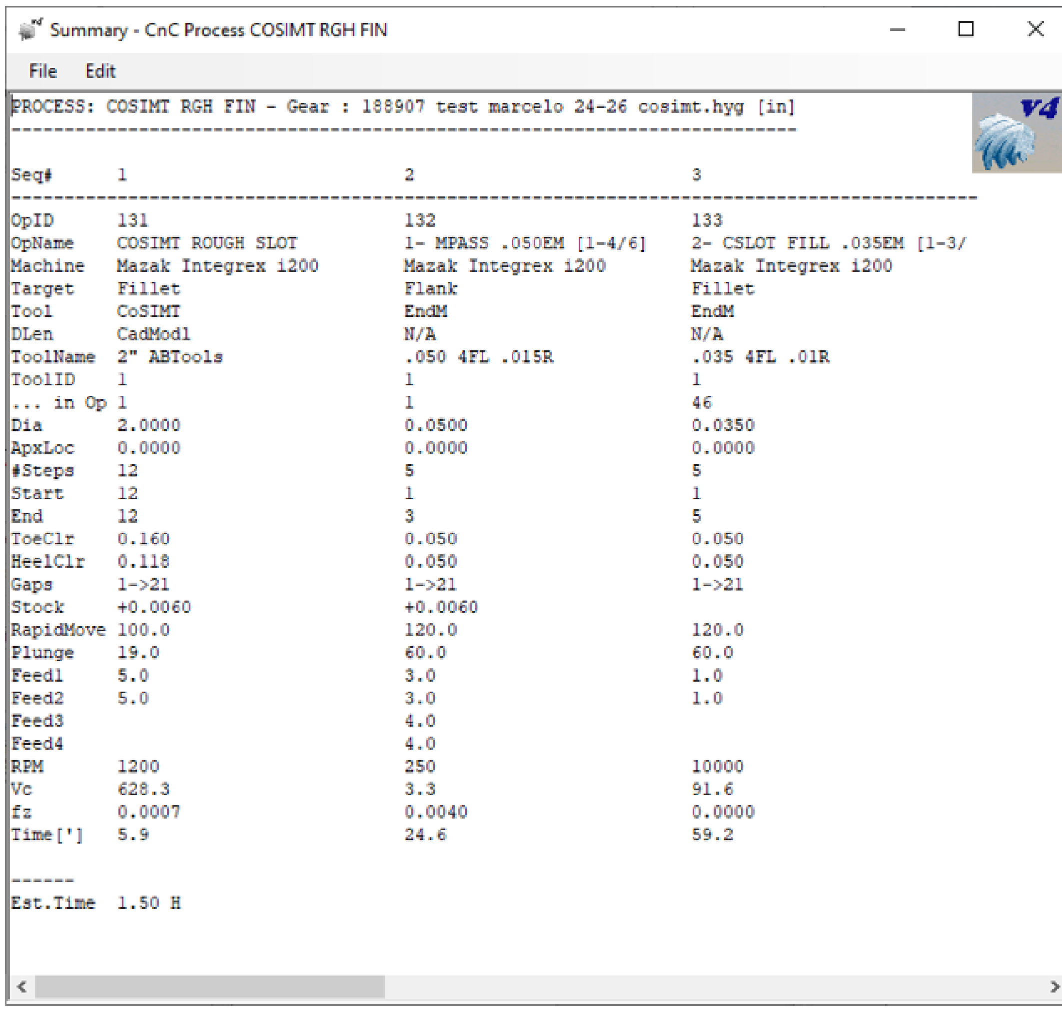
The following buttons allow control over Operations :

Save: saves the current *Process* named in the *Name* field; if the *Process* exists, confirmation is required to overwrite the existing definition; if it does not exist, it is added to the Processes list to the right of the *Name* field;

Delete: deletes the currently displayed Process; confirmation is required before deletion is completed;

Import: allows importing Processes from other geometries such that Processes can be re-used; when the *Import* button is clicked, a Windows Explorer window is displayed to navigate to the desired folder and select the relevant *Processes.fil* file;

Summ: generates and displays a short Process Summary, where the most significant elements are given in a table. The content can be saved to a text file for later consultation. This can be very useful for the machine operator who knows in which sequence Operations are carried out, and with which tool.



Summary - CnC Process COSIMT RGH FIN

File Edit

PROCESS: COSIMT RGH FIN - Gear : 188907 test marcelo 24-26 cosimt.hyg [in]

Seq#	1	2	3
OpID	131	132	133
OpName	COSIMT ROUGH SLOT	1- MPASS .050EM [1-4/6]	2- CSLOT FILL .035EM [1-3/
Machine	Mazak Integrex i200	Mazak Integrex i200	Mazak Integrex i200
Target	Fillet	Flank	Fillet
Tool	CoSIMT	EndM	EndM
DLen	CadModl	N/A	N/A
ToolName	2" ABTools	.050 4FL .015R	.035 4FL .01R
ToolID	1	1	1
... in Op	1	1	46
Dia	2.0000	0.0500	0.0350
ApxLoc	0.0000	0.0000	0.0000
#Steps	12	5	5
Start	12	1	1
End	12	3	5
ToeClr	0.160	0.050	0.050
HeelClr	0.118	0.050	0.050
Gaps	1->21	1->21	1->21
Stock	+0.0060	+0.0060	
RapidMove	100.0	120.0	120.0
Plunge	19.0	60.0	60.0
Feed1	5.0	3.0	1.0
Feed2	5.0	3.0	1.0
Feed3		4.0	
Feed4		4.0	
RPM	1200	250	10000
Vc	628.3	3.3	91.6
fz	0.0007	0.0040	0.0000
Time[']	5.9	24.6	59.2

Est.Time 1.50 H

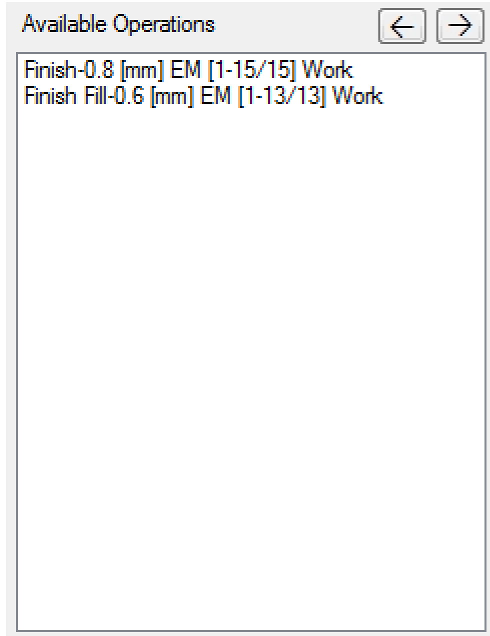
The information displayed includes:

- Seq#: the order in which each Operation is executed;
- OpID: the Operation ID given in the Operation data page;
- OpName: the name given to the Operation;

- Machine: name of the machine used (normally always the same);
- Target: either Fillet, Flank or Combined;
- Tool: FMill, CoSIMT, EndM, BallM;
- DLen: tool length compensation for CoSIMT tools;
- ToolName: name given to the tool;
- ToolID: ID given in the Operation data page and used by some controllers;
- ApexLoc: Apex Location value;
- Start: Start step;
- End: End step;
- ToeClr: Toe clearance;
- HeelClr: Heel clearance;
- Stock: stock, either + or -;
- RapidMove: Rapid move feed;
- Plunge: Plunge feed;
- Feed 1/2/3/4: Individual feeds, as entered in the Operations page;
- RPM: The current tool's RPM;
- Vc: Circumferential speed at the tool's OD;
- fz: Feed per tooth;
- Time[‘]: expected time required for each Operation;
- Est.Time: estimated total time required for the Process (in Hours).

Output: generates and displays all the part-programs for all the Operation contained in the defined Process.

Available Operations



The *Available Operations* lists all the Operations defined for the current geometry, to the exception of the Operations already selected in the *Process Content* list.

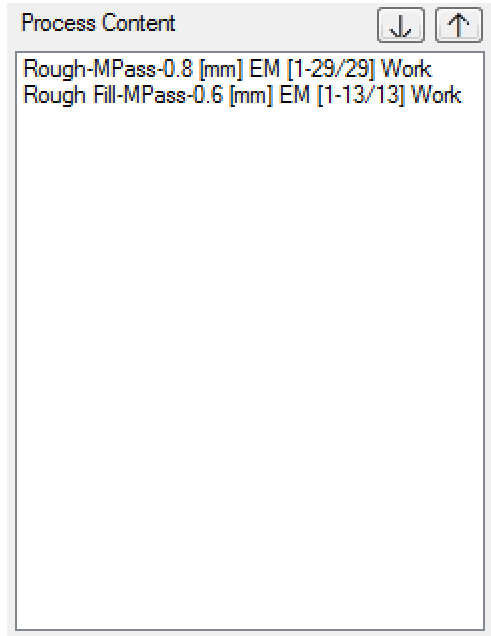
Double clicking on any Operation within the *Available Operations* list activates and displays this Operation and HyGEARS switches to the Cycle tab for review. However, if there is a problem with the tool, then focus is given to the tool's definition tab.

Several Operations may be selected at the same time, and moved to the Process Content list.

 adds the currently selected “Available Operation” at the end of the “Process Content” and removes it from the "Available Operations" list; an Operation cannot appear more than once in the Process Content;

 removes the currently selected Operation from the “Process Content” and adds it to the "Available Operations" list.

Process Content



The *Process Content* lists, in the requested order, all the selected Operations for the current Process.

Double clicking on any Operation within the *Process Content* list activates and displays this Operation and HyGEARS switches to the Cycle tab. However, if there is a problem with the tool, then focus is given to the tool's definition tab.

Several Operations may be selected at the same time, and moved back to the Available Operations list.

 moves Up one step the currently selected Operation in the *Process Content*;

 moves Down one step the currently selected Operation in the *Process Content*.

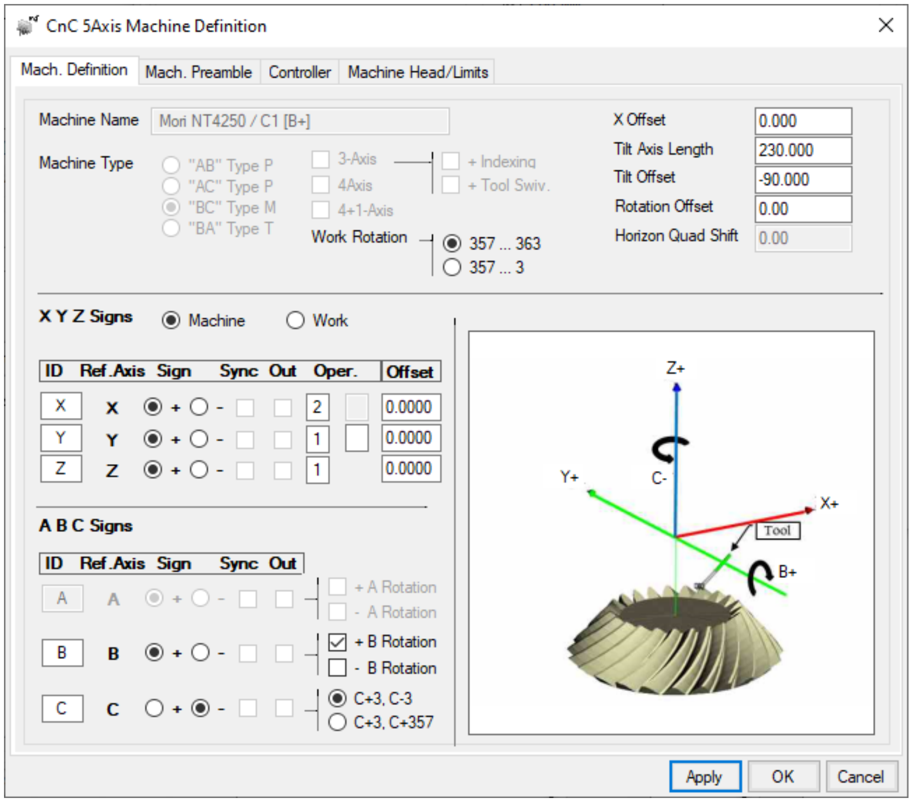
11.15 Machine Definition

The "*5 Axis CnC Machine Definition*" window is used to specify how a machine is built. The names, or IDs, of all axes may be specified, along with their positive direction.

Three data pages allow defining a machine:

- Machine Definition
- Mach. Preamble
- Controller

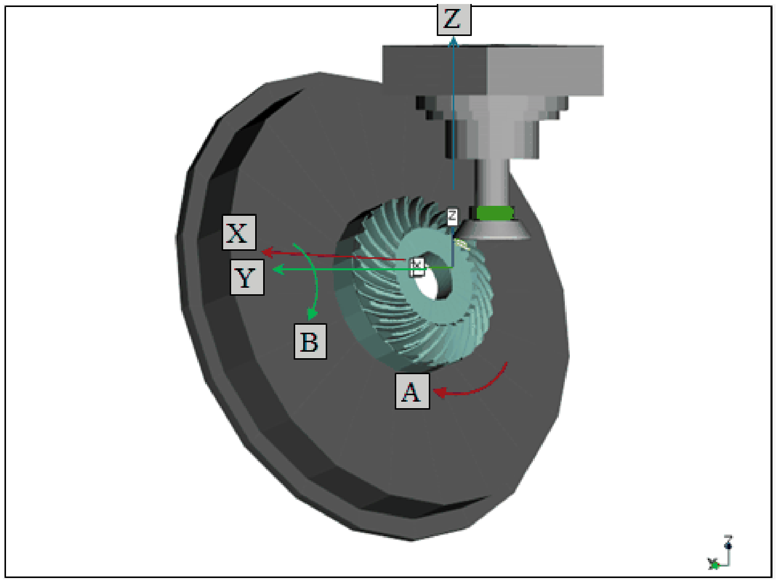
- Machine Head



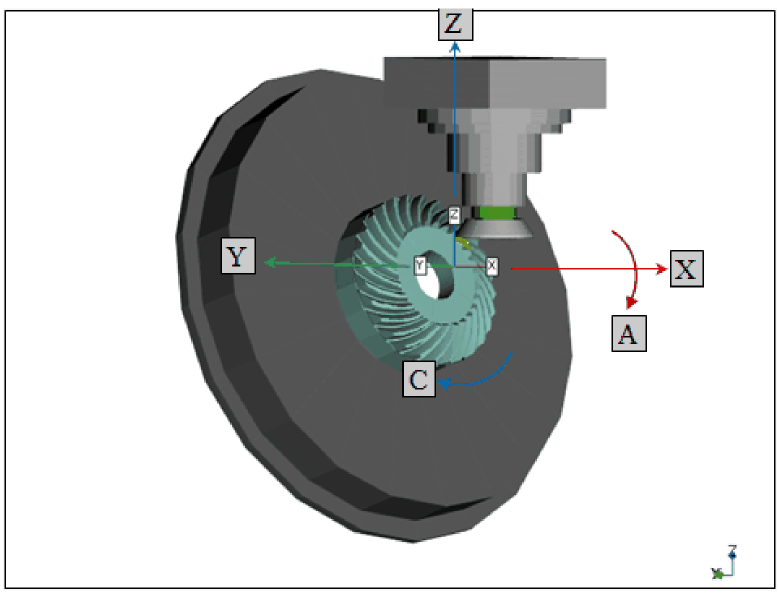
When a "New" machine is created, the machine type must be specified. Once specified, machine type cannot be changed - for example, when editing an existing machine ("Edit" button).

Machine Definition

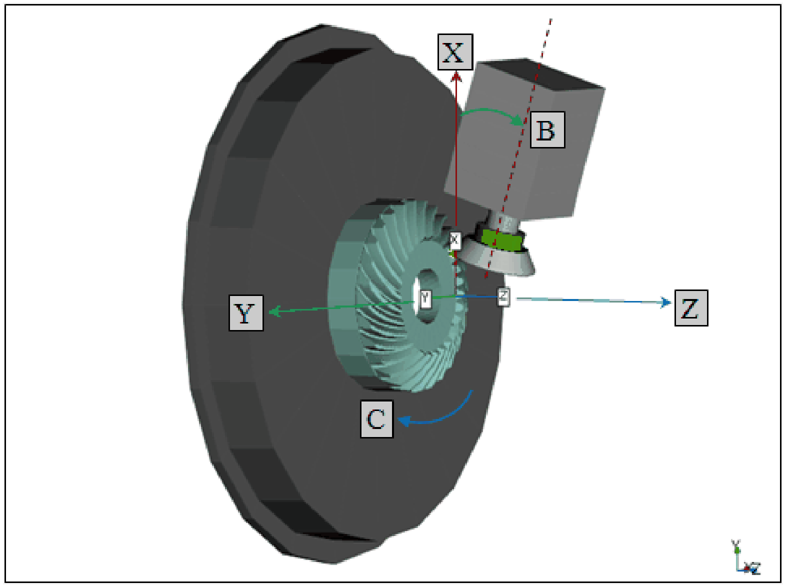
- *5 Axis machines* can be:
  "AB" [type P]: X, Y Z linear coordinates, rotation B about axis Y and workpiece rotation A:



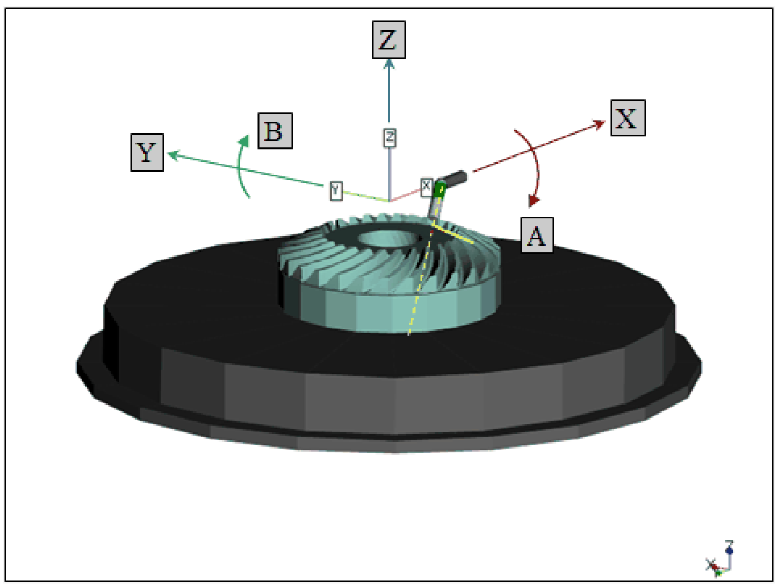
"AC" [type P]: X, Y Z linear coordinates, rotation A about axis X and workpiece rotation C:



"BC" [type M]: X, Y Z linear coordinates, tool tilt B about axis Y and workpiece rotation C:



"BA" [type T]: X, Y Z linear coordinates, tool swivel A about axis X and tilt B about axis Y:

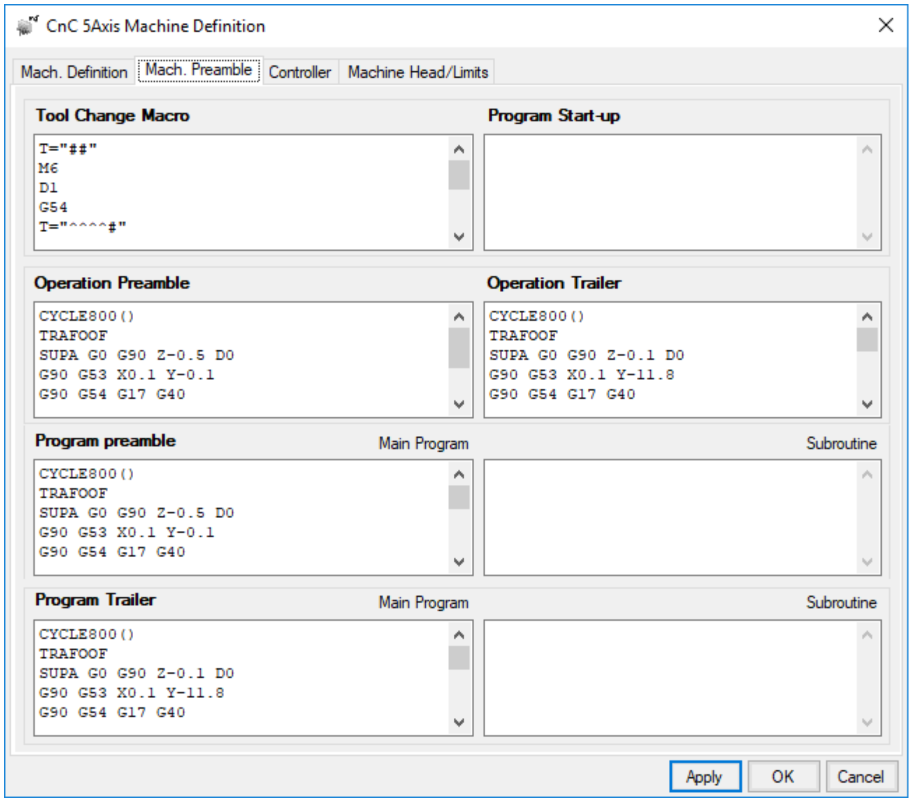


- *4 Axis machines* can have 1 axis which is not synchronized ("Sync" check boxes); it is also possible to specify which axis is outputted to the part program ("Out" below);
- *3 Axis machines* can allow indexation ("+ Indexing"), which means that only X, Y and Z coordinates are used to move the tool, but turntable rotation is used to index from tooth gap to tooth gap.

It is also possible to allow the tool to be swiveled ("+ Tool Swiv.") where a fixed tool angle may be imposed from the "Machine / Tool" data page of the "5Axis" window.

Mach. Preamble

The "Mach. Preamble" data page allows defining:



Tool Change Macro: this is a series of commands used to tell the controller how to load a specific tool; at execution time, the "##" character chain will be replaced by the tool ID; and the "??" character chain, if present, will be replaced the next required tool.

The "Tool Change Macro" can be several lines long.

When any of the following character chains is present in the "Tool Change Macro", it is replaced by:

"##"	Tool ID
"!!"	Tool Lookup Unit ID in tool changer
"??"	Calls the next required tool in the current Operation

"^^^^#"	Calls the tool required in the next Operation
"$$$$"	M code for CW / CCW rotation (typically M3 / M4)
"++++"	Tool Spindle RPM
"^^^^#"	Next Tool ID; used in Processes;
"?/!?/!"	Machining Tolerance (when required, such as in Siemens' CYCLE832)
"////"	If the Coolant On option in the Operation tab is selected, then the M8 command is given, otherwise, M9 is given.

Program Start-up: this is a series of commands used at the very beginning of the Program, before any declaration is done.

Program Preamble **Main Program**: series of commands that are placed at the *beginning of each part program*; these commands are machine and controller specific; the "Program preamble" can be several lines long.

When any of the following character chains is present in the Preamble, it is replaced by:

"####"	Tool ID
"!!!!"	Tool spindle RPM
"!!"	Tool Look-up ID (TLU)
"ALIGNANG"	Alignment angle
"!MODULE!"	Outer transverse module
"!N!"	Number of teeth
"$$$$"	M code for CW / CCW rotation (typically M3 / M4)
"?/!?/!"	Machining Tolerance (when required, such as in Siemens' CYCLE832)
"@??@??"	FcXP is inserted; this can be used to locate the tool prior to plunging;

"!TOOLLENGTH!"	overall length of the tool;
"@??@??"	Front Crown to Xp;
"?ANGLEA?"	first angular position around X axis;
"?ANGLEB?"	first angular position around Y axis;
"?ANGLEC?"	first angular position around Z axis;
"X!X!X!"	X coordinate at Center Roll position;
"Y!Y!Y!"	Y coordinate at Center Roll position;
"Z!Z!Z!"	Z coordinate at Center Roll position;
"VX!VX!VX!"	tool axis X direction at Center Roll position;
"VY!VY!VY!"	tool axis Y direction at Center Roll position;
"VZ!ZV!VZ!"	tool axis Z direction at Center Roll position;
"A!A!A!"	A angle at Center Roll position;
"B!B!B!"	B angle at Center Roll position;
"C!C!C!"	C angle at Center Roll position.

In the above, X Y Z A B C represent the reference labels for the considered axis; if this axis has been relabeled, for example C is rather called C2, then its given label is used.

Work piece coordinates are given if the program is work piece mode.

Subroutine: series of commands that are placed at the *beginning of each subprogram*; these commands are machine and controller specific; can be several lines long.

Operation Preamble	series of commands that are placed at the *beginning of each Operation*; these commands are machine and controller specific; the "Operation preamble" can be several lines long. When any of the following character chains is present in the Preamble, it is replaced by:

"?/!?/!"	Machining Tolerance (when required, such as in Siemens' CYCLE832)
"$$$$"	M code for CW / CCW rotation (typically M3 / M4)
"////"	If the Coolant On option in the Operation tab is selected, then the M8 command is given, otherwise, M9 is given.
"++++"	Tool Spindle RPM

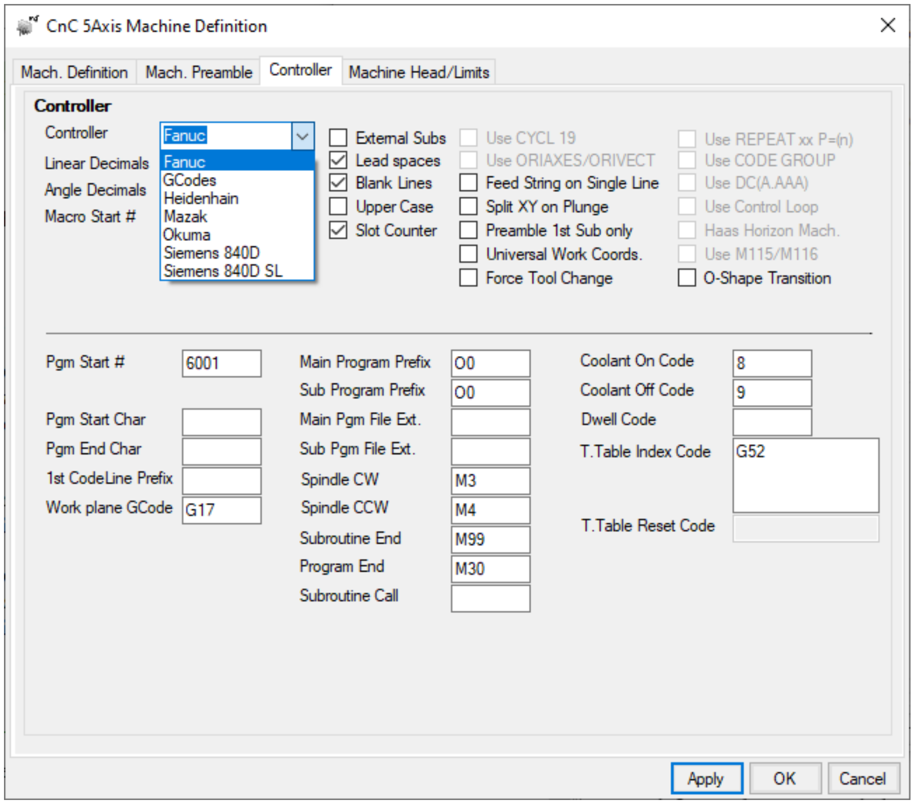
In the above, X Y Z A B C represent the reference labels for the considered axis; if this axis has been relabeled, for example C is rather called C2, then its given label is used.

Work piece coordinates are given if the program is work piece mode.

Program Trailer	**Main Program**: series of commands that are placed at the *end of each part program*; these commands are machine and controller specific; the "Program Trailer" can be several lines long. **Subroutine**: series of commands that are placed at the *end of each subprogram*; these commands are machine and controller specific; can be several lines long.

Controller

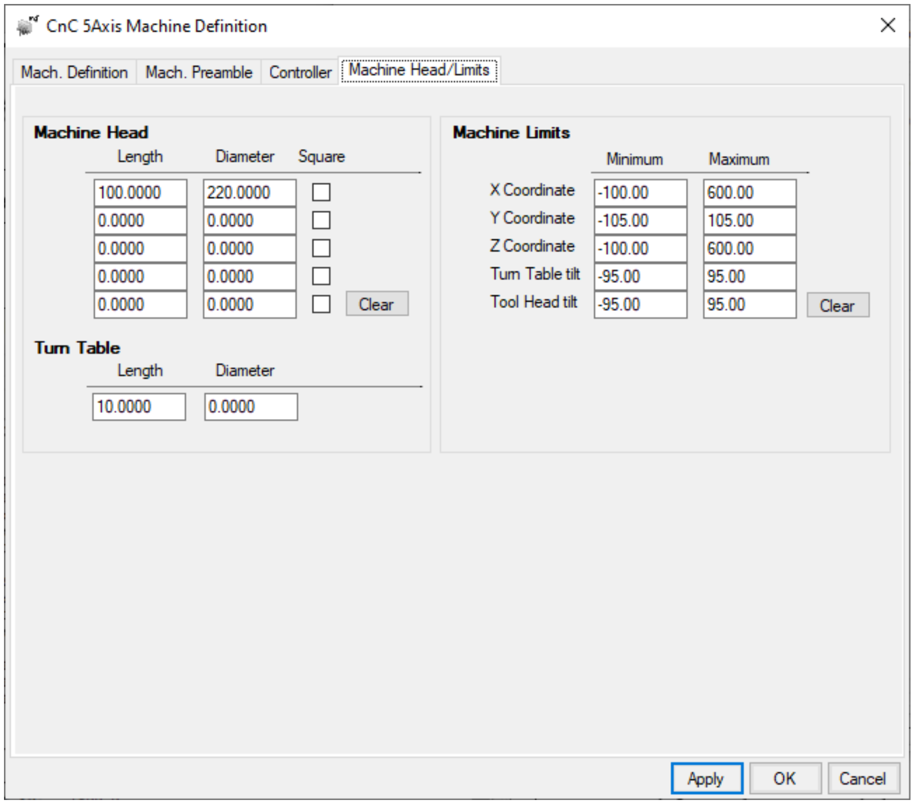
The "Controller" data page allows defining several controller switches and commands:



Controller: several controllers are offered in a list such as in the above picture; specifics for each controller are better defined with the help of Involute Inc.

Machine Head

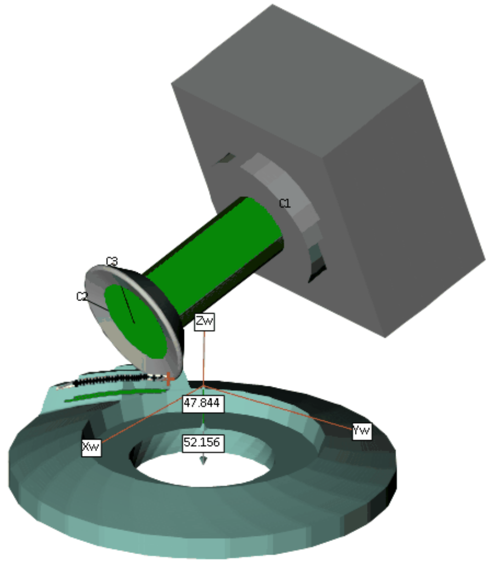
The "Machine Head" data page allows defining:



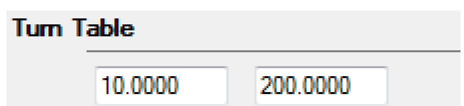
Machine Head: this is a series cylinders or boxes representing the machine head for visualization purposes; the 1st entry is closest to the tool (100 mm Length, 220 mm Diameter above), the last entry is farthest from the tool.

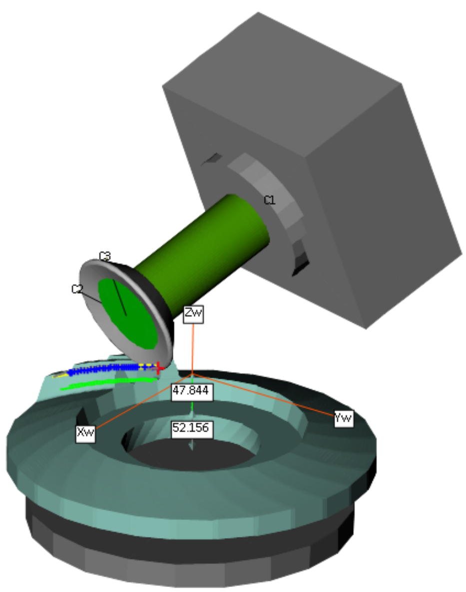
For example, figure below, the Machine Head comprises 2 parts:

- first, a cylindrical part of 175 mm diameter, 29 mm long;
- send, a square part 386 mm in side, 161 mm long.



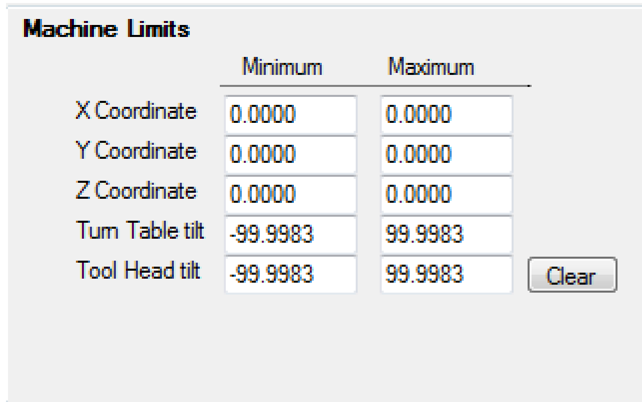
Turn Table: this is one cylinder, defined by its length and diameter, representing the turntable on which the work piece is installed; for visualization purposes; the turn table is displayed when the Display T.Table option is checked in the Machine-Tool tab of the 5Axis window.

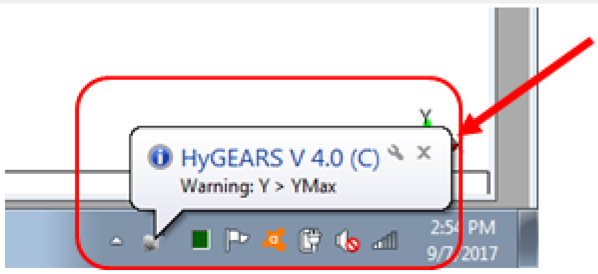




Machine Limits: values giving the linear and angular limits of the machine; when any value is exceeded during animation ("*Anim*" and

"+/-" buttons), HyGEARS displays a balloon at the lower right corner of the screen and indicates which limits have been exceeded. All limits refer to *machine coordinates*.





For this warning balloon to be displayed, the machine's limits must have been defined by editing the desired machine and entering the values in the Controller-Machine Head tab, Machine Limits section, as shown above.

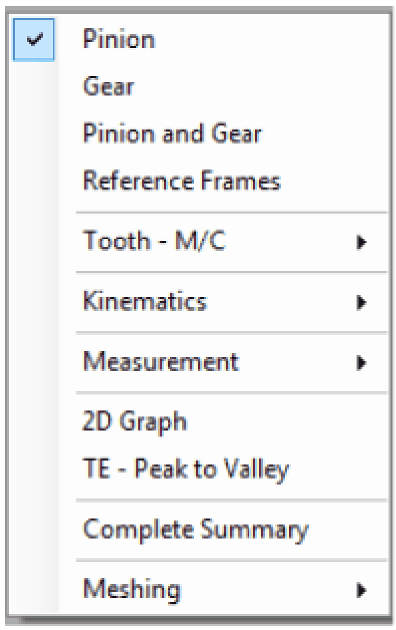
Since HyGEARS is distributed with the master Machine definition file, each time HyGEARS is installed, the current Machine file is updated and, therefore, any machine limits entered by a user should be transferred to Involute Inc. in order to maintain the master Machine file.

12 Graphic Display Functions

12.1 Displayed Geometry

Depending on the requested Graphics function, the HyGEARS Child Windows can display results for:

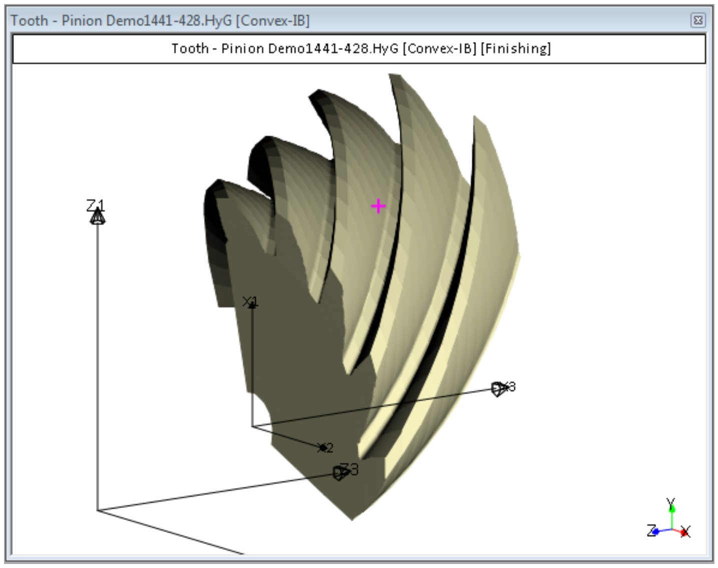
Pinion, or
Gear, or
Pinion and Gear at the same time,



HyGEARS can also display, or not, the general reference frame and the reference frames tied to several components like the pinion or the gear, depending on which Geometry is displayed.

The Displayed Geometry functions are used to make these selections by mouse click. Once a selection has been made, the selected entry shows a check mark "√" which identifies the active Geometry type and whether the reference frames will appear or not.

Any Child Window created afterward will include the active selections. The active selections will thus be an integral property of any Child Window.

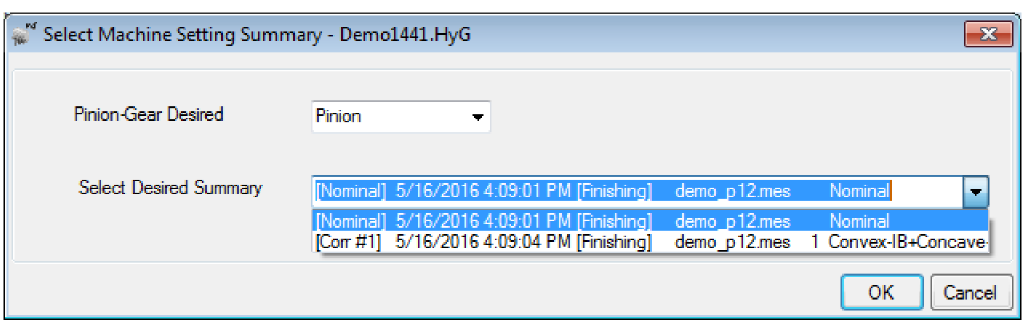


Therefore, if the Pinion and Reference Frames Graphics menu entries are checked, and a Tooth Child Window is created by clicking on the Tooth Graphics menu entry, the Child Window shown above will appear within the Parent window borders.

The pinion *X1X2X3* reference frame fully appears within the Child Window, while the general reference frame *Z1Z2Z3* is outside of the display because of its larger size.

12.2 Summary Version Selection Window

During the course of the development of a gear set, many Geometry Summary versions may be produced through [Corrective Machine Settings (Closed Loop)] iterations. By default, when a [Child Window] is created, HyGEARS always displays the Geometry in its Nominal version, e.g. the initial machine settings which were identified as the reference Summary (see Corrective Machine Settings (Closed Loop)).



It is possible, through the use of the Summary Version selection window, to activate any pinion or gear Summary version, and then to access the Summary itself through the Summary Editor.

However, any changes made to the Summary will be lost when either another Summary version is selected or when the HyGEARS session ends.

The Summary Selection window displays two selection fields:

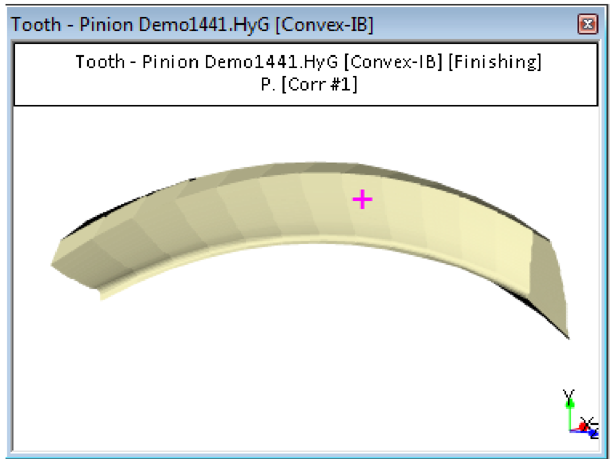
Pinion-Gear ... — the drop-down list box offers selection choices for either the pinion and/or the gear, depending on the displayed Geometry.

Desired Summary — the drop-down list box offers the complete list of the different Summary versions. If no Corrective Machine Settings (Closed Loop) action has been done, the Summary selection drop-down list box will be empty. The list includes the following information:

- time and date the Summary was created through the Corrective Machine Settings (Closed Loop) function;
- the Corrective Machine Settings (Closed Loop) function was applied to either the Finishing or Roughing Summary data;
- the name of the measurement data file;
- whether 1st (1) or 2nd (2) order Corrective Machine Settings (Closed Loop) were calculated and applied;
- the tooth flanks the Corrective Machine Settings (Closed Loop) were calculated for (Concave, Convex or both, e.g. Concave and Convex).

A selection is made by clicking on the desired Geometry (pinion or gear) and Summary version, and pressing the OK button or the Return key. Pressing the Cancel button or the Esc key ends the Summary Selection window without any changes.

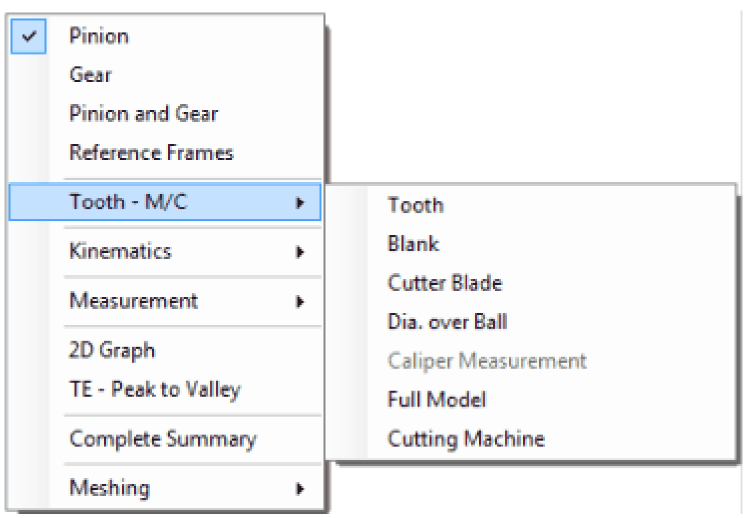
When a selection is made, the displayed tooth is redigitized to reflect the requested version. The title inside the Child Window will reflect the selection by either the [Nominal] or [Corr #X] identifications where #X is the number of the correction.



The Summary Version Selection window is accessed through the Sele Function Button, for selected Child Windows.

12.3 Teeth and Machines

This section concerns tooth and cutting machine display. Up to seven menu entries are offered in this section:

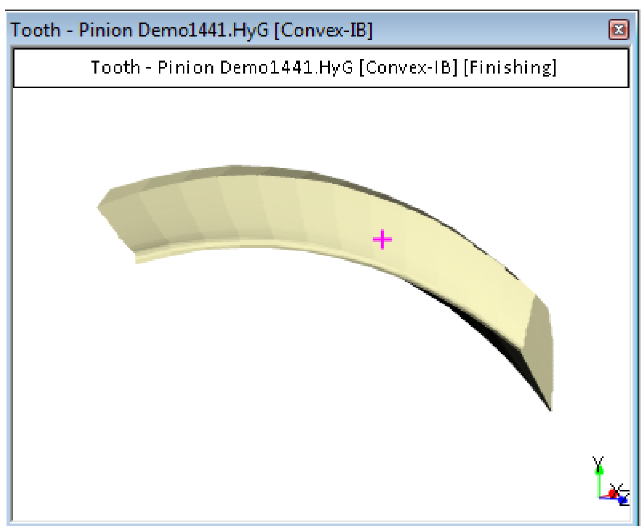


Tooth:	creation of a Child Window which displays the selected Geometry tooth;
Blank:	creation of a Child Window which displays the of the selected Geometry blank and tooth;

Cutter Blade:	creation of a Child Window which displays the of the cutter blade, including TopRem dimensions;
Dia. over Ball:	creation of a Child Window which displays two teeth of the current member, plus the ball used for measurement and the resulting value of the Dia. over Ball dimensions;
Caliper Mesurement:	creation of a Child Window which displays several teeth of the current member, plus the distance between opposed tooth sides, as would be obtained using a caliper; for spur and helical gears only;
Full Model:	creation of a Child Window which displays the selected Geometry complete model;
Cutting Machine:	creation of a Child Window which displays the selected Geometry cutting machine.

12.3.1 Tooth

The Tooth 3D Child Window is used to display the tooth as it would be manufactured by an actual cutting machine. The displayed tooth can be viewed in all HyGEARS projection modes.



This function is mainly useful to visually check tooth integrity after the digitization process. As explained in The Digitization Process section (See Editing Functions, Chapter 5), each time one tooth manufacturing parameter is modified, the tooth must be redigitized. If any parameter is faulty, the digitization process may fail which indicates that the tooth cannot be cut properly anyway. It is therefore a good idea to visually check tooth integrity after an edit session, or immediately after creating a new Geometry.

Since the Tooth Child Window is 3D by definition, the Parent window Tool Bar rotation buttons will be available, provided the projection mode is User Defined, and the Zooming buttons will be available if the Zoom mode is manual (see The HyGEARS GUI).

12.3.2 Blank

The Blank 3D Child Window is used to display the **blank and tooth contours**, mainly to visualize and simultaneously compare the finished tooth root lines of the I.B. (convex) and O.B. (concave) sides, and the roughed tooth root line, for Zerol, spiral- bevel and hypoid gears, or the left and right tooth root lines for straight-bevel and spur/helical gears.

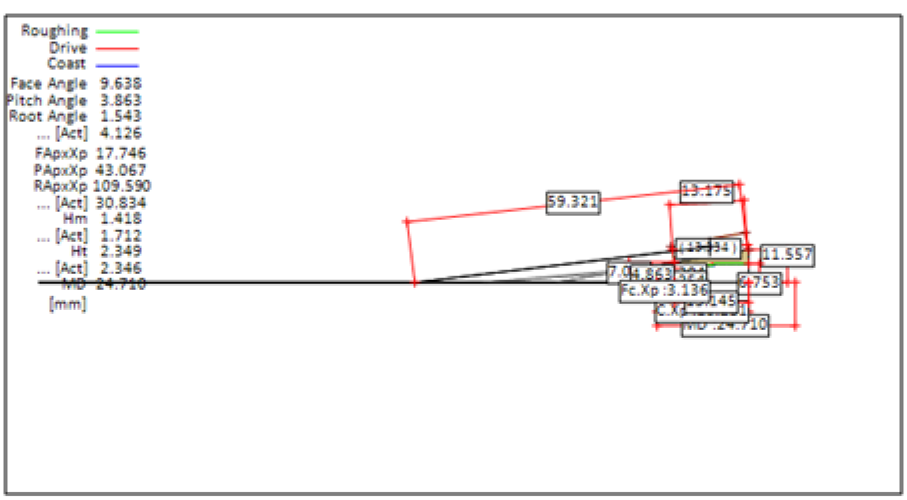
Basic Blank dimensions are provided on the display In particular, the *...[Act]* values refer to the *actual* values as obtained from the digitized tooth. These include:

Root Angle	the root angle of the tooth
RApxXp	the Root Apex to Crossing Point
Hm	the tooth depth at Mid-Face
Ht	the tooth depth at Heel

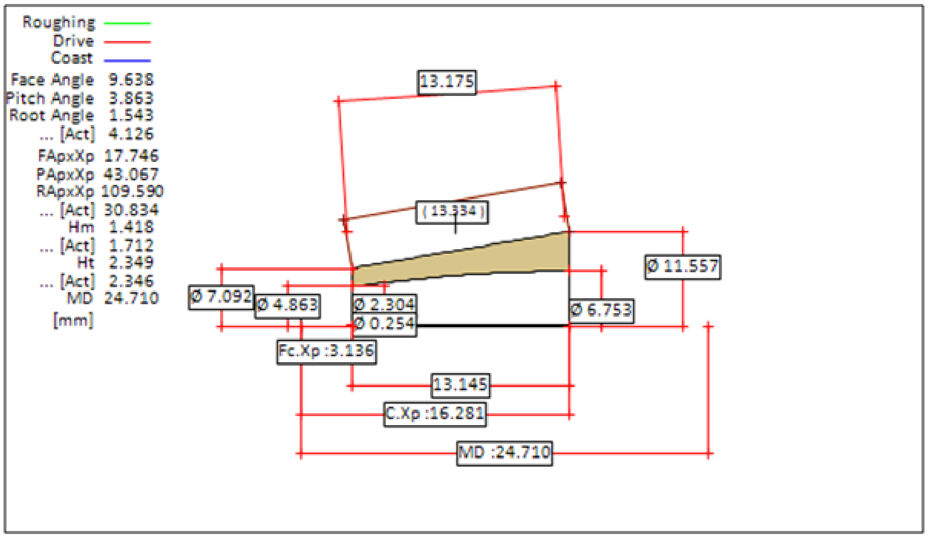
When the PApxXp, FApxXp or RApxXp of the pinion exceeds 25% of the Outer Cone Distance, the extension lines of the Pitch, Face and Root cones are omitted from the display such as to provide a better view of the Blank.

The diametral values are identified with the ϕ symbol.

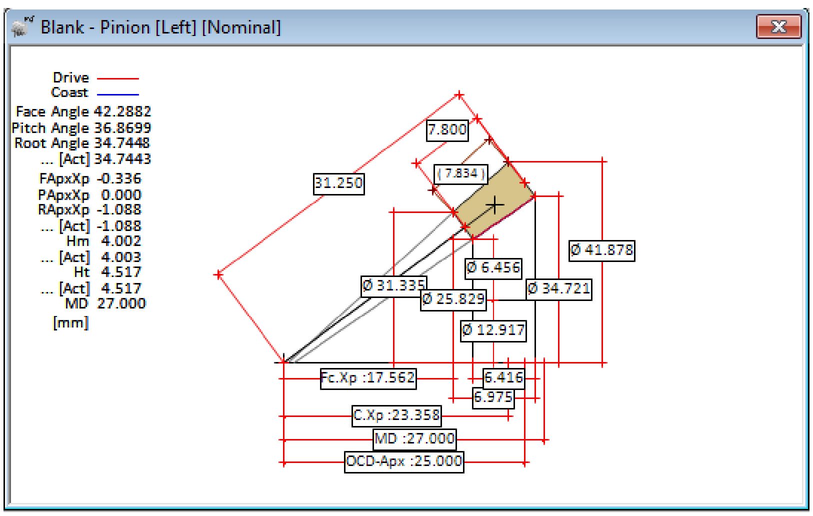
With Extension lines:



Without Extension lines:

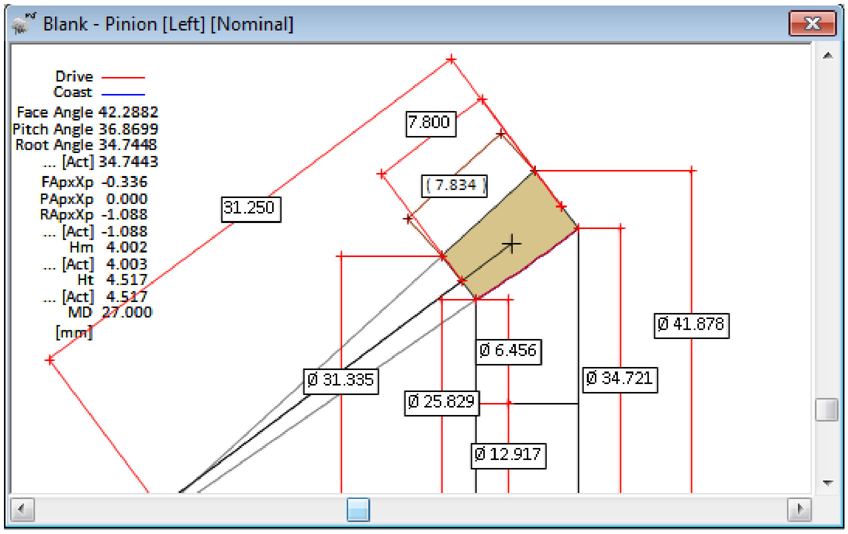


Hypoid pinion Blank



Straight-bevel pinion Blank

The displayed tooth blank is visible only in top view with dimensions (which can be toggled off using the *Dims* function button) and the color cues below.



Red Tooth **finished drive** side root line
Blue Tooth **finished coast** side root line

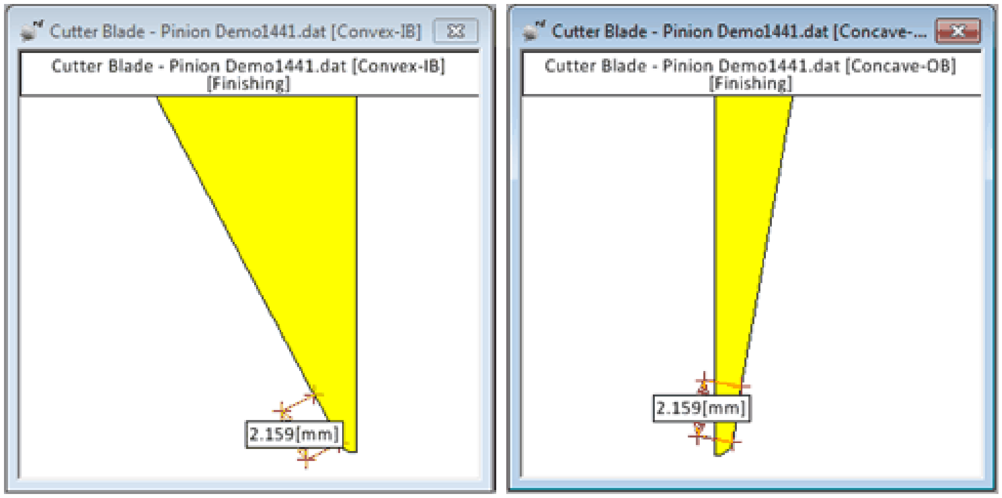
The pinion or gear cannot be shown together. Since the Blank Child Window is visible only in top view, the Tool Bar rotation buttons will not be available. However, the Zooming buttons will be available if the Zoom mode is manual (see The HyGEARS GUI).

12.3.3 Cutter Blade

The Cutter Blade 2D Child Window is used to display the cutter blade shape, including TopRem modifications, as per the data given in the Geometry Summary. When present, TopRem dimensions are displayed.

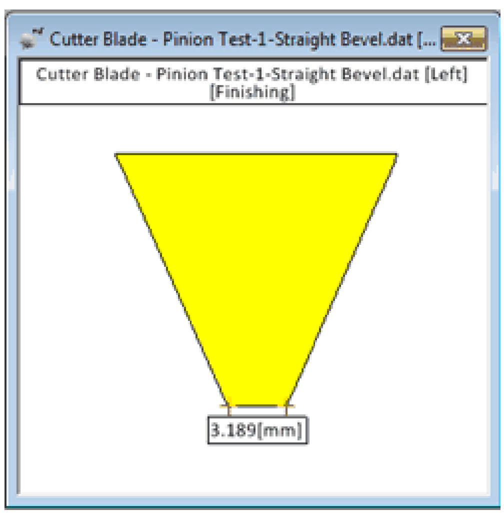
The pinion or gear cannot be shown together. Since the Cutter Blade Child Window is visible only in top view, only the Rotate about Z rotation buttons is available. The Zooming buttons will be available if the Zoom Property is manual (see The HyGEARS GUI).

The following figures show the IB and OB blades for an Hypoid pinion cut by the Fixed Setting process, such that separate cutters are used.

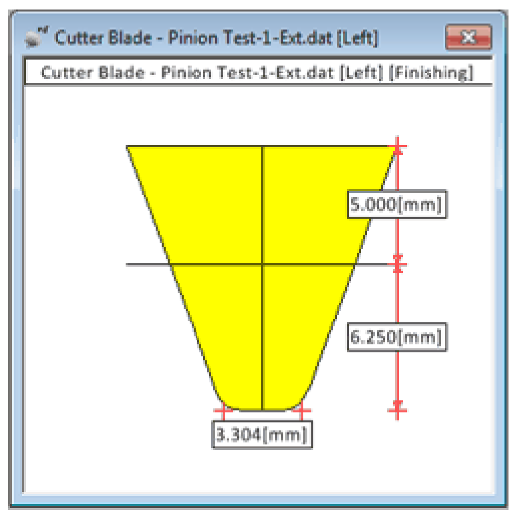


Fixed Setting Hypoid Cutter Blades

The following figures show the cutter blades for a straight-bevel pinion (left figure) and for a spur pinion.



Straight-Bevel Cutter Blade



Spur Cutter Blade

The Tool Bar will show a series of buttons representing functions specific to the Cutter Blade Child Window. Clicking on any Tool Bar function button with the left mouse button initiates the function the button stands for.

For more details on the function buttons behavior, please refer to The Parent Window Function Buttons.

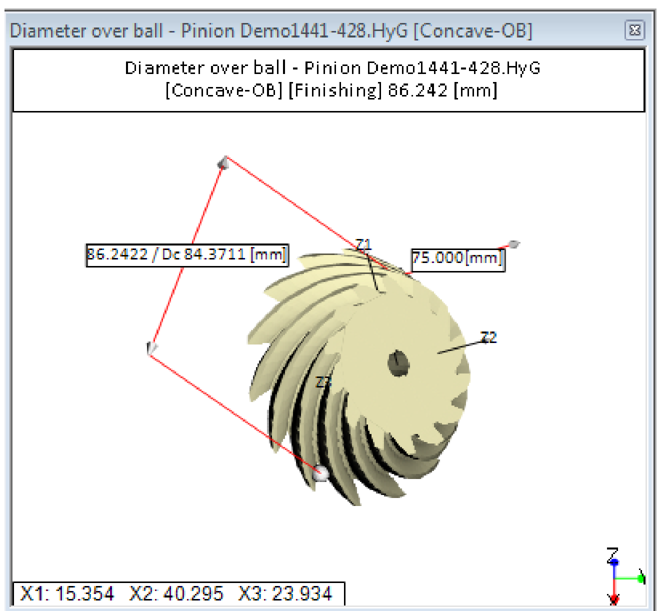
12.3.4 Diameter over Ball

In gear manufacturing, it is customary to measure the teeth to ensure constant and adequate manufacturing quality. One method to qualify the cutting process is the Diameter over Balls or Rollers.

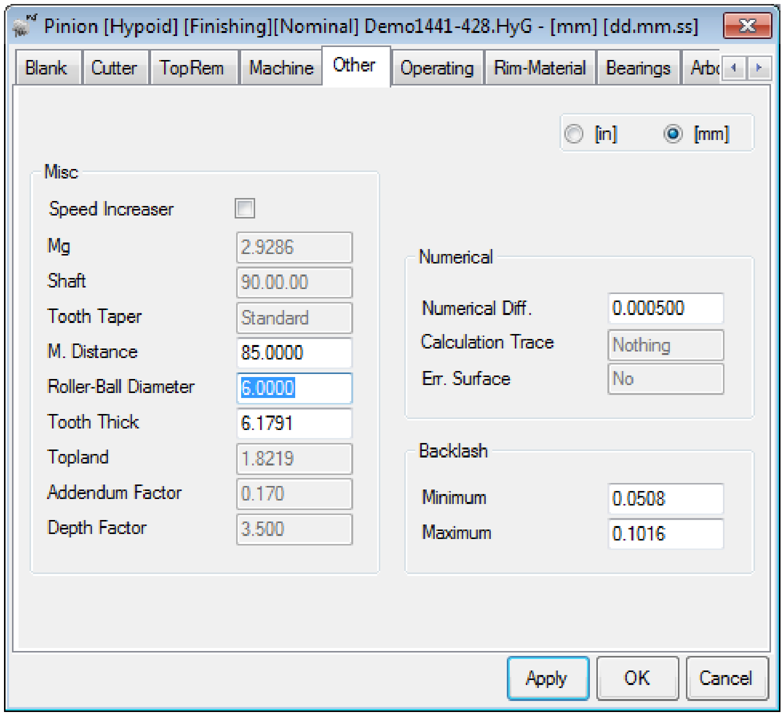
In this method, two balls or rollers, depending on the gear type, are inserted between tooth spaces diametrally opposed and the distance between the outside of the balls/rollers is recorded. Changes in the distance between the outside of the balls/rollers indicate errors in manufacturing.

The *Diameter over Balls* Child Window is used to display the calculated value of the diameter over ball, along with a sphere representing the Balls/Rollers used for measurement, and the position at which measurement is performed. The display can be viewed in all HyGEARS projection modes. HyGEARS uses a ball for all displays. Measurement is performed at a specific distance from the Apex. Obviously, while measurement will be constant along the tooth for spur and helical gears, it will vary for bevel gears.

The *Diameter over Ball* display presents only all teeth of the current pinion or gear member, and the result of the measurement (86.242 mm) is displayed in the Child Window title, and the axial location of the ball (75.0000 mm) is shown graphically, as in the figure below. The contact diameter between the Ball and the tooth flank is also given (Dc 84.3711 mm in the figure below).



The *Roller-Ball Diameter* can be edited in the Other data page of the Geometry Summary Editor.



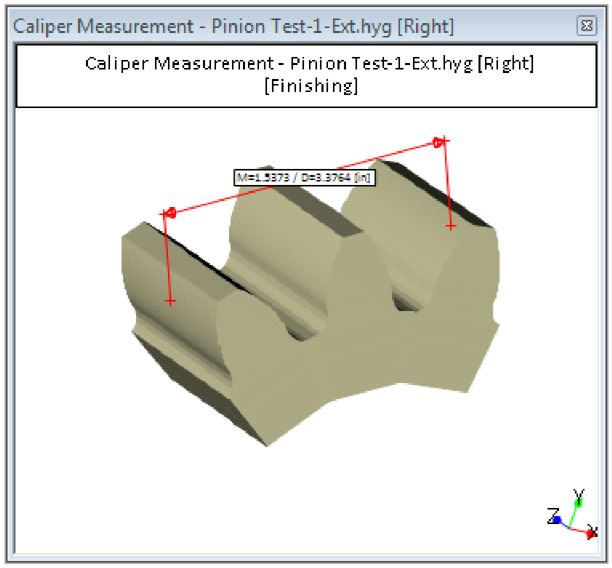
Since the Dia. over Ball Child Window is 3D by definition, the Tool Bar rotation buttons will be available, provided the projection mode is User Defined, and the Zooming buttons will be available if the Zoom mode is manual (see The HyGEARS GUI).

12.3.5 Caliper Measurement

Another method to qualify the cutting process, but for cylindrical gears only, is the Caliper Measurement. In this method, a caliper is used to measure the *distance* **M** between several teeth, at a given *diameter* **D**. Changes in distance **M** indicate errors in tooth manufacturing.

The Caliper Measurement Child Window is used to display the value calculated for a given number of teeth. The display can be viewed in all HyGEARS projection modes. Measurement is performed at a specific location along the tooth. Obviously, measurement should be constant along the tooth for spur and helical gears.

The Caliper Measurement displays the # teeth for which the measurement is performed.

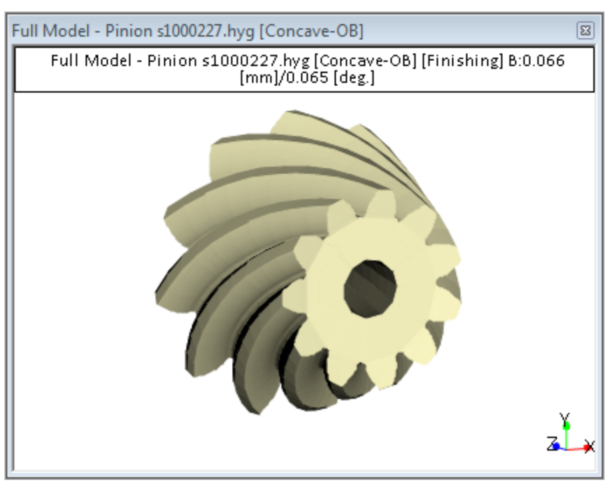


Since the Caliper Measurement Child Window is 3D by definition, the Tool Bar rotation buttons will be available, provided the projection mode is User Defined, and the Zooming buttons will be available if the Zoom mode is manual (see The HyGEARS GUI).

12.3.6 Full Model

The Full Model Child Window is used to display the pinion and/or gear models as they would appear in mesh, including the hub as described in the Summary editor. The displayed models can be viewed in all HyGEARS projection modes.

This function is mainly useful to visualize the overall look of a pinion, a gear or a gear set and to obtain volume and inertial properties for the complete gears.



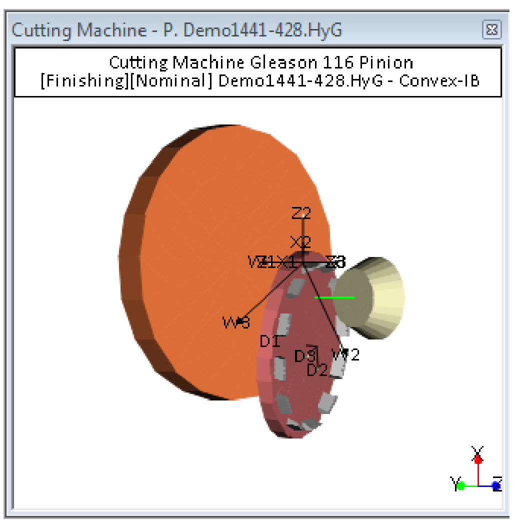
Since the Full Model Child Window is 3D by definition, the Tool Bar rotation buttons will be available, provided the projection mode is User Defined, and the Zooming buttons will be available if the Zoom mode is manual (see The HyGEARS GUI).

However, since all teeth are represented and there are therefore many more surfaces to calculate, graphics display time will be much longer than that of a simple tooth display.

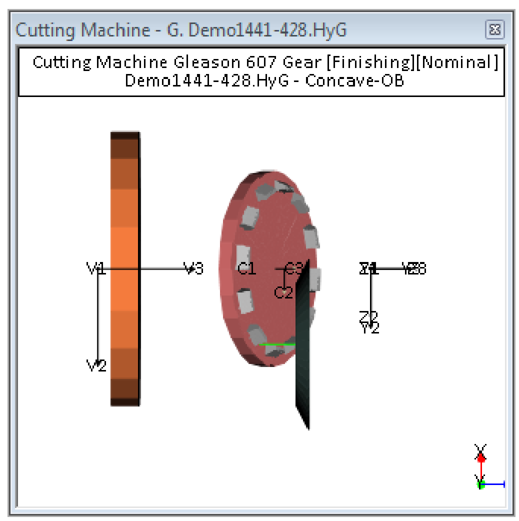
12.3.7 Cutting Machine

The Cutting Machine Child Window is used to display the cutting machine setup as it would appear to the machine operator. The displayed cutting machine can be viewed in all HyGEARS projection modes.

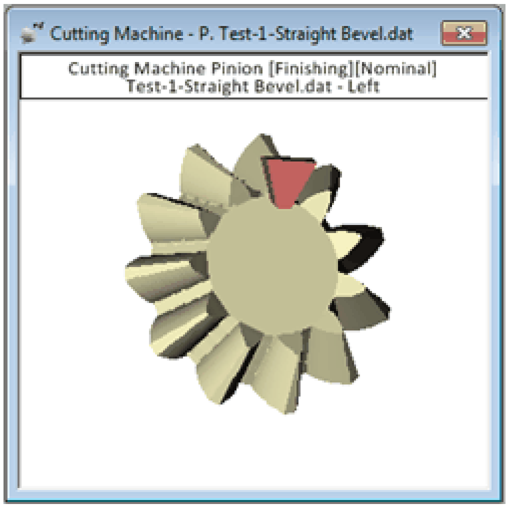
This function is mainly useful to visually check the cutting machine setup, either immediately after creating a new Geometry, or after modifying a Summary. As explained in The Digitization Process section, each time one machine setting parameter is modified, the tooth must be redigitized. If any parameter is faulty, the digitization process may fail which would indicate that the tooth cannot be cut properly anyway. It is therefore a good idea to visually check the tooth integrity after an edit session, or immediately after creating a new Geometry.



Face Milled Hypoid Pinion



Formate Hypoid Gear



Straight Bevel Pinion **Spur Pinion**

In addition to the general reference frame Z1Z2Z3, each Cutting Machine Child Window can display the following reference frames which either revolve or translate with the object they are tied to (see Chapter 2, The HyGEARS Simulation):

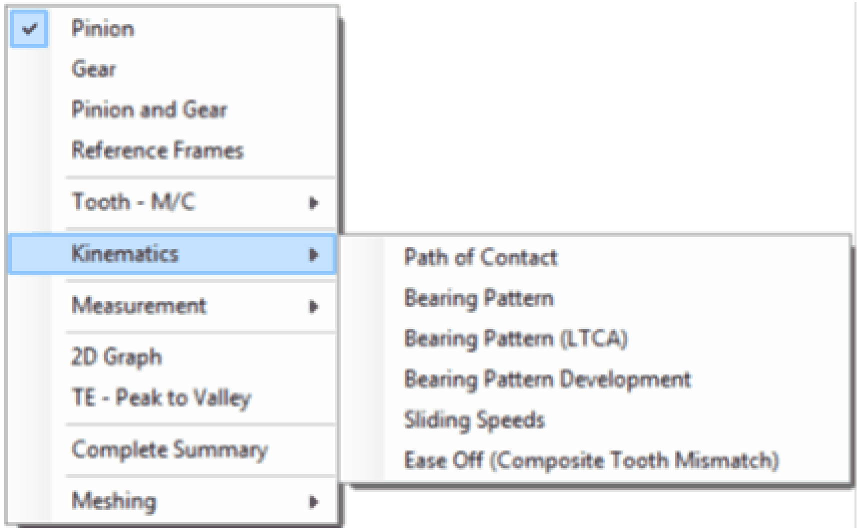
X1X2X3	pinion member reference frame.
D1D2D3	pinion cutter reference frame.
W1W2W3	pinion machine cradle reference frame.
Y1Y2Y3	gear member reference frame.
C1C2C3	gear cutter reference frame.
V1V2V3	gear machine housing reference frame.

Since the Cutting Machine Child Window is 3D by definition, the Parent window Tool Bar rotation buttons will be available, provided the projection mode is User Defined, and the Zooming buttons will be available if the Zoom mode is manual (see the HyGEARS GUI).

The Cutting Machine Child Window can display either the pinion or the gear cutting machines. If the "Pinion and Gear" selection has been made in the Displayed Geometry section of the Graphics pull down menu, the Child Window will default to the pinion cutting machine.

12.4 Kinematics and Bearing Pattern

This section deals with kinematics and Contact Pattern display. Six menu entries are offered in this section:

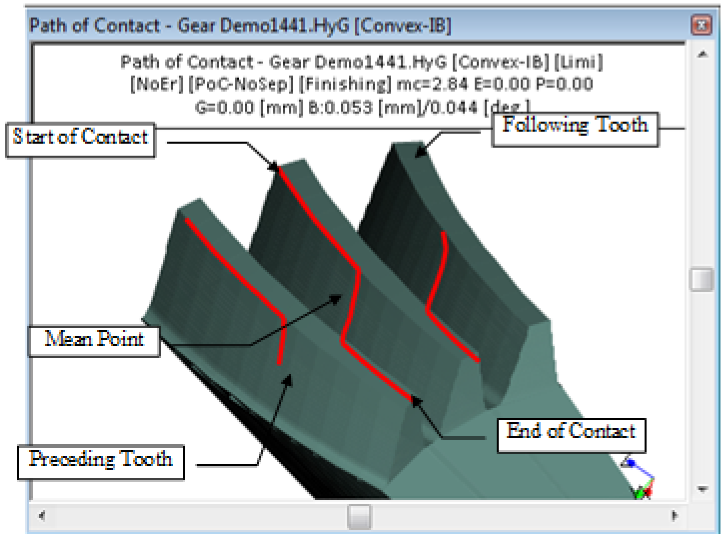


Path of Contact:	creation of a Child Window which displays the path of contact (PoC) on the pinion, gear or pinion and gear tooth;
Contact Pattern:	creation of a Child Window which displays the unloaded Contact Pattern on the pinion or gear;
Contact Pattern (LTCA):	creation of a Child Window which displays the Contact Pattern under load on the pinion or gear;
Contact Pattern Development:	creation of a Child Window which displays the unloaded Contact Pattern on the gear tooth and provides interactive tools to modify the Contact Pattern;
Sliding Speeds:	creation of a Child Window which displays the unloaded Contact Pattern on the pinion, gear or pinion and gear tooth and adds the sliding speed vectors to the Contact Pattern;
Ease Off:	creation of a Child Window which displays the unloaded Ease Off surface with the PoC and the Contact Pattern.

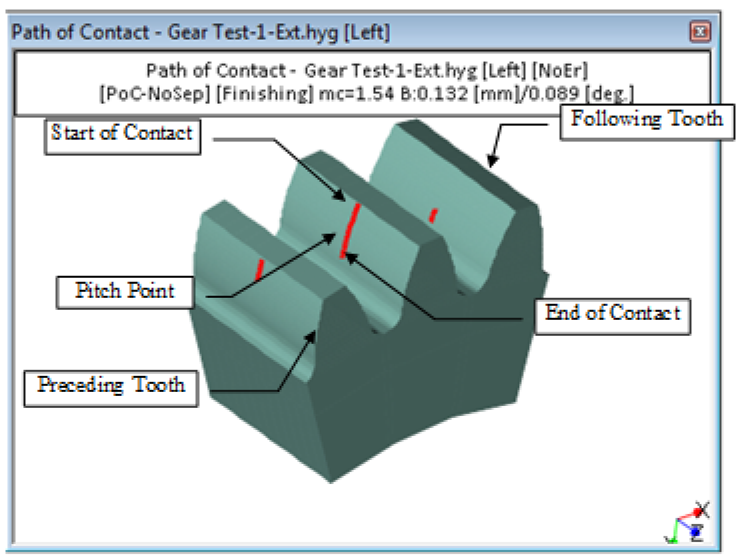
12.4.1 Path of Contact (POC)

Zerol, Hypoid and Spiral-Bevel	theoretically point-contact tooth surfaces, e.g. numerically speaking the teeth contact in a single point at any moment throughout meshing. In practice, due to the applied load, the theoretical contact point spreads to become an ellipse

of which the instant line of contact represents the major axis.



Straight-bevel, spur and helical gears rather have theoretically line contact surfaces, i.e. an instant line of contact extends over a significant part of the tooth.



The Path of Contact Child Window is used to display on the selected tooth flank the locus of several contact points as meshing proceeds from pinion tooth root to pinion tooth tip, which is called the path of contact (PoC).

Particularly in Hypoid gears, because the usually large pinion spiral angle, a good amount of overlap takes place throughout the meshing cycle. This overlap means that while the pinion and gear teeth may not be contacting due to profile relief, if the applied load is large enough they could actually come into contact since they are still overlapping one another (See The HyGEARS Simulation).

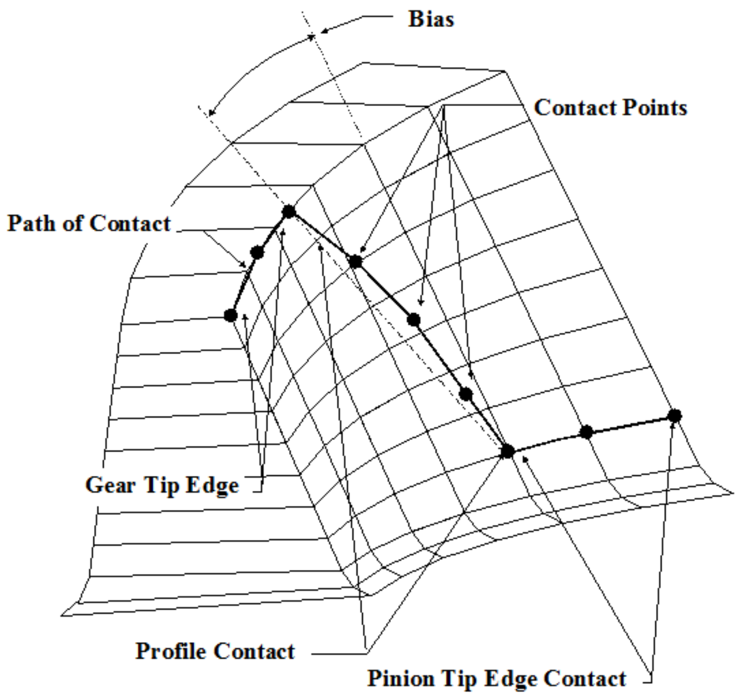
The PoC is to be interpreted in the following manner (see the figure below):

Gear Tip Edge first, contact theoretically starts at the root of the pinion tooth, thus at the tip of the gear tooth shown below. Hypoid and Spiral-Bevel gear teeth are usually designed to avoid contact in this area since the tooth is very sensitive to bending and contact stresses, and sliding speeds are the highest at tooth tip, by providing adequate profile relief. Therefore, the line shown along the tip of the gear tooth means that edge contact could occur along the gear tooth tip if the initial profile separation was closed for any reason. If contact were to occur in this region, the contacting areas of the tooth surfaces would be truncated to a fraction of their theoretical dimensions and contact stresses would therefore be very high.

Profile second, contact proceeds across the tooth profile, which is the profile contact portion of the PoC between the gear tooth tip and root. In this section, contact conditions are favorable as it proceeds normally across the contacting tooth profiles, and the contact areas will not be truncated. This area also usually displays the lowest sliding speeds.

PoC Bias is defined as the angle made between the profile portion of the PoC and a line perpendicular to the tooth root cone, as shown in the figure below. The Contact Pattern Development function offers tools to help control PoC Bias.

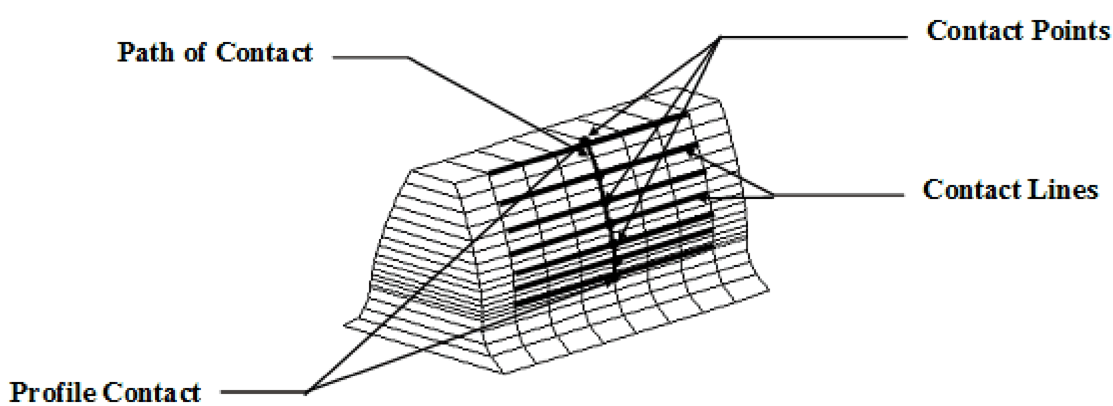
Pinion Tip Edge third, edge contact can occur again, this time along the tip of the pinion tooth. The same remarks apply as in the case of gear tip edge contact.



The PoC has the same number of points as the tooth profilewise number of points. The PoC is divided such as to attribute a maximum of 25% of the profilewise points on the gear and pinion tip edge contacts, and the remaining points on the profile contact portion of the PoC. Using a marker (Parent Window menu Mark function) of 1 or larger will reveal the PoC points.

Clearly, edge contact can be detrimental to the life of a gear set, but it is often partially unavoidable because of design, manufacturing and operating constraints.

In spur, helical and straight bevel gears, the PoC is all profile; however, pinion and gear tip edge contact can still occur, as shown below for a spur gear. Although contact is made along facewise lines on the tooth flank, by convention the PoC is shown at the center of such lines of contact, as displayed in the figure below.



In Zerol, Hypoid and Spiral-Bevel gears, because of the small pinion tooth number and its strong tooth lengthwise curvature, the PoC is best seen on the gear tooth flank as shown in the above figure. The marker in the center of the tooth is used to identify the current contact point, which changes when Animation is used.

12.4.2 Contact Pattern

As explained in the Path of Contact section, Zerol, Hypoid and Spiral-Bevel gears have theoretically point-contact tooth surfaces, e.g. numerically speaking the teeth contact in a single point at any moment throughout meshing. In practice, due to the applied load, the contacting surfaces deform and the theoretical contact point spreads to become a contact area in the form of an ellipse.

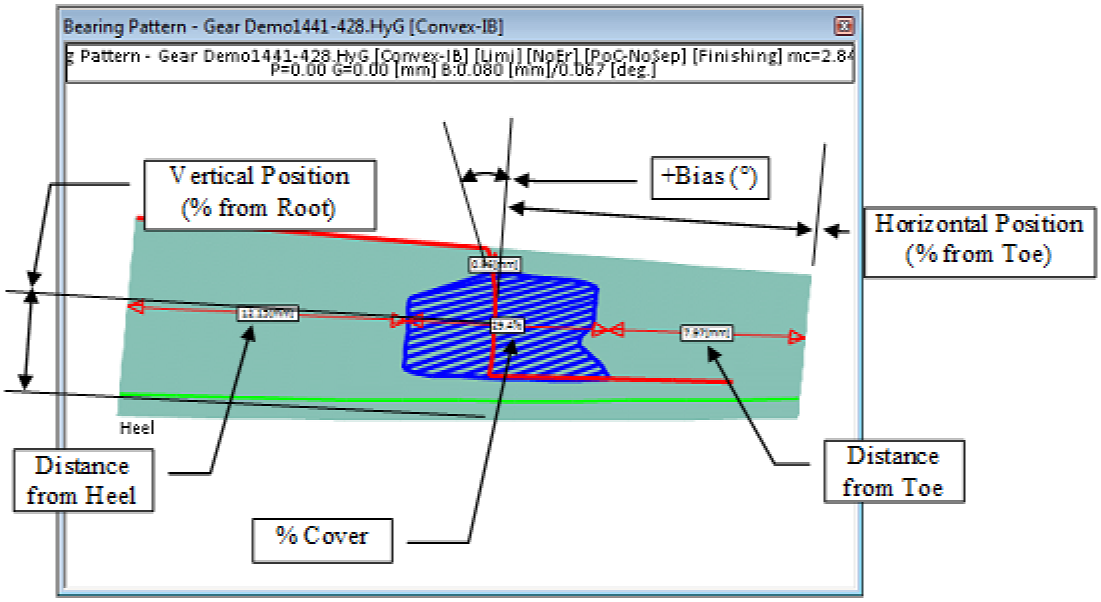
For spur and helical gears, which contact along a line rather than in one point, the contact area becomes a rectangle under load.

If the gear tooth flank was coated with a light marking compound of a given thickness, the succession of such contact ellipses, as meshing proceeds, would leave a trace indicating which part of the tooth flank came in contact. This trace is called the Contact Pattern. The usual marking compound thickness is 0,00025 [in] or 0,00635 [mm], an editable feature in HyGEARS.

In the gear industry, a gear pair is judged by its Contact Pattern which should be well positioned both lengthwise and profilewise, and should not present important deviations such as bias or a diamond shape. This verification is done to ensure adequate gearing quality.

In a simulation software such as HyGEARS, viewing the Contact Pattern is also essential, as it tells the gear designer what kind of behavior to expect from a gear set once it is in operation.

The Child Window Contact Pattern Graphics function is used to display a calculated Contact Pattern on the selected tooth flank as meshing proceeds from pinion tooth root to tooth tip. The displayed Contact Pattern can be viewed in all HyGEARS projection modes.



The Contact Pattern is calculated as follows:

- First, the PoC is calculated, and the tooth profile separation is obtained for each PoC contact point. The tooth profile separation is caused because an adjacent tooth, tooth +1 for example, comes into contact before the preceding tooth 0 has left contact, thereby relieving it from carrying motion, which is valid if the load is very small. If the load is larger, the tooth profile separation may be reduced due to tooth bending and shearing and contact deformation (see Contact Pattern (LTCA)).

- Second, each PoC contact point is checked to test whether the tooth profile separation is larger, equal or smaller than the requested marking compound thickness. If the tooth profile separation is smaller, then the contacting tooth surfaces are scanned to find the extent of the contacting area defined by a tooth separation equal to the difference between the marking compound thickness and the tooth profile separation. The extent of the contacting area is represented by a line, the **instant line of contact**, which corresponds to the major axis of the contact ellipse.

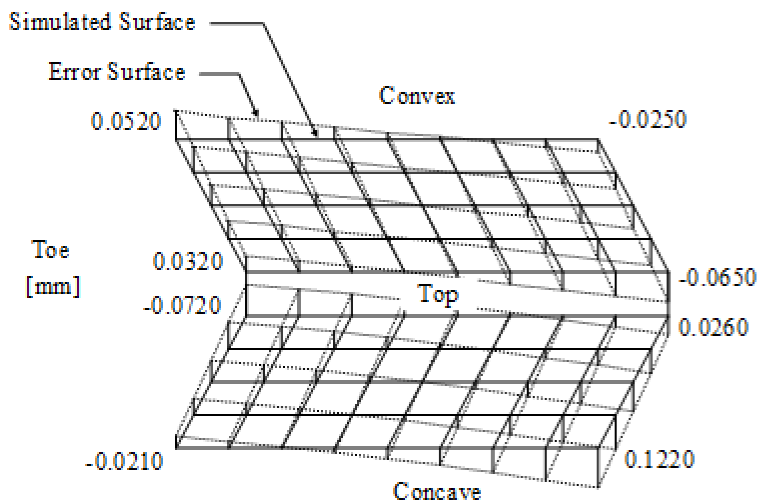
The Contact Pattern may have up to the same number of points as the PoC, which is the same as the tooth profilewise number of points. Only those portions of the tooth surfaces actually coming into contact will show on the Contact Pattern.

Therefore, increasing the tooth number of points is likely to increase the resolution of the Contact Pattern, thereby yielding a better picture of the results to expect.

12.4.2.1 Error Surface

Many Graphics functions offer the possibility to use the difference between the simulated, or reference, and measured tooth surfaces to produce kinematic results closer to the behavior of the actual tooth surfaces.

This difference is called the Error Surface, and is referred to as such in all the documentation.



Whenever measurement data is present within the current Geometry, the difference between the measured and simulated surfaces can be used to establish the overall correspondence between the manufactured surface and the one that is desired from the Geometry Summary (see Compare Mes-Sim Surfaces).

This comparison data can also be used to calculate variations needed in machine settings to correct the differences noted (see Corrective Machine Settings (Closed Loop)).

Another use of the difference between the measured and simulated surfaces is in the calculation of the Path of Contact and the Contact Pattern, where it is considered that the contacting surfaces become the measured surfaces instead of the simulated surfaces, thereby reflecting much more closely the kinematic behavior of the actual gear set.

See the Measurement and Compensation and Comp. Meas-Sim Surfaces sections for more details about measurement and interpretation, and Using the Error Surface in the example Creating a New Fixed Setting Hypoid Gear see, HyGEARS Examples, for information how the Error Surface can be used.

12.4.2.2 Bearing Pattern E/P Grid

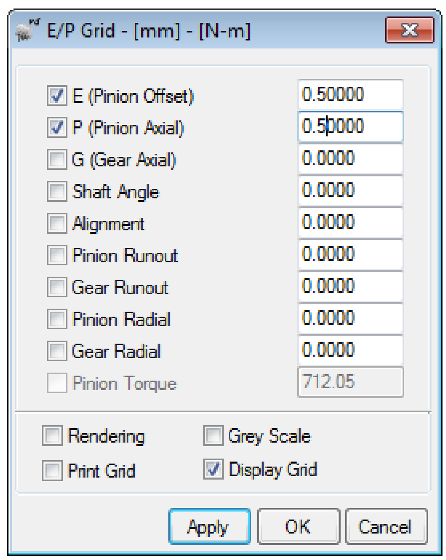
Users often want to know what the Contact Pattern, Transmission Error or Contact Stresses will be like when the operating positions are changed.

While the E/P and V-H functions are useful for this purpose, HyGEARS offers an automated function which calculates, for a specified range of positional and alignment error values, the expected TCA/LTCA Contact Patterns, 2D Graphs, Finite Strips and Contact Elements results which are then displayed in a grid form. The result is displayed on the screen, can be sent to the printer, and is also copied to the Windows Clipboard.

Basically, as shown in the figure below, positional and alignment errors can be inputted 2 at a time; (for Runout, HyGEARS uses the inputted value and indexes it around the axis of rotation, thereby showing the effect of runout as either the Pinion or Gear rotates).

HyGEARS then uses the inputted data to create a grid of Child Windows where the inputted values are used in stepwise combinations, the result is calculated and added to an Output graph that is then displayed on the screen.

This Output graph can be copied to the Clipboard (Ctrl C) or printed (Ctrl P).



Command Buttons

Apply the “Apply” command button tells HyGEARS to use the inputted positional and alignment error values, and then to proceed with the preparation and display of the grid. At least one pair of positional and alignment error values must be non-zero.

OK the “OK” command button tells HyGEARS to use the inputted E and P values, show the Printer Selection Window, calculate and print the Contact Patterns. Both E and P values must be non-zero.

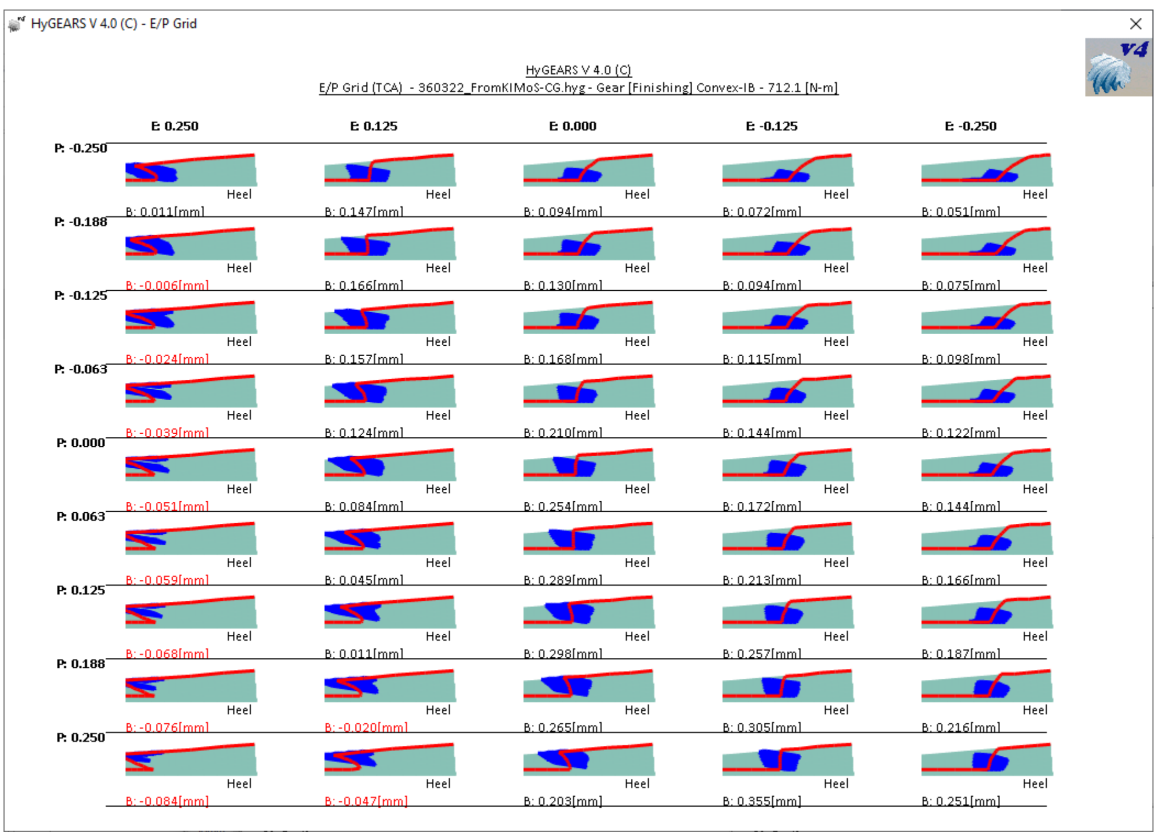
Cancel the “Cancel” button tells HyGEARS to exit the Contact Pattern E/P Grid function without further processing.

When called, the E/P Grid function first displays the above input window in which the desired positional and alignment error value ranges are inputted. If the entered values are null, the function aborts. To be used, an input must also be checked in the Check Box to the left of the input title. Only the two first checked data values will be used.

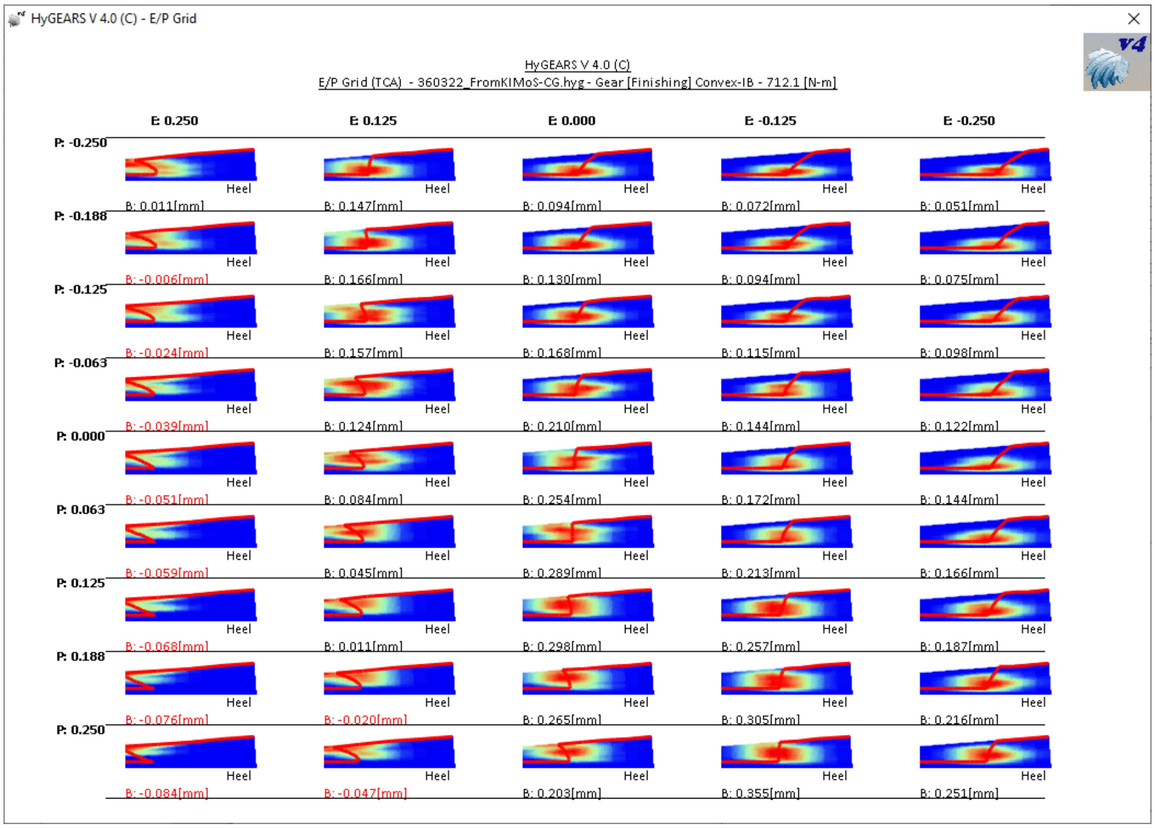
The output will show the calculated Contact Patterns, and display the resulting backlash; if backlash is negative, it is emphasized in red.

The Rendering, Print Grid and Display Grid options allow controlling the way the output behaves.

The Contact Pattern E/P Grid function produces an output similar to the following, subject to the paper size used on the printer.



E/P Grid – Rendering Off



E/P Grid – Rendering On

12.4.3 Contact Pattern (LTCA)

The Contact Pattern TCA function is used to evaluate the extent of the tooth flank which will come in contact under a very light load, which is a customary test in the development and production of Zerol, Spiral-Bevel and Hypoid gears.

In HyGEARS, it is also possible to estimate the extent of the tooth flank which will be in contact under any load using the Contact Pattern (LTCA) function, where LTCA stands for Loaded Tooth Contact Analysis.

In the LTCA, the meshing gear teeth are analyzed to calculate how they share the applied torque and, as a consequence, what the Contact Pattern will be once the actual load carried by a given tooth pair is known.

Knowing the tooth load carried by one tooth pair as it is going through mesh, the contact deformation and contact ellipse minor and major axes are easily calculated using Hertz' theory (see the Hertz Contact Stresses section). Then, the algorithm used to calculate the Contact Pattern under a very light load, with a separation equal to that of a marking compound, is used except that the pinion and gear tooth surfaces separation is now based on the contact deformation calculated from Hertz' theory.

HyGEARS offers sophisticated analysis and display tools based on how the load is shared between meshing teeth. For example, HyGEARS calculates and displays:

- the maximum *contact stress* sc;
- the maximum *subsurface shear stress*, which dictates the material requirements for proper contact life t;
- the *depth of* the maximum *subsurface shear stress*, which dictates the minimum depth of carburizing or heat treatment;
- the *ratio* of minimum *oil film thickness to surface roughness*, L, to determine if the oil viscosity is sufficient;
- the *temperature increase* in the oil film thickness as mesh proceeds.

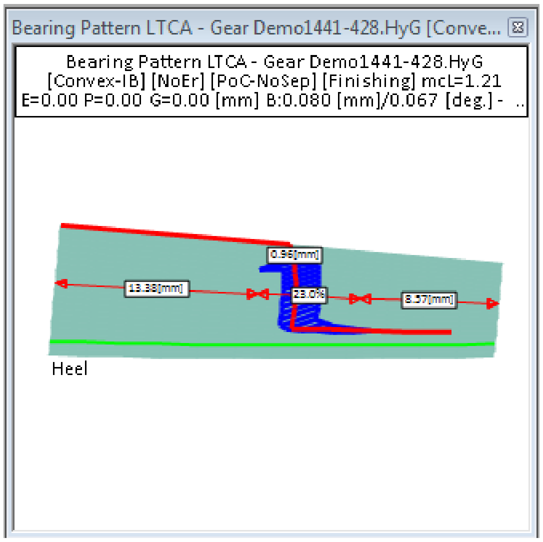
These results can be displayed in several forms:

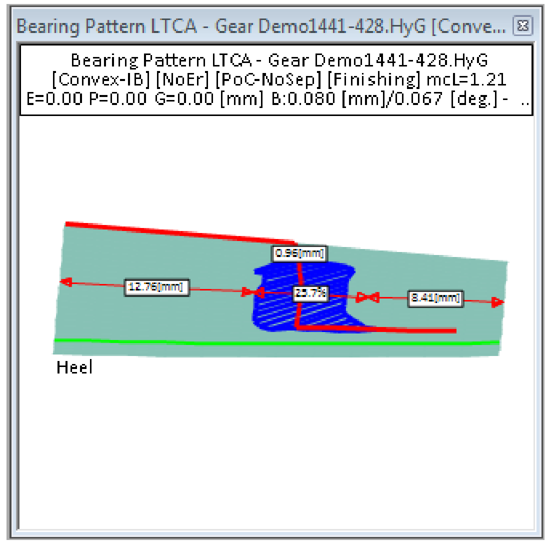
- as *color* or *grey-scale* maps projected on the tooth flank, for the complete mesh or individual contact positions;
- as *grid maps*, for the complete mesh or individual contact positions;
- as *sections* made through the tooth at any lengthwise position, for the complete mesh or individual contact positions.

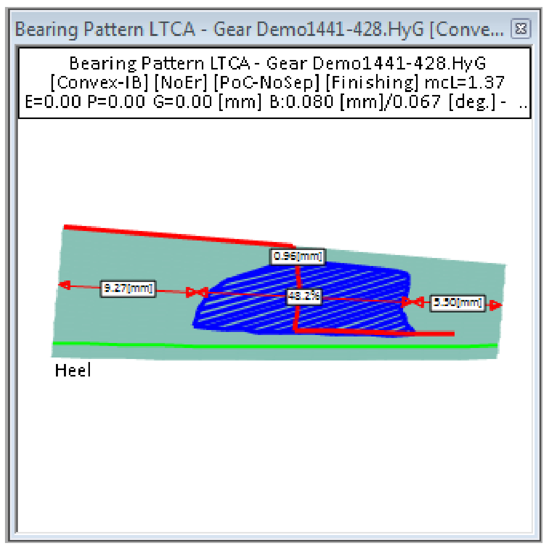
LTCA yields a close estimate of what the Contact Pattern is likely to be under a given load. Note that in these calculations, no provision is made for the bearing and gearbox housing stiffness, and while tooth bending stiffness is calculated and used to estimate how the load is shared between consecutive tooth pairs, there is no provision at this point as whether bending deformation is large enough to change the contact point position.

The tooth bending stiffness is calculated from the actual tooth dimensions applied to either the Westinghouse formula, the Nakada formula, or the Finite Strips. The tooth rotation caused by tooth base rotation on its rim and shearing of the web can also be included in the analysis.

For example, the three figures below show the expected Contact Pattern on the gear convex tooth flank, as the applied torque is stepped from 1 [N-m] to 10 [N-m] and then to 100 [N-m].





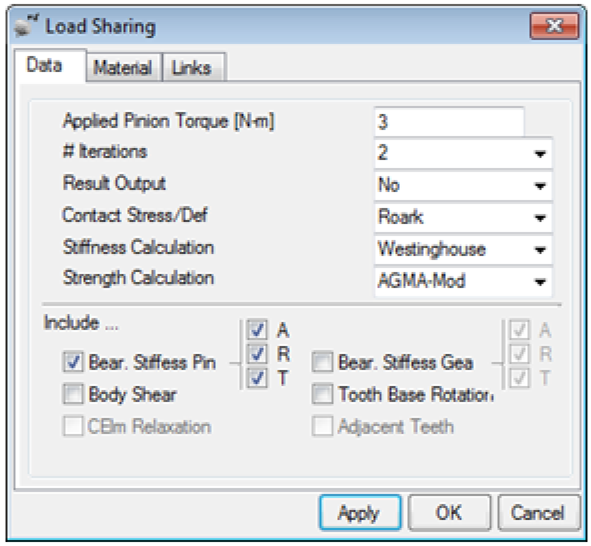


The Contact Pattern (LTCA) has the same number of points as the PoC and the unloaded Contact Pattern, which is the same as the tooth profilewise number of points. Only those portions of the tooth surfaces actually coming into contact will show on the Contact Pattern.

Therefore, increasing the tooth number of points is likely to increase the resolution of the Contact Pattern, thereby yielding a better picture of the results to expect.

12.4.3.1 LTCA Editor Window

HyGEARS offers, as an option, an advanced Loaded Tooth Contact Analysis function. For the LTCA, several options are available and may be changed through the LTCA Editor window, called through the Load function button.



Command Buttons

Apply	tells HyGEARS to use the entered data, recalculate the display, and remain in the input window;
OK	completes the input and exits;
Cancel	cancels any change done and exits.

The LTCA editor is divided in up to four different Data Pages.

Data data page

The *Data* data page, above figure, presents data related to torque, the number of iterations, etc.:

Applied Torque — The torque applied to the pinion is to be entered in the given units, which depend on the Linear Units selection made in the HyGEARS Configuration editor.

 # Iterations — The LTCA algorithm is iterative, in the sense that it supposes a given load share, calculates the dimensions of the Contact Pattern, from which several quantities are derived. Thus, the very first iteration, which is the default, is an educated guess. The second iteration will rely on the results of the first iteration, and so on, but require more calculation time.

Result Output — Either Yes or No, to print the Loaded Tooth Contact Analysis calculation results to a Text Results window. See the LTCA output for details.

Contact Stress/Def The contact deformation may be calculated by two equation sets derived from Hertz' work: one by Roark and the other by Brewe and Hamrock. Results are quite similar when the angle between the principal curvatures directions is small, but will differ increasingly as this angle increases. Roark is the recommended and default value.

Stiffness Calculation For the moment, three choices are available to calculate the pinion and gear teeth bending stiffness:

- the Westinghouse beam formula,
- the Nakada formula,
- the Finite Strips (optional).

Both the Westinghouse and Nakada formulae are fastest and were calibrated to produce results close or equivalent to the Finite Strips, which is the best overall but also the longest.

When the Finite Strips model is selected, a “Stop” button is added to the Parent window Toll Bar. Clicking on the “Stop” button cances the Finite Strips selection, reverts to Nakada and completes the calculations.

Strength Calculation As LTCA proceeds, HyGEARS also calculates the resulting Bending stresses, based on several different approaches. For the moment, three choices are available to calculate the pinion and gear teeth bending stresses:

- AGMA (e.g. J factor at each contact point),
- AGMA-Mod,
- Aida and Terauchi,
- the Finite Strips (which is an option).

Again, both the AGMA and Aida&Terauchi formulations are fastest, but the Finite Strips is the best overall and also the longest in terms of calculation time.

When the Finite Strips model is selected, a “Stop” button is added to the Parent window Toll Bar. Clicking on the “Stop” button cancels the Finite Strips selection, reverts to Westinghouse and completes the calculations.

When calculating the tooth mesh stiffness for LTCA, several components may be **included** or excluded (the contact mesh stiffness is calculated independantly at each iteration, for each point of the PoC):

Body Shear
As load is applied, the body of the pinion or gear member shears about its axis of rotation as it is somewhat like a disk . This effect may be included in the LTCA calculation. Its main effect on load sharing is sensible, and rather strong on overall stiffness and this may be significant in dynamic analyzes.

Tooth Base Rotation
This option should always be used, as it tells the LTCA to consider tooth rotation about its base when load is applied, and thus is extremely significant in tooth stiffness and how load is shared between meshing tooth pairs.

Adjacent Teeth
This option tells the LTCA to also consider tooth base rotation for neighbouring teeth.

Bear. Stiffness Pinion
When this check box is checked, it indicates HyGEARS to calculate the pinion movement under load, at all contact positions, recalculate the TCA in the modified positions, and then recalculate the LTCA in the modified positions. Be warned that this option involves much more computing time

- A: Axial component
- R: Radial component
- T: Tangent component

These offer to consider the desired applied load component on the tooth to establish which stiffness and load components are the most significant on BP shift under load.

Note: the LTCA always uses the full load to calculate Bending and Contact stresses; however, bearing displacements under load can be considered to be caused by the selected Load components.

Bear. Stiffness Gear
When this check box is checked, it indicates HyGEARS to calculate the gear movement under load, at all contact positions, recalculate the TCA in the modified positions, and then recalculate the LTCA in the modified positions. Be warned that this option involves much more computing time

- A: Axial load component
- R: Radial load component

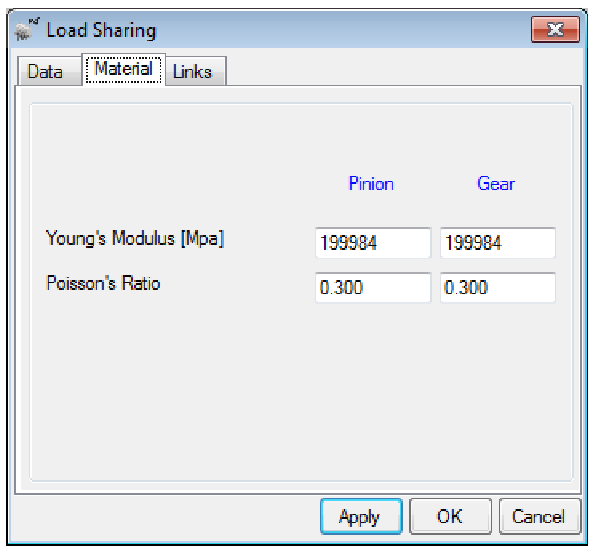
- T: Tangent load component

These allow considering a specific load component on the tooth to establish which stiffness and load components are the most significant on BP shift under load.

Note: the LTCA always uses the full load to calculate Bending and Contact stresses; however, bearing displacements under load can be considered to be caused by the selected Load components.

Material data page

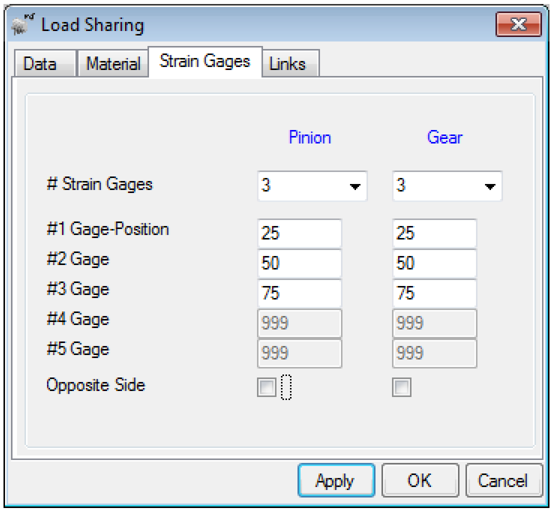
The *Material* data page presents material data, as shown below, offers the possibility to modify both the pinion and gear Young's modulus and Poisson ratio.

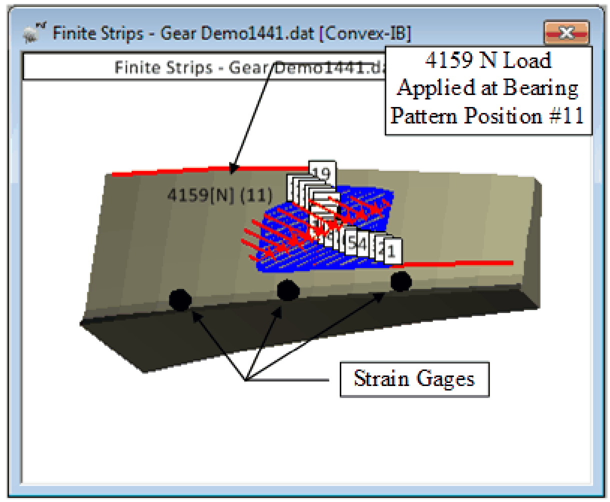


Strain Gages data page

If the *Finite Strips option* has been bought, the *Strain Gage* data page is made available to install "Strain Gages" at different places along the tooth fillet. The user can then evaluate how one strain gage is responding relative to another strain gage, as explained in the 2D Graphs section of this documentation.

Each of the Pinion and Gear can have up to 5 strain gages, the position of which is given in % of tooth facewidth.





The above figure shows three "Strain Gages" installed in the fillet of the gear tooth, respectively at 25, 50 and 75% of tooth facewidth. Load is applied in the same way as in the LTCA, e.g. at a position along the calculated Path of Contact.

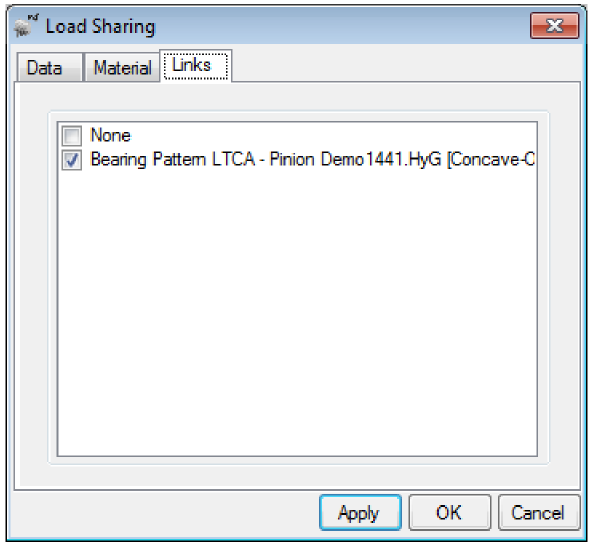
For Point contact gear types, such as Hypoids or Spiral Bevels, load can be distributed in an elliptical fashion; for Line contact gear types, such as Straight Bevels, Spur, Helical or Face Gears, load can be distributed in a constant fashion.

Links data page

The *Links* data page is used to tell HyGEARS which of the Child Windows associated to the currently loaded geometry are to be redisplayed when a change is made.

Normally, all Child Windows will be redisplayed, but one may desire to restrict this redisplay to selected windows in order to show what changes are taking place, for example on a LTCA result, or for some Contact Pattern or Kinematic result.

Only checked Child Windows are redisplayed.



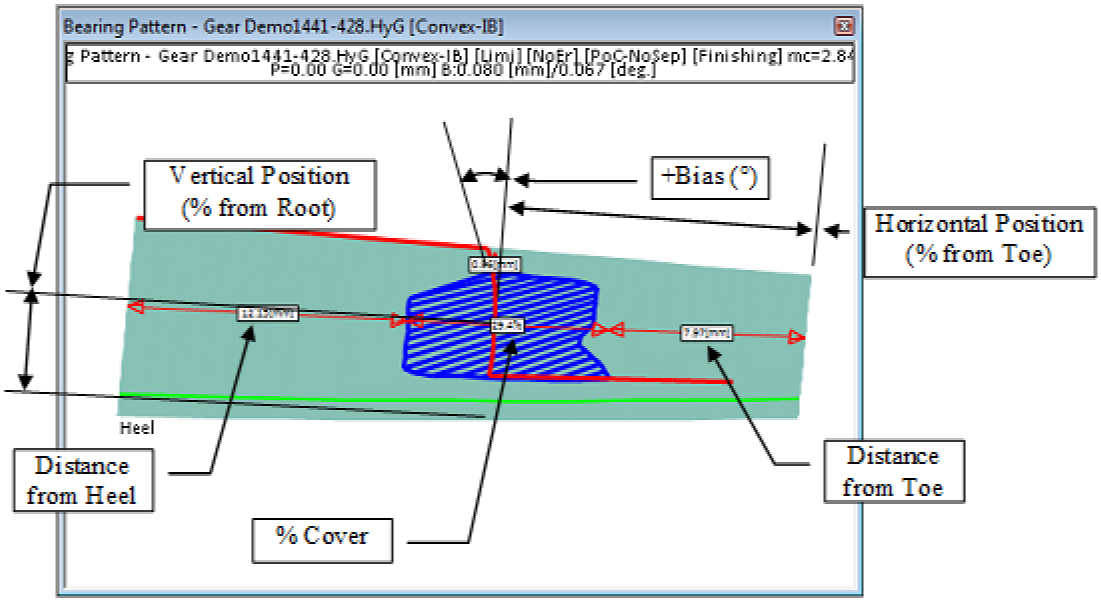
12.4.4 Contact Pattern Development

The Contact Pattern functions are used to visualize and verify what the Contact Pattern is likely to be, with or without load. However, it is often desirable to improve the behavior of a gear set through modification of several Contact Pattern characteristics.

Traditionally, the gear set designer was required either to run again an initial machine settings computer software, or to use proportional changes to manually calculate the modifications to be done on specific machine settings in order to modify one or another Contact Pattern behavior.

The HyGEARS Contact Pattern Development function was developed to free the gear set designer from such tedious work needed to attain specific performances, while providing a visual feedback on the results of any modification.

In the Contact Pattern Development Specification window, sophisticated functions are offered to easily and intuitively make the most frequent operations involved in the development of a Contact Pattern. HyGEARS performs calculations similar to proportional changes, except that they are based on the instantaneous Geometry configuration and are therefore always up to date.

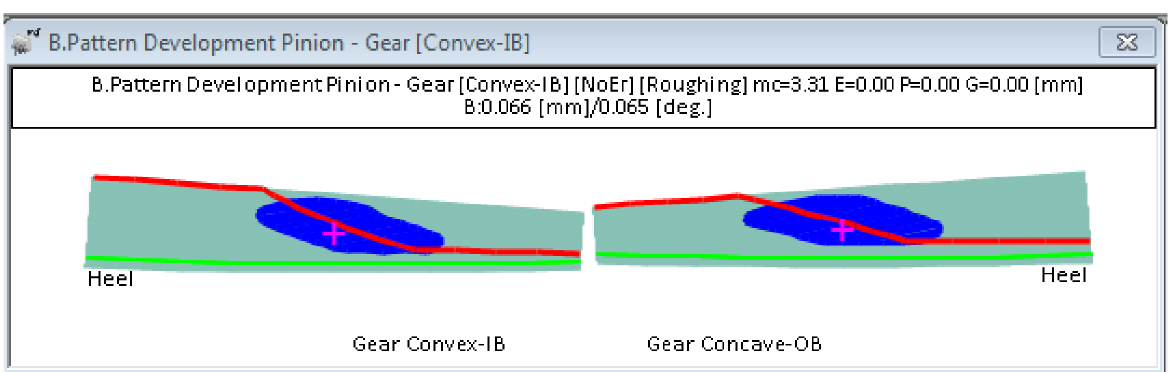


The above figure introduces the basic metrics used to describe, and develop, the Contact Pattern.

Note though that the Contact Pattern is calculated without any applied load and thus, here again, the designer must use knowledge and experience to select the appropriate modifications to be made.

By default, Contact Pattern Development is performed with the gear member displayed for Zerol, spiral-bevel and hypoid gears. Whatever the configured projection mode, Contact Pattern Development Child Windows are always created in 2D projection mode, which can be changed afterward if desired. If an attempt is made to use the Contact Pattern Development function with both the pinion and the gear displayed in the Child Window, HyGEARS will automatically display only the gear member.

Both the Gear IB and OB are displayed at the same time. The following figure identifies the tooth flanks and Heel, depending on the Gear tooth hand (LH: left hand gear, RH: right hand gear).



The Contact Pattern Development Child Window presents the Contact Pattern on the current tooth flank as selected from the Cvx/Con button, and the linear distance between the edges of the Contact Pattern and the tooth, as shown in the above figure. It is therefore possible to change the position and the shape of the Contact Pattern until the displayed results are satisfactory.

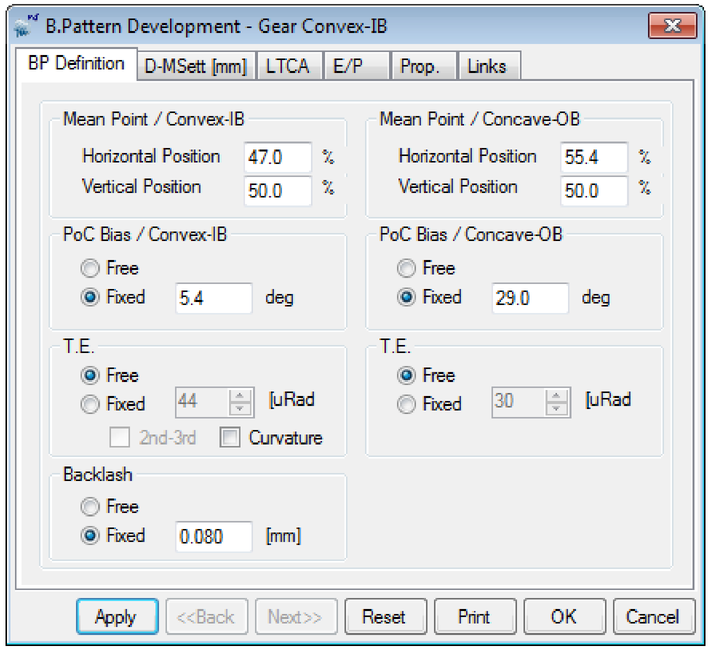
Since Contact Pattern development is not meant to be done either in Roughing mode or using an Error Surface, those buttons are not available for the Contact Pattern Development Child Window. It is not possible either to select a Summary version since all Contact Pattern development should be made **before any Corrective Machine Settings (Closed Loop) are applied**.

There are protections preventing the use of the Contact Pattern Development function after the Nominal Geometry Summary has been set (see Corrective Machine Settings (Closed Loop) later in this chapter), since any modification made after the Nominal has been set would be meaningless.

The Contact Pattern has the same number of points as the PoC, which is the same as the tooth profilewise number of points. Only those portions of the tooth surfaces actually coming into contact will show on the Contact Pattern. Therefore, increasing the tooth number of points is likely to increase the resolution of the Contact Pattern, thereby yielding a better picture of the results to expect, though at the expense of increased computing and display time.

12.4.4.1 BP Development Specification Window

The BP Development Specification Window is used to control how and where on the tooth the Contact Pattern will appear in the course of Contact Pattern Development.

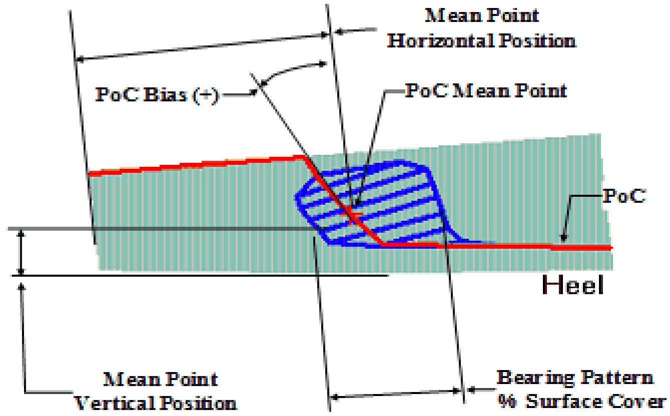


The Contact Pattern Specification window is organized in up to 6 data pages:

BP Definition	where the shape and position of the Contact Pattern are given;
D-MSett	where the changes in machine settings can be consulted;
LTCA	where Contact Pattern under load can be visualized, and the Bending Stresses can be assessed
E/P	where the behavior of the Contact Pattern under positional changes can be checked;
Prop	where proportional changes in machine settings can be imposed;
Links	which associated Child Window is redisplayed after a change in machine settings..

In the course of the development of a gear set, it is often necessary to “optimize” the position and shape of the Contact Pattern.

HyGEARS offers powerful functions where both the Horizontal and Vertical positions of the Mean Point (figure below) can be specified along the facewidth of the gear member.



For Fixed Setting, Modified Roll and Duplex Helical gearsets, the position of the Contact Pattern and the Bias of the PoC can be changed simultaneously through the use of Control Parameters. The Pinion machine settings are changed, and output is sent to the D-MSett data page of the Contact Pattern Development window for easy consultation.

The HyGEARS Contact Pattern Development window is *linked* to other Child Window such as 2D Graphs, Blank and Ease Off. Whenever a new set of machine settings is calculated in response to a user request, HyGEARS searches for opened Child Windows belonging to the current geometry. When found, the display of these Child Windows is updated, thus allowing the user to see what kind of consequences his Contact Pattern Development requests may have. The Child Windows to be updated may be selected through the Links data page.

Command Buttons

Next>>
<<Back up to 20 different configurations may be analyzed and kept in memory during any Contact Pattern Development session, and the user can step back and forth between these configurations using the *Next>>* and *<<Back* command buttons at the bottom of the Contact Pattern Development window. If Horizontal and Vertical positions were entered in the E/P data page, then HyGEARS also calculates the E/P values needed to match the requested Horizontal and Vertical position of the Contact Pattern.

Reset used to reset the machine settings to the state they were in when the Contact Pattern Development session was started. If the current data page is the E/P data page, the “Reset” button rather instructs HyGEARS to reset the E/P values to zero.

Print print the current Summary and changes in machine settings displayed in the D-MSett data page. It is therefore a form of Proportional Changes, to the difference that HyGEARS calculates everything for the user

OK tells HyGEARS to exit the Contact Pattern Development session and keep the current machine setting changes.

Cancel tells HyGEARS to exit the Contact Pattern Development session and reset the machine settings and E/P values to their state when the Contact Pattern Development session was started.

Apply when clicked, or the *Return* key is pressed, HyGEARS starts an iteration process where it calculates the necessary machine setting modifications to obtain the user-requested results.

HyGEARS stops the iteration process when the user-requested values 2.5% are reached, and displays the results in the D-MSett data page (see below). The calculated machine settings are temporarily saved, and the Next >> button becomes active if it is not already.

If the current data page is the E/P data page, the "Apply" button rather instructs HyGEARS to find the E/P values matching the requested Horizontal and Vertical position of the Mean Point

If an error arises during the iteration process, a warning message will be issued, and the process must be restarted using different values. Whether the results are accepted or not, HyGEARS returns automatically to the Contact Pattern Development window.

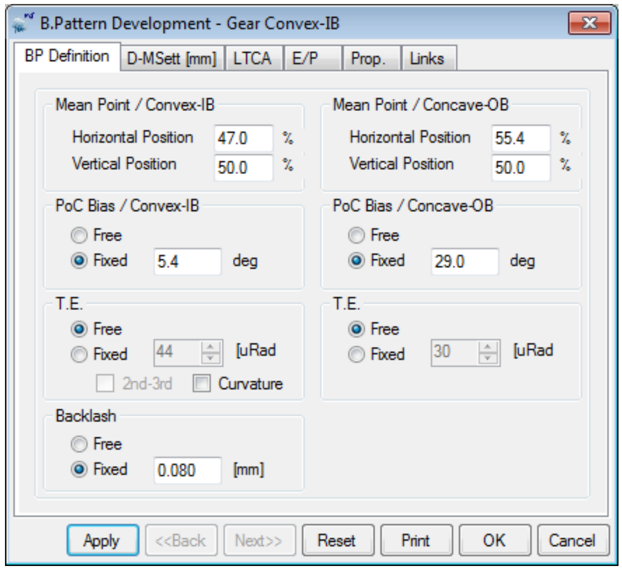
While HyGEARS will properly calculate new machine settings respecting the cutting machine Geometry and original setup, it cannot distinguish if the machine settings that are current at the start of the iteration process are adequate or not. It is therefore the responsibility of the user to make sure that the initial machine settings are appropriate.

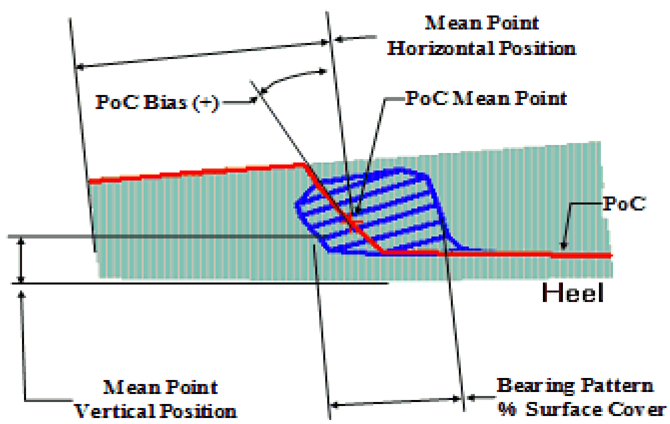
12.4.4.1.1 BP Definition Data Page

In the course of Contact Pattern Development, the Definition data page is used to specify the main Contact Pattern metrics. The following input fields are offered:

- Mean Point Position
- Backlash
- Bias of the PoC

- T.E.





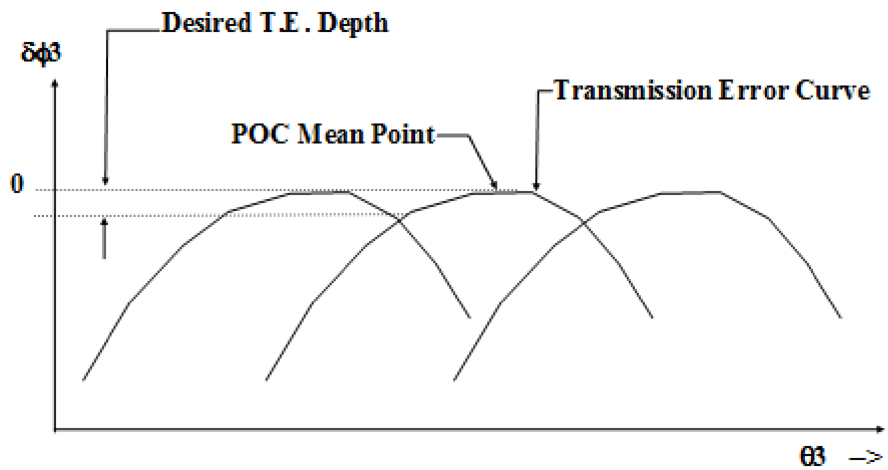
The BP Definition data page is used to specify the main Contact Pattern metrics. The following input fields are offered:

Mean Point Position

Horizontal Position: current horizontal position of the PoC Mean Point, in % of the Gear tooth face. Minimum and maximum values are 10% and 90% respectively.

Vertical Position: vertical position of the center of the PoC Mean Point, in % of tooth height at the current Horizontal position of the Mean Point. The vertical position specifies where along the PoC, the Transmission Error curve slope will be null (see figure below).

This value is 50% by default, to account for the tooth fillet portion, and should be changed with caution as it is directly linked to the following Profile Range value.



As a change in lengthwise Contact Pattern position is often required, a profilewise centering of the Contact Pattern is also a basic need in the course of Contact Pattern development, as was explained in Chapter 2, The HyGEARS Simulation (Well Centered Contact Pattern section).

In order to center the Contact Pattern profilewise, the Transmission Error curve must be convex, and the slope of the curve at the center point must be horizontal, as shown above.

Backlash

This Option is used to specify the desired operating backlash. For Fixed Setting and Modified Roll gear sets, the pinion tooth thickness is changed until the inputted value is obtained. For Completing cycles, the pinion Sliding Base is changed.

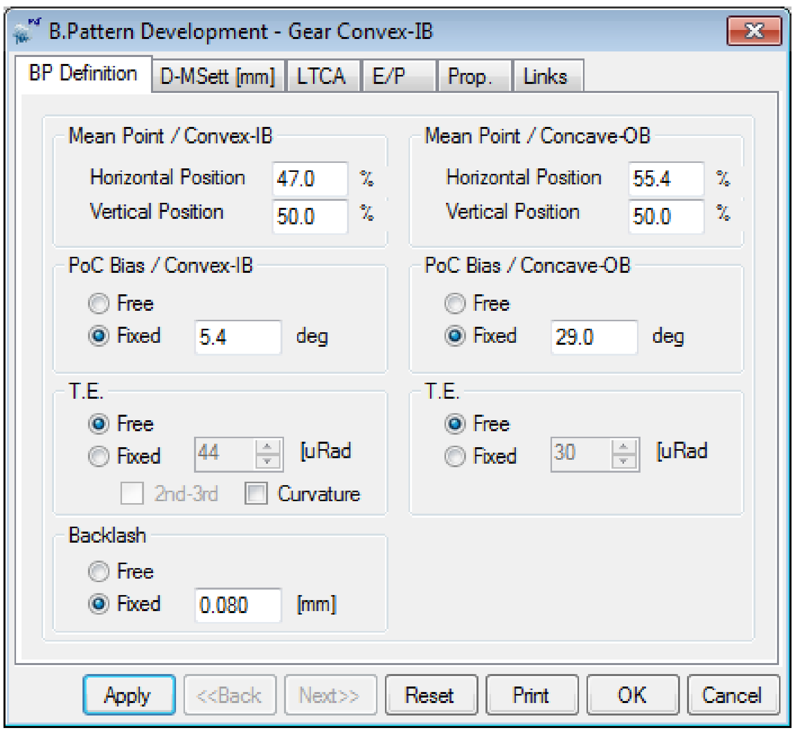
PoC Bias

This Option is used to specify the angle of the PoC at the Mean Point, relative to the tooth vertical direction. The positive direction corresponds to Bias Out. Positive values should normally be used, for both Drive and Coast tooth flanks. PoC Bias is normally controlled by Machine Center to Back, and Helical Motion for Duplex Helical gearsets, and is a very effective way to increase contact ratio.

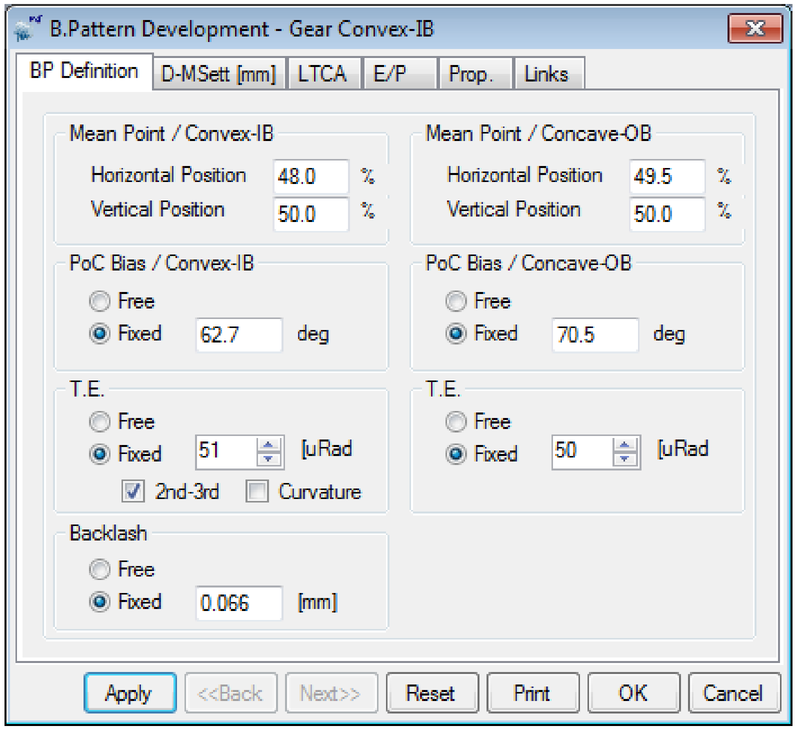
T.E. (Transmission Error)

This Option is used to control the depth of the Transmission Error Curve (T.E.) around the Mean Point of the PoC (see figure above). In HyGEARS, T.E. can be controlled by changing several machine and/or cutter settings.

For Fixed Setting and Modified Roll cycles, each tooth flank can be controlled individually; for Completing cycles, both tooth flanks are controlled simultaneously and, therefore, changing machine settings on one tooth flank will affect the other tooth flank.



By default, no change takes place, i.e. the "*Free*" button is checked. By clicking on the "*Fixed*" button, 3 options become available, as shown below:

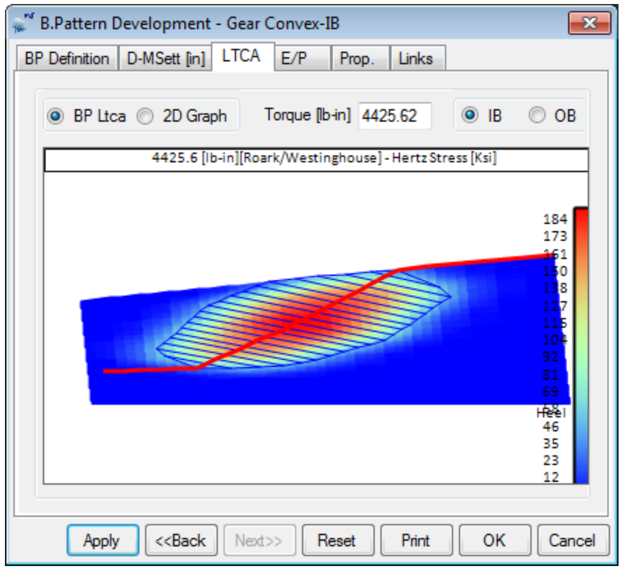


T.E. Amplitude	in the current T.E. units (uRad here), becomes active; when using the arrows to the right of the input field, values cannot exceed 0 at the bottom end and 1000 at the top end; however, values above 1000 can be entered manually;
2nd-3rd	indicates that the choice control parameters for T.E. will be higher order changes, currently limited to 2nd and 3rd order, or 2C and 6D in Gleason terminology; thus, the machine used should be either NC controlled or capable of Modified Roll;
Curvature	indicates that the choice control parameters for T.E. will be the curvature of the cutter blade

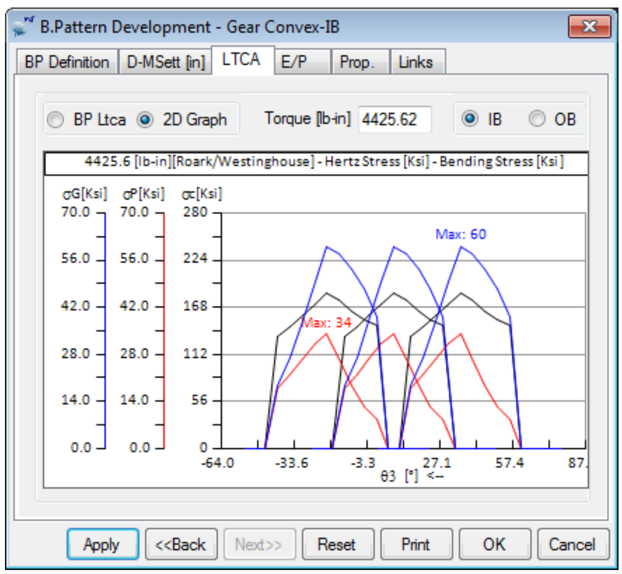
12.4.4.1.2 LTCA Data Page

The LTCA data page displays either:

- the Contact Pattern under load, figure below:



- a 2D Graph with the Contact Stress and pinion and gear Bending Stresses, figure below:



Access depends if the LTCA option has been purchased.

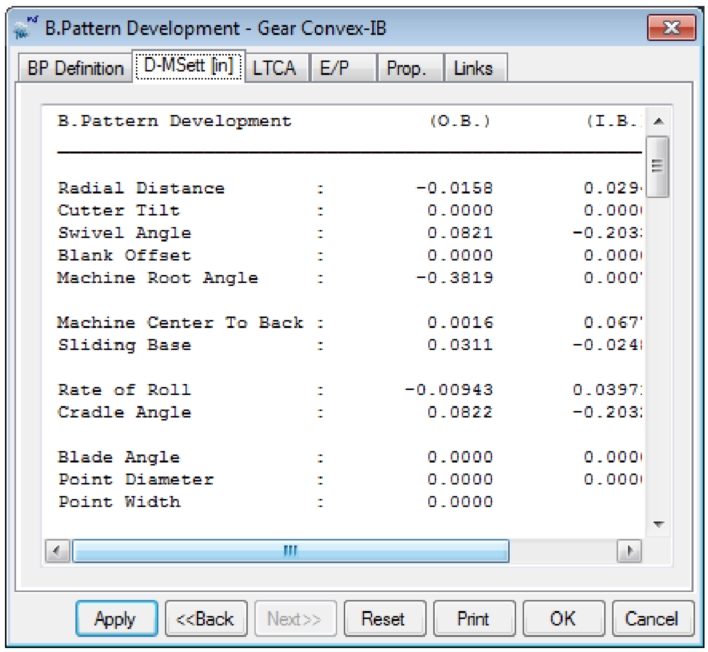
The applied *Torque* can be modified, and the display can be selected for either tooth flanks (*IB* or *OB*). Whenever a change is made to the display options, the *Apply* button must be clicked to instruct HyGEARS to recalculate and re-display.

12.4.4.1.3 D-MSett Data Page

The D-MSett data page displays the changes in machine settings needed to obtain the result displayed in the Child Window.

Its content may be selected, copied to the Windows clipboard (using the Ctl-C keyboard combination), or annotated at will. When the Print command button is used, the contents of the D-MSett data page is also printed.

Note that the contents of the D-MSett data page is lost whenever a new calculation is started.



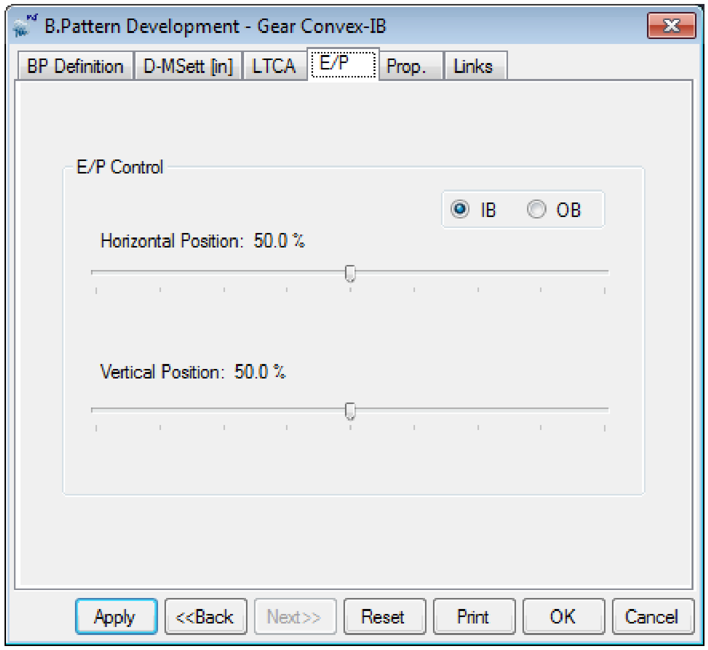
12.4.4.1.4 E/P Data Page

The E/P data page functions similarly to the E/P Control. It enables the verification of the behavior of the Contact Pattern when positional changes are introduced.

The desired position of the Mean Point of the Contact Pattern is specified with the Horizontal and Vertical Position sliders and clicking on the "Apply" button, which redraws the Contact Pattern.

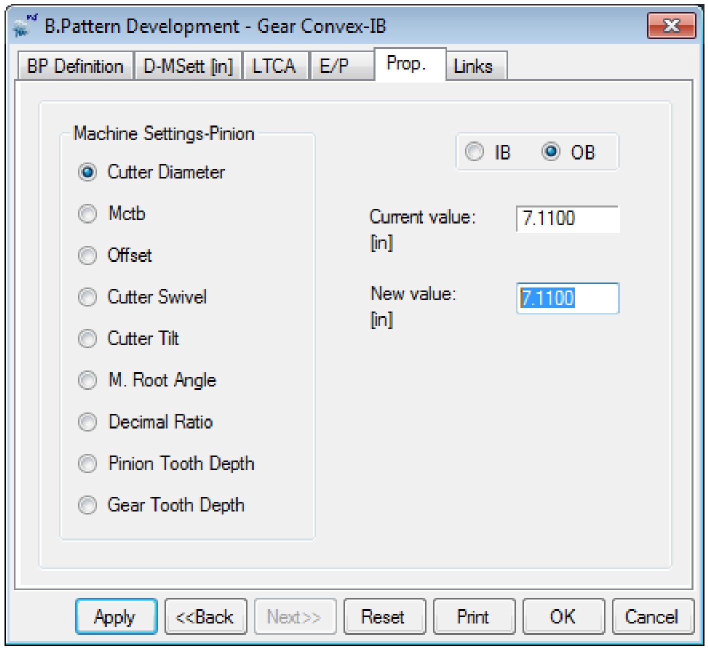
The "Reset" button resets the Horizontal and Vertical Position sliders to their default values, e.g. 50%, and re-displays the Contact Pattern.

The IB and OB radio buttons are used to specify on which tooth flank E/P calculations are to be carried.



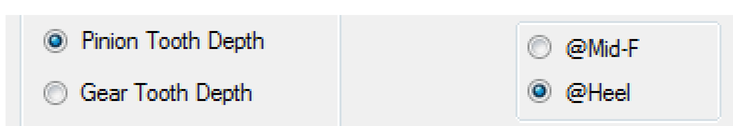
12.4.4.1.5 Prop Data Page

The Prop data page is used to modify individual machine settings on the Pinion, or to control tooth depth. Whenever the cutter, a machine setting or tooth depth is modified, the Bearing Patter is affected and HyGEARS will attempt to re-center the Contact Pattern to its location prior to modification.

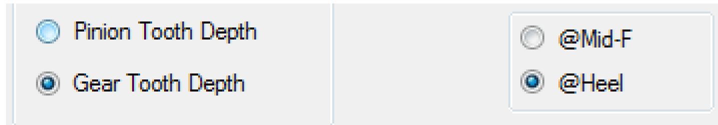


The following settings can be modified proportionally:

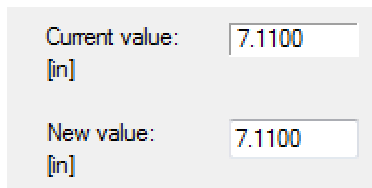
Cutter Diameter	The Point diameter for Fixed setting processes, or the Average diameter for Completing processes
Mctb	Machine Center to Back
Offset	Workpiece offset
Cutter Swivel	Swivel of the cutter
Cutter Tilt	Tilt of the cutter
M. Root Angle	Machine Root Angle
Decimal Ratio	In mechanical machines, or Ratio of Roll for NC machines such as the Phoenix
Pinion Tooth Depth	Either at Mid-Face or Heel



Gear Tooth Depth	Either at Mid-Face or Heel



By selecting a Machine Setting, its *Current value* is displayed and the *New value* can then be entered. Clicking on the *Apply* button instructs HyGEARS to apply the modification proportionally, i.e. without modification to tooth depth (unless Tooth Depth is the sought modification), and calculate the necessary machine settings to maintain the IB and OB Contact Patterns where they were located prior to the modification.



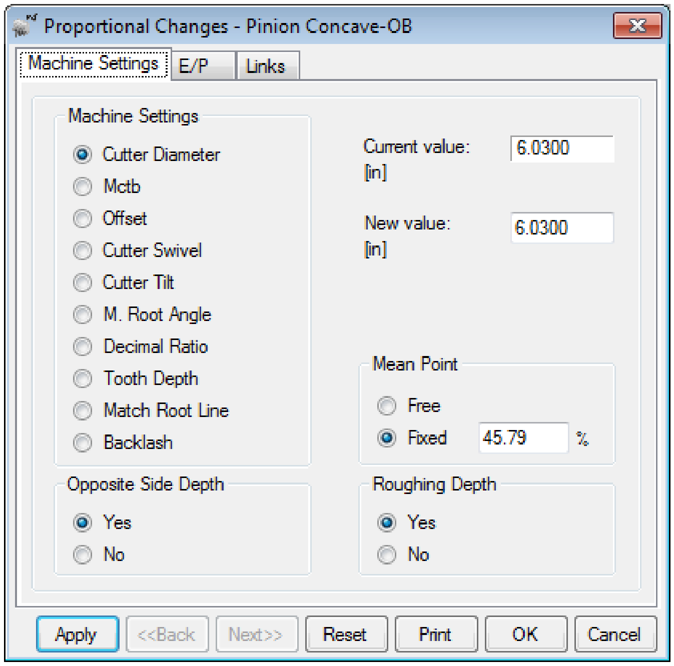
Fixed Setting: If the pinion is cut by a Fixed Setting process, then the IB and OB machine settings can be modified by selecting the appropriate tooth flank.

Completing: If the pinion is cut by a Completing process, then any modification applies to both tooth flanks simultaneously.

12.4.4.2 Proportional Changes Window

In the Proportional Changes Window, individual machine settings can be modified while respecting tooth rootline. Thus, it amounts to **Proportional Changes**, except that HyGEARS does all the work.

In short, HyGEARS offers the possibility to change individual machine settings, control tooth depth and tooth rootline, while maintaining the Mean Point horizontal location of the PoC.



Modifications can be applied on up to 12 different aspects of tooth machine settings or proportion. For each aspect, the Current value is displayed along with the units in use, and a New value is expected.

By default, the Horizontal Position of the Mean Point of the PoC is fixed to its current value, which means that after modifying the requested parameter, HyGEARS will reposition the PoC Mean Point at the current value before the change was made (see the Contact Pattern Development window). The Mean Point position may be set *Free* where, after any change in machine setting, the PoC is not centered.

The HyGEARS Proportional Changes window is ***linked*** to other Child Window types.

Whenever a new set of machine settings is calculated in response to a user request, HyGEARS searches for existing Child Windows belonging to the current Geometry. When found, the display of these Child Windows is updated, thus allowing the user to see what kind of consequences on Transmission Error and Tooth Root Line his/her requests may have.

Command Buttons

Apply HyGEARS starts an iteration process where it calculates the necessary machine setting modifications to obtain the user-requested results.

HyGEARS stops the iteration process when the user-requested values 2.5% are reached, and displays the results in the D-MSett data page (see below). The calculated machine settings are temporarily saved, and the Next >> button becomes active if it is not already.

The calculated changes are added to the current geometry until the user is satisfied and exits using the OK button, or cancels everything.

If an error arises during the iteration process, a warning message will be issued, and the process must be restarted using different values.

If the current data page is the E/P data page, the “Apply” button rather instructs HyGEARS to find the E/P values matching the requested Horizontal and Vertical position of the Mean Point.

Next>>
<<Back up to 10 different configurations may be analyzed and kept in memory during any Proportional Changes session, and the user can step back and forth between these configurations using the Next>> and <<Back command buttons at the bottom of the Contact Pattern Development window. If Horizontal and Vertical positions were entered in the E/P data page, then HyGEARS also calculates the E/P values needed to match the requested Horizontal and Vertical position of the Contact Pattern.

Reset used to reset the machine settings to the state they were in when the Proportional Changes session was started. If the current data page is the E/P data page, the “Reset” button rather instructs HyGEARS to reset the E/P values to zero.

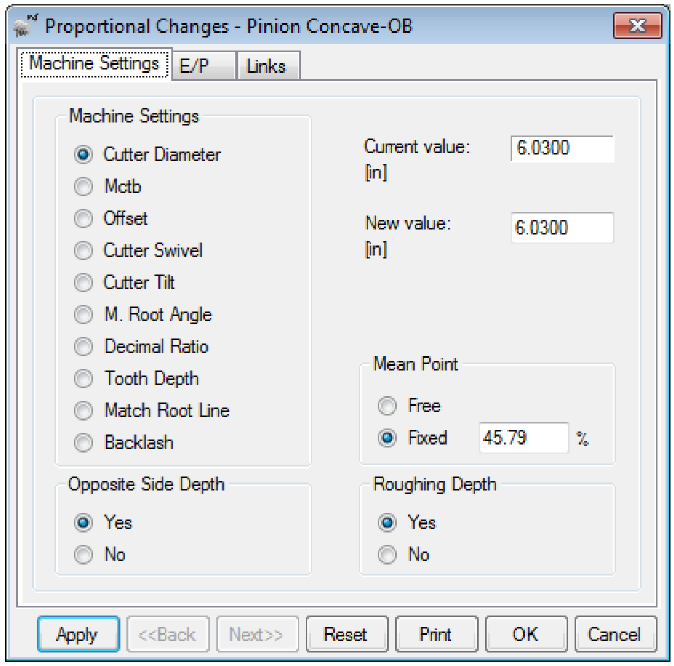
Print used to print the current Summary and changes in machine settings displayed in the D-MSett data page. It is therefore a form of Proportional Changes, to the difference that HyGEARS calculates everything for the user

OK tells HyGEARS to exit the Proportional Changes session and keep the current machine setting changes.

Cancel tells HyGEARS to exit the Proportional Changes session and reset the machine settings and E/P values to their state when the Proportional Changes session was started.

Machine Settings data page

The following machine settings can be changed proportionally:



Cutter Diameter

Change the pinion cutter point diameter. Useful to modify the length of the Contact Pattern on the tooth flank.

This function makes it possible to change the cutter Point or Average diameter, on the current pinion tooth flank. When a pinion cutter diameter change is made, the machine center to back and sliding base values are adjusted in order to conserve the pinion tooth proportions. Therefore, if the cutter change is large, the Contact Pattern position is likely to change and a readjustment may then be necessary although HyGEARS attempts to keep the Contact Pattern at the same lengthwise position.

Mctb

Change the pinion machine center to back. Useful to manually modify the bias of the Contact Pattern on the tooth flank.

The bias is best visualized on the PoC on the tooth flank. Bias is defined as the angle the profile portion of the PoC makes with a true vertical line (see the BPat function button).

Heavy bias may be detrimental since it tends to spread the Contact Pattern over a larger portion of the tooth flank, and may make it more sensitive to position and alignment errors. On the other hand, bias increases contact ratio, and therefore extends the duration of contact and reduce the load carried by individual tooth pairs.

Offset	Changes the pinion blank offset. Useful to manually modify the bias of the Contact Pattern on the tooth flank, or the % of tooth flank cover as the offset affects the tooth lengthwise curvature. *Note*: the sign of the offset value should not be changed.
Cutter Swivel	Change the pinion machine swivel angle. Useful to modify the profilewise position of the Contact Pattern on the tooth flank. Offered only if the gear member is non generated, e.g. cut either by the Formate or Helixform processes. When cutter tilt is used in the machine setup, the swivel angle is used to give the tilted cutter its orientation relative to the Mean Point on the tooth flank. A change in pressure angle at the Mean Point normally results in changes both in the lengthwise and profilewise position of the Contact Pattern. Therefore, if a change in the swivel angle is used to change the profilewise position of the Contact Pattern, the lengthwise position will be modified and should be corrected. A change in the cutter swivel angle is normally accompanied by changes in the machine root angle, eccentric angle, machine center to back and sliding base settings, which are automatically calculated by HyGEARS.
Cutter Tilt	Change in pinion cutter tilt. Useful to modify the profilewise position of the Contact Pattern on the tooth flank. While the Cutter Swivel option above changes the orientation of the tilted cutter, the Cutter Tilt option conserves the tilt orientation but modifies the amount by which the cutter axis is tilted. Cutter tilt is normally given by the cutter spindle rotation or swash angle. In order to simplify things, HyGEARS works directly with the cutter tilt value. A change in cutter tilt is normally reflected in a change in pressure angle at the Mean Point and, like in the Cutter Swivel option above, it can be used to manually control the profilewise position of the Contact Pattern.

A change in pressure angle at the Mean Point normally results in changes both in the lengthwise and profilewise positions of the Contact Pattern. Therefore, if a change in cutter tilt angle is used to change the profilewise position of the Contact Pattern, the lengthwise position will be modified.

A change of the cutter tilt angle is given by a change in the cutter spindle rotation or swash angle, and thus in the swivel angle. A change of the cutter tilt angle is normally accompanied by changes in the machine root angle, eccentric angle, machine center to back and sliding base settings, which are automatically calculated by HyGEARS.

M. Root Angle

Change in pinion machine root angle. Useful to modify a diamond shaped Contact Pattern.

Diamond shaped Contact Patterns are occasionally observed, and must be corrected if the diamond is too important. A good way to do so is to change the pinion machine root angle.

A change of the machine root angle is normally accompanied by changes in the machine center to back and sliding base settings, and in cutter tilt, thus changes in the cutter swivel and cutter spindle rotation angles, which are automatically calculated by HyGEARS.

Decimal Ratio

Change in pinion machine Decimal Ratio. Useful to modify the Bias of the Contact Pattern.

The bias is best visualized on the PoC on the tooth flank. Bias is defined as the angle the profile portion of the PoC makes with a true vertical line (see the BPat function button above in this chapter). Heavy bias may be detrimental since it tends to spread the Contact Pattern over a larger portion of the tooth flank, and may make it more sensitive to position and alignment errors. On the other hand, bias increases contact ratio, and therefore extends the duration of contact and reduce the load carried by individual tooth pairs.

Tooth Depth

Changes the Pinion tooth depth of the current tooth flank by a user defined amount during Contact Pattern Development.

Useful to increase or reduce the pinion tooth depth. Additionally, HyGEARS offers to automatically adjust the tooth depths of the opposite tooth flank of Fixed Setting or Modified Roll pinions and that of the Roughed tooth to the new depth of the current tooth flank.

The Depth change input field is used to specify by how much the current pinion tooth flank depth is to be changed. By specifying a very small value, 0.0001 [mm] for example, and using the Yes options for both the Opposite Side Depth and Roughing Depth, HyGEARS will ensure that the Finishing tooth depths are the same on both tooth flanks, and that the Roughing tooth depth is below both IB and OB tooth rootlines, thereby eliminating any possibility of interference when cutting.

Match Root Line

Matches the pinion tooth root line of the current tooth flank to that of the opposite tooth flank.

Useful to ensure that, for Fixed Setting or Modified Roll pinions, both IB and OB tooth flanks have parallel root lines. A change in the tooth root line normally results in changes both in the lengthwise and profilewise position of the Contact Pattern, and in its shape.

Therefore, when the root line of one tooth flank is matched to that of the other, the Pinion IB should be the modified tooth flank, and the Pinion OB tooth flank should be the target, as the Pinion IB tooth flank is normally the coast side, and its Contact Pattern does not have the same importance as that of the driving side.

A change in the tooth root line is normally accompanied by changes in the cutter swivel and tilt angles, eccentric angle, machine center to back and sliding base settings, which are automatically calculated by HyGEARS.

Backlash

Changes the Pinion tooth thickness in order to match a user defined backlash.

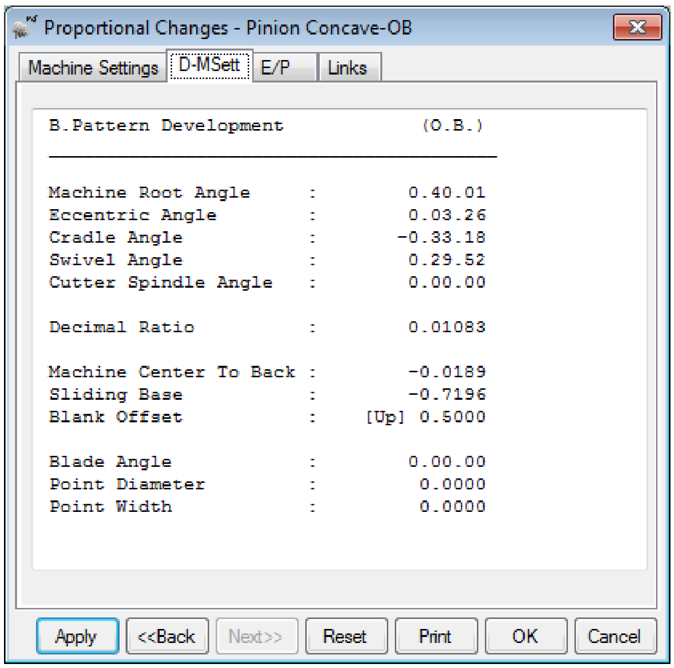
Useful to increase or reduce the operating backlash of the gearset, which is usually controlled by the pinion tooth thickness. Applicable only to Fixed Setting and Modified Roll pinions.

D-MSett data page

The D-MSett data page displays the **changes in machine settings** needed to obtain the result displayed in the Child Window.

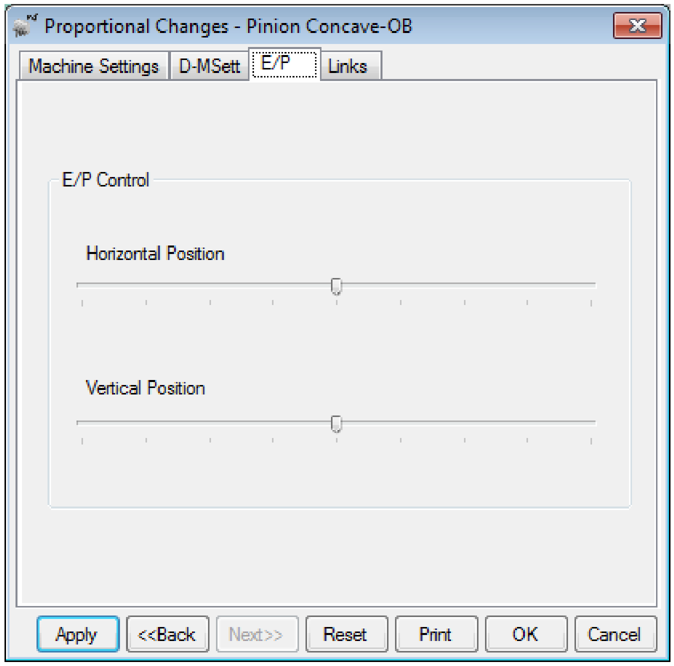
Its content may be **selected, copied** to the Windows clipboard (using the Ctl-C keyboard combination), or **annotated** at will.

When the **Print** command button is used, the content of the D-MSett data page is also printed. Note that the contents of the D-MSett data page is updated whenever a new calculation is started, and always reflects the changes in machine settings since the Proportional Changes window was called.



E/P data page

The E/P data page functions similarly to the E/P Control. It enables the verification of the behavior of the Contact Pattern when positional changes are introduced.

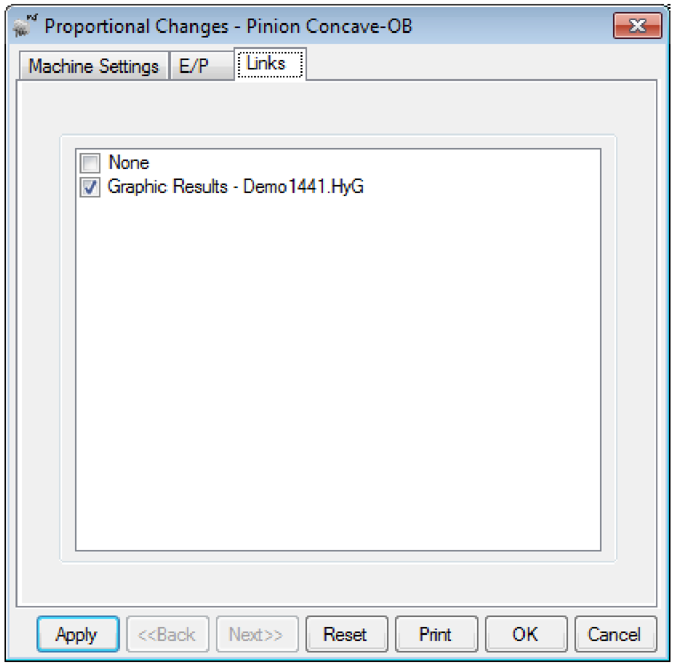


The desired position of the Mean Point of the Contact Pattern is specified with the Horizontal and Vertical Position sliders and clicking on the “Apply” button.

The “Reset” button resets the Horizontal and Vertical Position sliders to their default values, e.g. 50%, and redisplays the Contact Pattern.

Links data page

The Links data page is used to tell HyGEARS which of the Child Windows associated to the currently loaded geometry are to be redisplayed when a change is made.

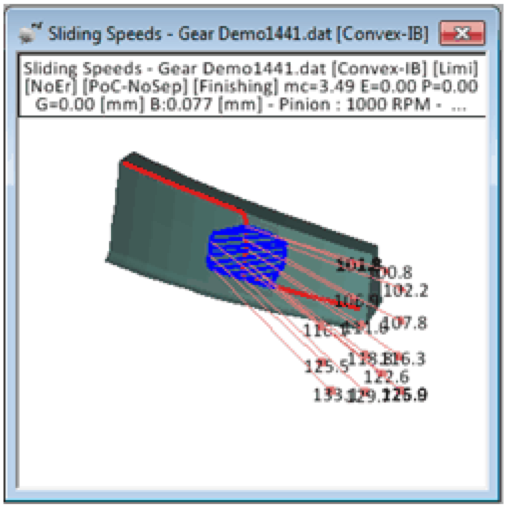


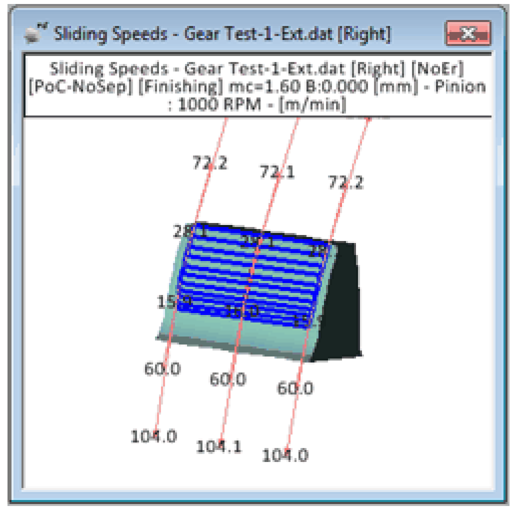
Normally, all checked Child Windows will be redisplayed, but one may desire to restrict this redisplay to selected windows in order to show what changes are taking place, for example on a LTCA result, or for some Contact Pattern or Kinematic result. Thus, only checked Child Windows are redisplayed.

12.4.5 Sliding Speeds

The Sliding Speeds function is used to calculate and display the sliding speeds between the pinion and gear tooth surfaces, over the Contact Pattern area.

Knowing the sliding speeds may be useful for the gear set designer to identify where on the Contact Pattern wear is most likely to occur. While the sliding speed by itself is not an absolute answer since it must be combined with the contact pressure, friction coefficient and the oil temperature to obtain a global picture of the operating conditions over the Contact Pattern, it is nevertheless a good indicator of the amount of sliding taking place and where wear is most likely to occur.





Hypoid Gear **Spur Gear**

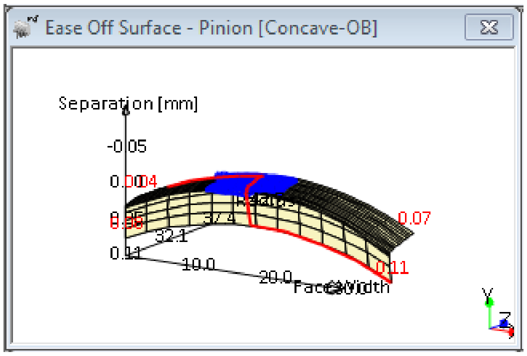
The Sliding Speeds Child Window presents the Contact Pattern on the current tooth flank as selected from the Cvx/Con button, and a series of vectors indicating the direction and magnitude of the sliding speed at the toe, center and heel position of each instant line of contact. In order not to clutter the Child Window, sliding speed vectors are presented at each other instant line of contact of the Contact Pattern. The pinion RPM and sliding speed units are displayed in the Child Window title.

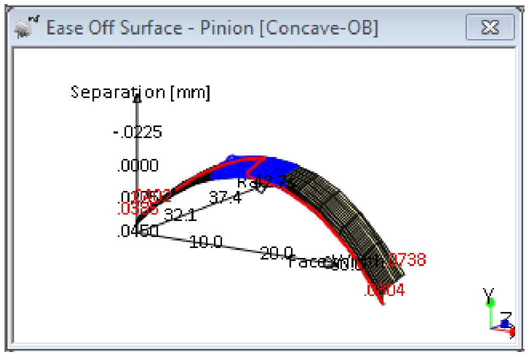
12.4.6 Ease Off Surface

As explained in The HyGEARS Simulation, to obtain the PoC and the Contact Pattern, the Ease Off surface is calculated.

In short, the Ease Off surface is a scan, on the gear tooth flank, of all contact points that can "theoretically" take place. To do so, contact points between the pinion and gear tooth surfaces are found for each point of the gear tooth flank, and the Ease Off surface is built from the rotation of each contact point relative to a reference contact point.

The Ease Off surface is displayed along 3 axes representing the pinion *Facewidth* and *Radius* in the horizontal plane and the actual *Separation* along the vertical axis. The PoC can selectively be displayed or hidden.





Ease Off With TopRem **Ease Off No TopRem**

Thus, the Ease Off surface incorporates simultaneously the error in conjugacy between the pinion and the gear, plus the errors in manufacturing and operating position.

In the absence of errors in manufacturing and operating position, the Ease Off surface essentially represents the difference between the actual pinion and a pinion fully conjugate to the mating gear member.

For example, in the above left figure, the Ease Off surface shows a large deviation at its fore-edge, which actually corresponds to the tooth section removed by the TopRem cutter.

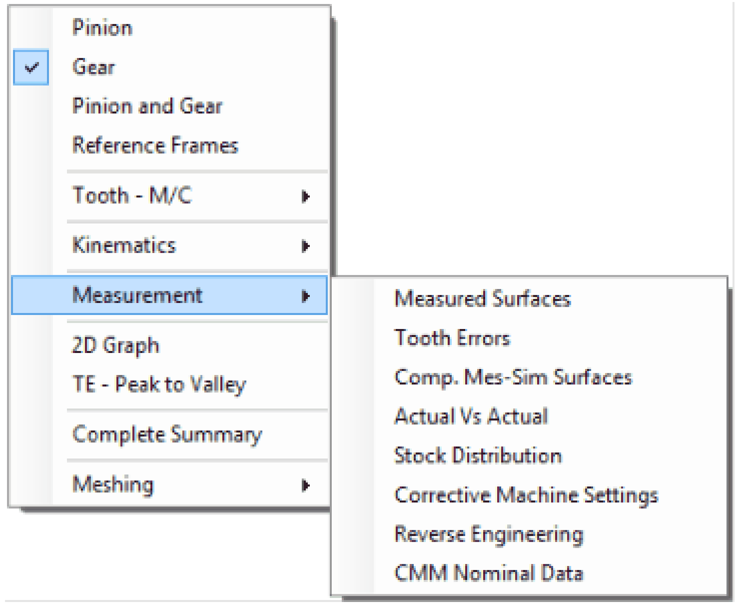
Since the Ease Off Child Window is 3D by definition, the Tool Bar rotation buttons will be available, provided the projection mode is User Defined, and the Zooming buttons will be available if the Zoom mode is manual (see The HyGEARS GUI). For more details on the function buttons behavior, please refer to section The Parent Window Function Buttons.

12.5 Measurement

Hypoid and Spiral-Bevel pinion and gear tooth surfaces can be machined by a wide variety of cutting machines and cutting processes. Given that machine type, age and state of wear can vary significantly, the machined tooth surfaces can be quite different from one machine to another. Even the same machine can produce different results if it is not set-up by the same operator.

Therefore, in the production of Spiral-Bevel and Hypoid gear sets, it is usual to measure the cut tooth surfaces and compare them to a known reference to ensure that they meet certain quality control criteria. Additionally, it may be necessary to calculate machine settings modifications to correct some surface errors.

This HyGEARS section offers such tools in which eight menu entries are offered:



Measured Surfaces: creation of a Child Window which simultaneously displays the simulated teeth and measurement data for either the pinion or the gear;

Tooth Errors: creation of a Child Window which calculates and displays tooth thickness and pitch errors, provided measurement compensation has been performed by HyGEARS, which implies that the tooth surface was measured by means other than a Zeiss CMM using Ram and Rfd files;

Compare Mes-Sim Surfaces: creation of a Child Window which displays the differences between the measured and simulated tooth surfaces for either the pinion or the gear;

Stock Distribution: creation of a Child Window which displays the differences between the Roughing and Finishing tooth surfaces, including tooth thickness distribution, for either the pinion or the gear;

Actual vs Actual: creation of a Child Window which displays the wo measurement data filesone against another;

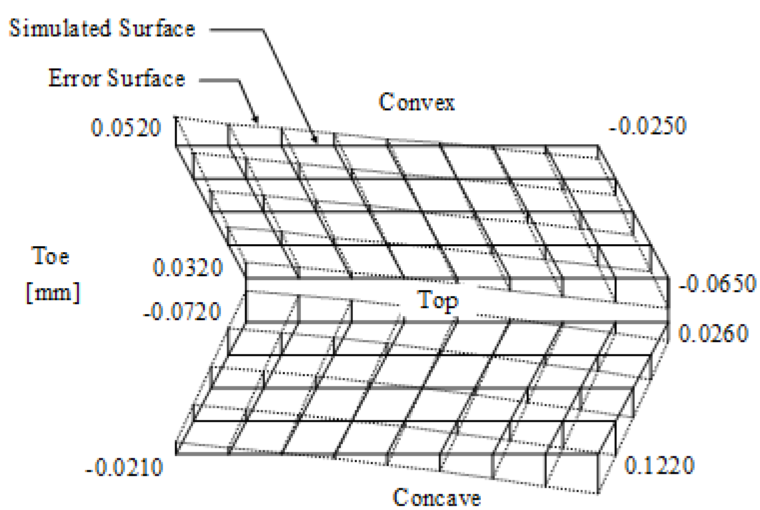
Corrective Machine Settings: creation of a Child Window which displays the differences between the measured and simulated tooth surfaces for either the pinion or the gear, and offers tools to calculate the machine setting modifications needed to

	bring the cut tooth surface coincident with the simulated surface, thereby correcting the displayed surface errors;
Reverse Engineering	creation of a Child Window which displays the differences between the measured and simulated tooth surfaces for either the pinion or the gear, and offers tools to match the simulated and the machined tooth surfaces, thereby "reverse-engineering" the measured tooth surface;
CMM Nominal Data:	creation of a Child Window which displays the simulated tooth surface, and offers tools to calculate a projected measurement surface and produce a CMM target grid file, in CMM Nominal, Gleason-Zeiss, Klingelnberg-P, MdM or Hoeffler formats.

12.5.1 Error Surface

Many Graphics functions offer the possibility to use the difference between the simulated, or reference, and measured tooth surfaces to produce kinematic results closer to the behavior of the actual tooth surfaces.

This difference is called the Error Surface, and is referred to as such in all the documentation.



Whenever measurement data is present within the current Geometry, the difference between the measured and simulated surfaces can be used to establish the overall correspondence between the manufactured surface and the one that is desired from the Geometry Summary (see Compare Mes-Sim Surfaces).

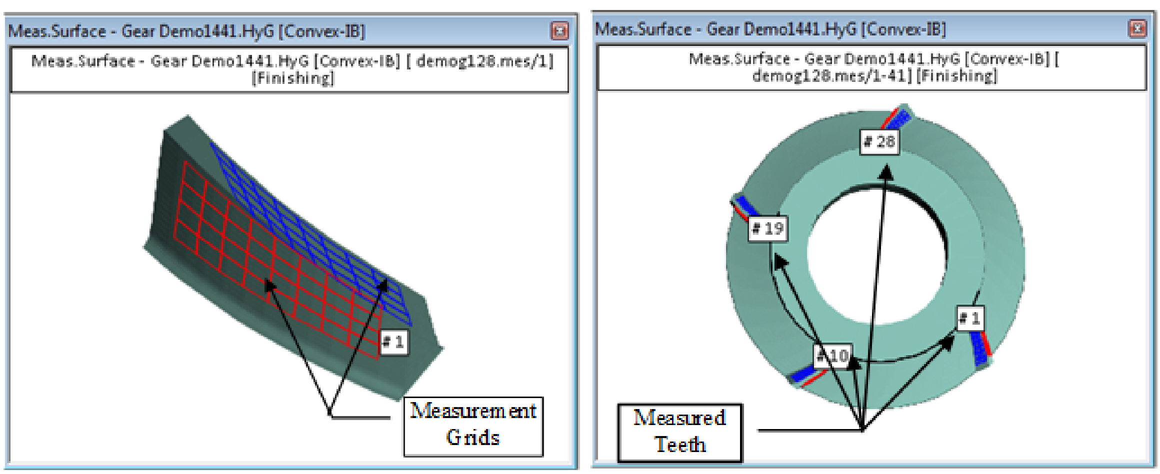
This comparison data can also be used to calculate variations needed in machine settings to correct the differences noted (see Corrective Machine Settings (Closed Loop)).

Another use of the difference between the measured and simulated surfaces is in the calculation of the Path of Contact and the Contact Pattern, where it is considered that the contacting surfaces become the measured surfaces instead of the simulated surfaces, thereby reflecting much more closely the kinematic behavior of the actual gear set.

See the Measurement and Compensation and Comp. Meas-Sim Surfaces sections for more details about measurement and interpretation, and Using the Error Surface in the example Creating a New Fixed Setting Hypoid Gear see, HyGEARS Examples, for information how the Error Surface can be used.

12.5.2 Measured Surfaces

The Measured Surfaces Child Window displays the simulated and measured tooth surfaces simultaneously. Since measurement data can be produced on a variety of CMMs, and by different softwares such as Gleason's TCA or HyGEARS, this function is especially useful to visualize which teeth were measured (below, right figure) and where the measurement data falls on the tooth flank (below, left figure).



The Measured Surfaces Child Window can display up to four pinion or gear measurement datasets contained within the same measurement data file.

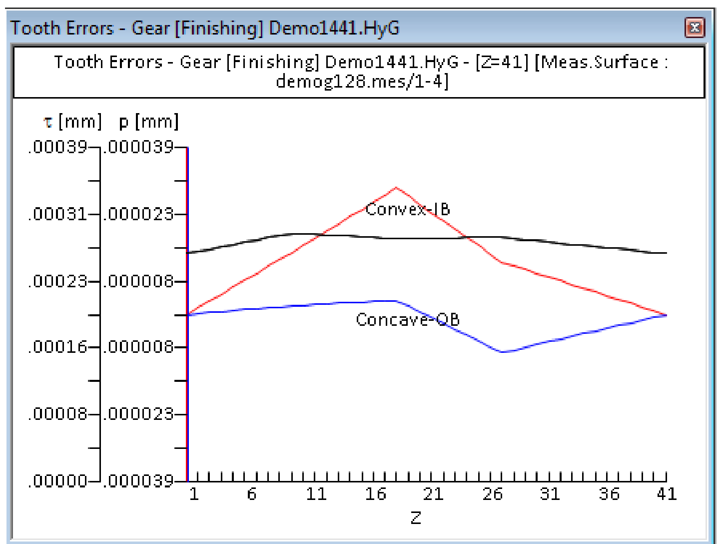
If both the pinion and the gear have been selected for display (see The Displayed Geometry above in this chapter), the Measured Surfaces Child Window will default to the pinion. The displayed data-set selection is made as described in the Measurement Data Selection window.

Since the Measured Surfaces Child Window is 3D by definition, the Tool Bar rotation buttons will be available, provided the projection mode is User Defined, and the Zooming buttons will be available if the Zoom mode is manual (see The HyGEARS GUI). For more details on the function buttons behavior, please refer to The Parent Window Function Buttons .

12.5.3 Tooth Errors

The Tooth Errors Child Window displays the difference between the calculated and measured tooth thickness, and the tooth accumulated pitch error, provided that the number of measured teeth is larger than one.

For the current version, HyGEARS supports up to four measurement datasets per measurement data file.



The Tooth Errors Child Window displays two vertical axes, one for the accumulated pitch error (p) for both the Convex-IB and Concave-OB tooth flanks, and the other for the tooth thickness error (τ), against an horizontal axis carrying the tooth number (Z) of the measured pinion or gear member. Tooth one corresponds to the first data-set in the measurement data file. Thickness and accumulated pitch errors are calculated at the middle point of a data-set, thus at point (3, 5) on a standard 5x9 measurement grid.

As can be seen in the figure above, tooth spacing error is null for tooth 1, but changes on both the IB (red line) and OB (blue line) sides for the other measured teeth.

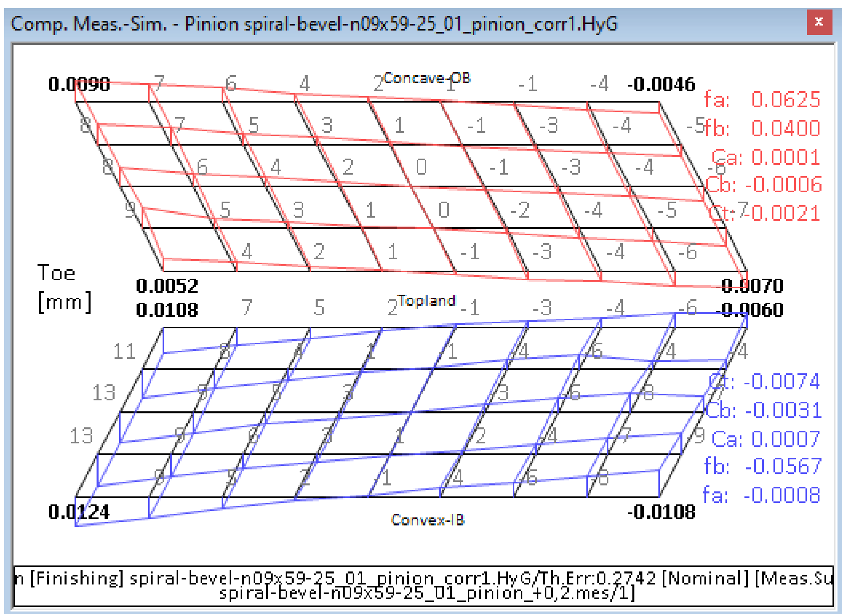
Tooth thickness error (dotted line) is not null on tooth 1, since the measured and calculated tooth thicknesses do not match at the middle point. The variation in tooth thickness corresponds to the difference between the Concave-OB and Convex-IB accumulated pitch errors. The Tooth

Errors Child Window makes no distinction between actual thickness and accumulated pitch error and runout.

If both the pinion and the gear have been selected for display (see The Displayed Geometry), the Tooth Errors Child Window will default to the pinion. The displayed data-set selection is made as described in the Measurement Data Selection window.

12.5.4 Compare Meas-Sim Surfaces

The *Compare Meas-Sim Surfaces* Child Window calculates and displays the difference between the simulated and measured tooth surfaces. It is mainly used to assess the quality of a pinion or a gear since it shows graphically by how much the theoretical and measured surfaces differ. For the calculation of the difference to take place, a proper measurement data file must be provided in the Measurement Data Selection window.



The *Compare Mes-Sim Surfaces* Child Window provides the following information:

- each point of the measurement data-set is compared to the theoretical surface obtained from the selected Summary version (see the Sele button function later);
- the difference between measurement and theoretical data is displayed in the Child Window as shown above;
- in this display, the theoretical surface is displayed in black continuous lines, while the measured surface is displayed in colored dotted lines;

- the distance between the theoretical and measured surfaces corresponds to the error between both surfaces, with the error at a preset point equal to zero (normally the data-set middle point when the numbers of both profilewise and lengthwise measured data points are odd such as in the above example);

- the left side of the window is the toe of the tooth, while the right side is the heel of the tooth;

- the upper display surface is the pinion concave/gear convex tooth surface, while the lower display surface is the pinion convex/gear concave tooth surface;

- the units in use are given at the left side of the display;

- the four corners of each displayed surface show the error values for reference;

- four surface statistics are given for each tooth flank:
  - *fa*: average pressure angle error
  - *fb*: average spiral angle error
  - *Ca*: average profile crowning error
  - *Cb*: average lengthwise crowning error

- the Child Window scale is automatically adjusted for the error surfaces to stay within the boundaries of the Child Window, unless the HyGEARS Configuration *Autoscale* feature has been set otherwise;

- the subtitle at the bottom of the Child Window identifies:
  - the displayed geometry, either pinion or gear;
  - the cutting status, Roughing or Finishing;
  - the selected Summary version;
  - the measurement data file name and the tooth number ("/10" above);
  - the measured tooth thickness error, at the middle point of the data-set ("Th.Err:-0.0003" above).

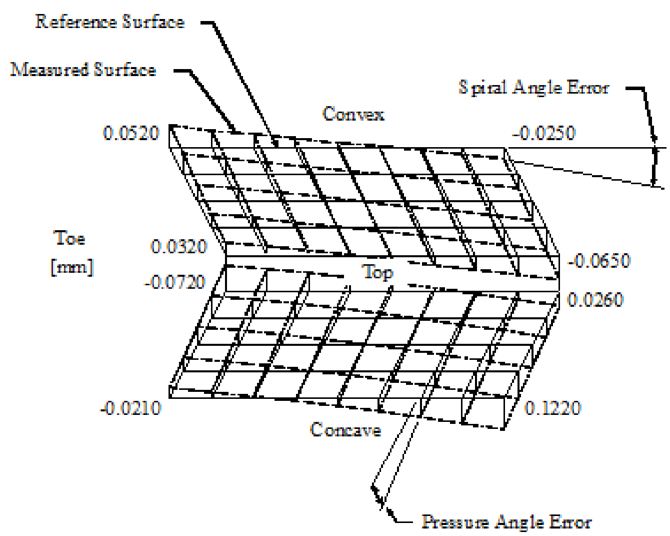
The *Compare Mes-Sim Surfaces* Child Window can show both 1st and 2nd order errors, which can be understood as follows:

- while each data point gives the local error between the measured and theoretical surfaces, more global trends are obvious both in the lengthwise and profilewise directions;

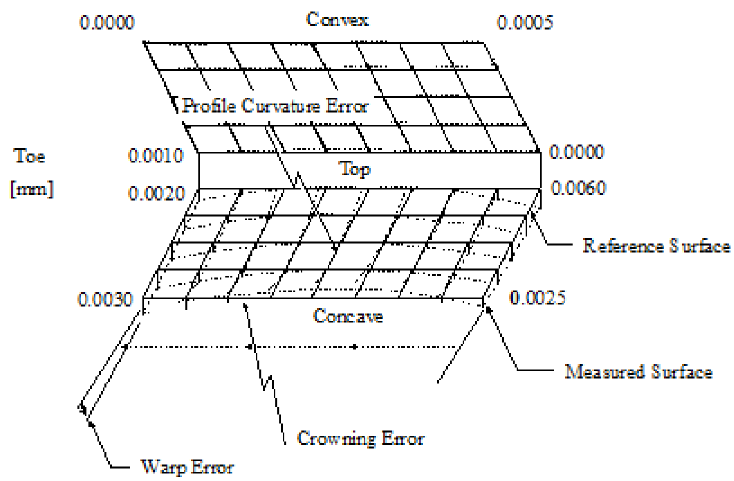
- the lengthwise trend depicts errors in spiral angle, which is the average tilt of lengthwise measurement data lines relative to the corresponding theoretical lengthwise data lines; an error in cutter point diameter, also called crowning error, is shown by a curve between the lengthwise measurement data lines relative to the corresponding theoretical lengthwise data lines;

- the profilewise trend depicts errors in pressure angle, which is the average tilt of profilewise measurement data lines relative to the corresponding theoretical data lines; a profile curvature error is shown by a curve between the measurement data lines relative to the corresponding theoretical profilewise data lines;

- second order errors take the more complex shape of a saddle, and can be a combination of spiral angle, pressure angle, bias, crowning and profile curvature errors.



1st Order Errors



2nd Order Errors

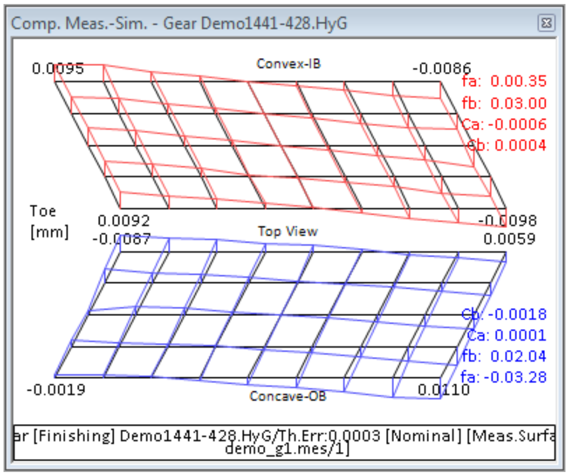
The calculated errors can be caused by machine setup, machine age and maintenance condition, or internal machine constant errors such as the spiral-bevel and hypoid gear generator eccentric constant which may differ slightly from its theoretical value.

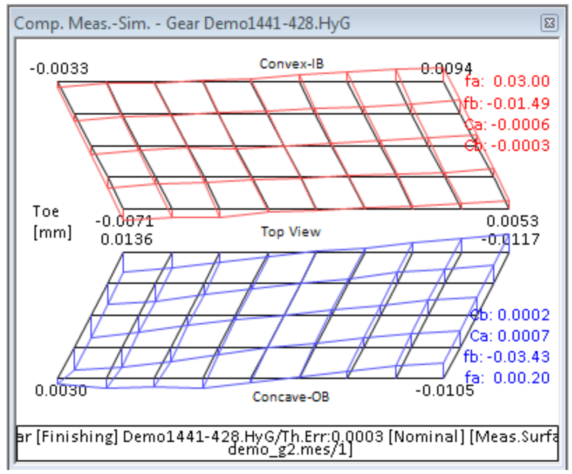
The Measured Surfaces Child Window can display the difference for up to four pinion or gear measurement datasets contained within the same measurement data file. When more than one data-set is selected for display, HyGEARS calculates the average error, e.g. the sum of errors for each selected data-set point, divided by the number of displayed datasets.

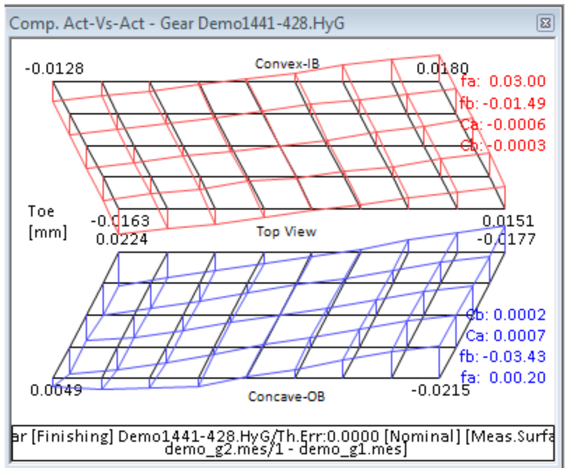
If both the pinion and the gear have been selected for display (see The Displayed Geometry), the Measured Surfaces Child Window will default to the pinion. The displayed data-set selection is made as described in the Measurement Data Selection window .

12.5.5 Actual vs Actual

The *Actual Vs Actual* Child Window displays the difference between two measurement data files. It can be useful in comparing a production gear to, say, its master reference.







The *Actual Vs Actual* Child window basically provides the same graphic information as the *Comp. Mes-Sim Surfaces* Child Window described above.

However, it differs in that two different measurement data files are compared one to another through the current geometry. For example, in the above figures, the top left measurement data file is “demo_g1.mes”, the top right measurement data file is “demo_g2.mes”, and in the bottom figure, “demo_g2.mes” is compared to “demo_g1.mes”.

One can clearly see that the point to point corner values of the bottom figure correspond to the difference between the point to point corner values of the top two figures.

For the current version, HyGEARS supports up to four measurement datasets per measurement data file. Each data file will use the same tooth index numbers.

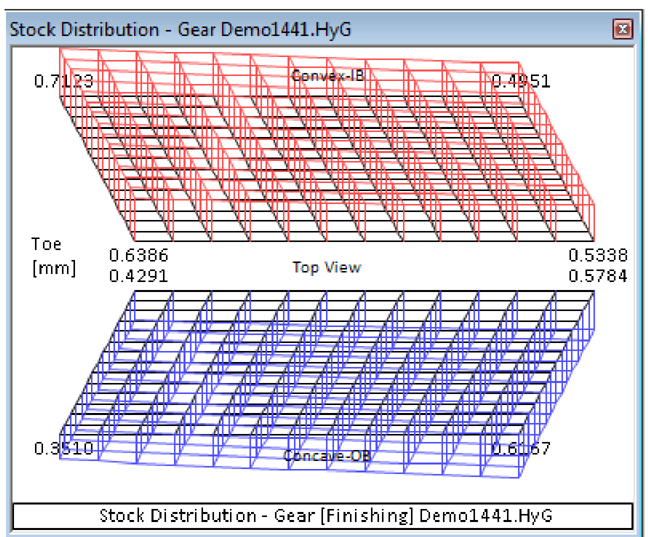
12.5.6 Stock Distribution

The Stock Distribution Child Window calculates and displays the difference between the Roughing and Finishing tooth surfaces, including tooth thickness distribution, such as to reveal how evenly material will be removed between the roughing and finishing cuts.

The Stock Distribution Child Window also offers tools to improve the Roughing machine settings for Fixed Setting, Modified Roll, Formate and Helixform cutting processes where the Roughing and Finishing cuts are done on separate machines (HyGEARS assumes that the Duplex Helical and Face Hobbing cutting processes rough and finish the work on the same machine).

The Stock Distribution Child Window basically provides the same graphic information as the Compare Mes-Sim Surfaces Child Window described above. However, it differs from the Compare Meas-Sim. Surfaces Child Window in that it automatically extracts the difference between the Roughing and Finishing tooth surfaces, such that the Measurement Data File does not have to be specified, and also shows thickness information.

Therefore, the Error Surface (Roughing tooth compared to the Finishing tooth) may not show a null error at the middle point, as is shown in the figure below.



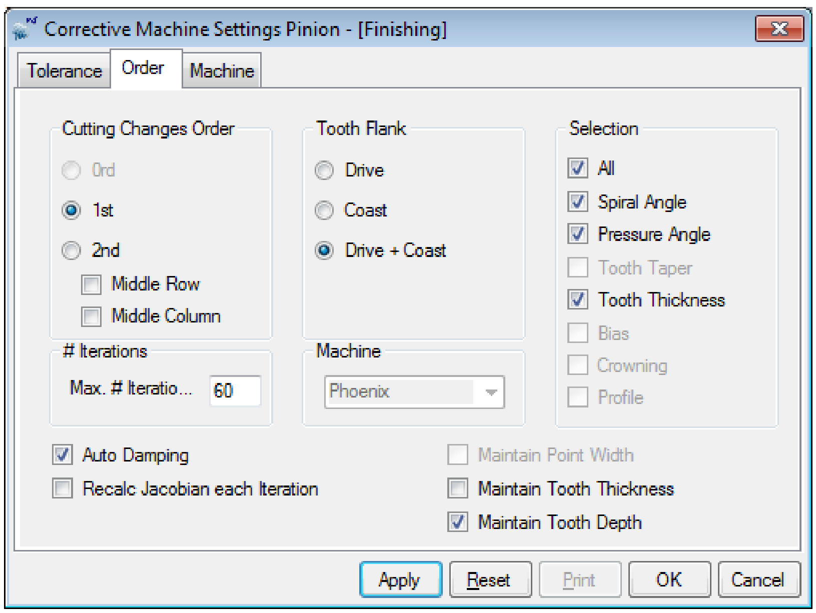
If both the pinion and the gear have been selected for display (see The Displayed Geometry above in this chapter), the Stock Distribution Child Window will default to the pinion. The Stock Distribution Child Window is always in AutoScale mode.

If both the pinion and the gear have been selected for display (see The Displayed Geometry), the Stock Distribution Child Window will default to the pinion. The Stock Distribution Child Window is always in AutoScale mode.

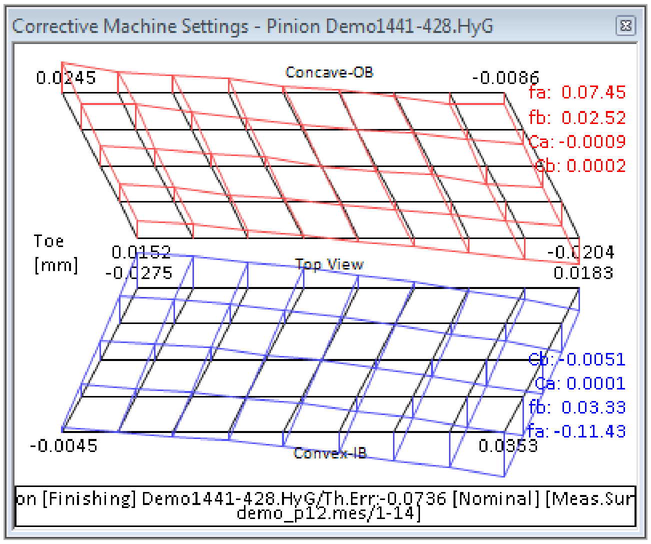
12.5.7 Corrective Machine Settings (Closed Loop)

Corrective Machine Settings (Closed Loop) and *Reverse Engineering (RE)* calculates and displays the difference between the simulated and measured tooth surfaces, and offers a series of tools used to calculate the machine settings modifications needed to eliminate 1st and 2nd order surface errors.

- *Closed Loop* is used to *improve the quality* of a pinion or a gear tooth by modifying the machine adjustments.
- *RE* is used to *identify* the machine settings of a pinion or gear tooth such as to obtain a reference summary.



For the calculation of the Corrective Machine Settings (Closed Loop) or RE to take place, a proper measurement data file must be provided in the Measurement Data Selection window.



The Corrective Machine Settings (Closed Loop) and RE Child Windows basically provides the same graphic information as the Compare Mes-Sim Surfaces Child Window .

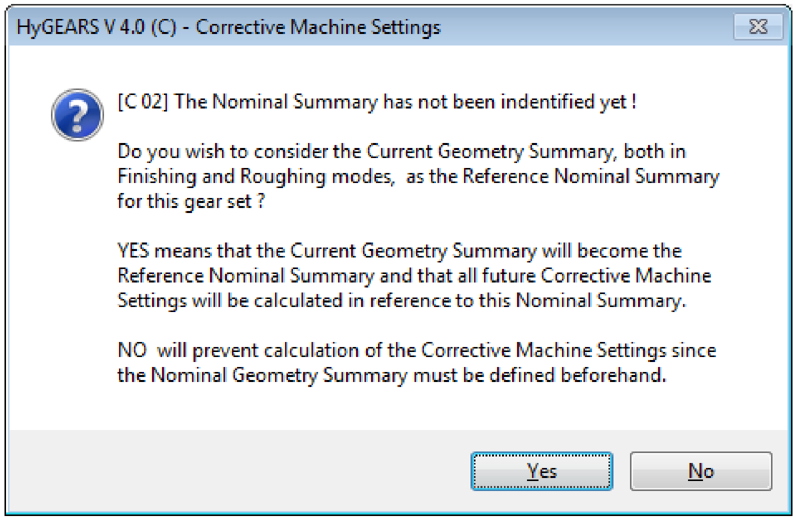
Corrective Machine Settings (Closed Loop) and RE can work with up to four pinion or gear measurement datasets contained within the same measurement data file. When more than one data-set is selected, HyGEARS bases the calculations on the average error, e.g. the sum of errors for each selected data-set point, divided by the number of displayed datasets.

If both the pinion and the gear have been selected for display (see The Displayed Geometry), the Corrective Machine Settings (Closed Loop) or RE Child Window will default to the pinion.

HyGEARS maintains an history of the different Corrective Machine Settings (Closed Loop) that were calculated for any Geometry, provided the Geometry is saved after Corrective Machine Settings (Closed Loop) have been calculated and applied, as will be seen later in this section.

The Corrective Machine Settings (Closed Loop) History can be reset, or completely erased, using the Main Menu Edit->Reset Corr MC History function, as explained in “Resetting the Corrective Machine Settings History”.

However, before calculating any Corrective Machine Settings (Closed Loop), the Nominal Summary must be defined. This is done automatically by HyGEARS upon confirmation by the user the first time the Corrective Machine Settings (Closed Loop) algorithm is accessed. Once the Nominal Summary has been defined, all Corrective Machine Settings (Closed Loop) will be calculated in reference to the defined Nominal.



In short, the Corrective Machine Settings (Closed Loop) algorithm uses the Nominal Summary to evaluate the difference between the measured and simulated tooth surfaces, and bases the modification of each machine setting on the surface error type and amplitude. Then, each machine setting modification is added to the latest Summary version in the history of the considered pinion or gear. It is therefore imperative that the Geometry data file be saved to disk after Corrective Machine Settings (Closed Loop) have been calculated and applied. HyGEARS automatically proposes to do so.

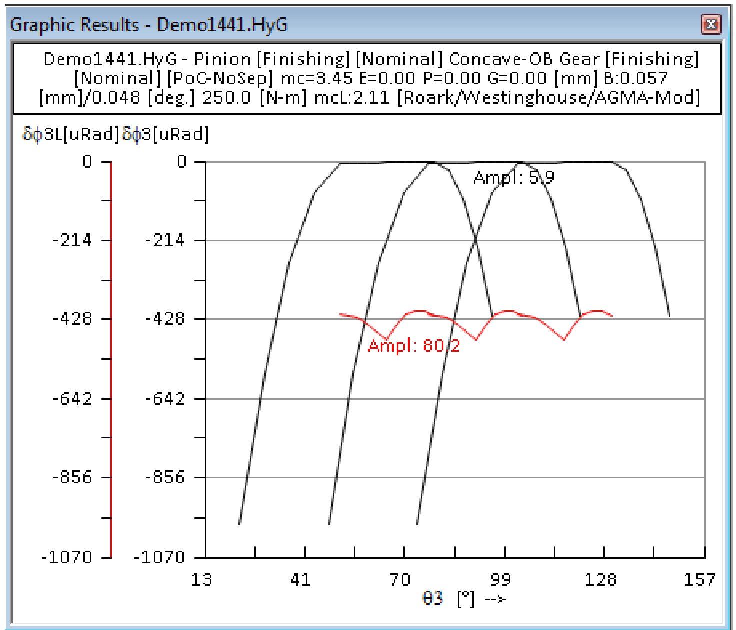
Logically, each Corrective Machine Settings (Closed Loop) step in the development of a gear set should use a different measurement data file. Therefore, it is not possible to use the same measurement data file more than once to calculate Corrective Machine Settings (Closed Loop), as HyGEARS keeps track of all the measurement data files which have been used for previous Corrective Machine Settings (Closed Loop) calculations.

Note: a measurement dataset is considered different if stored in a different folder, or has a different date stamp, even though the actual file name is the same.

Up to 7 Corrective Machine Settings (Closed Loop) steps are currently allowed in HyGEARS, which should be sufficient for most applications.

12.5.8 2D Graphs

The 2D Graphs function, accessed from the Graphics pull down menu, provides an easy interface to plot several simultaneous TCA and LTCA kinematic results such as Transmission Error and Tooth Load Share.



2D Graphs can be made of up to four vertical axes, called Y Axes, each one with its own data, linestyle and line color, and one horizontal axis called the X Axis. Kinematic data is plotted on the Y Axis, while the X Axis may be the pinion or the gear angular position, respectively q3 and f3. Additionally, when the Transmission Error Fourier transform is chosen as the Y Axis data, either TCA or LTCA, it is automatically plotted as a function of its frequency in Hz on the X Axis.

When the 2D Graphs function is called, a 2D Graphs Child Window is created and the 2D Graphs Selection window is presented. The Selection window is used to select the contents and appearance of the displayed results in the 2D Graph Child Window upon creation. It is also accessible after creation to change the initial contents or appearance of the selection. However, it is not possible to save a graph definition.

2D Graphs Child Windows apply to both the pinion and the gear by definition, since they are used to plot kinematic data based on the definition of both gear set members.

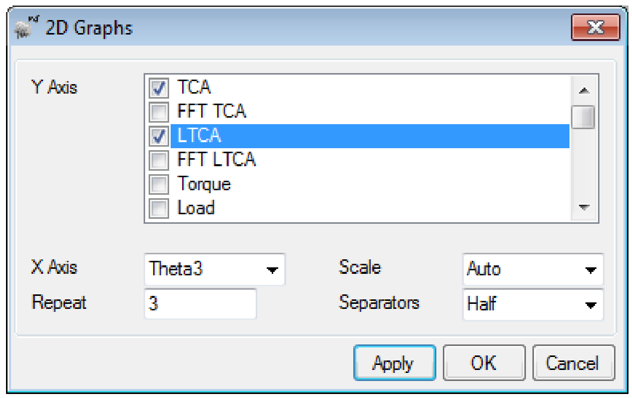
The following are typical 2D Graphs:

- TCA Transmission Error Curve
- FFT TCA Curve
- Profile Deviation Curve
- Crowning Deviation Curve
- LTCA Transmission Error Curve
- Load Share Graph
- Torque Share Graph
- Tooth Separation Graph
- Bending Stiffness Graph

- Combined Curves Graph

12.5.8.1 2D Graphs Selection Window

The 2D Graphs Selection window is used to select the contents and control the appearance of the displayed results of a 2D Graphs Child Window. It contains the following input and selection fields:



Command Buttons

Apply tells HyGEARS to use the entered data, recalculate the display, and remain in the input window;
OK completes the input.
Cancel cancels any input that was done.

Y Axis

The Y Axis input field is used to select what will be shown on the vertical axis; up to four selections can be displayed simultaneously on the Y Axis, provided none is a Fourier transform (FFT).

When a Fourier transform is selected, no additional Y Axis selection may be made until the Fourier selection has been removed from the selection list box. The units of each Y Axis selection are shown with the title of the selection on the graph.

To make or delete a selection, check or uncheck the selection name with a click of the left mouse button on the desired choice. Only the first four selections will be used.

The following choices are available for the Y Axis, for the currently pinion driving tooth flank which can be changed using the 2D Graphs Child Window “Con”/”Cvx” Function button:

TCA: unloaded Transmission Error curve;
Y Axis symbol: df3

FFT TCA: Fourier transform of the TCA Transmission Error curve; the X Axis input field automatically switches to “Hz” and is not-editable;
Y Axis symbol: FFT TCA

LTCA: Transmission Error curve under load; the applied torque may be changed using the 2D Graphs Child Window “Load” Function button;
Y Axis symbol: df3L

FFT LTCA: Fourier transform of the LTCA Transmission Error curve; the X Axis input field automatically switches to “Hz” and is not-editable;
Y Axis symbol: FFT LTCA

Profile Deviation: Profile deviation, Pinion or Gear, in relation to a true involute form profile; for cylindrical gears only;
Y Axis symbol: dPr

Crowning Deviation: Crowning deviation, Pinion or Gear, in relation to a non-crowned tooth face; for cylindrical gears only;
Y Axis symbol: dCr

Torque: torque sharing between adjacent meshing tooth pairs (LTCA);
Y Axis symbol: [N-m] or [lb-in]

Load: tooth normal applied load between adjacent meshing tooth pairs, as calculated from the LTCA algorithm;
Y Axis symbol: [N] or [Lb]

Transm. Force: Transmission Force; the Transmission Force is defined as:

$$T_f = \partial\varphi_3 \, R_g \, K_m$$

Where:

$\partial\varphi_3$ is the T.E. under load,

R_g is the radius of contact on the gear tooth,

K_m is the combined bending and contact mesh stiffness. In other words, it is the load needed to produce 1 arc-sec of Transmission Error rotation.

Y Axis symbol: Tf[N] or Tf[Lb]

Sum Load: sum of the tooth normal loads, as calculated from the LTCA algorithm;
Y Axis symbol: S[N] or S [Lb]

Bending Def.: tooth bending deformation as calculated from the torque sharing between adjacent meshing tooth pairs and the selected Stiffness function;
Y Axis symbol: sb

Contact Stress: tooth contact stress as calculated from the torque sharing between adjacent meshing tooth pairs and Hertz theory;
Y Axis symbol: sc

Contact Def.: tooth contact deformation as calculated from the torque sharing between adjacent meshing tooth pairs and Hertz theory;
Y Axis symbol: dc

Min. Oil Film: oil film thickness along the path of contact, as calculated from the normal load, relative curvatures, oil type and viscosity entered in the Operating data page of the Geometry Summary;
Y Axis symbol: HMin

Lamda: ratio of calculated oil film thickness to surface roughness entered in the Operating data page of the Geometry Summary;
Y Axis symbol: L

Efficiency: instantaneous mesh efficiency, which depends on the sliding action and coefficient of friction entered in the Operating data page of the Geometry Summary; for each contact position, HyGEARS calculates the sliding speed which multiplied by the normal load and the coefficient of friction, yields the power lost to friction HPf as though the full load was carried by only one tooth pair.

$$\eta = \frac{HP_{in} - HP_f}{HP_{in}} \times 100$$

Y Axis symbol: η

Efficiency Ltca: mesh efficiency under load; HyGEARS calculates for each part of the mesh the useful work, Tu, the work that is lost, TL, and from this derives the mesh efficiency under load; depends on the sliding action and coefficient of friction entered in the Operating data page of the Geometry Summary;

$$\eta_L = \frac{T_u}{T_u + T_L} \times 100$$

Y Axis symbol: hL

Frict. Coef. Ltca: coefficient of friction under load; HyGEARS can either use a constant coefficient of friction, when entered as a positive value, or a variable coefficient of friction if its value is negative in the Operating data page of the Geometry Summary Editor; if negative, HyGEARS will look up in a table built from Prof. H. Winter's work at T.U. Munich, where he experimentally characterized the coefficient of friction of several spur gear pairs of varying modules, operating under varying loads, temperatures and oils; when this data is used, the coefficient of friction is seen to vary throughout the mesh; the averaged values obtained are usually quite consistent with what can be found in the literature; this will of course affect the "Efficiency Ltca";
Y Axis symbol: mL

Temp Increase: increase in oil film temperature along the PoC, which depends on the sliding action and coefficient of friction entered in the Operating data page of the Geometry Summary;
Y Axis symbol: DT

B. Stress Pinion: pinion tooth root bending stress, as calculated using the selected strength formulation in the LTCA Selection window;
Y Axis symbol: sP

B. Stress Gear: gear tooth root bending stress, as calculated using the selected strength formulation in the LTCA Selection window;
Y Axis symbol: sG

J Factor-Pinion: pinion J Factor, either used for the calculation of the bending stress, if the AGMA Strength model is used, or derived from the bending stress if the Aida+Terauchi or Finite Strips model is used;
Y Axis symbol: Jp

J Factor-Gear: gear J Factor, either used for the calculation of the bending stress, if the AGMA Strength model is used, or derived from the bending stress if the Aida+Terauchi or Finite Strips model is used;
Y Axis symbol: Jg

Ic: I factor used for the calculation of the contact stress; this is obtained from the calculation of the principle curvatures at the point of contact;
Y Axis symbol: Ic

Z: Z is defined as the ratio of the contact stress to the square root of the torque; therefore, one obtains the contact stress by multiplying Z by the square root of the applied torque and the application factors;

$$Z = \frac{\sigma_c}{\sqrt{T_p}}$$

Y Axis symbol: Z

Qp: Qp is defined as the ratio of the Diametral Pitch to the product of the Facewidth, Pitch Diameter and applied pinion Torque; therefore, one obtains the pinion bending stress by multiplying Qp by the pinion torque and the application factors;

$$Q_p = \frac{2\,P_d}{F_p\,D_p\,T_p}$$

Y Axis symbol: Qp

Qg: Qg is defined as the ratio of the Diametral Pitch to the product of the Facewidth, Pitch Diameter and applied gear Torque; therefore, one obtains the gear tooth bending stress by multiplying Qg by the gear torque and the application factors;

$$Q_G = \frac{2\,P_d}{F_G\,D_G\,T_G}$$

Y Axis symbol: Qg

Kt - P: pinion stress concentration factor at the root of the tooth, obtained from the position of the applied load and tooth section proportions;
Y Axis symbol: Kt-P

Kt - G: gear stress concentration factor at the root of the tooth, obtained from the position of the applied load and tooth section proportions;
Y Axis symbol: Kt-G

#1... Gage Pinion: when the Finite Strips model is used for bending stiffness or strength, HyGEARS calculates and saves the ratio of deformation at the "strain gages" which may be installed at the root of the pinion tooth. Such information may be useful to calibrate, for example, experimental results. The "strain gage" results are adimensionalized to the largest value of the middle strain gage. Thus, the maximum value of the middle strain gage is 1.
Y Axis symbol: d1P -> d5P

#1... Gage Gear: same a above, but for the gear tooth;
Y Axis symbol: d1G -> d5G

%: % of the maximum major axis of the contact ellipse actually covered by the LTCA Contact Pattern; when calculating the LTCA, at each position along the PoC, the length of the maximum major axis of the contact ellipse is calculated as a reference. The % value indicates how much of this maximum major axis is used;
Y Axis symbol: %

K-Flex: tooth bending stiffness as calculated from the LTCA tooth bending stiffness model;
Y Axis symbol: Kb

K-Mesh: tooth mesh stiffness as calculated from the LTCA tooth bending stiffness model and Hertz theory for contact deformation;
Y Axis symbol: Km

Tooth Separation: tooth to tooth separation as obtained from the PoC (TCA);
Y Axis symbol: ds

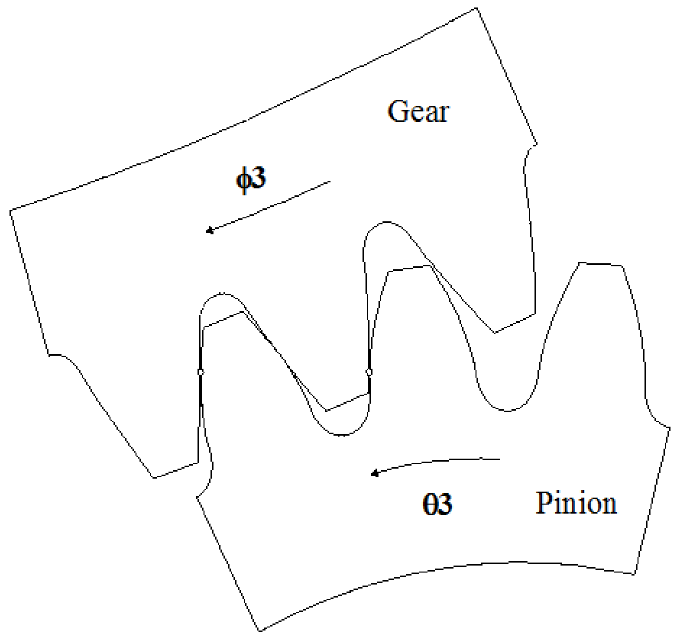
Sliding Speeds: mesh sliding speeds as calculated from the PoC (TCA);
Y Axis symbol: V

X Axis

The 2D Graphs display X and Y data; the X Axis input field is used to select what will be shown on the horizontal axis; two choices are offered, the units of both in degrees:

Theta3: pinion angular position (q3)
Phi3: gear angular position (f3)

When either Theta3 or Phi3 are chosen for the X Axis, the "-->" and "<--" symbols indicate the direction of rotation. The figure below shows the q3 and f3 directions.



When the Y Axis data is a Fourier transform (FFT), the X Axis automatically switches to Hz, which is the frequency symbol.

Repeat:

The number of times a Y Axis selection will be repeated along the X Axis. By default, a Repeat factor of 3 is provided, which means that the selected curves displayed on the Y Axis will be drawn 3 times along the X Axis, each one translated by one pinion circular pitch if the X Axis is q3, the pinion angular position, or by one gear circular pitch if the X Axis is f3, the gear angular position.

This field has no effect when the Y Axis selection is a Fourier transform.

***Separators**:*

HyGEARS automatically calculates the number of horizontal and vertical axes separations to keep the 2D Graphs informative without over-cluttering the Y Axis scale; the *Separators* field makes it possible to display horizontal and vertical separating dotted lines in the graph area to help in reading the graph. Three choices are available:

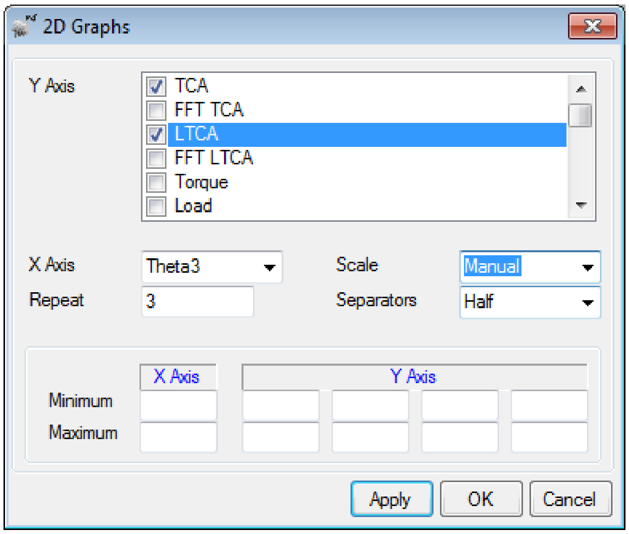
Simple: horizontal separators are plotted at every calculated separation along the Y Axis;
Half: horizontal separators are plotted at every other calculated separation along the Y Axis;
None: no horizontal separators are plotted.

Scales:

HyGEARS automatically calculates the values to display on the X and Y Axis to best fit the data area. However, it is possible to override this option and to input its own desired data by changing the *Scales* input field from Auto to Manual.

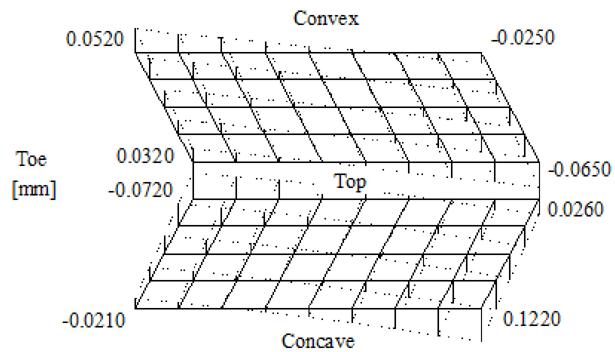
Once in Manual mode, the X and Y Axis *Minimum* and *Maximum* input fields at the bottom of the 2D Graphs Selection window are shown, and the desired *minima* and *maxima* must then be inputted in the current units. If no value is entered, HyGEARS will provide default values.

In Manual mode, however, no boundary checking is made and caution must be taken not to enter impossible values otherwise the 2D Graph may become meaningless.

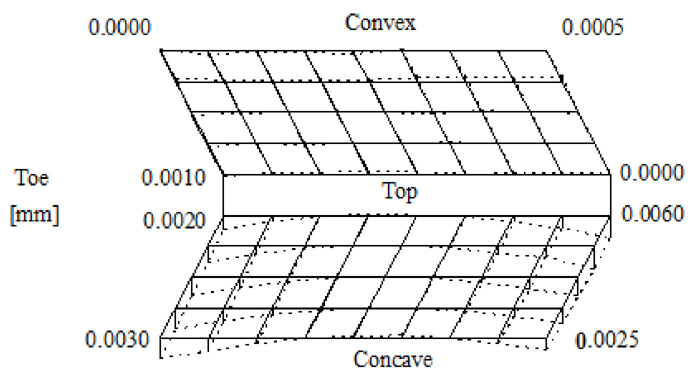


12.5.9 Reverse Engineering

The Reverse Engineering Child window calculates and displays the difference between the simulated and measured tooth surfaces, and offers a series of 0rd-1st-2nd order tools used to calculate the machine setting modifications needed to match the simulated tooth surface as closely as possible to the measured tooth surface, as the upper (*unmatched*) and lower (*matched, 1st order*) figures below show.



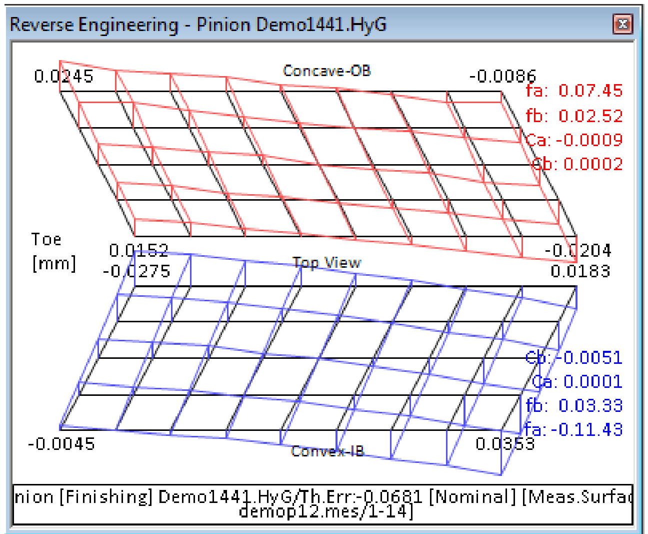
Unmatched



Matched

It is used primarily to match the rough tooth surfaces to the finish tooth surfaces in order to optimize the finishing cutting process in terms of stock removal. It can also be used to "*reverse-engineer*" a measured tooth surface whose exact machine settings are not known precisely. The matched surface can then be used confidently in various applications such as Path of Contact, Contact Pattern and Loaded Tooth Contact Analysis.

The *Reverse Engineering* algorithm is exactly the same as the one used for Corrective Machine Settings (Closed Loop). For Reverse Engineering to take place, a proper measurement data file must be provided in the Measurement Data Selection window.



The Reverse Engineering Child window basically provides the same graphic information as the Corrective Machine Settings (Closed Loop) and Compare Mes-Sim Surfaces Child windows.

The Reverse Engineering Child window can display and match surfaces based on up to four pinion or gear measurement datasets contained within the same measurement data file. When more than one data-set is selected, HyGEARS bases the surface match on the average error, e.g. the sum of errors for each selected data-set point, divided by the number of displayed datasets.

If both the pinion and the gear have been selected for display (see The Displayed Geometry), the Reverse Engineering Child window will default to the pinion. The displayed data-set selection is made as described in the Measurement Data Selection window.

As HyGEARS maintains an history of the different Corrective Machine Settings (Closed Loop) that were calculated for any Geometry, provided the Geometry is saved after Corrective Machine Settings (Closed Loop) have been calculated and applied, matching a simulated tooth surface to a measurement data-set involves the modification of the Geometry Summary.

Therefore, *Reverse Engineering* should be performed before any Corrective Machine Setting action takes place.

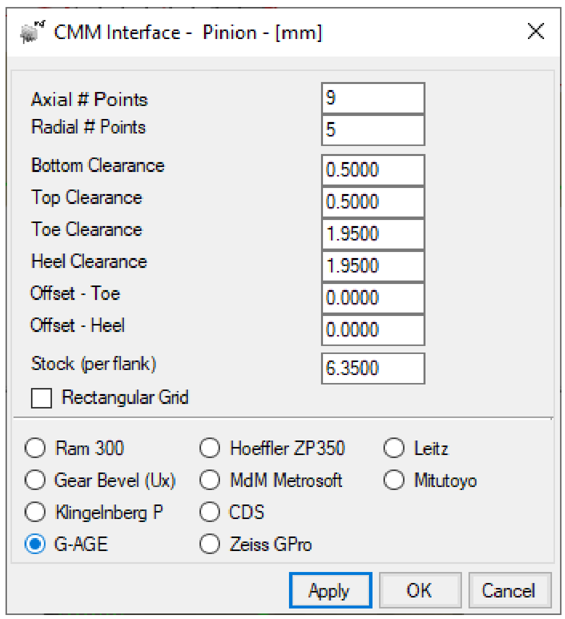
The Reverse Engineering algorithm uses the current Geometry Summary to evaluate the difference between the measured and simulated tooth surfaces, and bases the modification of each machine setting on the surface error type and amplitude. The algorithm stops when the errors between the measured and simulated tooth surfaces have reached either the target values within the tolerance range, or the maximum number of iterations.

The *Reverse Engineering* algorithm *permanently* modifies the current Summary of the simulated tooth surface to match as exactly as possible the simulated tooth surface to the measured tooth surface.

Incidentally, the measurement data can be the theoretical finished tooth surface, while the simulated surface can be the roughed surface, in order to match the rough data to the finish surface such as to optimize stock removal from roughing to finishing, which is what is done in the Stock Distribution Child Window.

12.5.10 CMM Nominal Data

The CMM Nominal Data Child Window calculates and displays the measurement grid points used by a Zeiss Coordinate Measurement Machine (CMM) to measure pinion and gear tooth surfaces. It also provides tools to specify the measurement grid size and location on the tooth surface.



The Nominal data produced by the CMM Nominal Data Child Window is essential to the operation of the Zeiss CMM in automatic mode, as it tells the CMM, in a predefined format, the coordinates of the desired measurement points and the tooth surface normals at these points.

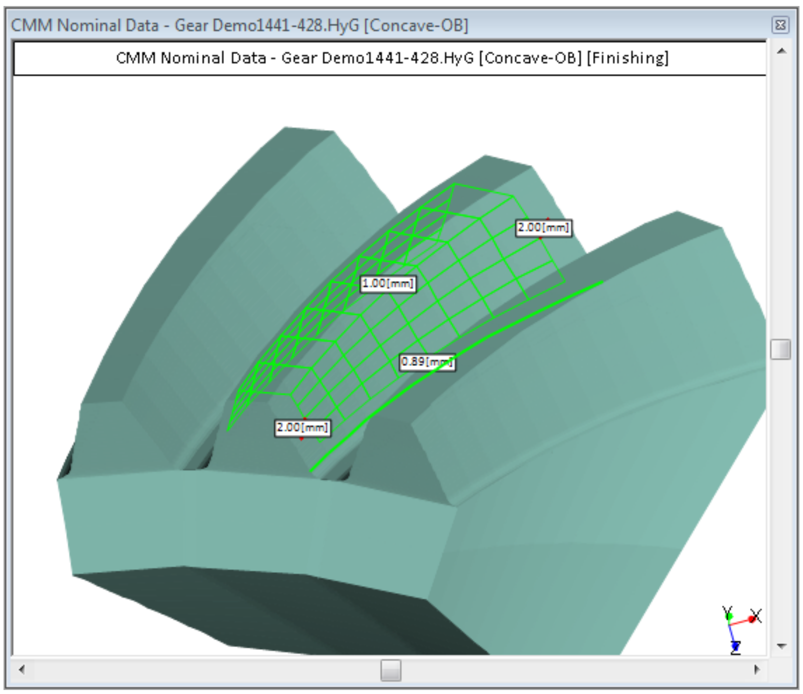
However, no Corrective Machine Setting calculation can be performed by the GAGE part of the software on the Zeiss CMM computer since, when the CMM Nominal Data is calculated by HyGEARS and downloaded to the Zeiss CMM, the manufacturing Summary nominal data is not known by GAGE. The CMM Nominal Data function is useful to measure pinion and gear teeth modeled with HyGEARS, and only HyGEARS can use the measurement data to calculate Corrective Machine Settings (Closed Loop).

As for other HyGEARS functions, the CMM Nominal Data is displayed on screen, and the user can interactively modify the size and location of the measurement grid.

When the displayed grid is satisfactory, its coordinates can be sent to a Text Results window in CMM format and can be saved to a disk file which should be located in the same sub-directory as the Geometry data file. All the CMM Nominal Data is saved within the Geometry data file.

By convention and for ease of use, the Ram 300 file should always use the ".ram" file extension. The file name should identify the grid size, the pinion or gear, and maybe a version number or letter. For example, "P9x5a.ram" identifies a pinion ram 9x5 grid, version "a".

Once the nominal data file has been created, it must be downloaded to the Zeiss CMM using the DCom software provided by Zeiss Japan. Measurement on the Zeiss CMM can then proceed, and the resulting measurement data must again be downloaded to a PC running HyGEARS to be useable by the Compare Mes-Sim Surfaces, Corrective Machine Settings (Closed Loop) or Reverse Engineering functions.



The CMM Nominal Data Child Window appears as green lines, depicting the measurement grid, over a black filled tooth for good visibility.

The measurement grid is defined by its lengthwise and profilewise number of points, and their distance from tooth toe, heel, tip and root. A marker "+" is displayed at the tooth center, for reference.

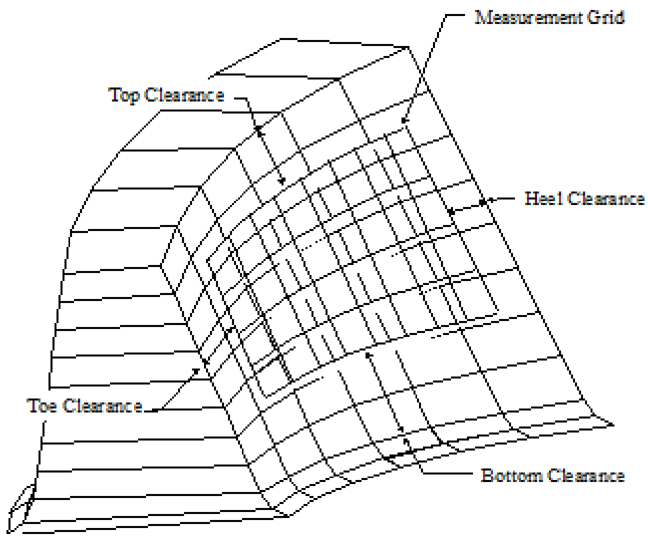
In HyGEARS, the default grid dimension is 9x5, and the distances are :

Bottom 0.2 / Diametral Pitch

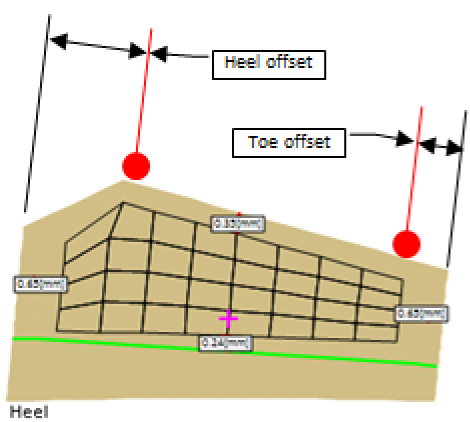
Top	0.2 / Diametral Pitch
Toe	Face Width / 10
Heel	Face Width / 10

with a maximum grid size of 29 lengthwise x 9 profilewise points. These dimensions are modified through the CMM Data Editor. accessed by the Nom Function button.

For reference, the Zeiss Ram data is normally made of an 9 x 5 grid, meaning 9 lengthwise points by 5 profilewise points. This grid can be extended up to 29 x 9 points.



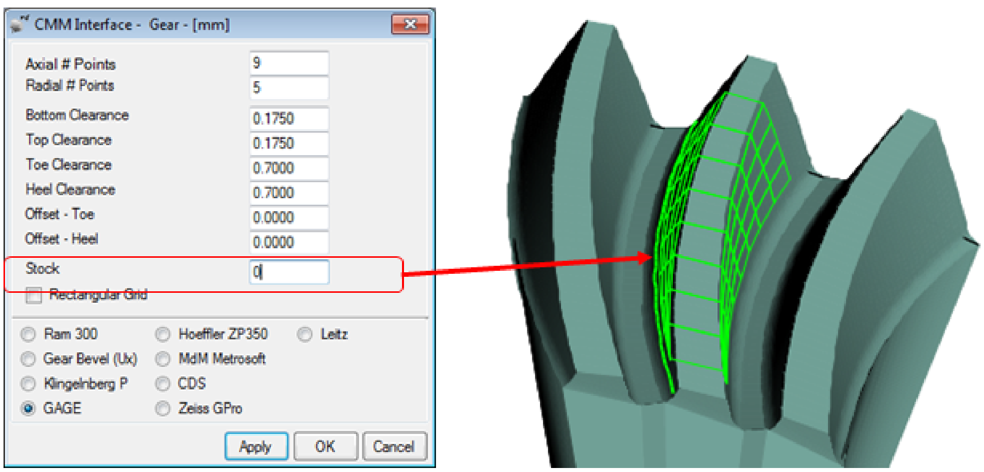
Offset Toe/Heel: When creating a CMM Target file for Gleason CMMs, it is possible to specify Toe and Heel offsets which are used to locate axially where the Root and Face cones will be measured. The offsets are understood as being along the pitch cone of the measured member. A positive offset value moves the measurement point inside the tooth boundaries.



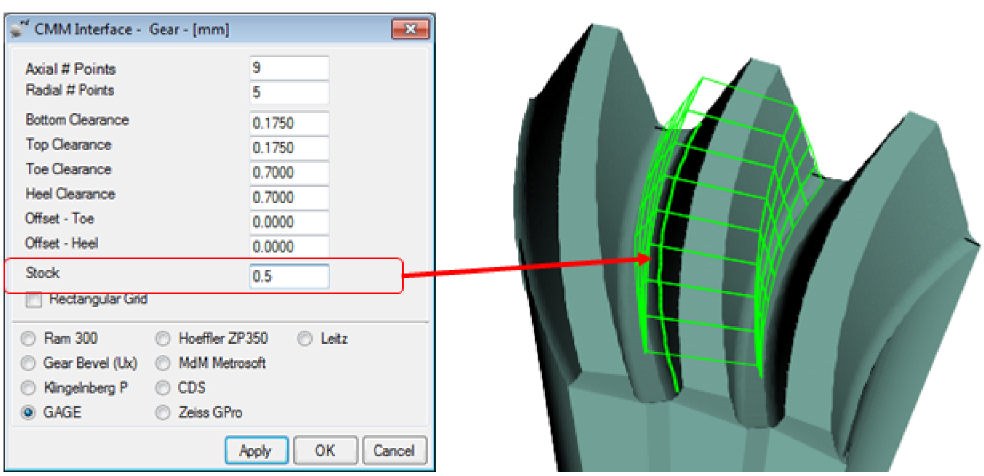
The Toe and Heel offsets can be useful when the Face cone has a chamfer at Toe or Heel, or a cropped diameter at Heel, and thus the CMM may give an error in the value of the Face Angle. It may also happen that the blank is a bit short at Toe or Heel, and then the CMM probe could fall outside of the blank.

Stock (per flank): when defining a CMM Target Grid, it is possible to add *Stock* to the grid of each tooth flank, such that the Target Grid follows the expected tooth shape when cut with stock. Useful when milling with CoSIMT, End Mill or Ball Mill tools.

Stock (per flank) = 0.000 mm

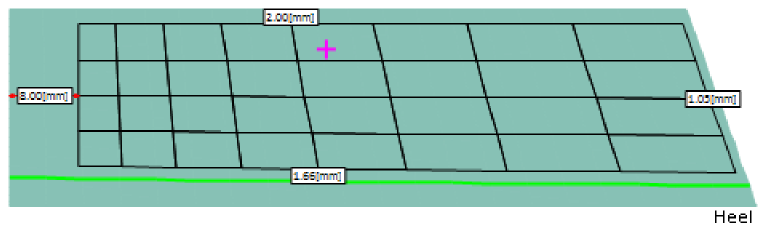


Stock (per flank) = 0.500 mm

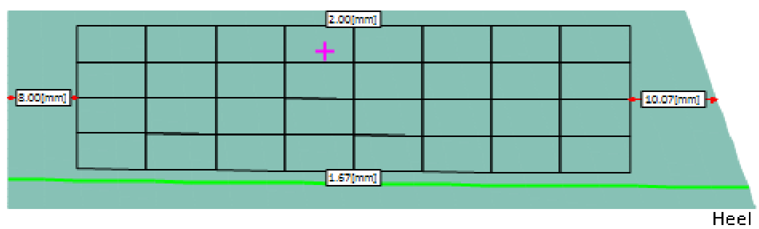


Rectangular Grid: the CMM Target Grid normally follows the contour of the tooth. But sometimes the tooth shape does not yield a correct grid. The *Rectangular Grid* switch forces HyGEARS to create a grid that will be based on the standard tooth proportions and will force Front and Back angles equal to the Pitch angle.

Normal Grid



Rectangular Grid



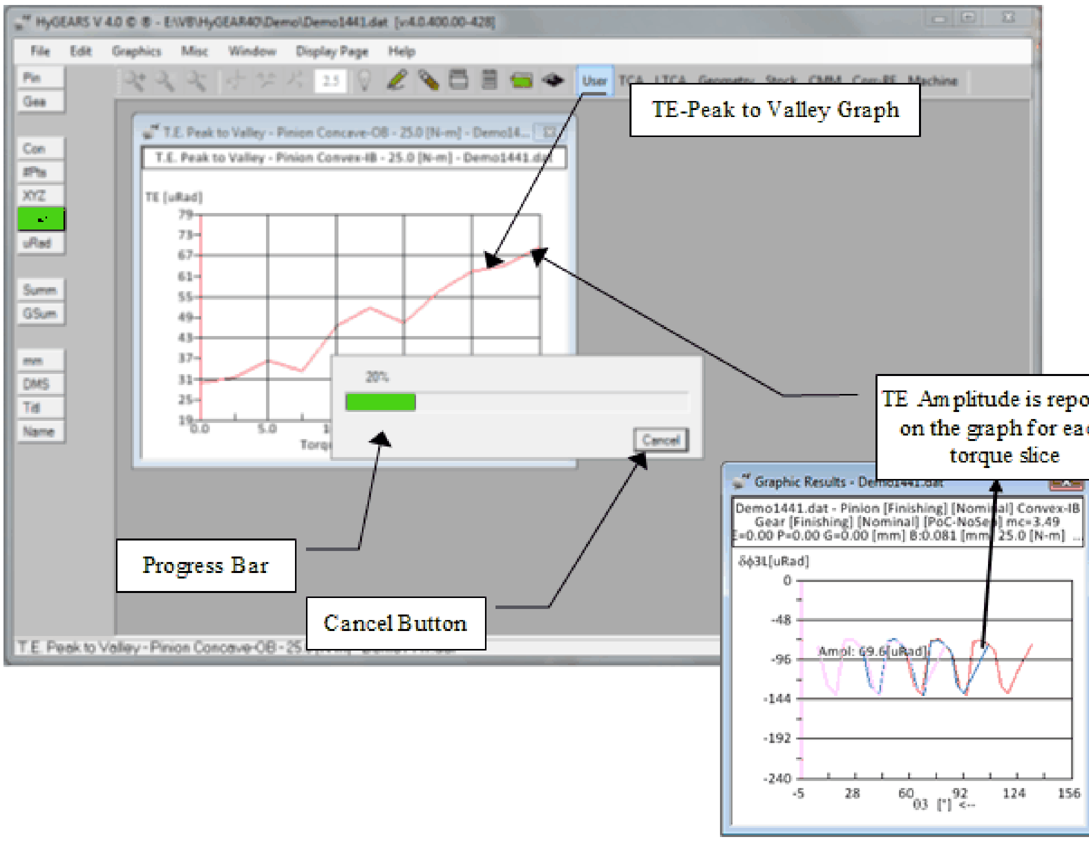
12.6 TE - Peak To Valley

When analyzing gear sets under load, it is sometimes desirable to see how the Transmission Error evolves with applied torque.

The *TE - Peak to Valley* Child Window creates a graphic of the amplitude of the Transmission Error curve under load – from Peak to Valley – subdividing the currently applied torque in 10 increments, thus starting at zero torque and ending with the currently applied torque.

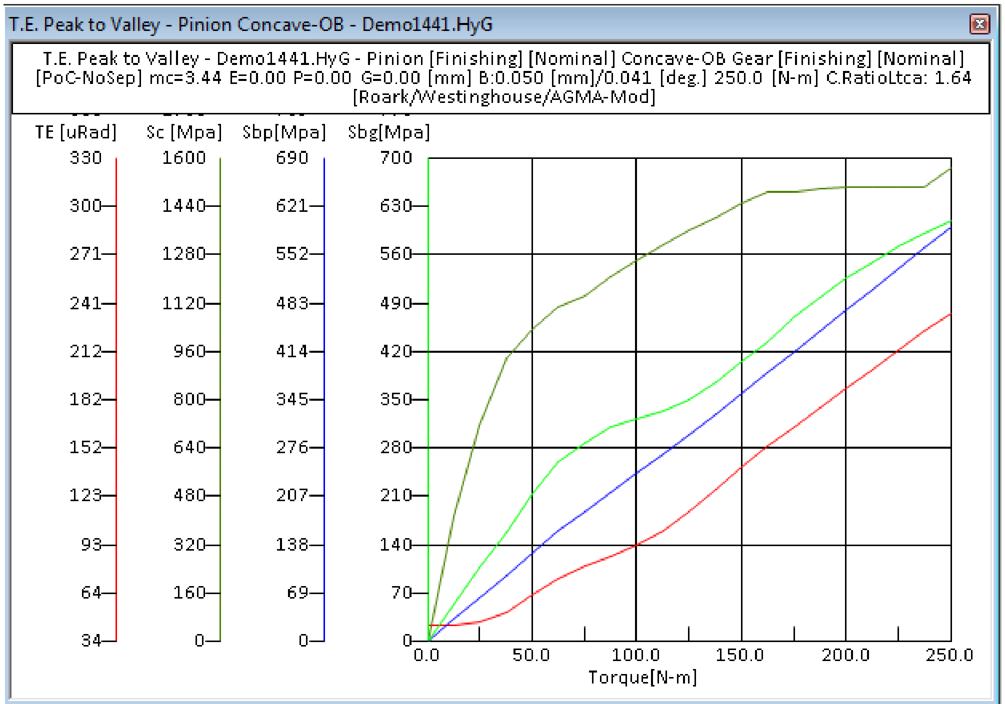
In other words, the currently applied torque is broken down in 10 slices starting at zero, the gear set is analyzed under load at each torque increment, the Peak to Valley value is recorded, and at the end of the process, the recorded values are displayed as a function of applied torque.

As shown in the figure below, a progress bar indicates the % of advancement of the calculations which can take up to 1 minute, depending on the system used. The “Cancel” button allows quitting the procedure at any time.



The end result is a 2D Graph where 4 different values are plotted as a function of Pinion torque:

TE [uRad]	transmission error, in the current TE units (URad here);
Sc [MPa]	Hertz contact stress, in the current pressure units;
Sbp [MPa]	pinion bending stress, in the current pressure units;
Sbg [MPa]	gear bending stress, in the current pressure units



Note: This function is optional and available only if the LTCA module has been purchased.

12.7 Complete Summary

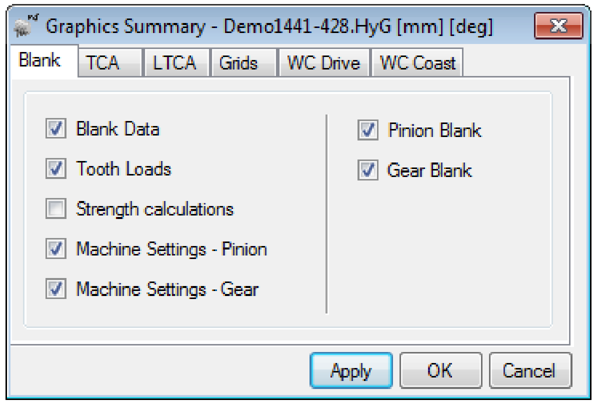
The Complete Summary entry in the Graphics menu produces and prints, in just one function, a complete pinion and gear machine settings and graphics Summary for the current gear set.

This function is identical to the Graphics Summary, and is repeated here for convenience.

The HyGEARS Graphics Summary allows the creation of a Pdf document containing several output types such as Blank and Machine data, Tca and LTCA graphs, Grids and Worst Case conditions where combinations of position and alignment errors can be produced automatically. All inputted data is stored with the current geometry, and can therefore be retrieved at a later time.

The Summary is presented in several pages, depending on the selection made by the user, as shown in the figures below:

The Graphics Summary Selection window is provided with six data pages, detailed below.



Command Buttons

Apply tells HyGEARS to use the entered data, recalculate the display, and remain in the selection window.

HyGEARS then creates a default name for the Pdf File, consisting of

- the directory containing the current geometry,
- the "GSumm" prefix,
- the version of the Summary given as "[#]" where # is a number from 0 to infinite, based on the fact that previous Summaries are already stored in the directory,
- the name of the current geometry,
- the Pdf extension.

For example: "E:\VB\Demo\GSumm[0]1149079mg.pdf"

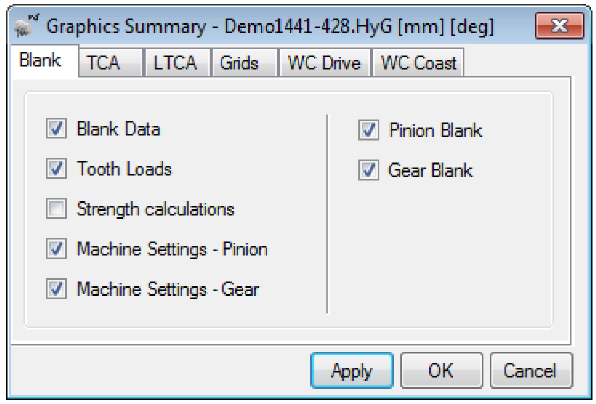
HyGEARS then proposes the most recent Summary name which is found in the directory; the user can accept this name, and then the most recent version is deleted and replaced by the newer version, or else, refuse the proposed name and then a new Summary fiel is created and added to the directory of the datafile.

Therefore, theoretically an infinite Summary number can be produced, and care must be exerted to avoid confusion. On the other hand, the "[#]" component of the Pdf file name tells the user which version is the most recent. The above Pdf filename also appears in the Pdf document.

OK Pressing the Enter key or the OK button terminates the input.
Esc Pressing the Esc key or the Cancel button cancels any input that was done.

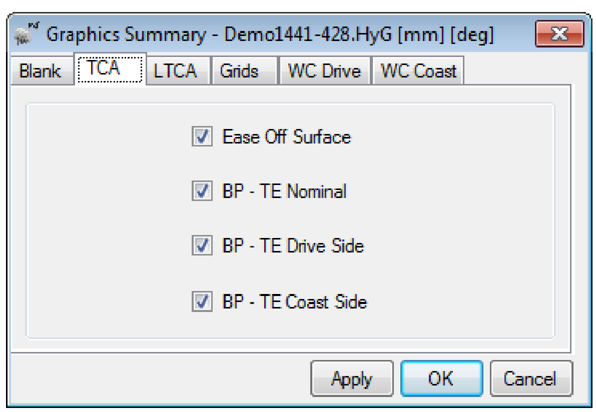
Blank data page

The Blank data page consists of several Check Boxes offering options related to gear blank data:



Blank Data	All data found in the Blank section of Geometry Summary
Tooth Loads	Graphic display of the Transverse, Axial and Radial loads at the Mean Point
Strength Calculations	All data found in the Strength Calculations section of the Geometry Summary
Pinion/Gear Machine Settings	All data found in the Machine Settings section of the Geometry Summary
Pinion/Gear Blank	Whether the Blank Child Window, for the pinion and gear, is to be added to the output

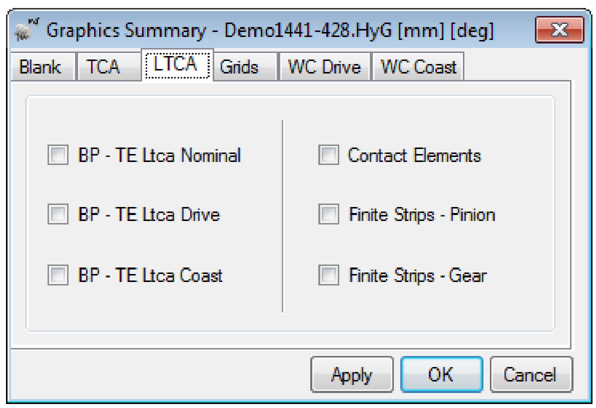
TCA Graphs data page



The TCA Graphs data page consists of several Check Boxes offering options related to TCA data:

Ease Off Surface	The Ease Off Surface correponds to the Ease Off Child Window, which displays the overall kinematical behavior of the gear pair in their nominal position.
BP - TE Nominal	Displays the drive and coast Contact Patterns, in the nominal operating position.
BP - TE Drive Side	Displays the Drive Contact Pattern, at toe and heel, i.e at 25% and 75% of the egar tooth flank. Only for spiral-bevel and hypoid gears
BP - TE Coast Side	Displays the Coast Contact Pattern, at toe and heel, i.e at 25% and 75% of the egar tooth flank. Only for spiral-bevel and hypoid gears.

LTCA Graphs data page



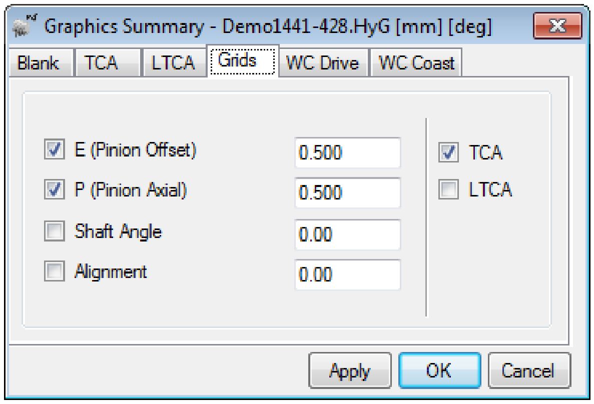
The LTCA Graphs data page consists of several Check Boxes offering options related to LTCA data: ; these Check Boxes are active only when the LTCA Option has been purchased:

BP-TE-Ltca Nominal	Adds to the output the LTCA Contact Pattern and Transmission Error graph of the gear set, on the Drive and Coast sides, in the Nominal position, i.e. without positional or alignment errors.
BP-TE-Ltca Drive	Adds to the output the LTCA Contact Pattern and Transmission Error graph for the Drive side of the gear set, at Toe and Heel, i.e. at 25% and 75% of the gear tooth flank. Only for spiral-bevel and hypoid gears.
BP-TE-Ltca Coast	Adds to the output the LTCA Contact Pattern and Transmission Error graph for the Coast side of the gear set, at Toe and Heel, i.e. at 25% and 75% of the gear tooth flank. Only for spiral-bevel and hypoid gears.

Contact Elements — Adds to the output the Contact Elements grid as meshing proceeds in the Nominal position of the gear set. Subject to the Contact Element option.

Finite Strips — Adds to the output the Finite Strips grid, for the pinion/gear, as meshing proceeds in the Nominal position of the gear set. Subject to the Finite Strips option.

Grids data page



The Grids data page consists of several Check Boxes offering options related to TCA and LTCA results as affected by operating position. The generated grids are combinations of E with the other errors.

HyGEARS Grids are graphics where combinations of, say, positional errors are imposed on the gearset, the requested data is calculated and the Contact Patterns are displayed in a X-Y format:

E (Pinion Offset) — This input specifies the maximum absolute E value that the grid is to reach; this means that the E value will vary from minus the inputted value to plus the inputted value in steps imposed by the dimension of the Child Window. Corresponds to Center Distance change for spur/helical gears.

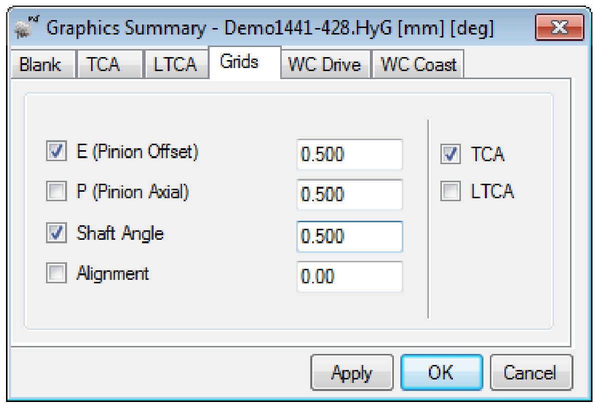
P (Pinion Axial) — This input specifies the maximum absolute P value that the grid is to reach; this means that the P value will vary from minus the inputted value to plus the inputted value in steps imposed by the dimension of the Child Window.

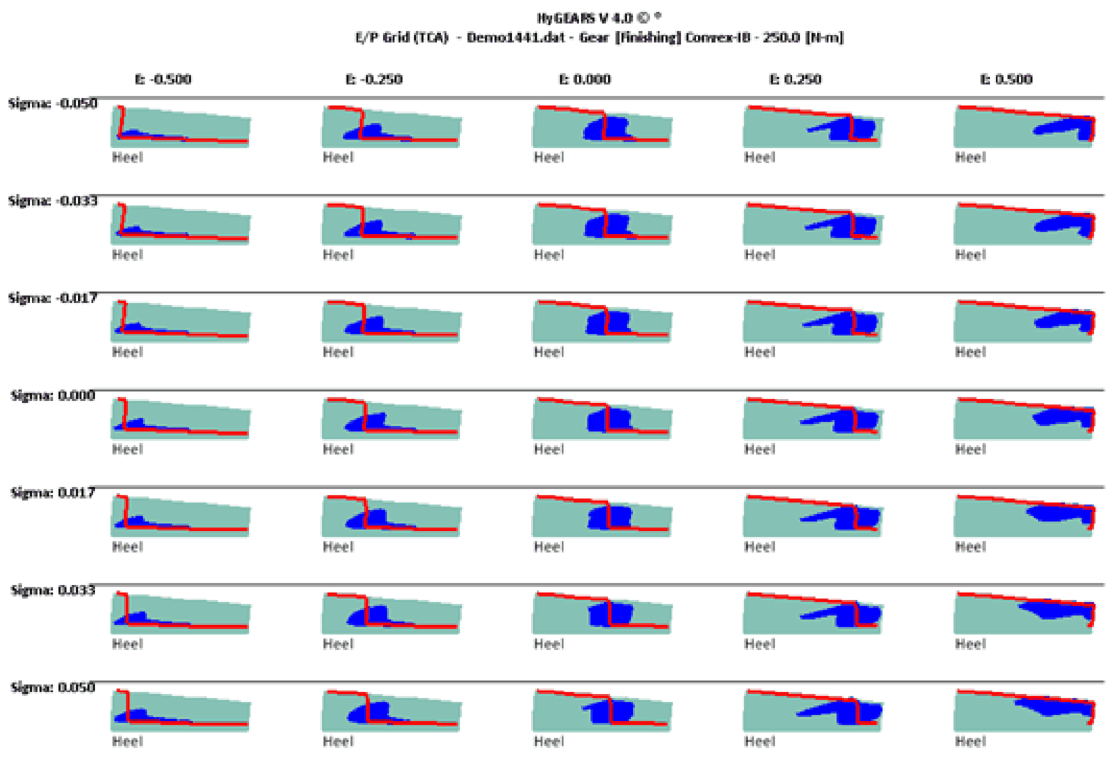
Shaft Angle — This input specifies the maximum absolute Shaft Angle deviation that the grid is to reach; this means that the Shaft Angle deviation value will vary from minus the inputted value to plus the inputted value in steps imposed by the dimension of the Child Window.

Alignment

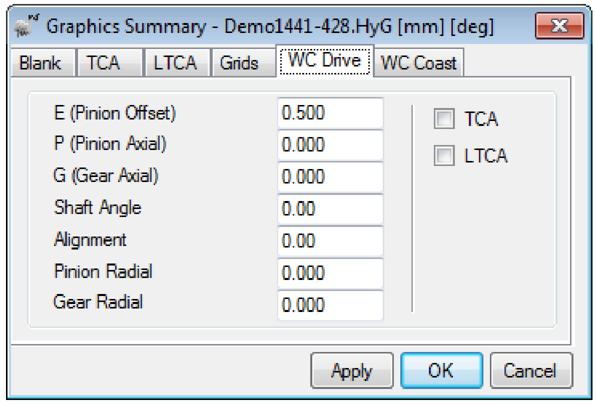
This input specifies the maximum absolute Misalignment that the grid is to reach; this means that the Misalignment value will vary from minus the inputted value to plus the inputted value in steps imposed by the dimension of the Child Window.

The figure below displays the Coast tooth flank Contact Pattern Grid for the selected geometry, along with the given input.





WC-Drive/Coast Data Pages

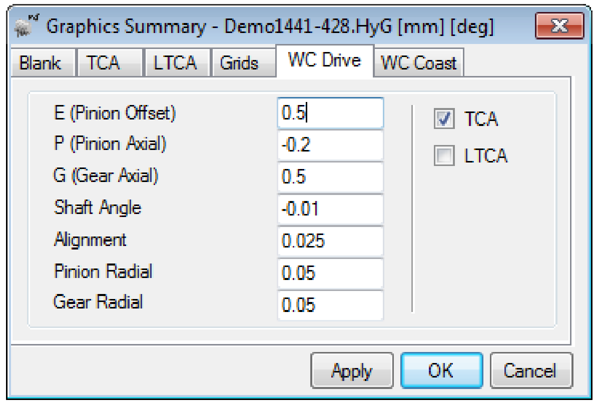


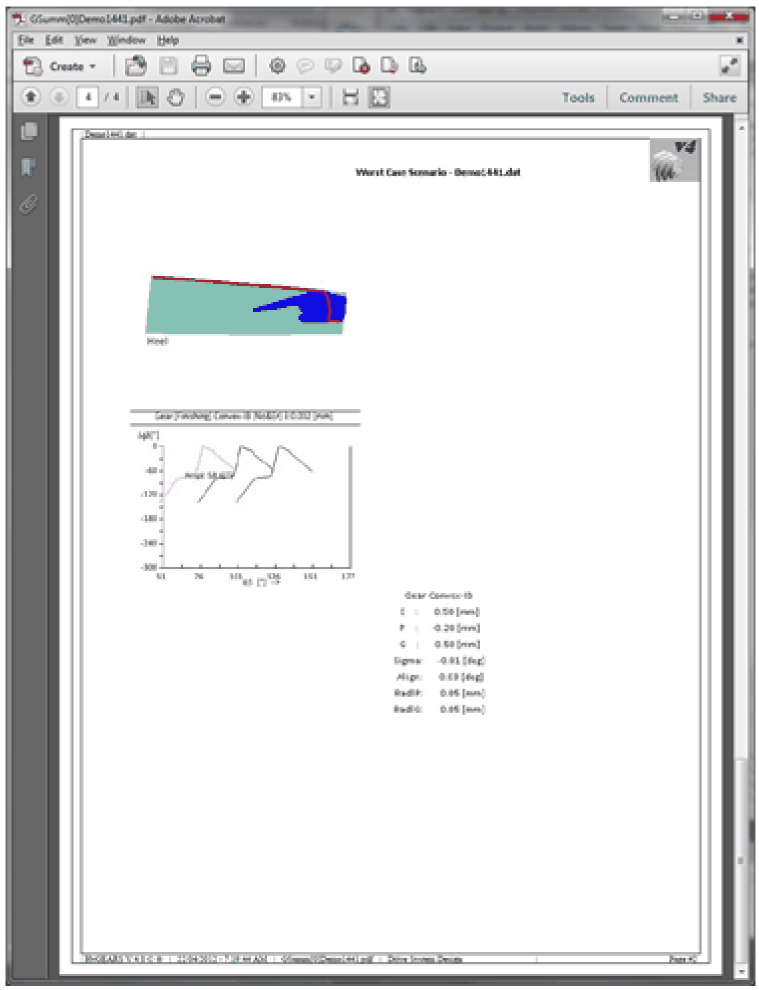
The WC-Drive/Coast Data Pages, where WC means Worst Case Scenario, consists of several Check Boxes offering options related to TCA and LTCA results as affected by operating position.

All inputted values are used as deviations in position with their signs, and imposed to the gearset for TCA and LTCA results:

E (Pinion Offset)	desired E value for the WC-Scenario. Corresponds to Center Distance change for spur/helical gears.
P (Pinion Axial)	desired P value for the WC-Scenario.
G (Gear Axial)	desired G value for the WC-Scenario.
Shaft Angle	desired Shaft Angle deviation for the WC-Scenario.
Alignment	desired Misalignment value for the WC-Scenario.
Pinion Radial	desired Pinion Radial value for the WC-Scenario.
Gear Radial	desired Gear Radial value for the WC-Scenario.

The figure below displays the WC/Drive Scenario for the selected geometry, along with the given input.





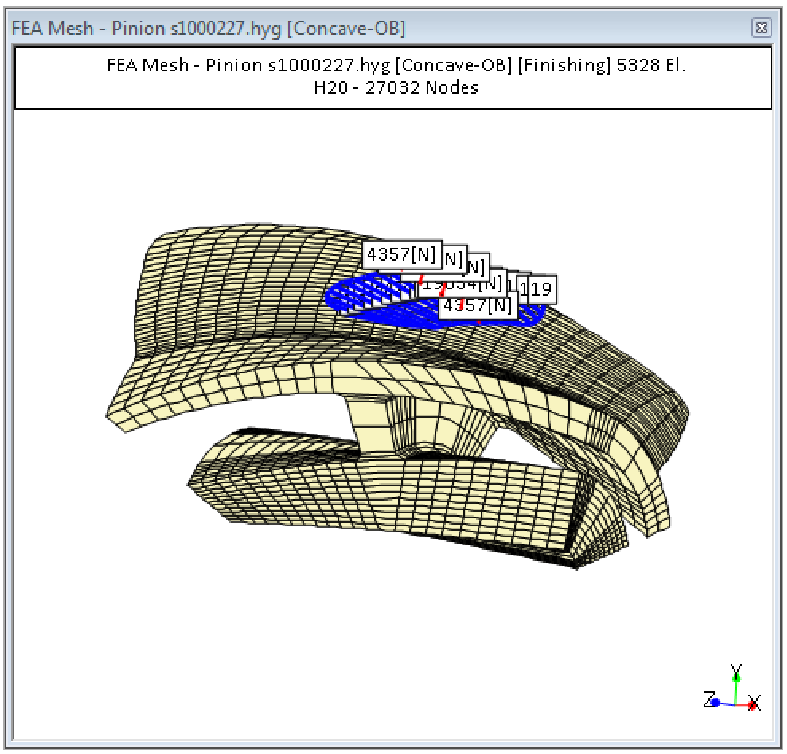
12.8 FEA Model

In the design process of a gear set, it is often desired to verify the bending strength of the pinion and gear members under load. While this can partially be done using the ISO or AGMA standards during the design process itself, it is a good idea to verify the results by the Finite Element Analysis method (FEA) to obtain more precise values.

However, the FEA method requires the use of a greatly defined model, which can be relatively easily done on spur and helical gears, but which is very difficult to produce on Spiral-Bevel and Hypoid gears because of the complex tooth shapes.

HyGEARS offers an integrated preprocessing function to prepare FEA models and apply loads wherever desired on the tooth flanks.

The FEA Model function, accessed from the Graphics pull down menu, provides a user friendly interface to Finite Element Analysis preprocessing, such as tooth and hub mesh definition, boundary conditions and load application, as the following thin rimmed pinion FEA Mesh figure shows:



A HyGEARS FEA Model can contain up to 50,000 elements and 500,000 nodes, whichever comes first. The HyGEARS FEA mesh is calculated as soon as a change is made to its definition, and is then redisplayed.

The FEA mesh can be shown for either the pinion or the gear separately, but not together. Therefore, if both the pinion and gear have been selected for display, HyGEARS will default to the pinion mesh.

The HyGEARS FEA preprocessor supports only 3 dimensional hexagonal 8 and 20 noded elements, without contact. Loads can be applied anywhere on the tooth flank, in multiple load cases, and meshing can be modified in the Contact Pattern zone in order to improve mesh density where contact conditions are to be reproduced.

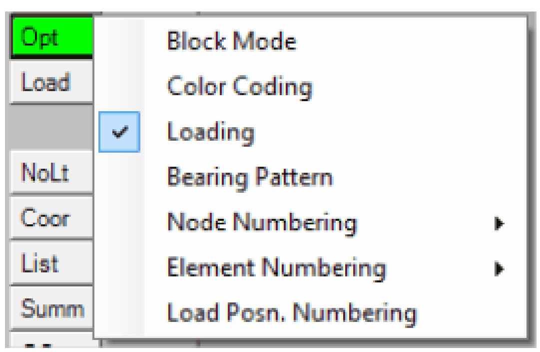
The preprocessor output is in a standard format, explained in the FEA Model Output section. The preprocessor output can easily be read and converted to that of any other FEA software input format upon user request.

Several display options are offered through the FEA Function button.

12.8.1 Display Options

When clicked, the FEA Model Graphics pull down menu calculates and displays the FEA model for the selected Geometry. The "Opt" button in the Parent window Tool Bar calls the following pop-up sub-menu which shows seven entries providing access to various options to be used by the meshing function.

Block Mode
Color Coding
Loading
Contact Pattern
Node Numbering
Element Numbering
Load Posn Numbering

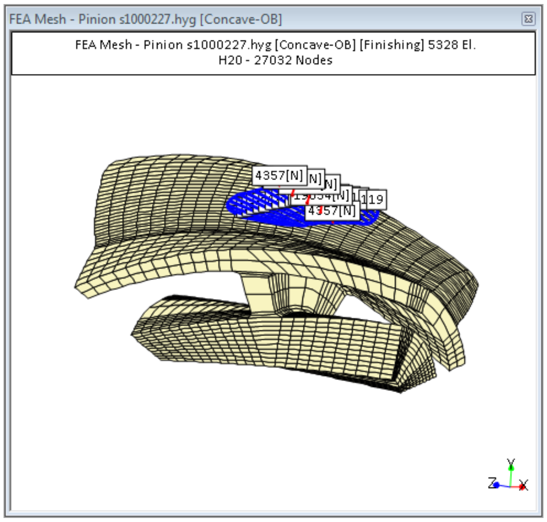


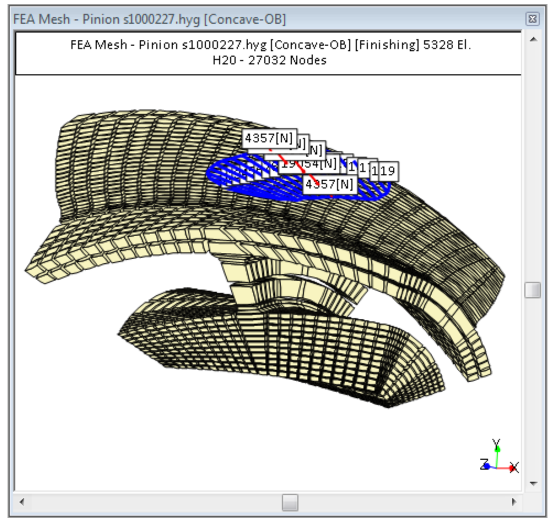
Clicking with the left mouse button on any entry toggles the checking mark identifying that the option symbolized by the entry name is activated or deactivated:

Block Mode

When the mesh is displayed in block mode, the elements are actually shrunk by an user defined scaling factor, equal to 80% by default. The size of the lesser elements of the mesh can thus be appreciated visually. The Block Mode option can be toggled On or Off, which is shown by a check mark .

For example, the right figure below is a zoomed Block-mode of the mesh displayed in the left figure. Relations in element shape and size can be appreciated readily.



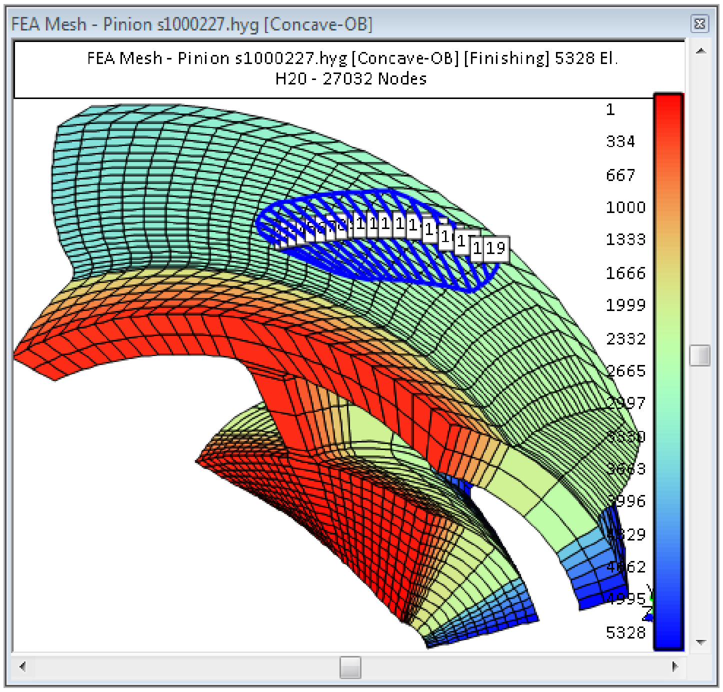


Color Coding

When the mesh is displayed in color coding, each element is given a color value indicating its rank in the mesh. Thus, the location of elements in the solution matrix may be understood easily. It is also useful to verify that the “advancing front” meshing technique has been successful.

The Color Coding option can be toggled On or Off, which is shown by a check mark . Color Coding excludes Block Mode, and vice-versa.

For example, in the following figure, the 1st element is located at the foreground, left side of the picture while the last element is at the background, right side of the figure. The color scale to the right of the figure gives the color coding order.



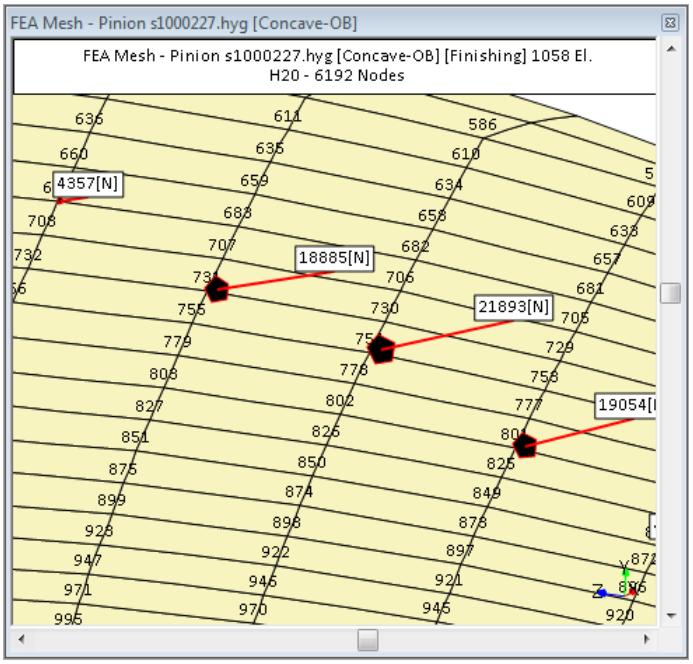
Loading

The Loading option can be toggled On or Off, which is shown by a check mark . It determines whether all already defined Load Cases will appear on the tooth flank, as shown below. The displayed tooth flank loads are conditioned by the selected tooth flank button, “Cvx”-“Con” or “Left”-“Right”, as explained the Cvx-Con .

The applied load appears as a red arrow terminated by an entry in the form “1000 [#]”, where:

- 1000 is the applied load value, e.g. 1000 [Lb] or [N] depending on the user selected units;
- [#] is the current Force units defined by the linear units in use;

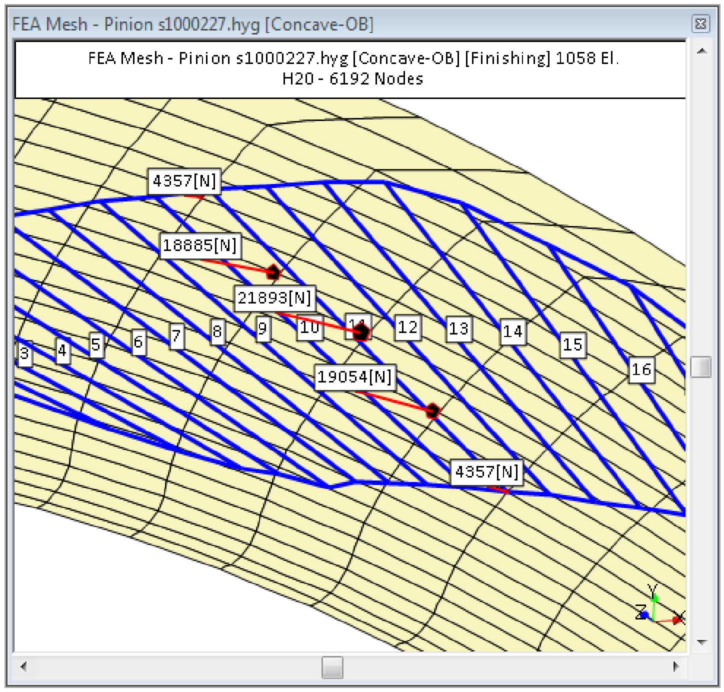
The figure below also shows load position numbering.



Contact Pattern

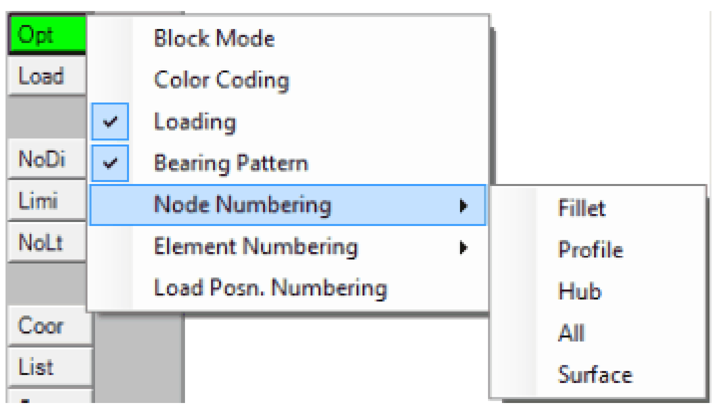
The Contact Pattern option can be toggled On or Off, which is shown by a check mark ; it determines whether the Contact Pattern for the selected tooth flank will be shown or not.

Showing the Contact Pattern superimposed to the tooth mesh can be useful to precisely apply loads where the pinion and gear teeth will be contacting. The Contact Pattern, when shown, is numbered along the PoC, e.g. from pinion tooth root to tip.



Node Numbering

The Node Numbering menu entry gives access to another submenu level, indicated by a >, where node numbering options can be set by toggling On or Off four choices. A choice which has been set On is shown by a check mark ; it determines whether the calculated node numbers will be shown, or not, in the FEA Mesh display.



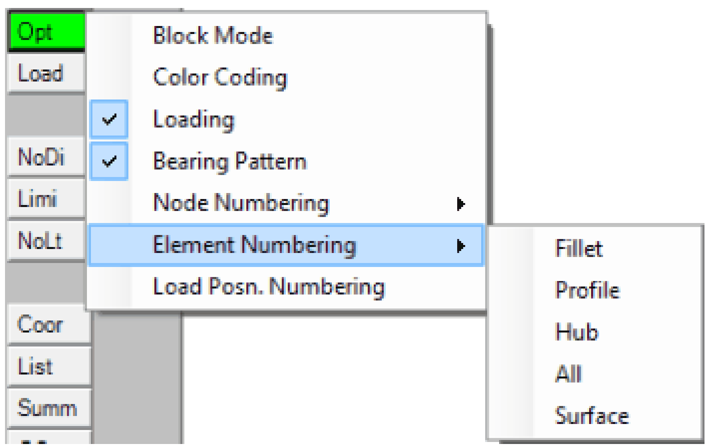
Mesh node numbers can be shown only if the mesh has been formally calculated, which is automatically performed by HyGEARS when node numbering is requested, or by toggling the display from the current hidden line removal mode to "No". If the display hidden line removal mode is changed to any other mode after formal mesh calculation, the calculated nodes will still be displayed until a modification is made to mesh definition, and then the process must be repeated.

The four following Node Numbering options are available:

Fillet where only those nodes in the fillet area of the tooth are displayed;
Profile where only those nodes in the profile area of the tooth are displayed;
All where all the mesh nodes are displayed.
Surface where only surface nodes are displayed, in the fillet, profile or fillet and profile areas.

Element Numbering

The Element Numbering menu entry gives access to another submenu level, indicated by a , where element numbering options can be set by toggling On or Off four choices. A choice which has been set On is shown by a check mark ; it determines whether the calculated element numbers will be shown, or not, in the FEA Mesh display.



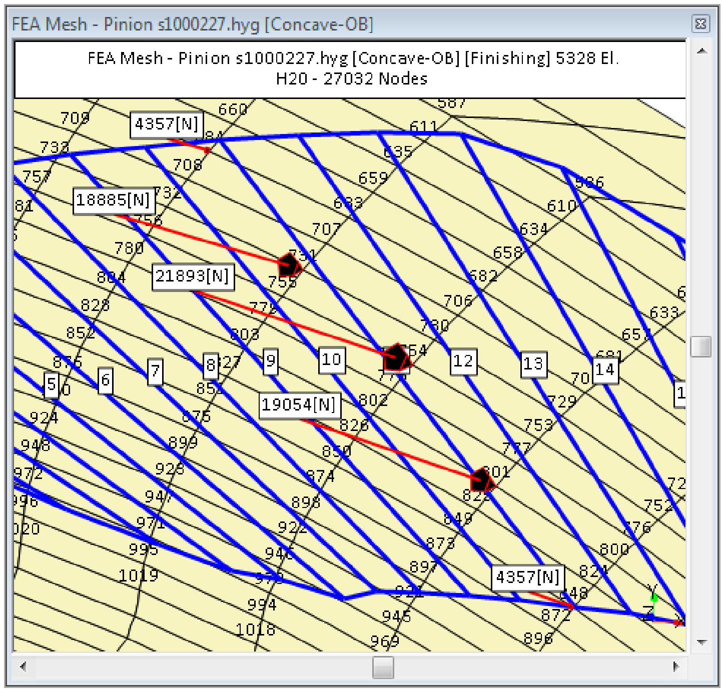
Element Numbering operates in the same manner as Node Numbering.

Fillet where only those Elements in the fillet area of the tooth are displayed;
Profile where only those Elements in the profile area of the tooth are displayed;
All where all the mesh Elements are displayed.
Surface where only surface Elements are displayed.

Load Position Numbering

The Load Position Numbering option can be toggled On or Off, which is shown by a check mark ; it determines whether the tooth surface Load Application Positions are displayed or not.

In HyGEARS, to simplify and speed load case definition, the tooth flank definition points are numbered and loads are applied at these points instead of the node numbers. A conversion is made from the Load Application Positions to the actual node numbers at the time the [FEA output](#) file is prepared.



The tooth surface Load Application Positions are numbered automatically by HyGEARS, and the displayed numbers are used to identify where on the tooth flank loads are to be applied.

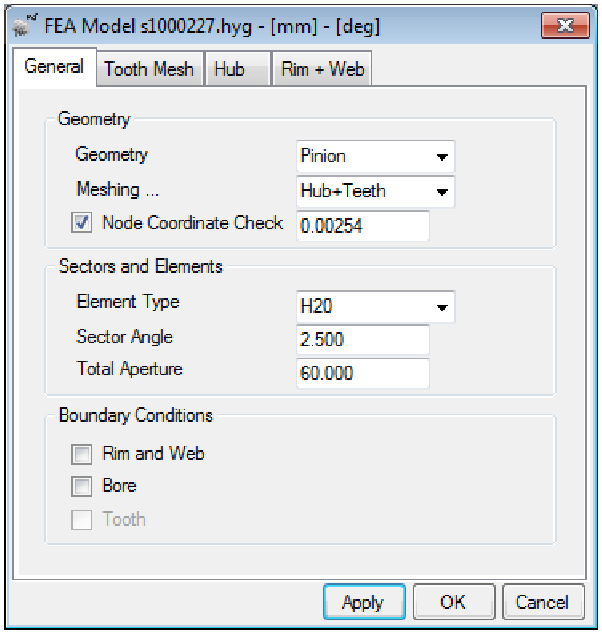
The above figure illustrates a pinion tooth flank on which the surface Load Application Positions and the applied load are displayed in red.

12.8.2 Mesh Editor

HyGEARS uses an FEA Mesh Editor window to help in the definition and refinement of an FEA model. The FEA Mesh Editor window shown below is called through the use of function button Mesh; it is divided in four data pages where specific data can be entered to control meshing behavior. The current units are displayed in the title bar.

The following Data Pages are offered:

General data page
Tooth data page
Hub data page
Rim+Web data page



Command buttons

Apply tells HyGEARS to use the current set of values to recalculate and redisplay the mesh.

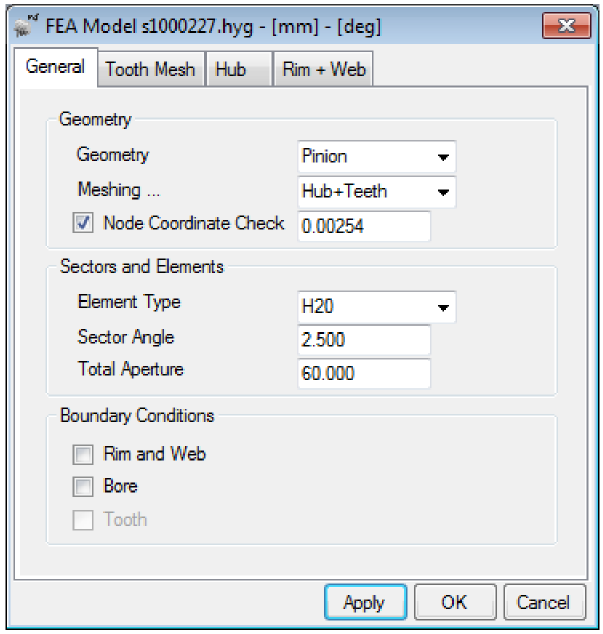
OK ends the FEA Mesh Editor window and applies the modified data to the displayed mesh; if the tooth mesh definition has been changed, the tooth will be redigitized (see Editing Functions, Chapter 5, The Digitization Process) before the mesh is redisplayed.

Cancel ends the FEA Mesh Editor window, without modifying the displayed mesh.

12.8.2.1 General data page

The General Data page is used to control the type of meshed Geometry, elements and what boundary conditions are to be applied.

Geometry
Sectors and Elements
Boundary Conditions



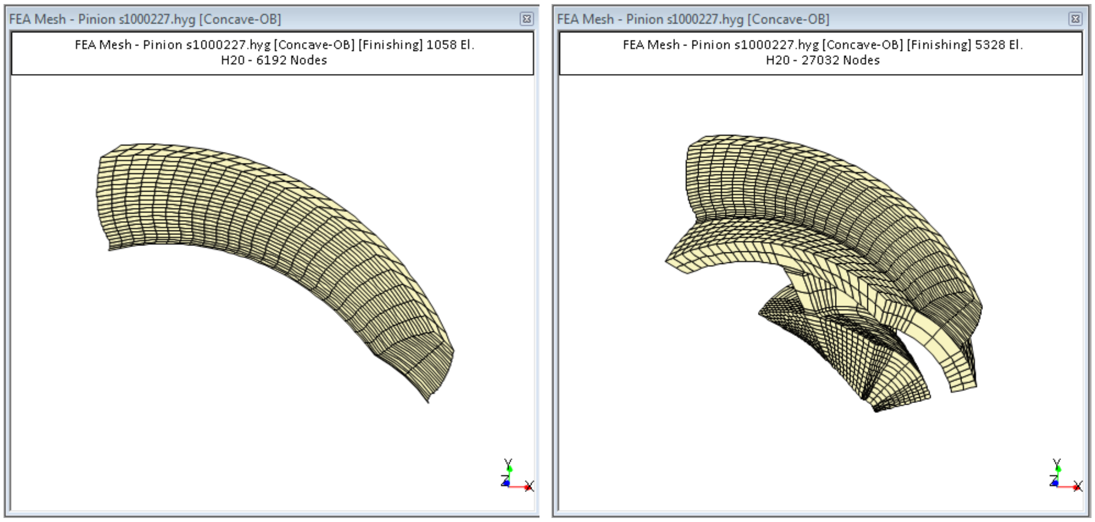
Geometry

The first section of the General data page is the Geometry definition, where the meshed pinion or gear is identified. Two fields are shown in the Geometry section:

Geometry	the Geometry field identifies whether the FEA Mesh Editor window displays pinion or gear data. It is not possible to change the selection in the Geometry field, as it is controlled by the Geometry displayed in the Child Window.
Meshing	the Meshing field identifies whether the FEA Mesh Editor window displays tooth only or hub and tooth data. The Meshing field drop-down list box offers two options:

Tooth	only the tooth is meshed and displayed;
Hub+Teeth	both hub and teeth are meshed and displayed.

The two following figures respectively illustrate Tooth and Hub+Teeth FEA Mesh displays for a thin rimmed pinion

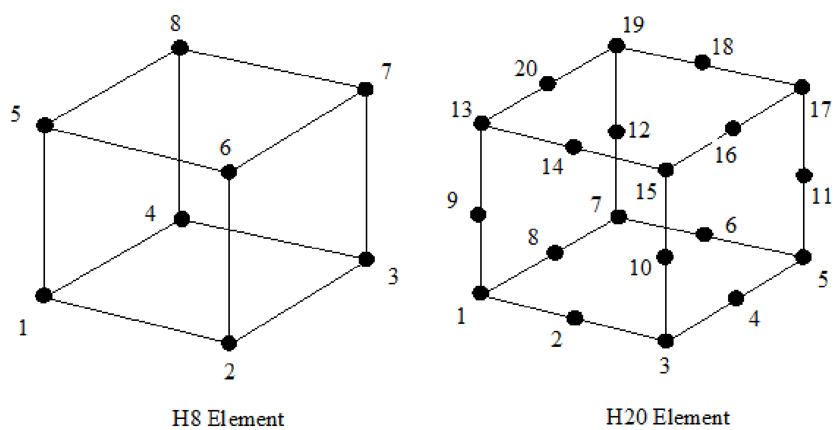


Sectors and Elements

The second section of the General data page is used to define the element used to mesh the model, and how the hub-rim part of the mesh is dimensioned. Three fields are available in this section:

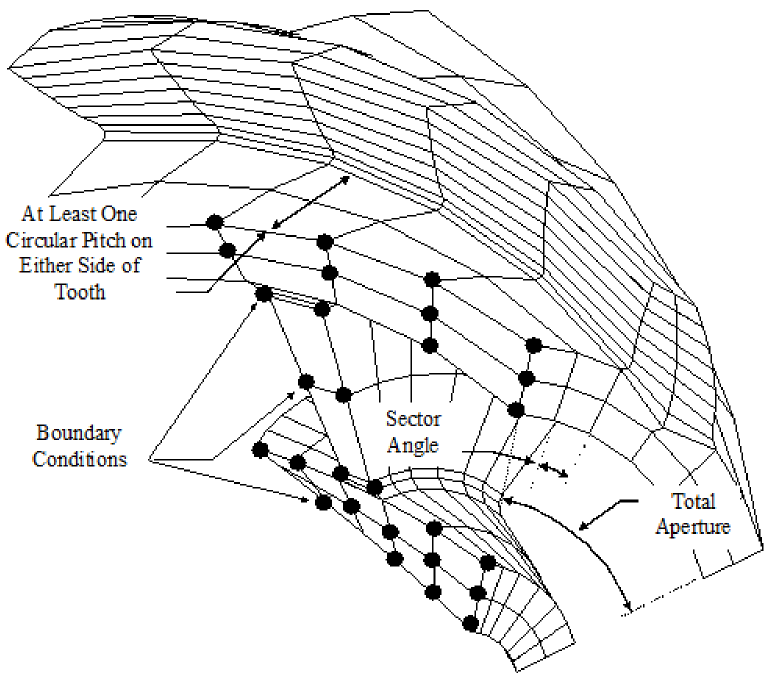
Element Type the Element Type field identifies whether the meshing element will be 1st or 2nd order. Two choices are offered:

H8: is an eight node linear element;
H20: is a twenty node quadratic element.



As a general rule, the H20 element will perform much better than an H8 element because of its quadratic definition, even if the total number of nodes is significantly less than that of an H8 model. The figure above illustrates how nodes are encoded in H8 and H20 elements.

Sector Angle the hub mesh is divided in sectors of equal value outside the tooth area, as shown in the figure below. The Sector Angle value is used to tell HyGEARS what dimension the sectors are to be. Smaller sector angle values will normally give better results as mesh density will be larger, but when the stress gradients are lower, as in the hub away from tooth fillet, sector angle values of 10 to 15 degrees can be acceptable.



Total Aperture is the overall dimension the hub aperture. Normally, the sides of the hub will be submitted to boundary conditions precluding displacements, such as to simulate a full gear hub. It is therefore recommended to provide at least one circular pitch on either side of the loaded tooth such as to properly spread tooth root stresses before boundary conditions are applied.

The Total Aperture is the arc-sector taken by the hub model, as illustrated above. A 360 degree Total Aperture results in a full hub.

Boundary Conditions

The third section of the General data page is used to define where the boundary conditions are to be applied on the FEA model. HyGEARS supports only fixed position boundary conditions, which means that the fixed nodes are not permitted to move in any direction. Three input fields are shown in this section:

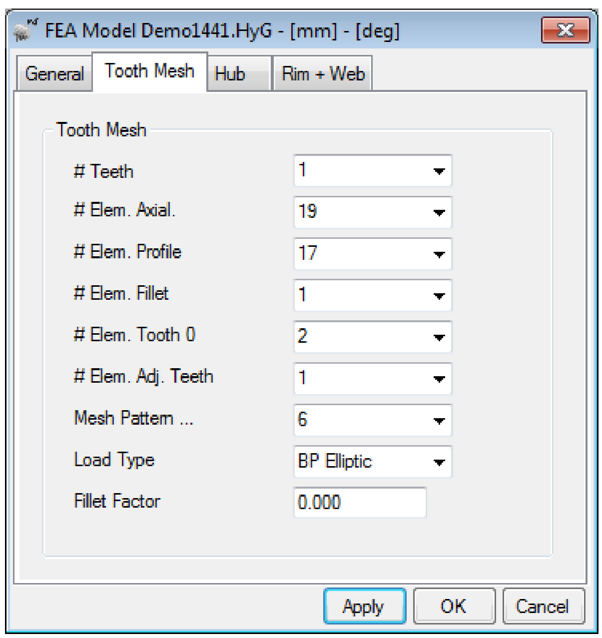
Rim And Web the rim, web and hub side nodes are fixed; this field is active only when the Meshing input field is set to Hub+Teeth;

Bore the bore nodes are fixed; this field is active only when the Meshing input field is set to Hub+Teeth;

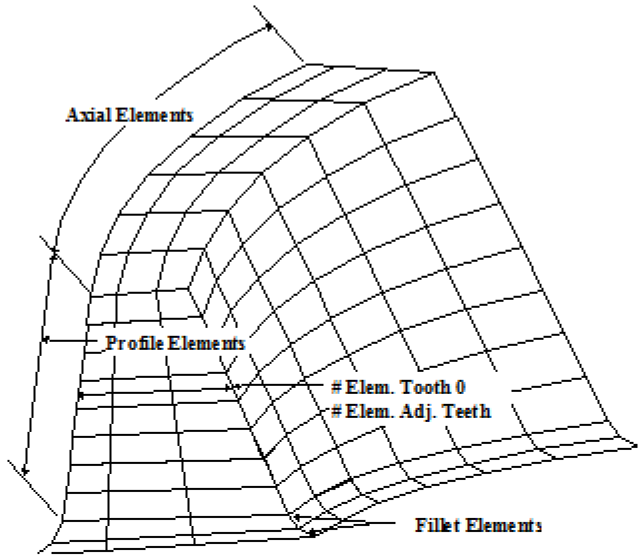
Tooth the tooth underside nodes are fixed; this field is active only when the Meshing input field is set to Tooth.

12.8.2.2 Tooth Mesh

The Tooth data page is used to define the number of meshed teeth and how each tooth is to be meshed. Up to ten input fields are used to define the tooth mesh, as described below:



 # Teeth the # Teeth input field, active when the Meshing input field is Hub+Teeth, defines the number of teeth that are to be meshed; the drop-down list box offers up to 5 teeth, but manually inputted values are accepted also. If more than one tooth is to be meshed, tooth 0 will be the only one submitted to loading, and adjacent teeth are sequentially meshed on both sides of tooth 0.

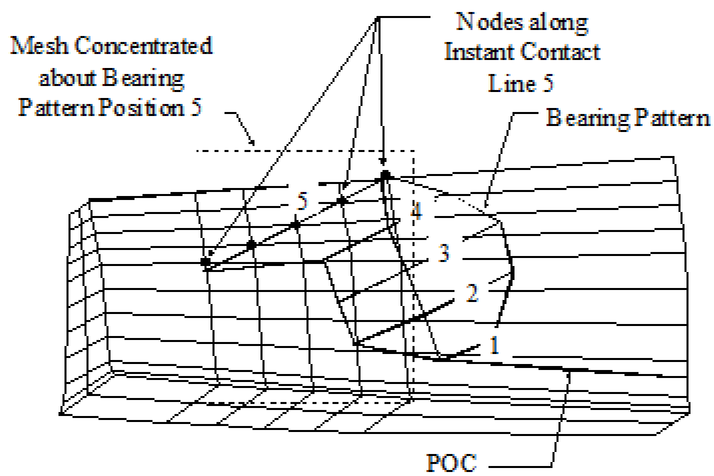


# Elem. Axial	the # Elem. Axial input field defines the tooth lengthwise number of elements. This value is the same for all meshed teeth, rim, and hub. Minimum and maximum values are respectively 3 and 19 elements.
# Elem. Profile	the # Elem. Profile input field defines the profilewise number of elements. This value is the same for all meshed teeth. Minimum and maximum values are respectively 3 and 14 elements.
# Elem. Fillet	the # Elem. Fillet input field defines the fillet number of elements. This value is the same for all meshed teeth. Minimum and maximum values are respectively 1 and 6 elements.
# Elem. Tooth 0	the # Elem. Tooth 0 input field defines the main tooth thicknesswise number of elements. This value is valid only for tooth 0, the tooth to which loading will be applied. Minimum and maximum values are 1 to 9 elements.
# Elem. Adj. ...	the # Elem. Adj. Teeth input field defines the thicknesswise number of elements for all the other teeth on either side of tooth 0. This field is active only when the # Teeth input field is larger than 1. Minimum and maximum values are 1 to 6 elements.
Mesh Pattern...	the Mesh Pattern input field is used to control either where the mesh is to be located on the tooth flank in relation to the Contact Pattern, or where it is to be located along the facewidth.

In the HyGEARS FEA Model, it is possible to specify which part of the tooth is to be more densely meshed in order to be able to accurately reproduce actual loading by a series of individual forces applied to element nodes.

The Mesh Pattern field offers several different options:

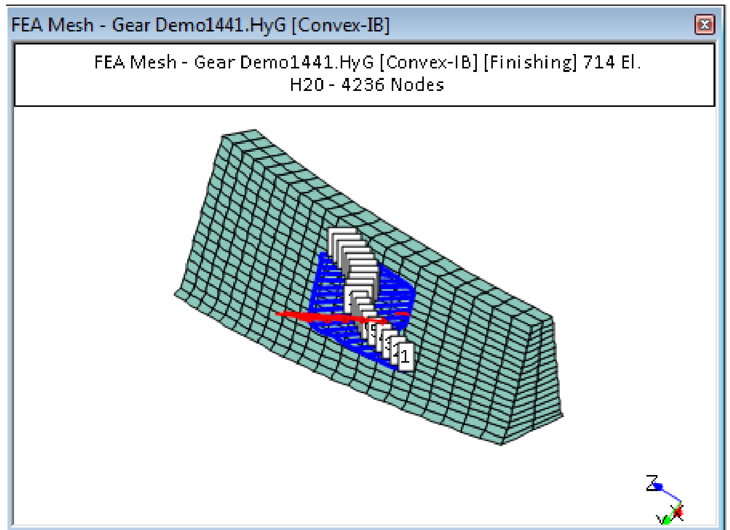
No	the mesh is evenly spread over the entire tooth facewidth;
Yes	the mesh extent is defined by the ends of the instant line of contact of the mid-point on the Contact Pattern. The mid-point is recognized by the blue marker;
Toe	the mesh will be concentrated in the lengthwise toe-section of the tooth;
Center	the mesh will be concentrated in the lengthwise mid-section of the tooth;
Heel	the mesh will be concentrated in the lengthwise heel-section of the tooth;
1, 2...	the mesh extent is defined by the ends of the instant line of contact of the Contact Pattern indicated by the chosen number.



For example, the above figure shows a meshed gear tooth; mesh was concentrated about Contact Pattern instant line of contact 5, along which 5 nodes can be used to apply loads accurately reproducing actual contact loading.

When this option is selected, the title of the following input field becomes “Load Type” and HyGEARS can then be requested to automatically find the surface nodes closest to the Contact Pattern instant line of contact selected, and apply the gear set torque at the positions found.

For example, in the figure below, the selected Load Type is BP Elliptic and HyGEARS has found several nodes at which the load is applied in a elliptical distribution. Note that the calculated loads can then be edited using the Load Editor.

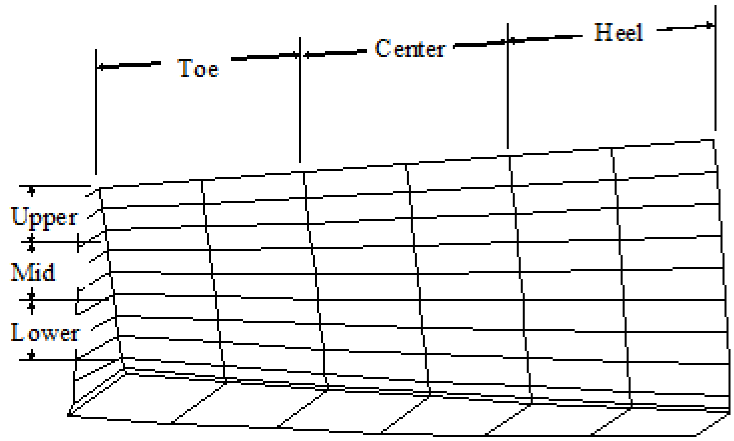


Mesh Radial... the Mesh Radial input field is used to control where the mesh is to be located profilewise on the tooth flank. It is ignored if a Contact Pattern instant line of contact position has been selected in the preceding Mesh Pattern field.

The Mesh Radial field offers several different choices:

- *No* the mesh is evenly spread profilewise over the tooth flank;
- *Lower* the mesh is concentrated in the profilewise lower tier of the tooth flank;
- *Center* the mesh is concentrated in the profilewise middle tier of the tooth flank;
- *Upper* the mesh is concentrated in the profilewise upper tier of the tooth flank.

The following figure describes the respective tooth flank areas.



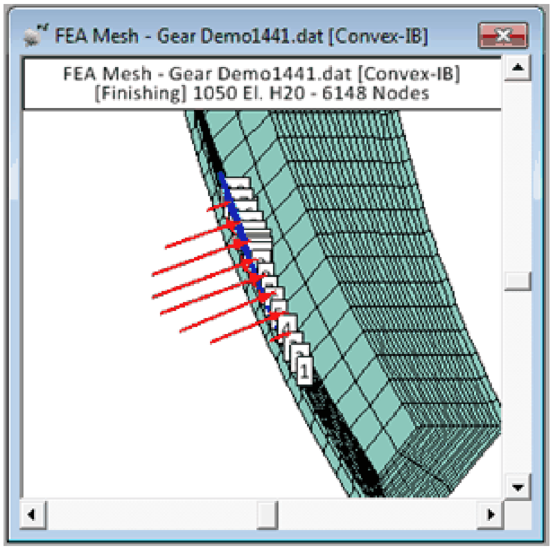
Load Type ... When, in the preceding “Mesh Pattern” field , the selection is an instant line of contact on the Contact Pattern, the title of the “Mesh Radial” field becomes “Load Type” for which 3 entries are offered.

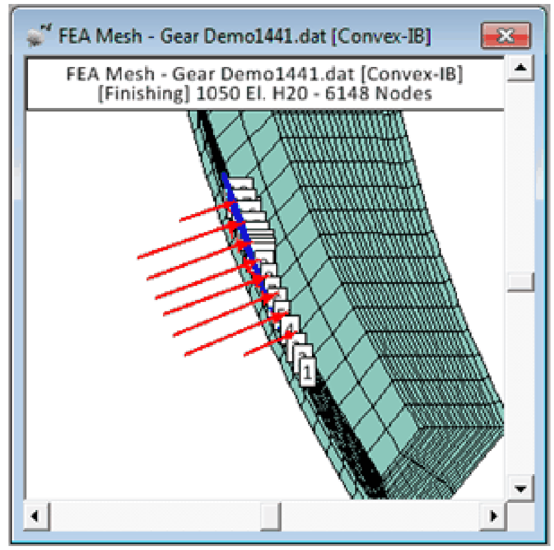
Point this tells HyGEARS that the user will input directly the loads to apply to the mesh;

BP Const HyGEARS will find the surface nodes closest to the selected instant line of contact and apply the torque in several identical loads, except for the first and last loads which will be halved;

BP Elliptic HyGEARS will find the surface nodes closest to the selected instant line of contact and apply the torque in several loads distributed in an elliptical fashion.

For example, the two following figures show a meshed gear tooth for which the “BP Elliptic” (left figure) and “BP Const.” (right figure) Load Types were applied.





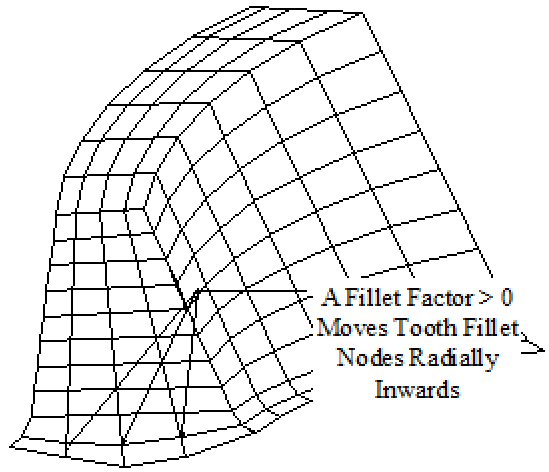
Note 1: when HyGEARS applies loads automatically, as above, the FEA Load matrix is erased and the calculated values are transferred to it directly, thereby replacing all existing load cases.

Note 2: Toggling the "Dims"/"NoDi" function button displays or hides the value of the applied loads, which can be helpful in evaluating their position and distribution.

Fillet Factor the Fillet Factor is used to modify the way the tooth fillet is meshed.

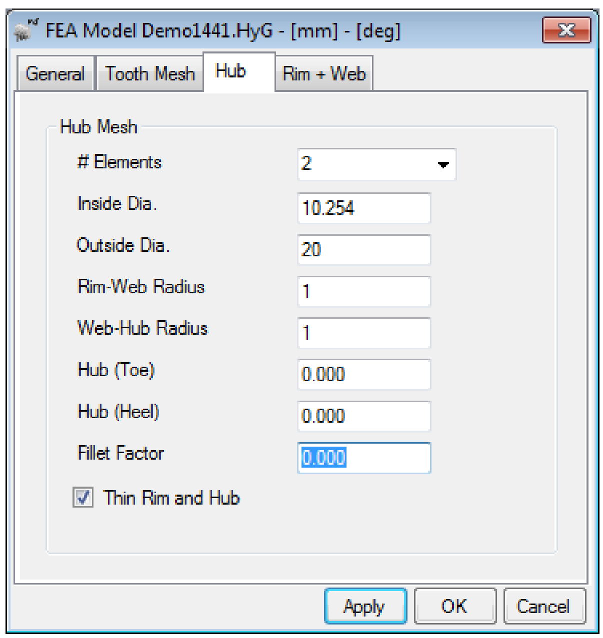
When the fillet factor is equal to 0, the tooth fillet is meshed ordinarily, e.g. with equally spaced filletwise nodes; when the fillet factor is larger than 0, the nodes in the center part of the tooth fillet are displaced inward, in order to improve the shape of the fillet elements, as shown below.

Note: For this to work, the Fillet number of elements must be at least 3.



12.8.2.3 Hub Mesh

The Hub data page is active when the Meshing input field is Hub+Teeth.

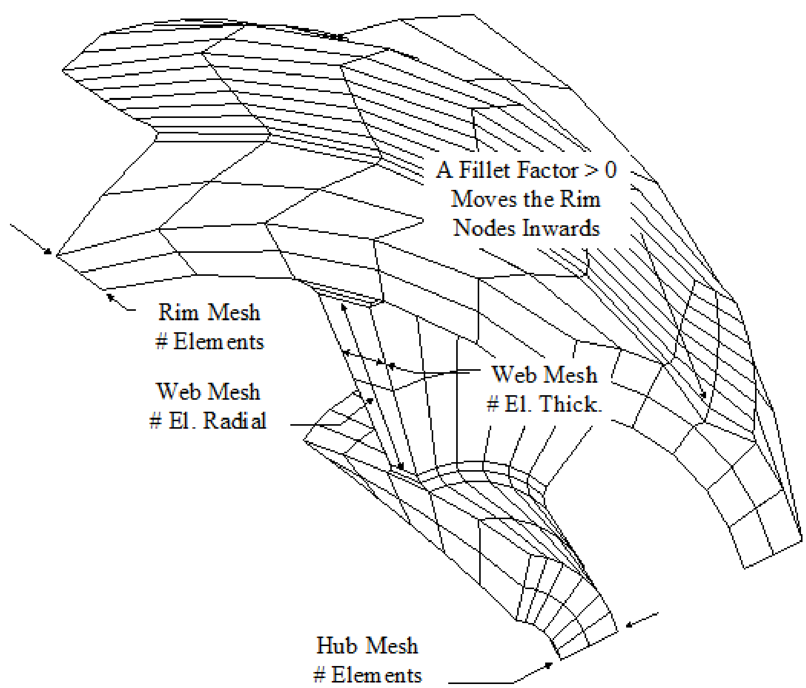


The components marked by an asterisk "*" are not shown when the meshed model is the gear member of a gear set of speed ratio above 3.5:1 or when the gear member is not generated (crown gear).

It is defined by the following input fields:

# Elements	radial number of elements defining the hub mesh;
Inside Dia.	hub inside diameter, assumed constant along the tooth facewidth;

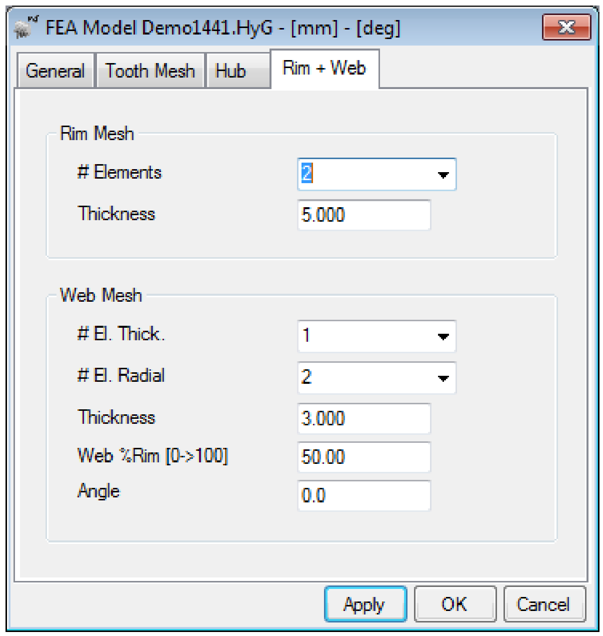
*Outside Dia. **	hub outside diameter, assumed constant along the tooth facewidth;
*Rim-Web Radius **	the rim to web radius, assumed constant along the tooth facewidth, is defined by two elements;
*Web-Hub Radius **	the web to hub radius, assumed constant along the tooth facewidth, is defined by two elements;
*Hub (Toe) **	extent of the hub ahead of tooth toe;
*Hub (Heel) **	extent of the hub after of tooth heel.
Fillet Factor	fillet factor used to modify the way the rim is meshed under the tooth. If a solid rim is used rather, this corresponds to the hub and is why it appears in the Hub data page. When the fillet factor is equal to 0, the rim is meshed ordinarily, e.g. with equally spaced radial nodes; when the fillet factor is larger than 0, the nodes under the tooth are radially displaced inward, in order to improve the shape of the fillet elements. The rim must be meshed with at least 3 elements for the fillet factor to be effective.
Thin Rim and Hub	tells HyGEARS that a thin rimmed gear is considered; however, If any of the above values is null or negative, a solid rim is assumed.



12.8.2.4 Rim+Web Mesh

The Rim + Web data page is active when the Meshing input field is Hub+Teeth.

The components marked by an asterisk "*" are not shown when the meshed model is the gear member of a gear set of speed ratio above 3.5:1 or when the gear member is not generated (crown gear).

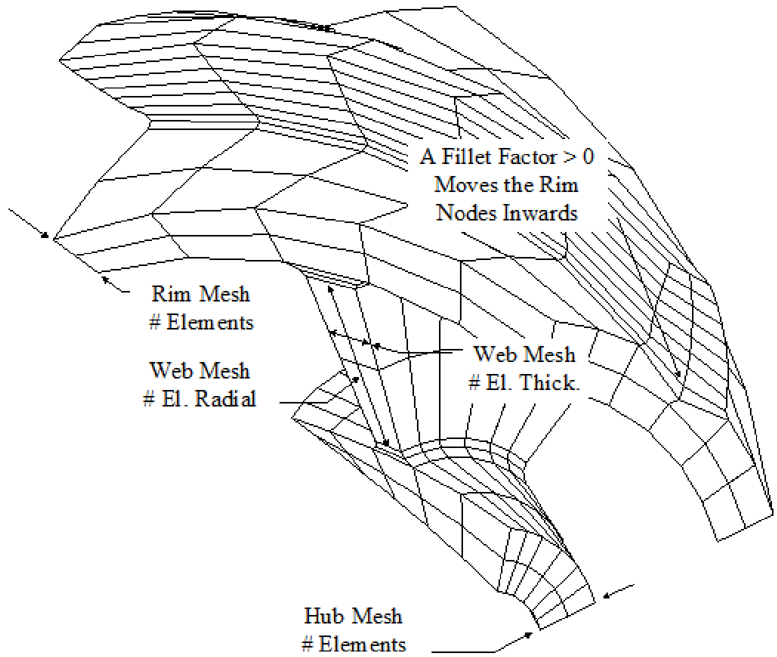


Rim Mesh

The Rim Mesh is defined by the following three input fields:

# Elements	radial number of elements defining the rim mesh;
Thickness	rim thickness, assumed constant along the tooth facewidth.

If any of the above values is null or negative, a solid rim will be assumed.

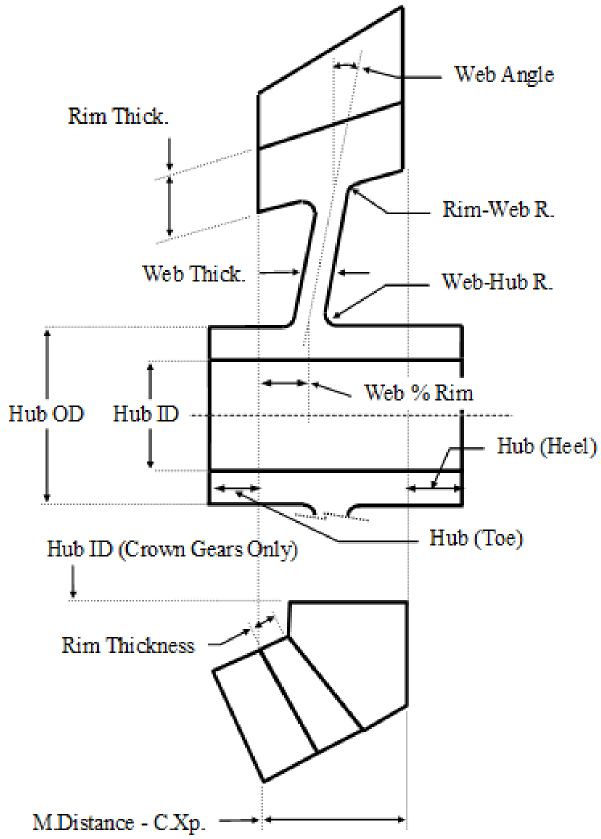


Web Mesh

The Web Mesh is defined by the following five input fields:

*# El. Thick **	is the thickness wise number of elements defining the web mesh;
*# El. Radial **	is the radial number of elements defining the web mesh;
*Thickness **	is the web thickness, assumed constant along the tooth facewidth;
*Web % Rim **	lengthwise location of the center of the web, in % of the tooth facewidth.;
*Angle **	is the tilt angle of the web.

If any of the above values is null or negative, except the *Web %Rim* and *Angle*, a solid rim is assumed.



12.8.3 Mesh Output

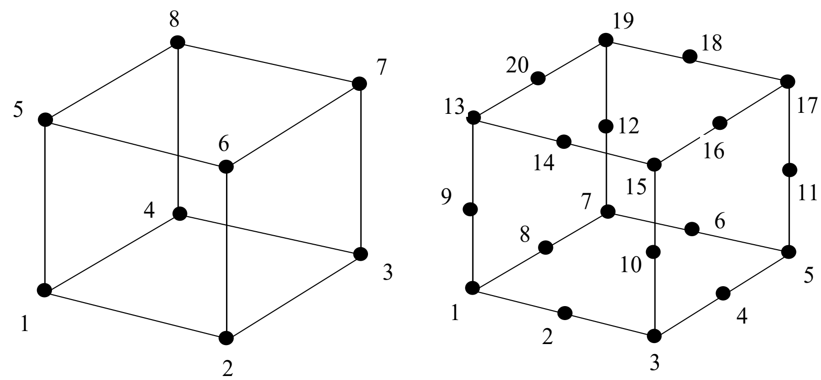
The FEA Model Output is sent directly to a data file which can then be submitted to a FEA solving software. As it is not possible to cover all the various Finite Element Analysis software data input formats, the following will explain the format used by HyGEARS, which is almost identical to that of FEA's Lusas solver.

The FEA Model Output is structured in six sections, as explained hereafter:

- The first section deals with the problem title, in which either the pinion or the gear is identified, the cutting mode (roughing or finishing), and the Geometry data file.

```
PROBLEM TITLE Pinion [Finishing]  demo.dat
```

- The second section deals with Element Topology. HyGEARS supports only H8 and H20 elements. The following figure illustrates how H8 and H20 element nodes are encoded.



H8 Element H20 Element

The Element Topology section identifies the type of element, either HX8 or HX20. Each element is identified by a number, followed by the node numbers of which it is made up. The line continuation symbol "..." is used to split lines longer than 80 characters.

```
HX20 ELEMENT TOPOLOGY
      1      1      2      3     13      6      5      4     14 ...
            17     18     19     20      7      8      9     15 ...
            12     11     10     16

      2      4      5      6     27     23     22     21     28 ...
            20     19     31     32     10     11     12     29 ...
            26     25     24     30
             .
             .
             .

    211   1339   1491   1492   1499   1497   1496   1344   1346 ...
          1342   1495   1500   1347   1315   1466   1467   1475 ...
          1473   1498   1345   1322

    212   1344   1496   1497   1503   1502   1501   1349   1350 ...
          1347   1500   1504   1351   1320   1472   1473   1481 ...
          1478   1477   1325   1328
```

- The third section deals node coordinates. Each node is identified by its number, followed by its X1X2X3 or Y1Y2Y3 coordinates, depending whether the pinion or the gear is the meshed member.

```
NODE COORDINATES
      1   -0.366551200    0.845268400    0.000000000

      2   -0.450766200    0.803522400    0.000000000
```

```
      3   -0.530289500    0.753413200    0.000000000

...
   1500   -0.088788450    0.232610900    0.756777400

   1501    0.008279314    0.201680500    1.064976000

   1502   -0.008477102    0.201672300    1.064976000

   1503   -0.033950050    0.197288900    0.931854200

   1504   -0.010491380    0.249592600    1.064976000
```

- The fourth section deals with material properties. Material properties are grouped in Material Groups. Each Material Group is identified by a number, followed by Young's modulus and Poisson's Ratio values established in the Operating section of the Pinion or Gear Summaries.

```
MATERIAL PROPERTIES
      1        30000000.0    0.28
```

Material Groups are then assigned to elements or element groups in the following manner:

```
MATERIAL ASSIGNMENTS
      1    212    1     1
```

where "`1   212   1   1`" respectively take the following meaning:

```
1st El.    Last El.     El. Inc.    Mat. Grp
```

1st El.	is the first element of the group to which the Material Case is to be applied;
Last El.	is the first element of the group to which the Material Case is to be applied;
El. Inc.	is the increment to apply between the 1st and last elements to identify all those element concerned;
Mat.Grp	is the Material Group number to apply to the listed elements.

- The fifth section deals with boundary conditions. It is a list of all the support nodes, and how they are restrained. Boundary Conditions are formatted in the following manner:

```
SUPPORT NODES
    223  223 0  R  R  R

    224  224 0  R  R  R
```

```
 225  225 0  R  R  R

 ...

1499 1499 0  R  R  R

1501 1501 0  R  R  R

1502 1502 0  R  R  R
```

where "`1499 1499 0   R   R`" respectively take the following meaning:

```
1st Node     Last Node     Node Inc.     Disp. 1      Disp. 2      Disp. 3
```

1st Node	is the first node number on which the boundary condition is applied;
Last Node	is the last node number on which the boundary condition is applied;
Node Inc.	is the increment between the 1st and last node number to which the prescribed boundary conditions are to be applied;
Disp 1	defines whether displacement in the X1 or Y1 directions permitted or not; an R indicates that displacement is restricted.
Disp 2	defines whether displacement in the X2 or Y2 directions permitted or not; an R indicates that displacement is restricted.
Disp 3	defines whether displacement in the X3 or Y3 directions permitted or not; an R indicates that displacement is restricted.

- The seventh section deals with Load Cases. It is a list of all the concentrated nodes where concentrated loads are applied and the load values in three orthogonal directions, Load Case by Load Case. The following format is used:

```
LOAD CASE
CL
    769 769 0    -18.8473400     16.5369200     37.3238800

LOAD CASE
CL
    663 663 0    -29.3163700     12.5396900     46.2851300
```

where "`663 663 0   -29.3163700  12.5396900  46.2851300`" respectively take the following meaning:

LOAD CASE	indicates the beginning of a Load Case section.
CL	indicates a concentrated load

```
1st Node   Last Node     Node Inc.      Force X1      Force X2      Force X3
```

1st Node	is the first node number on which the concentrated load is applied;
Last Node	is the last node number on which the concentrated load is applied;
Node Inc.	is the increment between the 1st and last node number to which the concentrated load is to be applied;
Force X1	defines the value of the load applied in the X1 or Y1 direction.
Force X2	defines the value of the load applied in the X2 or Y2 direction.
Force X3	defines the value of the load applied in the X3 or Y3 direction.

- The FEA Model data file ends with an "END" flag, as below:

```
END
```

12.8.4 Load Editor

HyGEARS offers a user friendly FEA Load Editor window to apply loads at selected tooth flank positions.

In HyGEARS, loads are grouped in Load Cases which can contain up to 20 loads of different values applied at different Load Application Positions on the same tooth flank. The Load Editor offers a visual approach at grouping and selecting Load Cases.

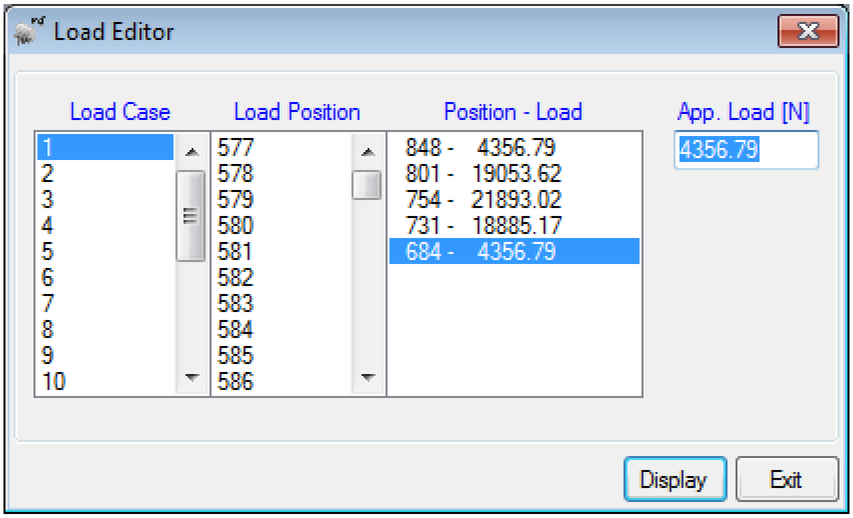
Up to 20 Load Cases, each with up to 20 different applied loads, can be set for any FEA or Finite Strips model. Each time the tooth mesh definition is modified, for example by increasing the number of axial elements, all the current FEA model Load Cases are reset to zero.

The Load Editor window is called from the FEA Model or Finite Strips Child Window Function button "Load".

To effectively apply loads on a meshed tooth flank, the Load Posn. Numbering option from the "Opt" function sub-menu must be checked such that the tooth flank will display the numbers where forces can be applied.

Toggling the "Cvx" to "Con" or "Left" to "Right" Function button displays the corresponding tooth flank load position numbers.

Loads are always applied in a direction normal to the tooth flank at the load position.



The Load Editor window shown above provides three data selection lists, one input field and two command buttons, which are described below:

Load Case — list that offers numbers identifying up to 20 load cases. The scroll bar to the right of the list box is used to scroll up or down within the listed Load Cases.

To select a Load Case, click on the number of the desired load case from within the "Load Case" list box. The "Position - Load" list box to the right, which displays the list of loads and positions for the currently selected Load Case, will then be updated to reflect those of the selected Load Case.

Load Position — list that offers numbers identifying all the Load Application Positions for the displayed tooth flank. A double click on a "Load Position" number adds the selected number to the "Position - Load" list box, which displays the list of loads and positions for the currently selected Load Case, and the FEA Load Editor then expects a Load value to be entered in the Load field.

Position - Load — displays every load application position and value on the tooth flank for the currently selected Load Case in the following format:

Load Position - Applied Load Value

A *single click* on any entry from the "Position - Load" list box makes it current and its load value can then be entered or modified in the Load field.

A *double click* on any entry from the "Position - Load" list box removes it from the currently selected Load Case.

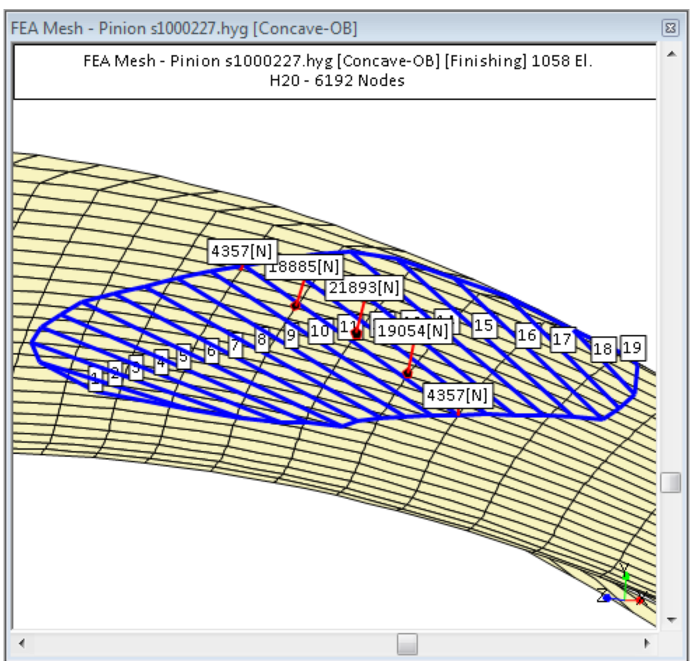
Load the "Load" input field is used to enter or modify the load value, in the current load units, applied at the currently selected "Position - Load". Terminating an entry with the Enter key does not redisplay the currently active FEA Model Child Window. To display the new status of a Load Case, use the Display button below.

Display used to force a recalculation and redisplay of the currently active FEA Model Child Window, with the updated currently active Load Case. Therefore, to display a load case, click on the desired load case from the "Load Case" list box and click the Display button.

Exit terminates the Load Editor window. All the inputted and modified values are saved.

The figure below shows the concave tooth flank of a pinion. The FEA Model sub-menu entry *Load Posn. Numbering* has been checked out, such that the current tooth flank loading positions do not appear in the display.

To improve clarity, the Child Window was Zoomed-In, such that both horizontal and vertical scroll bars appear. A *BP Elliptical* load is applied to instant line of contact #11, and constitutes Load Case #1.



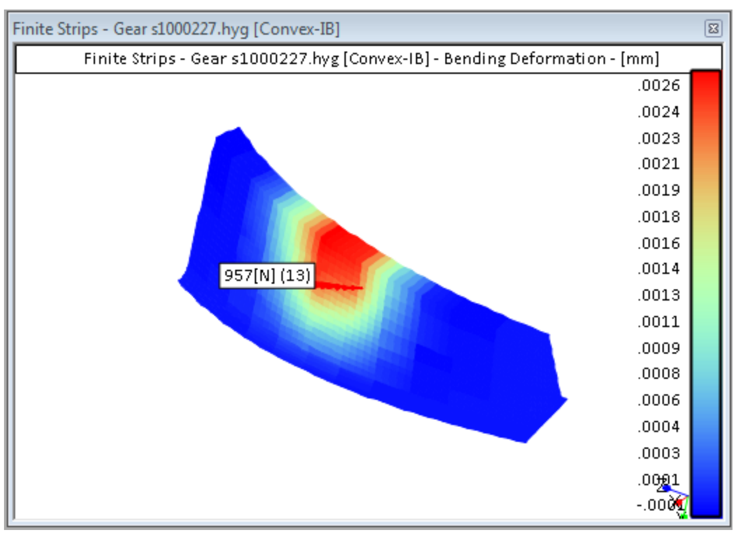
12.9 Finite Strips

In the design process of a gear set, it is often desired to verify the bending strength of the pinion and gear members under load, and to use the bending stiffness in applications like the Loaded Tooth Contact Analysis. Of course, this can be done using the Finite Element Analysis method (FEA), which usually gives excellent results, but at the cost of preparing extensive FEA meshes, exporting them to a solver which must be purchased, running the solver and then analyzing the results.

HyGEARS offers an integrated method to analyze gear teeth under load: the Finite Strips. Using the Finite Strips, tooth bending stiffness and stresses can be calculated in a matter of seconds, and HyGEARS' integrated support of the Finite Strips means that results can be consulted immediately, without requiring a separate solver or post-processor.

Given its speed, the Finite Strips is a most interesting design tool. Once the design has been defined using the Finite Strips, the use of Finite Element Analysis, using HyGEARS' advanced FEA Modeling capabilities, can be seen as a final confirmation tool.

The Finite Strips function, accessed from the **Graphics->Meshing->Finite Strips** pull down menu, provides a user friendly interface to Finite Strips pre and post-processing, such as tooth mesh definition, load application and result assessment, as the following pinion tooth deformation figure shows:



A HyGEARS Finite Strips Model can contain up to 21 strips with 5 nodes each. The HyGEARS Finite Strips mesh is calculated as soon as a change is made to its definition, and is then redisplayed.

The Finite Strips mesh can be shown for either the pinion or the gear separately, but not together. Therefore, if both the pinion and gear have been selected for display, HyGEARS will default to the pinion mesh.

The HyGEARS Finite Strips supports all gear tooth geometries: Spur, Helical, Beveloid, Straight-Bevel, Spiral-Bevel and Hypoid, and Face gears. Loads can be applied anywhere on the tooth flank, in multiple load cases, or along an instant line of contact of either the TCA or LTCA Contact Patterns.

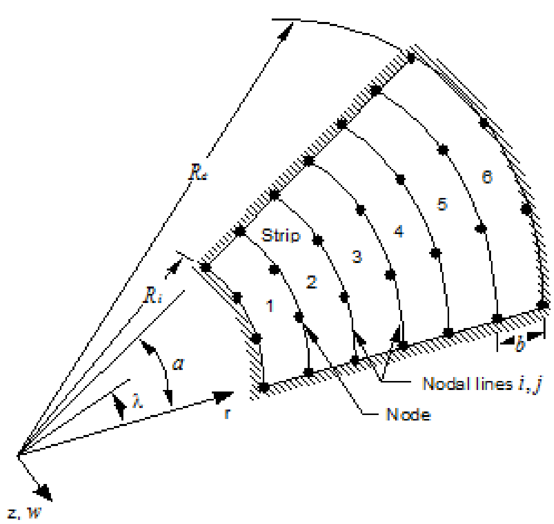
Numerical output is provided in the Finite Strips Model Output section.

12.9.1 Theoretical Background

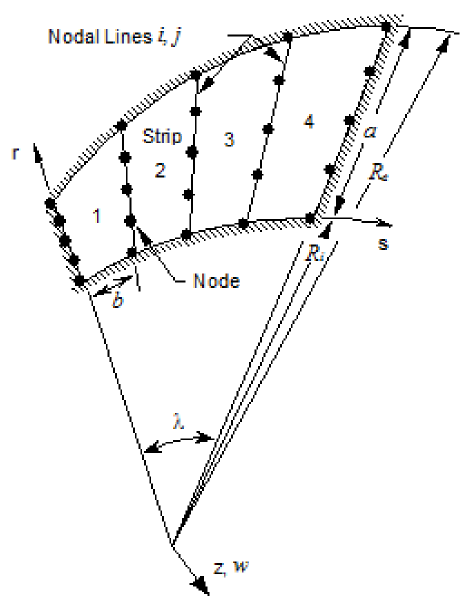
This method, introduced by Cheung and, independently, by Powell and Ogden, can be considered as a **special case of the FEA method**: the Finite Strip is a 2D element for the analysis of plates, based on simple polynomial functions in one direction - the tooth facewidth - and continuously differentiable smooth series in the other direction - the tooth height.

The variant of the Finite Strips Method presented here, to analyze variable height and thickness curved gear teeth, is based on Mindlin's theory.

A typical Finite Strip model for a variable-height plate is presented in the following: strips of width *b* and length *a* are parallel to the *l*-axis and connected by nodal lines; the nodes are used to define the displacement function.



Straight bevel-gear tooth



Spiral-bevel / Hypoid gear tooth

The displacement function of a strip is expressed as the sum of a series of l terms:

$$\delta = \sum_{m=1}^{l} \sum_{i=1}^{2} \Phi_i^m a_i^m$$

where Φ_i^m is a combination of polynomial Ni and series ϕ_m^w, $\phi_m^{\theta_r}$ and $\phi_m^{\theta_\lambda}$:

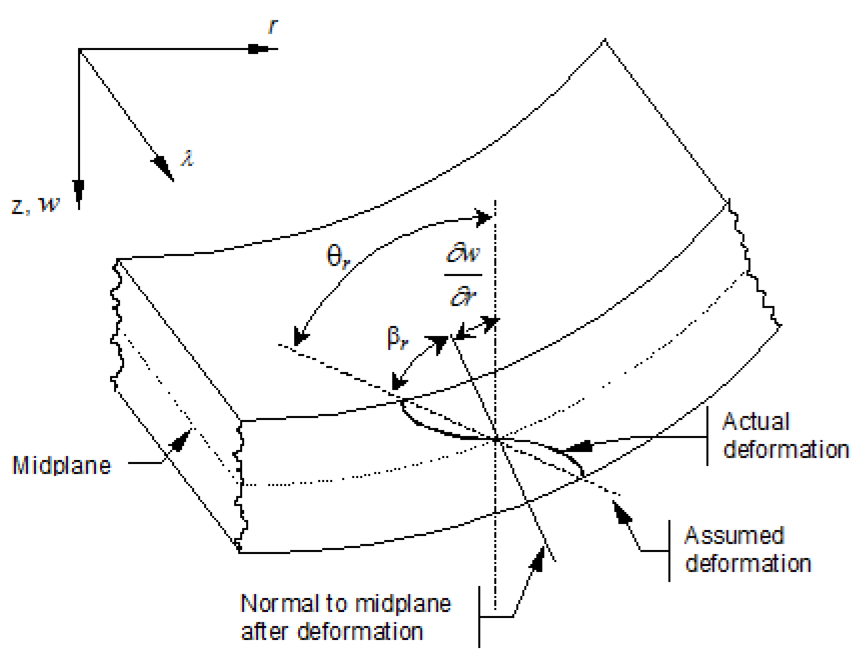
$$\Phi_i^m = \begin{bmatrix} N_i\phi_m^w & 0 & 0 \\ 0 & N_i\phi_m^{\theta_r} & 0 \\ 0 & 0 & N_i\phi_m^{\theta_\lambda} \end{bmatrix}$$

Using Mindlin's plate theory and referring to the following figure, the mid-plane displacement vector of a strip is:

$$\delta = \lfloor w, \quad \theta_r, \quad \theta_\lambda \rfloor^T$$

and the vector of nodal parameters of node i for the mth function:

$$a_i^m = \lfloor w_i^m, \quad \theta_{ri}^m, \quad \theta_{\lambda i}^m \rfloor^T$$



The Finite Strip stiffness matrix for functions m, n and nodal lines i, j is written as:

$$\left[k_{i,j}^{m,n}\right] = \iint \left[B_i^m\right]\left[D\right]\left[B_j^n\right] r\, d\lambda\, dr$$

The terms of the Finite Strip stiffness matrix are obtained by a double integration in the *r* and *l*-directions. The global stiffness matrix is obtained by assembling the stiffness sub matrices.

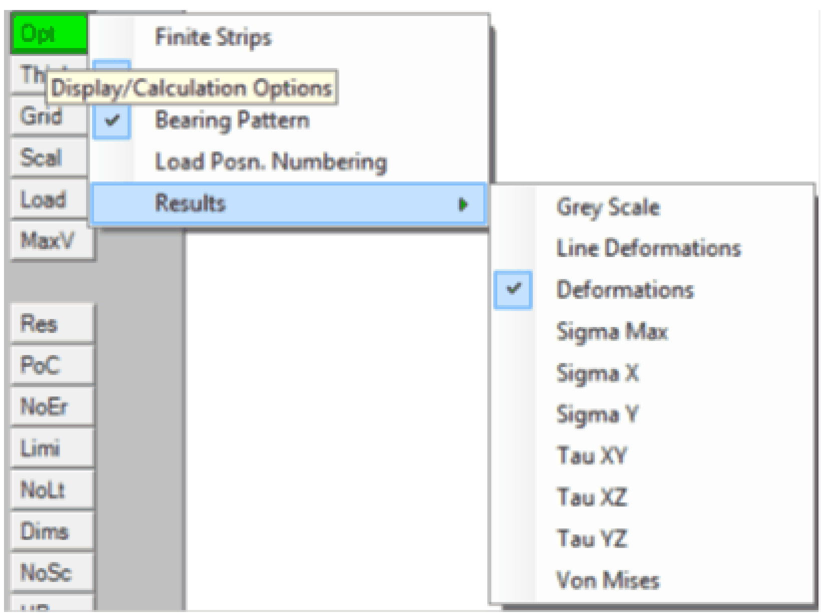
The load vector for function *m* and nodal line *i* is obtained as follows:

$$f_i^m = \iint \Phi_i^m q\, dr\, d\lambda$$

Transverse load *q* is a function of *r* and *l,* and can be local or distributed. Forces and moments about the *r* and *l* axes are respectively applied using the first, second and third column terms of matrix $\left[\Phi_i^m\right]$.

12.9.2 Display Options

When clicked, the Finite Strips calculates and displays the Finite Strips model for the selected Geometry using default values. The "*Opt*" button in the Tool Bar calls the following pop-up sub-menu which shows five entries providing access to various options to be used by the Finite Strips function.

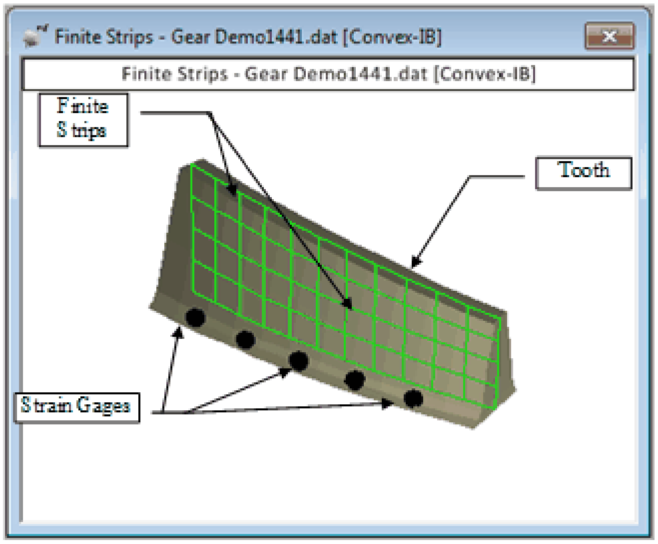


Clicking with the left mouse button on any entry toggles the checking mark identifying that the option symbolized by the entry name is activated or deactivated:

Finite Strips

The Finite Strips option can be toggled On or Off, which is shown by a check mark . When the Finite Strip model is displayed, its underlying structure, e.g. that of the Strips themselves, is not revealed until the "Finite Strips" Option is enabled using a mouse click.

Once this option is enabled, the Strips are displayed as follows:



Thus, in the above display, the Finite Strips mesh is 11 *strips* by 5 *nodes*. Since simple polynomial functions are used along the tooth facewidth, the number of strips is important and HyGEARS uses 7 strips by default, which is usually sufficient for the gear member, but may not suffice for a highly curved pinion member.

In the tooth height direction, since continuously differentiable smooth series are used, the number of nodes is limited to 5, which is normally sufficient. The default value provided by HyGEARS is 5 nodes.

Loading

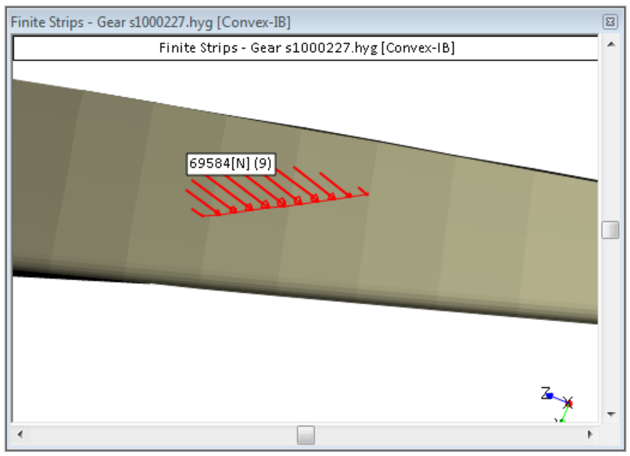
The Loading option can be toggled On or Off, which is shown by a check mark . It determines whether already defined Load Cases will appear on the tooth flank in the Child Window, as shown below. The displayed tooth flank loads are conditioned by the selected tooth flank button, "Cvx" or "Con", as explained later in the Function Buttons section.

Loads can be applied either as individual values at known locations on the tooth flank, or along an instant line of contact of either the TCA or LTCA Contact Patterns, as shown in the figure below.

The applied load appears as a red arrow terminated by an entry in the form "*100 [#] (1)*", where:

100	is the applied load value, e.g. 100 [Lb] or [N] depending on the user selected units;
[#]	is the current Force units defined by the linear units in use;
(1)	is the load case number, defined later in the Load Editor or in the Finite Strips Mesh Definition window.

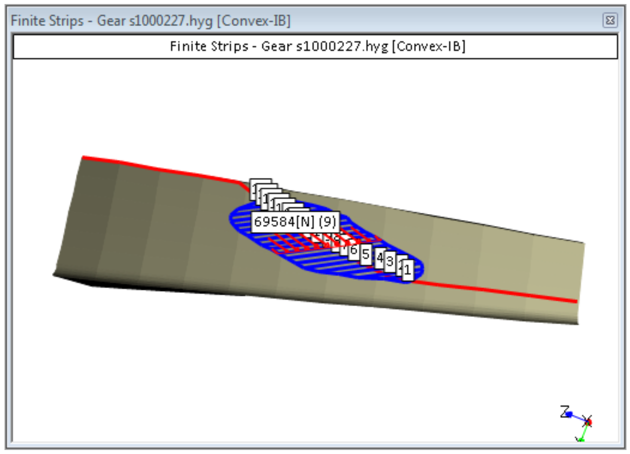
When the applied loads are along an instant line of contact, the value displayed is that of the entire load and also appears as a red arrow terminated by an entry in the form "100 [#] (1)". For example, in the figure below, 4180 [N] are applied in 11 loads distributed elliptically along instant line of contact #9 of the Contact Pattern.



Contact Pattern

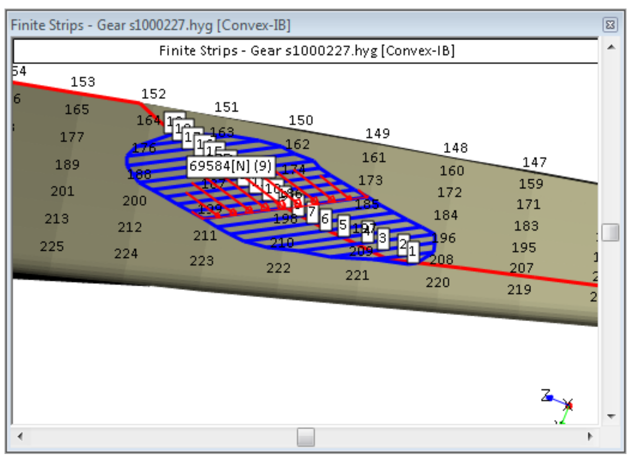
The Contact Pattern option can be toggled On or Off, which is shown by a check mark ; it determines whether the Contact Pattern for the selected tooth flank will be shown or not, which can then be used to apply loads.

Showing the Contact Pattern superimposed to the tooth mesh can be useful to precisely apply loads where the pinion and gear teeth will be contacting. The Contact Pattern, when shown, is numbered along the PoC, e.g. from pinion root to tip.



Load Position Numbering

Load Position Numbering option can be toggled On or Off, which is shown by a check mark ; it determines whether the tooth surface Load Application Positions are displayed or not.



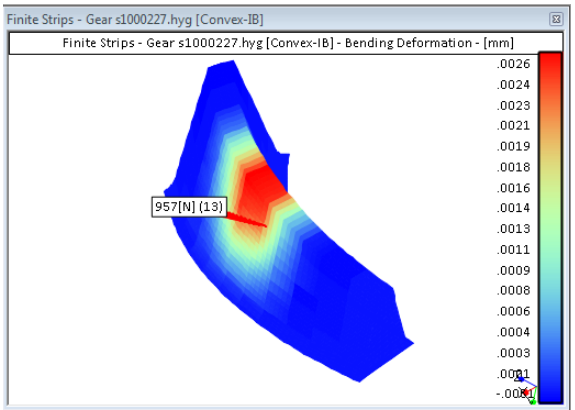
In HyGEARS, to simplify and speed load case definition, the tooth flank definition points can be numbered and loads applied at these points instead of the node numbers. A conversion is made from the Load Application Positions to the actual node numbers at the time the Finite Strips are solved.

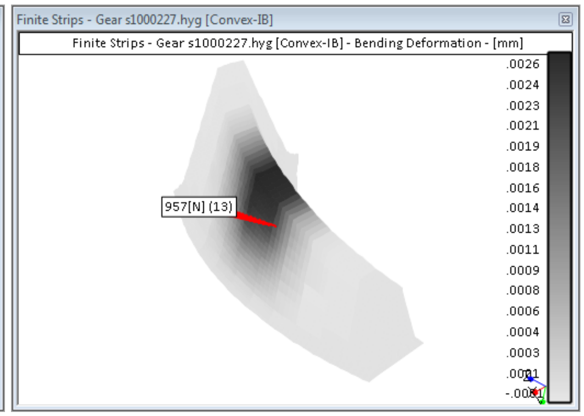
The tooth surface Load Application Positions are numbered automatically by HyGEARS, and the displayed numbers are used to identify where on the tooth flank loads are to be applied. The above figure illustrates a pinion tooth flank on which the surface Load Application Positions and the applied load are displayed in red.

Results

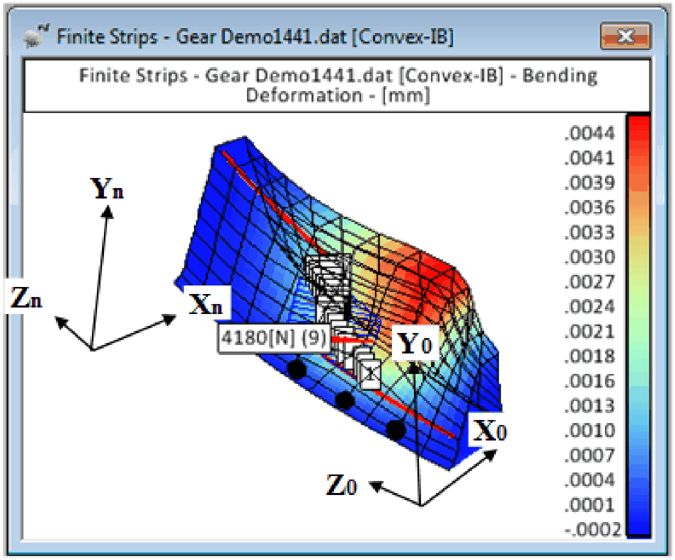
This option becomes available once Finite Strips results have been calculated using the Res-NoRs function buttons. HyGEARS offers the following options to display the results of the Finite Strips analysis:

Grey Scale	by default, results are displayed in 3D and 256 color scale, as in the left figure below, to assess deformations or stresses. For printing purposes, this can be toggled to 256 shades of grey using the Grey Scale option, as in the right figure below.





Line Deformations	this option, normally Off, is used to superimpose the line contours of the tooth deformation onto the color shaded result.
Deformations	default result type. All other results are stresses.
Sigma X	bending stress, in the X direction (see figure below).
Sigma Y	bending stress, in the Y direction (see figure below).
Tau XY	shear stress, in the XY plane (see figure below).
Tau XZ	shear stress, in the XZ plane (see figure below).
Tau YZ	shear stress, in the YZ plane (see figure below).
Von Mises	Von Mises stresses, calculated from above values



> **Note:**
>
> Strictly speaking, the X, Y and Z directions do not follow the tooth itself.
>
> Rather, they follow the Finite Strip, from position *0* to *n* in the above picture, which is "unwound" from the tooth at solution time. Thus, the X, Y and Z directions correspond to:
>
> X tooth local normal direction
> Y tooth local heightwise direction
> Z locally normal to X and Y

12.9.3 Load Editor

For Finite Strips, HyGEARS offers the same user friendly Load Editor window as for the FEA Mesh, to apply loads at selected tooth flank positions. Please refer to the FEA Load Editor section for details.

12.9.4 Mesh Editor

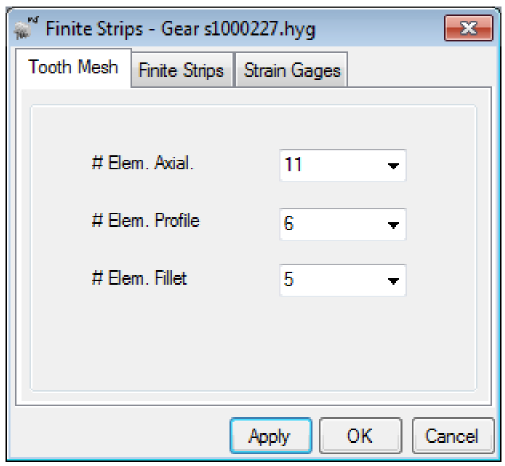
HyGEARS uses a Finite Strips Mesh Editor window to help in the definition and refinement of a Finite Strips model.

The Finite Strips Mesh Editor window shown below is called through the use of the Child Window function button "Mesh" described later in the Function Buttons section; it is divided in three Data Pages where specific data can be entered to control meshing behavior:

Mesh data page in which the tooth mesh is defined;

Finite Strips data page in which the Finite Strips mesh is defined, and Load Cases are selected;

Strain Gages data page in which the location of the tooth fillet strain gages are established.



Command Buttons

Apply tells HyGEARS to use the current set of values to recalculate and redisplay the mesh.

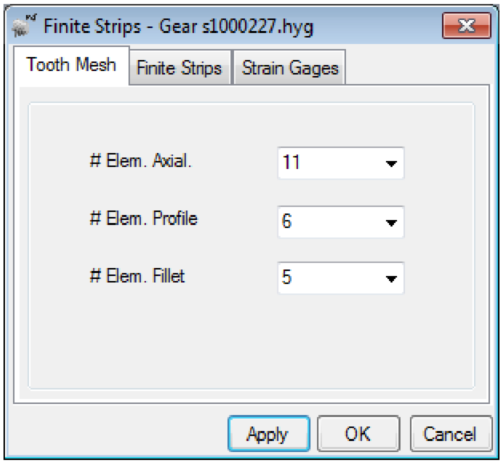
OK ends the Finite Strips Mesh Editor window and applies the modified data to the displayed mesh; if the tooth mesh definition has been changed, the tooth will be redigitized (see Editing Functions, Chapter 5, The Digitization Process) before the mesh is redisplayed.

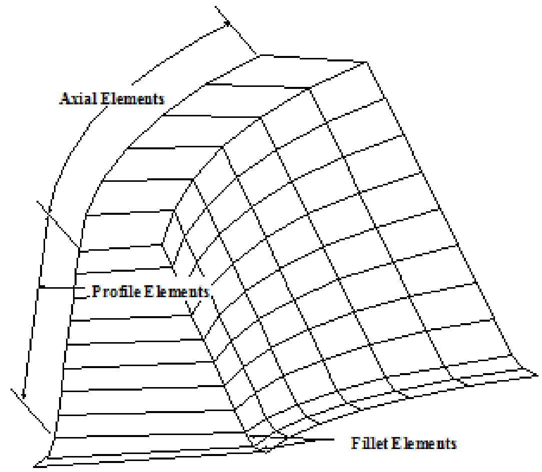
Cancel ends the Finite Strips Mesh Editor window, without modifying the displayed mesh.

12.9.4.1 Mesh Data Page

The Mesh data page is used to define how each tooth is to be meshed. Three input fields are used to define the tooth mesh, as described below.

Actually, the tooth mesh described here controls how the Finite Strips tooth will be digitized, how many load positions will be available on the tooth flank, and to what resolution the Finite Strips results can be extracted. It is thus different from the “virtual” strips and nodes model.





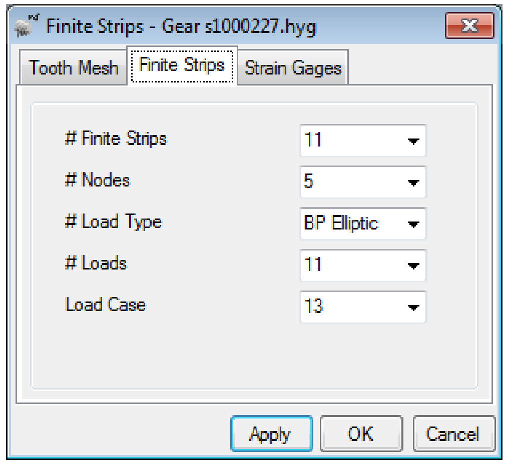
 # Elem. Axial defines the tooth lengthwise number of elements. Minimum and maximum values are respectively 3 and 16 elements. When changed, the # Finite Strips (Finite Strips data page) is changed accordingly in order to improve precision.

 # Elem. Profile defines the profilewise number of elements. Minimum and maximum values are respectively 3 and 11 elements.

 # Elem. Fillet defines the fillet number of elements. Minimum and maximum values are respectively 1 and 7 elements.

12.9.4.2 Definition Data Page

The *Finite Strips* Definition data page is used to define the Strips and loading. Five input fields are available:



 # Finite Strips defines the facewidth resolution of the numerical model. Since polynomial functions are used along the facewidth, increasing this value also increases the precision of the solution, at the expense of increased solution time. When changed, the # Axial Elements (Mesh data page) is changed accordingly in order to improve precision.

 # Nodes defines the tooth height resolution of the numerical model. Since smooth series are used along the tooth height, increasing this value beyond 5 is useless; however, using a value less than 5, which is possible, decreases model precision and computing time.

Load Type 4 loading possibilities are offered:

Point this tells HyGEARS that the user will input directly the loads to apply to the mesh; thus the Load Position option is desirable to apply loads at proper tooth flank positions;

BP Const HyGEARS will apply the torque in several identical loads, except for the first and last loads which will be halved, along the instant line of contact selected in the Load Case field;

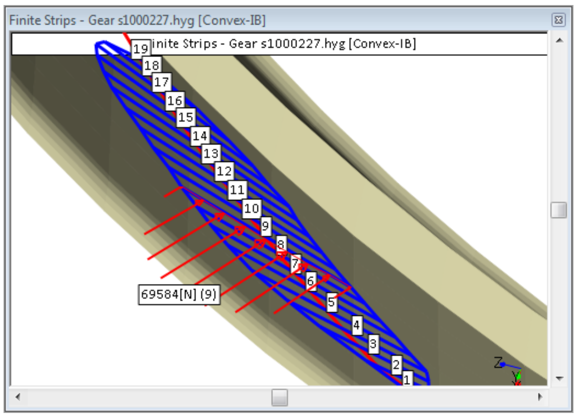
BP Elliptic HyGEARS will apply the torque in several elliptically distributed loads along the instant line of contact selected in the Load Case field.

Line Const HyGEARS will apply the torque in a constant series of loads along the selected tooth lengthwise line.

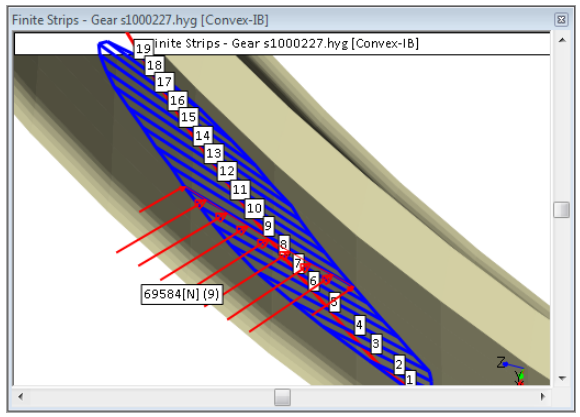
For example, the three following figures show a meshed gear tooth for which the “BP Elliptic” (left figure), “BP Const.” (right figure) and “Line Const.” (bottom figure) Load Types were selected.

Note 1 when HyGEARS applies loads automatically, as above, the Finite Strips Load matrix is erased and rebuilt. It is not editable by the user.

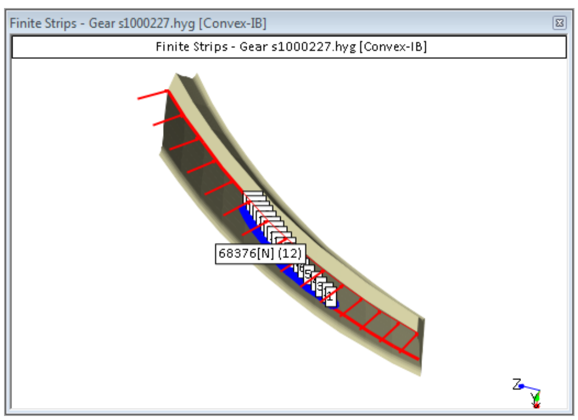
Note 2 Toggling the "Dims"/"NoDi" function button displays or hides the value of the applied loads, which can be helpful in evaluating their position and distribution.



"BP Elliptic"



"BP Const"

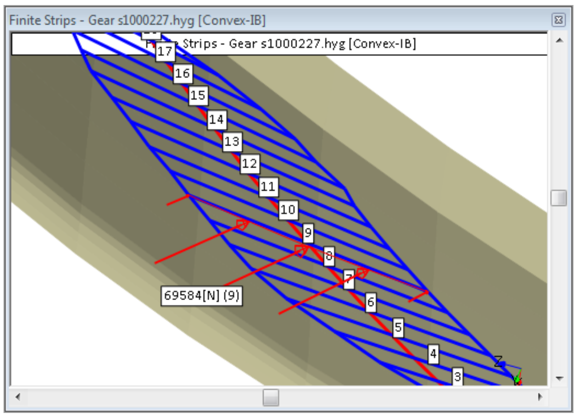


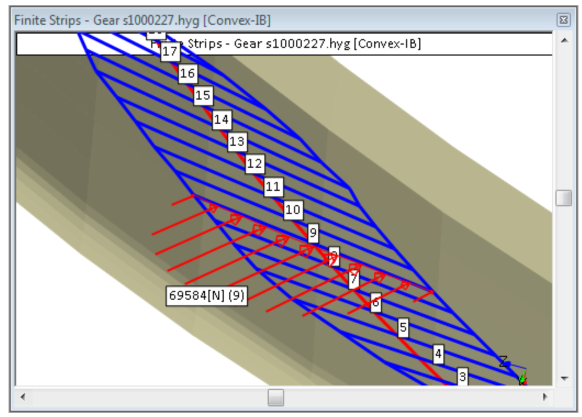
"Line Const."

 # Loads When the Load Type is either "BP. Const" or "BP Elliptic", this field is enabled and defines in how many individual values distributed loads will be segmented along the selected instant line of contact (in the Load Case field). Minimum is 3 and maximum is 11.

This value is of consequence as increasing the # Loads does not necessarily increase the precision of the solution. For the best solution, loads should fall exactly on nodes, which is impossible for loads distributed along an instant line of contact. Therefore, the # Loads should be selected such that the distributed values fall close to Strip boundary lines.

For example, the 5 loads in the left figure below, if they are close to nodes of the Finite Strips, may yield better results than the 11 loads in the right figure where half the values fall far from actual nodes.





Load Case the Load Case field is used to specify which load case is to be applied on the Finite Strips for analysis. The Load Case value depends on the Load Type field above:

Point tells HyGEARS to use a Load Case defined using the Load Editor;

BP Const tells HyGEARS to use the specified instant line of contact number in the Load Case field to distribute the load evenly;

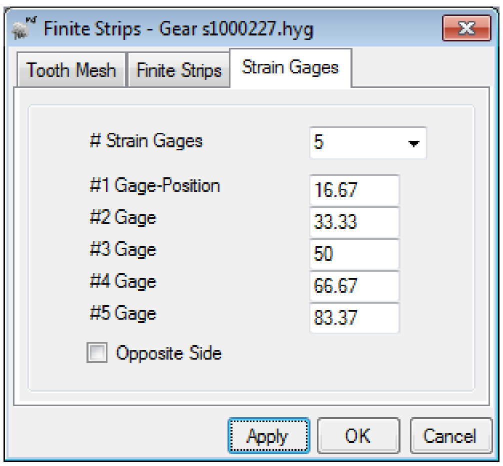
BP Elliptic tells HyGEARS to use the specified instant line of contact number in the Load Case field to distribute the load elliptically.

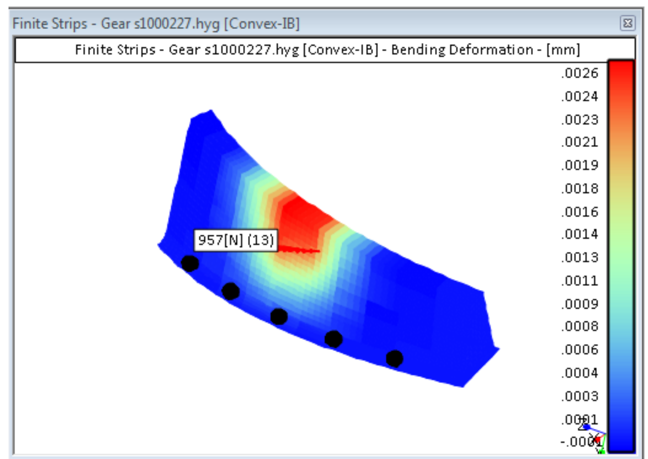
Line Const tells HyGEARS to use a lengthwise line along the tooth, and apply the loads along this line; line numbers from 1 at root to XX, depending on the number of profile and fillet elements.

12.9.4.3 Strain Gages Data Page

The Strain Gages data page is used to install “Strain Gages” at different places along the tooth fillet.

The user can then evaluate how one strain gage is responding relative to another strain gage, as explained in the 2D Graphs section of this documentation.





A Finite Strip mesh can have up to 5 strain gages, the position of which is given in % of tooth facewidth.

The above figure shows 5 “Strain Gages” installed in the fillet of the gear tooth, respectively at 16, 33, 50, 66 and 83% of tooth facewidth.

The “Opposite Side” check box allows to specify that strain gages are to be placed at the fillet of the opposite tooth flank.

12.9.5 Finite Strips Model Output

The Finite Strips Model output gives in tabular form, for each point of the Finite Strips mesh, the result displayed in the calling Child Window, plus the specifications of the current mesh.

The *1st table* is a header identifying the Load Case, the result type, the Geometry data file and the Pinion or Gear Member.

```
 Von Mises [Finite Strips] - Gear Demo1441.dat
                Load Case 1
```

```
Date / Time        : 12/31/2012 / 3:43:16 PM
General Units      : [mm] [dd.mm.ss]
Cutter  Units      : [in]
Prepared by        : John Who
Version            : 4.0.401.70
```

The *next 2 tables* give the specifications of the Tooth Mesh and Strip Mesh. The solution Order is always 3 (meaning cubic splines as the interpolation scheme).

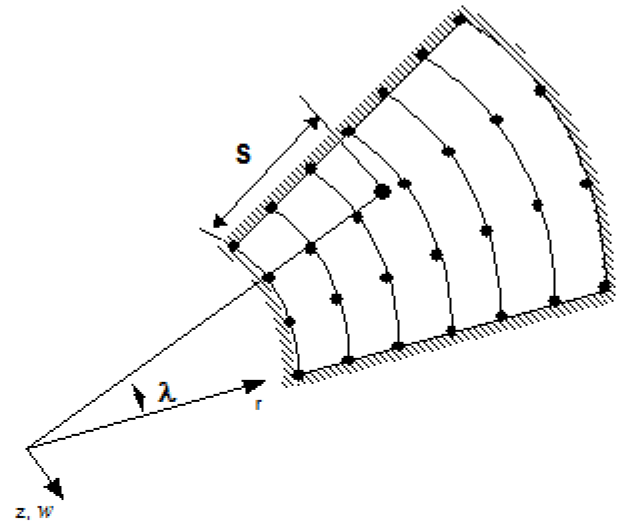
```
Finite Strips:
--------------
# Finite Strips     :   11
# Nodes             :    5
Order               :    3

Tooth Mesh:
-----------
# Elem. Axial.      :    6
# Elem. Profile     :    5
# Elem. Fillet      :    3
```

The *next table* describes the Load Case, e.g. how many individual loads and, for each load:

Lamda: where heightwise on the Finite Strips; if the tooth is of constant height, the Lamda value is in linear units and corresponds to the height of the load; otherwise, Lamda is in degree, and corresponds to the angle at which the load is applied;
S: where lengthwise on the Finite Strips;
FHoriz: the load actually applied on the tooth;
FVert : the vertical load;
Moment: the moment produced by the product of the tooth half thickness times the vertical load.

```
Load Case:
----------
    Lambda          S     FHoriz      FVert     Moment
 [Deg.Dec]       [mm]        [N]        [N]      [N-m]
------------------------------------------------------
     4.398     11.144     292.92      36.95      -0.20
     4.104     12.422    1459.28     184.07      -1.00
     3.817     13.698    1405.12     177.24      -0.96
     3.540     14.986    1119.87     141.26      -0.77
```

```
3.269    16.271    292.92     36.95     -0.20
```



The *next table* gives the normal tooth thicknesses, at each point of the tooth mesh. This information is used by the Finite Strips algorithm.

```
Normal Thick.
-------------
 [Tooth Root - Convex-IB]
     7.01958     7.52338     7.97285     8.36798     8.70878     8.99523
     6.63007     7.02476     7.38726     7.71758     8.01572     8.28167
     6.03512     6.43259     6.80120     7.14093     7.45179     7.73379
     5.69478     6.02232     6.34694     6.66866     6.98748     7.30339
     5.03128     5.30669     5.57777     5.84453     6.10696     6.36508
     4.36725     4.58969     4.80667     5.01819     5.22425     5.42486
     3.70326     3.87177     4.03398     4.18986     4.33944     4.48269
     3.03937     3.15288     3.25953     3.35933     3.45226     3.53834
     2.41134     2.44430     2.48001     2.51846     2.55966     2.60360
 [Tooth Tip]
```

The *next table* gives the Lamda value of each point of the tooth mesh. This information is used by the Finite Strips algorithm to locate the loads. The values along the tip and root should be constant.

```
Lamda
-----
 [Tooth Root - Convex-IB]
     0.00000     0.00000     0.00000     0.00000     0.00000     0.00000
     0.12612     0.11675     0.10902     0.10267     0.09748     0.09331
     0.33690     0.31143     0.29037     0.27296     0.25862     0.24695
     0.61194     0.56546     0.52696     0.49505     0.46869     0.44716
     1.53909     1.50198     1.47130     1.44584     1.42501     1.40782
     2.47769     2.44980     2.42698     2.40830     2.39287     2.38023
     3.41928     3.40071     3.38562     3.37334     3.36325     3.35499
     4.36284     4.35372     4.34622     4.34004     4.33520     4.33116
```

```
    5.30854     5.30854     5.30854     5.30854     5.30854     5.30854
[Tooth Tip]
```

The *next table* gives the S value of each point of the tooth mesh. This information is used by the Finite Strips algorithm to locate the loads. The maximum S value corresponds to the actual length of the tooth.

```
S
-
 [Tooth Root - Convex-IB]
     0.00000     4.75043     9.52304    14.29272    19.05897    23.82106
     0.00000     4.73705     9.50929    14.27857    19.04439    23.80599
     0.00000     4.71069     9.48259    14.25163    19.01711    23.77837
     0.00000     4.67574     9.44751    14.21635    18.98175    23.74287
     0.00000     4.57263     9.33680    14.09867    18.85696    23.61227
     0.00000     4.46967     9.22607    13.98007    18.73216    23.48174
     0.00000     4.36675     9.11524    13.86191    18.60736    23.35114
     0.00000     4.26393     9.00436    13.74417    18.48260    23.22060
     0.00000     4.16115     8.89336    13.62545    18.35778    23.08999
 [Tooth Tip]
```

The *next table* gives the Spiral Angle value of each strip along the tooth. This information is used by the algorithm to identify the shape of the Finite Strip unwound from the pitch cone.

```
Spiral Angle
------------
 [Tooth Root - Convex-IB]
    22.29006    24.16964    26.03772    27.90297    29.77439    31.65697
```

The *next table* gives the Stress Concentration factor Kt along the tooth fillet. The Finite Strips model calculates “nominal” bending stresses. To account for the increase in stresses in the fillet area, the Kt value is calculated from Dolan and Brogahmer’s well known formula and is applied to the stresse values in the fillet area of the tooth.

```
Kt
--
 [Tooth Root - Convex-IB]
     2.07933     2.07933     2.07933     2.07933     2.07933     2.16316
 [Tooth Root - Concave-OB]
     1.58417     1.58417     1.58417     1.58417     1.58417     1.72547
```

The *next table* gives the requested Finite Strip result value at each point of the tooth mesh. Negative stress values indicate compression.

```
Von Mises - [Mpa]
-----------------
 [Tooth Root - Concave-OB]
```

```
 -21.5699600 -53.5887900-150.2850000-193.1144000-108.9615000 -36.9253600
 -23.5238800 -56.9148800-159.6464000-199.4019000-111.6848000 -36.8827100
 -27.4564500 -73.0864800-224.1239000-321.8183000-181.8172000 -49.5282400
 -28.8188500 -65.2255400-183.9796000-268.8812000-154.2490000 -45.1054000
 -25.6846400 -56.7307600-163.9661000-245.5101000-113.9837000 -36.2652700
 -21.3024200 -50.6842200-147.3936000-237.5200000-100.9646000 -32.0121300
   . . .
[Tooth Tip]
   . . .
  21.0278500  50.6770200 139.4781000 225.2016000  97.1214100  32.0551900
  25.6317300  56.0918700 154.9083000 228.8500000 108.3937000  35.8706500
  29.9037600  69.7504200 199.1477000 259.8773000 140.2018000  42.3280600
  32.8741400  97.5900700 317.9332000 425.0534000 234.5337000  62.1702700
  26.8460900  71.1478300 216.7872000 299.4151000 168.4328000  49.7544000
  21.8592500  52.9928400 143.6976000 180.6252000 102.5593000  36.1929700
 [Tooth Root - Convex-IB]
```

The *last table* gives the requested Finite Strip result value at each Strain Gage of the tooth fillet. Negative stress values indicate compression.

```
Fillet Strain Gage Stresses [Mpa]
---------------------------------
 [Tooth Root - Convex-IB]
      #-1       #-2       #-3       #-4       #-5
    53.37    143.81    180.38    102.30     36.09
    72.16    217.27    298.62    167.60     49.54
   100.34    319.16    422.82    232.34     61.69
    72.31    200.29    257.59    138.23     41.87
```

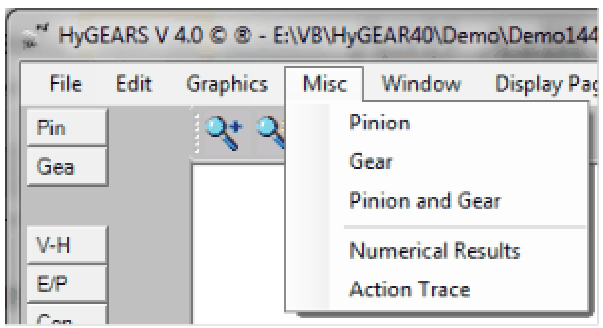
13 Numerical Output

This section covers the HyGEARS numerical output which numerically describes all the Graphic Display Functions.

The Main Menu Misc. pull down menu is inactive until either a Geometry data file has been opened, or a new Geometry has been created.

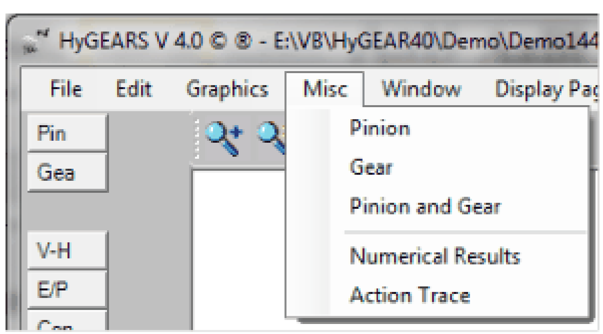
Once the Parent Window Misc. function is active, clicking on the Parent Window Misc. function opens the Misc. pull down menu. This section is divided in 3 parts, each corresponding to a specific Misc. menu function subtype, as shown below:

The Output Geometry
Numerical Results
Action Trace



13.1 Output Geometry

Depending on the requested Numerical Result, the HyGEARS Text Results windows will output results for:



pinion, or
gear, or

pinion and the gear at the same time.

A mouse click on any of the offered choices results in two actions:

- the selected Geometry type is identified in the *Misc. menu* by a check mark;
- the *Misc. menu* is redisplayed to the right of where the cursor lies.

Once an *Output Geometry* selection has been made, the selected entry shows a check mark, which identifies the active Geometry type. Any Numerical Results window created afterward will include the active selection.

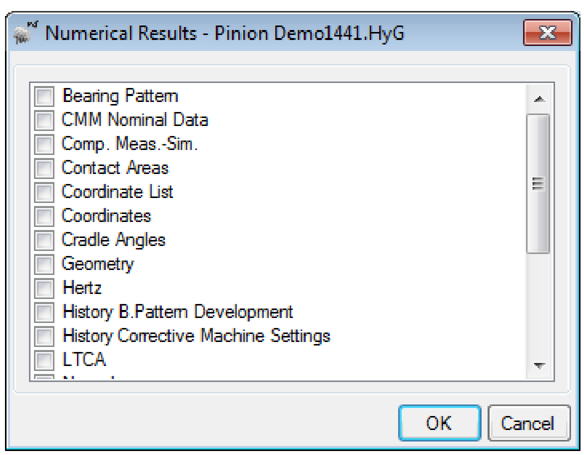
13.2 Numerical Results

HyGEARS offers different numerical output choices from a multiple-choice list. The following figure illustrates the **Numerical Results Selection window**.

The Numerical Results Selection window offers a selection list containing the possible Numerical Results choices, which depend on the selected Output Geometry.

To select an entry, simply click on the desired choice and a check mark will indicate that it is selected. To remove an entry, click on the choice to remove the check mark.

All selected entries are printed to different Text Results windows, which will be tiled across the screen from top to bottom and from left to right for easy access.



The following choices are offered from the Available list-box:

Contact Pattern: outputs the Contact Pattern coordinates for both the pinion convex and concave tooth flanks; the result is the same, whether the pinion or the gear was selected as the Output Geometry.

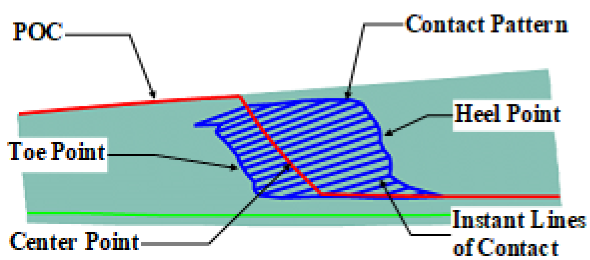
CMM Nominal Data:	outputs the CMM Nominal data; the result applies to the selected Output Geometry.
Comp. Meas-Sim.:	outputs the comparison between measured and simulated surfaces, either for Measurement Data or Stock Distribution; the result applies to the selected Output Geometry.
Coordinate List:	outputs the tooth flank coordinates in a list format; the result applies to the selected Output Geometry.
Coordinates:	outputs the tooth flank coordinates; the result applies to the selected Output Geometry.
Cutting Cycle:	outputs the cutting cycle cradle angles; the result applies to the selected Output Geometry.
Finite Strips:	outputs the Finite Strips model results; the result applies to the selected Output Geometry.
Geometry:	outputs the Geometry Summary; the result applies to the selected Output Geometry. If Corrective Machine Settings (Closed Loop) History is available, all Summary versions are listed with their respective version numbers.
Hertz:	outputs the calculated radii of curvature and Hertz contact ellipse dimensions for the current tooth flank (Pinion Convex/Gear Concave or Pinion Concave/Gear Convex).
History B.Pattern ...:	outputs the Contact Pattern Development History; the result applies only to the pinion member.
History Corrective ...:	outputs the Corrective Machine Settings History; the result applies to the selected Output Geometry.
LTCA:	outputs the Loaded Tooth Contact Analysis results for both the pinion convex and concave tooth flanks; the result is the same, whether the pinion or the gear was selected as the Output Geometry.
Roll Angles:	outputs the tooth flank generation roll angles and cutter angular positions; the result applies to the selected Output Geometry.
Sliding Speeds:	outputs the Contact Pattern Sliding Speed vectors for both the pinion convex and concave tooth flanks; the result is the same,

	whether the pinion or the gear was selected as the Output Geometry.
TCA:	outputs the Tooth Contact Analysis (Transmission Error) results bearing for both the pinion convex and concave tooth flanks; the result is the same, whether the pinion or the gear was selected as the Output Geometry.
Theo. Surface:	outputs the simulated tooth flank coordinates in a HyGEARS measurement data file format; the result applies to the selected Output Geometry.
Tooth Separation:	outputs the tooth separation along the PoC for both the pinion convex and concave tooth flanks; the result is the same, whether the pinion or the gear was selected as the Output Geometry.

13.2.1 Contact Pattern

The Contact Pattern is made of a series of instant lines of contact defined by three points each: one at the toe, one at the center and one at the heel end on each instant line of contact, as shown below.

The Contact Pattern output provides the coordinates of each instant line of contact on both the pinion and gear tooth flanks.



The Contact Pattern coordinates data is printed in one header and three tables:

The header identifies the pinion and gear cutting status, e.g. roughing or finishing, the pinion driving tooth flank (convex or concave), and the contact separation which is equivalent to the marking compound thickness:

HyGEARS V 4.0 © ®

Contact Pattern - Demo1441.dat

Pinion [Finishing] + Gear [Finishing]
Pinion Concave-OB [NoEr]

Date / Time	**: 12/31/2012 / 2:48:50 PM**
General Units	**: [in] [dd.mm.ss]**
Cutter Units	**: [in]**
Prepared by	**: John Who**
Version	**: 4.0.401.70**

Contact separation : 0.00025 [in]

Tables 1 and 2 give, for each PoC contact position identified by the Posn entry, the coordinates of the contact points at the toe, center and heel of an instant line of contact, respectively for the Pinion and the Gear members. An empty line indicates that no instant line of contact was found at the considered point (positions 1, 2, 8 and 9 below).

Pinion [in]

	Toe			Center			Heel		
Posn	X1	X2	X3	X1	X2	X3	X1	X2	X3
[Pinion Tooth Root]									
1									
2									
3	1.1669	0.5855	0.2946	1.2516	0.3716	0.5782	1.2537	0.3643	0.5872
4	1.3316	0.3611	0.4971	1.3500	0.2806	0.6011	1.3624	0.2043	0.6967
5	1.4415	0.2305	0.5306	1.4511	0.1469	0.6393	1.4553	0.0307	0.7862
6	1.5438	0.0739	0.5544	1.5439	-0.0283	0.6896	1.5369	-0.1199	0.8078
7	1.6231	-0.2019	0.6943	1.6231	-0.2019	0.6943	1.6138	-0.2594	0.7713
8									
9									

Gear [in]

	Toe			Center			Heel		
Posn	Y1	Y2	Y3	Y1	Y2	Y3	Y1	Y2	Y3
[Gear Tooth Tip]									

1									
2									
3	-2.4280	0.0273	-0.0550	-2.7794	-0.0651	-0.0151	-2.7906	-0.0682	-0.0145
4	-2.6257	-0.0655	0.0289	-2.7518	-0.1050	0.0441	-2.8683	-0.1426	0.0534
5	-2.6200	-0.1076	0.0860	-2.7485	-0.1531	0.1060	-2.9231	-0.2179	0.1243
6	-2.6078	-0.1490	0.1435	-2.7631	-0.2110	0.1727	-2.8998	-0.2683	0.1919
7	-2.7294	-0.2509	0.2329	-2.7294	-0.2509	0.2329	-2.8157	-0.2907	0.2496
8									
9									

Table 3 gives, for each pinion PoC contact position identified by the Posn entry, the separation between the pinion and gear tooth surfaces as calculated by the Contact Pattern algorithm. The Center separation is normally zero, since it corresponds to the PoC contact point. An empty line indicates that the toe and heel values are zero, such that no instant line of contact was found, while any value above zero indicates the calculated separation value.

Instant Contact Line Separation

Position	Toe	Center	Heel
[Pinion Tooth Root]			
1			
2			
3	0.00021	0.00000	0.00011
4	0.00024	0.00000	0.00025
5	0.00026	0.00000	0.00026
6	0.00025	0.00000	0.00025
7	0.00000	0.00000	0.00006
8			
9			

13.2.2 CMM Nominal Data

The CMM Nominal Data output is used to produce a CMM readable ASCII file describing the target measurement points on a pinion or gear tooth flank.

RAM

To be useable by a Zeiss CMM, the contents of the Text Results window to which the Ram data is sent must be saved to a disk file and must then be transferred to the Zeiss CMM using the DCom software provided by Zeiss Japan.

The following data is a typical Ram 300 measurement grid data file, where only part of the data is shown to conserve space. Note the %RAM% header at the beginning of the data file.

```
%RAM%
41 5 9
   0.0000
1
 3 5
  -4.4095
   58.8128    4.8261  -32.6833
    0.3278    0.9445   -0.0196
   59.1922    4.7098  -31.8992
    0.3284    0.9443   -0.0199
   59.5714    4.5936  -31.1149
.
.
.
   -0.6859    0.6713
   78.9693   -5.5813  -39.6357
   -0.2766   -0.6895    0.6693
   79.6624   -4.5992  -38.3047
   -0.2724   -0.6931    0.6674
%END%
```

Gear-Bevel Unix

Alternately, the measurement grid can be outputted in the newer Gear-Bevel format for Unix workstations, as shown below. The output format is determined in the CMM Nominal Data Editor window. The grid specification is unaffected by this choice.

```
*****************************************************************
                    SOLL - KOORDINATEN - LISTE                  *
                      *** RITZEL  KONKAV ***                    *
----------------------------------------------------------------*
ZEICHNUNGS-NR         ZAEHNEZAHL % Z! 9                         *
Pinion [Finishing] 11x45g.dat                                   *
ZAHNDICKENWINKEL % DEDI: -14.4042  [GRD] % (J,I) : (5,3)        *
----------------------------------------------------------------*
SPALTENZAHL % NSPG : 9  ;   ZEILENZAHL % NZLG : 5               *
----------------------------------------------------------------*
*****************************************************************
J I    X         Y        Z           Nx        Ny        Nz    *
================================================================*
1 1    21.4144  -19.4967  -88.0051    0.5188    0.4703    0.7139
1 2    22.3053  -20.5118  -88.0052    0.5395    0.4121    0.7342
1 3    23.0981  -21.6312  -88.0052    0.5516    0.3631    0.7509
1 4    23.8258  -22.8153  -88.0052    0.5582    0.3206    0.7653
…
```

Hoeffler

Yet another choice is the Hoeffler format, for PC driven CMMs, as shown below. The output format is determined in the CMM Nominal Data Editor window. The grid specification is unaffected by this choice.

```
*******************************************************************
*                      NOMINAL - COORDINATE - LIST   FILE:        *
*                      *** PINION CONCAVE ***                     *
*-----------------------------------------------------------------*
* PART # :                         NUMBER OF TEETH % Z ! 14       *
* Demo1441.dat                     PINION  THEORETICAL            *
* DIFF. ANG: % DEDI ! -13.3462     REF. PT.: ! (5, 3)             *
*-----------------------------------------------------------------*
* NUMBER COLUMNS: ! 9              NUMBER LINES: ! 5              *
*-----------------------------------------------------------------*
* DATE: 12/31/2012           TIME:2:54:14 PM          UNITS: mm
*
*******************************************************************
* C  L     XP        YP        ZP        NX         NY        NZ  *
*=================================================================*
  1  1   15.1202   24.1710   20.0451   -0.6358    0.1680    0.7534
  1  2   15.3682   25.1464   20.0451   -0.6031    0.1883    0.7751
  1  3   15.6779   26.0813   20.0452   -0.5762    0.2010    0.7922
  1  4   16.0120   26.9999   20.0451   -0.5532    0.2091    0.8063
  1  5   16.3656   27.9059   20.0452   -0.5331    0.2141    0.8185
  2  1   12.0821   27.1994   16.9488   -0.6535    0.0739    0.7534
  2  2   12.1993   28.2952   16.9488   -0.6225    0.0989    0.7764
  2  3   12.3868   29.3578   16.9488   -0.5967    0.1149    0.7942
…
```

MdM

The MdM format is also supported, as shown below. The output format is determined in the CMM Nominal Data Editor window. The grid specification is unaffected by this choice.

```
*******************************************************************
*         MDM MECATRONICS  - NOMINAL COORDINATES LIST FILE        *
*                      *** PINION CONCAVE ***                     *
*-----------------------------------------------------------------*
* PART # :                         NUMBER OF TEETH :   14         *
* Demo1441.dat                     PINION  THEORETICAL            *
* DIFF. ANG : -13.3462             REF. PT.: (5, 3)               *
*-----------------------------------------------------------------*
* NUMBER COLUMNS:   9              NUMBER LINES:   5              *
*-----------------------------------------------------------------*
* DATE: 12/31/2012           TIME:2:55:30 PM          UNITS: mm
*
*******************************************************************
* C  L     XP        YP        ZP        NX         NY        NZ  *
```

```
*=================================================================*
  1  1   19.1410   21.1301  -51.3249   -0.5963    0.2774    0.7534
  1  2   19.5570   22.0465  -51.3249   -0.5605    0.2915    0.7751
  1  3   20.0265   22.9123  -51.3249   -0.5318    0.2994    0.7922
  1  4   20.5172   23.7576  -51.3249   -0.5078    0.3033    0.8063
  1  5   21.0249   24.5871  -51.3248   -0.4870    0.3046    0.8185
  2  1   16.6838   24.6462  -54.4212   -0.6302    0.1878    0.7534
…
```

Kingelnberg – P

The P Machine format is also supported, as shown below. The output format is determined in the CMM Nominal Data Editor window. The grid specification is unaffected by this choice.

Output is in 2 files displayed on screen:

- For the Pinion: Sollmes1.dat and Sollmes2.dat
- For the Gear: Sollmes3.dat and Sollmes4.dat

```
RECHTE FLANKE RITZEL
DATUM / ZEIT         : 27/09/2012  /  07:42


---------------------------------------------------------------
  J  I       XP         YP         ZP       XN      YN      ZN
---------------------------------------------------------------
  IN SPALTE  5 / ZEILE  3 :  ZAHNDICKENWINKEL =  0.240995 rad
  1  1    15.9430    34.5720    76.3359  -.1807  .8658  .4666
  1  2    17.9609    35.2578    75.6960  -.1082  .8903  .4422
  1  3    20.2246    35.7415    75.0560  -.0340  .9079  .4177
  1  4    22.6868    36.0149    74.4160   .0411  .9186  .3931
  1  5    25.3340    36.0515    73.7762   .1168  .9223  .3684
  2  1    11.2411    35.0424    73.0578  -.2962  .8350  .4638
  2  2    13.0062    35.9275    72.4562  -.2284  .8694  .4382
…
```

CDS

The CDS format is also supported, as shown below. The output format is determined in the CMM Nominal Data Editor window. The grid specification is unaffected by this choice.

```
*****************************************************************
*                      NOMINAL - COORDINATE - LIST   FILE:      *
*                      *** PINION CONVEX  ***                   *
*---------------------------------------------------------------*
* PART # :                         NUMBER OF TEETH % Z ! 14     *
* Demo1441.dat                     PINION  THEORETICAL          *
* DIFF. ANG: % DEDI ! 13.5657      REF. PT.: ! (5, 3)           *
```

```
*-----------------------------------------------------------------*
* NUMBER COLUMNS: ! 9            NUMBER LINES: ! 5                *
*-----------------------------------------------------------------*
* DATE: 03/01/2011            TIME:5:21:54            UNITS: mm    *
*******************************************************************
* J  I     X         Y         Z         XN         YN         ZN  *
*=================================================================*
  1  1   35.5791   13.4471  -89.7257    0.8516   -0.2411   -0.4655
  1  2   36.2749   16.4848  -89.7258    0.8857   -0.1442   -0.4414
  1  3   36.6271   19.8377  -89.7259    0.9073   -0.0452   -0.4181
  1  4   36.6076   23.4303  -89.7256    0.9167    0.0543   -0.3958
  1  5   36.1763   27.2198  -89.7258    0.9145    0.1534   -0.3743
  2  1   35.7230    8.9851  -86.6294    0.8153   -0.3480   -0.4628
  2  2   36.7249   11.6923  -86.6293    0.8615   -0.2583   -0.4372
  2  3   37.4550   14.7285  -86.6292    0.8958   -0.1653   -0.4127
```

GAGE

The GAGE format is also supported, as shown below. The output format is determined in the CMM Nominal Data Editor window. The grid specification is unaffected by this choice.

```
*******************************************************************
*                     NOMINAL - COORDINATE - LIST   FILE:         *
*                     *** PINION CONCAVE ***                      *
*-----------------------------------------------------------------*
* PART # :                       NUMBER OF TEETH % Z ! 19         *
* Test-1-Ext.hyg/P               PINION  THEORETICAL              *
* DIFF. ANG: % DEDI ! 0.0000     REF. PT.: ! (5, 3)               *
*-----------------------------------------------------------------*
* NUMBER COLUMNS: ! 9            NUMBER LINES: ! 5                *
*-----------------------------------------------------------------*
* DATE: 08/06/2013            TIME:10:24:22           UNITS: mm    *
*******************************************************************
* J  I     X         Y         Z         XN         YN         ZN  *
*=================================================================*
  1  1   52.2059    5.5495  -10.0350    0.4383    0.8988   -0.0047
  1  2   50.1277    6.4575  -10.0350    0.3581    0.9337   -0.0047
  1  3   48.0579    7.1237  -10.0350    0.2559    0.9667   -0.0047
  1  4   46.0116    7.5354  -10.0350    0.1305    0.9914   -0.0047
  1  5   44.0144    7.6012  -10.0350   -0.1336    0.9910   -0.0047
  2  1   52.2048    5.5598   -7.5263    0.4381    0.8989   -0.0023
  2  2   50.1265    6.4674   -7.5263    0.3579    0.9338   -0.0023
  2  3   48.0565    7.1332   -7.5263    0.2557    0.9668   -0.0023
  2  4   46.0102    7.5444   -7.5263    0.1303    0.9915   -0.0023
```

LEITZ

The LEITZ format is also supported, as shown below. The output format is determined in the CMM Nominal Data Editor window. The grid specification is unaffected by this choice.

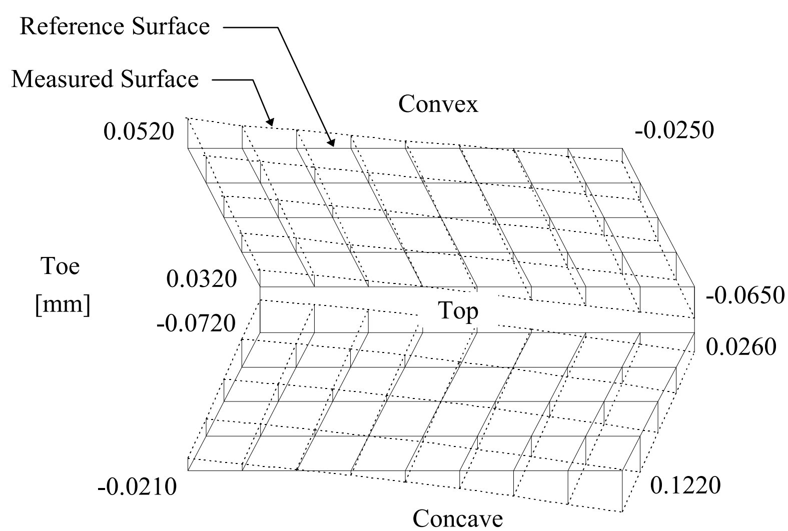
```
$ELE (NAM=ELE:GearM_KAV, TYP=ACT, FLD=(X,Y,A,B,D,E))

9,9,5,5,5,5
$END

$ELE (NAM=M_KAV,TYP=NPT,FLD=(X,Y,Z,U,V,W))
70.8620559  8.4596524   13.9521446  -0.5878677  0.6815866   -
0.4357193
71.0315304  8.0836108   13.1341016  -0.5854469  0.6840483   -
0.4351204
71.1989726  7.7069893   12.3155683  -0.5830189  0.6864991   -
0.4345203
71.3643860  7.3298035   11.4965437  -0.5805838  0.6889388   -
0.4339190
71.5277753  6.9520694   10.6770273  -0.5781416  0.6913675   -
0.4333166
69.1293378  6.7470975   13.5251039  -0.5666676  0.7025399   -
0.4304944
69.2817455  6.3948964   12.7487081  -0.5643489  0.7047512   -
0.4299256
69.4323423  6.0422139   11.9718810  -0.5620240  0.7069530   -
0.4293559
69.5811318  5.6890629   11.1946222  -0.5596931  0.7091452   -
0.4287851
69.7281181  5.3354570   10.4169310  -0.5573562  0.7113279   -
0.4282134
67.3580798  5.1055584   13.0922150  -0.5449961  0.7226244   -
0.4251979
67.4944306  4.7774369   12.3589335  -0.5427915  0.7245965   -
0.4246615
67.6289043  4.4487129   11.6252766  -0.5405786  0.7265631   -
0.4241235
67.7620675  4.1198176   10.8912438  -0.5383638  0.7285189   -
0.4235855
67.8933475  3.7903348   10.1568347  -0.5361407  0.7304693   -
0.4230458
65.5503789  3.5344910   12.6539072  -0.5228786  0.7418466   -
0.4198352
65.6713706  3.2303743   11.9651003  -0.5207955  0.7435943   -
0.4193322
65.7909035  2.9258966   11.2759701  -0.5187075  0.7453357   -
0.4188284
65.9089754  2.6210639   10.5865162  -0.5166144  0.7470709   -
0.4183237
66.0255840  2.3158821   9.8967384   -0.5145162  0.7487997   -
0.4178181
63.7083304  2.0334598   12.2106129  -0.5003409  0.7602119   -
0.4144114
63.8148260  1.7533362   11.5675331  -0.4983874  0.7617487   -
0.4139432
63.9200757  1.4729361   10.9241782  -0.4964299  0.7632800   -
0.4134742
```

```
64.0240777  1.1922643   10.2805479  -0.4944684  0.7648060   -
0.4130046
```

13.2.3 Comp.Meas-Sim (Measured Surface Errors)

The measured surface errors give in tabular form, data point by data point, the displayed surface errors used in the Comp Meas-Sim Surfaces or Stock Distribution Child Windows, as follows:

- The **first two tables list the measured surface errors** data point by data point, respectively for the pinion convex/gear concave, and the pinion concave/gear convex tooth flanks. If more than one data-set was selected for display from the Measurement Data Selection window, the table data below will be the averaged data for the number of datasets used. Each row and column respectively correspond to a row or a column of the measurement grid. The pinion or gear cutting state (Finishing or Roughing), Geometry data file name, tooth flank, data units and selected datasets are indicated in the table headers.




```
HyGEARS V 4.0 ©

Comp. Meas.-Sim. Pinion [Finishing] [mm] - Demo1441.dat

Date / Time    :  02-23-1999 / 20:55:54
General Units  :  [mm] [deg.min.sec]
Cutter  Units  :  [in]
```

Prepared by : John Doe
Version : 4.0.401.70

Measured data file : e:\vb\Demo\Demop12.mes

Difference - Side Concave-OB [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	-.00375	-.00327	-.00220	-.00052	.00146	.00197	.00324	.00543	.00516
2	-.00408	-.00283	-.00232	-.00066	.00095	.00239	.00311	.00489	.00558
3	-.00608	-.00425	-.00334	-.00221	.00000	.00102	.00329	.00381	.00579
4	-.00639	-.00322	-.00362	-.00188	-.00032	.00068	.00290	.00434	.00640
5	-.00682	-.00445	-.00349	-.00133	-.00072	.00075	.00289	.00462	.00571

Difference - Side Convex [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	-.00137	.00202	.00087	.00259	.00340	.00358	.00507	.00578	.00667
2	-.00145	.00076	.00052	.00063	.00143	.00198	.00365	.00284	.00601
3	-.00176	-.00032	-.00004	-.00057	.00000	.00109	.00168	.00340	.00437
4	-.00259	-.00104	-.00079	-.00075	-.00001	.00086	.00122	.00251	.00209
5	-.00294	-.00214	-.00073	-.00065	.00004	.00149	.00287	.00313	.00325

- The **next two tables list the difference between the radial position** of the measured and simulated surfaces comparison points, data point by data point, respectively for the pinion convex/gear concave, and the pinion concave/gear convex tooth flank: these values should normally be below 0,0002 [mm], which is the precision limit of the surface comparison algorithm. Any value larger than 0,0002 [mm] indicates a potential error and the comparison results should be treated with care. However, when measurement compensation is performed within HyGEARS and the tooth number is smaller than 7, differences up to 0,0010 [mm] may appear, which are not to be considered significant.

  If more than one data-set was selected for display from the Measurement Data Selection window, the table data below will be the averaged data for the number of datasets used.

Difference Radius - Side Concave [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
3	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
4	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
5	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

Difference Radius - Side Convex [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
3	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
4	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
5	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

- The **next two tables list the radial position** of the calculated point on the tooth flank, data point by data point, respectively for the pinion convex/gear concave, and the pinion concave/gear convex tooth flank

  If more than one data-set was selected for display from the Measurement Data Selection window, the data tables below are not printed.

Radius - Side Concave-OB [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
[Tooth Root]									
1	58.8771	61.1616	63.4496	65.7424	68.0403	70.3445	72.6554	74.9737	77.3012
2	59.2767	61.5927	63.9119	66.2343	68.5607	70.8917	73.2281	75.5698	77.9183
3	59.6784	62.0267	64.3770	66.7295	69.0846	71.4429	73.8043	76.1700	78.5396
4	60.0821	62.4626	64.8444	67.2271	69.6114	71.9970	74.3842	76.7734	79.1646
5	60.4877	62.9010	65.3144	67.7273	70.1411	72.5542	74.9672	77.3803	79.7935

Radius - Side Convex-IB [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9

[Tooth Root]

1	59.0101	61.3054	63.6026	65.9065	68.2152	70.5306	72.8535	75.1849	77.5250
2	59.3789	61.7036	64.0303	66.3612	68.6962	71.0365	73.3824	75.7338	78.0938
3	59.7478	62.1022	64.4579	66.8162	69.1774	71.5424	73.9107	76.2840	78.6615
4	60.1167	62.5008	64.8855	67.2716	69.6592	72.0487	74.4395	76.8332	79.2284
5	60.4858	62.8996	65.3136	67.7271	70.1409	72.5550	74.9690	77.3827	79.7965

- If measurement compensation is performed within HyGEARS, two other tables will be printed which respectively list the tooth transverse thickness, IB measurement point to OB measurement point, and the calculated tooth thickness error between the simulated model and the actual measurement for each measurement data grid point.

Tooth Trans. Thick. - [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
[Tooth Root]									
1	6.4972	7.0350	7.5498	8.0768	8.5838	9.1064	9.6383	10.1723	10.6818
2	6.0436	6.5085	6.9502	7.3852	7.8219	8.2602	8.6971	9.1113	9.5285
3	5.4719	5.8557	6.1935	6.5576	6.8981	7.2215	7.5575	7.8692	8.1479
4	4.7997	5.0683	5.3244	5.5606	5.7706	5.9870	6.1893	6.3590	6.5003
5	4.0126	4.1621	4.2851	4.3844	4.4919	4.5671	4.6126	4.6303	4.6012

Tooth Trans. Thick. Error - [mm] Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
[Tooth Root]									
1	-.0297	-.0198	-.0323	-.0343	-.0301	-.0260	-.0144	-.0081	-.0344
2	.0062	.0101	-.0037	-.0139	-.0194	-.0170	-.0090	-.0062	-.0262
3	.0173	.0204	.0023	.0063	-.0045	-.0043	.0038	.0168	.0003
4	.0157	.0079	-.0151	-.0155	-.0198	-.0107	-.0038	.0066	.0056
5	-.0066	-.0296	-.0466	-.0544	-.0496	-.0400	-.0255	-.0039	.0019

- The **next six tables list the theoretical** tooth surface normal vector components for each data point, respectively for the pinion convex/gear concave, and the pinion concave/gear convex tooth flank.

Normal (1) - Side Concave Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9

Tooth Root

1	0.1129	0.1386	0.1642	0.1895	0.2145	0.2393	0.2637	0.2878	0.3116
2	0.1108	0.1362	0.1614	0.1865	0.2112	0.2357	0.2598	0.2836	0.3071
3	0.1086	0.1338	0.1587	0.1834	0.2079	0.2320	0.2559	0.2794	0.3026
4	0.1065	0.1313	0.1560	0.1804	0.2045	0.2284	0.2519	0.2752	0.2980
5	0.1043	0.1289	0.1532	0.1773	0.2011	0.2247	0.2480	0.2709	0.2935

Normal (2) - Side Concave Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	-0.8091	-0.7961	-0.7819	-0.7666	-0.7501	-0.7324	-0.7135	-0.6933	-0.6717
2	-0.8101	-0.7973	-0.7835	-0.7685	-0.7524	-0.7351	-0.7166	-0.6969	-0.6759
3	-0.8111	-0.7986	-0.7850	-0.7704	-0.7546	-0.7378	-0.7197	-0.7005	-0.6801
4	-0.8121	-0.7999	-0.7866	-0.7723	-0.7569	-0.7404	-0.7228	-0.7041	-0.6842
5	-0.8131	-0.8011	-0.7882	-0.7742	-0.7591	-0.7430	-0.7259	-0.7076	-0.6883

Normal (3) - Side Concave Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	-0.5767	-0.5891	-0.6014	-0.6135	-0.6255	-0.6374	-0.6492	-0.6607	-0.6721
2	-0.5757	-0.5879	-0.6001	-0.6121	-0.6239	-0.6357	-0.6473	-0.6587	-0.6699
3	-0.5747	-0.5868	-0.5988	-0.6106	-0.6223	-0.6339	-0.6454	-0.6567	-0.6678
4	-0.5737	-0.5856	-0.5974	-0.6091	-0.6207	-0.6322	-0.6435	-0.6546	-0.6656
5	-0.5726	-0.5844	-0.5961	-0.6077	-0.6191	-0.6304	-0.6416	-0.6526	-0.6634

Normal (1) - Side Convex Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	-0.2997	-0.3311	-0.3624	-0.3936	-0.4247	-0.4556	-0.4862	-0.5166	-0.5466
2	-0.3007	-0.3321	-0.3634	-0.3946	-0.4257	-0.4566	-0.4872	-0.5176	-0.5477
3	-0.3017	-0.3331	-0.3644	-0.3956	-0.4267	-0.4576	-0.4883	-0.5187	-0.5487
4	-0.3028	-0.3341	-0.3654	-0.3966	-0.4277	-0.4586	-0.4893	-0.5197	-0.5498
5	-0.3038	-0.3351	-0.3664	-0.3976	-0.4287	-0.4596	-0.4904	-0.5208	-0.5509

Normal (2) - Side Convex Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9

Tooth Root

1	0.9538	0.9429	0.9307	0.9171	0.9020	0.8856	0.8677	0.8483	0.8273
2	0.9535	0.9425	0.9303	0.9166	0.9015	0.8850	0.8670	0.8476	0.8266
3	0.9531	0.9422	0.9299	0.9162	0.9010	0.8844	0.8664	0.8468	0.8258
4	0.9528	0.9418	0.9294	0.9157	0.9005	0.8839	0.8658	0.8461	0.8250
5	0.9525	0.9414	0.9290	0.9152	0.9000	0.8833	0.8651	0.8454	0.8242

Normal (3) - Side Convex Tooth 1

Ia3\Iac:	1	2	3	4	5	6	7	8	9
Tooth Root									
1	0.0217	0.0358	0.0497	0.0635	0.0772	0.0906	0.1038	0.1168	0.1294
2	0.0221	0.0362	0.0502	0.0640	0.0776	0.0910	0.1042	0.1172	0.1299
3	0.0226	0.0367	0.0506	0.0644	0.0780	0.0915	0.1047	0.1177	0.1304
4	0.0231	0.0371	0.0511	0.0649	0.0785	0.0919	0.1051	0.1181	0.1308
5	0.0235	0.0376	0.0515	0.0653	0.0789	0.0924	0.1056	0.1186	0.1313

- The **next two tables list the measured (Pnt.Mes.) and calculated (Calc.) tooth surface data** points column by column for each measurement grid data point, respectively for the pinion convex/gear concave, and the pinion concave/gear convex tooth flank. If measurement compensation is performed within HyGEARS, the compensated measurement point is added (Mes.Comp.) to the list.

  These tables are sent to the Text Results window when only one data-set was chosen for display. This data is useful to identify for a specific data point which coordinate contributes the most to the calculated error.

Coordinates - Side Concave [mm] Tooth 1

	X	Y	Z	
Mes. :	-59.16180	0.89159	33.12223	
Calc.:	-59.16187	0.88781	33.12224	
Mes. :	-60.10474	2.09894	31.21556	
Calc.:	-60.10497	2.09228	31.21556	1
Mes. :	-60.56742	2.70185	30.26177	
Calc.:	-60.56774	2.69480	30.26177	
Mes. :	-61.36442	-0.23550	34.38288	
Calc.:	-61.36440	-0.23873	34.38287	
Mes. :	-61.86676	0.41003	33.37365	
Calc.:	-61.86678	0.40735	33.37366	
Mes. :	-62.36259	1.05728	32.36540	
Calc.:	-62.36266	1.05282	32.36540	2

```
Mes. :        -62.85166        1.70244        31.35582
Calc.:        -62.85174        1.69928        31.35581

. . .

                   Coordinates - Side Convex [mm]  Tooth 1

                  X               Y               Z

Mes. :        -59.44136        6.59659        31.90058
Calc.:        -59.44107        6.59936        31.90058
Mes. :        -59.89287        6.47253        31.03487
Calc.:        -59.89253        6.47563        31.03487    1
Mes. :        -60.34381        6.34799        30.16915
Calc.:        -60.34340        6.35198        30.16915
. . .
```

13.2.4 Coordinate List

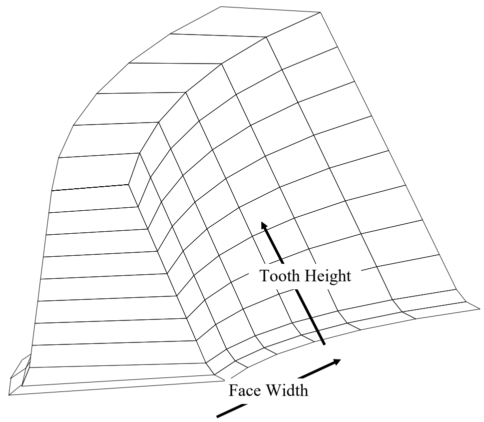
Many HyGEARS functions offer a printout of the displayed geometry tooth flank coordinates. The Tooth Flank Coordinate List may apply to the TCA, FEA or CMM Nominal tooth models.

The latter two are appropriately identified "FEA" and "CMM Nominal" on the printout header. This section describes the format in which the tooth flank coordinate list is given. When needed, this section will be referred to for appropriate explanations.

The coordinates are given from tooth root on one tooth flank to tooth root on the other tooth flank, axis by axis, in the following format:

The coordinate data is organized as a simple list; each line is made of the X1X2X3 or Y1Y2Y3 coordinates, respectively for the pinion and gear; coordinates are arranged from toe to heel, and from root to tip; the Pinion Convex/Gear Concave tooth flanks come first; the the pinion Concave/Gear Convex tooth flanks.

Therefore, the list will be made of coordinates of each point in the first column of the tooth, then the second, etc. The tooth flanks are separated by a blank line. Given its simplicity, this list can easily be programmed to be read by another software in which one desires to import the tooth geometry.




```
________________________________________________________

                 HyGEARS V 4.0 © ®

 Tooth Flank Coordinates Gear [Finishing] - Demo1441.dat

________________________________________________________

 Date / Time        : 12/31/2012 / 3:29:00 PM
 General Units      : [in] [dd.mm.ss]
 Cutter  Units      : [in]
 Prepared by        : John Who
 Version            : 4.0.401.70


*** Y1 ***   *** Y2 ***   *** Y3 ***

  -2.22596     0.00608    -0.00750
  -2.22913     0.02404    -0.01446
  -2.23495     0.03689    -0.02723
  -2.24599     0.05193    -0.05130
   .
   .
   .
   .
  -2.20351     0.31229    -0.00654
  -2.21104     0.29023    -0.01607
  -2.22143     0.27980    -0.03516
  -2.23282     0.27669    -0.05837
```

13.2.5 Coordinates (Tooth Flank)

Many HyGEARS functions offer a printout of the displayed Geometry tooth flank coordinates. The Tooth Flank Coordinates may apply to the TCA, FEA or CMM Nominal tooth models.

The latter two are appropriately identified “FEA” and “CMM Nominal” on the printout header. This section describes the format in which the tooth flank coordinates are given. When needed, this section will be referred to for appropriate explanations.

The coordinates are given from tooth root on one tooth flank to tooth root on the other tooth flank, axis by axis, in the following format:

The coordinate data is organized in rows and columns in three tables, one for each coordinate (X1, X2, X3 for the pinion, Y1, Y2, Y3 for the gear). Rows give coordinates from toe to heel (left to right), while columns give data from root on one side to root on the other side. For pinions, data starts at the root of the convex tooth flank, and ends at the root of the concave tooth flank; for gears, data starts at the root of the concave tooth flank, and ends at the root of the convex tooth flank

The coordinate data section below also gives a header indicating the dimensions of the tables, in the following format: 1, 11, 12, 22, 1, 7 where 1, 11, 12, and 22 indicate the row location addresses in the storage matrix, from tooth root on one tooth flank to tooth root on the other, and 1, 6 indicate the column location addresses in the storage matrix, from heel to toe (see the figure below). Of course, this header will vary with the number of axial and profilewise points selected for the tooth.

```
HyGEARS V 4.0 © ®

Tooth Flank Coordinates Gear [Finishing] - Demo1441.dat

Date / Time       : 12/31/2012 / 3:04:13 PM
General Units     : [in] [dd.mm.ss]
Cutter  Units     : [in]
Prepared by       : John Who
Version           : 4.0.401.70

  1, 11, 12, 22,  1,  6
```

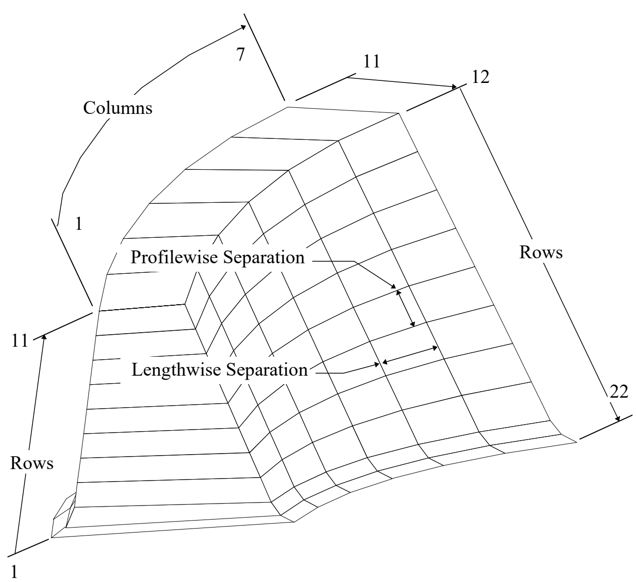
The first series of coordinates is given relative to the tooth origin, i.e. at toe-fillet.

```
*** Relative to Origin ***
--------------------------
*** Y1 ***
 [Tooth Root - Concave-OB]
    -2.22596    -2.39578    -2.56215    -2.72413    -2.88066    -3.03061
    -2.22913    -2.39954    -2.56654    -2.72919    -2.88646    -3.03719
    -2.23495    -2.40579    -2.57325    -2.73640    -2.89420    -3.04552
```

```
 [Tooth Tip]
          .....
[Tooth Root - Convex]
••• Y2 •••
[Tooth Root - Concave]
    -0.00225    -0.07629    -0.16129    -0.25747    -0.36511    -0.48450
     0.01570    -0.05810    -0.14284    -0.23876    -0.34613    -0.46524
     0.02852    -0.04510    -0.12965    -0.22539    -0.33256    -0.45148
     0.04353    -0.02843    -0.11132    -0.20540    -0.31096    -0.42831
[Tooth Tip]
          .....
[Tooth Root - Convex]
••• Y3 •••
[Tooth Root - Concave]
    -0.00750     0.07764     0.16193     0.24515     0.32704     0.40734
    -0.01446     0.07085     0.15533     0.23875     0.32086     0.40140
    -0.02722     0.05822     0.14284     0.22641     0.30868     0.38939
[Tooth Tip]
          .....
[Tooth Root - Convex]
```

A second series of coordinates is given relative to the apex of the pinion/gear. This applies only to bevel gears since spur/helical gears do not have an apex.

```
*** Relative to Apex ***
------------------------
*** Y1 ***
 [Tooth Root - Concave-OB]
    -2.22596    -2.39578    -2.56215    -2.72413    -2.88066    -3.03061
    -2.22913    -2.39954    -2.56654    -2.72919    -2.88646    -3.03719
    -2.23495    -2.40579    -2.57325    -2.73640    -2.89420    -3.04552
    -2.24599    -2.41861    -2.58799    -2.75316    -2.91308    -3.06658
          .....
```



The coordinate data also provides information as to how the data points are spread over the tooth flank, by giving the distance between two consecutive points in the lengthwise and profilewise directions, as shown in the table below and the figure above.

```
                    HyGEARS V 4.0 ©

Tooth Flank Coordinates Separation Gear [Finishing] - Demo1441.dat

Date / Time   :  02-24-1999 / 08:42:31
General Units :  [mm] [deg.min.sec]
Cutter  Units :  [in]
Prepared by   :  John Doe
Version       :  4.0.401.70
```

```
Length Wise [Tooth Root - Concave]
     0.18094     0.18354     0.18639     0.18956     0.19307     0.19697
     0.18131     0.18390     0.18675     0.18991     0.19340     0.19729
     0.18157     0.18416     0.18701     0.19016     0.19367     0.19754
[Tooth Tip]
          .....
Length Wise [Tooth Root - Convex]


Profile Wise [Tooth Root - Concave]
     0.01952     0.01977     0.02004     0.02034     0.02067     0.02103
     0.01902     0.01917     0.01933     0.01950     0.01969     0.01989
     0.03046     0.03349     0.03649     0.03942     0.04224     0.04493
[Tooth Tip]
          .....
Profile Wise [Tooth Root - Convex]
```

Finally, the coordinate data provides the transverse tooth thickness at all tooth flank points, and the corresponding radii on the IB and OB tooth flanks.

```
                HyGEARS V 4.0 ©

Tooth Trans. Thick. Gear [Finishing] - Demo1441.dat
```

```
Date / Time    :  02-24-1999 / 08:42:31
General Units :  [in] [deg.min.sec]
Cutter  Units :  [in]
Prepared by    :  John Doe
Version        :  4.0.401.70
```

```
[Tooth Root]
    0.30724    0.32862    0.35002    0.37144    0.39289    0.41441
    0.26701    0.28788    0.30870    0.32949    0.35024    0.37097
    0.24363    0.26426    0.28482    0.30531    0.32573    0.34606
    0.22573    0.24436    0.26288    0.28129    0.29961    0.31787
         .....
[Tooth Tip]
```

HyGEARS V 4.0 ©

Radius Gear [Finishing] - Demo1441.dat

```
Date / Time    :  02-24-1999 / 08:42:31
General Units :  [in] [deg.min.sec]
Cutter  Units :  [in]
Prepared by    :  John Doe
Version        :  4.0.401.70
```

```
[Tooth Root - Concave-OB]
     2.22732    2.37001    2.51309    2.65667    2.80088    2.94584
     2.23060    2.37320    2.51619    2.65968    2.80379    2.94864
     2.23661    2.37915    2.52208    2.66550    2.80952    2.95428
          .....
[Tooth Tip]
          .....
     2.24034    2.38332    2.52672    2.67065    2.81521    2.96055
     2.23136    2.37429    2.51764    2.66152    2.80603    2.95131
     2.22688    2.36971    2.51295    2.65671    2.80111    2.94626
[Tooth Root - Convex-IB]
```

The Tooth Flank Coordinates printout is accessed through the Parent window function buttons, or from the Parent Window "Misc." Menu pull down menu.

13.2.6 Cutting Cycle

The Cutting Cycle Output, or Cradle Angles, sent to a Text Results window, provides information on cradle angles during generation, and from what initial to final cradle position the cutter is expected to contact the blank.

```
____________________________________________________________________

                    HyGEARS V 4.0 © ®

Cradle Angles Pinion [Finishing] Machine Gleason 116 - Demo1441.dat

____________________________________________________________________

Date / Time         : 12/31/2012 / 3:33:34 PM
General Units       : [in] [dd.mm.ss]
Cutter  Units       : [in]
Prepared by         : John Who
Version             : 4.0.401.70
```

First, the cradle angle range over which the cutter is expected to be in contact with the work is presented for each tooth flank. Note that the values shown below exceed the values above, since the values below represent the expected beginning and end of the contact between the cutter and the outside of the blank, while the values above represent the cradle positions where generation of the active tooth flank is actually occurring.

```
Cutting Cycle - Machine Gleason 116
 __________________________________

Begin - End Convex-IB        :  127.450 ->  371.478 deg.
Begin - End Concave-OB       :   73.730 ->  374.675 deg.
```

Then, the Cutting Cycle itself is printed out. The cutting cycle indicates the minimum and maximum cradle angles for contact between the cutter blade and the active tooth flank (thus excludes the fillet):

```
Cradle Convex-IB      :  132.783 ->  167.753 deg.     |  Cradle :  146.24.52 deg.
Cradle Concave-OB     :  138.427 ->  165.720 deg.     |  Cradle :  152.16.00 deg.
```

Finally, the Cutting Cycle is presented in one table where the cradle angles, corresponding to the selected number of axial and radial points for the tooth flank, are presented from the pinion convex/gear concave tooth root to the pinion concave/gear convex tooth root, as below:

```
 [Tooth Root - Convex-IB]
   165.199    160.479    156.081    151.874    147.753    143.866
```

```
  166.476   161.346   156.687   152.352   148.230   144.348
  167.753   162.213   157.292   152.830   148.707   144.830
  …
[Tooth Tip]
  …
  160.696   156.333   152.031   147.689   143.195   138.427
  162.053   157.504   153.119   148.811   144.550   140.214
  163.409   158.676   154.207   149.934   145.905   142.001
[Tooth Root - Concave-OB]
```

13.2.7 FEA Model

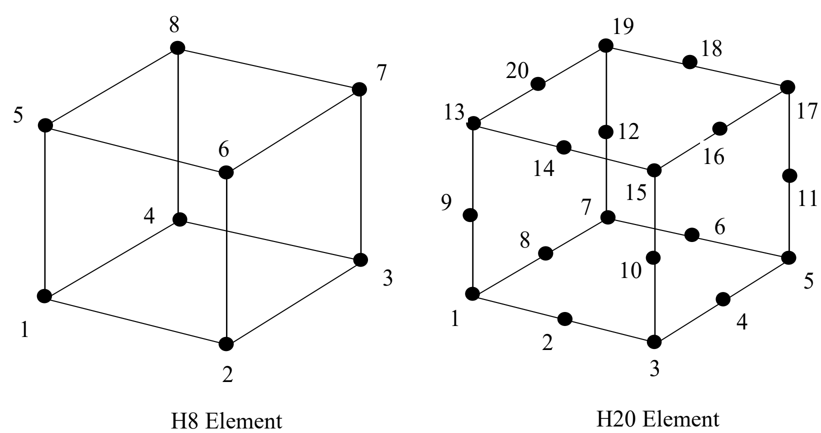
The FEA Model Output is sent directly to a data file which can then be submitted to a FEA solving software. As it is not possible to cover all the various Finite Element Analysis software data input formats, the following will explain the format used by HyGEARS, which is almost identical to that of FEA's Lusas solver.

The FEA Model Output is structured in six sections, as explained hereafter:

- The first section deals with the problem title, in which either the pinion or the gear is identified, the cutting mode (roughing or finishing), and the Geometry data file.

```
PROBLEM TITLE Pinion [Finishing]  demo.dat
```

- The second section deals with Element Topology. HyGEARS supports only H8 and H20 elements. The following figure illustrates how H8 and H20 element nodes are encoded.



The Element Topology section identifies the type of element, either HX8 or HX20. Each element is identified by a number, followed by the node numbers of which it is made up. The line continuation symbol "..." is used to split lines longer than 80 characters.

```
HX20 ELEMENT TOPOLOGY
     1      1      2      3     13      6      5      4     14 ...
           17     18     19     20      7      8      9     15 ...
           12     11     10     16

     2      4      5      6     27     23     22     21     28 ...
           20     19     31     32     10     11     12     29 ...
           26     25     24     30
             .
             .
             .

   211   1339   1491   1492   1499   1497   1496   1344   1346 ...
         1342   1495   1500   1347   1315   1466   1467   1475 ...
         1473   1498   1345   1322

   212   1344   1496   1497   1503   1502   1501   1349   1350 ...
         1347   1500   1504   1351   1320   1472   1473   1481 ...
         1478   1477   1325   1328
```

- The third section deals node coordinates. Each node is identified by its number, followed by its X1X2X3 or Y1Y2Y3 coordinates, depending whether the pinion or the gear is the meshed member.

```
NODE COORDINATES
     1   -0.366551200    0.845268400    0.000000000

     2   -0.450766200    0.803522400    0.000000000

     3   -0.530289500    0.753413200    0.000000000

...
  1500   -0.088788450    0.232610900    0.756777400

  1501    0.008279314    0.201680500    1.064976000

  1502   -0.008477102    0.201672300    1.064976000

  1503   -0.033950050    0.197288900    0.931854200

  1504   -0.010491380    0.249592600    1.064976000
```

- The fourth section deals with material properties. Material properties are grouped in Material Groups. Each Material Group is identified by a number, followed by Young's modulus and Poisson's Ratio values established in the Operating section of the Pinion or Gear Summaries.

```
MATERIAL PROPERTIES
      1        30000000.0    0.28
```

Material Groups are then assigned to elements or element groups in the following manner:

```
MATERIAL ASSIGNMENTS
      1    212    1     1
```

where "`1  212  1  1`" respectively take the following meaning:

```
1st El.    Last El.     El. Inc.    Mat. Grp
```

1st El.	is the first element of the group to which the Material Case is to be applied;
Last El.	is the first element of the group to which the Material Case is to be applied;
El. Inc.	is the increment to apply between the 1st and last elements to identify all those element concerned;
Mat.Grp	is the Material Group number to apply to the listed elements.

- The fifth section deals with boundary conditions. It is a list of all the support nodes, and how they are restrained. Boundary Conditions are formatted in the following manner:

```
SUPPORT NODES
    223  223 0  R  R  R

    224  224 0  R  R  R

    225  225 0  R  R  R

    ...

   1499 1499 0  R  R  R

   1501 1501 0  R  R  R

   1502 1502 0  R  R  R
```

where "`1499 1499 0  R  R`" respectively take the following meaning:

```
1st Node     Last Node      Node Inc.     Disp. 1       Disp. 2       Disp. 3
```

1st Node	is the first node number on which the boundary condition is applied;
Last Node	is the last node number on which the boundary condition is applied;

Node Inc.	is the increment between the 1st and last node number to which the prescribed boundary conditions are to be applied;
Disp 1	defines whether displacement in the X1 or Y1 directions permitted or not; an R indicates that displacement is restricted.
Disp 2	defines whether displacement in the X2 or Y2 directions permitted or not; an R indicates that displacement is restricted.
Disp 3	defines whether displacement in the X3 or Y3 directions permitted or not; an R indicates that displacement is restricted.

- The seventh section deals with Load Cases. It is a list of all the concentrated nodes where concentrated loads are applied and the load values in three orthogonal directions, Load Case by Load Case. The following format is used:

```
LOAD CASE
CL
    769 769 0    -18.8473400     16.5369200     37.3238800

LOAD CASE
CL
    663 663 0    -29.3163700     12.5396900     46.2851300
```

where "`663 663 0   -29.3163700  12.5396900  46.2851300`" respectively take the following meaning:

LOAD CASE	indicates the beginning of a Load Case section.
CL	indicates a concentrated load

```
    1st Node   Last Node     Node Inc.      Force X1      Force X2      Force X3
```

1st Node	is the first node number on which the concentrated load is applied;
Last Node	is the last node number on which the concentrated load is applied;
Node Inc.	is the increment between the 1st and last node number to which the concentrated load is to be applied;
Force X1	defines the value of the load applied in the X1 or Y1 direction.
Force X2	defines the value of the load applied in the X2 or Y2 direction.
Force X3	defines the value of the load applied in the X3 or Y3 direction.

- The FEA Model data file ends with an "END" flag, as below:

```
END
```

13.2.8 Geometry Summary

The Geometry is used to produce a Summary of the pinion, gear, or both, including blank definition, machine settings and Operating Conditions.

A *Geometry Summary* can contain several parts:

the **Summary Identifie**r, in which global information is provided;

the **Blank Summary**, in which the blank dimensions are given;

the **Strength Calculations**, in which bending and contact stresses are given;

the **Finishing Machine Settings**, in which the finishing machine setups are given;

the **Roughing Machine Settings**, in which the roughing machine setups are given.

The following paragraphs describe each part of a Summary, whether it has been requested through the Complete Summary function or a Child Window “Summ” function button.

Summary Identifier

The Summary Identifier gives basic information about the gear set, such as:

- name of the geometry datafile used for the Summary (Demo1441.dat in the example below); this is located in the upper left corner of the document;

Demo1441.dat

- the date and time the Summary was produced;
- the units used in the Summary;
- the registered user name and its company;
- the HyGEARS version number (4.0.400.00-428 in the example below);

This is located in the upper right corner of the document;

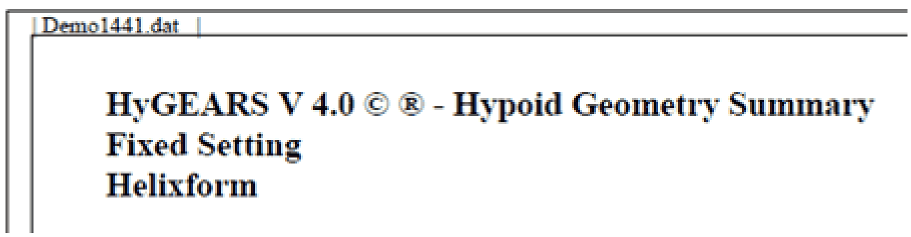
```
Date / Time       : 24/04/2012 / 6:15:41 PM
General Units     : [mm] [dd.mm.ss]
Cutter  Units     : [in]
Prepared by       : Claude Gosselin / Drive System Design
Version           : 4.0.400.00-428
```

- the pinion and gear Summary version numbers, which identify the number of Corrective Machine Settings (Closed Loop) iterations made on the pinion and gear, and the Summary version being printed; for example, [Corr#1] means that the printed Summary is that after the 1st Corrective Machine Settings (Closed Loop) iteration; when nothing is given, the Nominal is assumed.

  o when a Summary is requested from a Child Window or from the Misc. pull down menu, the prepared Summary is that of the displayed geometry in the Child Window, e.g. pinion, gear or both, and the Summary version number is the version number associated to the Child Window;

  o when the Summary is requested from the Complete Summary menu function, the Summary version number is the latest Summary version number corresponding to the last Corrective Machine Settings (Closed Loop) iteration, and both the pinion and gear data are printed.

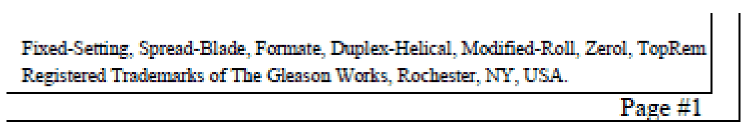
- the gear set type (Hypoid Fixed Setting / Helixform in the example below);



Demo1441.dat

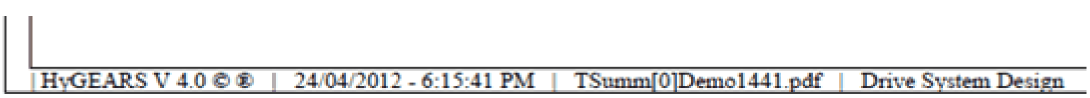
HyGEARS V 4.0 © ® - Hypoid Geometry Summary
Fixed Setting
Helixform

- credits to The Gleason Works for existing Trademarks which are used in HyGEARS, since they are common language gear manufacturers); this is shown in the bottom right corner of the Summary pages where used;



Fixed-Setting, Spread-Blade, Formate, Duplex-Helical, Modified-Roll, Zerol, TopRem
Registered Trademarks of The Gleason Works, Rochester, NY, USA.
Page #1

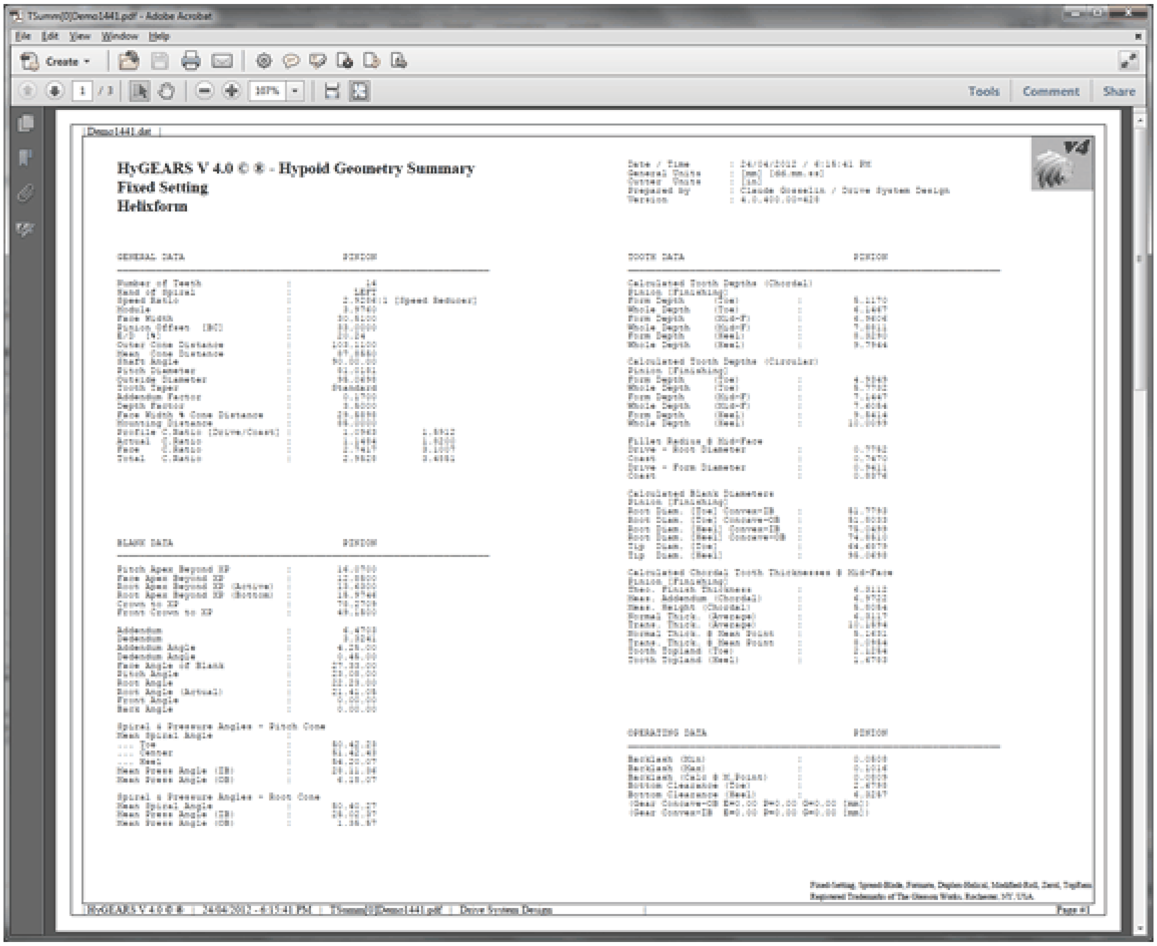
- HyGEARS identifier; date and time; the Pdf document file name (TSumm[0] Demo1441.pdf in the example below);



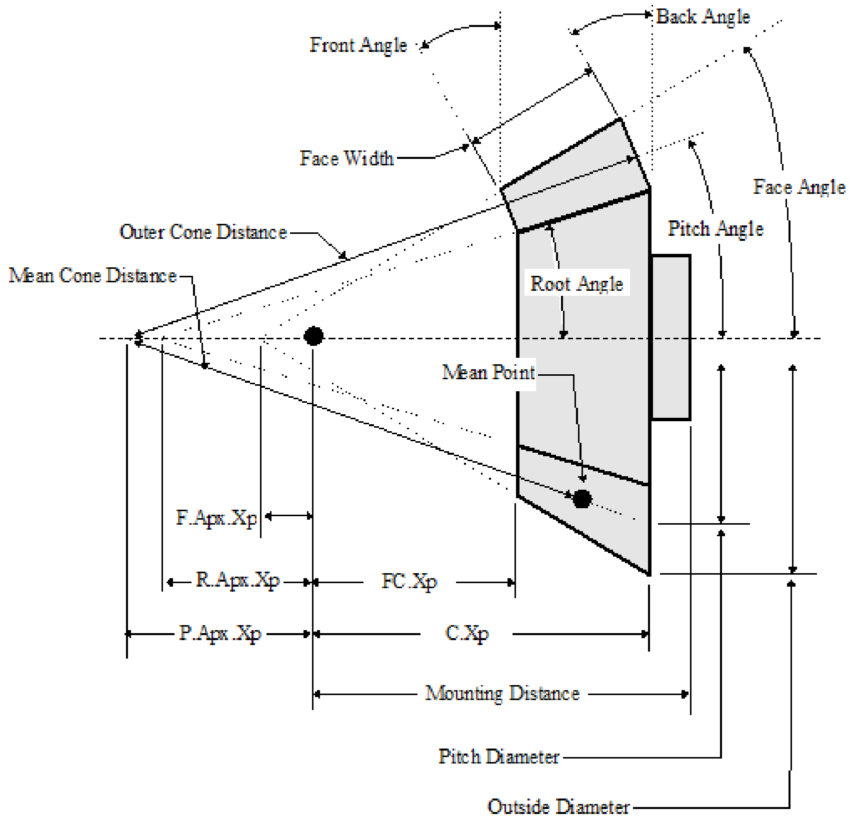
HyGEARS V 4.0 © ® | 24/04/2012 - 6:15:41 PM | TSumm[0]Demo1441.pdf | Drive System Design

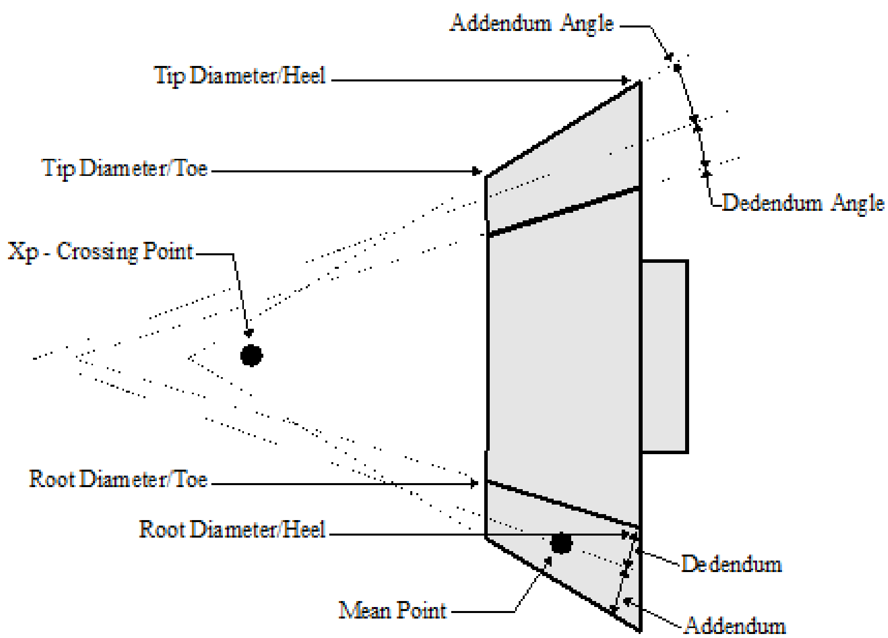
Blank Summary

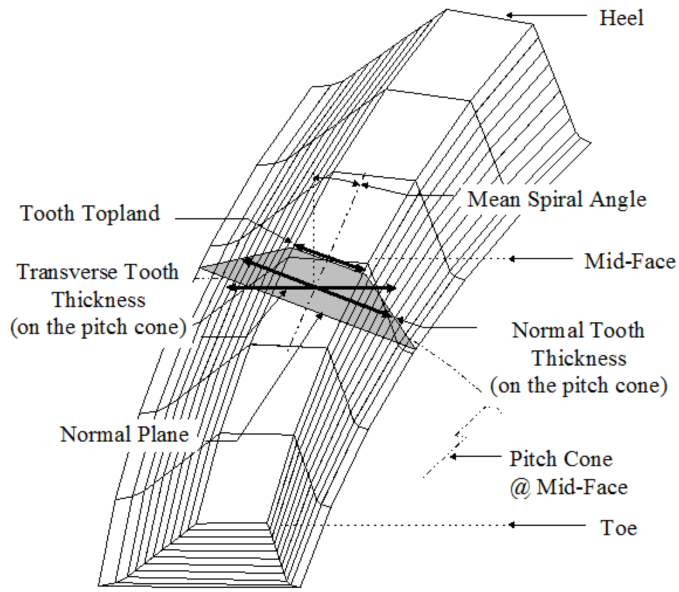
The Blank Summary, which appears on the 1st page, gives all the basic geometry information about the gear set members, such as tooth numbers, module, etc. The following figures illustrate the main geometry features given in the Blank Summary.



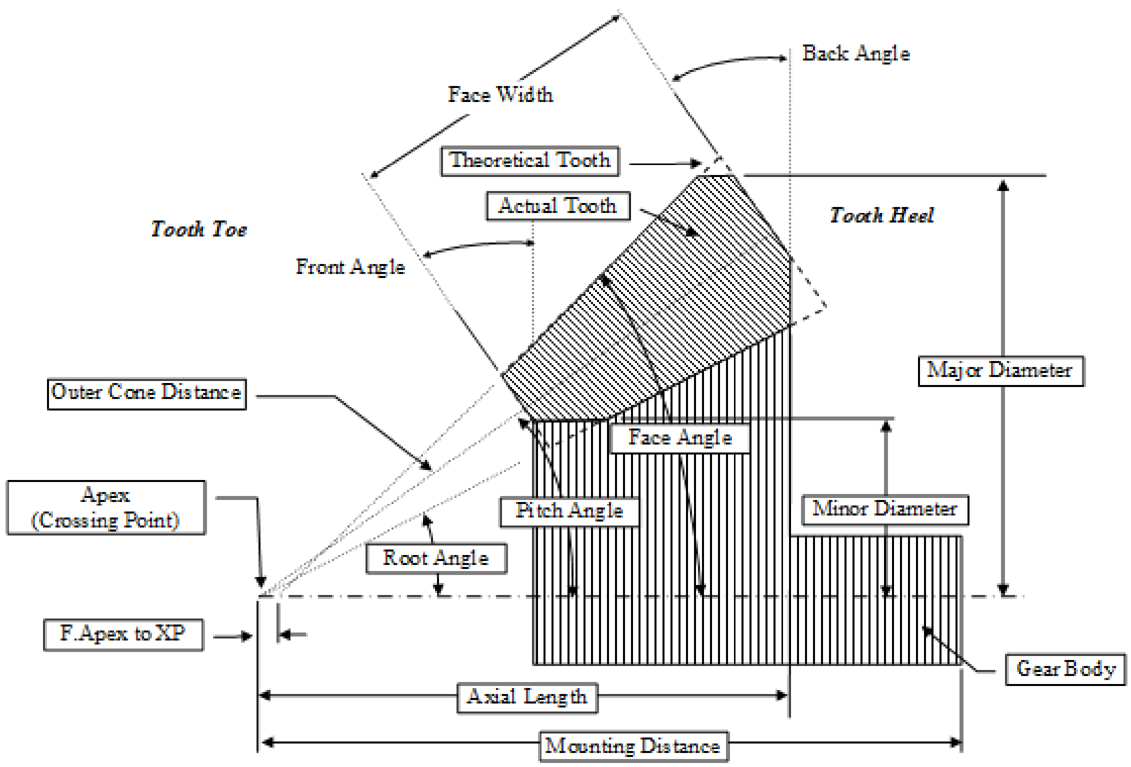
Zerol, Spiral-bevel and Hypoid Gears

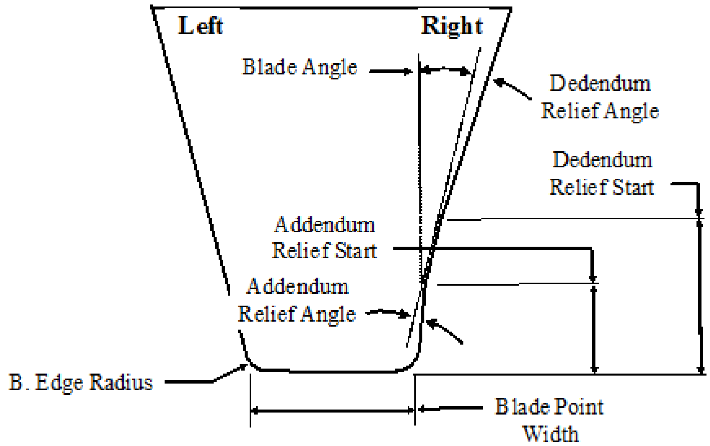

Front Angle
Back Angle
Face Width
Face Angle
Pitch Angle
Outer Cone Distance
Mean Cone Distance
Root Angle
Mean Point
F.Apx.Xp
R.Apx.Xp
FC.Xp
P.Apx.Xp
C.Xp
Mounting Distance
Pitch Diameter
Outside Diameter

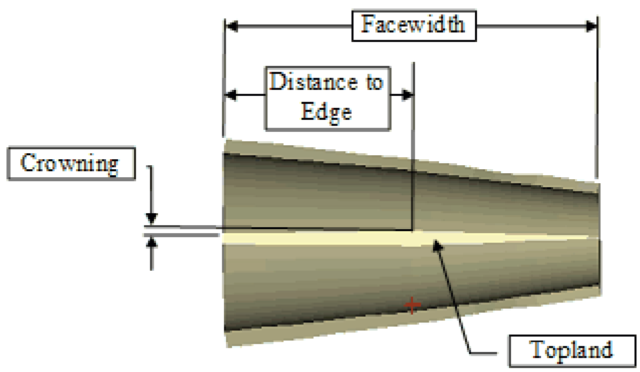

Addendum Angle
Tip Diameter/Heel
Tip Diameter/Toe
Dedendum Angle
Xp - Crossing Point
Root Diameter/Toe
Root Diameter/Heel
Dedendum
Mean Point
Addendum



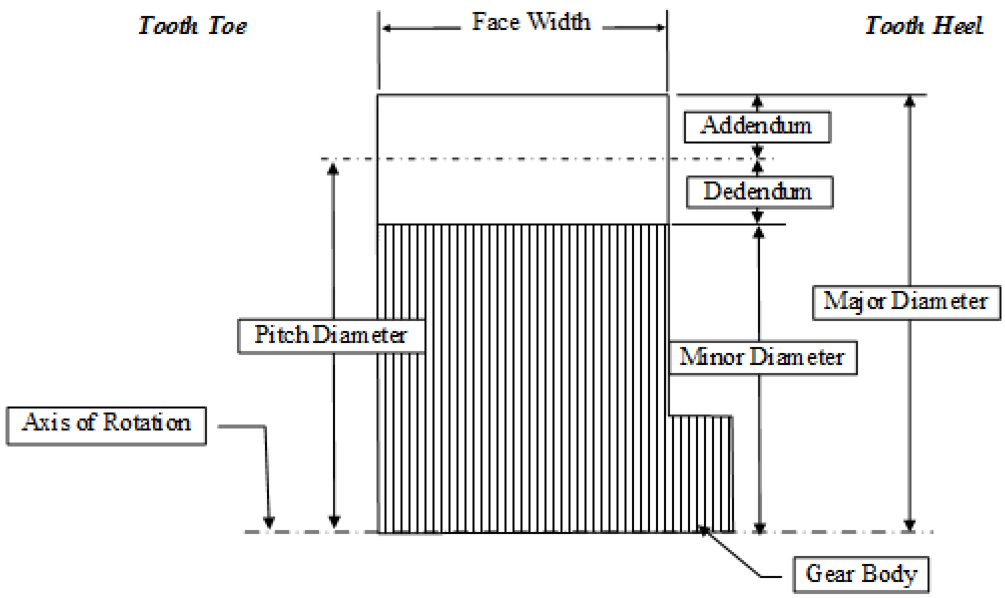
Straight-bevel and Coniflex Gears

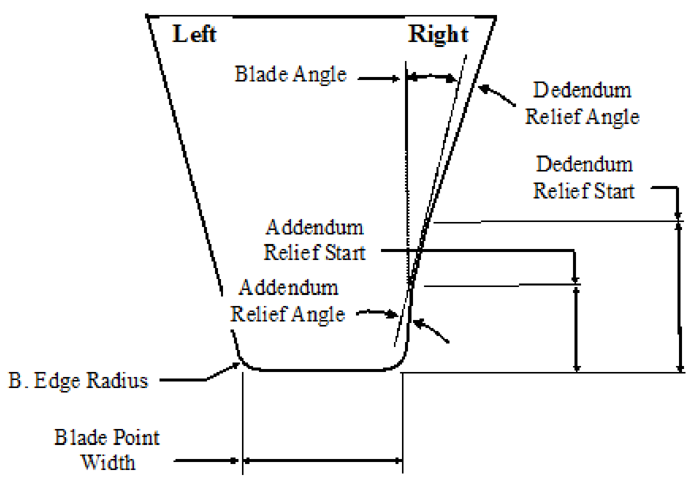


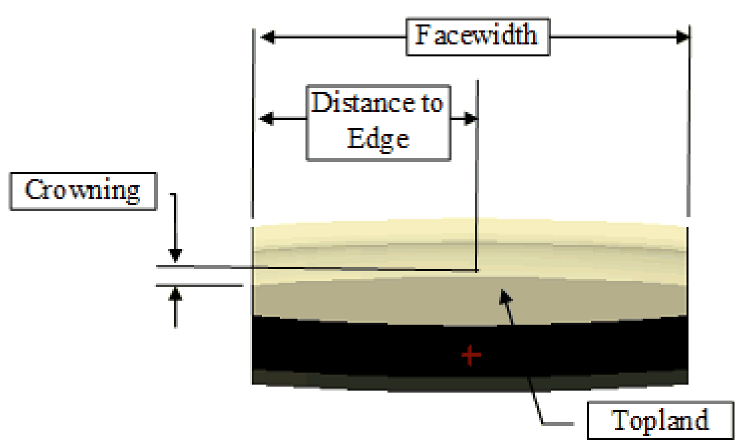




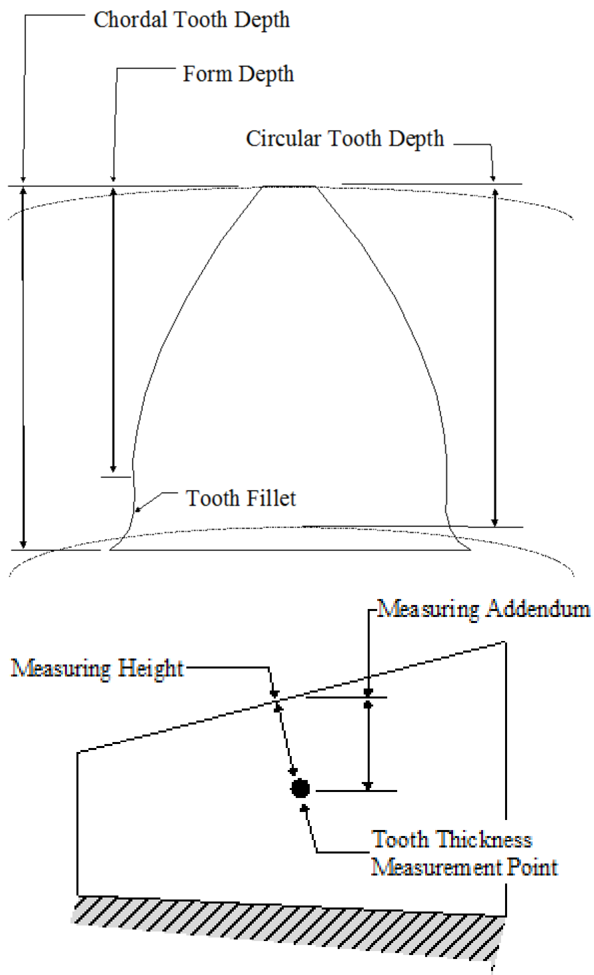
Spur, Helical and Beveloid Gears


Tooth Toe
Face Width
Tooth Heel
Addendum
Dedendum
Major Diameter
Pitch Diameter
Minor Diameter
Axis of Rotation
Gear Body


Left
Right
Blade Angle
Dedendum Relief Angle
Dedendum Relief Start
Addendum Relief Start
Addendum Relief Angle
B. Edge Radius
Blade Point Width


Facewidth
Distance to Edge
Crowning
Topland

Tooth Measurement



Blank data is organized in several sections, as follows:

Section 1: Blank dimensions

Zerol, Spiral-bevel and Hypoid gears

```
BLANK DATA                                    PINION          GEAR
___________________________________________________________________
```

```
Number of Teeth               :          14            41
Hand of Spiral                :        LEFT         RIGHT
Speed Ratio                   :      2.9286:1 [Speed Reducer]
Profile C.Ratio [Drive/Coast] :      1.0970        1.5912
Actual  C.Ratio               :      1.4918        2.0062
Face    C.Ratio               :      2.7722        3.0507
Total   C.Ratio               :      2.9814        3.4407
Module                        :      3.9760
Face Width                    :     30.5100       25.2000
Angular Face                  :                  22.24.15
Pinion Offset  [BC]           :     33.0000
E/D  [%]                      :     20.24
Outer Cone Distance           :    103.1100       90.0800
Mean  Cone Distance           :     87.8550       77.4800
Shaft Angle                   :    90.00.00
Pitch Diameter                :     81.0181      163.0136
Outside Diameter              :     95.0707      164.0845
Tooth Taper                   :    Standard
Addendum Factor               :                    0.1700
Depth Factor                  :                    3.5000
Face Width % Cone Distance    :     29.5898       27.9751
Mounting Distance             :     85.0000       62.0000
```

In the above, the following definitions apply:

- Profile C.Ratio: is the contact ratio of the profile part of the PoC.
- Actual C.Ratio: is the contact ratio of the actual part of the tooth in contact, and thus corresponds to the duration of the PoC along the Contact Pattern.
- Face C.Ratio: is the face contact ratio, calculated between the beginning and the end of the PoC.
- Total C.Ratio: is the total contact ratio, or $\sqrt{\text{Profile C.Ratio}^2 + \text{Face C.Ratio}^2}$
- Angular Face: is the angle swept by the gear cutter over the gear facewidth; if this angle is larger than 27.5 for Gleason 607 Helixform machine, then a variable pitch cutter must be used.
- E/D [%]: is the ratio of pinion offset to gear pitch diameter.

Straight bevel and Coniflex gears

```
BLANK DATA                                   PINION          GEAR
__________________________________________________________________

Number of Teeth               :           9            13
Speed Ratio                   :      1.4444:1 [Speed Reducer]
Profile C.Ratio [Drive/Coast] :      1.2641        1.2644
Actual  C.Ratio               :      1.0077        1.0083
Face    C.Ratio               :      0.0000        0.0000
Total   C.Ratio               :      1.2641        1.2644
Diametral Pitch               :      5.1303
```

```
Face Width                       :         0.6890        0.8031
Outer Cone Distance              :         1.5410        1.5410
Mean  Cone Distance              :         1.1965        1.1395
Shaft Angle                      :       90.00.00
Minor Diameter                   :         0.9849 Fixed  1.3780 Fixed
Heel Diameter                    :         1.7717
Pitch Diameter                   :         1.7543        2.5340
Major Diameter                   :         1.9293 Fixed  2.4776 Fixed
Axial Length                     :         1.2598 Fixed  1.0630 Fixed
Tooth Taper                      :       Standard
Addendum Factor                  :                       0.2500
Depth Factor                     :                       2.0000
Mounting Distance                :         1.5000        1.2500
```

In the above, the following definitions apply:

- Profile C.Ratio: is the contact ratio of the profile part of the PoC.
- Actual C.Ratio: is the contact ratio of the actual part of the tooth in contact, and thus corresponds to the duration of the PoC along the Contact Pattern.
- Face C.Ratio: is the face contact ratio, calculated between the beginning and the end of the PoC. Applicable to helical gears.
- Total C.Ratio: is the total contact ratio, or $\sqrt{\text{Profile C.Ratio}^2 + \text{Face C.Ratio}^2}$

Spur, Helical and Beveloid gears

```
BLANK DATA                                 PINION          GEAR
__________________________________________________________________

Number of Teeth                  :            25            50
Speed Ratio                      :         2.0000:1 [Speed Reducer]

Profile C.Ratio [Drive/Coast]    :         1.6826        1.6824
Actual  C.Ratio                  :         1.6826        1.6824
Face    C.Ratio                  :         0.0000        0.0025
Total   C.Ratio                  :         1.6826        1.6824

Diametral Pitch                  :         6.5003
Face Width                       :         1.0000        1.0000

Minor Diameter                   :         3.4635        7.3093
Pitch Diameter                   :         3.8460        7.6920
Outside Diameter                 :         4.1537        7.9996
Diameter over ball               :         4.4005        8.2741
Roller-Ball Diameter             :         0.3250        0.3250
Oper. C. Distance                :         5.7690
Sugg. C. Distance                :         5.7690

Addendum Factor                  :         1.0001        0.9998
Dedendum Factor                  :         1.2432        1.2438
Fillet Factor                    :         0.3800        0.3800
Addendum                         :         0.1539        0.1538
```

```
Dedendum                        :          0.1913         0.1914
```

In the above, the following definitions apply:

- Profile C.Ratio: is the contact ratio of the profile part of the PoC. For spur gears, its value is the same as that of the Actual Contact ratio.
- Actual C.Ratio: is the contact ratio of the actual part of the tooth in contact, and thus corresponds to the duration of the PoC along the Contact Pattern.
- Face C.Ratio: is the face contact ratio, calculated between the beginning and the end of the PoC. Applicable to helical gears.
- Total C.Ratio: is the total contact ratio, or $\sqrt{\text{Profile C.Ratio}^2 + \text{Face C.Ratio}^2}$

Section 2: Blank apex position

Zerol, Spiral-bevel and Hypoid gears

```
Pitch Apex Beyond XP            :         16.0700        -1.0100
Face Apex Beyond XP             :         12.8500        -1.0100
Root Apex Beyond XP             :         13.6300        -1.0100
Crown to XP                     :         76.2000        38.2100
Front Crown to XP               :         49.1500         0.0000
```

Straight-bevel and Coniflex gears

```
Face Apex Beyond XP             :         -0.0264        -0.0206
Root Apex Beyond XP             :          5.7390        -0.0041
Crown to XP                     :          1.1419         1.0630
Front Crown to XP               :          0.7482         0.5138
```

Section 3: Tooth proportions

Zerol, Spiral-bevel and Hypoid gears

```
Addendum                        :          6.4703         1.2578
Dedendum                        :          3.2526         6.9940
Addendum Angle                  :         4.25.00        0.48.00
Dedendum Angle                  :         0.45.00        4.40.00
Face Angle of Blank             :        27.33.00       65.36.00
Pitch Angle                     :        23.08.00       64.48.00
Root Angle                      :        22.23.00       60.08.00
Root Angle (Actual)             :        22.04.16       59.58.29
Front Angle                     :         0.00.00       64.48.00
Back Angle                      :         0.00.00       64.48.00
```

Please refer to the preceding figures to properly identify the above quantities. The Root Angle (Actual) is the calculated root angle, from the tooth root lines, thus from the actual machine settings. It may differ slightly from the nominal Root Angle.

Straigh-bevel and Coniflex gears

```
Addendum Angle               :       8.47.12       5.37.13
Dedendum Angle               :       5.37.14       8.47.12
Face Angle of Blank          :      43.28.55      60.55.30
Pitch Angle                  :      34.41.43      55.18.17
Root Angle                   :      29.04.29      46.31.05
Root Angle (Actual)          :       6.26.10      45.43.19
Front Angle                  :       0.00.00       0.00.00
Back Angle                   :      34.41.43      55.18.17
```

Spur, Helical and Beveloid gears

```
Addendum Factor              :        1.0001        0.9998
Dedendum Factor              :        1.2432        1.2438
Fillet Factor                :        0.3800        0.3800
Addendum                     :        0.1539        0.1538
Dedendum                     :        0.1913        0.1914
```

Section 4: Pressure and spiral angles

Zerol, Spiral-bevel and Hypoid gears

```
Spiral & Pressure Angles - Pitch Cone
Mean Spiral Angle            :
... Toe                      :      50.42.11      21.34.42
... Center                   :      51.32.12      27.22.33
... Heel                     :      54.00.46      33.27.11
Mean Press Angle (IB)        :      27.41.09       7.01.21
Mean Press Angle (OB)        :       5.41.33      28.40.15
```

In the above, the following definitions apply:

- Mean Spiral Angle: is the spiral angle calculated on the pitch cone, at tooth toe, mid-face and heel;
- Mean Press Angle: is the pressure angle calculated on the pitch cone, at tooth mid-face.

The same information is also produced on the Root Cone. However, only the mid-face spiral angle is outputted then.

```
Spiral & Pressure Angles - Root Cone
Mean Spiral Angle            :      50.40.05      27.01.16
Mean Press Angle (IB)        :      25.01.31       7.13.46
Mean Press Angle (OB)        :       1.34.35      29.37.08
```

Straight-bevel and Coniflex gears

```
Spiral & Pressure Angles - Pitch Cone
Mean Helix Angle (Right)      :        9.05.23       0.43.53
Mean Helix Angle (Left)       :        9.09.34       0.43.54
Mean Press Angle (Right)      :       34.44.12      24.08.37
Mean Press Angle (Left)       :       34.44.44      24.08.34
```

In the above, the following definitions apply:

- Mean Helix Angle: is the helix angle calculated on the pitch cone, at tooth toe, mid-face and heel;
- Mean Press Angle: is the pressure angle calculated on the pitch cone, at tooth mid-face.

Spur, Helical and Beveloid gears

```
Spiral & Pressure Angles - Pitch Cone
Mean Helix Angle (Right)      :
Mean Helix Angle (Left)       :
Mean Press Angle (Right)      :       19.59.13      19.59.45
Mean Press Angle (Left)       :       19.59.13      19.59.45
```

In the above, the following definitions apply:

- Mean Helix Angle: is the helix angle calculated on the pitch circle; it is printed only when non-zero;
- Mean Press Angle: is the pressure angle calculated on the pitch cone, at tooth mid-face.

Section 5: Tooth depths along the facewidth

Zerol, Spiral-bevel and Hypoid gears

```
Calculated Tooth Depths (Chordal)
Pinion + Gear [Finishing]
Form Depth     (Toe)          :         5.5243        5.3168
Whole Depth    (Toe)          :         6.2339        6.0576
Form Depth     (Mid-F)        :         7.2234        6.6196
Whole Depth    (Mid-F)        :         7.8300        7.3864
Form Depth     (Heel)         :         8.2955        7.5695
Whole Depth    (Heel)         :         9.3102        8.3683

Calculated Tooth Depths (Circular)
Pinion + Gear [Finishing]
Form Depth     (Toe)          :         5.3895        5.4378
Whole Depth    (Toe)          :         5.8151        5.9916
Form Depth     (Mid-F)        :         7.4759        6.8045
Whole Depth    (Mid-F)        :         7.5132        7.3306
Form Depth     (Heel)         :         9.4889        7.8399
```

```
Whole Depth    (Heel)         :         9.2882        8.3318
```

In the above, the following definitions apply:

- Form Depth: is the tooth depth between the end of the tooth fillet and the topland.
- Whole Depth: is the tooth depth between the tooth root and the topland.

Straight-bevel and Coniflex gears

```
Calculated Tooth Depths (Chordal)
Pinion + Gear [Finishing]
Form Depth     (Toe)          :         0.1284        0.1480
Whole Depth    (Toe)          :         0.1409        0.2143
Form Depth     (Mid-F)        :         0.0694        0.2619
Whole Depth    (Mid-F)        :         0.1227        0.3489
Form Depth     (Heel)         :         0.2699        0.1235
Whole Depth    (Heel)         :         0.3726        0.2245

Calculated Tooth Depths (Circular)
Pinion + Gear [Finishing]
Form Depth     (Toe)          :         0.1332        0.1442
Whole Depth    (Toe)          :         0.1426        0.2037
Form Depth     (Mid-F)        :         0.0664        0.2556
Whole Depth    (Mid-F)        :         0.1054        0.3334
Form Depth     (Heel)         :         0.2551        0.1211
Whole Depth    (Heel)         :         0.3332        0.2113
```

In the above, the following definitions apply:

- Form Depth: is the tooth depth between the end of the tooth fillet and the topland.
- Whole Depth: is the tooth depth between the tooth root and the topland.

Spur, Helical and Beveloid gears

```
Calculated Tooth Depths (Chordal)
Pinion + Gear [Finishing]
Form Depth     (Mid-F)        :         0.2626        0.2864
Whole Depth    (Mid-F)        :         0.3561        0.3509

Calculated Tooth Depths (Circular)
Pinion + Gear [Finishing]
Form Depth     (Mid-F)        :         0.2579        0.2835
Whole Depth    (Mid-F)        :         0.3451        0.3452
```

In the above, the following definitions apply:

- Form Depth: is the tooth depth at mid-facewidth between the end of the tooth fillet and the topland.

- Whole Depth: is the tooth depth at mid-facewidth between the tooth root and the topland.

Section 6 : Tooth fillet radii

Zerol, Spiral-bevel and Hypoid gears

```
Fillet Radius @ Mid-Face
Drive - Root Diameter        :        0.7687        0.9854
Coast                        :        0.7512        1.0248
Drive - Form Diameter        :        0.8746        0.9876
Coast                        :        0.8033        1.0577
```

In the above, the following definitions apply:

- Root Diameter: is the fillet radius when it becomes tangent to the root diameter;
- Form Diameter: is the fillet radius when it becomes tangent to the active profile section of the tooth at the form diameter.

Straight-bevel and Coniflex gears

```
Fillet Radius @ Mid-Face
Drive - Root Diameter        :        0.0850        0.0900
Coast                        :        0.0850        0.0900
Drive - Form Diameter        :        0.0850        0.0900
Coast                        :        0.0850        0.0900
```

In the above, the following definitions apply:

- Root Diameter: is the fillet radius when it becomes tangent to the root diameter;
- Form Diameter: is the fillet radius when it becomes tangent to the active profile section of the tooth at the form diameter.

Spur, Helical and Beveloid gears

```
Fillet Radius @ Mid-Face
Drive - Root Diameter        :        0.1070        0.0919
Coast                        :        0.1068        0.0917
Drive - Form Diameter        :        0.0802        0.0623
Coast                        :        0.0802        0.0623

Fillet Radius Pressure Angle @ Mid-Face
Drive - Root Diameter        :         80.82         80.38
Coast                        :         80.76         80.33
Drive - Form Diameter        :          6.56         13.47
Coast                        :          6.56         13.47
```

In the above, the following definitions apply:

- Root Diameter: is the fillet radius when it becomes tangent to the root diameter;
- Form Diameter: is the fillet radius when it becomes tangent to the active profile section of the tooth at the form diameter;
- Fillet Radius Pressure angle is the pressure angle of the fillet at the specified position; at the form diameter, if the pinion has a small number of teeth, its value should be close to zero; at the root diameter, it should be close to 90.

Section 7: Blank diameters:

Zerol, Spiral-bevel and Hypoid gears

```
Calculated Blank Diameters
Pinion + Gear [Finishing]
Root Diam. [Toe] Convex-IB    :      51.9013     113.0566
Root Diam. [Toe] Concave-OB   :      51.8033     113.0793
Root Diam. [Heel] Convex-IB   :      75.1729     157.0211
Root Diam. [Heel] Concave-OB  :      74.8510     156.9897
Tip  Diam. [Toe]              :      64.6874     118.1816
Tip  Diam. [Heel]             :      95.0707     164.0845

Calculated Blank Diameters
Pinion + Gear [Roughing]
Root Diam. [Toe]              :      51.2359     113.8237
Root Diam. [Heel]             :      73.2817     158.0013
```

From these, the actual tooth rootline angles can be obtained.

Straight-bevel and Coniflex gears

```
Calculated Blank Diameters
Pinion + Gear [Finishing]
Root Diam. [Toe] Convex-IB    :       1.4662       1.2957
Root Diam. [Toe] Concave-OB   :       1.4662       1.2960
Root Diam. [Heel] Convex-IB   :       1.5620       2.3849
Root Diam. [Heel] Concave-OB  :       1.5619       2.3849
Tip  Diam. [Toe]              :       1.3691       1.7740
Tip  Diam. [Heel]             :       2.1158       2.4776
```

From these, the actual tooth rootline angles can be obtained.

Spur, Helical and Beveloid gears

```
Calculated Blank Diameters
Pinion + Gear [Finishing]
Root Diam. [Toe]              :       3.4635       7.3093
Tip  Diam. [Toe]              :       4.1537       7.9996
```

Section 8: Tooth thickness

Zerol, Spiral-bevel and Hypoid gears

```
Calculated Chordal Tooth Thicknesses @ Mid-Face
Pinion + Gear [Finishing]
Theo. Finish Thickness        :         6.4014        3.1845
Meas. Addendum (Chordal)      :         6.0703        1.0923
Meas. Height (Chordal)        :         5.7579
Normal Thick. (Average)       :         6.4022        3.1845
Trans. Thick. (Average)       :         9.1090        3.5815
Normal Thick. @ Mean Point    :         4.8130        4.8777
Trans. Thick. @ Mean Point    :         6.6067        5.5182
Tooth Topland                 :         1.8851        2.4688

Calculated Chordal Tooth Thicknesses @ Mid-Face
Pinion + Gear [Roughing]
Meas. Addendum                :         6.0703        1.0923
Meas. Height                  :         5.7579
Normal Thick. (Average)       :         7.2861        4.6574
Trans. Thick. (Average)       :        10.3741        5.0556
```

Please refer to the above figures to properly identify the above quantities.

Straight-bevel and Coniflex gears

```
Calculated Chordal Tooth Thicknesses @ Mid-Face
Pinion + Gear [Finishing]
Theo. Finish Thickness        :         7.6638       10.4032
Meas. Addendum (Chordal)      :         4.7245        2.8750
Normal Thick. @ Mean Point    :         6.3930        6.6177
Trans. Thick. @ Mean Point    :         6.4395        6.6574
Trans. Thick. @ 30.002[mm]    :         6.4468
Trans. Thick. @ 30.002[mm]    :                       5.2117
Tooth Topland                 :         1.3347        2.4005
```

Please refer to the above figures to properly identify the above quantities.

In the above, the Trans. Thickness is given at both the Mean Point, i.e. mid-facewidth along the pitch cone, and at a given position along the outer-cone distance, on the pitch cone (30.0 [mm]) in the above, such that one knows exactly where measurement must take place.

Spur, Helical and Beveloid gears

```
Calculated Chordal Tooth Thicknesses @ Mid-Face
Pinion + Gear [Finishing]
Theo. Finish Thickness        :         0.2414        0.2416
```

```
Normal Thick. @ Mean Point    :         0.2415         0.2416
Trans. Thick. @ Mean Point    :         0.2415         0.2416
Tooth Topland                 :         0.1107         0.1193
```

Please refer to the above figures to properly identify the above quantities.

Section 9: Operating conditions.

Zerol, Spiral-bevel and Hypoid gears

```
Backlash (Min)                :         0.3048
Backlash (Max)                :         0.4064
Backlash (Calc @ M.Point)     :         0.1396
Backlash (Calc @ M.Poin[deg.] :         0.1336
Backlash (@Heel)              :         0.1659
Backlash (@Heel)       [deg.] :         0.1589
Bottom Clearance (Toe)        :         2.3486        4.5073
Bottom Clearance (Heel)       :         2.3489        2.6169
 (Gear Concave-OB E=0.00 P=-0.20 G=-0.50 [mm])
 (Gear Convex-IB  E=0.00 P=-0.20 G=-0.50 [mm])
```

The Backlash @ M. Point is the calculated actual operating backlash obtained from the current manufacturing and operating parameters.

Straight-bevel and Coniflex gears

```
Backlash (Min)                :         0.3048
Backlash (Max)                :         0.4064
Backlash (Calc @ M.Point)     :         0.1396
Backlash (Calc @ M.Poin[deg.] :         0.1336
Backlash (@Heel)              :         0.1659
Backlash (@Heel)       [deg.] :         0.1589
Bottom Clearance (Toe)        :         2.3486        4.5073
Bottom Clearance (Heel)       :         2.3489        2.6169
 (Gear Concave-OB E=0.00 P=-0.20 G=-0.50 [mm])
 (Gear Convex-IB  E=0.00 P=-0.20 G=-0.50 [mm])
```

The Backlash @ M. Point is the calculated actual operating backlash obtained from the current manufacturing and operating parameters.

The Bottom Clearance is that between the root of the current member and the tip of the mating member, at mid-facewidth.

Spur, Helical and Beveloid gears

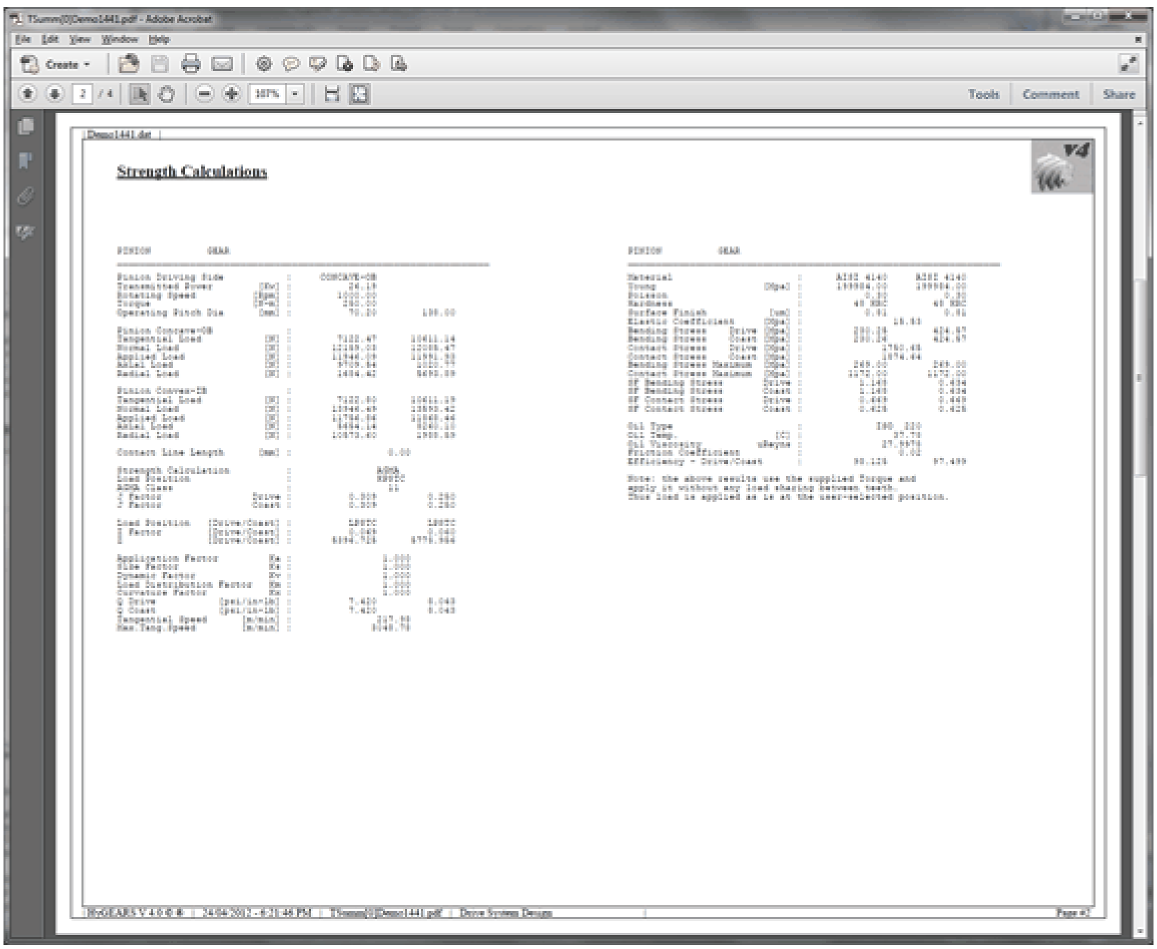
```
Backlash (Min)                :         0.0020
Backlash (Max)                :         0.0040
Backlash (Calc @ M.Point)     :         0.0000
Bottom Clearance              :         0.0375         0.0375
Oper. C. Distance             :         5.7690
```

The Backlash @ M. Point is the calculated actual operating backlash obtained from the current manufacturing and operating parameters.

The Bottom Clearance is that between the root of the current member and the tip of the mating member, at mid-facewidth.

Strength Calculations Summary

The Strength Calculations Summary gives an insight in the way the gear set is expected to perform in operation. The calculations results provided in the Strength Calculations Summary are based on the AGMA standards approach, except for the Contact Stresses which are calculated using Hertz theory and the meshing teeth principal curvatures and directions, without concern for load sharing.



The output for Zerol, Spiral-bevel, Hypoid, Straight-bevel, Coniflex, Spur, Helical and Beveloid gears is the same.

The Operating Summary is calculated and outputted only when both the pinion and gear data have been requested such as in a Graphics Summary, or when a Summary is requested through a Child Window "Summ" function button or through the Misc->Numerical Results function in which both the pinion and gear are displayed.

The Pinion Driving Side is, by default, the Concave (OB) tooth flank for spiral-bevel and hypoid gears, and the Left hand for straight-bevel, spur and helical gears. The Normal, Axial and Radial Loads are based on the Tangential Load, obtained from the applied torque and operating pitch diameters, the tooth surface normal at the PoC mean contact point and the normal, axial and radial directions calculated at this mean point.

Note that the outputted J Factors may be either forced by the user, when a positive value is entered in the Operating data page of the Geometry Summary, or calculated by HyGEARS, when a negative or null value is entered.

When the J Factor is calculated by HyGEARS, the load position may be set by the user (Operating data page) or set by the AGMA Class value:

AGMA Class < 9	Calculated at tooth Tip
AGMA Class > 8	Calculated at the HPSTC

The outputted J Factor may either be the actual calculated value, if the AGMA or AGMA-Mod models have been selected, or a derived value if the Aida+Terauchi model has been selected.

The following formulae are used to calculate the bending stresses:

AGMA: this is the traditional way, as per the following formula:

$$\sigma_b = \frac{2 T_p P_d K_a K_s K_m}{D F K_v K_x}$$

where:

Tp	is the torque seen by the pinion member,
Pd	is diametral pitch,
D	is the pitch diameter,
F	is the facewidth in the axial plane,
K	are the application factors.

In the above formula, the Contact Pattern is assumed to cover the full tooth facewidth in the axial plane, and the lesser of the pinion and gear facewidths is used.

AGMA-Mod: this is a variant of the above AGMA formula:

$$\sigma_b = \frac{2T_p P_d K_a K_s K_m}{D \frac{F}{2} K_v K_x}$$

where:

Tp is the torque seen by the pinion member,
Pd is diametral pitch,
D is the pitch diameter,
F/2 is half the facewidth,
K are the application factors.

In the above formula, the Contact Pattern is assumed to cover only half the tooth.

Aida+Terauchi: the following relation was developed by Aida and Terauchi for spur gears, but may also be used for Spiral Bevel gears, although with caution:

$$\sigma_{A+Tb} = \frac{2T_p}{DF}\left\{1+\frac{0.08T}{r_f}\right\} \frac{0.66S_b + 0.4\sqrt{S_b^2+36\tau^2} + 1.15S_c}{} \frac{K_a K_s K_m}{K_v K_x}$$

where:

Tp is the torque seen by the pinion member,
Pd is diametral pitch,
D is the pitch diameter,
F is the facewidth,
K are the application factors,
T is the tooth thickness at the fillet critical section,
rf is the fillet radius at the critical section,
X is half the tooth thickness at the point of loading,
H is the tooth height at the point of loading,
L is the pressure angle at the point of loading,

$$S_b = 6H\frac{\sin(\varphi_L)}{T^2}$$

$$S_c = \left\{1+6\frac{X}{T}\right\}\frac{\cos(\varphi_L)}{T}$$

$$\tau = \frac{\sin(\varphi_L)}{T}$$

If the K factors are equal to unity, an equivalent Geometry Factor Jeq is then obtained by the following equation:

$$J_{eq} = \frac{2 T_p P_d}{D F \sigma_{A+Tb}}$$

In the above, the stress concentration factor *kt* at the root of the tooth is given by:

$$k_t = \left\{ 1 + \frac{0.08 T}{r_f} \right\}$$

The I Factor, e.g. that used to calculate contact stresses, is a value obtained from the actual contact stresses calculated from the tooth surface curvatures and principle directions.

To obtain the I Factors, the contact stresses are first calculated by Hertz' theory; then the AGMA equation for contact stresses is reversed to extract an equivalent I Factor which is printed in the Strength Calculations below.

The fundamental surface durability formula is:

$$S_c = C_p \sqrt{\frac{W_t}{d F I} \frac{C_a C_s C_m C_f}{C_v}}$$

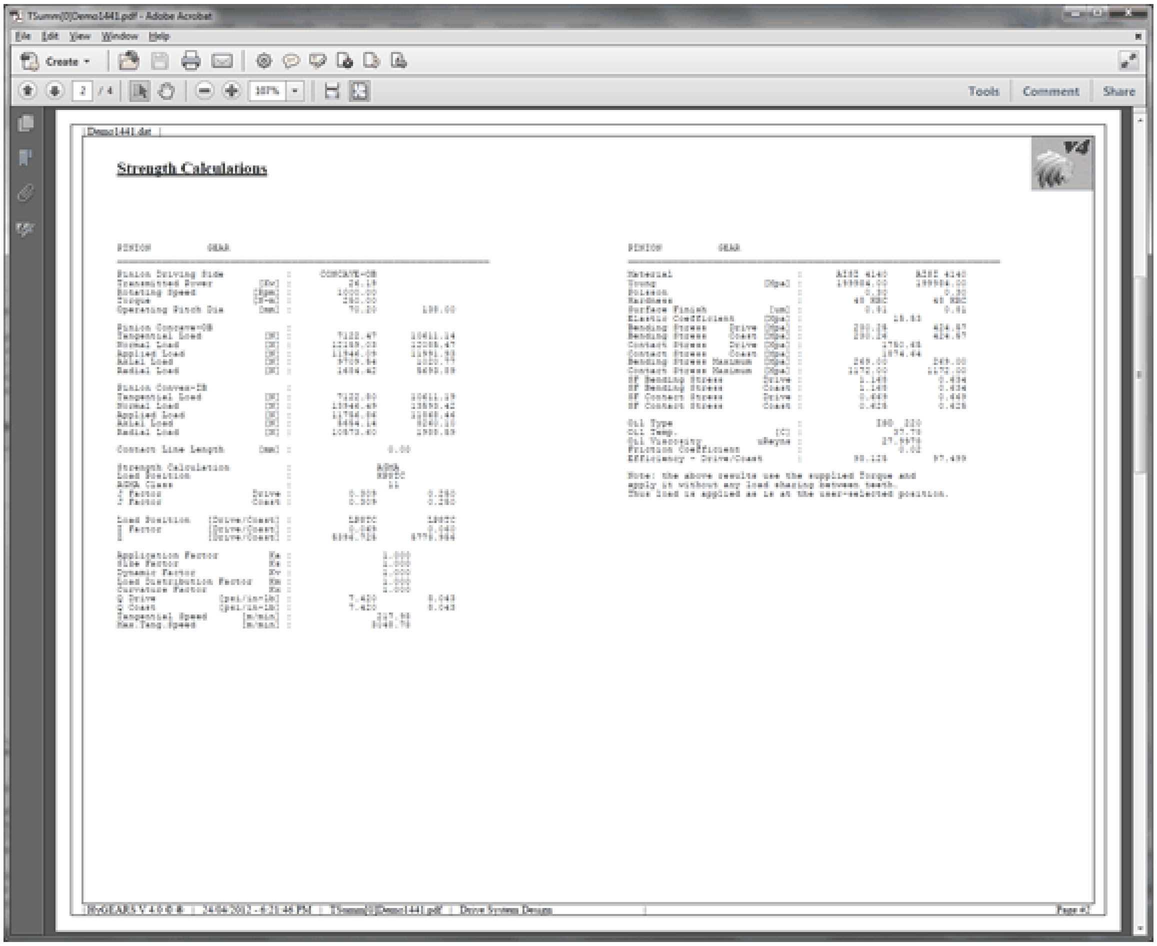
where:

Cp is the material elastic coefficient,
Wt is the tangential load,
I is contact geomety factor,
d is the pinion pitch diameter,
F is the facewidth,
C are the application factors.

If the contact stress is known, and equivalent *I* factor can be calculated as follows, assuming that the *C* application factors are all equal to unity:

$$I = C_p^2 \frac{W_t}{d F \sigma_c^2}$$

The Size Ks, Dynamic Kv and Curvature Kx Factors are automatically calculated when their entries have been left blank in the Operating data page (see Editing the Geometry Summary). Otherwise, the printed values are those inputted in the Operating Conditions Data page.

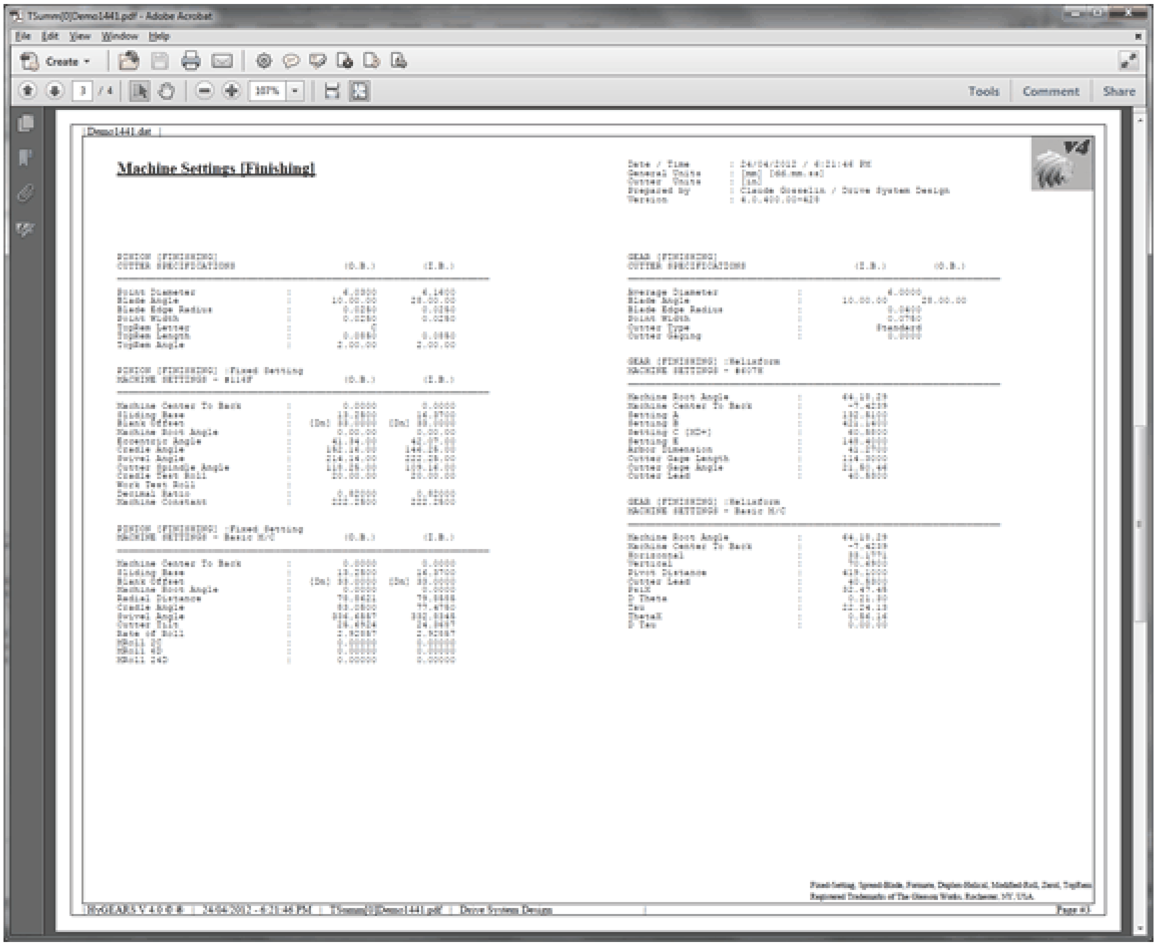


The Bending and Contact Stresses are calculated according to the inputted geometry. The Bending and Contact Stresses Maximum are the values associated to the selected material, given in the “material.fil” file.

The “SF Bending” and “SF Contact Stresses” is the Factor of Safety, e.g. the ratio of the Maximum, or allowable, stress to the calculated stress. A safety factor larger than 1.0 should normally be obtained.

Machine Settings Summary

The Machine Settings [Finishing] Summary gives all the machine adjustments necessary to cut the pinion and gear as modeled. Cutter data is presented first, then machine adjustments are given.



The Machine Settings Summary identifies the machine in use. HyGEARS also outputs the Basic Machine Settings.

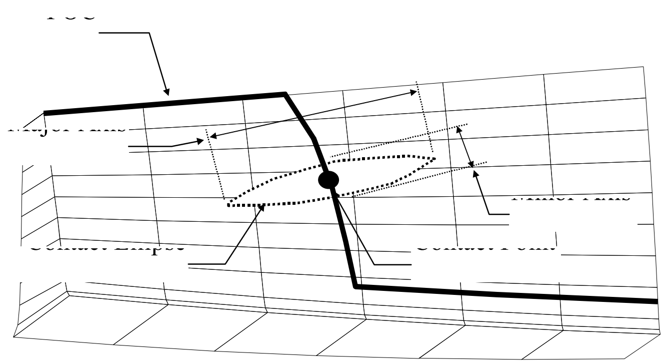
Machine Settings [Roughing] Summary

When roughing machine settings are present, the Machine Settings [Roughing] Summary is presented in the same manner as the Finishing Summary, but on a separate page.

13.2.9 Hertz Contact Stresses

When two contacting surfaces such as those of spiral-bevel or hypoid gear teeth are pressed one against the other, the surfaces deform and the theoretical contact point becomes an ellipse, as shown in the figure below.

Hertz developed the theory to calculate the dimensions of the contact ellipse and the maximum compressive stress, from the pinion and gear tooth surfaces principal curvatures, the angle between these principal curvatures, the applied load and the respective pinion and gear material characteristics.



No load sharing calculation is performed here: the applied torque is calculated from the pinion speed and transmitted power, which can be edited in the Operating data page when editing the pinion or gear Summary, and applied directly to the teeth. The data is presented in three different tables.

The result header identifies the source of the surface elliptic integrals equations and factors. For example, Roark's data was used here.

```
_______________________________________________

             HyGEARS V 4.0 © ®

Contact Stresses and Axes (Roark) - Demo1441.dat

Tooth :     0
Pinion [Finishing] + Gear [Finishing]
Pinion Concave-OB [NoEr]
_______________________________________________

Date / Time        : 1/1/2012 / 10:44:10 AM
General Units      : [mm] [dd.mm.ss]
Cutter  Units      : [in]
Prepared by        : John Who
Version            : 4.0.401.70

Torque :   202.07  [N-m]
________________________
```

Table 1 contains the respective pinion and gear contact point radii, which are used to calculate the transverse load from the applied torque.

Contact Radius [mm]

Position	Pinion	Gear
[Pinion Tooth Root]		
1	34.0517	69.7337
2	34.3442	69.2497
3	34.8051	68.7843
4	35.4633	68.3260
5	36.2806	67.8686
6	37.2808	67.4096
7	36.3544	65.3885
8	35.1625	63.1495
9	34.0190	60.9663

Table 2 contains the normal tooth surface loads, which are obtained from the calculation of the angle between the tooth surface normal and the transverse plane in which the torque vector is defined, the minor and major contact ellipse axes, the contact deformation and the resulting contact stresses, in the current units.

The Direction value is the angle made between the direction of the major radius of curvature of the pinion member and the direction of the major axis of the contact ellipse. A positive value denotes a clockwise rotation of the major axis of the contact ellipse about the tooth flank normal.

Contact Stresses and Axes

Position	Load [N]	Minor Axis [mm]	Major Axis [mm]	Direction	Deform. [mm]	Stress [Mpa]
[Pinion Tooth Root]						
1	9627.72	0.9384	12.7001	2.0844	0.02659	1543
2	9691.15	1.0763	12.1884	2.8065	0.02648	1411
3	9756.64	1.2194	11.7143	3.5119	0.02652	1305
4	9825.02	1.3559	11.4769	4.5966	0.02633	1206
5	9896.23	1.5105	10.9925	5.5954	0.02651	1139
6	9971.31	1.6439	10.8845	7.2068	0.02625	1065
7	10205.11	1.6368	10.9679	7.0728	0.02674	1086
8	10483.84	1.6104	11.1185	6.7132	0.02735	1119
9	10781.52	1.5846	11.2829	6.4230	0.02797	1152

Table 3 contains the respective pinion and gear tooth surface principal radii of curvature at each contact point, and the angle between the directions of the pinion and gear principal curvatures.

An entry equal to 999999 indicates that the radius of curvature is infinite at the considered point. In the following table for example, since the gear cutting process is Helixform, the gear minimum radius of curvature (profilewise) will be infinite. The Position entry indicates the sequence number of the considered point along the PoC.

```
Rad. of Curvature [mm]
______________________

                       Pinion                   Gear

Position  |     Ray Min.   Ray. Max.   Ray. Min    Ray. Max   Angle Between
___________________________________________________________________________
[Pinion Tooth Root]

    1          16.7418    -84.6173     999999     75.1852       9.426
    2          21.2786    -85.5482     999999     75.3232      10.002
    3          26.2360    -86.5196     999999     75.4700      10.131
    4          31.8956    -87.8908     999999     75.6366      10.948
    5          38.0649    -89.3159     999999     75.8225      11.135
    6          45.0019    -91.1935     999999     76.0237      12.246
    7          43.9188    -91.2725     999999     76.0567      12.337
    8          41.7788    -91.1613     999999     76.0726      12.320
    9          39.8040    -91.1355     999999     76.0900      12.396
```

13.2.10 History - Contact Pattern Development

The Contact Pattern Development History gives in tabular form the sequence of corrective operations performed when developing a given gear set using the VH>> function (see Graphic Display Functions, Contact Pattern Development).

The History is presented in a single table, as follows:

Date	date when the modification was performed;
Time	time when the operation was performed;
Process	cutting process: Finishing;
Tooth Flank	the pinion tooth flank on which the action was performed;
E, P, G	the inputted V-H settings, in the current units ([mm] here).

```
____________________________________________________

                HyGEARS V 4.0 © ®

C.Pattern Development History  - PINION Demo1441.dat

____________________________________________________

Date / Time        : 1/1/2012 / 10:47:39 AM
General Units      : [mm] [dd.mm.ss]
Cutter  Units      : [in]
Prepared by        : John Who
Version            : 4.0.401.70
```

```
            Date        Time       Process       Tooth Flank           E         P         G
      [mm]
            ________________________________________________________________________________
      —

            1/1/2012 10:47:17 AM [Finishing]   Nominal Convex-IB
                                               Nominal Concave-OB

            1/1/2012 10:47:32 AM [Finishing]   Concave-OB             0.05      0.01      0.02
```

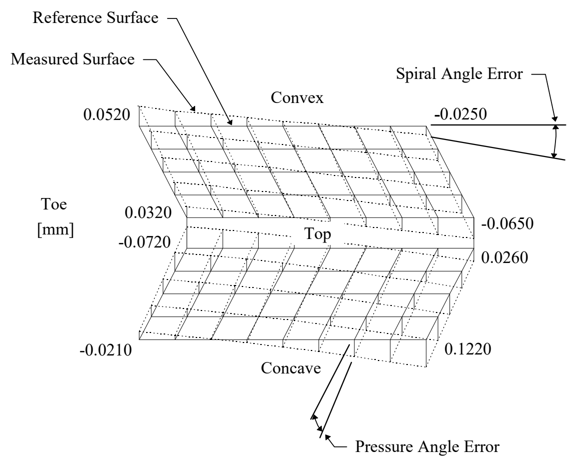
13.2.11 History - Corrective Machine Settings

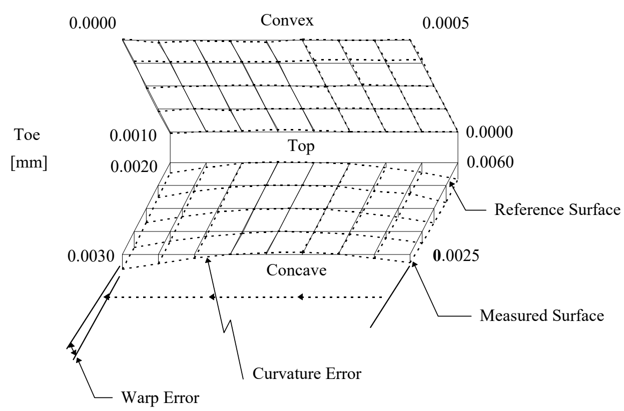
The Corrective Machine Settings (Closed Loop) History gives in tabular form the sequence of corrective operations performed on a given pinion or gear. The History is presented in three tables, as follows:

The *first table* lists the following data:

#	the sequence number of the correction;
Date	date when the modification was performed;
Time	time when the operation was performed;
Process	cutting process, Roughing or Finishing;
F. Measure	measurement data file name;
Corr.Order	correction order, 0, 1st, 2nd
Tooth Flank	Concave, Convex or Concave+Convex if both tooth flanks were treated simultaneously.

```
                  _________________________________________________

                  Date / Time        : 1/1/2012 / 10:49:46 AM
                  General Units      : [mm] [dd.mm.ss]
                  Cutter  Units      : [in]
                  Prepared by        : John Who
                  Version            : 4.0.401.70


       #      Date        Time       Process      F.Measure    Corr.Order    Tooth Flank
       __________________________________________________________________________________

              1/1/2012 10:49:15 AM [Finishing]   demo_g1.mes                 Nominal Concave-
OB
                                                                             Nominal Convex-IB
       [2/3]  1/1/2012 10:49:18 AM [Finishing]   demo_g1.mes      1          Concave-
OB+Convex-IB
       [3/3]  1/1/2012 10:49:38 AM [Finishing]   demo_g2.mes      1          Concave-
OB+Convex-IB
```





The *second table* provides, for each correction, the evolution of the surface statistics as corrective action is taken:

#	the sequence number of the correction;
Process	cutting process, Roughing or Finishing;
Tooth Flank	Concave or Convex;
E.Spir	spiral angle error;
E.Press	pressure angle error;
E.Warp	warp error;
E.Curv	crowning error.

```
      #     #Tooth   Process      Tooth Flank       E.Spir.   E.Press.  E.Warp
E.Curv.
      ___________________________________________________________________________
__

                     [Finishing]  Concave-OB        0.02.04  -0.03.28  -0.05.06  -
0.00.14
```

```
                                       Convex-IB        0.03.00    0.00.35    0.01.34
0.00.03
      [2/3]   1       [Finishing]  Concave-OB        0.02.04   -0.03.28   -0.05.06   -
0.00.14
                                       Convex-IB        0.03.00    0.00.35    0.01.34
0.00.03
      [3/3]   1       [Finishing]  Concave-OB       -0.03.43    0.00.20    0.03.19
0.00.02
                                       Convex-IB       -0.01.50    0.03.00    0.06.43   -
0.00.03
```

The *third table* provides, for each correction, whether the correction was made in Actual vs Actual mode, and the corresponding reference Measurement data file if so:

#	the sequence number of the correction;
AcVsAct	a “x” identifies that the correction was done in Actual vs Actual mode;
F.Actual	reference Measurement data file name;
Objectives	the currently corrected errors.

```
      #      ActVsAct      F.Actual      Objectives
      ________________________________________________________________________________
____


      [2/3]                              Spiral A   Pressure   Bias      Tooth Ta   Tooth
Th
      [3/3]                              Spiral A   Pressure   Bias      Tooth Ta   Tooth
Th
```

13.2.12 HyGEARS Measurement Data File Format

HyGEARS uses its own measurement data file format, different from that of Gleason or CMM manufacturers. Tools are offered to convert any CMM measurement data file into a HyGEARS measurement data file (see Measurement and Compensation).

In the HyGEARS measurement data file, all numbers are in free format and must be separated by a comma; data lines must be entered on a single line and must be terminated by a combination of carriage return and linefeed.

The HyGEARS measurement data file format is as follows:

```
***HYGEARS MEASUREMENT DATA***
1000
; GEAR
; CMM   : Zeiss [ThErr:0.0000]
; #Meas: 1   /0/0/0/0/
; Date : 12/30/2012 11:15:15 AM
; By    : John Who/Some Good Company.
```

```
; Files: e:\vb\demo\demo_g.ram/E:\VB\Demo\Demo_g2.rfd
; Units: [mm]
; MDist: 62.0000 [mm]
; DelZ :
; Pnts :
; UNUSD:
; UNUSD:
;
1,1,5,6,10,10,9,9
   59.0821        3.1852      -33.1184
   59.5320        3.7958      -32.1576
   59.9768        4.4168      -31.2040
….
   77.5172       -0.2080      -41.5493
   78.0874       -0.3590      -40.2432
   78.6578       -0.5093      -38.9373
   79.2282       -0.6592      -37.6313
0    0
1
```

- the *1st line* identifies the HyGEARS measurement data file; if the first line does not match the standard header, then HyGEARS will test if the files are of known formats, such as RAM or RFD; if so, HyGEARS will automatically enter a conversion module described later in this section;

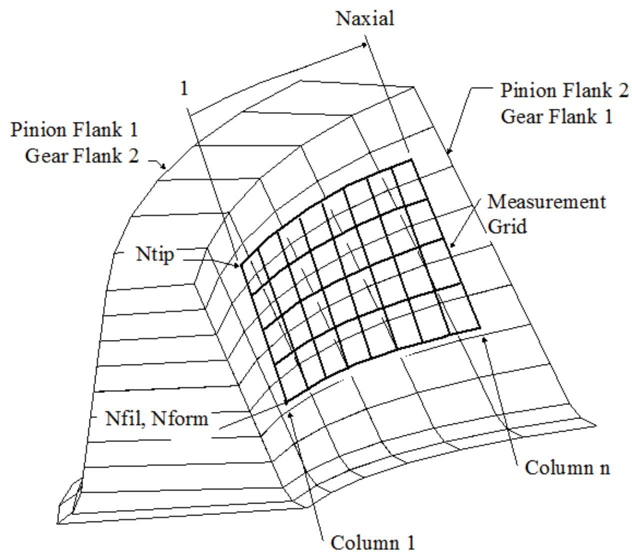
- the *2nd line* is a file version number. At the present time, it should be 1000. If different, an error will be generated and HyGEARS will refuse it;

- the *next 12 lines* are comment lines which give a number of informations about the contents and source of the current measurement data file. The number of comment lines is limited to 12, and each comment line must start by a semi-colon character (;). The signification of the comment lines is:

PINION/GEAR	the member to which the file applies;
CMM	the CMM from which the data is extracted (Zeiss/MdM/GAGE, etc.);
#Meas	the number of datasets within the file;
Date	the date and time on which the file was created;
By	operator and company;
Files	the source files (CMM output files);
Units	the units of the datasets measurements;
MDist	the mounting distance of the Pinion or Gear member;
DelZ	unused;
Pnts	unused;
UNUSD	1st free user comment line;
UNUSD	2nd free user comment line.

In HyGEARS, both the fillet and profile parts of the teeth are calculated, but since the cutter Geometry for the fillet is different from that used for the profile, the simulation routines are different and the way to know that a given point falls either into the fillet or the profile areas of the tooth is to identify fillet and profile storage matrix locations properly and independently.

- Therefore, the *15th line* identifies the internal HyGEARS measurement data storage matrix locations in the following manner:



Nfil_1, Nform_1, Ntip_1, Ntip_2, Nform_2, Nfil_2, Naxial_1, Naxial_2

  - *Nfil_1* identifies the storage location of the first fillet measurement data point and this number should always be a one (1); by convention, Nfil_1 is on the pinion convex/gear concave tooth flank, for left and right hand gear sets;

  - *Nform_1*, also a (1) in the above example, identifies the storage location of the first profilewise measurement data point for the pinion convex/gear concave tooth flank, just after the fillet, and this number should always be equal to 1 + the number of measured fillet points; if, as in the present example, no measurement was made in the fillet area, Nform_1 must be equal to 1;

  - *Ntip_1* is the storage location of the last profilewise point, thus near tooth tip, for the pinion convex/gear concave tooth flank; this number should always be equal to Nform_1 + the number of profilewise data points -1; in the current example, 5 profile measurement data points were taken, and since Nform_1 is 1, the address of the last profilewise pinion convex/gear concave point Ntip_1 must be 5;

- *Ntip_2* is the storage location of the last profilewise point, near tooth tip, for the pinion concave/gear convex tooth flank; this number should always be equal to Ntip_1 + 1; in the current example since Ntip_1 is equal to 5, the address of the last profilewise pinion concave/gear convex Ntip_2 point must be 6;

- *Nform_2* is the storage location of the first profilewise point, near tooth fillet, for the pinion concave/gear convex tooth flank; this number should always be equal to Ntip_2 + the number of profilewise measurement data points -1; in the current example since Ntip_2 is equal to 6, the address of the first profilewise pinion concave/gear convex point Nform_2 must be 10 because there are 5 profilewise measurement data points;

- *Nfil_2* is the storage location of the first fillet measurement data point, for the pinion concave/gear convex tooth flank; this number should always be equal to Nform_2 + the number of fillet measurement data points -1; in the current example since Nform_2 is equal to 10, the address of the first fillet pinion concave/gear convex point Nfil_2 must be 10 since there are no fillet measurement data points;

- *Naxial_1* and *Naxial_2* are the number of axial measurement data points, respectively for the pinion convex/gear concave tooth flank, and the pinion concave/gear convex tooth flanks; in the above example, since 9 points were measured axially on both tooth flanks, Naxial_1 and Naxial_2 must be 9, 9.

- the *next n lines*, n being equal to the total number of measurement data points (90 in the above example as there is one 5x9 grid for each tooth flank) give the measurement coordinate data X, Y and Z, column by column, from *Nfil* to *Ntip* on tooth flank 1 (pinion convex/gear concave), and then from *Nfil* to *Ntip* on tooth flank 2 (pinion concave/gear convex), as shown below:

- the *2 last lines* respectively give the compensating radii of the measurement probe sphere in the same units as the measurement data points, for the coast (pinion convex/gear concave) and drive tooth flanks, and the total number of measurement data sets in the data file; in the example above, since there is only one measurement data set, the last number is equal to 1. If there were 2 measurement data sets, the measurement data file would look as follows:

```
•••HYGEARS MEASUREMENT DATA•••
1000
; GEAR
; CMM  : Zeiss
; #Meas: 4
; Date : 05-26-1996 11:25:01
```

```
; By   : John Doe/Gear Perfect Corp.
; Files: c:\hygears\demo\demofing.ram/c:\hygears\demo\demo_g1.rfd; ...
; Units: [mm]
; MDist: 61.9989[mm]
; DelZ :
; Pnts :
;
;
1,1,5,6,10,10,9,9
59.08232, 3.189249, -33.12116
59.53289, 3.811009, -32.16794
59.97754, 4.430684, -31.21338
.
.
.
78.39951,-6.285560, -38.93511
78.95784,-6.476131, -37.62926
0.03320, 0.03320
2
1,1,5,6,10,10,9,9
59.08232, 3.189249, -33.12116
59.53289, 3.811009, -32.16794
59.97754, 4.430684, -31.21338
61.80400, 2.814287, -33.37330
.
.
.
78.39951,-6.285560, -38.93511
78.95784,-6.476131, -37.62926
0.03320, 0.03320
2
```

thus, the header is repeated at the beginning of each data set, and so on for each additional data set, while the last number of each data set identifies the total number of data sets in the data file. For the current HyGEARS version, only four data sets are allowed in a data file; any data set beyond the permitted four will be ignored.

13.2.13 LTCA (Loaded Tooth Contact Analysis)

HyGEARS can calculate how the load is shared between simultaneously meshing tooth pairs by establishing the relative torque share taken up by each tooth pair and the corresponding rotation caused to each tooth pair.

After establishing initial values for load sharing based on the tooth bending stiffness, HyGEARS uses an iterative Newton-Raphson scheme to establish the load share of each tooth pair. The following output is a Summary of the results of all the calculation steps and geometric values used in the calculation of the Loaded Tooth Contact Analysis:

The first part is a header identifying the:

- geometry data file;

- pinion and gear cutting modes (roughing or finishing);
- pinion driving side;
- date and time the output was generated;
- the units in use;
- the HyGEARS version number;
- applied torque;
- the gearset speed ratio;
- the tooth bending stiffness calculation method;
- the contact deformation and stress calculation method;
- the Ltca stiffness switches (body shear, tooth base rotation, consider tooth base rotation for adjacent teeth);
- the current operating conditions, i.e. positional and angular errors; for spur and helical gears, E is replaced by the operating center distance;
- whether pinion and gear bearing stiffnesses are used, and what are the resulting displacements and misalignment.

```
___________________________________________

            HyGEARS V 4.0 © ®

Loaded Tooth Contact Analysis- Demo1441.dat

Pinion [Finishing] + Gear [Finishing]
Pinion Concave-OB [NoEr]
___________________________________________

Date / Time        : 1/1/2012 / 11:02:07 AM
General Units      : [mm] [dd.mm.ss]
Cutter  Units      : [in]
Prepared by        : John Who
Version            : 4.0.401.70


Torque      [N-m] :   202.070
Speed Ratio       :     2.929
Friction Coeffici :    -0.020

Bending Stiffness :  Westinghouse/AGMA
Contact Stiffness :  Roark


Body Shear        :  Yes
Tooth Base Rotati :  Yes
Adjacent Teeth    :  Yes

E            [mm] :     0.000
P            [mm] :     0.000
G            [mm] :     0.000
DSigma      [deg] :     0.000
DAlign      [deg] :     0.000
```

```
RadlP        [mm] :     0.000
RadlG        [mm] :     0.000

Bearing Stiffness
--- Pinion        :  Yes
... DZ1      [mm] :    0.0266
... DZ2      [mm] :    0.0065
... DZ3      [mm] :    0.0225
... DSigma  [deg] :    0.1165
... DAlign  [deg] :   -0.0097
--- Gear          :  Yes
... DZ1      [mm] :    0.0330
... DZ2      [mm] :   -0.0126
... DZ3      [mm] :    0.0019
... DSigma  [deg] :   -0.2396
... DAlign  [deg] :    0.0410
```

The first two to six tables give, for each PoC contact point from pinion tooth root to tip, the calculated pinion and gear bending stiffnesses for each tooth considered in the analysis. Basically, the pinion and gear Tooth Bending stiffness is always printed in the first two tables; if the Tooth Base Rotation switch is on, the Tooth Base Rotation stiffness is printed in the next two tables; finally, if the Body Shear switch is on, the Body Shear Stiffness is printed in the next two tables.

Tooth Bending Stiffness Pinion[N/mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2	Total
[Pinion Tooth Root]						
1	3519558.00	2480590.00	3498679.00			9498826.00
2	2341933.00	3184841.00	1546660.00			7073434.00
3		2884231.00	3264400.00	2606655.00		8755286.00
4		2438119.00	2943447.00	1790670.00		7172236.00
5		2120750.00	3779765.00	2075076.00		7975591.00
6			3306136.00	2813191.00	3120159.00	9239485.00
7			2644989.00	3149867.00	2315468.00	8110323.00
8			2272595.00	3358858.00	1701220.00	7332673.00
9			1933251.00	3479880.00	2542422.00	7955552.00

Tooth Bending Stiffness Gear[N/mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2	Total
[Pinion Tooth Root]						

```
    1      1086648.00    796299.90    228504.00
2111452.00
    2      1698664.00   1018482.00    662210.90
3379357.00
    3                   1449644.00    908835.40    426697.20
2785177.00
    4                   1691569.00    972651.50    607995.80
3272216.00
    5                   1730538.00   1131431.00    738078.20
3600047.00
    6                                1049917.00    844053.00    312604.90
2206575.00
    7                                1676309.00    931608.40    491394.30
3099312.00
    8                                1703779.00   1051520.00    684401.80
3439700.00
    9                                1763580.00   1079819.00    805177.40
3648576.00


                       Body Shearing Stiffness Gear[N/mm]
                       ----------------------------------
  Pos        Tooth -2     Tooth -1      Tooth 0     Tooth +1     Tooth +2
Total
___________________________________________________________________________________
___
[ Pinion Tooth Root ]
    1        95530.21    103130.90     62258.97
260920.10
    2       107923.00     93297.41     74394.12
275614.50
    3                     97266.79    127248.50     67804.43
292319.80
    4                    104716.30     92768.11     72877.17
270361.60
    5                    116781.00     94601.86     90653.34
302036.20
    6                                  96291.65    113364.90     64612.12
274268.70
    7                                  97819.74    114944.10     69614.66
282378.50
    8                                 110234.50     93678.96     79149.88
283063.40
    9                                 124864.60     95671.77    105033.50
325569.90


                      Base Rotation Stiffness Pinion[N/mm]
                      ------------------------------------
  Pos        Tooth -2     Tooth -1      Tooth 0     Tooth +1     Tooth +2
Total
___________________________________________________________________________________
___
[ Pinion Tooth Root ]
    1       846419.90   1876308.00    813870.90
3536598.00
    2       403026.80   1452341.00   1281619.00
3136987.00
```

3		448452.50	2375406.00	1027620.00		3851479.00
4		396102.30	1559986.00	1223148.00		3179237.00
5		418153.60	1187048.00	1618093.00		3223294.00
6			567036.20	2088095.00	904572.80	3559703.00
7			381209.60	2084421.00	1097395.00	3563026.00
8			408018.50	1374743.00	1380036.00	3162797.00
9			430668.60	794478.80	1915680.00	3140827.00

Base Rotation Stiffness Pinion[N/mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2	Total
[Pinion Tooth Root]						
1	846419.90	1876308.00	813870.90			3536598.00
2	403026.80	1452341.00	1281619.00			3136987.00
3		448452.50	2375406.00	1027620.00		3851479.00
4		396102.30	1559986.00	1223148.00		3179237.00
5		418153.60	1187048.00	1618093.00		3223294.00
6			567036.20	2088095.00	904572.80	3559703.00
7			381209.60	2084421.00	1097395.00	3563026.00
8			408018.50	1374743.00	1380036.00	3162797.00
9			430668.60	794478.80	1915680.00	3140827.00

Base Rotation Stiffness Gear[N/mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2	Total
[Pinion Tooth Root]						
1	474832.00	351117.20	101497.00			927446.20
2	553906.60	442215.90	215014.90			1211137.00
3		506631.40	465342.40	153371.80		1125346.00
4		548766.30	417598.90	200824.70		1167190.00

5		569174.30	502885.30	292021.30		1364081.00
6			451822.60	399587.30	123509.50	974919.40
7			537710.80	448305.00	170305.50	1156321.00
8			557612.00	459961.80	237539.00	1255113.00
9			583451.40	470554.30	360128.00	1414134.00

The next table gives the gear rotation due to initial profile separation for each PoC contact point on tooth pair 0, in arc-seconds.

Tooth Separation - Gear Rotation - Seconds

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.00	92.50	243.00		
2	41.22	0.00	160.22		
3		0.00	132.35		
4		2.87	0.00	198.43	
5		43.18	0.00	160.01	
6		110.27	0.00	143.04	
7			0.00	90.21	242.07
8			26.33	0.00	167.94
9			125.08	0.00	139.35

The next 2 tables give the calculated initial and final tooth surface normal load sharing between meshing tooth pairs, for each PoC contact position on tooth pair 0. The total load is summed up at the end of each line:

Initial Load Share

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2	Total
[Pinion Tooth Root]						
1	2421.95	2745.88	0.00			5167.82
2	0.00	5157.75	0.00			5157.75
3		5113.09	87.13			5200.22
4		1394.22	3724.28	0.00		5118.51
5		236.43	4920.41	0.00		5156.84

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2	Total
6		0.00	5168.71	0.00		5168.71
7			2853.48	2289.22		5142.70
8			502.18	4648.74	0.00	5150.92
9			0.00	5175.29	0.00	5175.29

Final Load Share

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2	Total
[Pinion Tooth Root]						
1	3349.72	1791.92	0.00			5141.64
2	0.00	5157.75	0.00			5157.75
3		5200.22	0.00			5200.22
4		2013.60	3131.11	0.00		5144.71
5		751.07	4425.71	0.00		5176.78
6		0.00	5168.71	0.00		5168.71
7			3720.70	1406.06		5126.75
8			1110.84	4062.17	0.00	5173.01
9			0.00	5175.29	0.00	5175.29

The next table gives the calculated efficiency under load, i.e. the ratio of useful work to the total work, which includes the sliding friction along the meshing tooth profiles.

Efficiency Ltca

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	94.62	100.00	100.00		
2	99.49	95.29	100.00		
3		93.15	100.00	100.00	
4		94.62	100.00	100.00	
5		100.00	96.60	100.00	
6			96.36	100.00	100.00
7			95.64	100.00	100.00
8			94.20	96.38	100.00
9			100.00	99.83	100.00

The next table gives the calculated coefficient of friction; if the coefficient of friction was entered as a negative value in the Operating data page of the Geometry Summary Editor, HyGEARS uses a lookup table based on the current sliding, load, oil and temperature conditions and retrieves an actual coefficient of friction which is displayed below; the lookup table is built from Prof. Hans Winter of T.U. Munich, who ran numerous experimental cases of spur gears with different modules, loads, speeds, oils and operating temperatures to obtain averaged coefficients of friction.

Friction Coefficient Ltca

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.03				
2	0.03	0.04			
3		0.03			
4		0.02			
5			0.03		
6			0.03		
7			0.03		
8			0.03	0.07	
9				0.03	

The next table gives how much of the maximum length of the instant line of contact is actually used by the LTCA Contact Pattern. The maximum length of the instant line of contact is limited by the tooth boundaries.

% Tooth

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	34.50				
2	20.71	67.40			
3		34.79			
4		32.28	92.42		
5		20.45	66.74		
6			41.83		
7			34.54		
8			24.21	72.73	
9				39.28	

The next two tables give, for the pinion and gear, the calculated J Factors, even if they are not used.

J Factor - Pinion

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.2954				
2	0.2796	0.5184			

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
3		0.3253			
4		0.2881	0.7078		
5		0.2793	0.5133		
6			0.3814		
7			0.2937		
8			0.2817	0.5566	
9				0.3620	

J Factor - Gear

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.7435				
2	0.7816	0.3288			
3		0.6363			
4		0.7625	0.2782		
5		0.7821	0.3302		
6			0.4353		
7			0.7497		
8			0.7773	0.3186	
9				0.5047	

The next two tables give, for the pinion and gear, the calculated bending stresses, calculated according to the strength model selected for the LTCA analysis (Load function button).

Bending Stress - Pinion - [Mpa]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	451.56				
2	189.97	104.29			
3		415.27			
4		278.40	37.48		
5		187.69	107.17		
6			350.32		
7			453.88		
8			210.28	83.75	
9				379.08	

Bending Stress - Gear - [Mpa]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	341.64				
2	159.77	244.88			
3		394.26			
4		214.86	138.02		
5		157.59	248.38		
6			476.28		
7			338.51		
8			178.98	216.69	

9				438.27	

The next table gives the contact stress at each PoC contact for tooth pair 0.

Contact Stresses [Hertz] [Mpa]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	777				
2	575	933			
3		826			
4		682	1177		
5		572	891		
6			770		
7			620		
8			508	971	
9				868	

The next 2 tables give the contact ellipse dimensions at each PoC contact for tooth pair 0.

Minor Contact Axis [Hertz] [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.5444				
2	0.4717	0.2973			
3		0.5216			
4		0.4575	0.2275		
5		0.4721	0.2998		
6			0.4538		
7			0.5453		
8			0.4307	0.2783	
9				0.4759	

Major Contact Axis [Hertz] [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	21.9483				
2	19.0196	11.9875			
3		21.0298			
4		18.4465	9.1716		
5		19.0355	12.0891		
6			18.2969		
7			21.9882		
8			17.3640	11.2193	
9				19.1868	

The next 4 tables give the pinion and gear minimum and maximum radii of curvature, at each PoC contact for tooth pair 0. A negative curvature value indicates that the center of curvature lies outside of the tooth. A curvature value of 999999 indicates that the tooth flank is straight, such as for Formate and Helixform gear members.

Pinion Min. Curvature Radius [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	37.62877	4.87646	1.53276		
2	44.34564	16.85702	2.50937		
3		33.77793	3.25353		
4		35.98030	9.06915	1.94949	
5		44.63241	17.08792	2.52625	
6		57.08331	26.91601	3.01249	
7			37.85632	4.97958	1.54438
8			33.64520	15.16502	2.40280
9			29.46528	29.22726	3.10648

Pinion Max. Curvature Radius [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	-77.21825	-72.60094	-73.93405		
2	-78.19602	-73.67933	-73.19936		
3		-76.64690	-72.90965		
4		-77.07355	-72.67545	-73.56075	
5		-78.22865	-73.72495	-73.19190	
6		-79.32665	-75.51125	-72.98342	
7			-77.25015	-72.59405	-73.91869
8			-76.83239	-73.38319	-73.26030
9			-76.35978	-75.90853	-72.94934

Gear Min. Curvature Radius [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	999999	999999	999999		
2	999999	999999	999999		
3		999999	999999		
4		999999	999999	999999	
5		999999	999999	999999	
6		999999	999999	999999	
7			999999	999999	999999
8			999999	999999	999999
9			999999	999999	999999

Gear Max. Curvature Radius [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	75.50192	74.60796	74.39672		
2	75.78474	74.95483	74.46535		
3		75.39819	74.54752		
4		75.52741	74.74171	74.42137	
5		75.79292	74.96096	74.46555	
6		76.15414	75.21796	74.51382	
7			75.50777	74.61154	74.39666
8			75.54816	74.91022	74.45542
9			75.58230	75.27953	74.52497

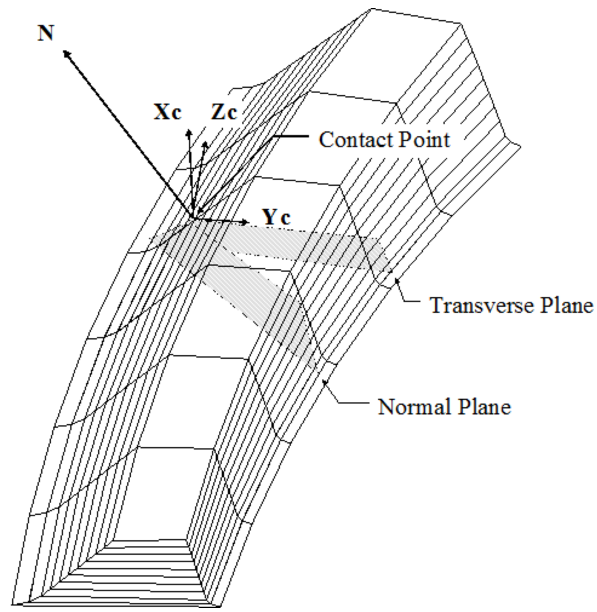
The next 2 tables give the pinion and gear contact radii at each PoC contact for tooth pair 0.

Pinion Contact Radii [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	37.2993	33.9924	38.4417		
2	34.4748	34.8550	36.1578		
3		36.8310	33.8929		
4		36.1528	34.1942	37.4952	
5		34.4309	34.8725	36.1226	
6		32.7364	35.9524	34.7606	
7			37.3263	33.9982	38.4149
8			34.7911	34.7215	36.4280
9			32.3205	36.2559	34.4609

Gear Contact Radii [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	67.2329	69.7744	79.9983		
2	61.7366	68.6100	75.0682		
3		67.4820	70.0245		
4		64.9626	69.2671	77.9551	
5		61.6523	68.5925	74.9899	
6		58.3939	67.9493	71.9568	
7			67.2185	69.7600	79.9403
8			62.3450	68.7428	75.6516
9			57.5940	67.7879	71.2893



The next 2 tables give the pinion bending displacements, respectively in the normal plane at the contact point, and then in the transverse plane in the Yc direction, at each PoC contact point for tooth pair 0.

Pinion Normal Bending Displacements [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.06903660				
2	0.02546540	0.01656857			
3		0.05259538			
4		0.04061802	0.00893544		
5		0.02509147	0.01681582		
6			0.03704346		
7			0.07034343		
8			0.02874555	0.01465207	
9				0.04116218	

Pinion Tangent Bending Displacements [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.03869312				
2	0.01449924	0.00996832			
3		0.02988493			
4		0.02290804	0.00549158		
5		0.01428908	0.01011129		
6			0.02158561		
7			0.03939426		

8			0.01634418	0.00885360	
9				0.02377934	

The next 2 tables give the gear bending displacements, respectively in a direction normal to the tooth surface, and then in the transverse plane in the Yc direction, at each PoC contact for tooth pair 0.

Gear Normal Bending Displacements [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.02830248				
2	0.01020701	0.03551506			
3		0.02914419			
4		0.01632166	0.04148574		
5		0.01005866	0.03541567		
6			0.03168381		
7			0.02826125		
8			0.01150792	0.03599868	
9				0.03061533	

Gear Tangent Bending Displacements [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.02514674				
2	0.00928327	0.03158809			
3		0.02589967			
4		0.01464403	0.03689083		
5		0.00915136	0.03149986		
6			0.02816690		
7			0.02510982		
8			0.01044159	0.03201688	
9				0.02721358	

The next 2 tables give the contact displacements, respectively in a direction normal to the pinion and gear tooth surfaces, and then in the transverse plane in the Yc direction, at each PoC contact for tooth pair 0.

Contact Normal Displacements [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.01992948				
2	0.01278653	0.01307304			
3		0.02030578			
4		0.01470009	0.01422959		
5		0.01272931	0.01311686		

6			0.01917621		
7			0.01988636		
8			0.01390025	0.01272464	
9				0.01945498	

Contact Tangent Displacements [mm]

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.01756026				
2	0.01150586	0.01153486			
3		0.01789645			
4		0.01306710	0.01255482		
5		0.01145768	0.01157354		
6			0.01690909		
7			0.01752201		
8			0.01248202	0.01122737	
9				0.01715203	

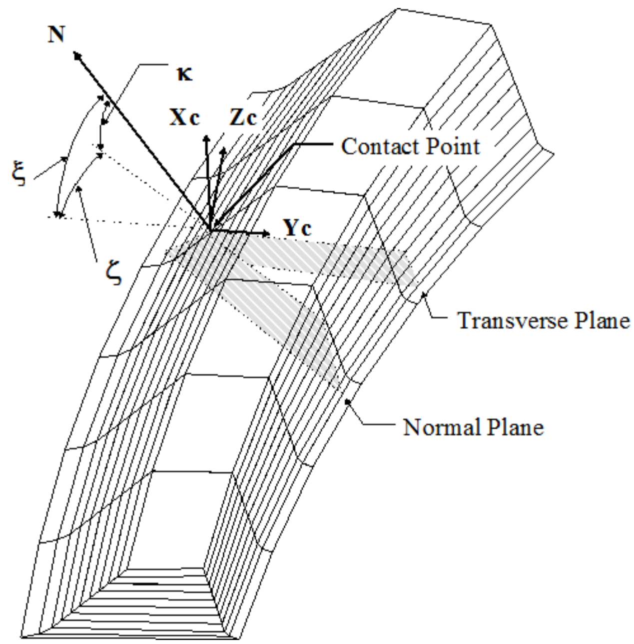
The next 8 tables give the pinion and gear tooth surface projection components into the normal and transverse planes as shown in the figure below. In the HyGEARS LTCA, a local reference frame is defined at each PoC contact point to establish precisely how the applied torque is converted to the tooth surface normal load such as to balance the torque shared by each meshing tooth pair, and how the bending and contact displacements are converted in actual rotation to ensure that each loaded tooth pair is submitted to the same rotation.

In the figure below, the local reference frame of the contact point is called XcYcZc. The Xc axis is normal to the pitch cone of the pinion or gear member, at the contact point axial position. The Yc axis lies in the transverse plane at the contact point, and is normal to the contact radius. The Zc axis is normal to Xc and Yc.

The tooth normal load is applied in the direction of the point of contact tooth surface normal vector **N.**

As the HyGEARS stiffness models define the bending displacement in a direction normal to the tooth neutral plane, angle κ defines the normal load component which will be used to calculate the bending deflection.

Angle ζ defines the component of the above bending deflection which will be converted in actual pinion and gear rotation.



Angle ξ defines the component of the tooth normal load which is actually converted in torque, and is therefore the contact deformation component converted in actual pinion or gear rotation.

The next 2 tables give the pinion bending and contact tangential components, e.g. the cosine of angles ζ and ξ, or what part of the bending and contact displacements is actually seen in the transverse plane, at each PoC contact for tooth pair 0.

Pinion Bending Tangential Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.56047	0.62022	0.59816		
2	0.56937	0.60164	0.61187		
3		0.56820	0.62300		
4		0.56399	0.61458	0.60384	
5		0.56948	0.60130	0.61205	
6		0.57371	0.58271	0.61874	
7			0.56003	0.62012	0.59832
8			0.56858	0.60426	0.61025
9			0.57474	0.57770	0.62021

Pinion Contact Tangential Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.54216	0.61794	0.59802		
2	0.54961	0.59292	0.61128		
3		0.55146	0.62178		

4		0.54499	0.61017	0.60351	
5		0.54971	0.59247	0.61145	
6		0.55348	0.56889	0.61776	
7			0.54163	0.61772	0.59817
8			0.54890	0.59641	0.60971
9			0.55441	0.56287	0.61914

The next 2 tables give the gear bending and contact tangential components, e.g. the cosine of angles ζ and ξ or what part of the bending and contact displacements is actually seen in the transverse plane, at each PoC contact for tooth pair 0.

Gear Bending Tangential Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.88850	0.88865	0.84286		
2	0.90950	0.88943	0.86642		
3		0.88867	0.88836		
4		0.89721	0.88924	0.85262	
5		0.90980	0.88943	0.86676	
6		0.92137	0.88900	0.87995	
7			0.88849	0.88867	0.84314
8			0.90734	0.88939	0.86363
9			0.92421	0.88889	0.88286

Gear Contact Tangential Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.88112	0.88184	0.83882		
2	0.89984	0.88234	0.86118		
3		0.88135	0.88161		
4		0.88891	0.88230	0.84809	
5		0.90010	0.88234	0.86150	
6		0.91013	0.88177	0.87378	
7			0.88111	0.88185	0.83908
8			0.89797	0.88233	0.85854
9			0.91259	0.88163	0.87649

The next 2 tables give the pinion and gear torque tangential components, e.g. the cosine of angle ξ or what proportion of the tooth surface normal load is actually converted in torque, at each PoC contact for tooth pair 0.

Pinion Torque Tangential Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.54216	0.61794	0.59802		
2	0.54961	0.59292	0.61128		
3		0.55146	0.62178		
4		0.54499	0.61017	0.60351	
5		0.54971	0.59247	0.61145	

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
6		0.55348	0.56889	0.61776	
7			0.54163	0.61772	0.59817
8			0.54890	0.59641	0.60971
9			0.55441	0.56287	0.61914

Gear Torque Tangential Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.88112	0.88184	0.83882		
2	0.89984	0.88234	0.86118		
3		0.88135	0.88161		
4		0.88891	0.88230	0.84809	
5		0.90010	0.88234	0.86150	
6		0.91013	0.88177	0.87378	
7			0.88111	0.88185	0.83908
8			0.89797	0.88233	0.85854
9			0.91259	0.88163	0.87649

The next 2 tables give the pinion and gear bending force components, e.g. the cosine of angle κ or what proportion of the normal load is actually transmitted as a tooth bending force, at each PoC contact for tooth pair 0.

Pinion Bending Force Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.96732	0.99630	0.99976		
2	0.96529	0.98551	0.99903		
3		0.97044	0.99803		
4		0.96633	0.99281	0.99946	
5		0.96528	0.98531	0.99902	
6		0.96475	0.97629	0.99841	
7			0.96714	0.99621	0.99975
8			0.96539	0.98698	0.99912
9			0.96462	0.97427	0.99828

Gear Bending Force Components

Pos	Tooth -2	Tooth -1	Tooth 0	Tooth +1	Tooth +2
[Pinion Tooth Root]					
1	0.99169	0.99233	0.99520		
2	0.98939	0.99203	0.99396		
3		0.99176	0.99240		
4		0.99076	0.99220	0.99469	
5		0.98935	0.99203	0.99394	
6		0.98780	0.99187	0.99300	
7			0.99169	0.99233	0.99519
8			0.98968	0.99206	0.99411
9			0.98742	0.99183	0.99279

The next table gives, for each PoC contact point on tooth pair 0, the TCA and LTCA Transmission Error values, in arc-seconds, the number of iterations needed to find a solution, the number of loops needed to reach the solution, and whether divergence was detected during the course of the numerical solution.

Transmission Error

[Pinion Tooth Root]

Pos	TCA	LTCA	#Iter.	#Loops	Divergence
1	-243.02	-204.10	1	1	0
2	-162.15	-151.71	2	1	0
3	-132.69	-191.35	1	1	0
4	-11.07	-169.62	2	1	0
5	-1.68	-151.63	3	1	0
6	-0.93	-180.05	1	1	0
7	0.00	-205.15	1	1	0
8	-30.10	-151.49	2	1	0
9	-125.80	-181.91	1	1	0

Finally, a series of tables give, for each point along the PoC, information on calculated data for 9 positions along the major axis of the contact elipse.

The following information is provided:

Posn: The contact point along the PoC
1,2, … Position along the major axis of the contact elipse

Lamda: Ratio of oil film thickness to surface roughness
DeltaC: Contact deformation
SigmaC: Calculated contact stress
S Indx: Calculated scoring index
DeltaT: Increment in temperature caused by sliding and friction
Sliding: Sliding speed

```
Posn:  5          1          2          3          4          5          6          7
    8          9
--------------------------------------------------------------------------------------
----------------
Lamda    :      0.496      0.496      0.496      0.496      0.496      0.496      0.496
 0.496      0.496
DeltaC   :      0.001      0.017      0.017      0.016      0.015      0.014      0.012
 0.009      0.000 [mm]
SigmaC   :     69.297   1229.409   1213.548   1173.472   1105.943   1004.886    857.503
631.933     27.748 [Mpa]
```

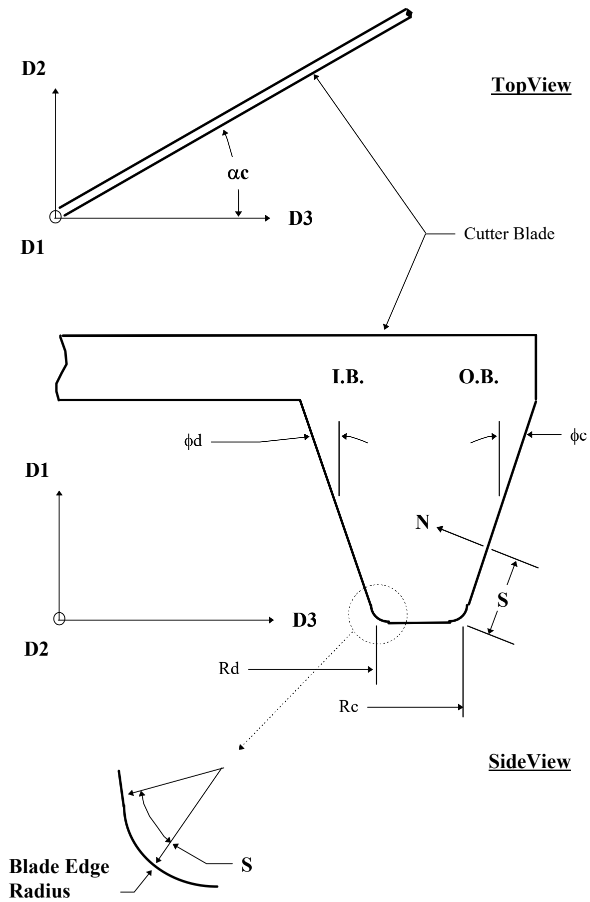
```
S Indx  :   723.295  6274.912  6236.173  6102.450  5857.439  5470.035  4873.107
3889.084   374.297
DeltaT  :     3.063    12.902    12.819    12.605    12.237    11.665    10.775
 9.250     1.938 [C]
Sliding :    99.788   101.387   103.392   105.805   108.591   111.746   115.271
119.150   123.372 [m/min]

Posn:  6          1         2         3         4         5         6         7
     8         9
-----------------------------------------------------------------------------------
----------------
Lamda   :     0.351     0.351     0.351     0.351     0.351     0.351     0.351
 0.351     0.351
DeltaC  :     0.001     0.020     0.021     0.021     0.020     0.018     0.015
 0.011     0.001 [mm]
SigmaC  :    36.832  1294.223  1362.789  1330.278  1263.082  1154.531   989.978
732.466    35.129 [Mpa]
S Indx  :   631.129  9136.611  9526.301  9383.618  9052.884  8488.013  7585.709
6069.232   623.794
DeltaT  :     3.399    20.146    20.673    20.424    19.902    19.028    17.619
15.156     3.319 [C]
Sliding :   100.251   101.805   103.674   105.816   108.216   110.884   113.811
116.995   120.440 [m/min]
```

13.2.14 Roll Angles

Gear teeth are bi-parametric surfaces, which means that they are functions of two parameters.

generated teeth	the surface parameters are the roll angle α_3 and the finishing cutter blade edge phase angle α_c.
non-generated teeth	the surface parameters are the distance S along the blade edge where a contact point is considered, and the finishing cutter blade edge phase angle α_c.

The Roll Angles output gives, for each tooth flank and fillet point, the work roll and cutter angles, in the following format:



A *1st table* prints, **for generated teeth only, the roll angles** at each tooth flank point, from tooth fillet on the pinion convex/gear concave side to tooth on the pinion concave/gear convex side. All angles are in decimal format. A short Summary at the end of the table (Cutting Cycle) prints the minimum and maximum roll angles for each tooth flank.

```
_____________________________________________

          HyGEARS V 4.0 © ®

Roll Angles Pinion [Finishing] - Demo1441.dat

_____________________________________________

Date / Time       : 1/1/2012 / 11:33:39 AM
General Units     : [mm] [dd.mm.ss]
Cutter  Units     : [in]
Prepared by       : John Who
Version           : 4.0.401.70


[ Pinion Convex-IB Tooth Root ]
   483.79550   472.51290   460.99210   450.44630   440.65950   430.76630
421.32280
```

```
   487.53530   475.06400   463.13290   452.20440   442.05620   432.16440
422.73410
   491.27520   477.61500   465.27360   453.96260   443.45290   433.56250
424.14540
   486.60040   473.05960   460.81380   449.56720   439.08830   429.19340
419.73500
   481.92550   468.50410   456.35390   445.17190   434.72360   424.82430
415.32480
   477.25070   463.94860   451.89400   440.77650   430.35900   420.45520
410.91450
   472.57590   459.39320   447.43410   436.38120   425.99440   416.08610
406.50420
   467.90100   454.83770   442.97430   431.98580   421.62980   411.71700
402.09380
   463.22620   450.28220   438.51440   427.59040   417.26520   407.34790
397.68350
   458.55140   445.72670   434.05450   423.19510   412.90050   402.97880
393.27330
   453.87650   441.17130   429.59460   418.79970   408.53590   398.60970
388.86290

[Tooth Tip]

   485.32380   474.82550   464.50560   454.28590   444.08750   433.83190
423.44030
   483.48470   472.96480   462.62170   452.36340   442.10040   431.74010
421.18440
   481.64570   471.10420   460.73790   450.44090   440.11330   429.64820
418.92860
   479.80660   469.24340   458.85400   448.51840   438.12630   427.55630
416.67270
   477.96750   467.38280   456.97010   446.59590   436.13920   425.46440
414.41690
   476.12850   465.52210   455.08620   444.67350   434.15210   423.37250
412.16100
   474.28940   463.66140   453.20240   442.75090   432.16510   421.28060
409.90520
   472.45030   461.80070   451.31850   440.82850   430.17800   419.18880
407.64930
   470.61130   459.94000   449.43460   438.90590   428.19090   417.09690
405.39340
   474.58370   463.36370   452.59950   442.13580   431.68820   421.28060
410.62700
   478.55610   466.78740   455.76440   445.36550   435.18540   425.46440
415.86060
[ Pinion Concave-OB Tooth Root ]

   Cutting Cycle
   _____________

   Convex-IB    :      388.863 ->      491.275 deg.
   Concave-OB   :      405.393 ->      485.324 deg.
   Cradle       :       62.263 deg.
```

A *2nd table* prints the work cutter angles corresponding to the above generation roll angles for each tooth flank point, from tooth fillet on the pinion convex/gear concave side to tooth on the pinion concave/gear convex side. All angles are in decimal format.

```
_______________________________________________

              HyGEARS V 4.0 © ®

Cutter Angles Pinion [Finishing] - Demo1441.dat

_______________________________________________

Date / Time       : 1/1/2012 / 11:33:39 AM
General Units     : [mm] [dd.mm.ss]
Cutter  Units     : [in]
Prepared by       : John Who
Version           : 4.0.401.70


[ Pinion Convex-IB Tooth Root ]
    18.34760    21.74904    25.36139    29.01127    32.82943    36.65282
40.61881
    19.08856    22.36110    25.86521    29.46229    33.23576    37.06502
41.04278
    19.89150    23.01422    26.39540    29.93421    33.65860    37.49478
41.48583
    20.74230    23.69133    26.93338    30.40805    34.07848    37.92252
41.92782
    20.06962    23.18133    26.56539    30.17103    33.96883    37.94310
42.08750
    19.47331    22.73692    26.25519    29.98642    33.90799    38.01015
42.29254
    18.96078    22.36315    26.00630    29.85522    33.89386    38.11748
42.53241
    18.52040    22.05209    25.81190    29.77302    33.92370    38.26535
42.80909
    18.15174    21.80348    25.67425    29.74183    34.00030    38.45585
43.12565
    17.85147    21.61634    25.59229    29.76171    34.12489    38.69150
43.48445
[Tooth Tip]
    23.49619    27.60408    31.75125    35.94622    40.19505    44.50229
48.87072
    22.47502    26.47494    30.50591    34.56997    38.65853    42.76490
46.87669
    21.57201    25.49528    29.44476    33.41714    37.40472    41.39371
45.36934
    20.76329    24.62558    28.51460    32.42348    36.34263    40.25616
44.14994
    20.01977    23.83360    27.68014    31.54403    35.41736    39.28162
43.12610
    19.32826    23.10327    26.91126    30.73888    34.57611    38.40804
42.22093
    18.69698    22.44144    26.22139    30.02368    33.83595    37.64579
41.44240
```

```
    19.10712    22.80996    26.56248    30.35365    34.19236    38.04771
41.91153
    19.66017    23.31602    27.03849    30.81899    34.69075    38.60519
42.55816
    20.36265    23.96468    27.65393    31.42439    35.33863    39.32898
43.40033
[ Pinion Concave-OB Tooth Root ]
```

A *3rd table* prints, for generated and non-generated teeth, the distance **S** along the blade edge; the fillet values then correspond to the angular position **S** along the blade edge radius. All angles and positions **S** are in decimal format.

```
                    _____________________________________

                            HyGEARS V 4.0 © ®

                    'S' Pinion [Finishing] - Demo1441.dat

                    _____________________________________

                    Date / Time        : 1/1/2012 / 11:33:39 AM
                    General Units      : [mm] [dd.mm.ss]
                    Cutter  Units      : [in]
                    Prepared by        : John Who
                    Version            : 4.0.401.70


[ Pinion Convex-IB Tooth Root ]
    80.00000    80.00000    80.00000    80.00000    80.00000    80.00000
80.00000
    62.66666    62.66666    62.66666    62.66666    62.66666    62.66666
62.66666
    45.33333    45.33333    45.33333    45.33333    45.33333    45.33333
45.33333
    -0.00071     0.00007     0.00001     0.00000     0.00006     0.00001
0.00000
    -0.00032     0.00003     0.00000     0.00000     0.00003     0.00000
0.00000
     1.04836     1.11352     1.19602     1.29523     1.41163     1.54696
1.70371
     2.00410     2.14325     2.31260     2.51224     2.74382     3.01130
3.32030
     2.87772     3.10043     3.36359     3.66889     4.01999     4.42418
4.88976
     3.70266     4.01422     4.37483     4.78809     5.26025     5.80172
6.42487
     4.49219     4.89653     5.35674     5.87954     6.47369     7.15306
7.93397
     5.25792     5.75751     6.31910     6.95243     7.66888     8.48629
9.42514
[Tooth Tip]
     5.19685     5.49775     5.80752     6.15424     6.56360     7.06108
7.67153
     4.00649     4.20397     4.39934     4.61014     4.84576     5.11436
5.41859
```

```
     2.99290     3.12281     3.24601     3.37307     3.51106     3.66052
3.82037
     2.11363     2.19491     2.26963     2.34398     2.42238     2.50280
2.58421
     1.33254     1.37860     1.42150     1.46176     1.50353     1.54285
1.58057
     0.62944     0.64906     0.66670     0.68239     0.69877     0.71300
0.72524
     0.00000     0.00000     0.00036     0.00024     0.00077     0.00004
0.00007
     0.00000     0.00000     0.00080     0.00055     0.00174     0.00009
0.00015
    33.33334    33.33334    33.33334    33.33334    33.33334    33.33334
33.33334
    56.66667    56.66667    56.66667    56.66667    56.66667    56.66667
56.66667
    80.00000    80.00000    80.00000    80.00000    80.00000    80.00000
80.00000
[ Pinion Concave-OB Tooth Root ]
```

13.2.15 Surface Statistics

The measured surface errors statistics give in numbers what is displayed in the Child Window graphs. The surface statistics are presented as follows:

- the result header identifies the cutting machine and cutting process, the measurement data file, the pinion or gear cutting state (Finishing or Roughing), the selected Summary version (Nominal 1/2, etc.), the Geometry file name, and the linear and angular units used;

```
___________________________________________________

HyGEARS V 4.0 © ® - Measured Surface Statistics

             Some Good Company.
                Somewhere, ElseWhere

      116F - Meas.Surface : demo_p12.mes/1-14
          Pinion [Finishing]  Demo1441.dat
___________________________________________________

   Date        :  1/1/2012
   Time        :  11:35:38 AM
   Units       :  [mm] [dd.mm.ss]
   Prepared by :  John Who
```

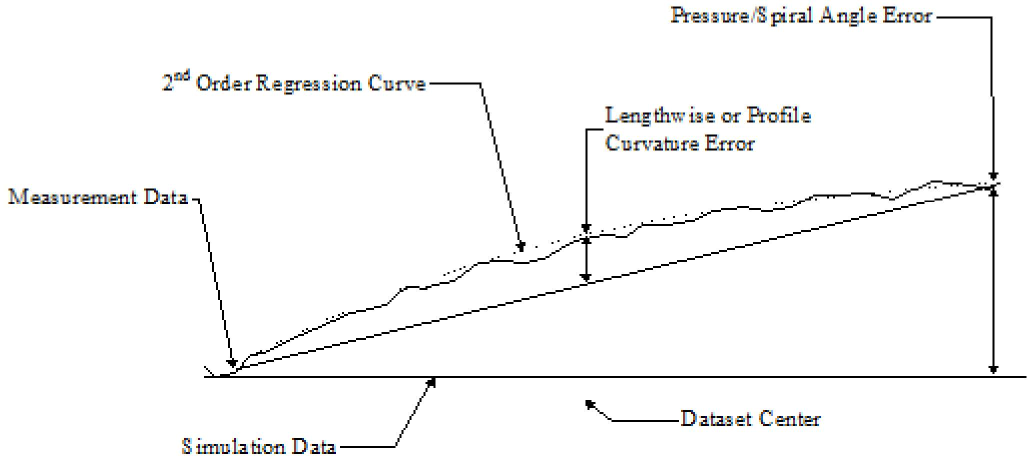
- the statistical data is presented in a table like the following, and gives the averaged errors for both the convex (I.B.) and concave (O.B.) tooth flanks. The averaged errors for both pressure and spiral angles correspond to the slope of a second order curve passing through the error data points using the least squares method, as shown in the figures below.

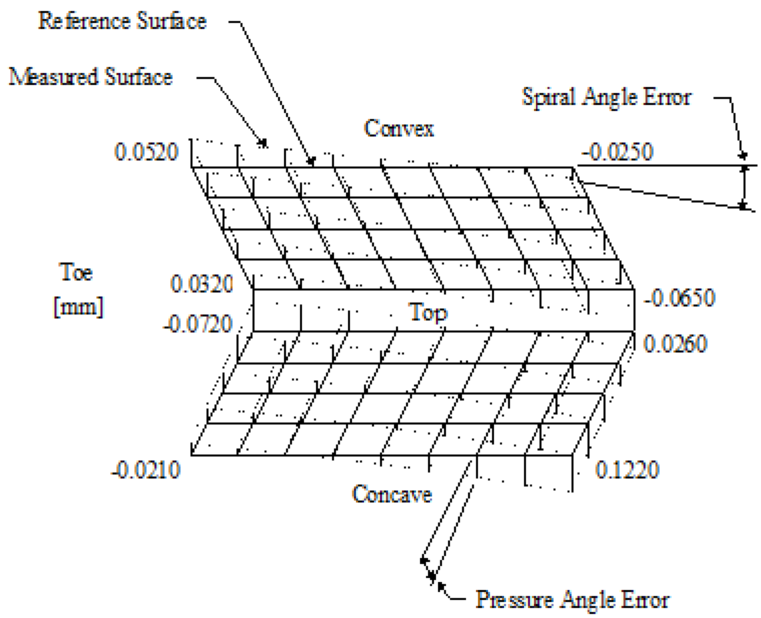
```
AVERAGE ERRORS                          (O.B.)        (I.B.)
__________________________________________________________________
Tooth Thickness         [mm] :          0.2002
Pressure Angle[deg.min.sec] :         0.07.45      -0.11.43
Spiral Angle  [deg.min.sec] :         0.02.52       0.03.34
Crowning                [mm] :          0.0002       -0.0051
Profile Curvature       [mm] :         -0.0009        0.0001
Warp Factor         [/10 mm] :         0.11.42      -0.09.01
Sum Errors Squared      [in] :      0.00000990    0.00001833
```

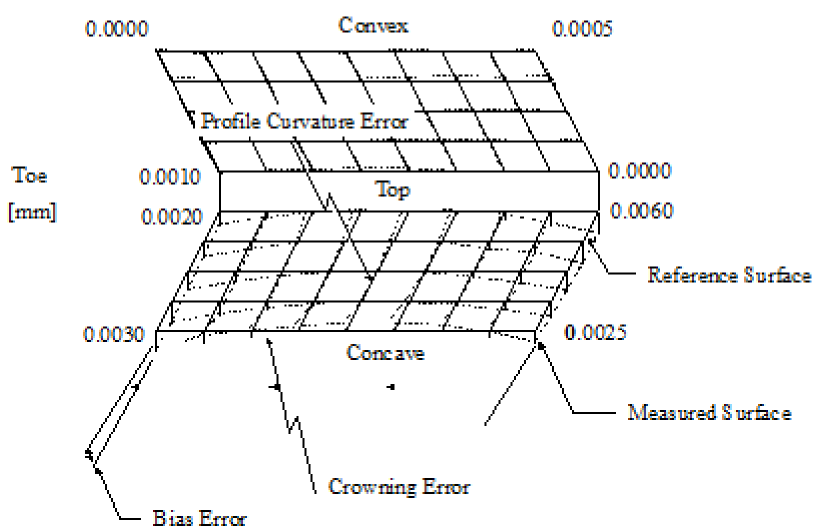
The Spiral Angle error is calculated from the lengthwise error data, while the Pressure Angle error is calculated from the profilewise error data. The tooth taper error, given only for Spread Blade cutting processes, is the difference in spiral angle between the IB and OB tooth flanks.

The Warp Factor is the difference in pressure angle between the toe and heel profilewise error data, and is given for each 10mm of tooth facewidth.

Finally, the Sum Errors Squared is simply the direct sum of all the squared surface errors, divided by the total number of data points for each tooth flank.


Pressure/Spiral Angle Error
2nd Order Regression Curve
Lengthwise or Profile Curvature Error
Measurement Data
Dataset Center
Simulation Data


Reference Surface
Measured Surface
Spiral Angle Error
Convex
0.0520
-0.0250
Toe
[mm]
0.0320
-0.0720
Top
-0.0650
0.0260
-0.0210
0.1220
Concave
Pressure Angle Error


0.0000
Convex
0.0005
Profile Curvature Error
Toe
[mm]
0.0010
0.0020
Top
0.0000
0.0060
Reference Surface
0.0030
0.0025
Concave
Measured Surface
Crowning Error
Bias Error

The following equations give the formulation used to calculate the surface statistics.

- average pressure angle error:

$$\Phi = \frac{\sum_{col=1}^{j} \frac{\left[\sum_{row=1}^{i} \frac{\varepsilon_{i,j} - \varepsilon_{1,j}}{y_{i,j} - y_{1,j}} \right]}{i}}{j}$$

- average spiral angle error:

$$\Psi = \frac{\sum_{row=1}^{i} \frac{\left[\sum_{col=1}^{j} \frac{\varepsilon_{i,j} - \varepsilon_{i,1}}{x_{i,j} - x_{i,1}} \right]}{j}}{i}$$

- average crowning error:

$$\Xi = \frac{\sum_{row=1}^{i} \frac{(2\varepsilon_{i,mid} - (\varepsilon_{i,1} + \varepsilon_{i,j}))}{2}}{i}$$

- average profile curvature error:

$$\xi = \frac{\sum_{col=1}^{j} \frac{(2\varepsilon_{mid,j} - (\varepsilon_{1,j} + \varepsilon_{i,j}))}{2}}{j}$$

- bias error:

$$\zeta = \Phi_1 - \Phi_j$$

where:

i	is the index of row measurement data, along the tooth flank;
j	is the index of column measurement data, across the tooth flank;
mid	is the index of the mid-column or mid-row measurement data;
$e_{i,j}$	is the error value at point *ij* of the measurement grid;
$x_{i,j}$	is the distance between measurement points along the tooth flank;

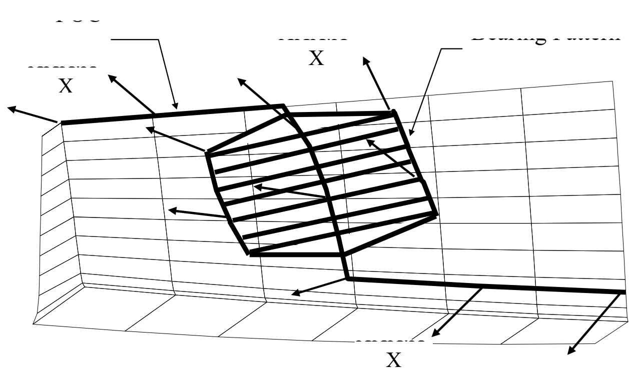
$y_{i,j}$ is the distance between measurement points across the tooth flank.

13.2.16 Sliding Speeds

The Sliding Speeds output provides the value of the relative speeds between the pinion and gear tooth surfaces, at selected points on the Contact Pattern and along the Path of Contact.

The Sliding Speeds header identifies the current Geometry, which pinion tooth flank is driving and the sliding speed units as defined by the linear units established in the HyGEARS Configuration editor, or by the [mm]/[In] Child Window function button:

```
                HyGEARS V 4.0 ©

 Sliding Speeds [m/min] - Demo1441.dat

Pinion [Finishing] + Gear [Finishing]
Pinion Concave-OB [NoEr]

Date / Time    :  02-24-1999 / 19:24:00
General Units  :  [mm] [deg.min.sec]
Cutter  Units  :  [in]
Prepared by    :  John Doe
Version        :  4.0.401.70
```



The Contact Pattern is made of a series of instant lines of contact defined by three points each: one at the toe, one at the center and one at the heel end of the instant line of contact. For each data point of the Contact Pattern, the sliding speed vector components in the tied reference frames (X1X2X3 for the pinion, Y1Y2Y3 for the gear) are printed in two tables such as the following.

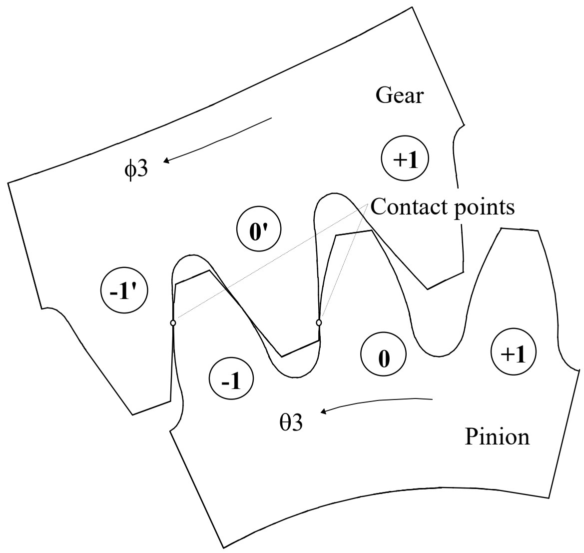
The *Posn* entry refers to the PoC contact point number.

```
Pinion Rpm :   341.5
__________

                 Toe                     Center                  Heel

Posn     |  X1       X2       X3    |  X1       X2       X3    |  X1       X2       X3
_______________________________________________________________________________
[Pinion Tooth Root - Concave-OB]

  1     -28.2      4.6    -19.2   -28.2      4.6    -19.2   -28.2      4.6    -19.2
  2     -28.3      3.2    -19.4   -28.6      7.7    -20.6   -28.9     12.5    -21.9
  3     -28.4      1.1    -19.5   -29.2      7.5    -21.1   -30.3     14.1    -22.9
  4     -28.7      1.0    -20.0   -30.4      8.1    -21.9   -32.4     15.6    -23.9
  5     -29.8      2.5    -21.0   -32.0      8.8    -22.7   -34.6     15.4    -24.4
  6     -31.5      3.7    -21.9   -33.3      7.5    -23.0   -35.3     11.5    -24.0
  7     -35.7      7.9    -23.7   -35.7      7.9    -23.7   -35.7      7.9    -23.7

Gear Rpm :   116.6
________

                 Toe                     Center                  Heel

Posn     |  Y1       Y2       Y3    |  Y1       Y2       Y3    |  Y1       Y2       Y3
_______________________________________________________________________________
[Gear Tooth Tip - Convex-IB]

  1      27.6     14.6    -14.6    27.6     14.6    -14.6    27.6     14.6    -14.6
  2      28.3     14.1    -13.9    30.6     16.1    -10.3    33.0     18.3     -6.7
  3      28.6     13.3    -13.8    31.9     16.1     -8.9    35.5     19.2     -3.7
  4      30.0     13.3    -12.2    33.9     16.6     -6.7    38.1     20.3     -0.9
  5      32.3     14.2     -9.4    36.1     17.3     -4.4    40.0     20.7      0.7
  6      34.8     15.1     -6.6    37.3     17.1     -3.5    39.8     19.2     -0.4
  7      39.7     17.9     -1.3    39.7     17.9     -1.3    39.7     17.9     -1.3
```

13.2.17 TCA (Tooth Contact Analysis)

The Tooth Contact Analysis results, or TCA, performed in many HyGEARS functions, can be sent to a Text Results window for consultation, printing or saving in a data file. The following format applies to the TCA output.

The TCA kinematic data is divided in four tables, and provides all the information about the calculated contacting positions along the PoC. Each table identifies the contacting pinion tooth flank and the tooth number. Tooth 0 is considered the main tooth in contact, tooth -1 is the first tooth before tooth 0, and is going out of mesh, tooth -2 is the second tooth before tooth 0, etc.; , tooth +1 is the next tooth after tooth 0, and is coming into contact, tooth +2 is the second next after tooth 0, etc., as shown below.



The *TCA header* identifies the Geometry data file, its status (finishing or roughing), the date and time the TCA data was outputted, plus:

Speed Ratio	Gear set speed ratio.
Prof. Contact Ratio	Gear set profile contact ratio;
Actual Contact Ratio	Gear set actual contact ratio;
Total Contact Ratio	Gear set total contact ratio;
PoC Contact Bias	Bias, in degrees, of the profile portion of the PoC;
Units	Current linear units in use. All angular data is given only in the degrees.decimal format to conserve space.

```
        HyGEARS V 4.0 © ®

  Kinematical Results - Demo1441.dat

Pinion [Finishing] + Gear [Finishing]
Pinion Concave-OB [NoEr]

Date / Time        : 1/1/2012 / 11:58:27 AM
General Units      : [mm] [dd.mm.ss]
Cutter  Units      : [in]
Prepared by        : John Who
Version            : 4.0.401.70
```

```
Speed Ratio         :   2.929
Prof. Contact Ratio :   1.097
Actual Contact Ratio:   1.492
Total Contact Ratio :   2.981
PoC Contact Bias    :   8.705 deg.
Units               :   [mm]
```

Table 1 gives, for each contacting tooth pair, the *pinion and gear tooth surface parameters* as meshing proceeds from pinion tooth root to pinion tooth tip. A table row filled with zeroes means that no contact is occurring on the said tooth for the given angular positions Phi3 and Theta3. The following data constitutes table 1:

Phi3	Gear angular position, in degrees.
D-Phi3	Transmission Error, in arc-seconds.
Theta3	Pinion angular position, in degrees.
Alfa3	Pinion roll angle, in degrees.
Alfcp	Pinion cutter angular position, in degrees.
Beta3	Gear roll angle, in degrees (zero if Formate or Helixform).
Alfcg	Gear cutter angular position, in degrees.
Sp	Contact point position along the pinion blade edge, in [units].
Sg	Contact point position along the gear blade edge, in [units].

```
                     Tooth : -2  Pinion Convex
                     _________________________

    Phi3   D-Phi3   Theta3   Alfa3   Alfcp   Beta3   Alfcg    Sp       Sg
__________________________________________________________________________
 [Pinion Tooth Root]
   35.47        0   124.60  430.61  156.12    0.00  302.10  0.1697  0.1666
   29.93       -8   108.35  414.49  157.40    0.00  303.47  0.2824  0.0538
   24.40      -72    92.11  398.22  164.55    0.00  310.35  0.3483  0.0320
       0        0        0       0       0       0       0       0       0
       0        0        0       0       0       0       0       0       0
  ...

                     Tooth : 0  Pinion Convex
                     ________________________

    Phi3   D-Phi3   Theta3   Alfa3   Alfcp   Beta3   Alfcg    Sp       Sg
__________________________________________________________________________
 [Pinion Tooth Root]
   35.53     -233   124.60  481.56  144.76    0.00  291.02  0.0421  0.2351
   29.96     -121   108.35  465.49  149.45    0.00  295.52  0.0385  0.2669
   24.40      -74    92.11  449.38  155.02    0.00  300.85  0.0401  0.2999
   21.17        0    82.73  440.09  155.33    0.00  301.25  0.1078  0.2283
   17.97       -9    73.35  430.78  156.11    0.00  302.08  0.1685  0.1678
   14.77      -14    63.97  421.48  156.85    0.00  302.88  0.2326  0.1036
   11.57      -17    54.59  412.17  157.58    0.00  303.66  0.2993  0.0370
    8.29      -44    44.96  402.51  162.29    0.00  308.19  0.3323  0.0337
    5.05     -145    35.39  392.92  167.34    0.00  313.02  0.3710  0.0271
```

Table 2 gives, for each contacting tooth pair, the pinion and gear *tooth surface contact point coordinates*, in the pinion X1X2X3, gear Y1Y2Y3 and general Z1Z2Z3 reference frames:

Tooth : 0 Pinion Convex

X(1)	X(2)	X(3)	Y(1)	Y(2)	Y(3)	Z(1)	Z(2)	Z(3)
[Pinion Tooth Root]								
-0.692	0.853	0.050	-2.320	0.166	-0.221	1.095	-1.214	1.985
-0.473	1.096	0.302	-2.535	0.081	-0.127	1.189	-1.196	2.237
-0.158	1.296	0.578	-2.779	-0.045	-0.015	1.301	-1.189	2.513
-0.052	1.378	0.601	-2.753	-0.085	0.044	1.360	-1.074	2.536
0.097	1.455	0.639	-2.750	-0.133	0.106	1.422	-0.975	2.574
0.270	1.520	0.670	-2.742	-0.182	0.169	1.485	-0.875	2.605
0.469	1.567	0.694	-2.731	-0.231	0.233	1.549	-0.774	2.629
0.809	1.531	0.878	-2.897	-0.375	0.338	1.654	-0.788	2.813
1.155	1.418	1.065	-3.060	-0.545	0.447	1.763	-0.812	3.000

Table 3 gives, for each contacting tooth pair, the pinion and gear tooth surface contact point *normal vector components in the general reference frame*, respectively NZP1... and NZG1..., followed by their difference, which should always be zero except for tip or edge contact:

Tooth : 0 Pinion Convex

NZP1	NZP2	NZP3	NZG1	NZG2	NZG3	DNZ1	DNZ2	DNZ3
[Pinion Tooth Root]								
0.5453	0.6687	0.5055	-0.5429	-0.6658	-0.5119	0.0024	0.0029	-0.0064
0.5671	0.6660	0.4846	-0.5658	-0.6646	-0.4880	0.0012	0.0015	-0.0034
0.5919	0.6546	0.4704	-0.5919	-0.6546	-0.4704	0.0000	0.0000	0.0000
0.5959	0.6750	0.4350	-0.5959	-0.6750	-0.4350	0.0000	0.0000	0.0000
0.6017	0.6900	0.4023	-0.6017	-0.6900	-0.4023	0.0000	0.0000	0.0000
0.6080	0.7025	0.3700	-0.6080	-0.7025	-0.3700	0.0000	0.0000	0.0000
0.6148	0.7124	0.3383	-0.6148	-0.7124	-0.3383	0.0000	0.0000	0.0000
0.6397	0.6855	0.3478	-0.6406	-0.6865	-0.3440	-0.0010	-0.0010	0.0038
0.6643	0.6541	0.3617	-0.6665	-0.6562	-0.3537	-0.0022	-0.0022	0.0080

Table 4 gives, for each contacting tooth pair, the pinion and gear tooth surface *contact point normal vectors*, in the pinion X1X2X3, and gear Y1Y2Y3 reference frames, plus:

Conjug identifies the result of the Condition of Meshing which states that the common contacting surfaces normal must be perpendicular to the relative speed, or:

$\overline{N} \bullet \overline{V}_r = 0$

therefore this entry should always be null along the profile section of the PoC; along the edge portion of the PoC, exact meshing conditions are not necessarily met and this value may therefore be different from 0.

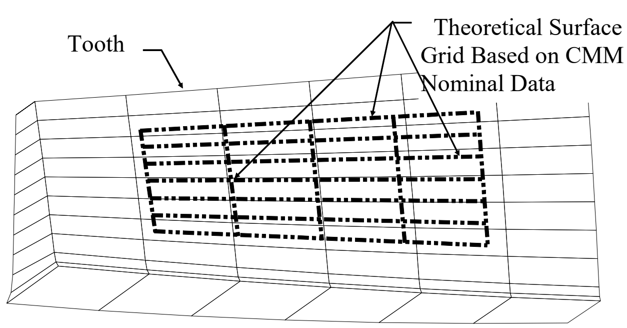
Angle the angle between the common contact contacting surfaces normal and the sliding speed vector, which should always be about 90 along the profile section of the PoC; along the edge portion of the PoC, exact meshing conditions are not necessarily met and this value may therefore be different from 90.

MgIns the instantaneous speed ratio.

```
                    Tooth : 0   Pinion Convex
                  ________________________

    NXP1     NXP2     NXP3     NYG1     NYG2     NYG3   Conjug    Angle    MgIns
_____________________________________________________________________________
[ Pinion Tooth Root]

 -0.5634 -0.3563 -0.7454 -0.5754  0.8059  0.1395  0.0106  89.392  2.9122
 -0.4605 -0.4843 -0.7439 -0.5106  0.8525  0.1120  0.0046  89.734  2.9227
 -0.3281 -0.5840 -0.7425 -0.4430  0.8927  0.0827  0.0116  89.335  2.8890
 -0.2424 -0.5939 -0.7672 -0.4378  0.8955  0.0805  0.0012  89.934  2.9254
 -0.1620 -0.5898 -0.7911 -0.4344  0.8972  0.0790  0.0003  89.983  2.9283
 -0.0884 -0.5736 -0.8144 -0.4327  0.8982  0.0782  0.0003  89.983  2.9284
 -0.0197 -0.5473 -0.8367 -0.4306  0.8992  0.0773 -0.0014  90.078  2.9346
  0.1080 -0.5429 -0.8328 -0.3635  0.9304  0.0476 -0.0100  90.575  2.9522
  0.2311 -0.5083 -0.8296 -0.2970  0.9547  0.0177 -0.0046  90.266  2.9176
```

13.2.18 Theo. Surface

The Theo. Surface output is used to produce a theoretical data file, similar to Gleason's Nominal data, but directly in the HyGEARS measurement data file format. The data is sent to a Text Results window which, if saved to a disk file, can be used as reference data for the Reverse Engineering graphic function for example.



The theoretical surface is based on the currently defined Theoretical tooth parameters, i.e. number of points. See the HyGEARS Measurement Data File Format for detailed explanations about the file format.

13.2.19 Volume and Moments of Inertia

Given the 3 dimensional nature of HyGEARS objects, their volume and moments of inertia are easily calculated.

The results are given in the currently selected units (See Configuration Editor). They include the volume, the mass and the moments of inertia about the tied reference frame (X1X2X3 for the pinion, Y1Y2Y3 for the gear), and appear in the following format:

```
______________________________________________________________

                    HyGEARS V 4.0 © ®

Inertial Properties - Tooth - Pinion [Finishing]- Demo1441.dat
______________________________________________________________

Date / Time        : 1/1/2012 / 12:01:44 PM
General Units      : [mm] [dd.mm.ss]
Cutter  Units      : [in]
Prepared by        : John Who
Version            : 4.0.401.70

Volume         :       2047.166 [mm^3]
Mass           :          0.016 [kgm]
Inertia Axis 1:           8.398 [kgm-mm^2]
Inertia Axis 2:          15.345 [kgm-mm^2]
Inertia Axis 3:          14.459 [kgm-mm^2]
```

13.3 Action Trace Output

For most user actions, HyGEARS keeps a trace in the Action Trace window (which is hidden). The Action Trace format varies with the action performed. The following is a Summary of the Action Trace messages displayed by HyGEARS. As most messages are self explanatory, only those messages which need specific explanations are commented.

The contents of the Action Trace Window can be displayed in a Text Results window by clicking on Misc -> Action Trace Parent Window menu entry.

Access to Language File:

Read Language File English.bng ”English.bng” is the file name

Open/Save Geometry Data File:

Open Geometry c:\hygears\demo\demo.HyG in progress ...
Open Geometry c:\hygears\demo\demo.HyG done !
Save Geometry c:\hygears\demo\demo.HyG in progress ...
Save Geometry c:\hygears\demo\demo.HyG done !

Calling the Geometry Summary Editor:

Summary Editor in Preparation
Summary Editor

Child Window Function Button Actions:

Button ' NoDi '	Dimensions Toggle from “On”
Button ' Dims '	Dimensions Toggle from “Off”
Button ' 1st '	1st to 2nd Order Toggle
Button ' 2nd '	2nd to 1st Order Toggle
Button ' ( ) '	Tooth Flank Both Sides to Convex Toggle
Button ' Ang '	Display Cutting Machine Cutter Angles
Button ' Anim '	Start Cutting Machine/PoC Multiple Animation
Button ' BPat '	Call the Contact Pattern Development window
Button ' Con '	Tooth Flank Concave to Convex Toggle
Button ' Coor '	Coordinates Output
Button ' Crad '	Display Cutting Machine Cradle
Button ' Cutt '	Cutter Change / Contact Pattern Development
Button ' Cvx '	Tooth Flank Convex to Concave Toggle
Button ' ErrS '	Use the Error Surface Toggle
Button ' FEA '	Call the FEA Model sub-menu
Button ' Fini '	Finishing Summary Toggle
Button ' Gea '	Call the Gear Summary Editor
Button ' GSum '	Call the Graphics Summary
Button ' Hertz '	Call the Hertz Contact Stresses
Button ' Hist '	Corrective Machine Settings (Closed Loop) History
Button ' Load '	Call the FEA Load Editor
Button ' Ltca '	Call the LTCA Editor
Button ' Mesh '	Call the FEA Mesh Editor

Button ' NoAn '	Do Not Display Cutting Machine Cutter Angles
Button ' NoCr '	Do Not Display Cutting Machine Cradle
Button ' NoEr '	Do Not Use the Error Surface Toggle
Button ' NoPo '	Do Not Display the Path of Contact
Button ' Outp '	Output Numerical Results to Text Results Window
Button ' Pin '	Call the Pinion Summary Editor
Button ' PoC '	Display the Path of Contact
Button ' #Pts '	Call the Tooth # of Points Editor
Button ' Ram '	Call the CMM Nominal Data Editor
Button ' RamF '	Converts Measurement data into Ram Nominal Data
Button ' Roug '	Roughing Summary Toggle
Button ' Rpm '	Call the Pinion RPM Editor
Button ' Scal '	Call the Measurement AutoScale Selection Window
Button ' Sele '	Call the Summary Version Selection Window
Button ' Sep '	Path of Contact Separation Output
Button ' Sett'	Call the Proportional Changes window or the Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection window.
Button ' Stat '	Surface Statistics Output
Button ' Stop '	Stop Cutting Machine/PoC Multiple Animation
Button ' Summ '	Geometry Summary Output
Button ' Tca '	Path of Contact Summary Output
Button ' V-H '	Call the Position and Alignment Editor
Button ' VH>>'	VH Settings Conversion /Contact Pattern Develop.
Button ' Vol '	Volume and Inertia Output
Button ' XYZ '	Call the Measurement Data Editor

Child Window Graphics Display**:**

The Graphics Display messages indicate the Child Window name, the gear set member in display and the display time. The display time is useful in getting a feeling of the computer speed. For example, the display time for the pinion Tooth is .33 sec, while that of the Full Model is 3.13 sec., or almost 10 times longer, which tells the user that some actions are longer than others.

Graphics Display - Contact Pattern Gear - Calc.Time: .11 sec.
Graphics Display - Contact Pattern (LTCA) Gear - Calc.Time: 4.29 sec.
Graphics Display - Blank Gear - Calc.Time: .29 sec.
Graphics Display - Comp. Meas.-Sim. Pinion - Calc.Time: .16 sec.
Graphics Display - Corrective Machine Settings Pinion - Calc.Time: .22 sec.
Graphics Display - Cutting Machine Pinion - Calc.Time: .33 sec.
Graphics Display - Development Contact Pattern Gear - Calc.Time: .98 sec.
Graphics Display - FEA Mesh Pinion - Calc.Time: .82 sec.
Graphics Display - Full Model Pinion - Calc.Time: 3.13 sec.
Graphics Display - Graphic Output 2D Gear - Calc.Time: .12 sec.

Graphics Display - Meas.Surface Gear - Calc.Time: .23 sec.
Graphics Display - Path of Contact Gear - Calc.Time: 1.70 sec.
Graphics Display - CMM Nominal Data Pinion - Calc.Time: .77 sec.
Graphics Display - Sliding Speeds Gear - Calc.Time: .22 sec.
Graphics Display - Reverse Engineering Pinion - Calc.Time: .22 sec.
Graphics Display - Tooth Errors Pinion - Calc.Time: .33 sec.
Graphics Display - Tooth Pinion - Calc.Time: .33 sec.

Child Window Operations: Rotations About X, Y and Z

The Rotations messages indicate the axis about which the rotation was performed, and the rotation angle defined either in the HyGEARS Configuration Editor, or in the Rotation Angle Parent window button..

Rot. X -45. deg.
Rot. X 45. deg.
Rot. Y -45. deg.
Rot. Y 45. deg.
Rot. Z -45. deg.
Rot. Z 45. deg.

Child Window Operations: Window Manipulations

Window Cascade	Cascade Child Windows within Parent Window
Window Tile	Tile Child Windows within Parent Window
Window Close	Close Active Child Window
Window Close All	Close All Child Windows and Parent Window

Computations:

The Computations messages indicate what calculation is underway, to which gear set member it is applied, and if applicable, which pinion or gear tooth flank is concerned. Calculation times are provided for the user to get a feeling of the average wait time to expect. Most Computations messages are in two consecutive messages: the first indicates what calculation has been initiated, the second part indicates that the calculation is completed and what time was needed for the requested computation.

Calculating New Geometry Definition
Developing Contact Position Pinion Convex-IB
Developing Transmission Error Pinion Convex-IB
Developing Contact Pattern Length Pinion Convex-IB
Developing Path of Contact Bias Pinion Convex-IB

Checking RootLine Pinion Convex-IB
Checking Backlash

Calculating Contact Pattern - Pinion Concave ...
Contact Pattern Pinion Concave - Calc.Time: .77 sec

Calculating Contact Pattern LTCA - Pinion Concave ...
Contact Pattern LTCA Pinion Concave - Calc.Time: .55 sec

Calculating Inertial Properties Pinion [Finishing] ...
Inertial Properties Pinion [Finishing] - Calc.Time: .11 sec

Calculating Load Sharing - Pinion Concave ...
Load Sharing Pinion Concave - Calc.Time: 3.46 sec

Calculating Path of Contact - Pinion Concave ...
Path of Contact Pinion Concave - Calc.Time: .98 sec

Comp. Meas.-Sim. Pinion Convex+Concave - Interpolation in progress.
Comp. Meas.-Sim. Pinion Convex+Concave - Calc.Time: .95 sec

Corrective Machine Settings Convex+Concave Pinion [Finishing]
Corrective Machine Settings Convex+Concave Pinion [Finishing] - Calc.Time: 10.75 sec

Digitizing Pinion [Finishing] Tooth Data ...
Digitizing Pinion [Finishing] Tooth Data - Calc.Time: 1.27 sec

Digitizing Pinion [Finishing] FEA Data ...
Digitizing Pinion [Finishing] FEA Data - Calc.Time: .45 sec

Digitizing Pinion [Finishing] Ram Data ...
Digitizing Pinion [Finishing] Ram Data - Calc.Time: .43 sec

FEA Mesh Pinion [Finishing] in progress...
FEA Mesh Pinion [Finishing] 80 Elements / 537 Nodes - Calc.Time: .28 sec

Reverse Engineering Convex+Concave Pinion [Finishing]
Reverse Engineering Convex+Concave Pinion [Finishing] - Calc.Time: 10.75 sec

14 Function Buttons

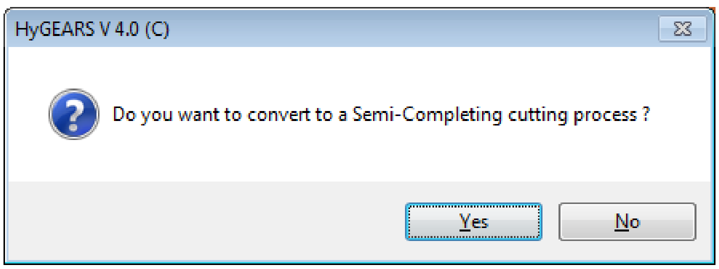
The HyGEARS tool bar installed to the left of the Parent Window contains *function buttons* whose title varies with the displayed Child Window or the selected Pre-Defined mode.

All function buttons are detailed here.

14.1 ->SC

The *->SC* function button is displayed only when the Pinion or Gear uses either the Duplex Helical or Spread Blade cutting processes. It allows to convert a completing process into a Semi-Completing process.

When the *->SC* function button is clicked, the following message is displayed, which asks for user confirmation to convert to a Semi-Completing process:



Semi-Completing has some advantages over Duplex Helical and Spread Blade in that it allows different machine settings on the IB and OB flanks, and thus BP development can be more flexible. On the downside, the IB and OB will be cut separately, and will therefore take more machining time.

14.2 >>IB

The *>>IB* function button is used to during Contact Pattern Development to convert actual E, P and G *V-H Settings* into machine settings changes used to produce the desired Contact Pattern.

It therefore behaves in the same manner as the *VH>>* function, except that it is applied to the Convex flank of the Pinion.

14.3 >>OB

The >>*OB* function button is used to during Contact Pattern Development to convert actual E, P and G *V-H Settings* into machine settings changes used to produce the desired Contact Pattern.

It therefore behaves in the same manner as the *VH>>* function, except that it is applied to the Concave flank of the Pinion.

14.4 {} Cvx Con

Toggles the Corrective Machine Settings (Closed Loop) and Reverse Engineering Child Window between the Convex (Cvx), Concave (Con) or both ( ) tooth flanks of the displayed tooth. For Spiral-Bevel and Hypoid gears.

When both ( ) tooth flanks are selected, HyGEARS will apply the chosen Correction mode to both tooth flanks simultaneously; otherwise, only the selected tooth flank will be corrected.

The Convex and Concave tooth flanks of Spread Blade, Duplex Helical, Face Hobbed pinions and gears and Formate and Helixform gears are always treated simultaneously.

14.5 0rd 1st 2nd

Toggles between the 0rd, 1st and 2nd order Corrective Machine Settings (Closed Loop) or Reverse Engineering.

For the current HyGEARS version, 2nd order Corrective Machine Settings (Closed Loop) or Reverse Engineering are applicable to Fixed Setting and Modified Roll pinions, and generated Duplex Helical and Spread Blade pinions and gears.

14.6 +/-

Moves the contact point stepwise along the PoC towards pinion tooth tooth tip (+) or root (-). When either tooth tip or root is reached, movement is stopped.

A (+) is produced by a **left mouse** button click, a (-) is produced by a **right mouse** button click.

Keeping the mouse button pressed produces a continuous movement.

14.7 #Pts

Calls the Number of Points Editor (see Editing Functions).

14.8 #Tee

Opens an input window through which changes to the *number of displayed teeth* can be made.

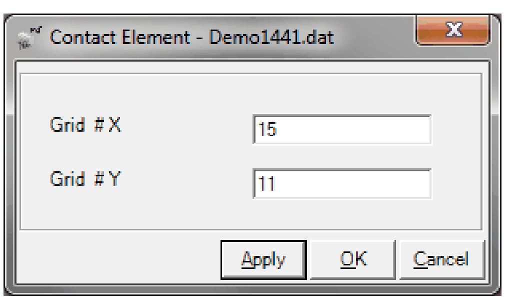
Depending on the selected Child Window, the minimum is 0 or 1 the maximum is the number of teeth of the component.

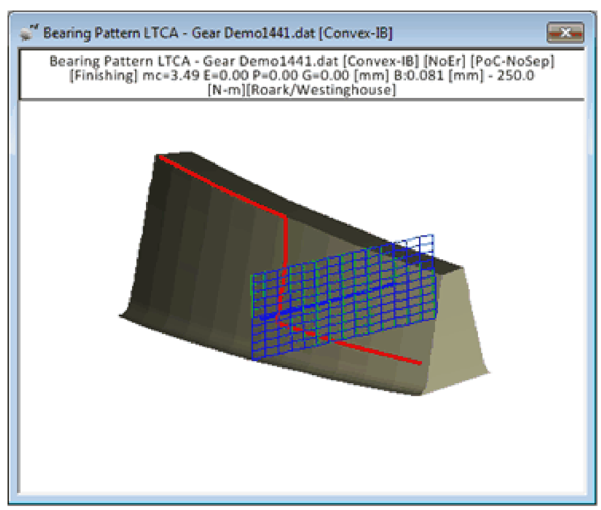
14.9 #X-Y

Allows the definition of the grid density for the *Contact Elements*.

Contact Elements allow the calculation of the contact stresses in a much more precise way than the traditional Hertz formulae, as they account for the exact tooth flank curvatures, and tooth surface errors if the Error Surface is present.

X along the Major axis of the contact area
Y along the Minor axis of the contact area

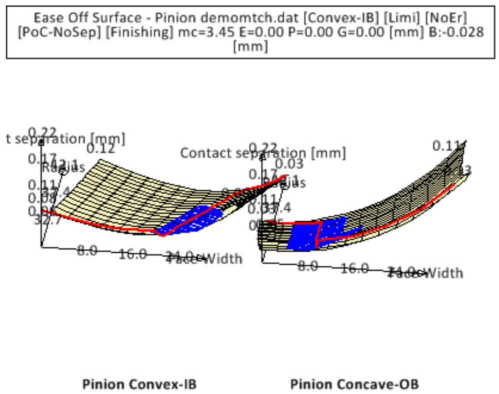


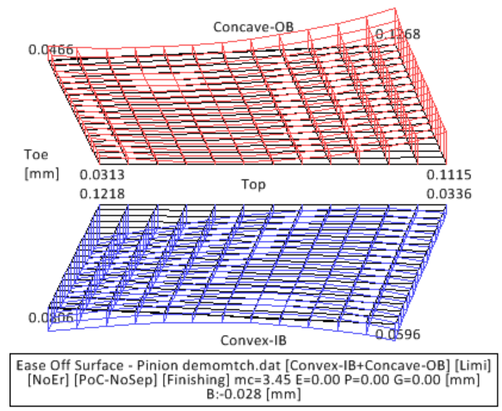


14.10 3D-2D

Ease Off Child Window

Toggles the display between 2D and 3D. When in 2D, the Ease Off display is similar to that of the Error Surface.

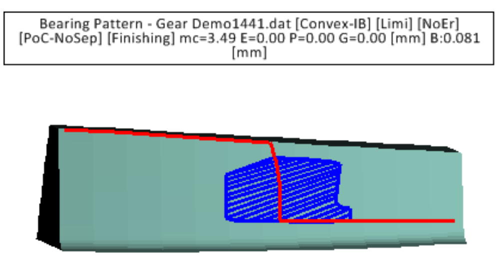


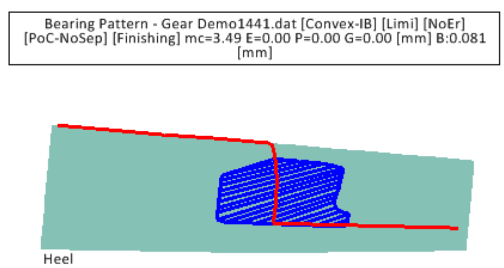


3D Display **2D Display**

Other Child Windows

Toggles the display between 2D and 3D. For some displays such as Contact Pattern and Contact Pattern Development, it is often easier to visualize the results in 2D.





3D Display **2D Display**

14.11 5Axis

Gives access to the Universal 5 Axis CnC Machine programming interface.

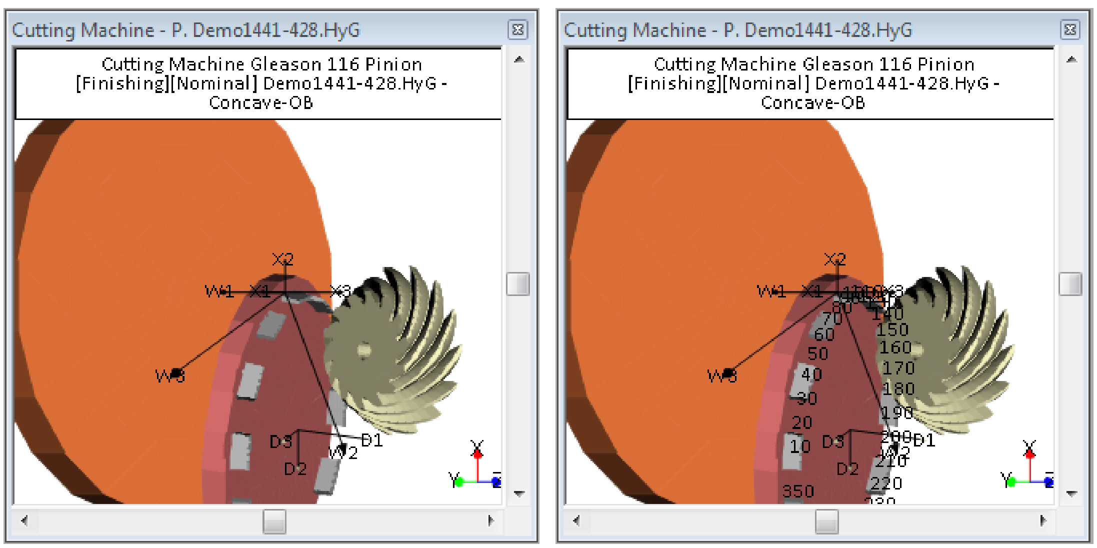
14.12 Actu

Calls the Measurement Data Selection window, which is used to modify the “Actual”, or second, measurement data file name selection in the Actual vs Actual Child Window.

See the Measurement Data Selection window section for detailed explanations.

14.13 Ang-NoAn

Toggles between the display or not of the cutter angle values. Useful to track initial value problems when tracing is used in the digitization process (see Editing the Pinion and Gear Summary).



The tooth digitization process attempts to establish the physical boundaries of a tooth by finding initial, or seed, values for all machine setting variables, and then applying Newton-Raphson iterative schemes to solve the non-linear generation equations. One such variable is the cutter angular position at every tooth flank position, in relation to cutter reference axes D3 for the pinion and C3 for the gear.

For example, in the figure above, the respective cutter angle values at toe and heel ends of the work are approximately 20 and 40. Therefore, the digitization process tracing window cutter angle values should display values similar to the ones visible in the Cutting Machine Child Window above. See Appendix C for more details about the digitization process tracing window.

14.14 Anim

Starts an animation of the Cutting Machine, the PoC or the Finite Strips.

Cutting Machine Animation

The animation reproduces all the movements a cutting machine actually makes during the cutting process. As in actual machines, the cutter can be seen cutting the space between two consecutive teeth, retracting, indexing, cutting another tooth space and so on.

When the “Anim” button is pressed, if the displayed machine is a generator, the Arbor Definition window is loaded from which the supporting arbor may be defined and animation can be controlled.

If the displayed machine is not a generator, then the “Anim” button is changed to “Stop” and animation is started. To stop the animation process, simply click on the “Stop” button.

If the cutting process involves generation, as in the Spread Blade, Fixed Setting, Modified Roll and Duplex Helical processes, the cutting machine cradle will revolve about the machine center, carrying the cutter along. If the generator is a CNC machine, such as a Gleason Phoenix machine, the cradle is rather seen as moving sideways.

If the cutting process involves the advance of the cutter as the Helixform process does, the cutter will be seen moving axially.

PoC Animation

The animation reproduces the progression of meshing between the pinion and the gear tooth, provided the Child Window projection mode is other than Auto.

When the “Anim” button is pressed, it is automatically changed to “Stop”. To stop the animation process, simply click on the “Stop” button.

Finite Strips Animation

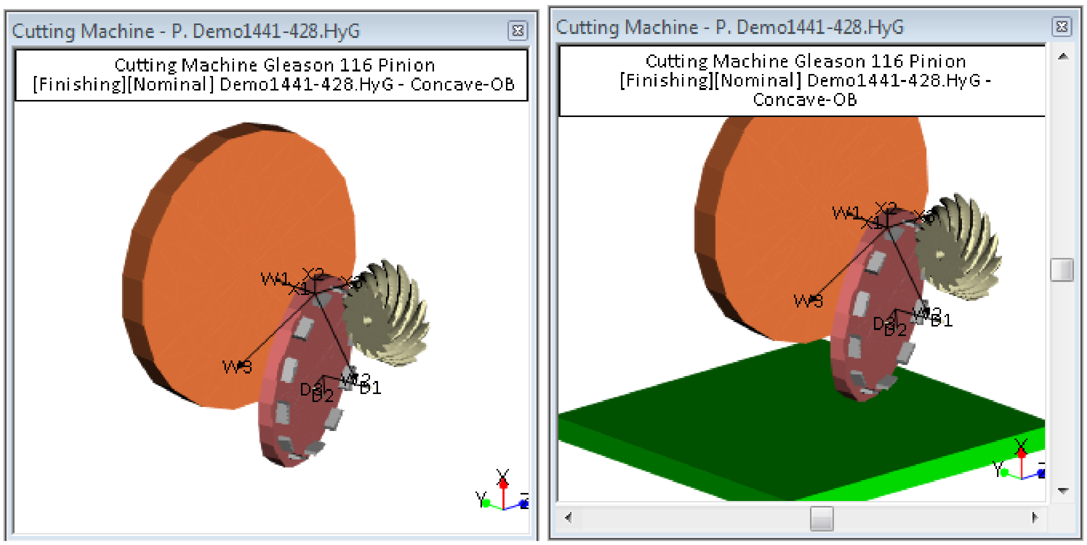
Starts an animation of the Finite Strips. Available only if the Load Type is either “BP Const” or “BP Elliptic”.

The animation automatically steps the Load Case along the Contact Pattern, calculates the solution and redisplays the results. The Speed Control Selector is also shown. To change the current speed, move the slider and click on the Apply button.

When the “Anim” button is pressed, the “Anim” button is changed to “Stop” and animation is started. To stop the animation process, simply click on the “Stop” button.

14.15 Base-NoBa

Toggles on and off the display of the Cutting Machine base. Useful to give a reference when the cradle is moving at generation time. For Zerol, spiral-bevel and Hypoid gears only.

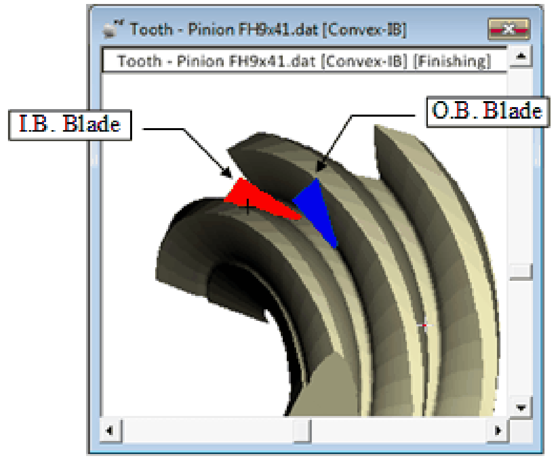


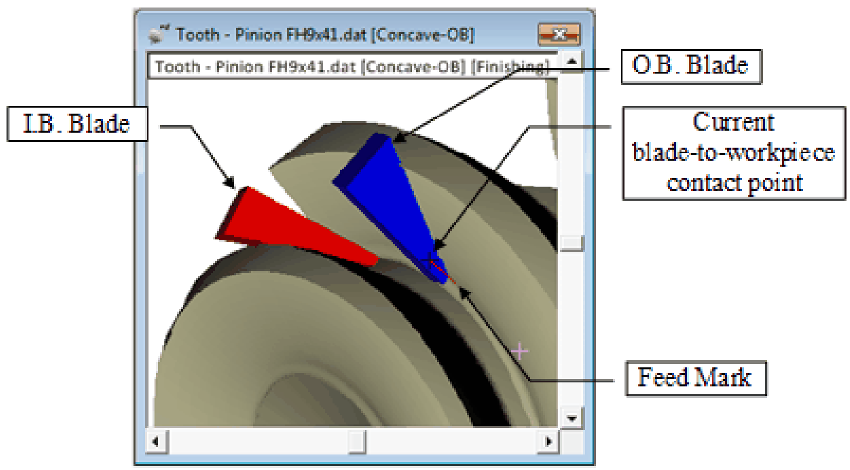
14.16 Blad-NoBl

Toggles On and Off the display of the Cutter Blades that can be animated along the tooth flank. *For Face-Hobbed pinions and gears only.*

The "Blade Thickness" entry in the Cutter data page of the Geometry Summary is used to define the length of the blade in the cutting direction, i.e. perpendicular the the plane containing the cutting edge.

When this option is activated, the "Intr-NoIn", "Anim" and "+/-" function buttons are shown.



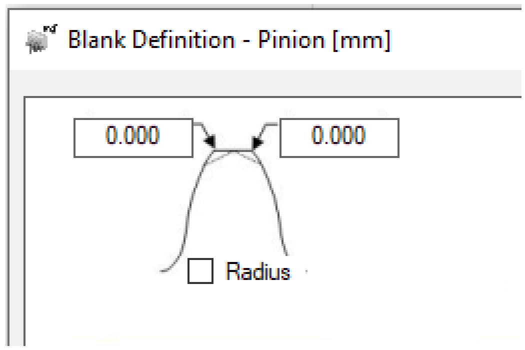


14.17 Blank

The Blank Definition window allows entering the values defining the blank without having to follow a defined sequence as is the case when editing the Blank from within the Summary Editor.

Tooth Tip can be chamfered in order to determine where tip-to-fillet interference stops. The Tip Chamfer value is assumed to bisect the tooth flank and topland in equal parts to the given depth. If the "Radius" option is checked, then the chamfer is rather an arc of circle tangent to the tooth profile and the topland.

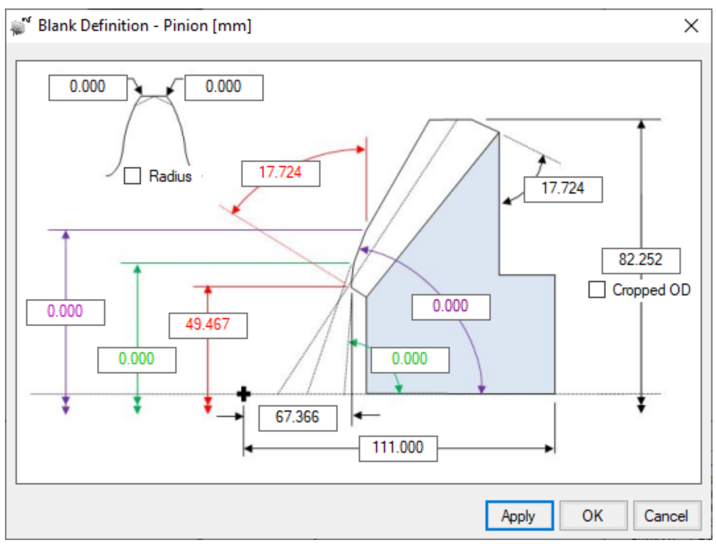
It is used **solely for kinematic purposes**, i.e. to determine how large the chamfer/tip radius should be in order to prevent tip to fillet interference, and therefore has no connection with any Operation in 5Axis mode.



When the mouse is hovering over an entry field, figure below, a “Tool Tip” is displayed to describe the expected entry - see figure below.

Spiral-Bevel Gears

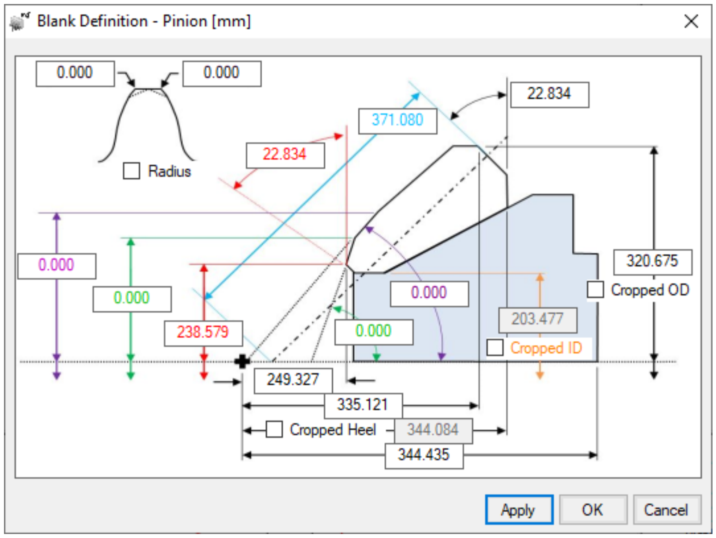
A Cropped OD is not allowed when the Back angle is larger than 89 deg.



Straight-Bevel Gears

A Cropped OD is not allowed when the Back angle is larger than 89 deg. For Straight-bevels, 3 additional options are offered:

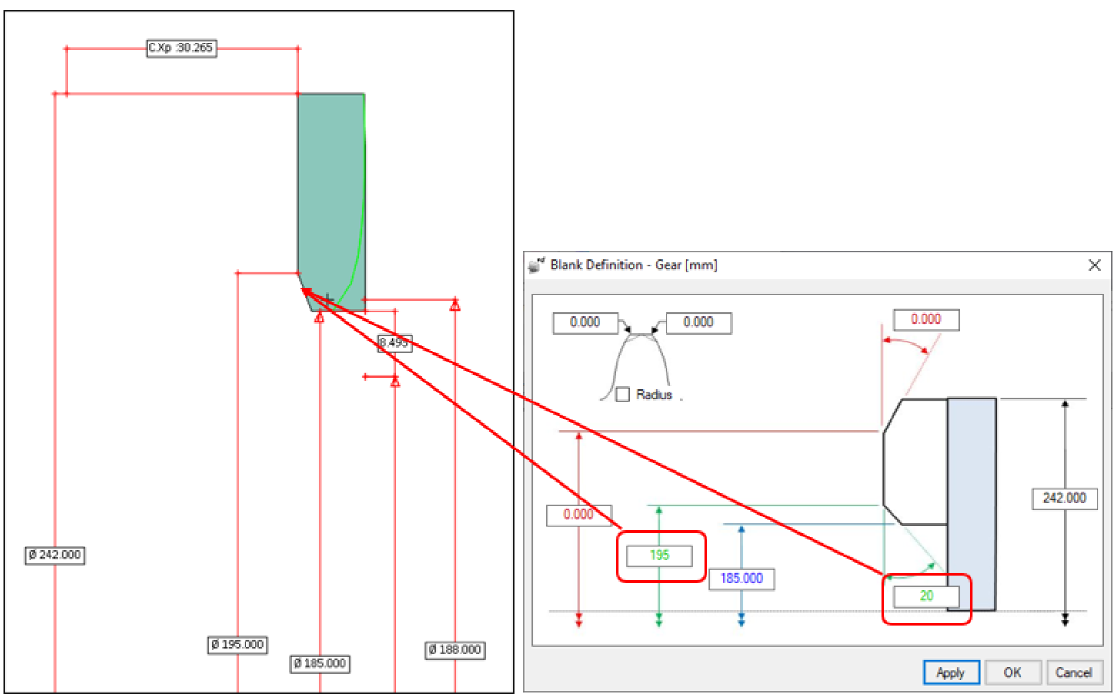
- the Toe ID can be cropped by selecting "Cropped ID;
- the Heel can be cropped by selecting "Cropped Heel";
- the Outer Cone Distance (OCD) can be modified.



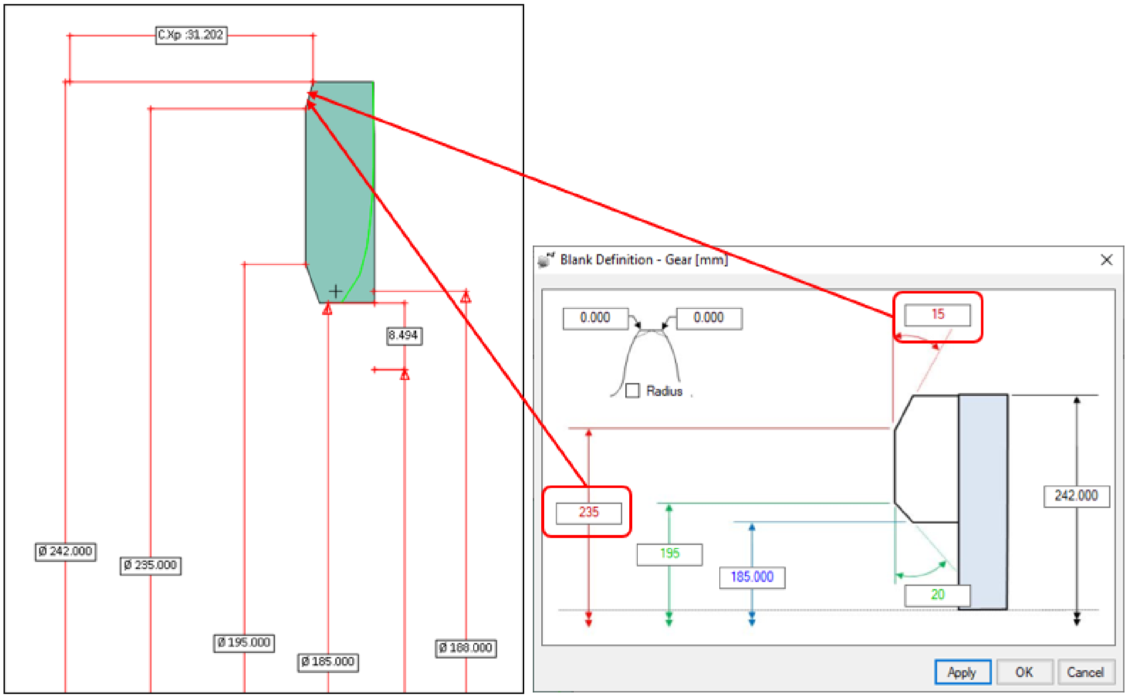
Face Gears

The angles are entered with positive values, and are deviations relative to the normal Topland.

Example 1: Toe dia: 195 mm
Angle: 20 deg.

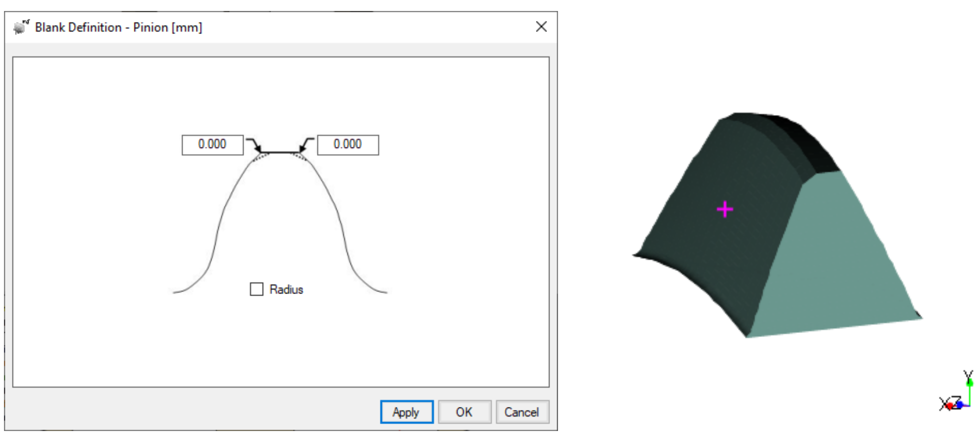


Example 2: Heel dia: 235 mm
Angle: 15 deg.



Cylindrical Gears

Only the tip chamfer can be modified at this time. Is the "Radius" option is checked, then the chamfer is rather a radius tangent to the profile and topland.



Command Buttons

Apply: Retrieves the current blank definition and refreshes the display.

OK: Records the blank definition, terminates the Blank Definition Window, and returns control to the HyGEARS Parent window.

Cancel: Deletes changes made to the blank definition, terminates the Blank Definition Window, and returns control to the HyGEARS Parent window.

14.18 BPat

Calls the Contact Pattern Development Specification Window, in which the location and characteristics of the Contact Pattern can be specified.

14.19 CElm-NoCE

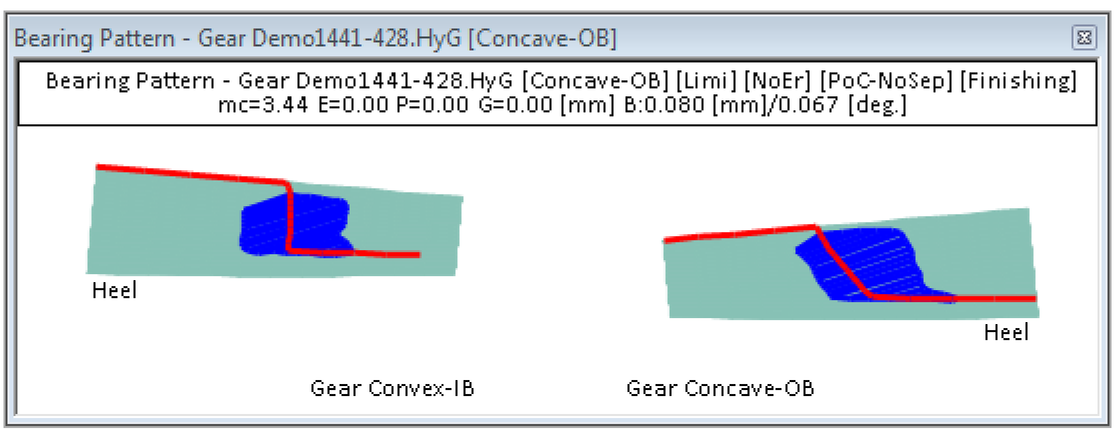
Toggles on and off the calculation and display of the Contact Elements along the Contact Pattern, if this option has been purchased.

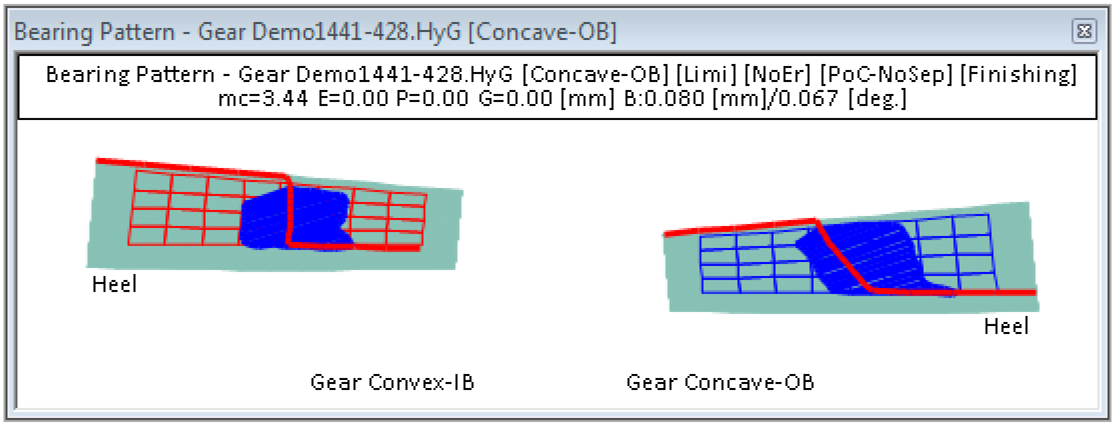
Contact Elements allow the calculation of the contact stresses in a much more precise way than the traditional Hertz formula, as they account for the exact tooth flank curvatures, and errors is the Error Surface is present.

See the Contact Elements section for more details.

14.20 CMM-NoCM

Toggles on and off the display of the CMM grid, if available, on the tooth flank.. See the "XYZ" function button for CMM data.





14.21 Coor

Prints the coordinates of the displayed tooth (pinion, gear or both) in a Text Results window.

See the Coordinates (Tooth Flank) section for details on the coordinates output format.

14.22 Corr

Calls the Corrective Machine Settings (Closed Loop) Selection Window

When the *Corrective Machine Settings (Closed Loop)* Selection Window is shown, HyGEARS uses the current tooth flank and correction order.

Correction order may be changed from the Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection Window.

After the desired correction choices have been made, pressing the “*Apply*” key will initiate the calculation of the changes required in machine settings.

When the *Corrective Machine Settings (Closed Loop)* function is accessed the first time for a given pinion or gear, HyGEARS defines the Nominal Summary _after_ user confirmation, which is equivalent to copy the current Summary as the first entry in the pinion or gear History. The so-called *Nominal Summary* will then be used as the reference to calculate Corrective Machine Settings (Closed Loop).

The display is updated while calculations proceed such that the user may appreciate the results. Once either the imposed limits or the maximum number of iterations have been reached, HyGEARS calculates the machine setting modifications as the difference between the machine settings before and after the application of the Reverse Engineering algorithm.

The user can then:

- Review the results from the Child Window display, the “Correction” or “Expected Stats” Data Pages;
- Issue a new request after changing the selections in the Machine and Order Data Pages;
- Print the obtained results;
- Keep the obtained results with the *OK button*;
- Exit the Corrective Machine Settings (Closed Loop) Selection Window and cancel all calculations with the *Cancel button*.

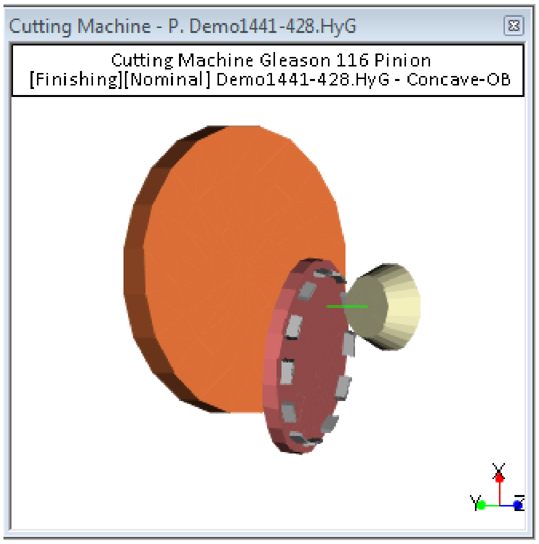
If the requested correction has already been performed, e.g. the selected tooth flank(s) and measured datafile appear in the Corrective Machine Settings (Closed Loop) History, HyGEARS asks the user if he/she desires to output this correction step. If agreed, then HyGEARS displays the “expected error surface after correction”, and the user is prompted to decide whether it should be printed or not. Whether the Geometry Summary is printed or not, it is outputted to a Text Results window.

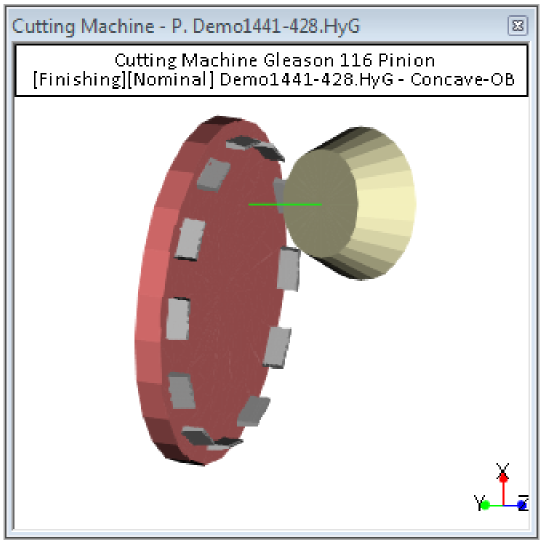
To obtain Corrective Machine Settings (Closed Loop) for a different machine than that with which the above data was calculated, change the cutting machine in the Geometry Summary Editor and request the correction as above.

14.23 Crad-NoCr

Toggles On and Off the display of the Cutting Machine cradle. Useful to get a closer look of the cutter setup when in Auto Zoom mode.

For example, the left figure below shows the pinion generator Gleason 116 in Fixed Setting mode with the cradle, while the right figure shows the same machine setup in the same projection, but without the cradle, such that the cutter-work relationship is seen in more detail.





14.24 Cvx-Con

Toggles between the convex (Cvx) or concave (Con) sides of the displayed pinion or gear Tooth, Cutting machine, PoC, Contact Pattern, etc..

When both the pinion and gear teeth are shown in the Child Window, toggling between “Cvx” and “Con” will show the teeth contacting either on the pinion convex or pinion concave side.

When only either the pinion or the gear tooth is shown in the Child Window, toggling between “Cvx” and “Con” will show the displayed tooth with either its convex or concave side mean point radially aligned with the Z1-Z3 plane.

For the Completing cutting processes, toggling between the convex and concave tooth flanks has no effect on machine setup.

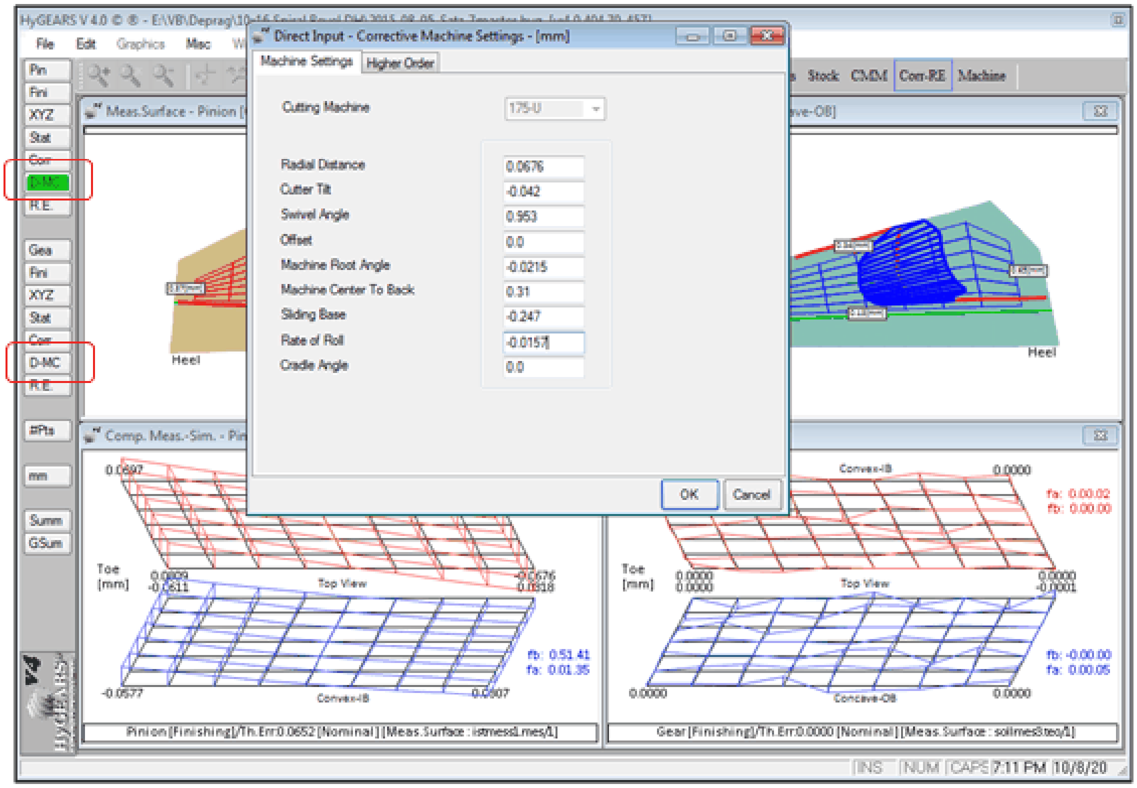
14.25 Cycl

Calls the Cutting Cycle function. For Zerol, spiral-bevel and hypoid gears only

The Cutting Cycle function calculates, and displays in a Text Results window, the cutting cycle, e.g. the cradle angles corresponding to all the points on the tooth flank, plus the cradle angles from the first to the last contact between the cutter blade and the blank. See Numerical Output, Cutting Cycle Output, for more details.

14.26 D-MC

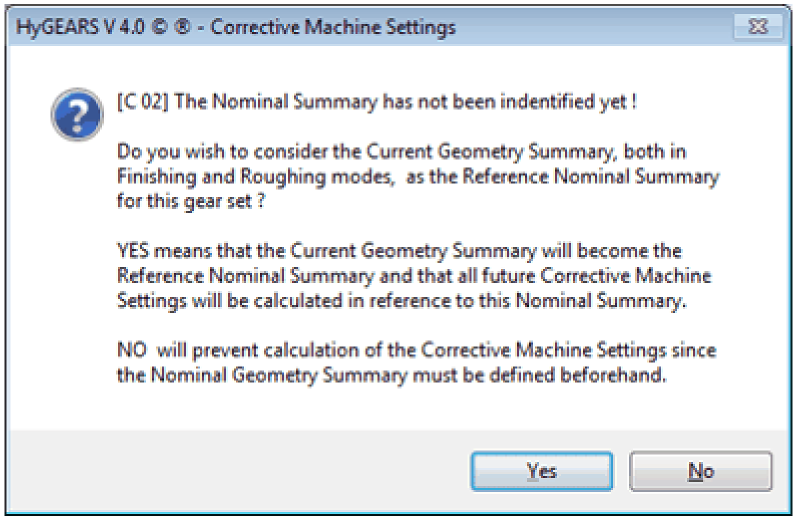
The *D-MC* function button, for each of the Pinion and Gear, allows to directly enter machine setting corrections obtained from Gleason’s GAGE or Klingelnberg’s KOMET.



The current linear units are given in the title bar itself and the currently selected machine is displayed below the title bar of the input window.

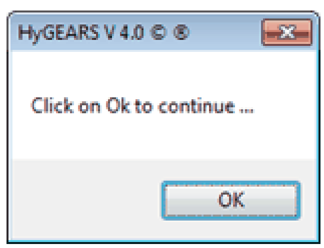
This is available for all the currently machines supported in HyGEARS. The desired machine is selected in the Pinion or Gear Summary Editor, Machine data page. Higher order changes are given in the "Higher Order" data page.

When the "Ok" button is clicked, if the Nominal has not already been defined, the user is requested to confirm that the current set of machine settings are to be considered as the reference Nominal to which the entered values are to be added.



Once confirmation has been given by clicking on the “Yes” button, HyGEARS proceeds as for usual Corrective Machine Settings (Closed Loop), i.e.:

- the entered changes in machine settings are added to the Nominal to create a modified set of machine settings describing the 1^{st} correction iteration;
- the display is updated to show the expected error surface after correction; a prompt is then shown to give the user the time needed to view the expected error surface after correction, such as follows:

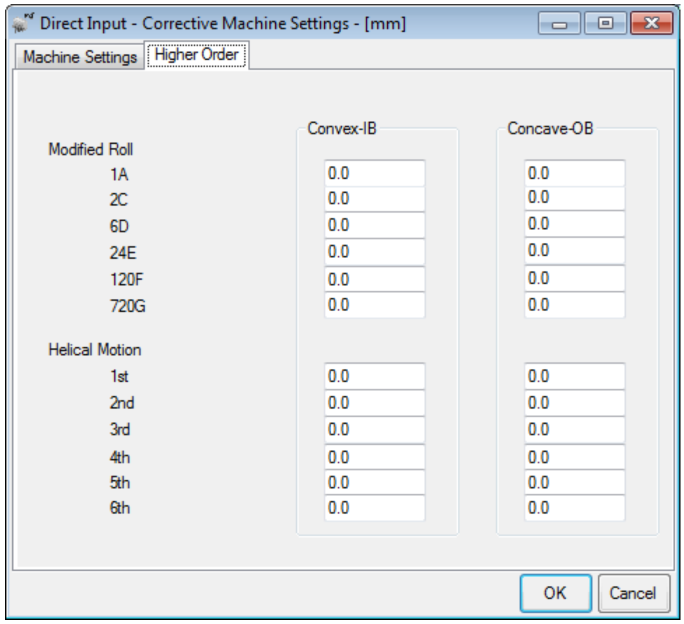


- a correction Summary is generated and displayed with Blank data, corrected machine settings, machine setting changes, and error surfaces before and expected after correction;
- once this is completed, the geometry should be saved in order to conserve the entered data; it is good practice to add “-CorrP” or “-CorrG” at the end of the filename (but before the “.HyG” extension) in order to identify that the geometry file contains correction data.

Note: For Phoenix machines, it appears that KOMET correction for Helical Motion is given in “mm/20 cradle angle” rather than in the usual units of “mm/Radian”; it is therefore necessary to multiply the KOMET Helical Motion correction data by 180/p/20, i.e. 2.8648, to obtain the correct Phoenix value.

14.26.1 D-MC Higher Order

The Higher Order data page covers the coefficients of 6th order Taylor Series used to modify:



Modified Roll

Controls the position of the cradle in reference to the work piece: the modified cradle angle L_{1m} is:

$$L_{1m} = \alpha_3 R_r + \frac{2C}{2}(C_r - \alpha_3 R_r)^2 - \frac{6D}{6}(C_r - \alpha_3 R_r)^3 + \frac{24E}{24}(C_r - \alpha_3 R_r)^4 - \frac{120F}{120}(C_r - \alpha_3 R_r)^5 + \frac{720G}{720}(C_r - \alpha_3 R_r)^6$$

where:

α_3	is the roll angle of the work piece
R_r	is the ratio of roll of the work piece to the cradle
C_r	is the cradle angle given in the machine settings
2C	is the 2nd order coefficient of the Taylor series
6D	is the 3rd order coefficient
24E	is the 4th order coefficient
120F	is the 5th order coefficient
720G	is the 6th order coefficient

Helical Motion

Controls the Sliding base position X_{bm} of the work piece in reference to the machine plane and roll angle:

$$X_{bm} = X_b + 1_{st}\,(C_r - \alpha_3 R_r) + 2_{nd}\,(C_r - \alpha_3 R_r)^2 + 3_{rd}\,(C_r - \alpha_3 R_r)^3 + 4_{th}\,(C_r - \alpha_3 R_r)^4 + 5_{th}\,(C_r - \alpha_3 R_r)^5 + 6_{th}\,(C_r - \alpha_3 R_r)^6$$

where:

α_3	is the roll angle of the work piece
R_r	is the ratio of roll of the work piece to the cradle
C_r	is the cradle angle given in the machine settings
1_{st}	is the 1^{st} order coefficient of the Taylor series (typically called Helical Motion parameter)
2_{nd}	is the 2^{nd} order coefficient
3_{rd}	is the 3^{rd} order coefficient
4_{th}	is the 4^{th} order coefficient
5_{th}	is the 5^{th} order coefficient
6_{th}	is the 6^{th} order coefficient

14.27 Dec-DMS

Toggles the current angular units from the decimal [Dec] format to the Degree.Minute.Second [DMS] format.

However, for all angular inputs, HyGEARS differentiates between the Decimal and Degree.Minute.Second formats by counting the number of periods separating the data:

- for 1 period, such as in "xx.yy", where
  - "*xx*" is considered the integer and
  - "*yy*" is considered the decimal;

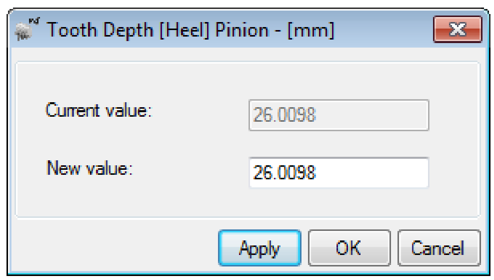
- for 2 periods, such as in "dd.mm.ss", where
  - "*dd*" is considered the angle,
  - "*mm*" is considered the minutes and
  - "*ss*" is considered the seconds.

Therefore, by adhering to the above, all angular inputs can be made in any suitable format at any time.

14.28 Depth

The Depth function allows modifying the tooth depth in a controlled way, i.e. by modifying machine settings.

When called the Depth window displays the current tooth depth at Heel, and waits for an input in the *New Value* field.



Command Buttons

Apply: Retrieves and applies the New value and refreshes the display.

OK: Records the New value, terminates the Depth Window, and returns control to the HyGEARS Parent window.

Cancel: Deletes changes made to the tooth depth, terminates the Depth Window, and returns control to the HyGEARS Parent window.

14.29 Dims NoDi

Contact Pattern Child Window

Toggles on and off the display of the dimensions, for example the Contact Pattern dimensions, such as Contact Pattern position relative to tooth toe, heel and tooth flank percent coverage, or the Loading in the FEA Meshing.

Contact Elements

Toggles on and off the display of the results at the center of the contact area.

14.30 DXF

The DXF function exports different aspects of the tooth of the selected member:

- Tooth Section,
- Gap Section,
- 3D Tooth Model (with 1 to Z teeth).

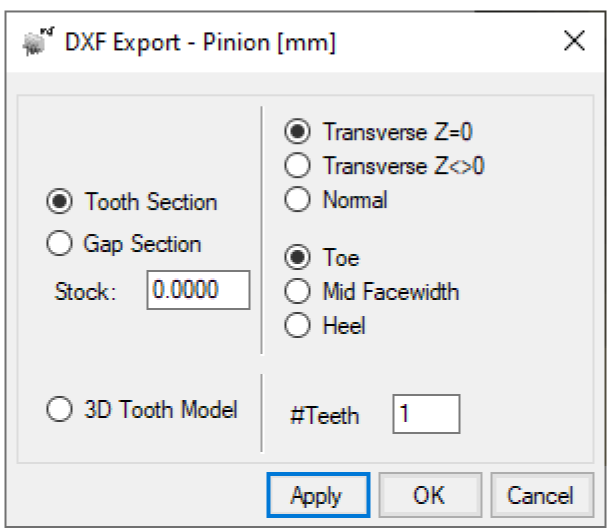
The Tooth and Gap sections can be obtained:

- at Toe,
- at Mid Facewidth,
- at Heel.

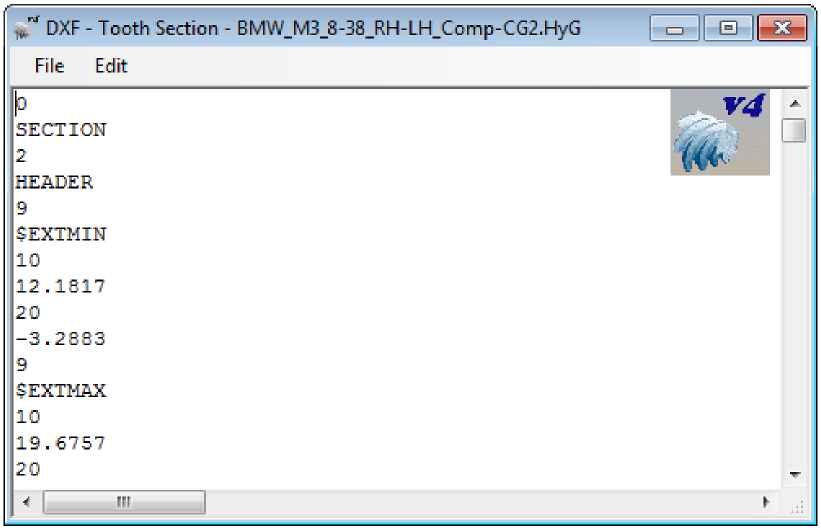
and can contain Stock if desired; positive Stock increases tooth thickness and decreases gap width.

Furthermore, the Tooth and Gap sections can be obtained:

- in the Transverse plane, with the axial coordinate Z = 0,
- in the Transverse plane, with the actual axial coordinate Z,
- in the Normal plane.



The selected output is sent to a Text Results window which can be saved as desired.



Command Buttons

Apply tells HyGEARS to use the entered data and send the output to a Text Results window;

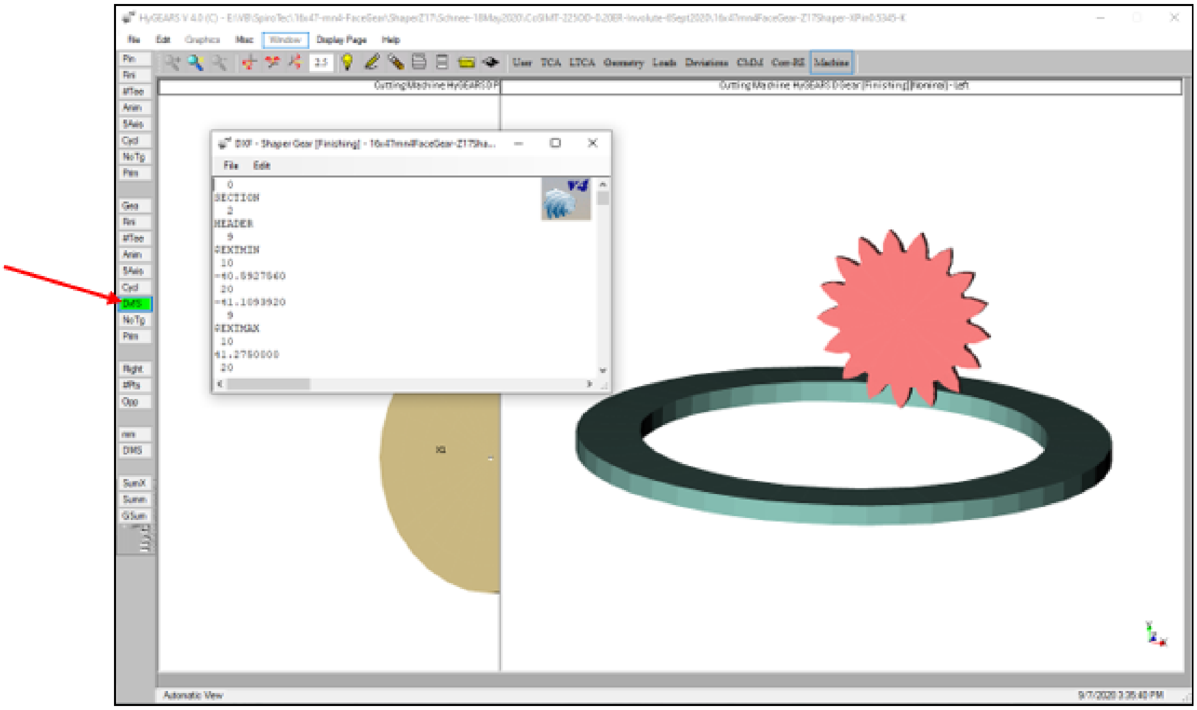
OK tells HyGEARS to use the entered data and send the output to a Text Results window and terminate the input.

Cancel cancels any change done and exits.

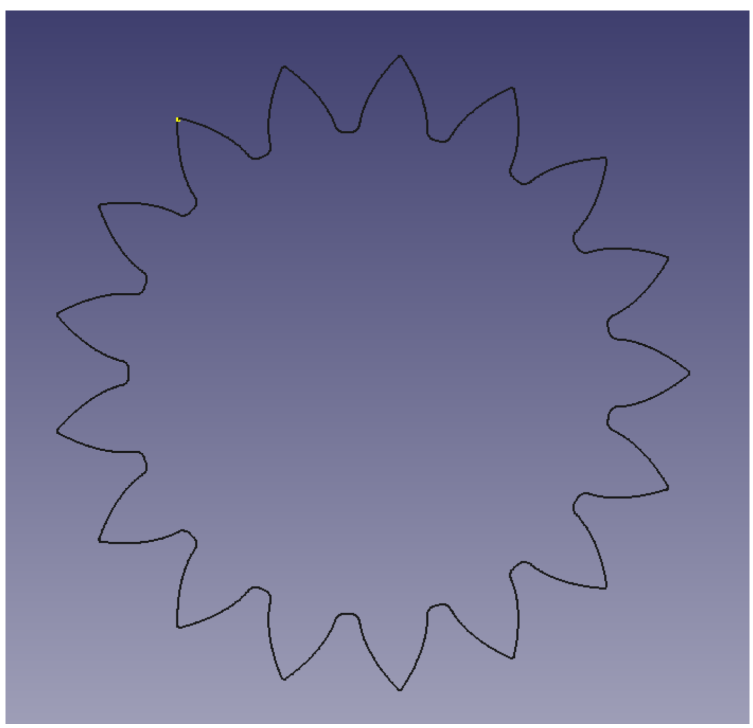
14.31 DxfS

If the reference tool used is a Shaper, such as for a Face Gear, the [DxfS] function button is displayed.

The [DxfS] function produces a Dxf file containing the coordinates for all the teeth of the Shaper tool. The text output can then be saved to a disk file.

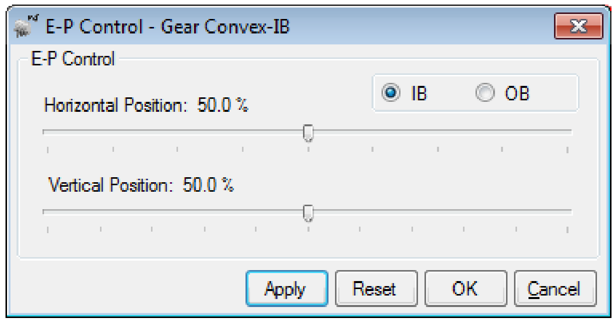


Import of the generated Dxf file in a CAD software produces the display shown below (imported here in FreeCad 0.18).



14.32 E/P

In HyGEARS, the pinion and gear members can be moved virtually in space, such as to simulate relative displacements in actual use. Besides the V-H Editor , HyGEARS offers the *E/P Control* Window through which the position of the mean point of the Contact Pattern is set.



A set of Sliders is used to control the Horizontal and Vertical positions of the mean point of the Contact Pattern. The IB and OB buttons allow switching from Gear Convex to Gear Concave with one mouse click.

When the sliders are moved left or right, the position values are updated; then clicking on the *Apply* button tells HyGEARS to find the E-P combination for the mean point of the BP to lie at the requested position on the tooth flank.

If the [NoEr]-> [ErrS] function button has been clicked, which tells HyGEARS to account for the Error Surface when calculating the TCA, the P and G values, respectively the pinion and gear axial positions, are used to locate the Contact Pattern as desired; otherwise, the E and P values, respectively pinion offset and axial position, are used to locate the Contact Pattern position.

Command Buttons

Apply	tells HyGEARS to use the entered data, e.g. the Horizontal and Vertical Positions, recalculate the display, and remain in the input window;
Reset	tells HyGEARS to restore the original values;
OK	terminates the input.
Cancel	cancels any change done.

14.33 ErrS-NoEr

Toggles the PoC or Contact Pattern between using (*ErrS*) and not using (*NoEr*) the calculated differences between the measured and simulated surfaces, if present. (See the Error Surface).

When the "*NoEr*" button is toggled to "*ErrS*" and back, the PoC or Contact Pattern is automatically recalculated to reflect the new state, provided measurement data files have previously been identified for both the pinion and the gear.

The measurement data files are identified through the "XYZ" Function button, for the Measured Surfaces, Compare Mes-Sim Surfaces, Corrective Machine Settings (Closed Loop) and Reverse Engineering Graphics menu functions.

14.34 FEA

Calls the FEA Model Display Options window, used to specify how a Finite Element Model is to appear on screen.

14.35 Fini-Roug

Toggles between the Finishing and Roughing modes of the pinion or gear Summary.

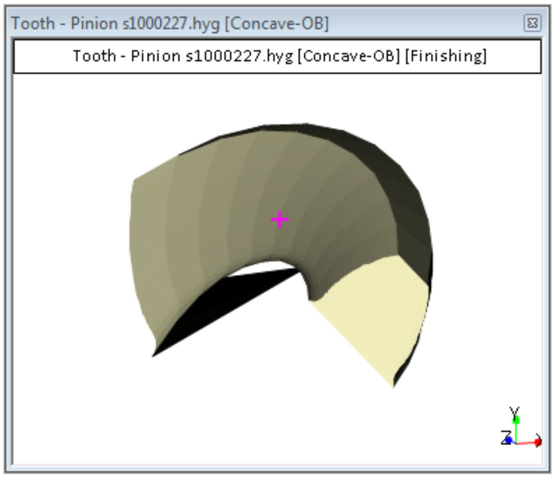
The displayed tooth is automatically recalculated to reflect its new state, and the Child Window title identifies the cutting mode, [Roughing] or [Finishing].

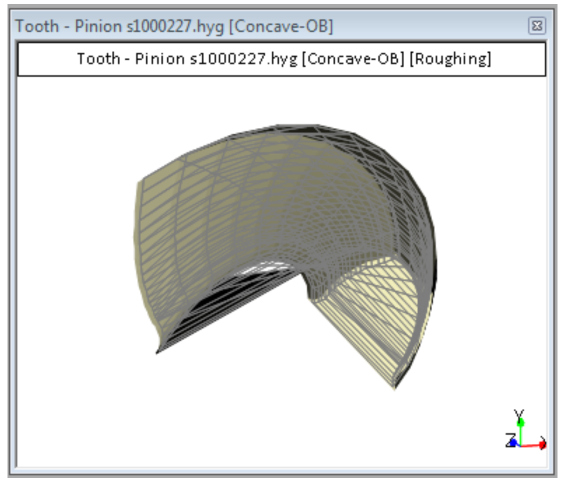
Available only if *Roughing* data is present in the Geometry Summary.

14.36 FiRo-NoFR

Toggles on and off the simultaneous display of the Finished and Roughed teeth.

In the left figure below, the Pinon tooth in its Finished state is shown by itself; if the "NoFR" button is clicked, it changes to "FiRo' and the display is updated to show the Finished tooth as a solid model, and the Roughed tooth in a grey outline, as in the right figure below.



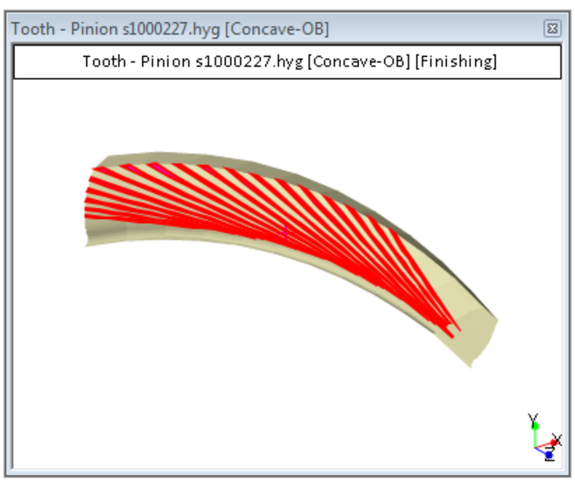


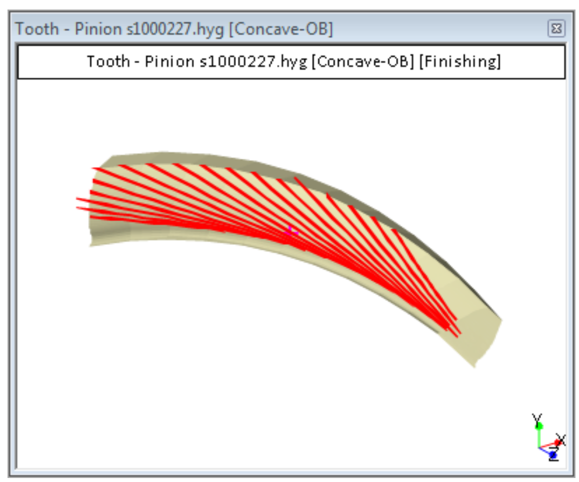
Finished Tooth **Finished and Roughed Teeth**

14.37 FMrk-NoFM

Toggles On and Off the display of the Feedmarks, or the traces left by the cutting tool during manufacturing.

When this option is activated, the RPM function button is shown, from which the Tool and Work speeds may be set.





Slower tool speed (fatter Feedmarks) **Faster tool speed (leaner Feedmarks)**

14.38 Gea

Calls the gear Geometry Summary Editor. (see Editing Functions, Editing the Pinion or Gear Geometry Summary).

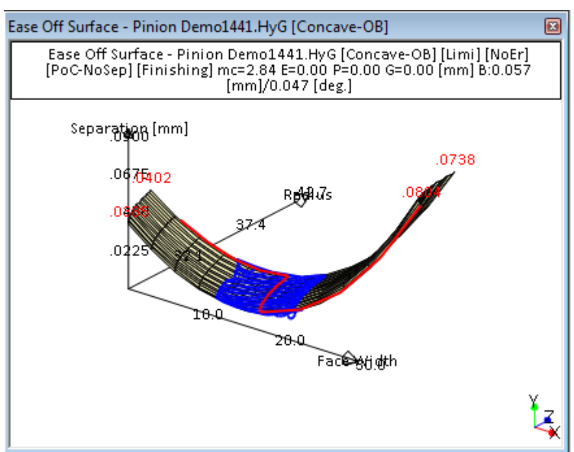
14.39 Graf

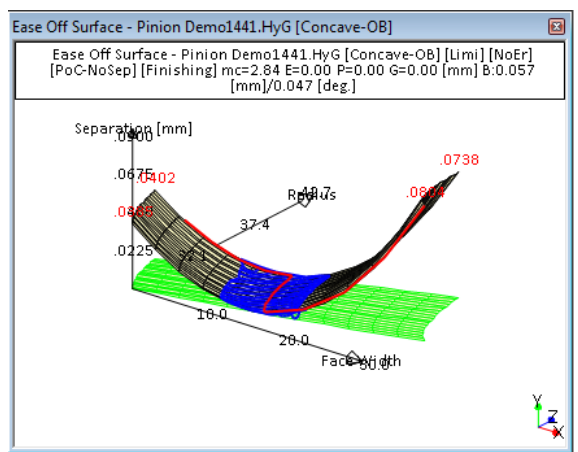
Calls the 2D Graphs Selection window.

14.40 Grid-NoGr

Ease Off Child Window (Ease Off Surface)

Toggles on and off the display of a reference grid at the bottom of the Ease Off surface. The display then reflects more closely that of Gleason and Klingelnberg.





14.41 GSum

Calls:

1) the Graphics Summary selection window, which is used to create a Pdf document containing both text and graphics describing the Summary.

2) the Compare Mes-Sim Surfaces Graphics Summary printing function for the **Compare Meas.Sim Surfaces** Child Window.

14.42 Hertz

Prints the Hertz contact stresses and axes along the PoC to a Text Results window.

14.43 Hist

Prints the Corrective Machine Settings (Closed Loop) History or the Contact Pattern Development History to a Text Results window.

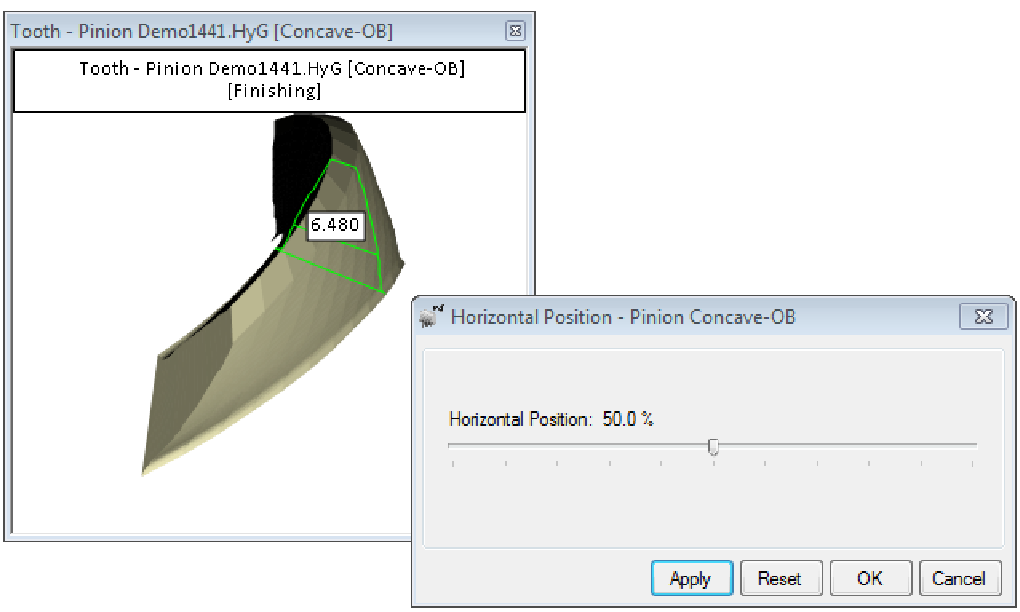
See the History - Corrective Machine Settings (Closed Loop) or History - Contact Pattern Development.

14.44 HPos

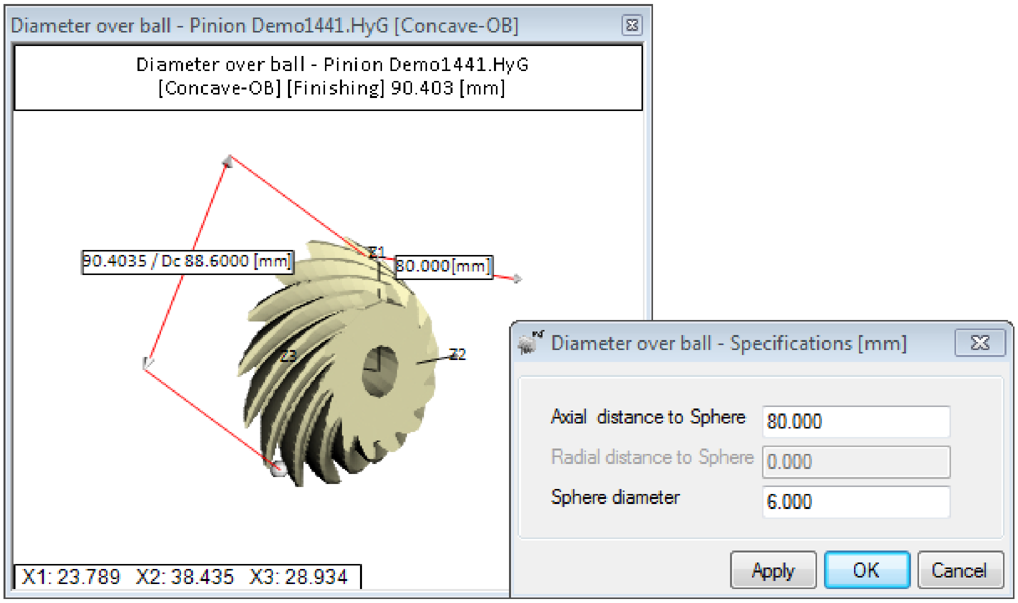
In HyGEARS, several displays need the specification of a distance along the tooth facewidth, what is called the *Horizontal Position*.

Rather that input a value manually, HyGEARS offers a slider-type Horizontal Position Selector to indicate where along the facewidth the result is desired.

When displayed, the Horizontal Position Selector also instructs HyGEARS to show the required section on the actual tooth, such as in the figure below where a green tooth section is displayed. Using the Selector, results can be viewed anywhere along the tooth flank.



For Diameter over Balls, the location where measurement is to be performed is entered manually as follows:.



- If the Pitch angle is less than 60°, the “Axial distance to Sphere”, which is given along the axis of rotation between the center of the sphere and the Pitch Apex, is the value to give, and the corresponding diameter of contact will be calculated;
- If the Pitch angle is larger than 60°, then the “Radial distance to Sphere” is the value to provide, between the center of the sphere and the axis of rotation, and the distance between the center of the sphere and the Pitch Apex will be returned.

14.45 Hub-NoHu

Toggles On and Off the display of the **hub** of the current Child Window member. The **hub dimensions** may be edited in the Geometry Summary editor.

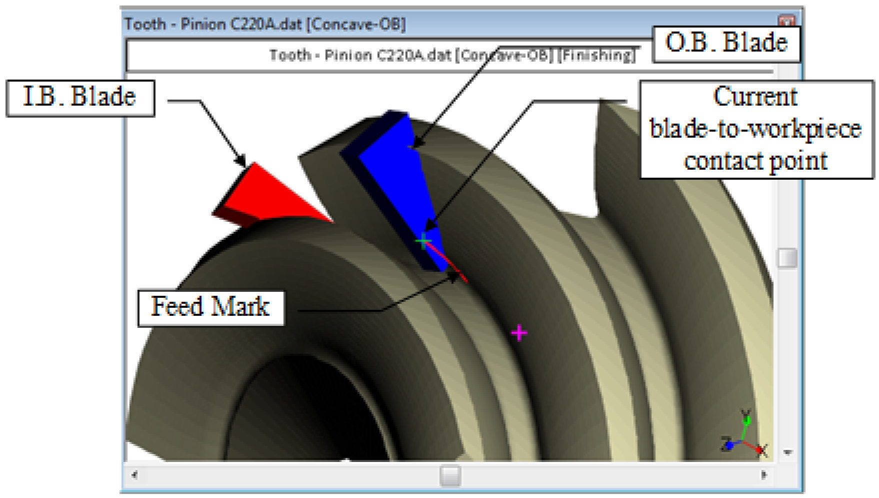
14.46 Intr-NoIn

Machine Child Window

Toggles on and off the display of any interference that may occur between the opposite tooth flank and the current blade, i.e. the blade cutting the current tooth flank, as indicated in the Child Window title.

The green crosshair indicates the current blade-to-workpiece contact point; if the Feedmarks have been turned on, they appear as a red trace running till the green crosshair.

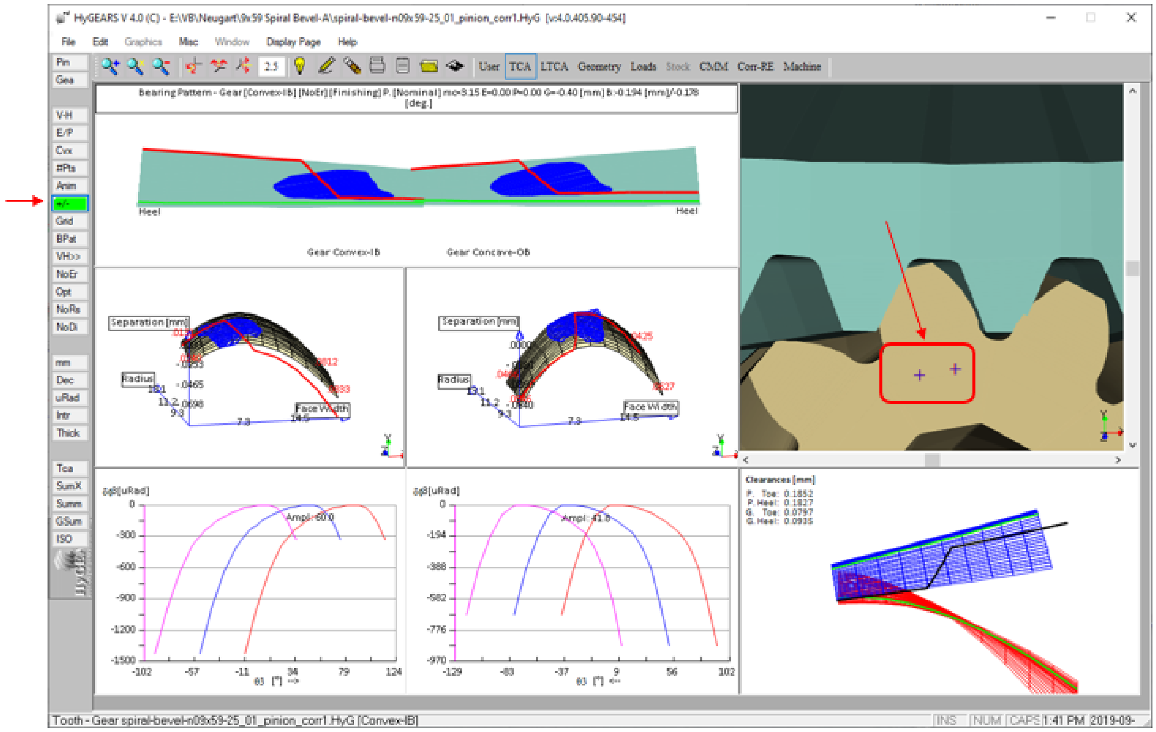
In the figure below, since the current tooth flank is Concave-OB, any interference would be checked on the Convex-IB blade and would be indicated by a crosshair. None is present in the figure below.



TCA Mode

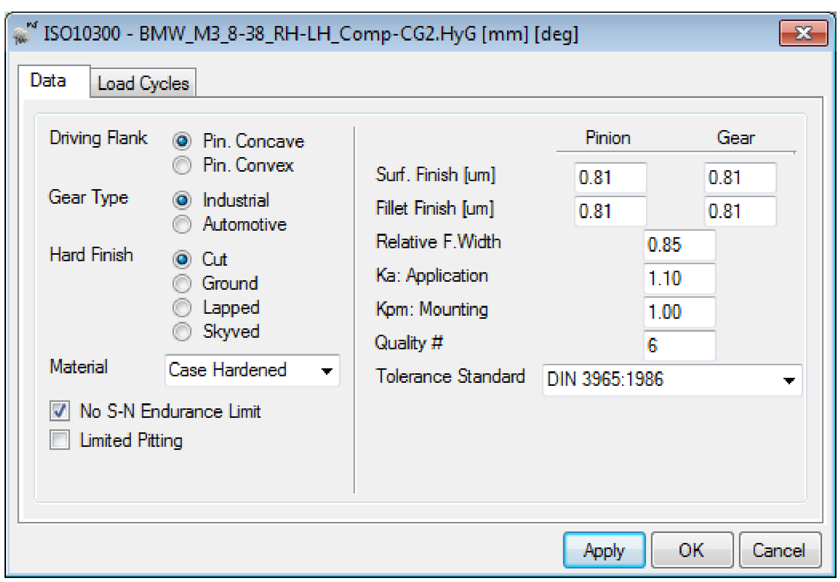
Toggles on and off the display of any interference that may occur between the tip of the pinion tooth with the fillet of the gear and vice-versa. Any interference is displayed as crosshairs in the Complete Model Child Window, upper right corner, as shown below.

The [+/-] function button can be used to manually move through the meshing cycle in order to check all contact positions.



14.47 ISO

Displays the *ISO1300:2014 – Calculation of load capacity of bevel gears* (optional) input window, where input fields allow the specification of the calculation; selections are conserved when the HyGEARS geometry file is saved:



The following input fields allow defining how the ISO-10300 calculations will be performed. Inputs are divided in 2 data pages:

- *Data*: where the actual material and conditions for analysis are given;
- Load Cycles: where up to 20 combinations of Pinion Torque, RPM and #Hours can be given.

Data Page

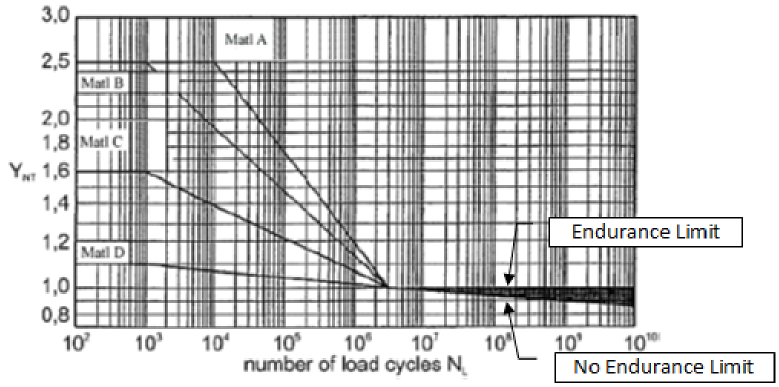
Driving Flank: Pinion Concave (Right for straight bevels)
Pinion Convex (Left for straight bevels)

Gear Type: Industrial (i.e. Low Profile Crowning)
Automotive (i.e. High Profile Crowning)

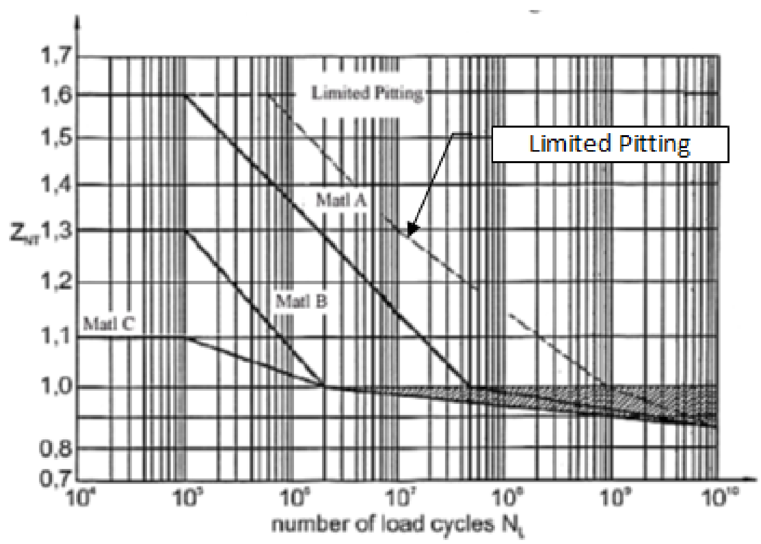
Hard Finish: Cut
Ground
Lapped
Skyved

Material: Grey Cast Iron
Tempered Steel
Induction Hardened, Flame Hardened, Case Hardened
Nitrided Steel
Nitro-carburized Steel
Normalized Cast Steel
Tempered Cast Steel
Normalized Steel

No S-N Endurance Limit: indicates whether the bending and contact Endurance Limit of the S-N curve for the selected material is considered or not. For example, figure below where S-N curves for bending are displayed for different materials, if the Endurance Limit of the S-N curve is considered, factor Y_{NT} will be obtained from the appropriate curve and above 3×10^6 load cycles, $Y_{NT} = 1$; if the Endurance Limit is <u>*not*</u> considered, then Y_{NT} is obtained from the lower boundary of the gray area from 3×10^6 load cycles and above.



Limited Pitting: indicates that limited pitting is allowed when calculating for limited life (i.e. the S-N curve is shifted to higher load). For example, figure below where S-N curves for contact are displayed for different materials, in the worst case the Endurance Limit is set at 5 x 10^7 cycles; if limited pitting is allowed, factor Z_{NT} is rather taken from the dotted line to the right, which in practice allows higher contact loading.



Surf. Finish [um]: the expected surface roughness of the Pinion and Gear tooth *flank* surfaces;

Fillet Finish [um]: the expected surface roughness of the Pinion and Gear tooth *fillet* surfaces;

Rel. F. Width: Ratio of face width [covered by the Contact Pattern] under load to actual face width;

Ka: Application: load *application* factor;

Km: Mounting: pinion *mounting* factor;

Pin. Torque: Pinion Torque [Nm];

Pin. RPM: Pinion rotational speed [min^{-1}];

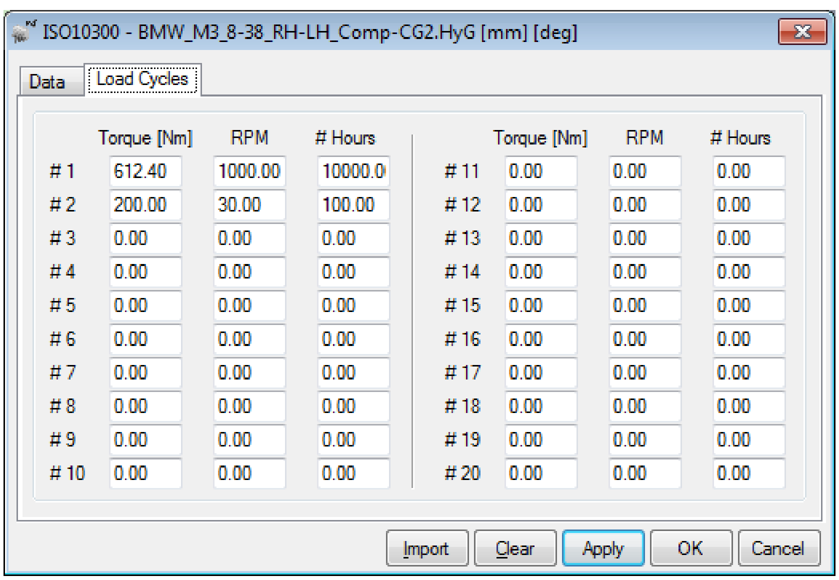
 # Hours: number of hours for requested gear set life. If set to 0, then an infinite life is assumed, the S-N curves are ignored, life factors are set to 1, and no calculation of life limit is performed according to the S-N curves for the selected material;

Quality #: target quality number of the gear set – related to the selected *Tol. Standard* below;

Tol. Standard: tolerance standard targeted for *Quality #*:

- DIN 3965:1986
- ISO17485:2006
- AGMA2000-A88
- AGMA2009-B01

Load Cycles Page



Load Cycles are given in combinations of Pinion *Torque*, *RPM* and *#Hours* of operation. Up to 20 load cycles can be entered.

Import: the *Import* button expects to read a file in CSV format, with data in the same order, i.e. Pinion *Torque*, *RPM* and *#Hours* of operation.
Clear: the *Clear* button clears all fields and sets everything to zero.

The ISO 10300 output is given in 2 different pages:

A) *INPUT DATA* , i.e. data from the above input fields, and extracted from the current gear set, and
OUTPUT – Factors, i.e. intermediate values used in the calculation of Contact and Bending:

| BMW M3 8-38 RH-LH Comp-CG2.HyG |

Hypoid / ISO-10300:2014 (Method B1)
Duplex Helical Pinion
Non Gen. (Formate) Gear

Date / Time	: 11/27/2017 / 8:55:46 AM
General Units	: [mm] [dd.mm.ss]
Cutter Units	: [mm]
Prepared by	: Claude Gosselin /
Version	: 4.0.405.80-461

v4

INPUT DATA

		PINION	GEAR
Pinion Offset	[mm] :	30.0000	
Pinion Offset Angle - Axial Plane	[°] :	20.6871	
Pinion Offset Angle - Pitch Plane	[°] :	21.3888	
Tooth Number	:	8	38
Mean Spiral Angle	[°] :	48.0000	26.7991
Pitch Angle	[°] :	14.8681	74.1058
Effective Pressure Angle - Drive	[°] :	20.9030	20.9030
Effective Pressure Angle - Coast	[°] :	21.1709	21.1709
Pressure Angle - Drive	[°] :	16.0340	16.0340
Pressure Angle - Coast	[°] :	26.0399	26.0399
Limit Pressure Angle	[°] :	-4.8690	
Mean Normal Module	[mm] :	3.7058	3.7058
Face width	[mm] :	38.9096	31.4342
Mean Cone Distance	[mm] :	85.3288	82.0194
Mean Pitch Diameter	[mm] :	43.7897	157.7675
Mean Addendum	[mm] :	3.6414	3.7033
Mean Dedendum	[mm] :	4.7165	4.5465
Addendum Factor	:	0.9910	0.9910
Dedendum Factor	:	1.2451	1.2451
Profile Shift Coefficient	:	-0.0084	0.0084
Thickness Modification Coefficient	:	0.0214	-0.0841
Protuberance Height - Concave	[mm] :	0.0000	0.0000
Protuberance Height - Convex	[mm] :	0.0000	0.0000
Protuberance Angle - Concave	[°] :	0.0000	0.0000
Protuberance Angle - Convex	[°] :	0.0000	0.0000
Protuberance Radius - Concave	[mm] :	0.0000	0.0000
Protuberance Radius - Convex	[mm] :	0.0000	0.0000
Tool Edge Radius - Concave	[mm] :	0.6350	1.5000
Tool Edge Radius - Convex	[mm] :	0.6350	1.5000
Tool Radius	[mm] :	76.2000	76.2000
# Blade Groups	:	0	0
Tool Module	[mm] :	0.0000	0.0000
Relative Face width (Wheel)	[%] :	85.0000	
Application Factor	:	1.1000	
Mounting Factor	:	1.0000	
Quality #	:	6	
Tolerance Standard	:	DIN 3965:1986	
Flank Roughness	[um] :	0.8100	0.8100
Fillet Roughness	[um] :	0.8100	0.8100
Oil Type	:	ISO 220	
Oil Viscosity (@40 °C)	[mm2/s] :	219.9505	
Material	:	16 MnCr 5	16 MnCr 5
Treatment	:	Case Hardened	
Surface Hardness	[HV] :	674.0000	674.0000
Poisson's Ratio	:	0.3000	0.3000
Modulus of Elasticity	[N/mm2] :	206000.0014	206000.0014
Allowable Stress Number (Contact)	[MPa] :	1500.0000	1500.0000
Allowable Stress Number (Bending)	[MPa] :	960.0000	960.0000

OUTPUT - Factors

		PINION	GEAR
Active flank	:	Pinion Concave-OB	
Production method	:	Face Milling	
Generated wheel	:	No	
Finish process	:	Cut	
No S-N Endurance Limit	:	Yes	
Limited Pitting	:	No	
Profile crowning	:	Industrial (High)	
Number of blade groups	:	0	
Tool radius	[mm] :	76.2000	
Tool radius (Eff.)	[mm] :	76.2000	

DATA OF VIRTUAL CYLINDRICAL GEAR - TRANSVERSE SECTION

		PINION	GEAR
Tooth number	:	9.7123	123.4949
Gear ratio	:	12.7153	
Relative face width	[%] :	85.0000	
Face width	[mm] :	29.8912	
Effective face width	[mm] :	25.4075	
Helix angle	[°] :	37.3996	
Reference diameter	[mm] :	45.3066	576.0849
Tip diameter	[mm] :	52.5893	583.4916
Root diameter	[mm] :	35.8736	566.9920
Transverse module	[mm] :	4.6648	
Transverse pressure angle (Drive/Coast)	[°] :	19.8880	31.5929
Eff. transverse pressure angle (Drive/Coast)	[°] :	25.6763	25.9898
Relative radius of curvature (Drive/Coast)	[mm] :	14.1546	14.3033
Profile contact ratio	:	1.1417	
Face contact ratio (Nom./Eff.)	:	1.5594	1.3255
Virtual contact ratio (Nom./Eff.)	:	2.7011	2.4672

DATA OF VIRTUAL CYLINDRICAL GEAR - NORMAL SECTION

		PINION	GEAR
Tooth number	:	18.0304	229.2609
Gear ratio	:	12.7153	
Reference diameter	[mm] :	66.8178	849.6056
Tip diameter	[mm] :	74.1006	857.0123
Root diameter	[mm] :	57.3848	840.5127
Base diameter	[mm] :	62.4203	793.6895
Normal pressure angle	[°] :	16.0340	
Eff. normal pressure angle	[°] :	20.9030	

GENERAL INFLUENCE FACTORS

		PINION	GEAR
Application factor	:	1.1000	
Dynamic factor	:	1.0000	
Tangential speed at mid face width	:	2.2928	1.7391
Mounting factor	:	1.0000	
Stiffness	[N/mm-um] :	14.0000	20.0000
Single pitch deviation	[um] :		13.0000

Fixed-Setting, Spread-Blade, Formate, Duplex-Helical, Modified-Roll, Zerol, TopRem
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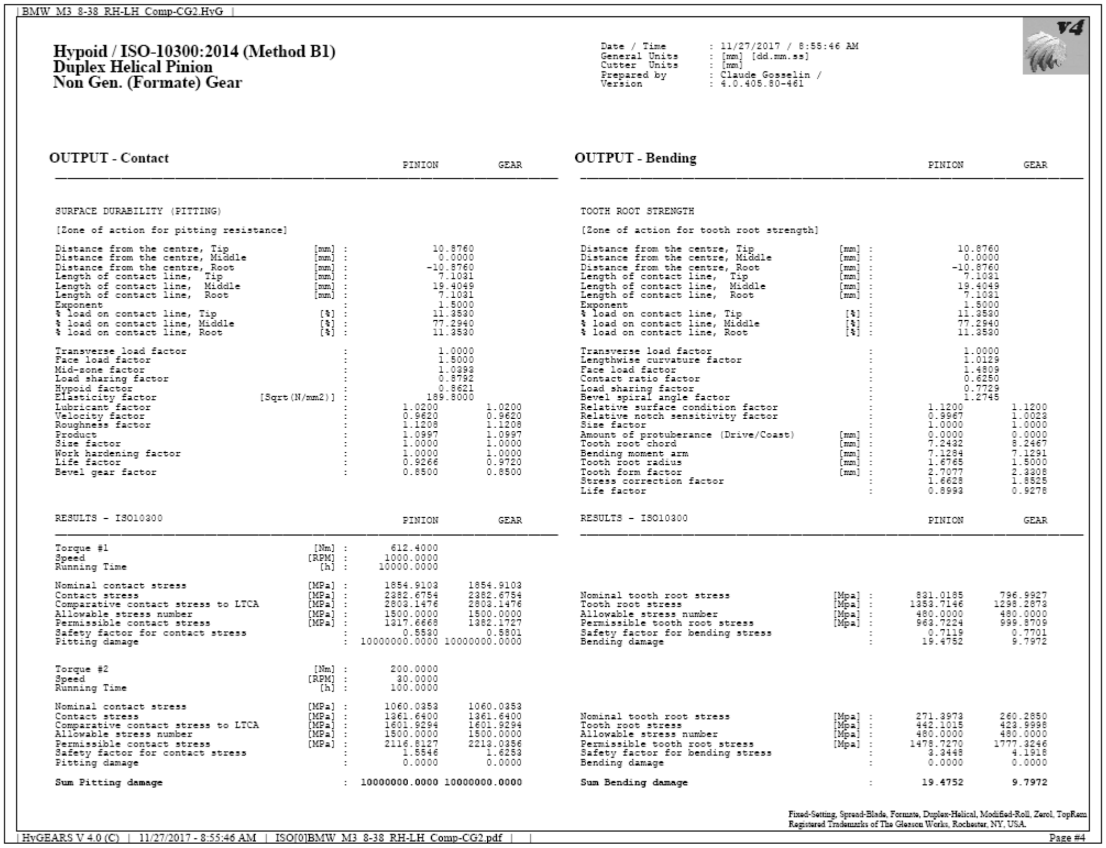
B) *OUTPUT – Contact*, i.e. Surface Durability for Pitting and Contact stresses, and
OUTPUT – Bending, i.e. Tooth Root Strength.

HyGEARS goes through all Loads Cycles, calculates and prints the Pitting and Bending damage, and displays the Sum Damage at the end of the load cycles.



BMW M3 8-38 RH-LH Comp-CG2.HyG

Hypoid / ISO-10300:2014 (Method B1)
Duplex Helical Pinion
Non Gen. (Formate) Gear

Date / Time	: 11/27/2017 / 8:55:46 AM
General Units	: [mm] [dd.mm.ss]
Cutter Units	: [mm]
Prepared by	: Claude Gosselin /
Version	: 4.0.405.80-461

OUTPUT - Contact

SURFACE DURABILITY (PITTING)

[Zone of action for pitting resistance]

	Unit	PINION	GEAR
Distance from the centre, Tip	[mm] :	10.8760	
Distance from the centre, Middle	[mm] :	0.0000	
Distance from the centre, Root	[mm] :	-10.8760	
Length of contact line, Tip	[mm] :	7.1031	
Length of contact line, Middle	[mm] :	19.4049	
Length of contact line, Root	[mm] :	7.1031	
Exponent	:	1.5000	
% load on contact line, Tip	[%] :	11.3530	
% load on contact line, Middle	[%] :	77.2940	
% load on contact line, Root	[%] :	11.3530	
Transverse load factor	:	1.0000	
Face load factor	:	1.5000	
Mid-zone factor	:	1.0393	
Load sharing factor	:	0.8792	
Hypoid factor	:	0.8621	
Elasticity factor	[Sqrt(N/mm2)] :	189.8000	
Lubricant factor	:	1.0200	1.0200
Velocity factor	:	0.9620	0.9620
Roughness factor	:	1.1208	1.1208
Product	:	1.0997	1.0997
Size factor	:	1.0000	1.0000
Work hardening factor	:	1.0000	1.0000
Life factor	:	0.9266	0.9720
Bevel gear factor	:	0.8500	0.8500

RESULTS - ISO10300

	Unit	PINION	GEAR
Torque #1	[Nm] :	612.4000	
Speed	[RPM] :	1000.0000	
Running Time	[h] :	10000.0000	
Nominal contact stress	[MPa] :	1854.9103	1854.9103
Contact stress	[MPa] :	2382.6754	2382.6754
Comparative contact stress to LTCA	[MPa] :	2803.1476	2803.1476
Allowable stress number	[MPa] :	1500.0000	1500.0000
Permissible contact stress	[MPa] :	1317.6668	1382.1727
Safety factor for contact stress	:	0.5530	0.5801
Pitting damage	:	10000000.0000	10000000.0000
Torque #2	[Nm] :	200.0000	
Speed	[RPM] :	30.0000	
Running Time	[h] :	100.0000	
Nominal contact stress	[MPa] :	1060.0353	1060.0353
Contact stress	[MPa] :	1361.6400	1361.6400
Comparative contact stress to LTCA	[MPa] :	1601.9294	1601.9294
Allowable stress number	[MPa] :	1500.0000	1500.0000
Permissible contact stress	[MPa] :	2116.8127	2213.0356
Safety factor for contact stress	:	1.5546	1.6253
Pitting damage	:	0.0000	0.0000
Sum Pitting damage	:	**10000000.0000**	**10000000.0000**

OUTPUT - Bending

TOOTH ROOT STRENGTH

[Zone of action for tooth root strength]

	Unit	PINION	GEAR
Distance from the centre, Tip	[mm] :	10.8760	
Distance from the centre, Middle	[mm] :	0.0000	
Distance from the centre, Root	[mm] :	-10.8760	
Length of contact line, Tip	[mm] :	7.1031	
Length of contact line, Middle	[mm] :	19.4049	
Length of contact line, Root	[mm] :	7.1031	
Exponent	:	1.5000	
% load on contact line, Tip	[%] :	11.3530	
% load on contact line, Middle	[%] :	77.2940	
% load on contact line, Root	[%] :	11.3530	
Transverse load factor	:	1.0000	
Lengthwise curvature factor	:	1.0129	
Face load factor	:	1.4809	
Contact ratio factor	:	0.6250	
Load sharing factor	:	0.7729	
Bevel spiral angle factor	:	1.2745	
Relative surface condition factor	:	1.1200	1.1200
Relative notch sensitivity factor	:	0.9967	1.0023
Size factor	:	1.0000	1.0000
Amount of protuberance (Drive/Coast)	[mm] :	0.0000	0.0000
Tooth root chord	[mm] :	7.2432	8.2467
Bending moment arm	[mm] :	7.1284	7.1291
Tooth root radius	[mm] :	1.6765	1.5000
Tooth form factor	[mm] :	2.7077	2.3308
Stress correction factor	:	1.6628	1.8525
Life factor	:	0.8993	0.9278

RESULTS - ISO10300

	Unit	PINION	GEAR
Nominal tooth root stress	[Mpa] :	831.0185	796.9927
Tooth root stress	[Mpa] :	1353.7146	1298.2873
Allowable stress number	[Mpa] :	480.0000	480.0000
Permissible tooth root stress	[Mpa] :	963.7224	999.8709
Safety factor for bending stress	:	0.7119	0.7701
Bending damage	:	19.4752	9.7972
Nominal tooth root stress	[Mpa] :	271.3973	260.2850
Tooth root stress	[Mpa] :	442.1015	423.9998
Allowable stress number	[Mpa] :	480.0000	480.0000
Permissible tooth root stress	[Mpa] :	1478.7270	1777.3246
Safety factor for bending stress	:	3.3448	4.1918
Bending damage	:	0.0000	0.0000
Sum Bending damage	:	**19.4752**	**9.7972**

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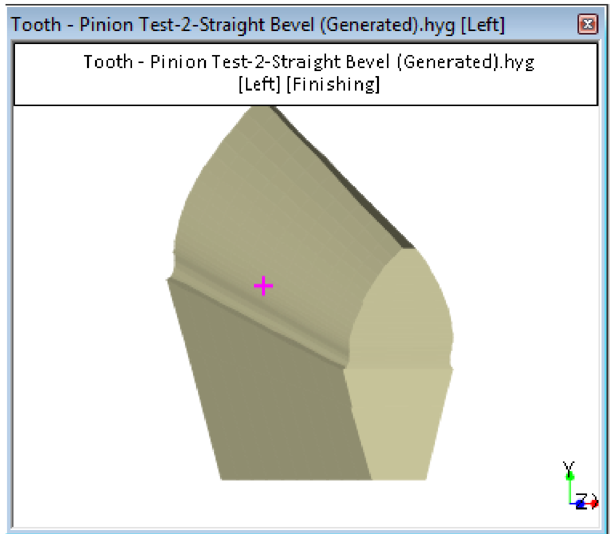
HyGEARS V 4.0 (C) | 11/27/2017 - 8:55:46 AM | ISO[0]BMW M3 8-38 RH-LH Comp-CG2.pdf | Page #4

14.48 Left-Right

Toggles between the Left or Right sides of the displayed pinion or gear Tooth, Cutting machine, PoC, Contact Pattern, etc...

The Left tooth flank is at the left of the tooth when viewed from the toe, with the tooth pointing up. In the figure below, *[Left]* is identified in the title bar and a pink crosshair is displayed at the *Mean Point* on the left tooth flank.

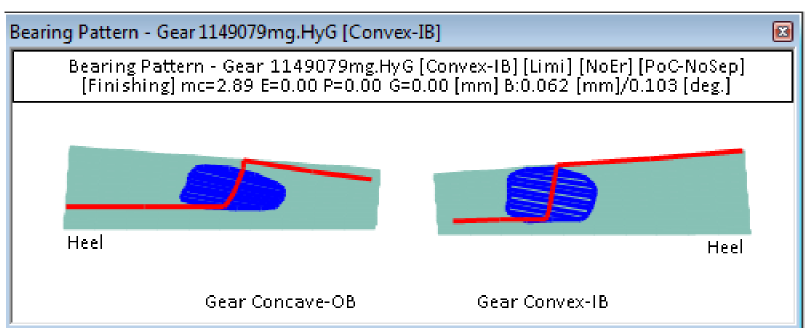


When both the pinion and gear teeth are shown in the Child Window, toggling between "*Left*" and "*Right*" will show the teeth contacting either on the *pinion Left* or *pinion Right* side.

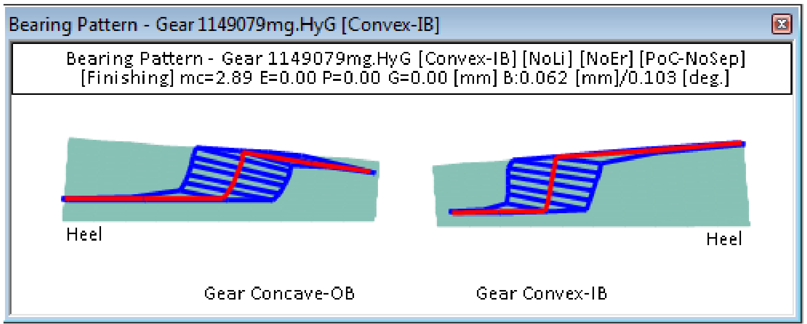
When only either the pinion or the gear tooth is shown in the Child Window, toggling between "*Left*" and "*Right*" will show the displayed tooth with either its Left or Right side mean point aligned with the Z1-Z3 plane.

14.49 Limi-NoLi

Toggles the calculation of the Contact Pattern between using (Limi) and ignoring (NoLi) the difference between marking compound thickness and the tooth profile separation calculated with the PoC.



Limi



NoLi

Each “Limi” and “NoLi” toggle forces a Contact Pattern recalculation.

In short, using “NoLi” gives a good idea of what the Contact Pattern would look like if *only one tooth pair were in contact*, thereby ignoring the effects of adjacent teeth.

14.50 List

Prints the coordinates of the displayed tooth (pinion, gear or both) in a list style to a Text Results window. This list can easily be imported in a CAD system.

See Coordinate List Output for details on the output format.

14.51 Load

Finite Element Model

Calls the FEA Load Editor window, used to apply loads at selected nodes on a meshed Finite Element Model . (see Chapter 6, FEA Model, The FEA Load Editor window).

Finite Strips Model

Calls either the Finite Strips Load Editor window or the LTCA Editor window, depending on the Load Type.

If the Load Type is “Point”, e.g. concentrated loads, the Finite Strips Load Editor window is displayed, from which Load Cases can be defined. See the FEA Load Editor section for details.

Otherwise, e.g. distributed loads along an instant line of contact, the LTCA Editor window is displayed, from which the applied torque can be specified. If the calculation mode is "Ltca" (see the Ltca-NoLt function buttons), then the LTCA Editor window also controls the behavior of the LTCA algorithm.

Loaded Tooth Contact Analysis
Contact Pattern (LTCA)
2D Graphs
Finite Strips

Calls the Loaded Tooth Contact Analysis editor window, in which the various LTCA parameters can be modified.

14.52 Ltca-NoLt

Toggles between using, or not, the results of the Loaded Tooth Contact Analysis as the normal load values and the corresponding extents of the Contact Pattern LTCA.

Finite Strips

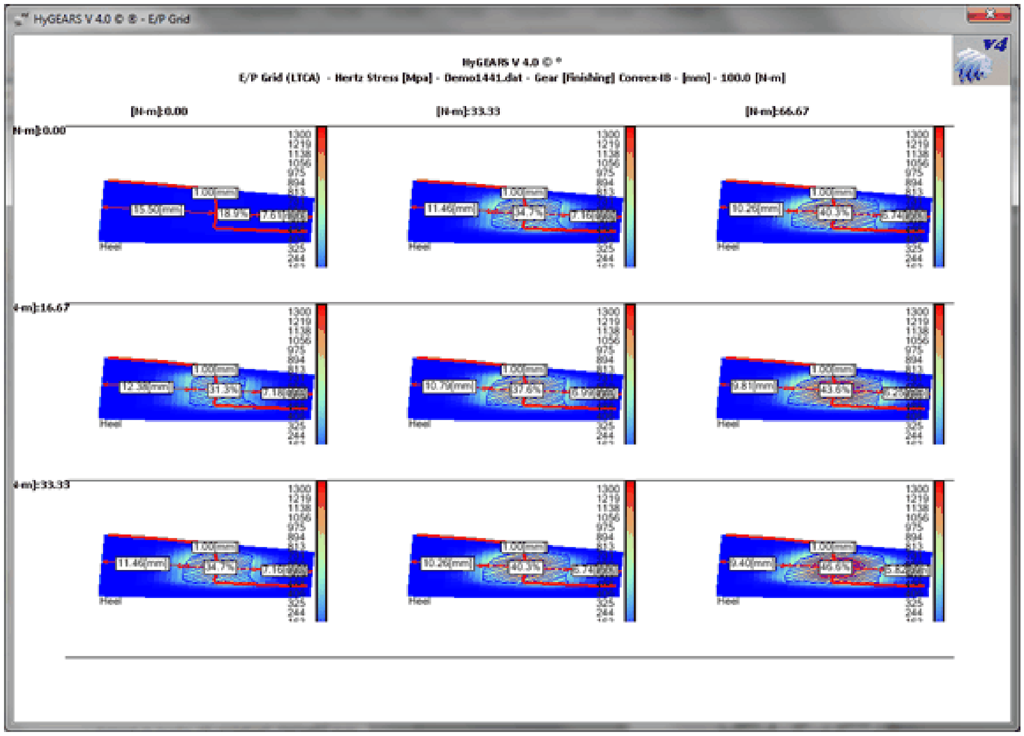
When in "Ltca" mode, the dimensions of the Contact Pattern and the loads applied on the instant line of contact are obtained from the LTCA results. Thus, the "Load" function button loads the LTCA Editor window, from which the LTCA switches may be modified.

In "NoLt" mode, the dimensions of the Contact Pattern are obtained from the current compound thickness (see the "Thick" function button in the Contact Pattern Child window) and the applied loads are obtained from the applied torque. The "Load" function button loads the LTCA Editor window, from which the applied torque may be changed, but LTCA switches have no effect.

14.53 MaxV

Allows imposing a maximum value to the rendering of the LTCA Contact Pattern results. For example, if one desires a Grid of the LTCA Contact Pattern, with an upper constant maximum value, and the color rendering scaled to this maximum value, the MaxV function allows imposing this maximum value, which will be reflected in the Grid afterward.

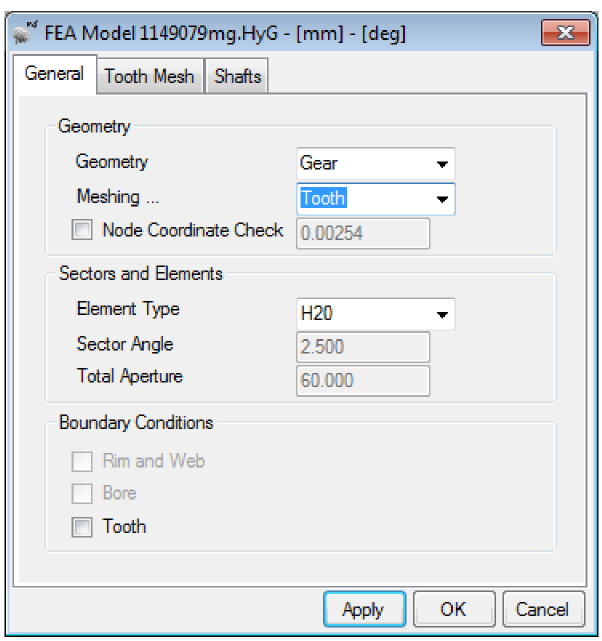
Figure below, the Hertz contact stress varies as a function of applied torque, but the maximum value of the color scale is always the same because the MaxV value has been imposed.



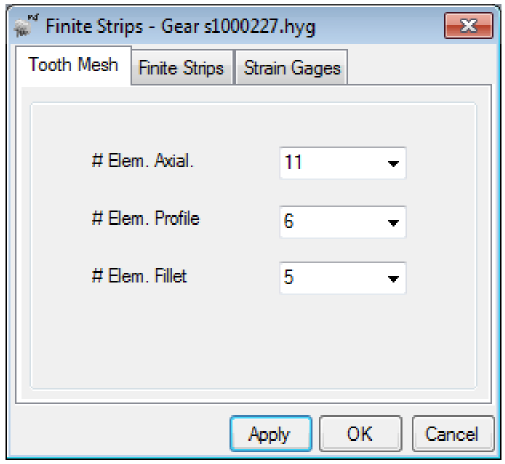
14.54 Mesh

Calls :

- the FEA Mesh Editor window, used to define the mesh of a Finite Element Model or



- the Finite Strips Mesh Editor window, used to define the mesh of a Finite Strips Model.



14.55 mm-In

Toggles the current linear units between metric [mm] and imperial [In] systems. The following table gives the units in use when linear units are either [In] or [mm]:

	[In]	[mm]
Torque	[lb-in]	[N-m]
Force	[lb]	[N]
Stress	[Ksi]	[Mpa]
Power	[HP]	[Kw]
Stiffness	[lb/in]	[N/mm]
Volume	[in^3]	[mm^3]
Mass	[lbm]	[kgm]
Inertia	[lbm- in^2]	[kgm- mm^2]
Speed	[ft/min]	[m/min]
Misalignment	[In/in]	[mm/mm]
Surface Finish	[µin]	[µm]
Temperature	[F]	[C]
Warp	[/0.1 in]	[/10 mm]

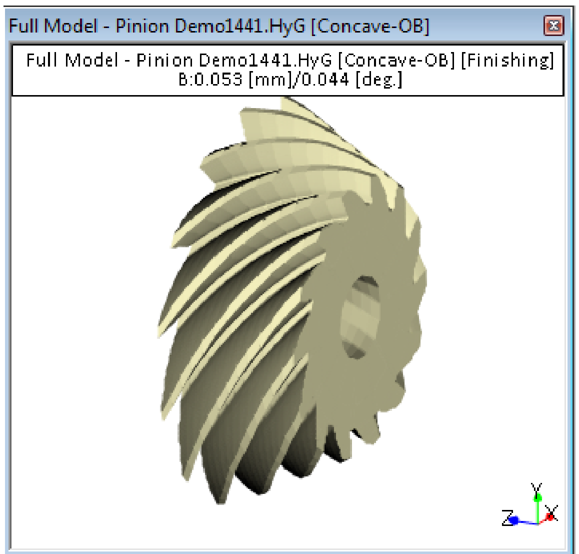
14.56 Name-NoNa

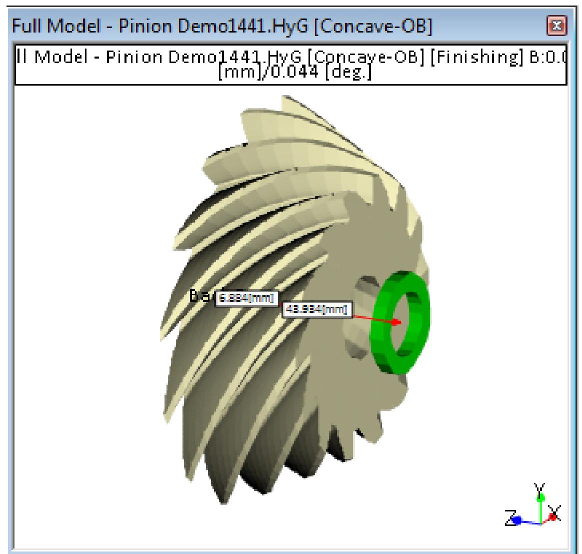
Toggles On and Off the display of the *current Geometry name* in the Child Window title

14.57 NoBr-Brg

Toggles "On" and "Off" the display of the support bearings. The support bearing dimensions are edited in the Bearings Datapage of the Summary Editor. The bearings are normally displayed in green.

When the bearings are displayed, the reactions they support, which are caused by the applied torque and the location of the bearings relative to the center of pressure (contact point along the Path of Contact) can be shown by accessing the Gearing Primitives.



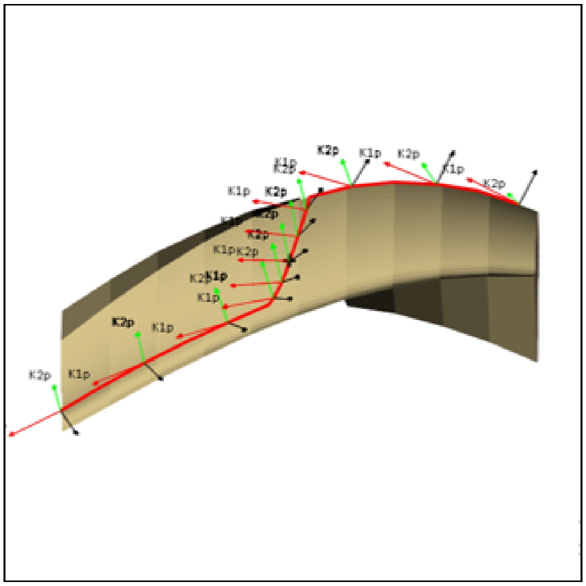


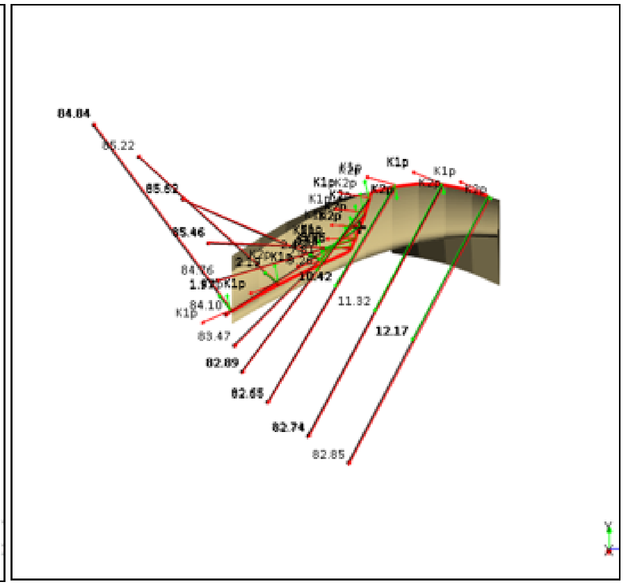
14.58 NoCur-Curv

In User Mode, for the Path of Contact Child Window (in Kinematics), when the display of the Principle Curvatures is toggled On by clicking on the [NoPD] button, the [NoCur] button is displayed immediately below the [PDir] button.

The [NoCur] button can then be toggled into [Curv] which tells HyGEARS to display also the principle radii of curvature at different points along the PoC.

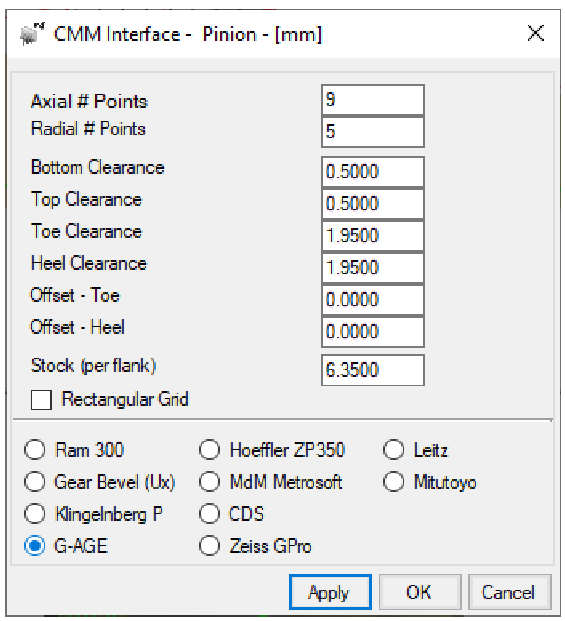
For example, left figure below, the principle directions are displayed as K1 and K2, where K1 (in red) is the direction of the major principle curvature and K2 (in green) is the direction of the minor principle curvature. The same are displayed in the right figure, but in addition the value of each principle radius of curvature is given.





14.59 Nom

Calls the CMM Data editor, which is used to modify the current CMM target measurement grid size and location.



14.60 Opp

Reverses the hand of the gearset. When this function is used, the current gearset hand is reversed, i.e. from left hand to right hand, and vice-versa.

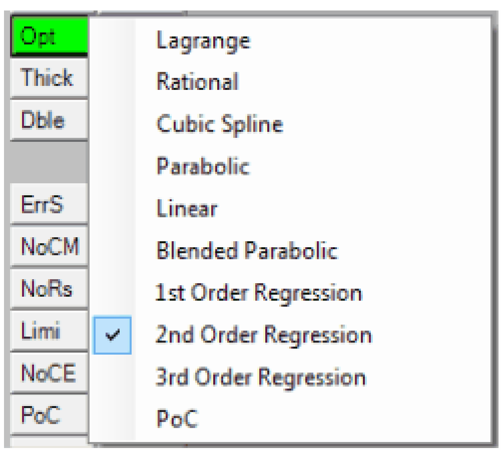
14.61 Opt

Several Child Windows offer different display options. Each time options are proposed, the "Opt" function button produces a pop-up menu containing the relevant choices, which are described below.

- Interpolation Options
- PoC Options
- Grey-Scale Options
- LTCA Results Options
- FEA Model Options
- Finite Strips Options
- Contact Elements Options

Interpolation Options

When the tooth flanks of the pinion and gear members have been measured, the difference calculated between the theoretical and measured surfaces is called the Error Surface, which can be used in the calculation of the Path of Contact and Contact Pattern. Whenever the Error Surface is used in the calculation of the Path of Contact or the Contact Pattern, interpolation is needed.



HyGEARS offers the following interpolators which can be changed through the use of the “Opt” function button. The number in the right table column below indicates our order of preference, in terms of computing speed and result quality in the kinematic calculation. N/R means not recommended: although the interpolator will normally work, the results are not of adequate precision or quality in our opinion.

Interpolator Name	Order of Preference
Lagrange	N/R
Rational	N/R
Cubic Spline	# 4
Parabolic	# 2
Linear	# 1
Blended Parabolic *	N/R
1^{st} Order Regression	# 3
2^{nd} Order Regression	N/R
3^{rd} Order Regression	N/R

* The Blended Parabolic interpolation is simply an average of two Parabolic interpolations, respectively preceding and following the section of interest.

PoC Option

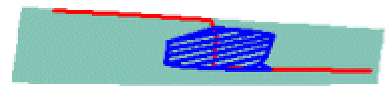
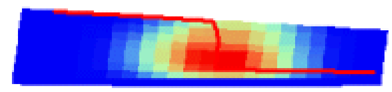
In the Options menu, the PoC option may be checked or not. When checked, the Contact Pattern is displayed PoC position by position.

The "+/-" function button may then be used to step through the PoC, and display selective results such as the Principle Directions at the same time.

Grey-Scale Option

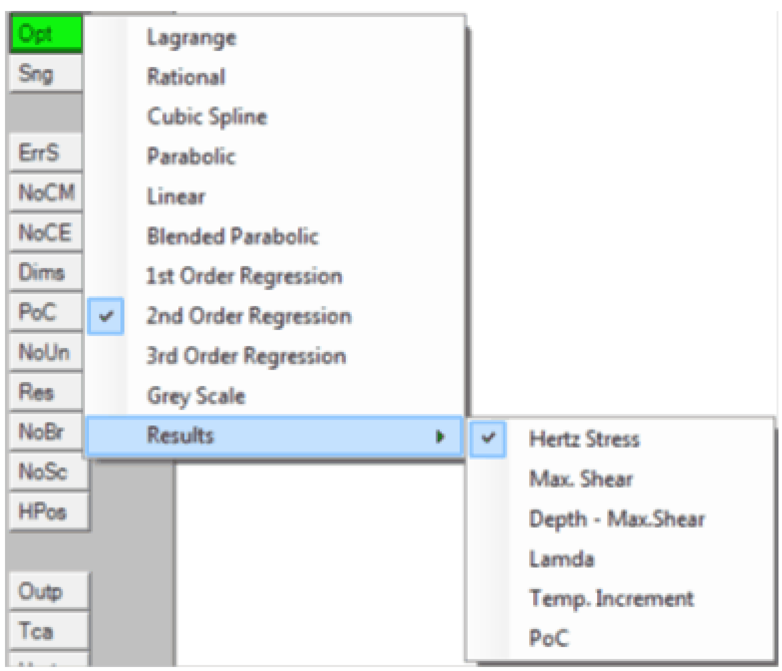
As several results are displayed using Color Coding to convey the desired information, it is possible in certain contexts to toggle the Color Coding for a Grey-Scale Coding, and vice-versa, through "Opt" function button.

For example, in the following table, the Contact Pattern is displayed in three different rendering techniques. Usually, the Grey-Scale is the closest when compared to measured Contact Patterns.

Standard Display	
Rendering – Color	
Rendering – Grey Scale	

LTCA Results Option

While performing the Loaded Tooth Contact Analysis, HyGEARS calculates several results which are quite useful in evaluating the performance of a gear pair under load:



Grey Scale Toggles the results rendering from Color to Grey Scale (see Grey-Scale Option above);

Hertz Stress Tooth Hertz contact stress;

Max Shear Maximum subsurface shear stress;

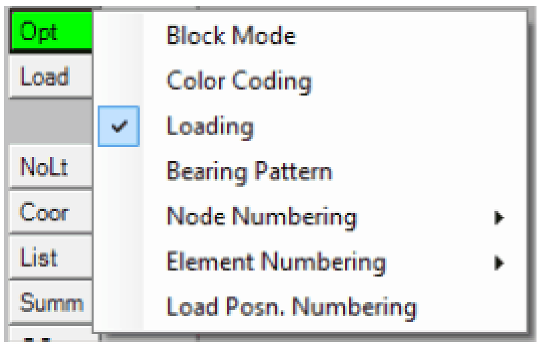
Lamda Ratio of minimum oil film thickness to surface roughness;

Temp. Inc Oil film temperature increment;

PoC Toggles from full Contact Pattern display to actual contact position along the PoC. Using this toggle, it is possible to display the stress distribution at any contact position.

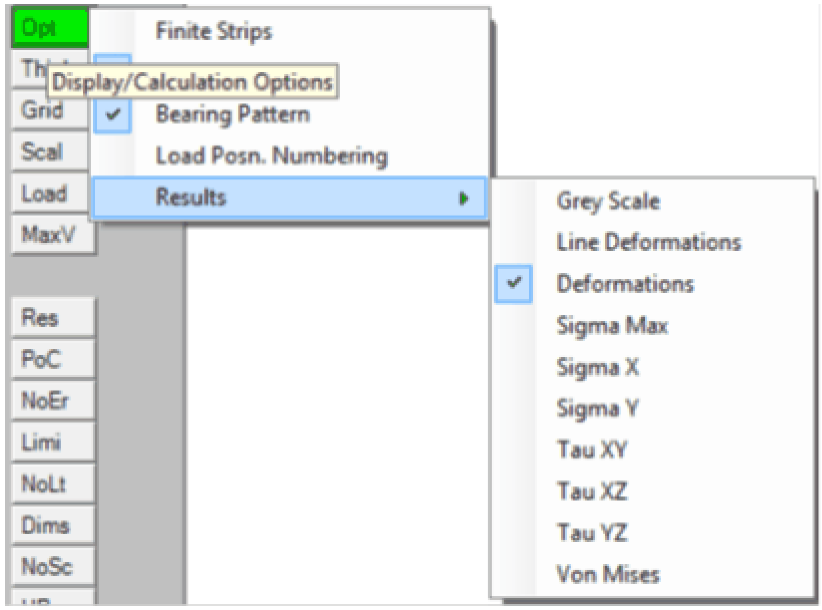
FEA Model Options

Displays the FEA options sub-menu where the different display options can be set. See the FEA Model Display Options section.



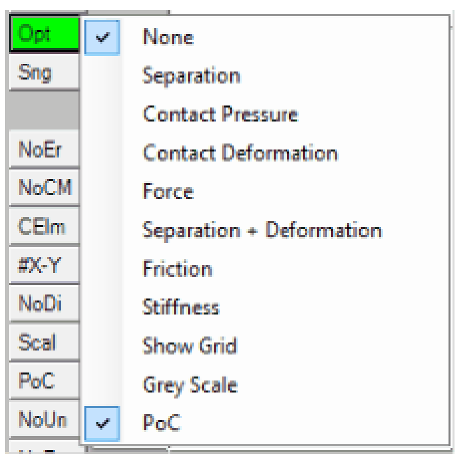
Finite Strips Model Options

Displays the Finite Strips options sub-menu where the different display options can be set. See the Finite Strips Display Options section.



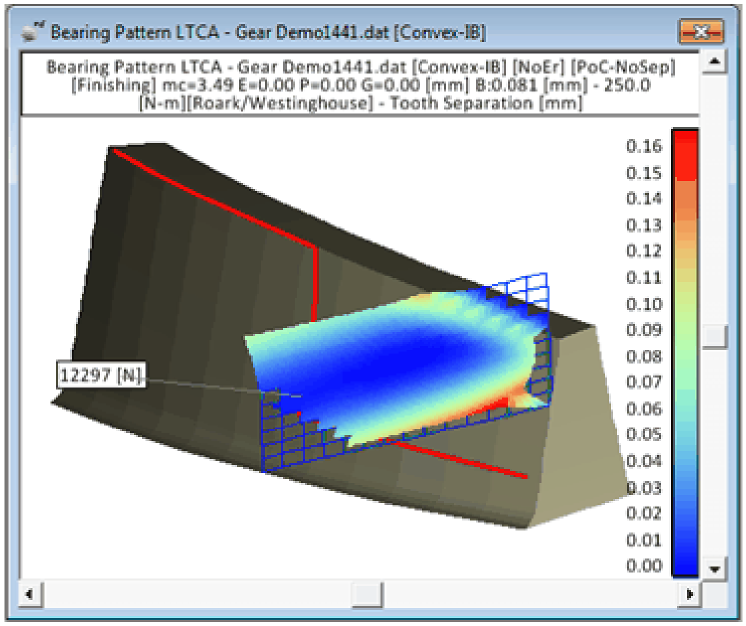
Contact Elements Options

Displays the Contact Element options sub-menu where the different display options can be set. See the Contact Elements section.

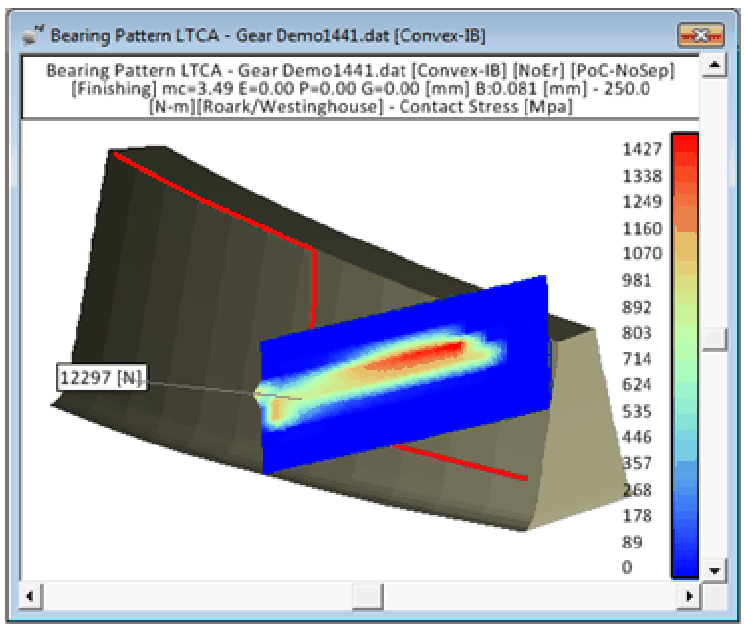


Available choices include:

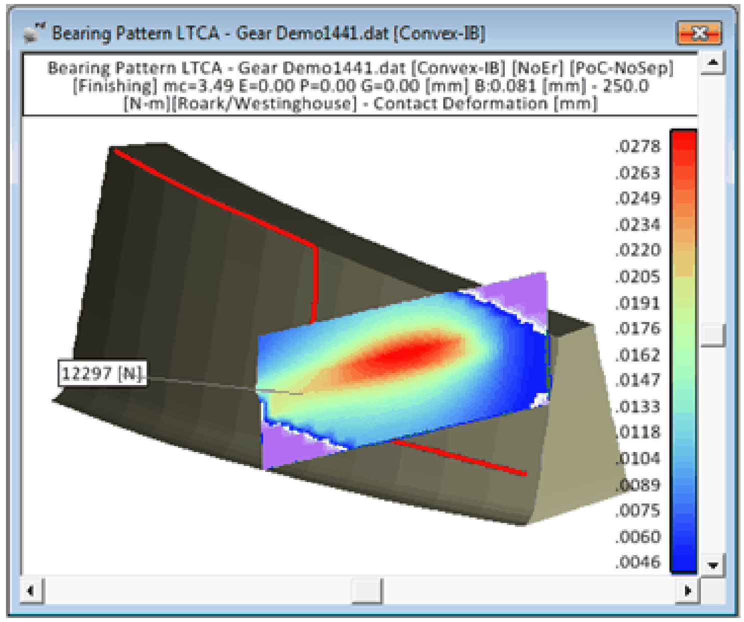
Tooth Separation where the initial separation between the meshing teeth is displayed for each contact cell;



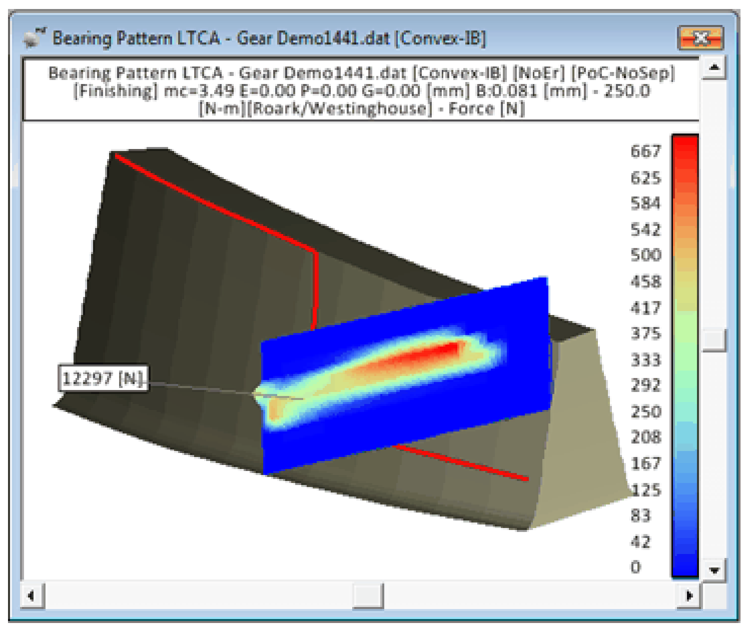
Contact Pressure where the contact stress for each cell is displayed; one can see the relationship between maximum contact stresses and the tooth separation above;



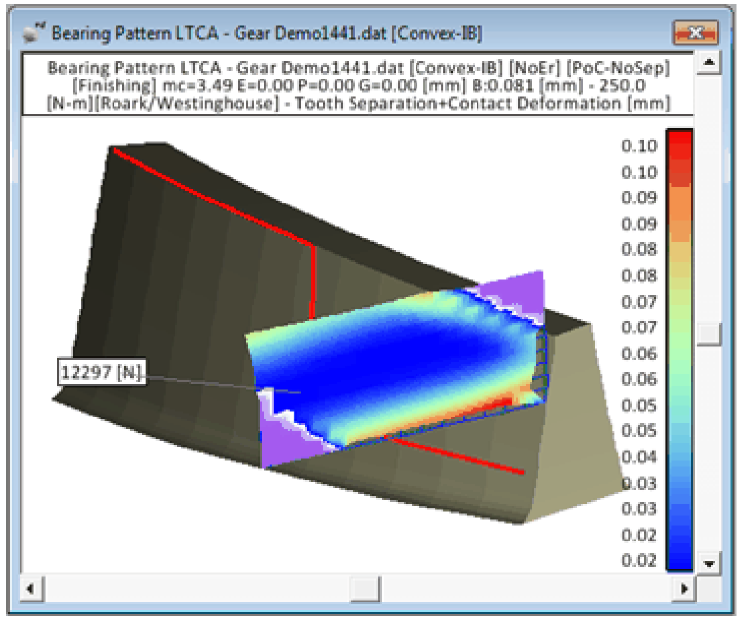
Contact Deformation where the amount of surface deformation under load is displayed;



Force where the the pressure on each cell is summed up to provide the actual force acting on a cell;

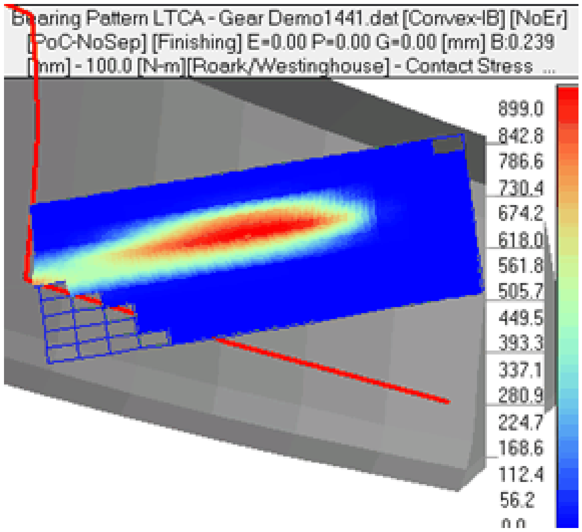


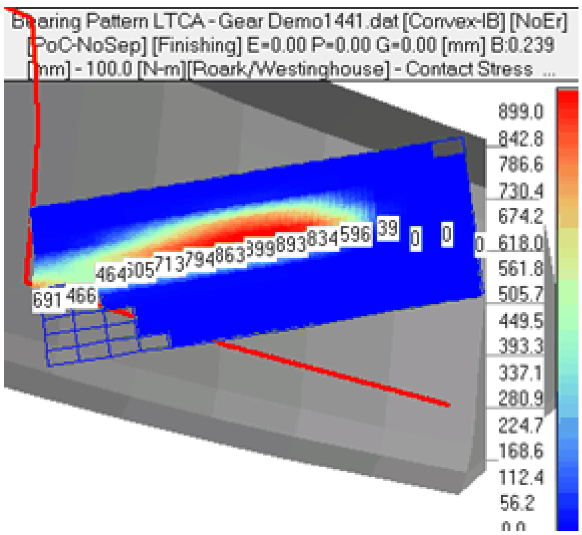
Separation and Deformation which is the condition of convergence of the Contact Element, where the sum of the initial tooth separation and tooth deformation under load is displayed; in the actual contact zone, this should be constant, and where it is seen to increase along the borders of the contact area, pressures tend toward zero;



Show Grid	which allows to show or hide the cell grid;
Grey Scale	which allows a grey scale display, useful to include the results say in scientifi papers, or black and white documentations.

When the “NoDi”, i.e. Hide Dimensions, is toggled into “Dims”, i.e. Show Dimensions, the actual values on several cells are displayed:





14.62 Outp

Prints, in a Text Results window, one of the following, depending on the currently active Child Window::

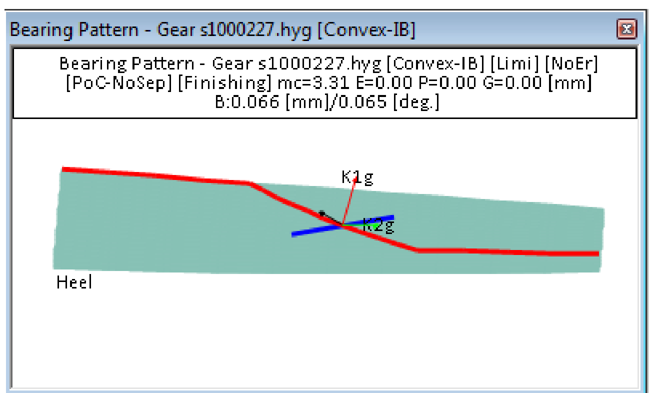
- coordinates of the Contact Pattern instant lines of contact;
- results of the Sliding Speeds;
- results of the Compare Meas.Sim Surfaces or the Stock Distribution;
- CMM measurement target grid ;
- plotting points of 2D-Graphs curves;

- separation values of the Ease Off surface at each contact point.
- FEA Model Output file (because of its size, this output is sent directly to a data file);
- Finite Strips Model Output .

14.63 PDir-NoPD

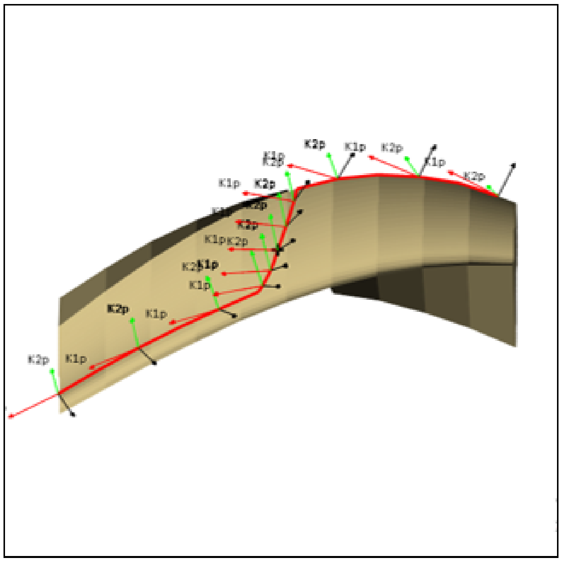
Toggles On and Off the display of the **Principle Directions** along the tooth facewidth and profile.

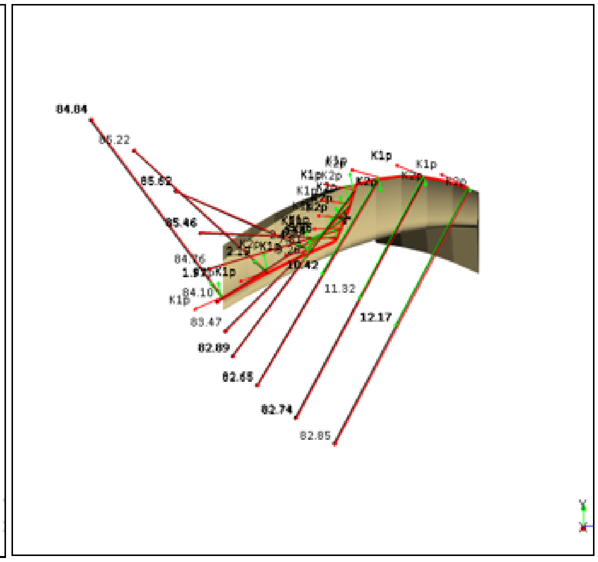
The direction of Major curvature K1 is displayed in Red, that of Minor curvature K2 is in Green, and the tooth flank Normal is in Black.



In User Mode, for the Path of Contact Child Window (in Kinematics), when the display of the Principle Curvatures is toggled On by clicking on the [NoPD] button, the [NoCur] button is displayed immediately below the [PDir] button. The [NoCur] button can then be toggled into [Curv] which tells HyGEARS to display also the radii of curvature at different points along the PoC.

For example, left figure below, the principle directions are displayed as K1 and K2, where K1 is the direction of the major principle curvature and K2 is the direction of the minor principle curvature. The same are displayed in the right figure, but in addition the value of each radius of curvature is given.





14.64 Pin

Calls the pinion Geometry Summary editor.

14.65 PoC-NoPo

Toggles the current display between displaying and not displaying of the Path of Contact (PoC/NoPo) and or the Contact Pattern.

Contact Pattern Child Window

As some people prefer to see only the Contact Pattern, it is possible to show *or* hide the Path of Contact on top of the Contact Pattern.

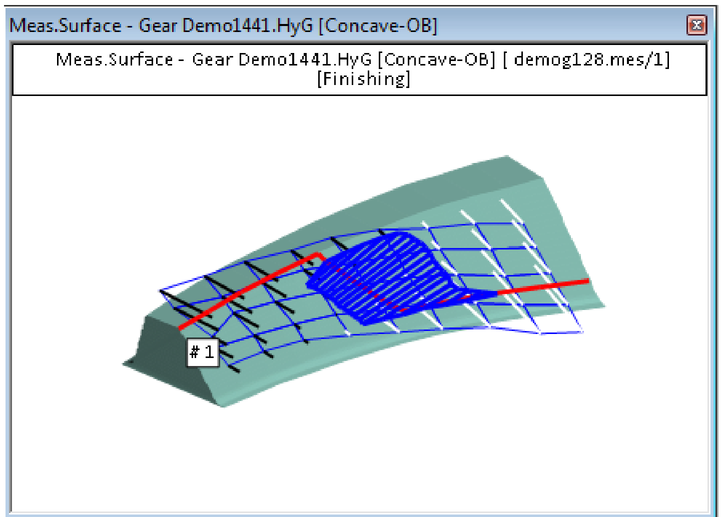
Ease Off Child Window

Toggling between PoC and NoPo displays or hides the PoC *and* the Contact Pattern at the same time

Measured Surfaces Child Window

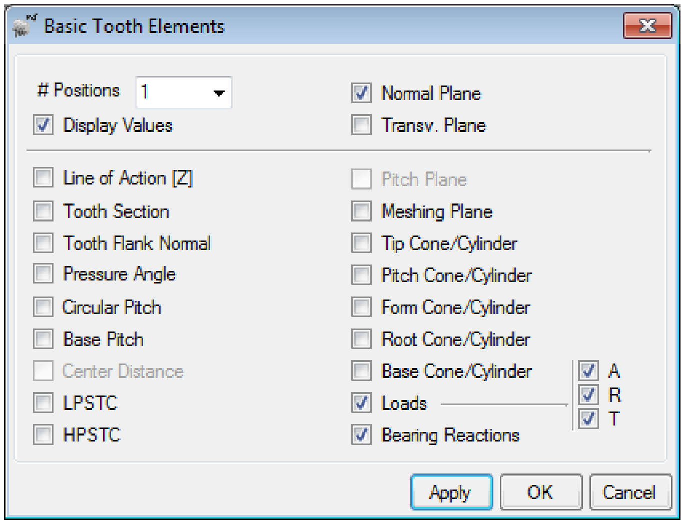
Toggles between display and no display of the Path of Contact (PoC/NoPo) and Contact Pattern, as it can be interesting to see how the Contact Pattern is related to the measurement grid location.

When this option is set (PoC), the measurement data of the opposite tooth flank is hidden, in order to ease interpretation.



14.66 Prim

Calls the Gearing Primitives Selection window, from which selected primitives may be chosen for display on the current Child Window.

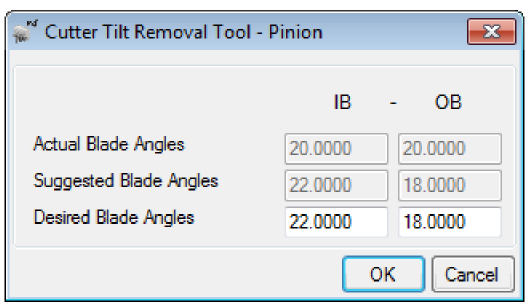


14.67 R.E.

Calls the Reverse Engineering Selection Window. See also the explanations for the "Corr" button.

14.68 RemT

The RemT function is used to remove cutter tilt from either the pinion or gear machine settings.



The following fields are displayed:

Actual Blade Angles: current IB and OB cutter blade angles;
Suggested Blade Angles: recommended blade angles based on the amount of cutter tilt to be removed;
Desired Blade Angles: desired IB and OB blade angles, based on available cutters.

Command Buttons

Ok	initiates the cutter tilt removal algorithm, and the modified teeth are redisplayed.
Cancel	reverts the geometry to its initial status

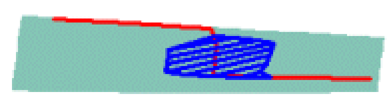
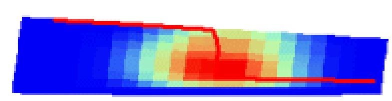
Note: removing cutter tilt is applicable only if the gear member is generated. Removing cutter tilt usually affects substantially the TE and shape of the Contact Pattern. The upside is that the part can then be generated on a cheaper machine such as the YH603.

14.69 Res-NoRs

Contact Pattern

Toggles the display from standard to rendering mode. In rendering mode, a special technique is used to project the Contact Pattern on the tooth flank and display it such that it more closely resembles the actual Contact Pattern.

For example, in the following table, the Contact Pattern is displayed in three different rendering techniques. Usually, the Grey-Scale is the closest when compared to measured Contact Patterns. Change to Grey- Scale is done through the "Opt" function button.

Standard Display	
Rendering – Color	
Rendering – Grey Scale	

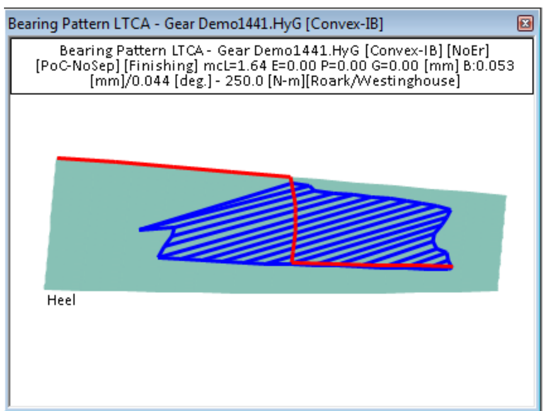
Contact Pattern (LTCA)

Toggles the display from standard to rendering mode. In rendering mode, tooth surface results such as Hertz Contact Stress, maximum subsurface Shear, etc. are displayed using a rendering technique.

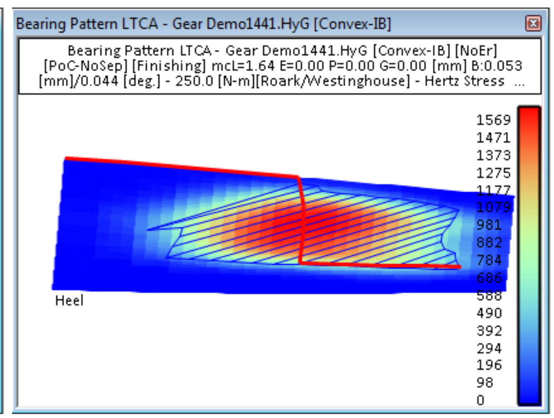
In color by default, the results can be displayed in a Grey-Scale using the "Opt" button.

For example, in the following figure, the maximum Hertz Contact Stress is displayed in color mapping .

The Color Scale to the right of the display gives a visual cue as to where the maximum stresses are on the tooth flank. In the case shown below, they are near the gear tooth root, somewhat close to the heel, and reach 1550 [Mpa].



NoRs



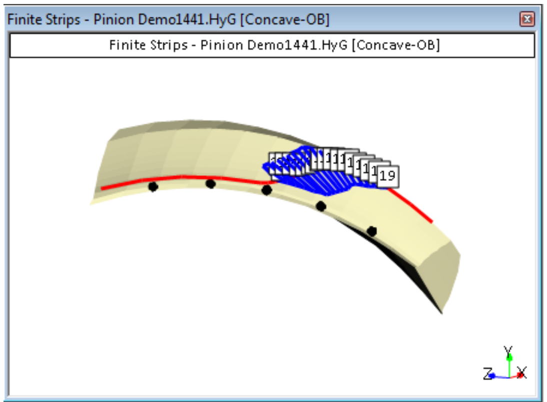
Res

Finite Strips

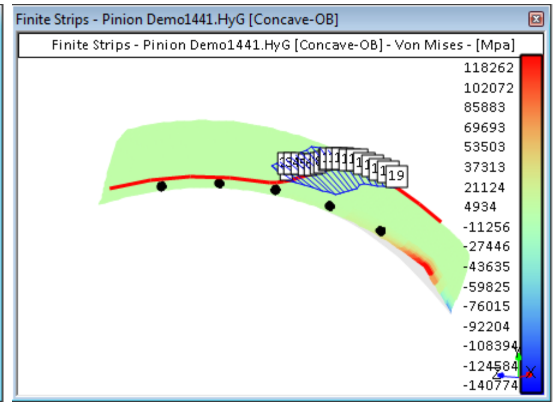
Toggles On and Off the calculation and display of the Finite Strips.

NoRs mode the tooth displayed as usual, along with the Contact Pattern, Load, etc., as defined in the Display Options.

Res mode the Finite Strips calculations are carried out, and the requested result (from the Opt function button) is displayed.



NoRs



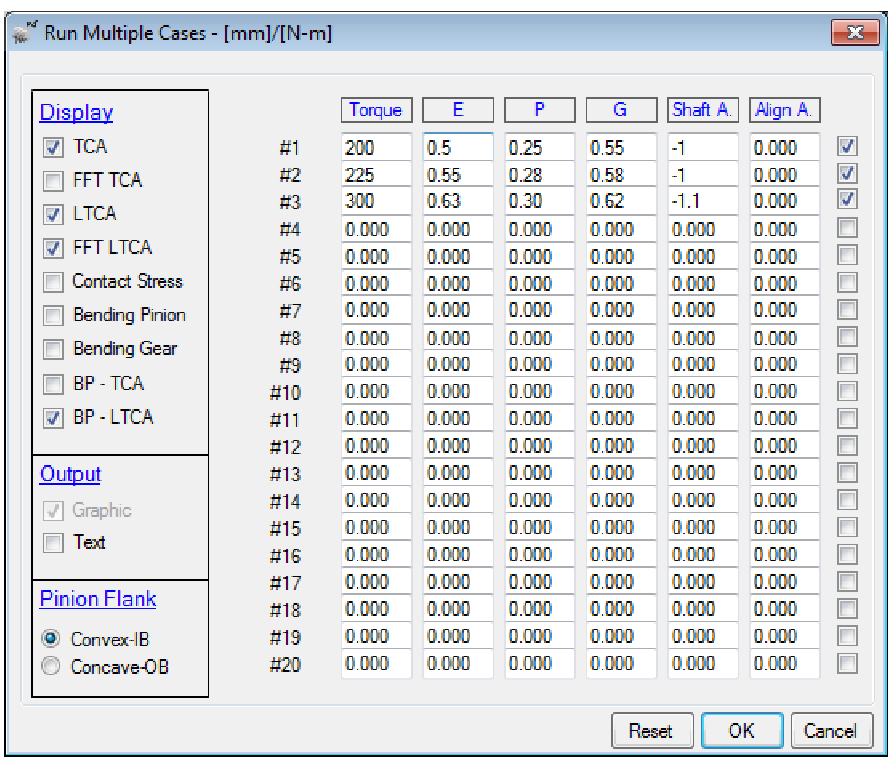
Res

14.70 RMC

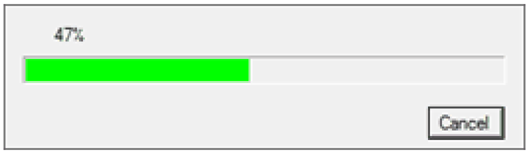
This function allows to run up to 20 combinations of Torque, E, P, G, Shaft angle and Alignment angle, and display selected results either graphically and in text mode.

The figure below shows the RMC input window, where 3 load and position cases are entered, and several results are requested:

2D Graphs TCA, LTCA, FFT LTCA, Contact Stress
BP LTCA

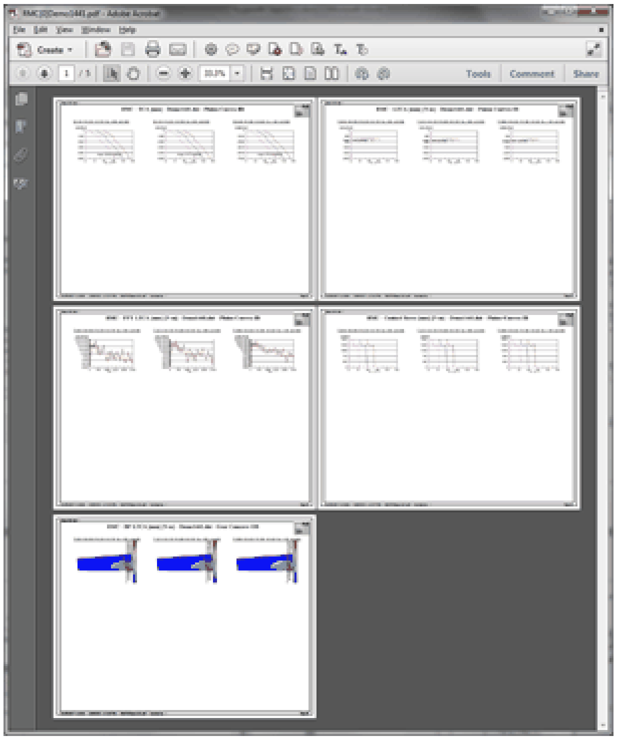


Upon clicking the "*OK*" button, the following progress bar is displayed, which tells the state of advancement of the analysis, and allows stopping the work at any time by clicking on "*Cancel*".



The requested analyses are stored in the Geometry data file along with all other data, and are therefore available each time the geometry is opened, provided the user has saved the data file.

The requested results are summed in a Pdf file and are then displayed on screen for user consultation, as shown in the figure below.



14.71 Rpm

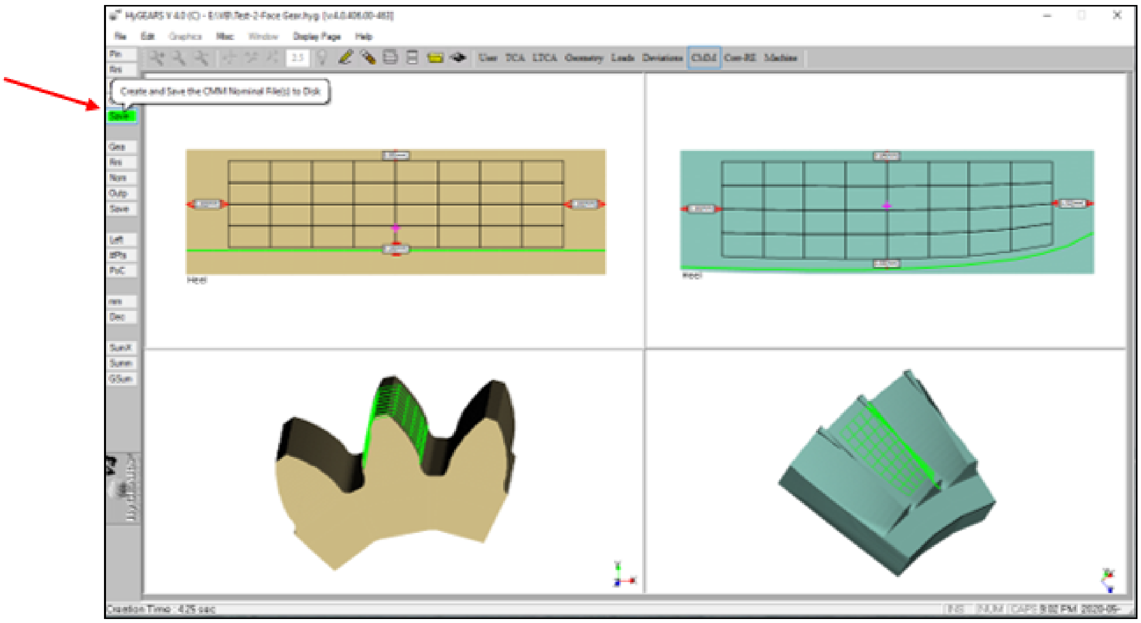
Change in Pinion operating speed, or Work and Tool speeds.

In the former case, the current pinion Rpm is presented in an input window, where a new value can be entered to evaluate different operating speed conditions.

In the latter case, the Work and Tool Speed Editor is displayed, from which different cutting conditions may be explored.

14.72 Save

When comes the time to output the defined CMM Nominal, some CMMs such as the Klingelnberg P machine require up to 4 files, and it is tedious to have to Select, Save, Delete the window with the text, and move on to the next output.



The [Save] function button calls the output from the [Outp] button, saves the content of all the generated text windows with CMM data, and then deletes the text windows, all in one Click. A real time saver.

14.73 Scal

Comp Mes.Sim Surfaces
Reverse Engineering
Stock Distribution

Calls theMeasurement AutoScale Selection window, used to adjust the scale factor of **Measurement Comparison windows**.

See Tooth Surface Measurement and Corrective Machine Settings (Closed Loop), The Measurement AutoScale Selection window.

Finite Strips

Calls the Display Scale Selection window, used to adjust the scale factor.

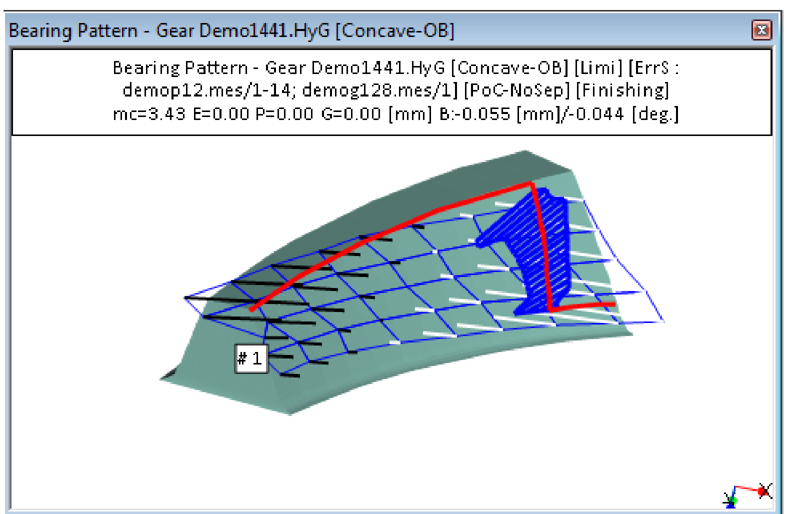
FEA Mesh

Calls the Display Scale Selection window, used to adjust the scale factor.

Contact Pattern
Contact Pattern (LTCA)

Calls the Display Scale Selection window, used to adjust the scale factor. Changing the scale of the tooth surface errors, when the CMM grid is shown, evidences the relationship between tooth surface errors and the location and shape of the Contact Pattern.

In the figure below, a scale factor of 750 dramatically increases the display of the surface errors; one can then appreciate the calculated Contact Pattern in relation to the shape of the Error Surface.



14.74 Sec-uRad-um-uin

Toggles the current Transmission Error units between arc-seconds (Sec), µRadians (uRad), µMeters (um) and µInches (uin).

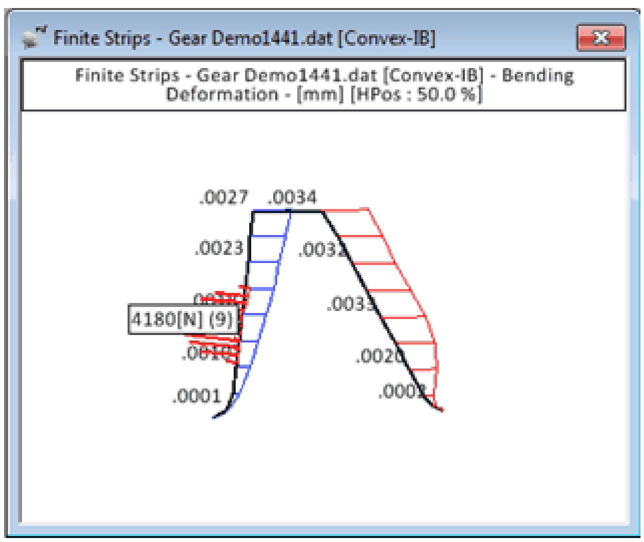
µMeters and µInches results are the product of the Base radius by the Transmission Error.

Applicable only to the BP-LTCA Pre-Defined Mode.

14.75 Sect-NoSc

Toggles the display from *2D Section* to *3D mode* back and forth.

When in 2D Section mode, the results appear along the tooth profile, as shown below, for a given tooth lengthwise position controlled through the HPos function button.



14.76 Sele

Calls the Summary Version Selection window, which is used to select the Geometry Summary version.

14.77 Sep

Prints the tooth to tooth separation along the PoC in a Text Result window. See the Tooth Separation for detailed explanations.

14.78 Sett

Calls either the *Proportional Changes Window*, used in Contact Pattern Development, or the *Corrective Machine Settings (Closed Loop)* and *Reverse Engineering* Selection Window used in Corrective Machine Settings (Closed Loop), Reverse Engineering and Stock Distribution.

Contact Pattern Development

Calls the Proportional Changes Window in which individual machine settings can be modified while respecting tooth rootline.

In short, HyGEARS offers the possibility to change individual machine settings, control tooth depth and tooth rootline, while maintaining the horizontal location of the PoC Mean Point.

Corrective Machine Settings (Closed Loop)

When the Corrective Machine Settings (Closed Loop) Selection Window is shown, HyGEARS uses the current tooth flank and correction order. While the correction order may be changed from the Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection Window, for Fixed Setting and Modified Roll cutting processes the corrected tooth flank may not and should therefore be selected prior to clicking on the “Sett” button.

After the desired correction choices have been made, pressing the “Apply” key will initiate the calculation of the changes required in machine settings.

As explained before, when the Corrective Machine Settings (Closed Loop) function is accessed the first time for a given pinion or gear, HyGEARS defines the Nominal Summary without user confirmation, which is equivalent to copy the current Summary as the first entry in the pinion or gear History. The so-called Nominal Summary will then be used as the reference to calculate Corrective Machine Settings (Closed Loop).

The display is updated while calculations proceed such that the user may appreciate the results. Once either the imposed limits or the maximum number of iterations have been reached, HyGEARS calculates the machine setting modifications as the difference between the machine settings before and after the application of the Reverse Engineering algorithm.

The user can then:

- Review the results from the Child Window display, the "Correction" or "Expected Stats" Data Pages;
- Issue a new request after changing the selections in the Machine and Order Data Pages;
- Print the obtained results;
- Keep the obtained results with the OK button
- Exit the Corrective Machine Settings (Closed Loop) Selection Window and cancel all calculations with the Cancel button.

If the requested correction has already been performed, e.g. the selected tooth flank(s) and measured datafile appear in the Corrective Machine Settings (Closed Loop) History, HyGEARS asks the user if he/she desires to output this correction step. If agreed, then HyGEARS displays the "expected error surface after correction", and the user is prompted to decide whether it should be printed or not. Whether the Geometry Summary is printed or not, it is outputted to a Text Results window.

To obtain Corrective Machine Settings (Closed Loop) for a different machine than that with which the above data was calculated, change the cutting machine in the Geometry Summary Editor and request the correction as above.

Reverse Engineering

When the Reverse Engineering Selection Window is shown, HyGEARS uses the current tooth flank and matching order. While the matching order may be changed from the Corrective Machine Settings (Closed Loop) and Reverse Engineering Selection Window, for Fixed Setting and Modified Roll cutting processes the selected tooth flank may not and should therefore be selected prior to clicking on the "Sett" button.

After the desired matching choices have been made, pressing the "Apply" key will initiate the calculation of the changes required in machine settings.

The display is updated while calculations proceed such that the user may appreciate the results. Once either the imposed limits or the maximum number of iterations have been reached, HyGEARS calculates the machine setting modifications as the difference between the machine settings before and after the application of the Reverse Engineering algorithm.

The user can then:

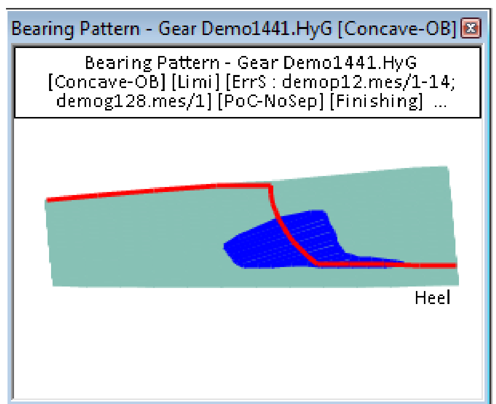
- Review the results from the Child Window display, the "Correction" or "Expected Stats" Data Pages;

- Issue a new request after changing the selections in the Machine and Order Data Pages;
- Print the obtained results;
- Keep the obtained results with the OK button
- Exit the Reverse Engineering Selection Window and cancel all calculations with the Cancel button.

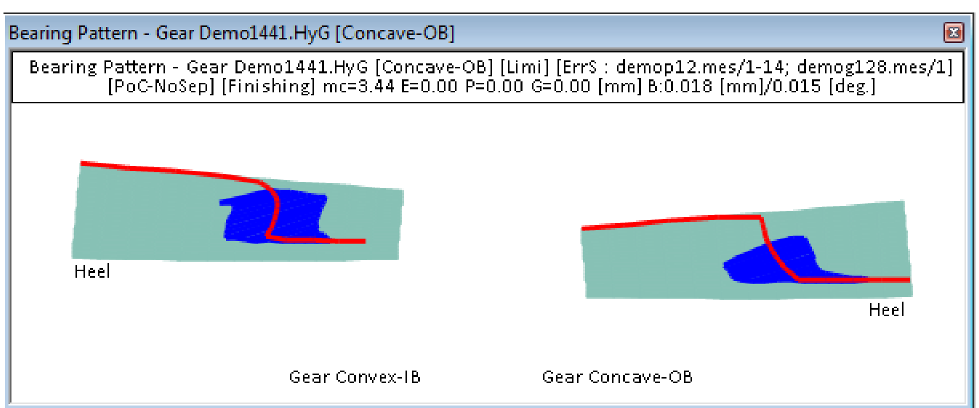
14.79 Sng-Dble

Toggles the display from single tooth flank mode to double tooth flank mode. When in single tooth flank mode, only the current tooth flank is displayed; in double mode, both tooth flanks are displayed side by side.

Best when viewed in 2D mode.



Single Tooth Flank



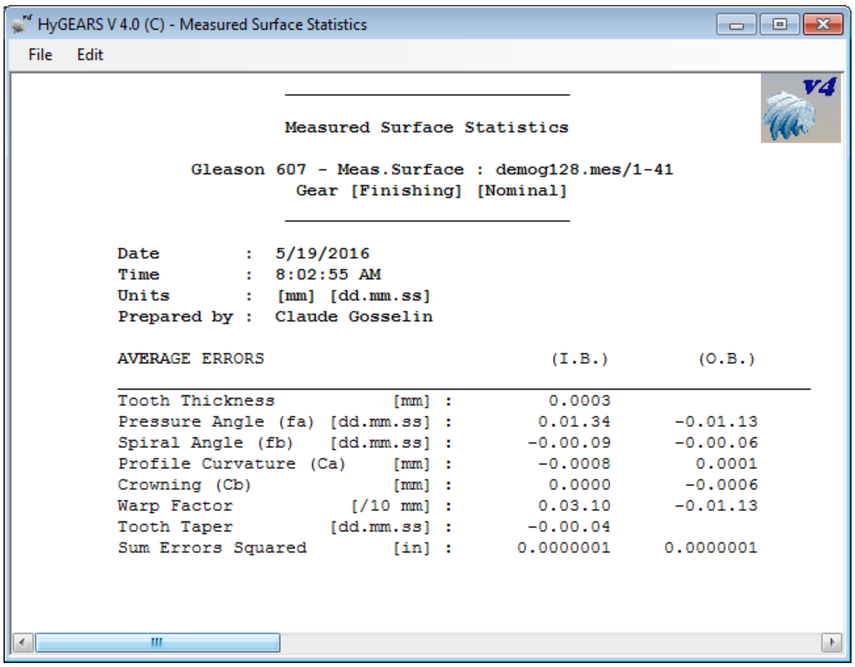
Double Tooth Flank

14.80 SpErr

Calls the Tooth Spacing Error editor. Applicable only to LTCA results.

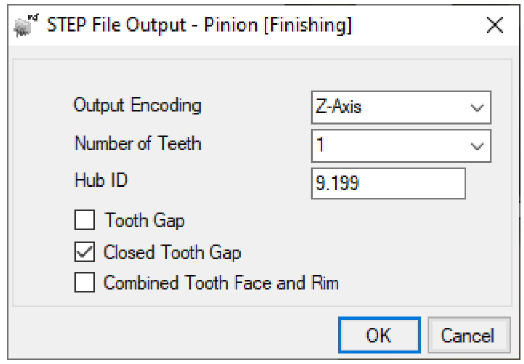
14.81 Stat

Displays the measured surface errors statistics in a Text Results window. See the Surface Statistics section for detailed explanations.



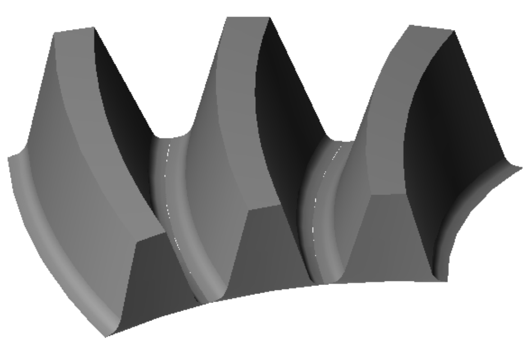
14.82 STEP

Initiates the preparation and output (in a Text Results Window) of a STEP file to export the tooth coordinates to a CAD/CAM software.

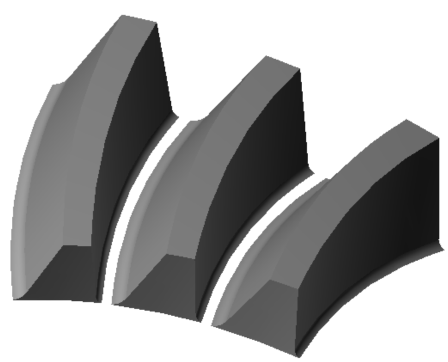


When clicked, the *STEP* function button displays the selection window displayed above, where the following options offered:

Output Encoding	*X, Y, Z or* Haas Horizon (optional), depending to where the STEP file is targeted; this dictates the direction of the axis of rotation;
Number of Teeth	how many teeth will be included in the STEP file
Hub ID	diameter of the hub under the teeth; if non-zero, the hub is included in the STEP file; this is especially useful when considering a differential Straight bevel gear where the tooth is cropped at Toe, resulting in a discontinuous tooth root line;
Tooth Gap	instead of the tooth, the gap between the teeth can be outputted in the STEP file;
Closed Tooth Gap	whether the coordinates defining the tooth roots of each flank are left with a small space as digitized or have the same coordinates; note that a closed tooth gap does not imply that the lines bounding the tooth roots will be exactly // to each other since the fillet area on each tooth is different and in the STEP file is modeled as a B-Spline;

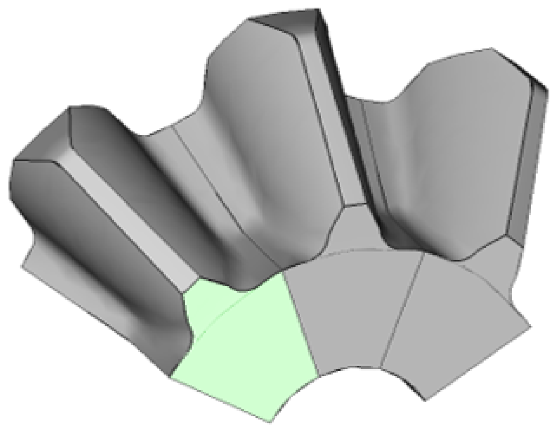


Closed Tooth Gap



Open Tooth Gap

Combined Tooth Face ... whether the tooth front and back faces are continuous B-Splines with the hub, or separate B-Splines; works best when Tooth Gap is **not** used. In the figure below, the front face is combined with the hub which results in a unique B-Spline / tooth (green patch).

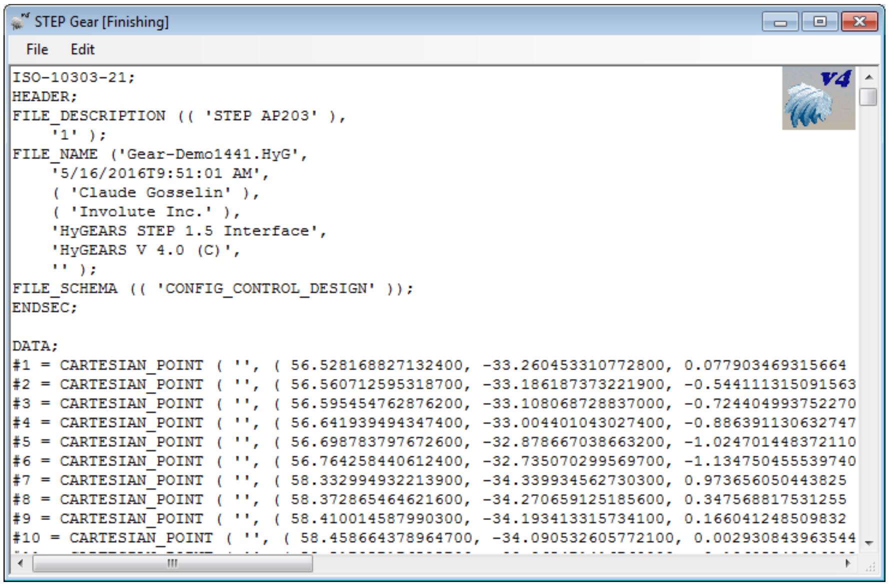


Combined Tooth Face and Rim

Clicking on "*OK*" initiates the STEP output, which may take a while if several teeth have been requested. The STEP output is sent to a Text Results window which is shown on screen once output is completed. The content can then be saved to disk.

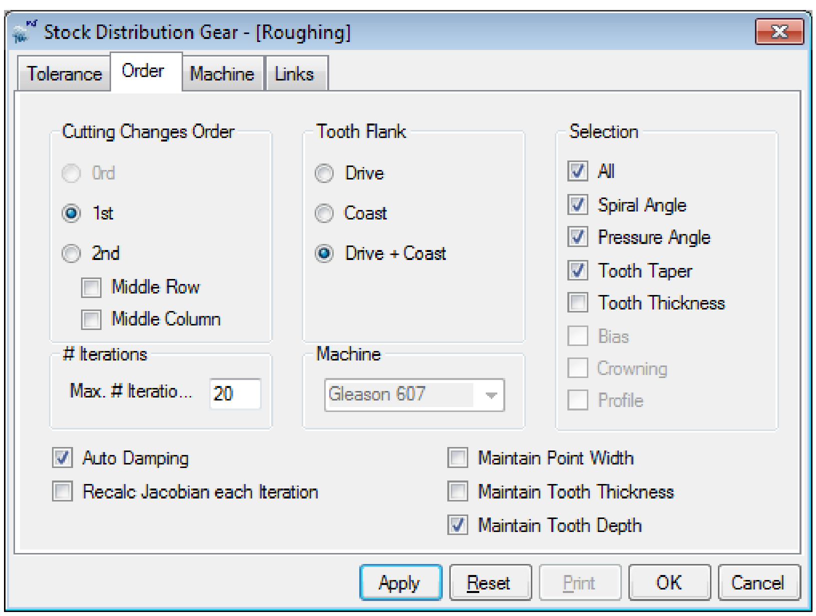
Note: the HyGEARS STEP output does not contain the axis of rotation of the part; however, this axis is described by the following points which depend on the selected *Output Encoding*:

X Encoding:	{0, 0, 0} {1, 0, 0}
Y Encoding:	{0, 0, 0} {0, 1, 0}
Z Encoding:	{0, 0, 0} {0, 0, 1}



14.83 Stock

Calls the [Reverse Engineering Selection Window](). Applicable to the [Stock Distribution Pre-Defined]() mode.



When the Reverse Engineering Selection Window is shown, HyGEARS creates a "theoretical" data file of the finished tooth surfaces which will be used to optimize the machine settings of the roughing cut.

The correction order may be changed from the Reverse Engineering Selection Window, and both tooth flanks are corrected at the same time.

After the desired correction choices have been made, pressing the “Apply” key will initiate the calculation of the changes required in machine settings.

The display is updated at the end of the calculation process such that the user may appreciate the results. Once either the imposed limits or the maximum number of iterations have been reached, HyGEARS calculates the machine setting modifications as the difference between the machine settings before and after the application of the Reverse Engineering algorithm.

The user can then:

- Review the results from the Child Window display, the “Correction” or “Expected Stats” Data Pages;
- Issue a new request after changing the selections in the Machine and Order Data Pages;
- Print the obtained results;
- Keep the obtained results with the OK button
- Exit the Reverse Engineering Selection Window and cancel all calculations with the Cancel button.he Cancel button.

14.84 Summ

Displays the *Text Geometry Summary* in a Pdf document. This is a variant of the Graphics Summary that contains the same information, except that no graphics are included.

The Pdf document is automatically saved in the directory of the geometry datafile.

HyGEARS creates a default name for the Pdf File, consisting of

- the directory containing the current geometry,
- the “TSumm” prefix,
- the version of the Summary given as “[#]” where # is a number from 0 to infinite, based on the fact that previous Summaries are already stored in the directory,
- the name of the current geometry,
- the Pdf extension.

For example: “E:\VB\Demo\TSumm[0]1149079mg.pdf”

Therefore, theoretically an infinite number of Summaries can be produced, and care must be exerted to avoid confusion. On the other hand, the “[#]” component of the

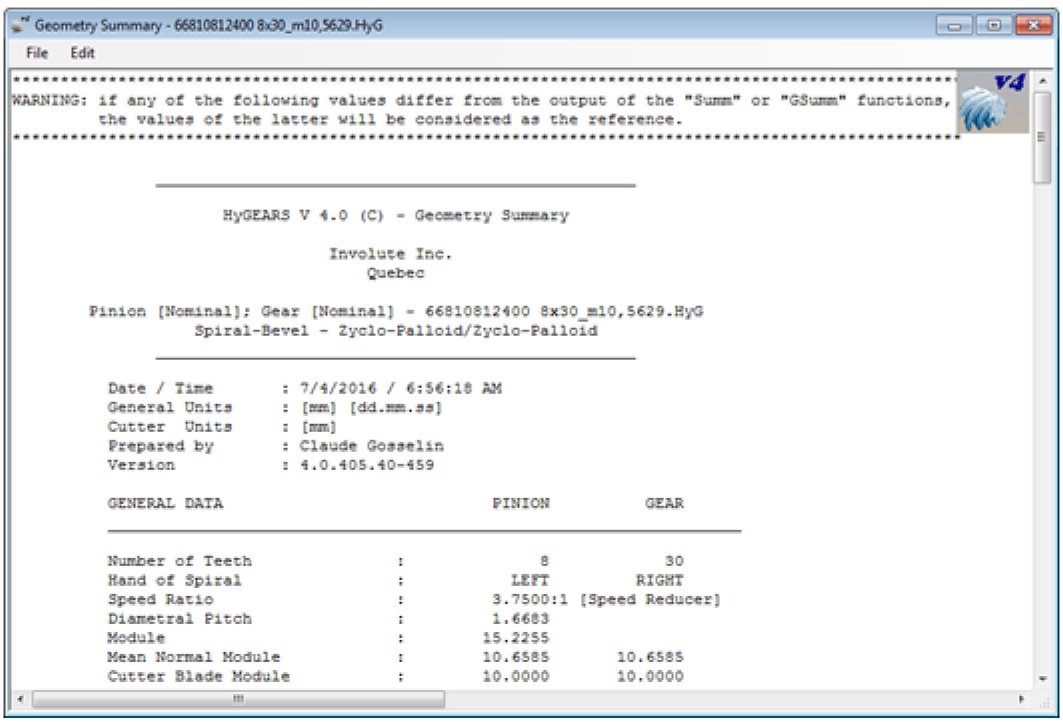
Pdf file name tells the user which version is the most recent. The above Pdf filename also appears in the Pdf document.

When both the pinion and the gear are displayed in the same Child Window, the Strength Calculations (bending and contact stresses) are added to both Summaries.

See the Geometry Summary for a detailed description of the pinion and gear Summaries.

14.85 SumX

Alias *Summary Export*. The Blank, Cutter and Finishing Machine Settings are sent to a Text Results window rather than to a Pdf document. The content of the Text Results window can then be saved as a text file for import by a 3rd party application.



Whenever a *Summary Export* is produced, the following Warning appears at the beginning of the output:

```
********************************************************************************
****************
WARNING: if any of the following values differ from the output of the "Summ" or
"GSumm" functions,
         the values of the latter will be considered as the reference.
********************************************************************************
****************
```

This implies that the “Official” Summary data is considered at all times as being that contained in the Graphics Summary (“GSum” function button) or Text Summary (“Summ” function button) since the data contained within those Pdf documents cannot be tampered with.

14.86 TCA

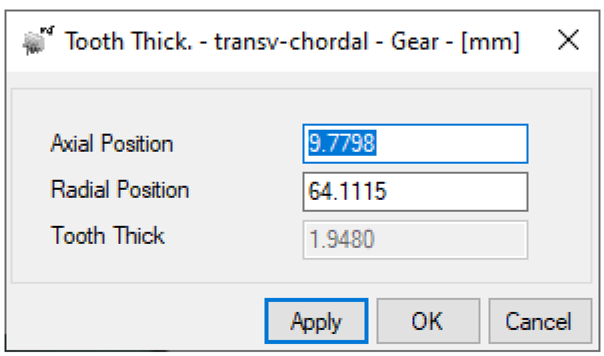
Displays the PoC kinematic data to a Text Result window. Refer to TCA Output for detailed explanations.

14.87 Thick

Calls an input window where the marking compound thickness can be changed, which will affect the extent of the Contact Pattern.

14.88 TThk

Calls an input window where the tooth thickness is calculated at any radial and axial position. The axial position is from the Crossing Point (Xp) for bevel gears. The returned tooth thickness is chordal, in the Transverse plane, i.e. perpendicular to the axis of rotation.



14.89 Titl-NoTi

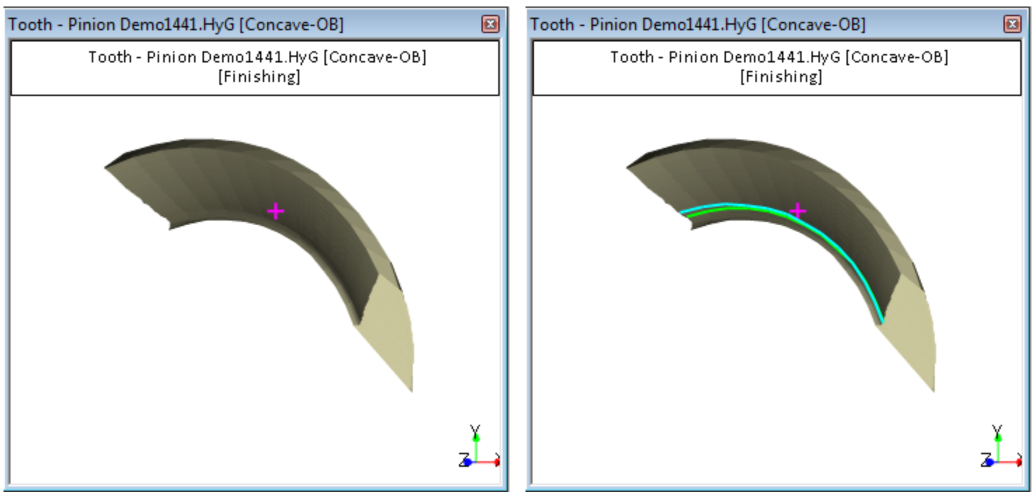
Toggles On and Off the display of the Child Window title

14.90 Undr-NoUn

Toggles On and Off the display of the undercutting and fillet limits.

The *undercutting limit* is displayed in cyan, only for generated members, if it is close to the fillet. Otherwise, it is not shown. For example, in the right figure below, the undercutting limit is seen as a line extending from tooth Toe.

The *fillet limit* is displayed in green.



14.91 uRad-sec

Toggles the current angular units of the 2D Graphs Child Window from micro-radians (uRad), arc-seconds (sec), micro-meters (um) or micro-inches (uIn) and vice-versa.

14.92 V-H

Calls the V-H Settings editor.

14.93 VH>>

The VH>> function is used during Contact Pattern Development to convert actual E, P and G *V-H Settings* into machine settings changes used to produce the desired Contact Pattern.

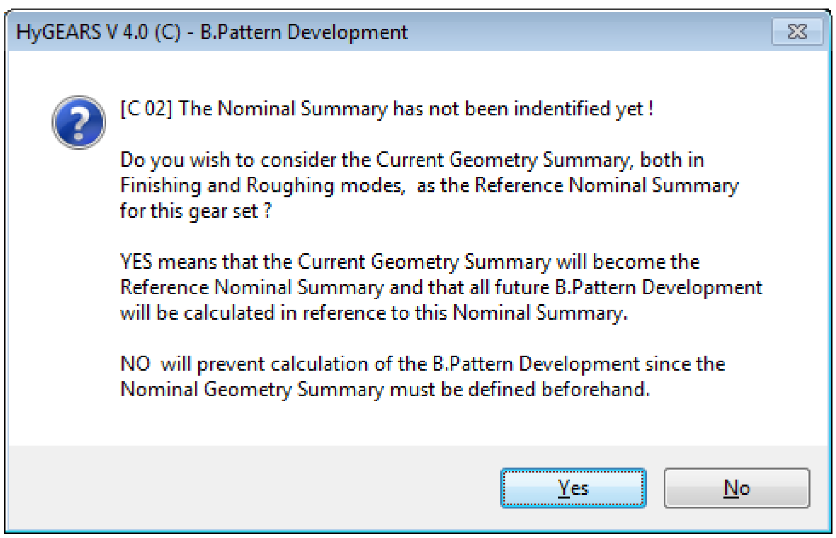
At the manufacturing stage of a gear set, it is common practice to use surface measurement to quantify the difference between the theoretical tooth surfaces and those produced on actual machines, which requires the use of a Coordinate Measurement Machine, or CMM.

When a CMM is not available, the V-H test is used, where the pinion and gear members are operated under a light load using marking compound to locate the Contact Pattern on the tooth flank and modify the relative operating positions of the pinion and gear member until the desired Contact Pattern is obtained.

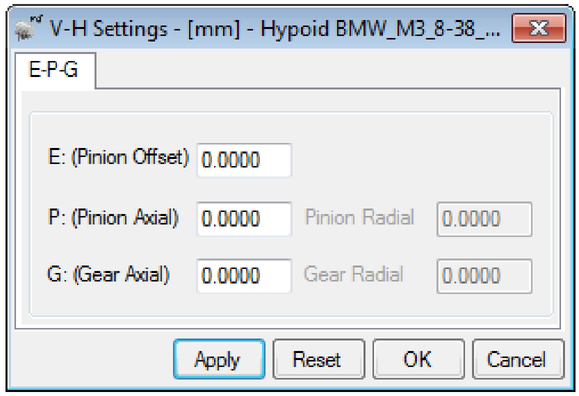
Once the E P G positions needed to produce the desired Contact Pattern are found, they must be converted to actual pinion machine settings changes. The VH>> function is used to convert the E P G values of the V-H test into actual machine settings.

As for Corrective Machine Settings (Closed Loop), before calculating any VH>> machine settings changes, the Nominal Summary must be defined. This is done by HyGEARS upon confirmation by the user the first time the VH>> machine settings changes algorithm is accessed (see figure below).

Once the Nominal Summary has been defined, all *VH>>* machine settings changes will be calculated in reference to the defined Nominal.



The E P G values required for the VH>> function are entered through the following *V-H Settings* window, which is displayed after the above confirmation has been done:



The E P G values and signs are as recorded on the VH tester, i.e.:

P+: when the Pinion moves away from the Xp
G+: when the Gear moves away from the Xp;
E+: when a LH Pinion goes up (the movement is considered on the Pinion).

In short, the VH>> algorithm uses the Nominal Summary to evaluate the differences between the theoretical and actual (meaning under E, P and G changes) Contact Pattern location, and bases the modification of each machine setting on the amount of change in Contact Pattern position.

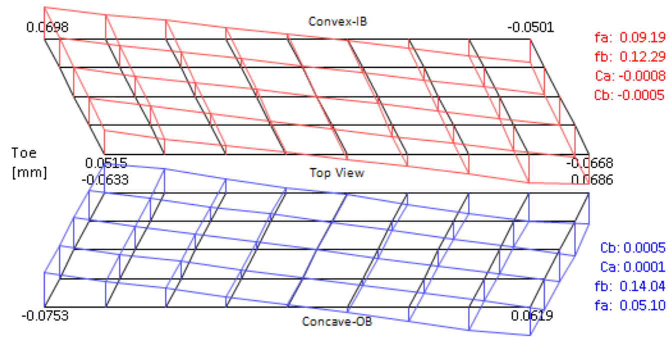
Each machine setting modification is then added to the latest Summary version in the history of the considered pinion. It is therefore imperative that the geometry data file be saved on disk after VH>> machine settings changes have been calculated and applied. HyGEARS automatically proposes to do so.

HyGEARS maintains a history of the different VH>> machine settings changes that were calculated for the pinion, provided the geometry is saved after VH>> machine settings changes have been calculated and applied. The Contact Pattern Development History can be reset, or completely erased, using the Main Menu *Edit->Reset Contact Pattern History* function.

Up to 7 VH>> machine settings changes steps are currently allowed in HyGEARS, which should be sufficient for most applications.

Example:

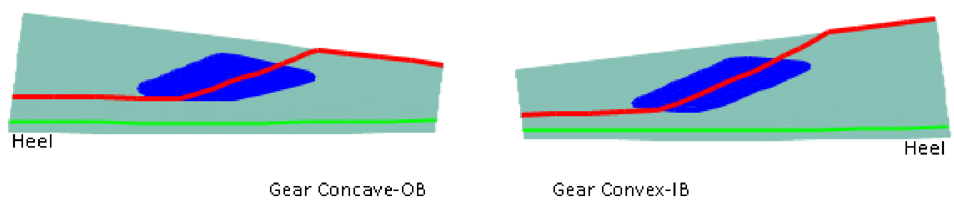
A 9x37 RH spiral bevel gear set is being developed. The gear member is already cut - but differs from the original design as shown below - and the pinion needs to be cut to mesh correctly with the gear.



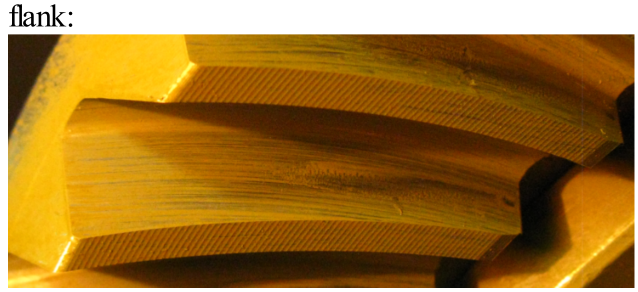
Gear [Finishing]/Th.Err:-0.2978 [Nominal] [Meas.Surface : cor1_271017.mes/1]

The target contact patterns appear below:

Bearing Pattern - Gear [Convex-IB] [NoEr] [Finishing] mc=2.58 E=0.00 P=0.00 G=0.00 [mm] B:0.141 [mm]/0.091 [deg.]



Upon running the gear set on the VH tester with the design MD (mounting distance), the contact patterns came out as show below, i.e Toe heavy on the gear convex flank, and a bit towards Heel on the gear concave flank:



Concave Flank **Convex Flank**

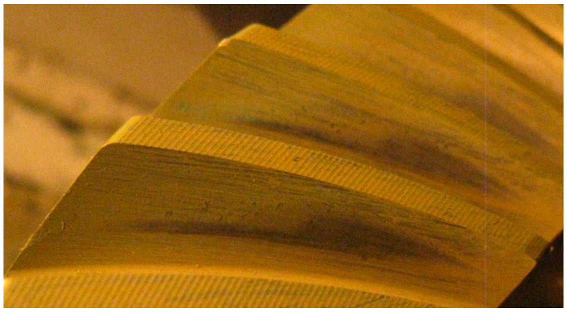
In order to center the contact pattern on the tester, the following E P G values were required, which yielded the contact patterns shown below:

- E: -0.62 mm
- P: +0.70 mm
- G: -0.35 mm

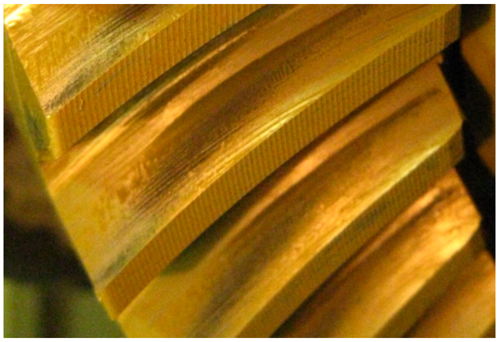
Concave Flank **Convex Flank**

Using the VH>> function, the above values were entered in HyGEARS, a new pinion Summary was obtained and used to cut the pinion, and the following contact patterns were obtained on the gear:

Concave Flank **Convex Flank**

Clearly, the contact patterns went where desired by the developer at the 1st iteration.. The fact that the gear member was not cut to target does affect the precision of the solution, but does not prevent obtaining a good solution. Doing a 2nd iteration yielded the following result:

Concave Flank **Convex Flank**

Here, what would be needed is to :

- Reverse Engineer the gear to the CMM data using the HyGEARS *R.E.* function,
- develop the contact pattern by modifying the pinion machine settings using the HyGEARS *BPat* function,
- use the HyGEARS *VH>>* function as explained above.

Doing so, the results shown below are obtained after 1 iteration. Clearly, the results converge very quickly. A 2nd iteration could be applied in order to improve a bit more the contact pattern on the Concave flank.

Concave Flank

Convex Flank

Command Buttons

Apply the entered E P G values are used to recalculate and display the Contact Pattern, which should be similar to that found on the VH tester when the pinion and gear are in nominal position;

Reset returns the E P G values to 0;

Ok the entered E P G values are used by the *VH>> algorithm* to calculate modified machine settings, the modified Pdf Summary is displayed and the *VH Settings* window is closed;

Cancel reverts the geometry to its initial status and exits the *VH Settings* window.

14.94 Vol

Calls the calculation of the displayed object (Tooth or Full Model Child Windows) volume, mass and moments of inertia, and prints the results in a Text Result window.

See Volume and Moments of Inertia for details.

14.95 XYZ

Calls the Measurement Data Selection window, which is used to modify the current measurement data file name selection.

15 HyGEARS Help

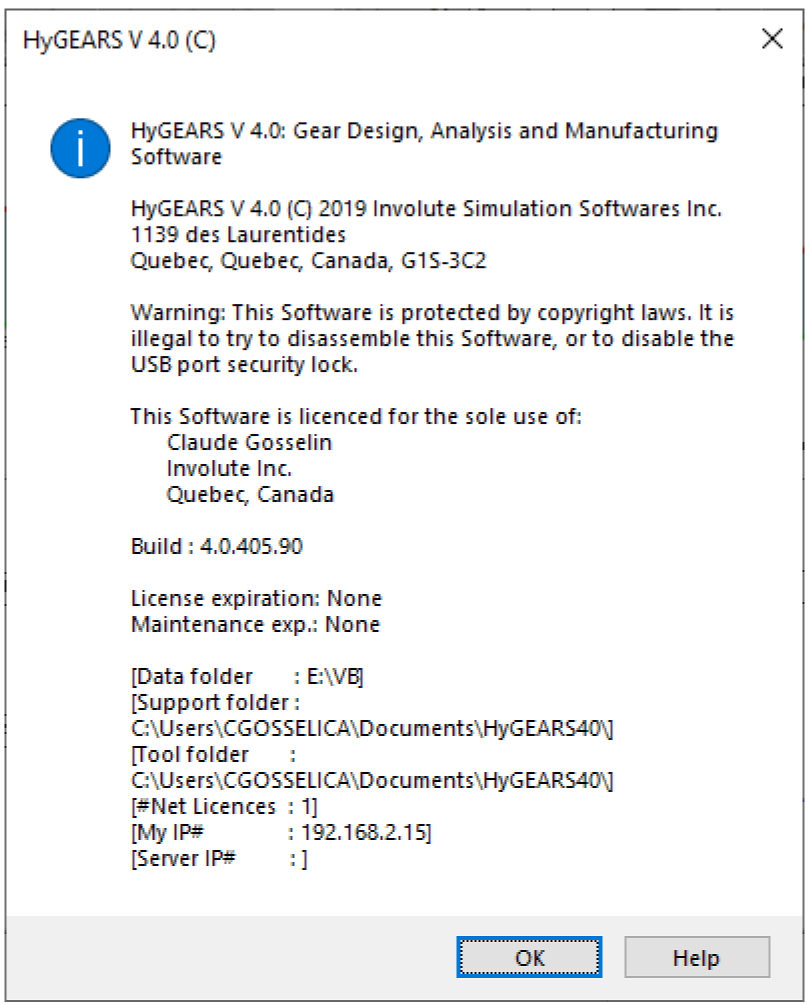
This section covers the HyGEARS Help System, in which several tools are offered to provide on-line user support. It is therefore a frequent reference point for new users.

This section is divided in 2 topics:

- About HyGEARS
- HyGEARS Help

15.1 About HyGEARS

The About HyGEARS function is used to display the Copyright notice which is shown automatically at the start of each new session, as shown in the figure below.

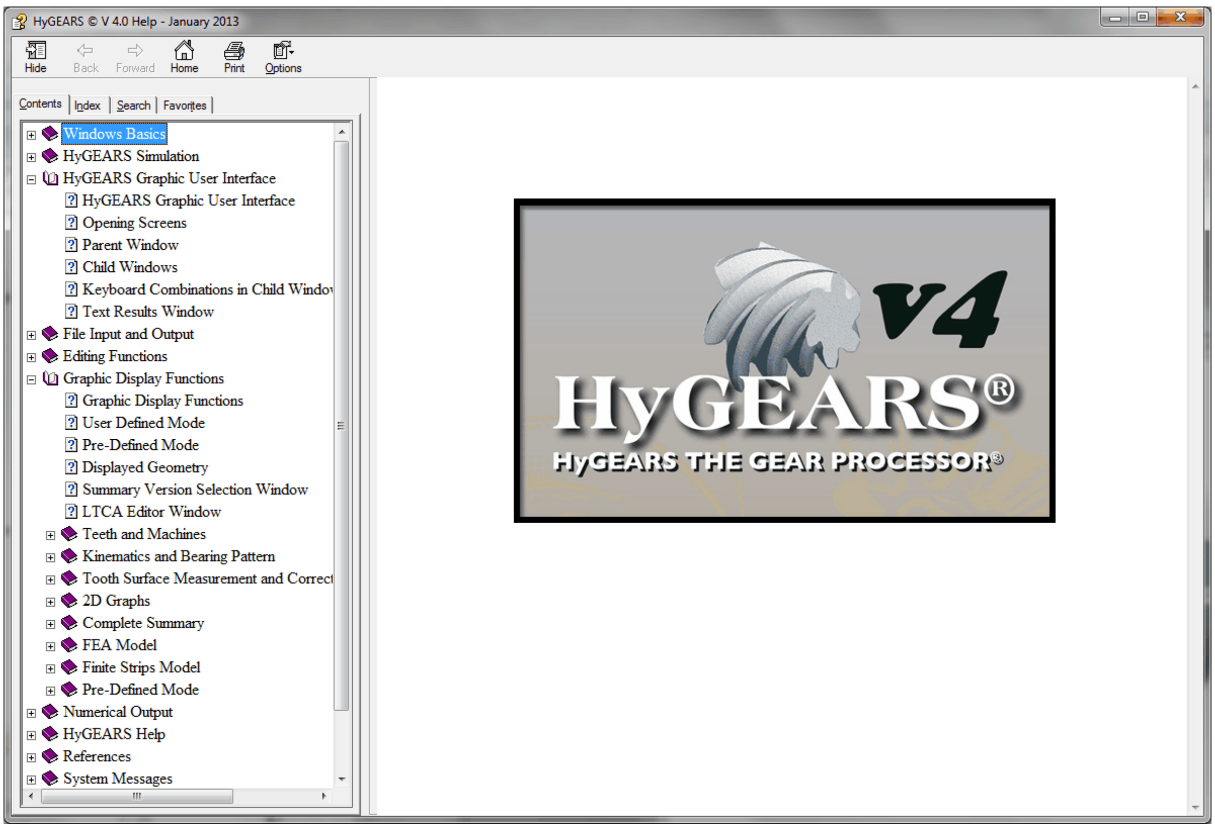


15.2 HyGEARS Help

By clicking on this function, HyGEARS loads its own Help System and displays the Contents of the HyGEARS Help (see the figure below). The HyGEARS Help Contents is really a series of Hypertext links to the main sections of each chapter of the printed user documentation.

Documentation is organized in Books and Topics. A double-click on a Book opens it and reveals its contents, which may be Books and Topics. A double-click on a Topic leads to the documentation for the selected Topic.

The HyGEARS Help System is also context sensitive, which means that wherever you are standing in HyGEARS, pressing the "F1" keyboard function key will load the HyGEARS Help and bring you to the appropriate documentation subject, from where you can navigate as usual.



16 References

Throughout the design and development of HyGEARS, numerous papers and books were consulted. The following sections, which list the main references used during the software development and validation phases, are not exhaustive by any means.

While the material contained in HyGEARS is original in the sense that it reproduces the author's comprehension and knowledge on Spiral-Bevel and Hypoid gear simulation, countless ideas came from lectures.

Since a software user documentation is not meant to be a treatise on any subject, and given the breadth of knowledge involved in Spiral-Bevel and Hypoid gear simulation and design, the user is invited to consult the following, whenever the explanations given in HyGEARS user's guide do not provide enough depth.

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17 System Messages

This section enumerates various messages HyGEARS may issue to the user when in operation. When necessary, a brief explanation will be given. The section is organized in topics referring to specific message types.

The following topics are covered:

17.1 Autosave Messages

The Autosave data file exists, probably due to a previous system crash.
Do you want to recall the Autosave data file and restore the system as it was ?

Explanation: HyGEARS automatically saves to disk the current Geometry data at user-defined intervals during its operation. When HyGEARS is exited properly, this file is erased. On the other hand, if the computer crashes, this file will not be erased and HyGEARS will detect its presence the next time it is run. When HyGEARS detects the Autosave file, it offers to restore the contents of this file into memory, such that the data you were working on when the computer failure occurred can be retrieved.

Refer to “Editing the HyGEARS Configuration” in Chapter 5 for more details.

17.2 Contact Pattern Development Messages

An error has occurred while modifying the current parameter!

The operation underway is canceled such that you can review your parameters and issue a revised request.

Explanation: If a parameter exceeds some practical limit when developing a Contact Pattern using the predefined Function buttons, it may happen that the obtained teeth are unusable or that HyGEARS cannot calculate the path of contact or the Contact Pattern. If such an error condition arises, this message is issued and the requested changes must be revised or applied in smaller steps.

Refer to “Kinematics and Contact Pattern - Contact Pattern Development” in Chapter 6 for more details.

The requested position value on the tooth flank cannot be less than 10% or more than 90%.

Explanation: If a parameter exceeds some practical limit when developing a Contact Pattern using the predefined Function buttons, it may happen that the obtained teeth are unusable or that HyGEARS cannot calculate the path of contact or the Contact Pattern. If such an error condition arises, this message is issued and the requested changes must be revised or applied in smaller steps.

Refer to “Kinematics and Contact Pattern - Contact Pattern Development” in Chapter 6 for more details.

The maximum number of changes has been reached for the requested. No more changes will be allowed.

Explanation: Up to 7 VH>> machine settings changes are allowed per Geometry, for each the pinion and gear. When this number has been reached, HyGEARS issues a message and does not permit any other changes. If more change space is required, please refer to your distributor for action to take.

Refer to "Kinematics and Contact Pattern - Contact Pattern Development" in Chapter 6 for more details. for more details.

The Nominal Geometry Summary has not been identified yet and cannot be defined with the Summary for Roughing.
Please set the Summary for Finishing before resuming.

Explanation: For VH>> action to take place, the nominal Summary must first be identified, which cannot be done when the Geometry is in roughing mode. Revert to the finishing mode prior to attempting any corrective action.

Refer to "Kinematics and Contact Pattern - Contact Pattern Development" in Chapter 6 for more details. for more details.

The Nominal Summary has not been identified yet !

Do you wish to consider the Current Geometry Summary as the Reference Nominal Summary for this gear set ?

YES **means that the Current Geometry Summary will become the Reference Nominal Summary and that all future Contact Pattern Development will be calculated in reference to this Nominal Summary.**

NO **will prevent calculation of the Contact Pattern Development since the Nominal Geometry Summary must be defined before hand.**

Explanation: For VH>> action to take place, the nominal Summary must first be identified to HyGEARS. The nominal Summary defines the theoretical surface shape and machine settings, and will be used in computing all subsequent machine settings changes.

Refer to "Kinematics and Contact Pattern - Contact Pattern Development" in Chapter 6 for more details. for more details.

Apply the calculated machine settings changes ?

YES to change the proposed Geometry to reflect the calculated changes.
NO to return the current Geometry to its original Summary values.

Explanation: Once machine settings changes have been calculated, they can be applied to the current Geometry if the on-screen results seem acceptable, or rejected if unacceptable. If the machine settings changes are applied, a copy of the current machine settings plus the corrective changes will be kept as part of the Geometry data file.

Refer to "Kinematics and Contact Pattern - Contact Pattern Development" in Chapter 6 for more details. for more details.

The Current Geometry Summary has been modified by Corrective Changes.
This Geometry should be saved on disk.

Do you want to do it now ?

Explanation: For machine settings changes to be kept permanently for later use, the Geometry data file must be stored on disk. HyGEARS proposes to do so automatically after corrective action has been accepted by the user. If this offer is not accepted, one must remember to save the Geometry before exiting HyGEARS.

Refer to "Kinematics and Contact Pattern - Contact Pattern Development" in Chapter 6 for more details. for more details.

There are E, P or G values entered, which should be set to zero prior to this function.

Do you want HyGEARS to do so ?

Explanation: When applying the VH>> function, HyGEARS needs to calculate the position of the actual Contact Pattern without any E, P or G positional errors. If such values are detected, HyGEARS issues a warning message and offers to reset them to zero for you. HyGEARS will not continue unless the E, P and G values are zero.

Refer to "Kinematics and Contact Pattern - Contact Pattern Development" in Chapter 6 for more details. for more details.

Since there are no E, P or G values entered, no correction can be made on the Contact Pattern.

Explanation: When applying the VH>> function, HyGEARS needs to calculate the new position of the Contact Pattern under E, P or G positional errors. If such values are not entered when the VH Editor window is presented, HyGEARS issues a warning message and will not continue.

Refer to "Kinematics and Contact Pattern - Contact Pattern Development" in Chapter 6 for more details. for more details.

17.3 Corrective Machine Settings and Reverse Engineering Messages

The maximum number of changes has been reached for the requested. No more changes will be allowed.

Explanation: Up to 7 Corrective Machine Settings changes are allowed per Geometry, for each the pinion and gear. When this number has been reached, HyGEARS issues a message and does not permit any other changes. If more change space is required, please refer to your distributor for action to take.

Refer to "Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings" for more details.

This Corrective Machine Settings operation has already been performed. Change either the Tooth Flank, Measurement Data or Cutting Mode.

Explanation: A corrective action cannot take place more than once. If the measurement data file and/or the corrected tooth flank are the same, HyGEARS assumes that the same corrective action is requested, and issues a message preventing it.

Refer to "Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings" for more details.

The number of measurement data points exceeds the maximum number of points. Calculation of the surface errors cannot continue.

Explanation: HyGEARS measurement data files cannot exceed a given size. If an attempt is made at exceeding any limit value, HyGEARS issues a message preventing it.

Refer to “Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings” for more details.

Caution: a Fixed Cutter Spindle Angle should be used only when tooth surface errors are small.

Explanation: You are selecting to keep the Cutter Spindle Angle (Swash Angle) fixed when calculating Corrective Machine Settings or Reverse Engineering. This can be used only if tooth surface errors are small as tooth rootline will not be maintained parallel and a solution may not be reached by HyGEARS.

Refer to “Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings” for more details.

Caution: the combination of Decimal Ratio and Offset as control parameters does not always give reliable results

Explanation: When calculating Corrective Machine Settings, many control parameter choices may be made. However, the combination of Decimal Ratio and Offset is not a proper combination as their effects on tooth rootline and bias are not compatible.

Refer to “Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings” for more details.

The Nominal Geometry Summary has not been indentified yet and cannot be defined with the Summary for Roughing.
Please set the Summary for Finishing before resuming.

Explanation: For corrective action to take place, the nominal Summary must first be identifed, which cannot be done when the Geometry is in roughing mode. Revert to the finishing mode prior to attempting any corrective action.

Refer to “Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings” for more details.

You cannot permanently modify a Pinion/Gear tooth surface by Reverse Engineering, that has already been submitted to Corrective Machine Settings.

Before doing so, you must reset the Corrective Machine Settings History.

Explanation: Tooth Reverse Engineering may be tried, even though Corrective Machine Settings ahve already been calculated and applied, in order for example to check what if situations. However, HyGEARS will not permit you to apply and keep the machine settings changes calculated by the Surface Match function in this case, unless the Corrective Machine Settings History has been reset (see Resetting the Corrective Machine Settings History).

Refer to "Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings" for more details.

17.4 Corrective Machine Settings History Messages

This operation will reset the selected Pinion or Gear Geometry to its original state preceding Corrective Machine Settings.

Do you wish to continue ?

Explanation: It is possible to erase all corrective action already associated with a data file using this function. When activated, the Geometry reverts to its nominal Summary definition, and all corrective changes are discarded.

Refer to "Resetting the Corrective Machine Settings History" for more details.

This operation will set the selected Pinion or Gear Geometry to the choosen state in the Corrective Machine Settings History.

Do you wish to continue ?

Explanation: At any moment, when corrective action has taken place, it is possible to load a selected version of the Summary from the Corrective Machine Settings History. Doing so temporarily replaces current machine settings by those of the selected version. The selected version is attached to the current Child Window only, and will be made current each time this Child Window is made active.

Refer to "Tooth Surface Measurement and Corrective Machine Settings - Corrective Machine Settings" or "Summary Version Selection Window" for more details.

17.5 Geometry Creation Messages

One of the input values is null, negative or incorrect ...
Please check before continuing.

Explanation: In the New Geometry Definition window, one of the input values is incorrect, empty of negative. Review your input data before reissuing the OK command.

Refer to "Creating a New Geometry" for more details.

The following calculations will completely overwrite current memory data.
Do you want to continue ?

Explanation: When the OK command is given in the New Geometry Definition window, all the currently active data is erased and replaced by the newly defined Geometry. Therefore, it is a good idea to save the current Geometry before creating a new one.

Refer to "Creating a New Geometry" for more details.

HyGEARS has created the requested Geometry.

Please consult the Pinion and Gear Cutting Machines Child Windows to make sure that the calculated machine settings are correct.

Explanation: HyGEARS has created a new Geometry. It is always safer to visually check the machine settings for both the pinion and gear members, before attempting any other operation.

Refer to "Creating a New Geometry" for more details.

An error has occured while calculating the initial machine settings

The operation underway is cancelled such that you can review your parameters and issue a revised request.

Explanation: When creating a new Geometry, it can happen that the enterede parameters are not compatible and that has not been detecetd by HyGEARS. If so, errors can occur when developping the initial Geometry which will be trapped by HyGEARS and this message is then displayed. A typical error can be a very small pressure angle, too small in fact for the given configuration.

Refer to "Creating a New Geometry" for more details.

When creating a new Geometry, a data file name must be entered, with a sub-directory name different from the default HyGEARS sub-directory.

Please fill-in these fields.

Explanation: Each time a new Geometry is created, HyGEARS must know how to name it and where to save it. Therefore, the Geometry file and directory names must be given. The file name can be anything, but the directory name must be different than the defautl HyGEARS directory..

Refer to "Creating a New Geometry" for more details.

The entered Addendum Factor, equal to: XXX.XXXX, is larger than the maximum recommended value of: YYY.YYYY.

Do you want to modify it now ?

Explanation: The Addendum Factor you entered is larger than the maximum recommended value.

Refer to "Creating a New Geometry" for more details.

The entered Depth Factor, equal to: XXX.XXXX, is larger than the maximum recommended value of: YYY.YYYY.

Do you want to modify it now ?

Explanation: The Depth Factor you entered is larger than the maximum recommended value.

Refer to "Creating a New Geometry" for more details.

The entered Gear Tooth Facewidth, equal to: XXX.XXXX, is larger than the maximum recommended value of: YYY.YYYY.

Do you want to modify it now ?

Explanation: The gear facewidth you entered is larger than 30% of the outer cone distance, which is the maximum recommended value. A larger facewidth may cause the tooth to become excessively thin at the toe, and undercut may occur.

Refer to "Creating a New Geometry" for more details.

One of the Gear Root IB or OB Pressure Angle, respectively equal to : XXXX/YYYY, differs by more than 1 degree from the corresponding IB or OB Blade Angle, respectively equal to : AAAA/BBBB.

These should be modified to match as closely as possible the Gear Root Pressure Angles.

Do you want to do so now ?

Explanation: When creating a new generated or Helixform Hypoid gear set, the gear root pressure angles should match as closely as possible with the blade angles. When they do not match, HyGEARS will modify the root angle until they match. It is therefore better to have blade angles as close as possible to the root pressure angle. The threshold is 1 .

Refer to "Creating a New Geometry" for more details.

The Gear Cutter Radius exceeds the Mean Cone Distance, equal to XXXX. It is recommended that the Gear Cutter Diameter does not exceed the value of YYYY.

Do you want to change the Gear Cutter Diameter now ?

Explanation: The maximum gear cutter radius should not exceed the gear mean cone distance. If so, the sum of the dedendum angles is increased and adverse tooth proportions result, with a shallow tooth at the inner end and too deep a tooth at the outer end..

Refer to "Creating a New Geometry" for more details.

The Gear Cutter Radius is smaller than the Minimum recommended value. It is recommended that the Gear Cutter Diameter does not go below the value of XXXX.

Do you want to change the Gear Cutter Diameter now ?

Explanation: The minimum gear cutter radius should not be less than a value based on the gear mean cone distance. If so, the sum of the dedendum angles is decreased and if the cutter radius reaches $A_{mG} \sin(\text{✡})$ or less, the teeth could actually be deeper at the inner end than at the outer end.

Refer to "Creating a New Geometry" for more details.

The Pinion Cutter Center Horizontal Position Exceeds the Capacity of the Generator.

Please Increase the Cutter Diameter.

Explanation: In generators, the cutter center is installed on an eccentric. If the cutter radius is too small, the eccentric may not be large enough to produce the required spirtal angle, and the cutter diameter should be increased.

Refer to "Creating a New Geometry" for more details.

The Pinion O.B. Cutter Tilt Angle Exceeds 30 Degrees.
The Pinion I.B. Cutter Tilt Angle Exceeds 30 Degrees.

Please Change the Specified Blade Angle.

Explanation: In generators, the cutter is tilted using two 15 slanted disks facing each other. If the required tilt is larger that the maximum tilt of 30 , this message is issued.

Refer to "Creating a New Geometry" for more details.

HyGEARS cannot adjust the I.B. / O.B. pinion Machine Root Angle for the given Shaft Angle.

Explanation: In Formate and Helixform gears, the pinion machine root angle depends on the pitch angle of the gear member, which depends on the gear set shaft angle. If the shaft angle is less than 90 , it is probable that the pinion machine root angle will go below that of the generator minimum angle of -12 , and this message will be issued. It is then necessary to check the pinion machine settings.

Refer to "Creating a New Geometry" for more details.

In Formate gears, the Gear Blade Angles must equal the Mean Pressure Angle, equal to : XXXX. In this setup the I.B. and O.B. Gear Blade Angles are respectively equal to : AAAA/BBBB.

These should be modified to match as closely as possible the Mean Pressure Angle.

Do you want to do so now ?

Explanation: In Formate gears, the gear blade angles are generally set at half the Sum of Pressure Angles, thus 19 for a 38 Sum, 20 for a 40 Sum, etc. When HyGEARS detects that there is a difference with the recommended value, this message is issued. Improper teeth can result if the difference is too large.

Refer to "Creating a New Geometry" for more details.

Attention: the Gear Angular Face of XX.YY is larger than 27.5 degrees !

Do you want to use a Variable Pitch Cutter ?

Explanation: In Helixform gears, the gear member finishing cutter must move along an helicoid, the limit of which is 27.5 on the Gleason 607 machine, considered as the lower limit here. If the gear member angular face is larger than 27.5 , this message is issued if a standard cutter has been chosen, since variable pitch cutters and setup must be used.

Refer to "Creating a New Geometry" for more details.

Attention: the Gear Angular Face of XX.YY is less than 27.5 degrees !

Do you want to use a Variable Pitch Cutter ?

Explanation: If a Variable Pitch cutter has been selected for a Helixform gear member, although the Gear Angular Face is less than the maximum limit, HyGEARS issues this message as a warning and offers the chance to change the selection.

Refer to "Creating a New Geometry" for more details.

Attention: the I.B. Machine Root Angle is smaller than -12 degrees !
Attention: the O.B. Machine Root Angle is smaller than -12 degrees !

Explanation: In Formate and Helixform gears, the pinion machine root angle depends on the pitch angle of the gear member, which depends on the gear set shaft angle. If the shaft angle is less than 90 , it is probable that the pinion machine root angle will go below that of the generator minimum angle of -12 , and this message will be issued. It is then necessary to check the pinion machine settings.

Refer to "Creating a New Geometry" for more details.

A Shaft Angle smaller than 80 degrees is not supported by HyGEARS
A Shaft Angle larger than 100 degrees is not supported by HyGEARS

Explanation: HyGEARS does not support Spiral-Bevel gears with shaft angles less than 80 or larger than 100 .

Refer to "Creating a New Geometry" for more details.

A Shaft Angle different other than 90 degrees is not supported by HyGEARS.

Explanation: HyGEARS does not support Hypoid gears with shaft angles other than 90 .

Refer to "Creating a New Geometry" for more details.

The Pinion Offset, equal to XXXX exceeds either the lower or upper recommended limits which are respectively equal to AAAA/BBBB.

Do you want to modify the entered Pinion Offset ?

Explanation: In general, Hypoid offset should not exceed 25 % or the gear pitch diameter to limit sliding, and in heavy duty drives, it should be limited to 12,5 %. The default value used by HyGEARS is 10 %.

Refer to "Creating a New Geometry" for more details.

17.6 Geometry Data File Input/Output Messages

XXXX.YYY is already loaded - Open File is not permitted.
To make it current, double-click on Graphic Window ZZZZ.

Explanation: Each time a new Child Window is created, the currently active Geometry file name is attached to it. It is not permitted to open a Geometry data file while Child Windows attached to it are still alive. To make the requested Geometry data file active, double-click on any Child Window linked to it. To re-open the original Geometry data file, all Child Windows linked to it must first be closed.

Refer to "Opening an Existing File on Disk - Opening an Existing Geometry Data File" for more details.

XXXX.YYY : The requested data file is not a permitted Geometry of type ZZZ.

Explanation: You are attempting to open a file which is not of HyGEARS type, or of a type not supported by HyGEARS.

Refer to "Opening an Existing File on Disk - Opening an Existing Geometry Data File" for more details.

The requested path does not exist. Do you want to create it ?

Explanation: When saving a Geometry to disk, if the requested sub-directory does not exist, HyGEARS will automatically offer to create it before saving.

Refer to "Saving an Existing File on Disk, Under a New Name or in a Different Directory" for more details.

No Measured Data File Given ...

Use the Surface Comparison Function to Enter a Data File Name.

Explanation: An attempt was made to use the Error Surface option (ErrS) while no measurement data file name is associated with the currently loaded Geometry. Note that to use this option, both the pinion and gear members must have an associated measurement data file. To associate a measurement data file name to a pinion or a gear, any of the Tooth Surface Measurement and Corrective Machine Settings (Closed Loop) functions may be used. When the data file is stored on disk, the associated measurement data file name is also stored.

Refer to "Tooth Surface Measurement and Corrective Machine Settings (Closed Loop)" for more details.

XXXX.YYY : This Measured Data File is not Available ...
Use the XYZ Function button or Surface Comparaison Function to Enter a Data File Name.

Explanation: An attempt was made to use the Error Surface option (ErrS) with an invalid associated measurement data file. Note that to use this option, both the pinion and gear members must have an associated measurement data file. To associate a measurement data file name to a pinion or a gear, the XYZ Function button or any of the Tooth Surface Measurement and Corrective Machine Settings (Closed Loop) functions may be used. When the data file is stored on disk, the associated measurement data file name is also stored.

Refer to "Tooth Surface Measurement and Corrective Machine Settings (Closed Loop)" for more details.

17.7 HyGEARS Dll Version Messages

HyGEARS V 4.0 : Gear Design and Analysis Software
Involute Simulation Softwares Inc., "1995-2020"

Invalid Dll Version Number !

Explanation: HyGEARS uses "Dll" files, or dynamic link libraries, in which the main computational engine is stored. You are attempting to run HyGEARS with the wrong library, which is not permitted. Please refer to your distributor for action to take.

17.8 HyGEARS Hardware Lock Messages

The Hardware Security Lock is either not attached, faulty or the wrong one.
HyGEARS cannot continue operating.
Please check with your distributor.

Explanation: HyGEARS is protected against illegal operation by a parallel port (printer port) hardware security key, which is valid only for a group of licenses within the same organization. Attempting to run HyGEARS without this hardware security lock or with the wrong one, or removing it during HyGEARS operation is not permitted, and HyGEARS will terminate at once.

You have backed your computer's clock, which may prevent HyGEARS to operate properly.
Please reset your computer's date and time properly.

Explanation: HyGEARS is protected against illegal operation by a parallel port (printer port) hardware security key, which is valid only for a group of licenses within the same organization. Every time HyGEARS is started or ended, it accesses the security lock and registers the date and time of start and end. If your license is limited by a date (see the Copyright screen when starting HyGEARS), attempting to back your computer's clock in order to extend the license period will be detected, and HyGEARS will issue this message if it detects so.

If the license expiration date in the opening screen is [None], then the version of HyGEARS you are running is not considered as limited by time.

The following error has occurred while accessing the Hardware Security Lock : #
Please note the error (number) and report it to your distributor.

Explanation: An error has occurred while attempting to access the hardware security lock. Please note the error number, and report it at once to your distributor. Since the hardware security lock can be written to about 1,000,000 times, it is possible that after some time, it becomes useless and has to be replaced, which would then generate such an error.

17.9 HyGEARS Language Files Messages

Cannot find requested language file XXXXX.YYY !

HyGEARS will default to English !

Explanation: HyGEARS uses language files for the screen menus and user interaction. When HyGEARS is started, it checks for the existence of the selected language file. If this file does nit exist, HyGEARS will automatically default to English.

Refer to "Setting Up HyGEARS - To run HyGEARS" and "Editing the HyGEARS User Configuration" for more details.

Cannot find any language file !
HyGEARS will terminate now !

Explanation: HyGEARS uses language files for the screen menus and user interaction. When HyGEARS is started, it checks for the existence of the selected language file. If this file does nit exist, HyGEARS will automatically default to English. If the English language file does not exist, HyGEARS cannot be run at all.

Refer to "Setting Up HyGEARS - To run HyGEARS" and "Editing the HyGEARS User Configuration" for more details.

The selected language file XXXXX.YYY is not of the proper type.
Please consult with your representative for action to take.

Explanation: The selected language file is not of the proper HyGEARS type. HyGEARS cannot be run at all if the English language file is not available.

Refer to "Setting Up HyGEARS - To run HyGEARS" and "Editing the HyGEARS User Configuration" for more details.

The version number of the language file is wrong.
Please consult with your representative for action to take.

Explanation: HyGEARS language files are identified by a version number, which is synchronized to the HyGEARS version itself. If the selected language file version number is not correct, HyGEARS cannot use it. HyGEARS cannot be run at all if the English language file is not available.

Refer to "Setting Up HyGEARS - To run HyGEARS" and "Editing the HyGEARS User Configuration" for more details.

17.10 HyGEARS License Messages

HyGEARS V 4.0 : Gear Design and Analysis Software
Involute Simulation Softwares Inc., "1995-2020"

License Expiration Date Reached.

Please consult your dealer for action to be taken.

Explanation: Your license has expired. It is not possible to legally run HyGEARS until a new license has been granted. Please refer to your distributor for action to take.

17.11 LTCA Messages (Loaded Tooth Contact Analysis)

The Westinghouse Stiffness calculation of Point # on Tooth #: is not possible.
Please increase the axial # of points of the tooth.

Explanation: When the Loaded Tooth Contact Analysis function is run, it needs to calculate the tooth thickness at various positions along the tooth flank, which is done using the Westinghouse formula. This cannot be done reliably if the definition of the tooth is too coarse, meaning that the lengthwise number of points is too small, especially so if the pinion tooth number is small. Simply increase the number of points to bypass this problem. As a guideline, 9 axial points is usually sufficient for pinions of less than 10 teeth.

Refer to “Loaded tooth Contact Analysis” , “Editing the Pinion and Gear ToothNumber of Points”, “LTCA Editor Window” or “Kinematics and Contact Pattern - Contact Pattern (LTCA)” for more details.

17.12 System Error Messages

HyGEARS uses a large number of numerical procedures, and often has to open and save data files. In each case, errors can occur. Errors can be of human cause, such as requesting the access to a drive which is not ready, or caused by an error in calculation.

Although such errors rarely happen, a comprehensive error messaging system has been built in HyGEARS to guide the user in dealing with such errors when the occur.

It is also possible to set the Log file "On" in the HyGEARS Configuration window and try to reproduce the same error. When the Log file is enabled, all HyGEARS actions are recorded in a session file called HYGEARS.LOG, which can then be read to identify the cause of the failure. This Log file shou`ld also be sent along with the Geometry data file at the time a Software Performance Report is submitted.

The following is a **non-exhaustive** list of error messages displayed when such errors happen. Error messages are made of two to four parts:

<xxxxx>	the routine in which the error occurred;
Pinion/Gear	whether the pinion or gear member was under consideration at the time of the error;
Convex/Concave	whether the convex or concave side of the pinion or gear member was under consideration at the time of the error;
*** *Error Type* ***	a description of the error.

Geometry Creation Related Errors

Path of Contact Related Errors

Contact Pattern Related Errors

LTCA Related Errors

Digitization Related Errors

Surface Comparison Related Errors

Finite Element Meshing Related Errors

Machine Conversion Related Errors

Printer Related Errors

File Handling Related Errors

System Resources Related Errors

18 Examples

This section presents several examples how to use HyGEARS. Along with the presented examples, explanations on choices and results are also given to enhance understanding.

This section should *not* be considered as a course on gear design. The user should have some familiarity with gear design, kinematics unloaded and loaded, and manufacturing.

The following topics are covered:

Preliminary Considerations in Spiral-Bevel and Hypoid Tooth Dimension Selection;

Establishing the Correct Bevel Gear Blank

Using the Error Surface in TCA Calculations

Reproducing a Master Gear or Pinion

Creating a Theoretical Measurement Data File

Checking and Improving the Roughing Machine Settings

A Look at the Contact Pattern under Load

Using the Finite Strips to Asses Tooth Strength

Using Reverse Engineering to Change Cutter Dimensions

Creating a New Fixed Setting Hypoid gear set;

Creating a New Duplex Helical Hypoid gear set

Creating a New Duplex Helical Spiral Bevel gear set

Creating a New Duplex Helical Spiral Bevel gear set without Cutter Tilt

Creating a New "New Shape" Straight Bevel gear set

Creating a New External Helical gear set

Creating a New Spur gear set

18.1 Preliminary Considerations

Many gear industries have a long history of manufacturing gear sets, and past experience is always an excellent guide to find a starting point when creating a new gear Geometry.

In any case, in this section we will give some landmarks as where to look to find a starting point when creating a Geometry from scratch. From our findings, we will then create a new Geometry and optimize it using some of the HyGEARS Contact Pattern Development functions.

Module and Diametral Pitch

Gear tooth dimensions are normally referred to by their module “m” (or their diametral pitch “P” in the imperial system). Module definition, and conversion from module to diametral pitch, are given by the following formulae:

$$m = \frac{D}{N} = \frac{25.4}{P}$$

where D is the pitch diameter and is N the number of teeth. Clearly, the gear diameter (or size) is directly linked to the number of teeth and the module. This is the “transverse module”, or “apparent module”, by opposition to the “normal module” which is defined in the normal plane, and therefore requires a more complex formulation.

The larger the module, the bigger the tooth, and vice-versa for the diametral pitch.

Gear Size

In general, gears are limited in size by the location where they are to be installed, for example in the housing of a car or truck differential. In the preliminary design, the gearset speed ratio is normally already known. The speed ratio is defined by the following equation:

$$m_G = \frac{N_G}{N_P}$$

where NP and NG respectively refer to the pinion and gear tooth numbers.

Once the gear pitch diameter is known from the available space, and the desired speed ratio is established, the module can be calculated by knowing the pinion minimum tooth number.

It is generally recommended not to use less than 6 to 8 teeth on a spiral-bevel or hypoid pinion, depending on the spiral angle. The larger the spiral angle, the smaller the pinion tooth number can be. For straight and spur gear, the minimum number of teeth is closer to 15, depending on the blade angle; for helical gears, it can be lower, again depending on the blade angle and the helix angle.

If the pinion tooth number is above the minimum recommended values, there is some room for the adjustment of the diametral pitch which, as is shown in the following section, is linked to the power capacity of the gear set.

A good habit though is to avoid gear ratios which are an exact number, especially so when the pinion tooth is an even number, as the pinion teeth will come in contact with the same gear teeth more often.

Power Capacity

The capacity of a gear set is normally limited by its ability to withstand the high contact pressures generated during the meshing cycle. However, calculating the contact pressures is not an easy task, and is almost impossible as a first guess. Therefore, we will have a look here at the effect of the diametral pitch on the bending strength of a gear tooth, and draw conclusions which can help in selecting a starting point.

The elementary tooth bending strength formula is (excluding application factors):

$$\sigma_b = \frac{2 T_P P}{F d J}$$

where:

sb	bending stress;
Tp	applied torque (at the pinion);
P	diametral pitch;
F	tooth facewidth;
d	pinion pitch diameter;
J	geometry factor, taken from tables, or calculated by HyGEARS.

Assuming a constant torque and a constant geometry factor, which is independent of the tooth size but depends on pressure angle, spiral angle, gear set ratio and pinion offset, we will demonstrate that the diametral pitch is a prime factor in the above formula.

Let us define the following quantities:

approximate *pinion pitch diameter*:

$$d = \frac{D}{m_G}$$

approximate *gear pitch diameter*:

$$D = \frac{N_G}{P}$$

recommended maximum *gear tooth facewidth* (for spiral-bevel, hypoid and straight-bevel gears; no real minimum for spur and helical gears):

$$F = 0{,}3\ A_0$$

gear *outer cone distance* (for spiral-bevel, hypoid and straight-bevel gears):

$$A_0 = \frac{0{,}5D}{\sin(\Gamma)}$$

where Γ is the gear pitch angle.

If we combine the above in the bending stress formula, σ_b becomes, for spiral-bevel and hypoid gears:

$$\sigma_b = \frac{12 T_P P^3 \sin(\Gamma)}{N_P N_G J}$$

which means that the bending stress increases as the cube of the diametral pitch. Since the diametral pitch is the inverse of the module, and thus a higher diametral pitch means a smaller tooth, we can conclude that the smaller the tooth, the higher the bending stresses it will likely be submitted to for a given torque.

For spur and helical gears, one can arrive at the following relation, where the necessary diametral pitch, *Pnec*, is seen as the cubic root of the admissible material stress in bending, σ_{adm}, T_t is the applied torque, and N is the tooth number:

$$P_{néc} = \sqrt[3]{\frac{\sigma_{adm} N^2 J \lambda}{2 T_t}}$$

Of course, this conclusion cannot be taken exactly as the above equation suggests, but it still indicates a trend in the increase in bending stress with a decrease in tooth size. Therefore, it is preferable to use larger teeth whenever possible.

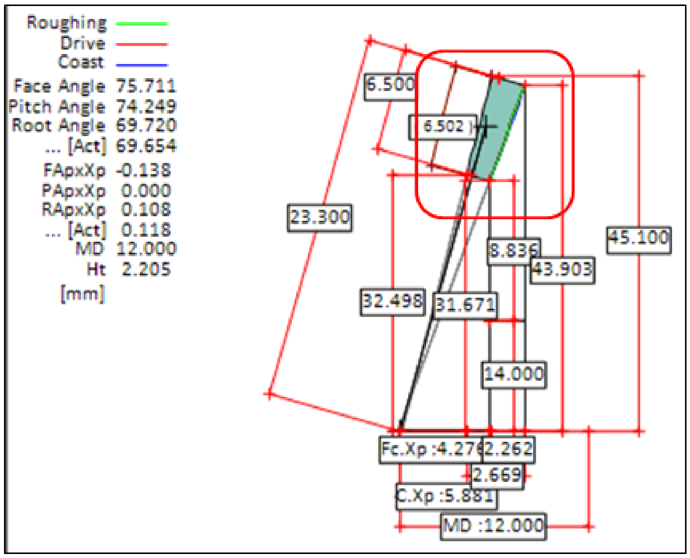
18.2 Establishing the Correct Bevel Gear Blank

Turned OD at Heel
Cropped OD at Heel

[Tapered OD at Toe]

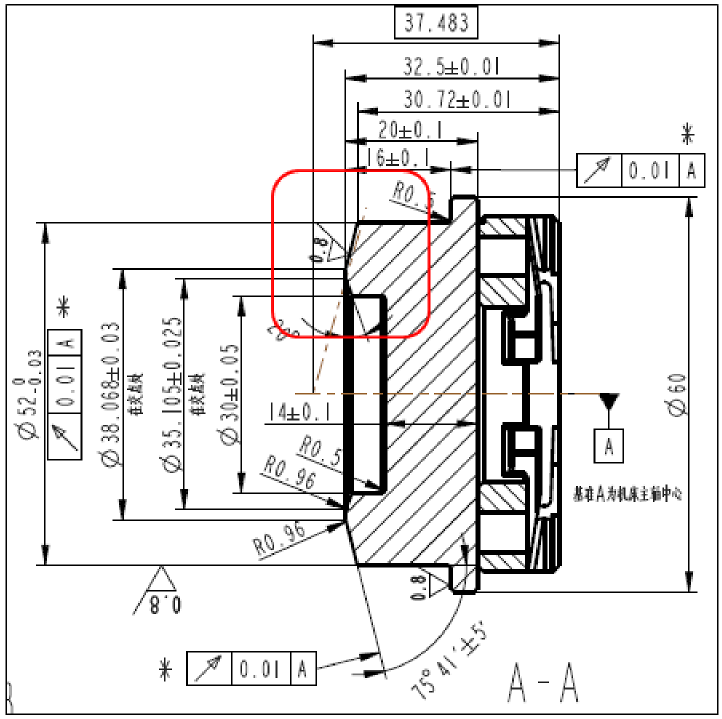
Bevel gear blanks generally differ from the default blank shape assumed when the gear set is created. When HyGEARS creates a new bevel gear, it is assumed that (see figure below):

- the Front and Back angles are equal to the Pitch angle;
- the Front angle can be imposed when creating the geometry, if known;
- the Outside Diameter (OD) at Heel is pointed



However, the shape of the blank may differ significantly. For example, figure below,

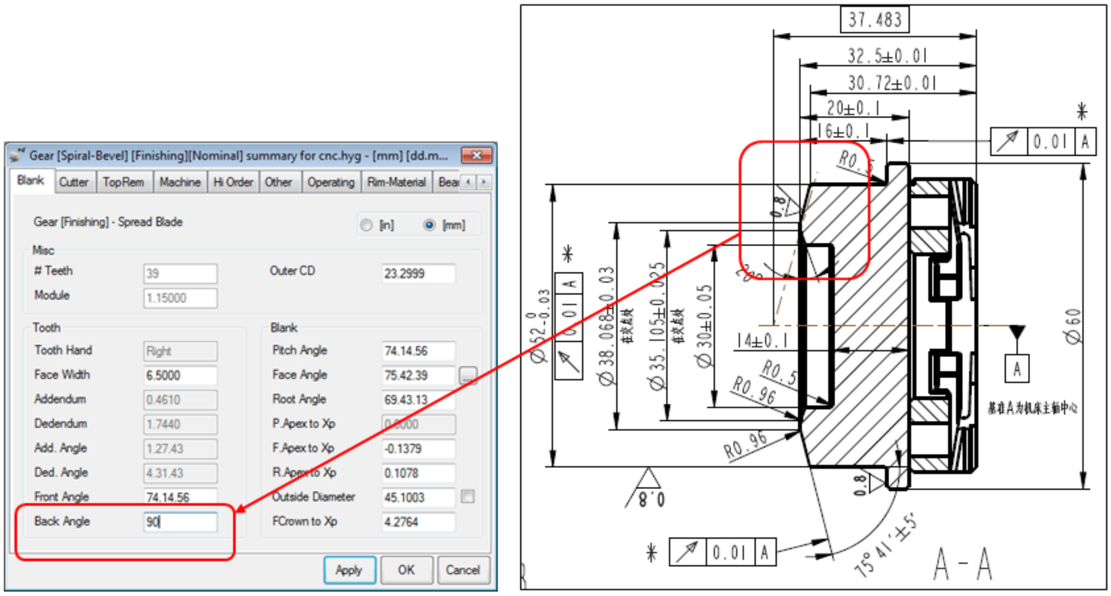
- the Heel may be a turned OD;
- the tooth tip at Toe may be tapered in 1 or 2 steps



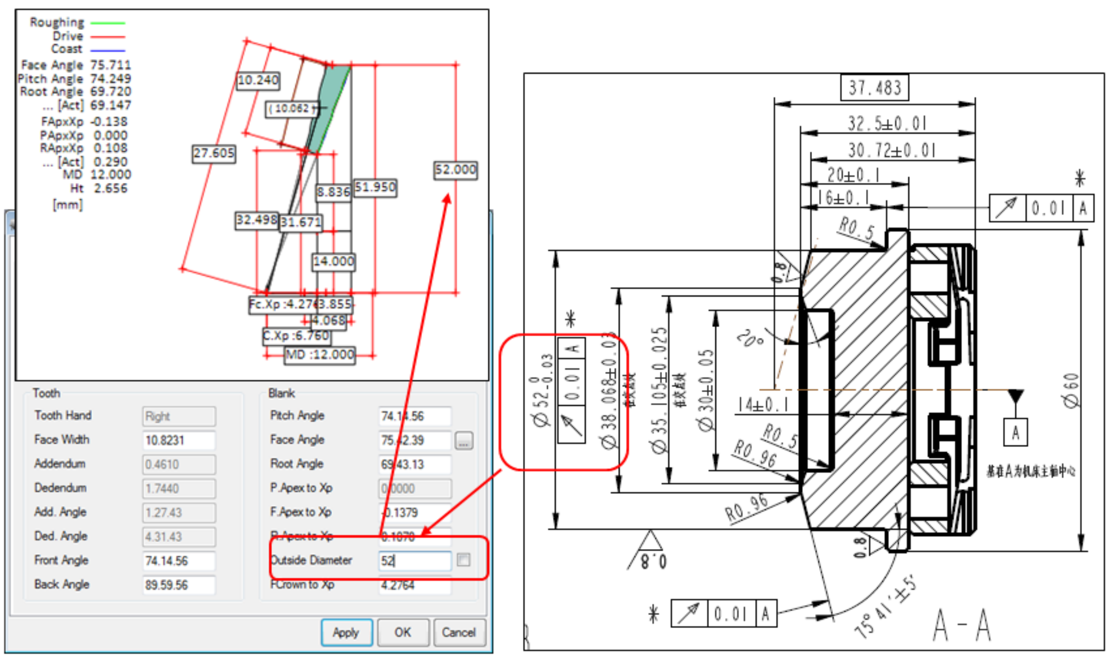
Turned OD at Heel

A *Turned OD* is often used in bevel gears; it allows a simple turning operation on the blank and is therefore economical. If 5Axis CnC milling is to be used with CoSIMT, End Mill or Ball Mill tools, it is recommended to replicate the actual blank *Turned OD* as closely as possible, as explained in the following steps:

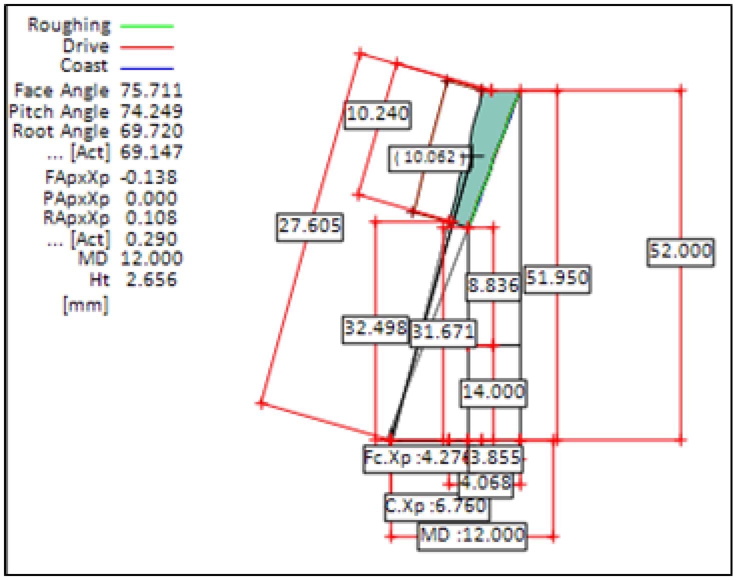
- Click on the *Gea* (gear Summary Editor) or *Pin* (pinion Summary Editor) function button on the tool bar at the left of the Parent Window;
- On the Blank data page, enter 90 for the Back Angle; HyGEARS will limit this value to 89.99° to prevent an infinite tangent value;



- Enter the desired *Turned OD*;



- Click on *Apply* to tell HyGEARS to proceed with the desired request; HyGEARS will then modify the Face Width and OCD such that the tip OD at Toe remains constant and the requested *Turned OD* is obtained.

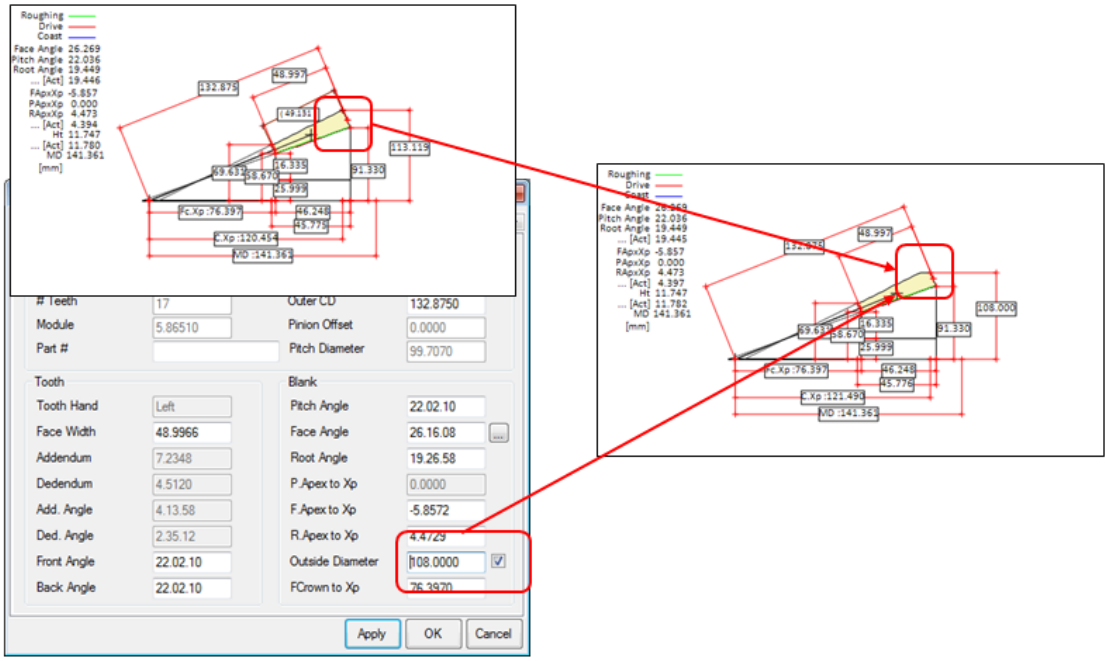


Cropped OD at Heel

A *Cropped OD* is often present in bevel gears; it consists in a turning operation of the OD at Heel, such that the Face cone shows a step before Heel. When a *Cropped OD* is imposed, HyGEARS limits the OD at the imposed value.

The Following steps are to be followed to impose a *Cropped OD* at Heel:

- click on the *Gea* (gear Summary Editor) or *Pin* (pinion Summary Editor) function button on the tool bar at the left of the Parent Window;
- click on the check box to the right of the Outside Diameter input field;
- enter the desired *Cropped OD* value;
- click on the *Apply* button to see the updated display;
- click on the *Ok* button to conserve the entered values;
- click on the *Cancel* button to discard any change made.

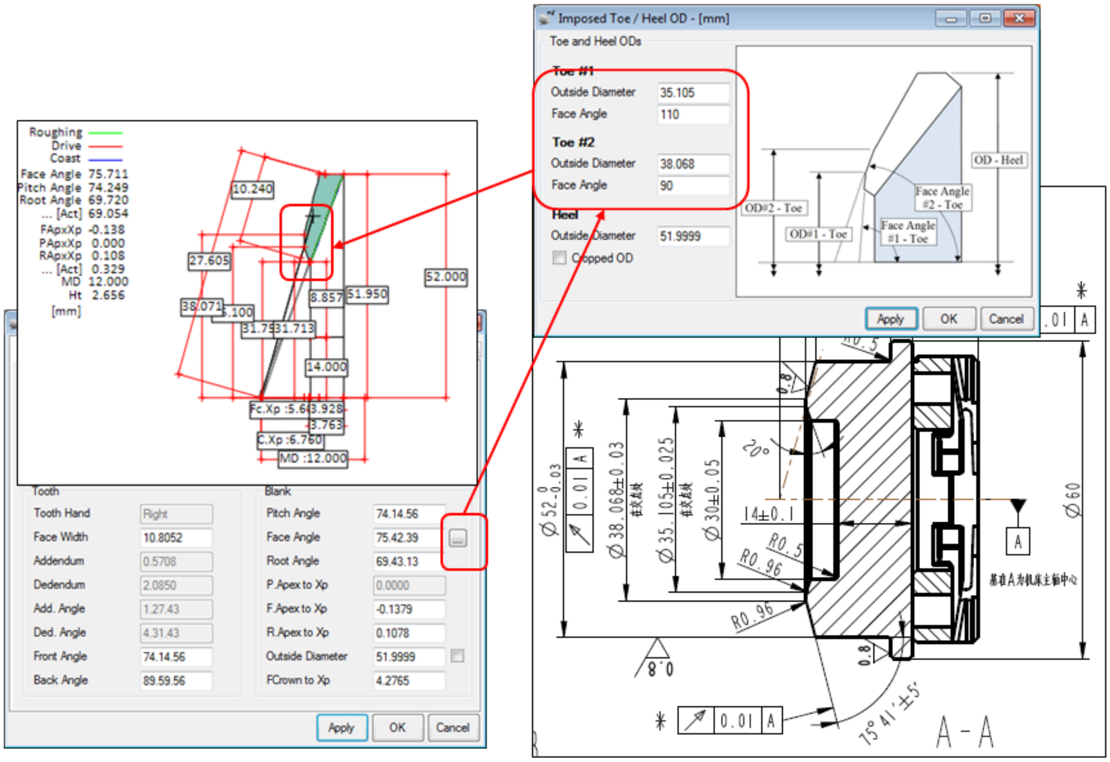


Tapered OD at Toe

A *Tapered OD* is sometimes present in bevel gears; it consists in a turning operation of the OD at Toe in 1 or 2 steps, such that the Face cone shows a series of steps starting at Toe. When a *Tapered OD* is imposed, HyGEARS limits the OD at the imposed values and Face angles along tooth tip.

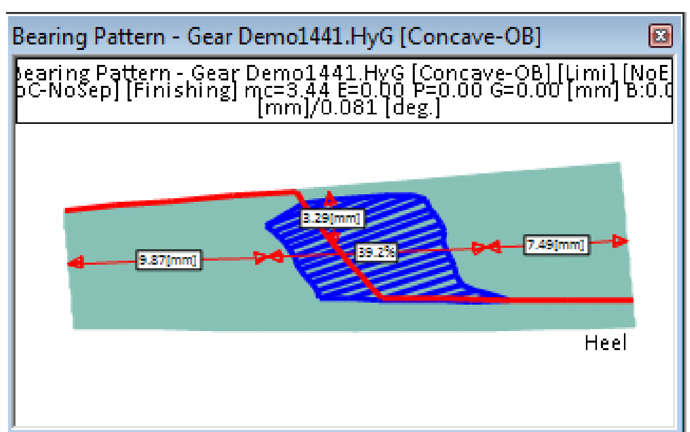
The Following steps are to be followed to impose a *Tapered OD* at Toe:

- click on the *Gea* (gear Summary Editor) or *Pin* (pinion Summary Editor) function button on the tool bar at the left of the Parent Window;
- on the Blank data page, click on the [...] button to the right of the Face Angle input field; the *Imposed Toe / Heel OD* will be displayed;
- in the *Imposed Toe / Heel OD* window, enter the *Toe #1* and/or the *Toe #2* values;
- click on the *Apply* button to see the updated display;
- click on the *Ok* button to conserve the entered values;
- click on the *Cancel* button to discard any change made.



18.3 Using the Error Surface in TCA Calculations

As explained in the Path of Contact, Contact Pattern, Contact Pattern LTCA and 2D Graphs sections, it is possible to calculate what the actual path of contact, Transmission Error curve and Contact Pattern will be using the Error Surface obtained from CMM measurement data.



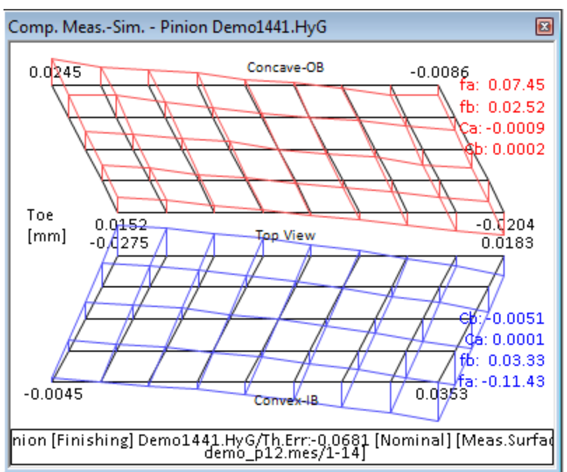
Reference BP

However, the Error Surface used in these instances is different from the one calculated and displayed in the surface comparison Child Windows (Comp. Meas-Sim Surfaces, Corrective Machine Settings (Closed Loop) and Reverse Engineering).

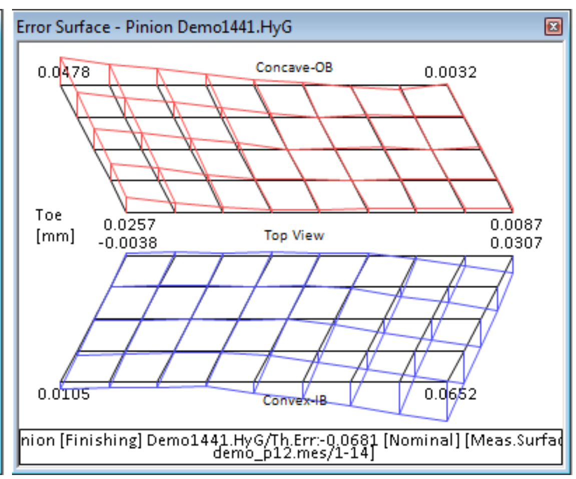
In the case of the surface comparison Child Windows, if more than one tooth is selected for display (see the Measurement Data Selection window), the average error is calculated point by point as the sum of all errors for any given point divided by the number of points.

In the case of the Path of Contact and Contact Pattern Child Windows, if the speed ratio of the gear set is exactly 1, each pinion tooth is always in contact with the same gear tooth. Otherwise, each pinion tooth will eventually come into contact with all gear teeth. The obtained Contact Pattern will therefore be a combination of the imprints left by each pinion tooth on a given gear tooth. The Error Surface used in these instances must thus be the combination of the maximum error, point by point, as the teeth with "plus" material will leave a larger trace than those with "minus" material, for any given measurement point.

The two figures below show respectively the average error surface calculated and displayed by the Comp. Meas-Sim. Surfaces Child Window, and the Error Surface used by the Path of Contact and Contact Pattern Child Windows. The difference is obvious, as the values in the first figure are smaller than those in the second figure.



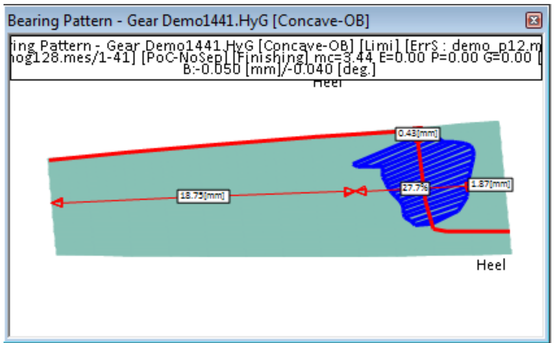
Comp. Meas-Sim. Surfaces



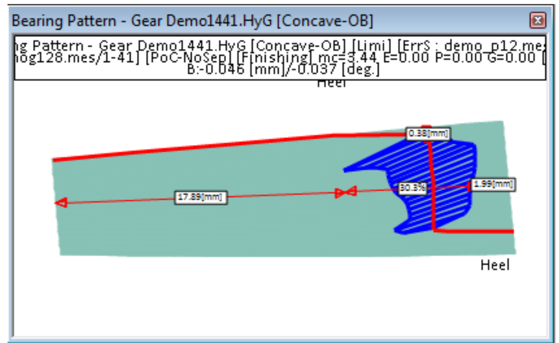
Error Surface

The two figures below show the resulting Contact Pattern on gear member measured tooth 1 when the Error Surface is based respectively on measured pinion tooth 1, and on measured pinion teeth 1 to 14. As the speed ratio of this gear set just below 3:1, any gear member tooth is likely to see the imprint of all the pinion teeth as the Contact Pattern test is made. The right figure should therefore be much closer to reality than the left figure, where only one pinion tooth was used to calculate the Error Surface.

The selected teeth used for the calculation of the Error Surface are chosen in the the Measurement Data Selection window, called using the "XYZ" function button.



Pinion tooth #1



Pinion teeth #1 to #14

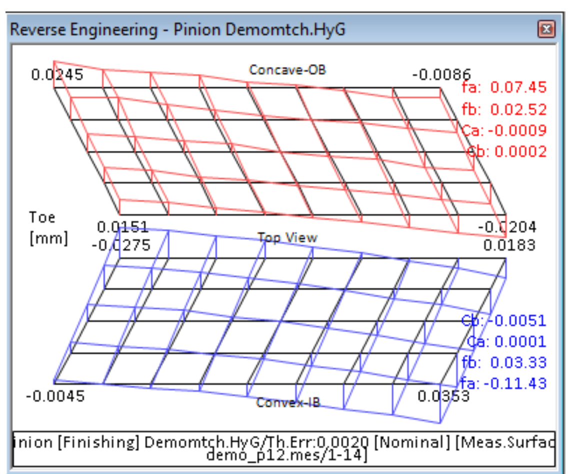
18.4 Reproducing a Master Gear or Pinion

Is is usual, in the development phase of a gear set, to obtain a pinion and gear which will be considered as the Masters for production control. The peculiarity of Masters is that they operate properly, with low noise and good Contact Patterns over the operating range.

Given the varying age and setup of the cutting machines from different production lines, it is also usual that pinions or gears produced in one production line operate differently from those from another production line.

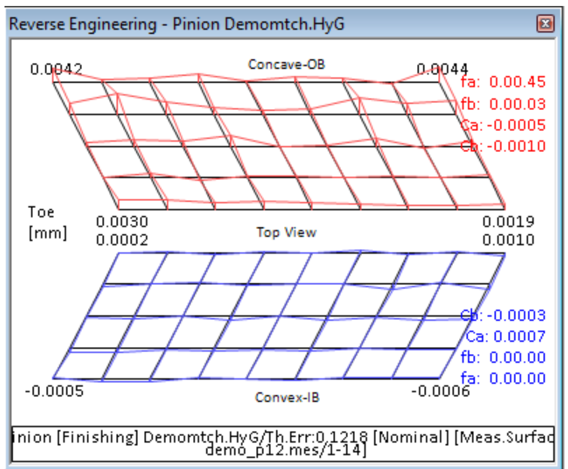
One difficulty is thus to ensure that different production lines are producing the same gears. The following example will show how to use some of the HyGEARS functions to find out the machine settings changes to match a pinion from one production line to that of another.

Suppose that pinion 1 is produced on line 1. When operated with a gear member, it is found to be very quiet and vibration free, and the Contact Pattern is good. The figure below shows the comparison between the theoretical and actual pinion tooth surfaces.



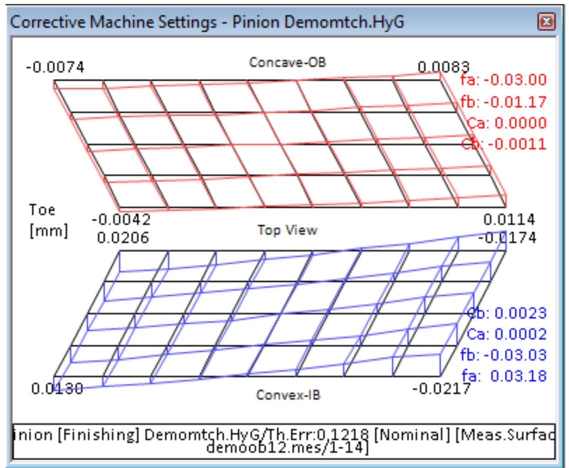
While the match between the theoretical and actual surfaces is not good, since pinion 1 is giving good performance, it will be used as a reference. The problem, then, is to find the machine settings of the theoretical surface matching that of the actual surface above, in order to be able to calculate Corrective Machine Settings (Closed Loop) for other pinions we want to match pinion 1.

We will create a Reverse Engineering Child Window, in which we will ask HyGEARS to match the theoretical surface (2nd order) to that of the actual surface given by the HyGEARS measurement data file “demo_p12.mes”, and save the new geometry under a different name, say “Demomtch.HyG”. The following result is obtained after Reverse Engineering, using the Cutter Point Diameter and Machine Center to Back as control parameters, where it is obvious that the theoretical surface is almost perfectly matched to that of the measured surface.

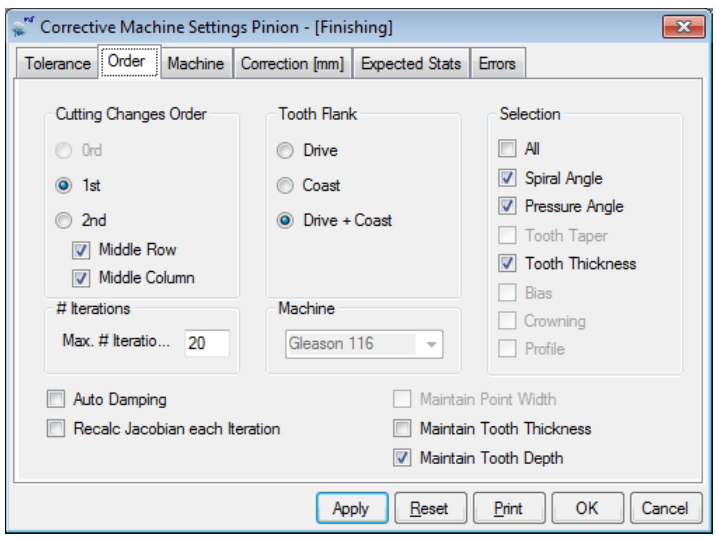


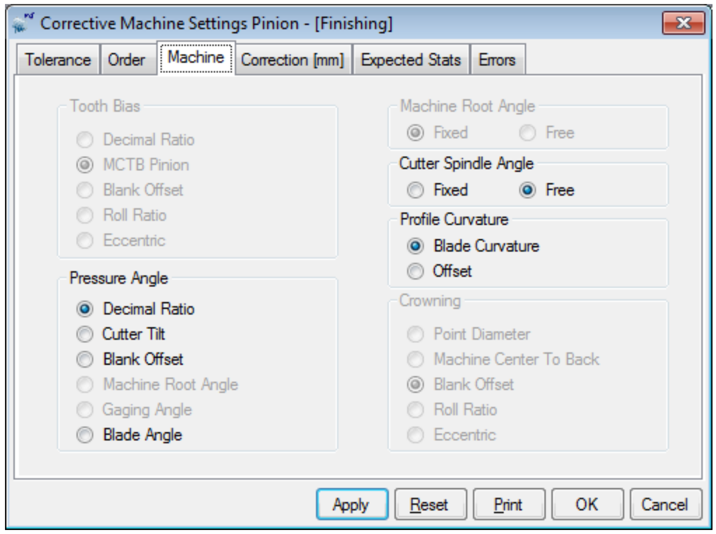
Note that the name of the data file is now “Demomtch.HyG”. To do so, the “File->Save As” pull down menu function was used, after which the Reverse Engineering Child Window was created.

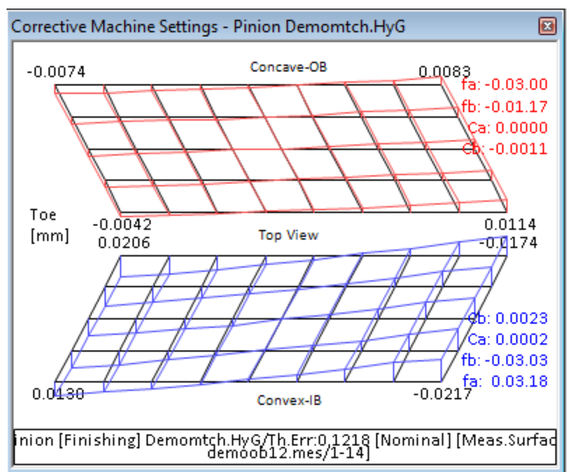
A Corrective Machine Settings (Closed Loop) Child Window will now be created, which will calculate the amount of machine setting correction needed to correct a pinion of production line 2, using the HyGEARS measurement data file “demoOb12.mes”, such that it matches the theoretical surface of the pinion “Demomtch.HyG”. Only 2nd order Correction will be used here.



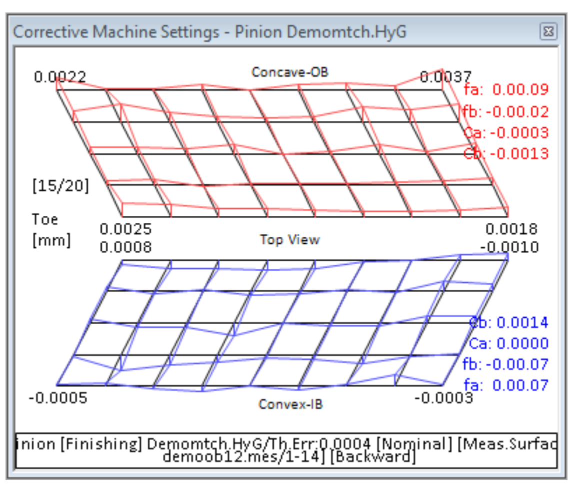
The first figure below shows the comparison between the pinion "Demomtch.HyG" and the measured pinion from production line 2 "demoOb12.mes". The second figure shows the expected surface comparison once the calculated Corrective Machine Settings (Closed Loop) have been applied.





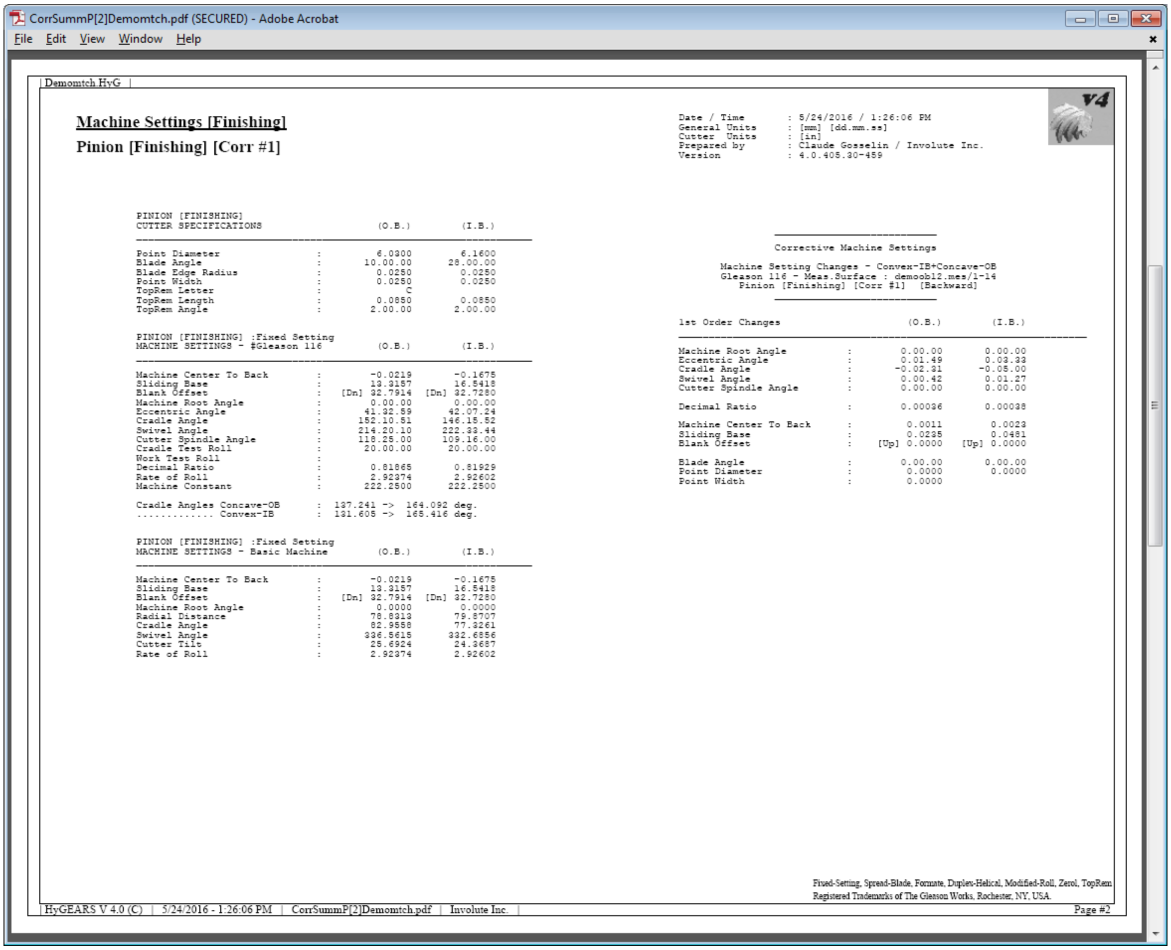


Pinion Tooth Error Surface Before Correction



Pinion Tooth Error Surface Expected After 1st Order Correction

The figures below are outputted when the Ok button is clicked. They show the amount of correction needed to bring pinion 2 in line with the theoretical surface, and the surface statistics before and expected after surface correction.



CorrSummP[2]Demomtch.pdf (SECURED) - Adobe Acrobat

File Edit View Window Help

Demomtch.HyG

Machine Settings [Finishing]

Pinion [Finishing] [Corr #1]

Date / Time : 5/24/2016 / 1:26:06 PM
General Units : [mm] [dd.mm.ss]
Cutter Units : [in]
Prepared by : Claude Gosselin / Involute Inc.
Version : 4.0.405.30-459

PINION [FINISHING] CUTTER SPECIFICATIONS		(O.B.)	(I.B.)
Point Diameter	:	6.0300	6.1600
Blade Angle	:	10.00.00	28.00.00
Blade Edge Radius	:	0.0250	0.0250
Point Width	:	0.0250	0.0250
TopRem Letter	:	C	
TopRem Length	:	0.0850	0.0850
TopRem Angle	:	2.00.00	2.00.00

PINION [FINISHING] :Fixed Setting MACHINE SETTINGS - #Gleason 116		(O.B.)	(I.B.)
Machine Center To Back	:	-0.0219	-0.1675
Sliding Base	:	13.3157	16.5418
Blank Offset	:	[Dn] 32.7914	[Dn] 32.7280
Machine Root Angle	:	0.00.00	0.00.00
Eccentric Angle	:	41.32.59	42.07.24
Cradle Angle	:	152.10.51	146.15.52
Swivel Angle	:	214.20.10	222.33.44
Cutter Spindle Angle	:	118.25.00	109.16.00
Cradle Test Roll	:	20.00.00	20.00.00
Work Test Roll	:		
Decimal Ratio	:	0.81865	0.81929
Rate of Roll	:	2.92374	2.92602
Machine Constant	:	222.2500	222.2500

Cradle Angles Concave-OB : 137.241 -> 164.092 deg.
.... Convex-IB : 131.605 -> 165.416 deg.

PINION [FINISHING] :Fixed Setting MACHINE SETTINGS - Basic Machine		(O.B.)	(I.B.)
Machine Center To Back	:	-0.0219	-0.1675
Sliding Base	:	13.3157	16.5418
Blank Offset	:	[Dn] 32.7914	[Dn] 32.7280
Machine Root Angle	:	0.0000	0.0000
Radial Distance	:	78.8313	79.8707
Cradle Angle	:	82.9558	77.3261
Swivel Angle	:	336.5615	332.6856
Cutter Tilt	:	25.6924	24.3687
Rate of Roll	:	2.92374	2.92602

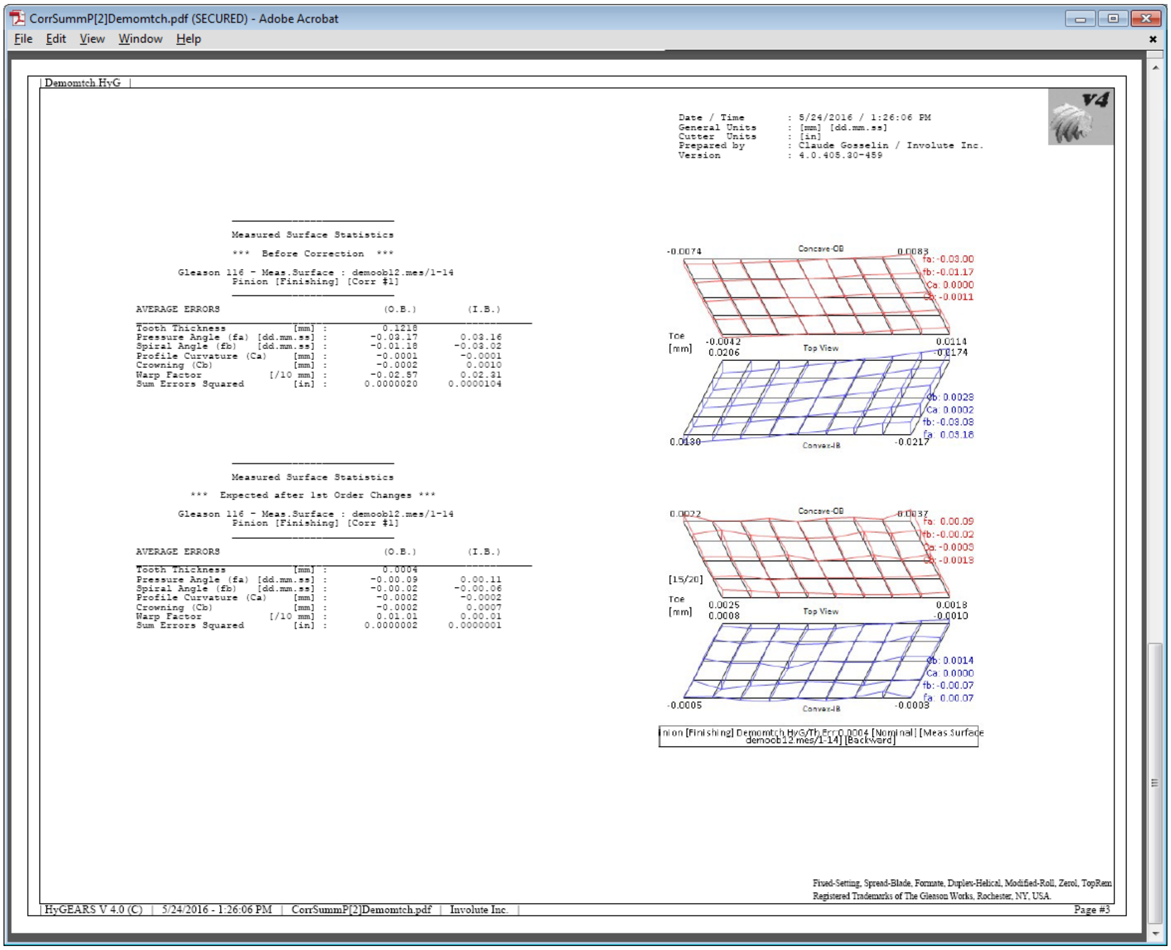
Corrective Machine Settings

Machine Setting Changes - Convex-IB+Concave-OB
Gleason 116 - Meas.Surface : demoob12.mes/1-14
Pinion [Finishing] [Corr #1] [Backward]

1st Order Changes		(O.B.)	(I.B.)
Machine Root Angle	:	0.00.00	0.00.00
Eccentric Angle	:	0.01.49	0.03.33
Cradle Angle	:	-0.02.31	-0.05.00
Swivel Angle	:	0.00.42	0.01.27
Cutter Spindle Angle	:	0.00.00	0.00.00
Decimal Ratio	:	0.00036	0.00038
Machine Center To Back	:	0.0011	0.0023
Sliding Base	:	0.0235	0.0481
Blank Offset	:	[Up] 0.0000	[Up] 0.0000
Blade Angle	:	0.00.00	0.00.00
Point Diameter	:	0.0000	0.0000
Point Width	:	0.0000	

Fixed-Setting, Spread-Blade, Formate, Duplex-Helical, Modified-Roll, Zerol, TopRem Registered Trademarks of The Gleason Works, Rochester, NY, USA.

HyGEARS V 4.0 (C) | 5/24/2016 - 1:26:06 PM | CorrSummP[2]Demomtch.pdf | Involute Inc. | Page #2



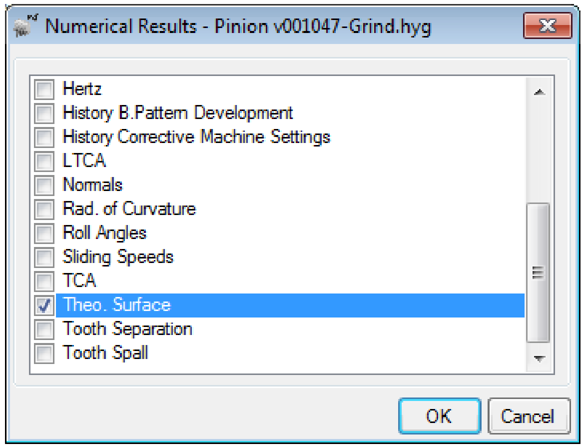
18.5 Creating a Theoretical Measurement Data File

HyGEARS offers many ways to analyze surface data. One such way is to create a theoretical surface data file, or nominal data file, and use this data to see how evenly material will be removed when finishing the pinion.

To achieve this, we use the HyGEARS function "Theo. Surface" from the *Misc. -> Numerical Output* in the menu of the Parent Window. The following sequence is used:

- make sure the desired geometry data file is loaded in memory ;
- also make sure the geometry is in Finishing mode, when displayed in the currently active Child Window;
- call the *Misc.->Numerical Output* function from the menu of the Parent Window, and make sure the selected geometry is "Pinion";

- from the List, select the “Theo. Surface” entry by clicking on it, which will then be selected;



- click on the OK button, and a Text Results window will appear, containing the nominal data for the finished pinion; the contents should look similar to the following:

```
***HYGEARS MEASUREMENT DATA***
1000
; PINION
; CMM  : THEO Finishing
; #Meas: 1
; Date : 06/09/2011 8:59:44 AM
; By   : Claude Gosselin/Involute Simulation Softwares Inc.

; Files: 11x45b.dat
; Units: [mm]
; MDist: 137.0000[mm]
; DelZ :
; Pnts :
; UNUSD:
;
   1,    1,    5,    6,   10,   10,    9,    9
    11.05182,     25.08467,     83.01960
    12.59518,     25.98014,     83.01949
    14.42174,     26.68499,     83.01952
    16.47096,     27.19414,     83.01959
    18.71163,     27.48998,     83.01938
    17.22828,     23.39933,     89.62286
    19.21687,     23.97998,     89.62286
    21.47603,     24.26276,     89.62286
    23.93790,     24.24969,     89.62283
    26.56002,     23.92487,     89.62289
    ....
```

- next, save the contents of the Text Results window to a nominal measurement data file by clicking on the *File->Save* function from the Text Results window menu;

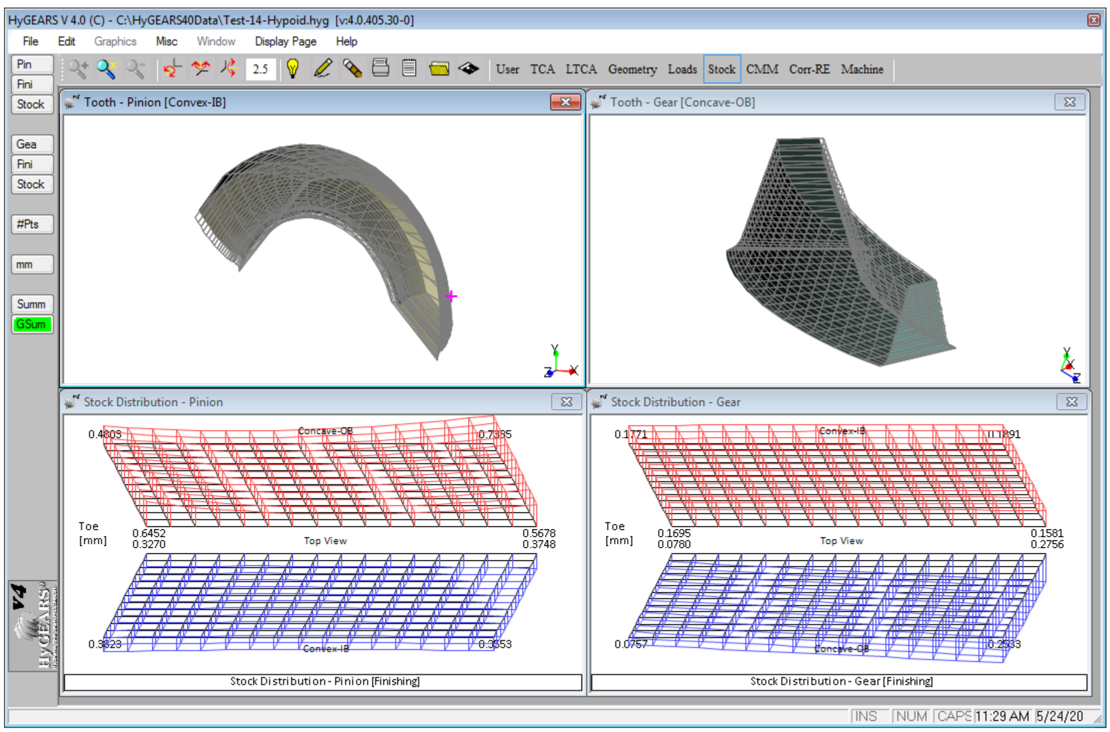
- HyGEARS will then request the name of the file to which the data should be saved, and will provide the path of the current geometry by default; simply enter a file name at the end of the suggested path, and click on the OK button;

- HyGEARS will then confirm the Save operation.

18.6 Checking and Improving the Roughing Machine Settings

HyGEARS offers automated functions to display and, if needed, improve the Roughing machine settings.

To display the Stock Distribution, which reveals the distribution of material that will be removed between the Roughing and Finishing cuts, click on the “Stock” entry in the menu bar. The following display should appear.

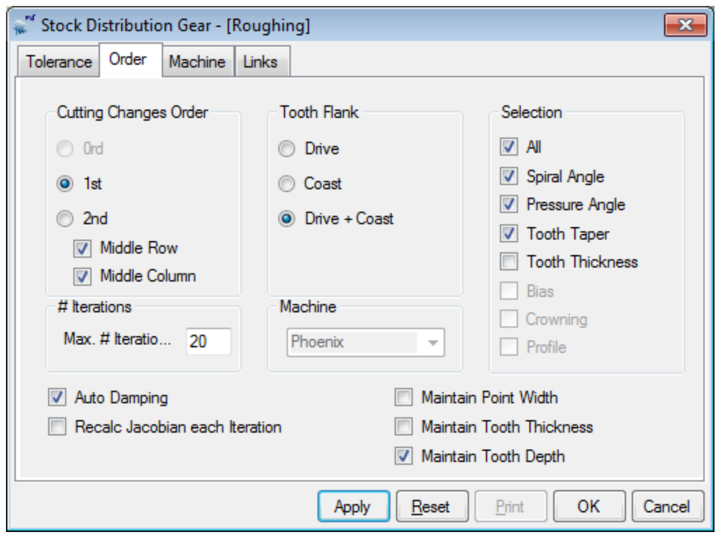


What this display shows is:

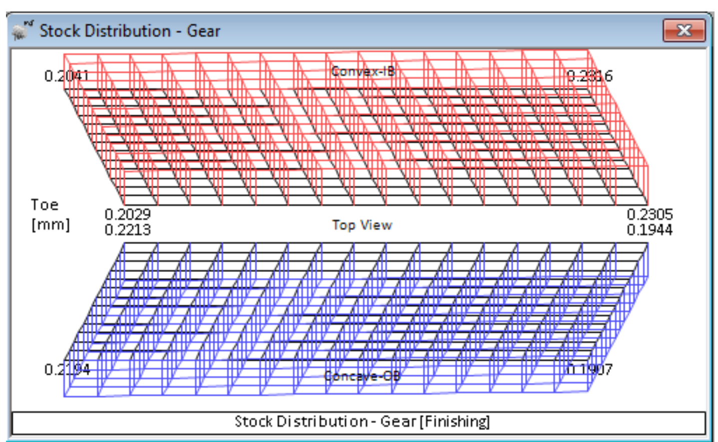
- In the upper left Child Window, the Roughed Pinion tooth is displayed as wireframe grey lines over the Finished tooth in solid model;
- In the upper right Child Window, the Roughed Gear tooth is displayed as wireframe grey lines over the Finished tooth in solid model;
- In the lower left Child Window, the Pinion stock distribution between Roughing and Finishing is displayed; the Rough tooth is in colors, whereas the Finish tooth is in black lines; Stock Distribution shows positive material removal over most of the tooth; it is fairly even on both flanks;

- In the lower right Child Window, the Gear stock distribution between Roughing and Finishing is displayed; the Rough tooth is in colors, whereas the Finish tooth is in black lines; Stock Distribution shows positive material removal over all the tooth; it is evenly distributed over the Convex-IB flank, but shows spiral angle error on the Concave-OB flank.

To improve on the Stock Distribution, say on the gear, click on the “Stock” function button of the Gear group. You will be presented with the following input window, which in fact is the same as that for Corrective Machine Settings (Closed Loop) and Reverse Engineering:



With the above choice, the result below is obtained. It is clear that Stock is distributed more evenly over the tooth flanks, which should result in better surface finish and longer tool life.

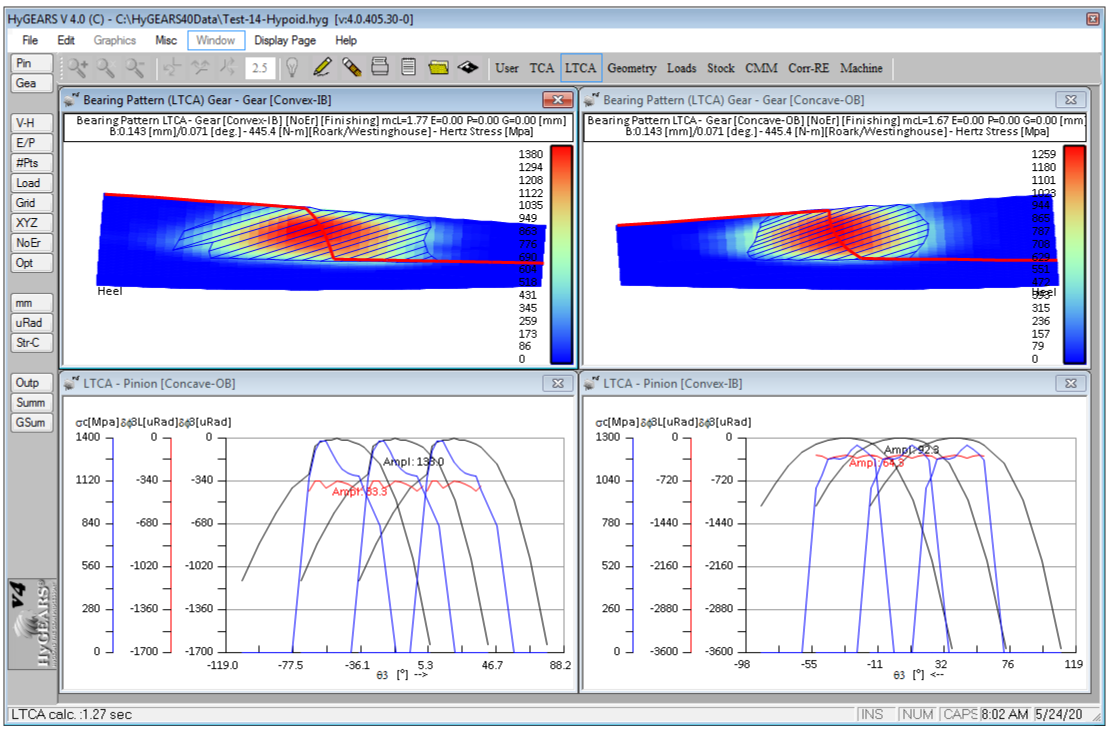


After these changes, the geometry should be saved to disk if the results are satisfactory.

18.7 A Look at the Bearing Pattern under Load

The operations performed before led to the design of a gear set with adequate Contact Pattern when operated without load. We will now look at the shape of the gear I.B. and O.B. Contact Patterns under full load, and the corresponding Transmission Error curves.

The figures below respectively show the gear I.B. and O.B. Contact Patterns and T.E. curves when the full torque is applied to the gear set. In the following, the Westinghouse formula is used as the Stiffness model.



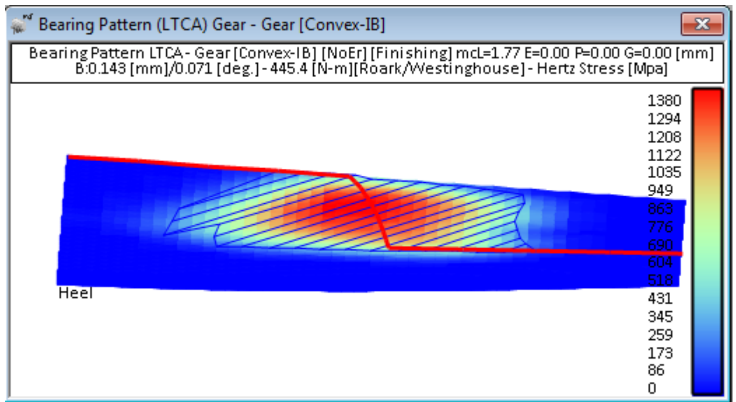
What the Transmission Error curves reveal is:

- the Transmission Error curve under full load, δφ3L, is above the contact entry unloaded Transmission Error (δφ3) level for the pinion Concave-OB and Convex-IB tooth flanks, which means that contact will not occur in that area of the tooth; should df3L be below the contact entry unloaded Transmission Error (δφ3) level, loaded contact would likely occur in that area of the tooth;

- the right graph also shows that Transmission Error under load for the gear O.B. tooth flank is slightly larger than that of the I.B., which may result in a noisier gear set. However, while the above considerations are indicative of trends in a gear set, any conclusion drawn from this should be supported by actual measurements, as there are many more variables in gear noise and dynamics than the sole Transmission Error curve under load.

We will now use some HyGEARS' advanced analysis and display functions to look in more details at what is happening in the Contact Pattern under load. For this section, only the Drive side will be considered (Pinion O.B., Gear I.B.).

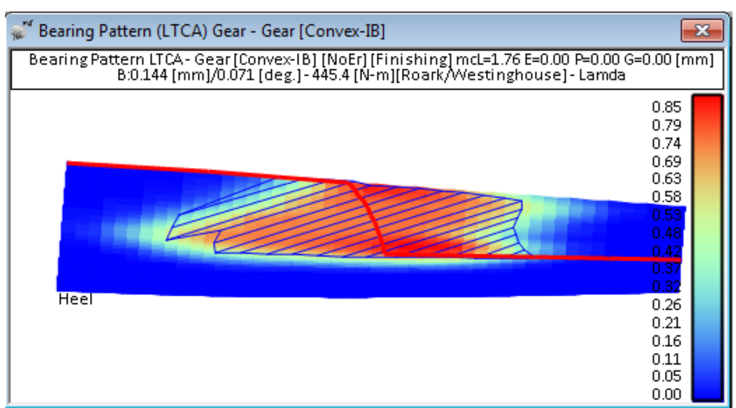
Make sure the current tooth flank is the Gear (Convex-IB) by clicking on the Child Window.



What this shows is that the maximum contact stress is located in the center of the Contact Pattern. At around 1.4 GPa, the maximum contact stress is very acceptable; but one must keep in mind that in the LTCA, load sharing is calculated without application factors.

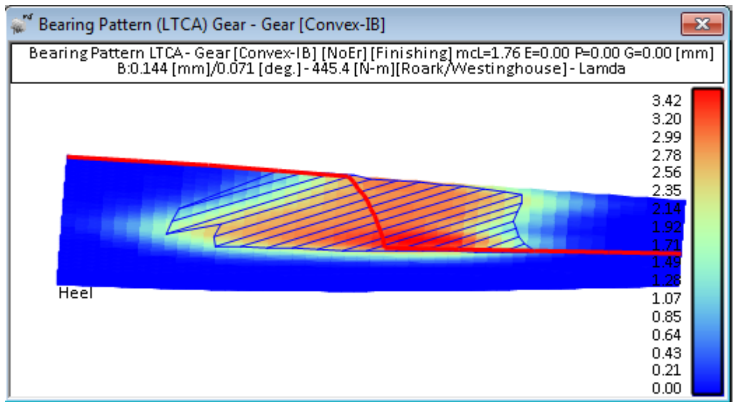
A click on the "Opt" function button shows the available LTCA results; select "Results -> Lamda".

The Lamda value is the ratio of the minimum oil film thickness to the surface roughness, calculated using the current geometry, loads, temperature, etc. To keep a margin of safety, Lamda should not be allowed to drop below 1.



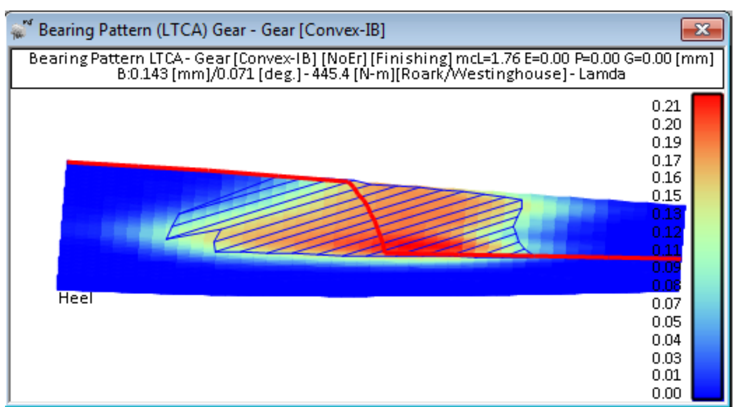
In the above figure, Lambda is on average, in the center part of the tooth, around 0.85, which is insufficient. Here oil type is ISO 220, which *is not an EP* oil used for Hypoid gears; if the details of a particular oil are known, they can be entered in the "Oil.fil" file contained in the installation directory of HyGEARS; this is a text file that contains instructions on how the oil characteristics are given, and that can be modified by the user. Temperature is 40 C and surface roughness is 0.81 mm.

In the Pinion or Gear Summary editor, Operating data page, the oil type can be changed to 75W 140; when doing so, the oil film thickness is recalculated, and now display a healthier Lamda value of 3.42.



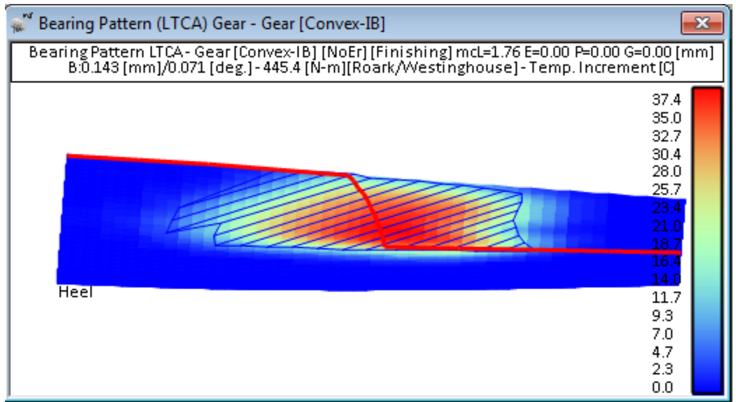
If surface roughness can be decreased, or if the oil used can be increased to a higher viscosity, the Lamda ratio should improve.

Let us see what happens if the oil is changed from 75W 140 (figure above) to ISO 150 and its temperature is raised from 40 C to 80 C (figure below).



Obviously, the new Lamda value (0.21) is unacceptable, and the oil grade should be improved, if the oil temperature cannot be lowered.

Let us now look at the oil temperature rise, or Flash Temperature, during mesh. Returning to the “Opt” function, we now choose “Results -> Temp. Increment” from the proposed list of results.



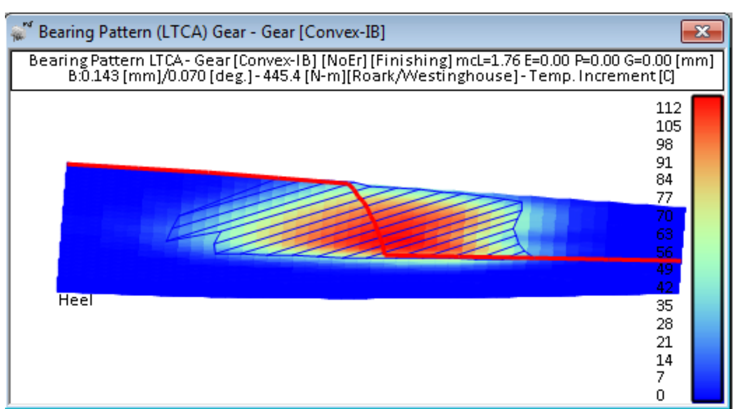
In Hypoid gear, sliding is highest at the root of the gear tooth, thus at pinion tip. Because of sliding action, and because of friction in the oil and on the gear tooth surfaces, work is lost which is converted in heat.

Blok and several other researchers developed a formulation to quantify the increase in temperature during mesh. In the figure above, the increase in temperature is highest where sliding is highest.

While the calculated values should not be taken at face value, they nevertheless indicate trends in behavior.

In the figure above, the coefficient of friction is left at its default value of 0,02 (Geometry Summary Editor, Operating data page). In the figure below, it has been raised to 0.06, a not uncommon value according to AGMA and many specialists.

Although temperature increment seems low in the above figure (37.4 C), it is much larger in the next figure (112 C) and may lead surface problems, although its value is still within acceptable limits according to Dudley (see the Lubrication chapter in Dudley's Gear Handbook, 2nd Edition).



> **Note :** Many of the tools provided in HyGEARS should not be considered as a definite answer to a given strength or reliability problem, but rather as a guide as to what may be happening.
>
> Recognized formulations have been used to develop these tools but, as usual, these should be used in perspective to one's own experience and knowledge.

18.8 Using the Finite Strips to Assess Tooth Strength

HyGEARS incorporates the *Finite Strips Model* as an optional advanced analytical technique, similar to the FEA if only much faster and solved within HyGEARS.

We will use the Finite Strips to look at the bending stresses in the pinion tooth as it goes through mesh.

Therefore, first click on *User Mode*; then call the *Graphics->Meshing->Finite Strips* sequence from the Graphics menu to create a Finite Strips Child Window. Make sure to *select the Gear*.

Using the "Opt" function button, make sure the Loading and Contact Pattern options are checked.

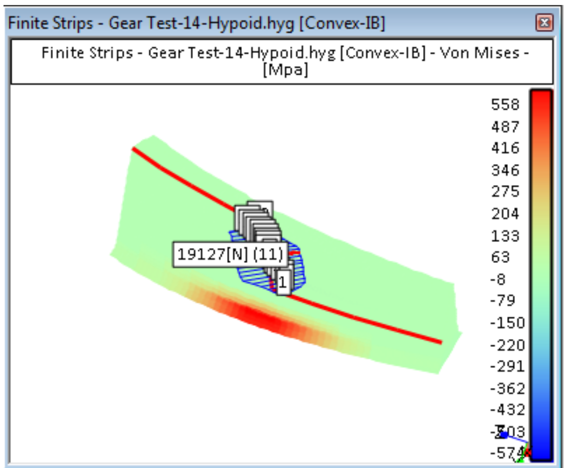
Next, clicking on the "Mesh" function button loads the Finite Strips mesh Editor. Enter the following values:

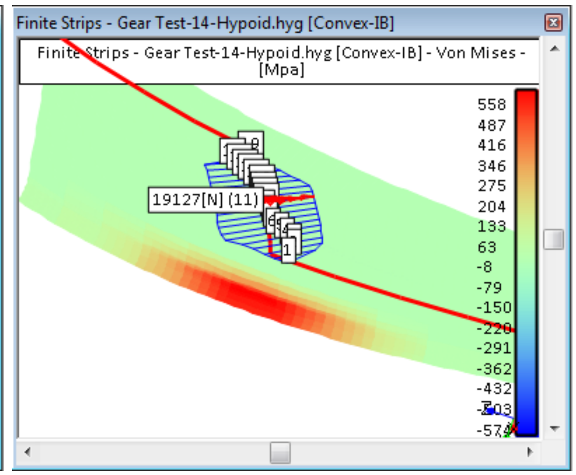
Meshing Data Page:	# Elem. Axial	11
	# Elem Profile	7
	# Elem Fillet	4
Finite Strips Data Page:	# Finite Strips	11
	# Nodes	5
	Load Type	BP Elliptic
	# Loads	11
	Load Case	11

The # Finite Strips really is the resolution of the numerical solution, while the # Elem. Axial is the resolution at which we will look at the results (the tooth itself) and they need not be the same.

The Load Type should normally be BP Elliptic for Spiral Bevel and Hypoid gears. The # Loads specifies in how many individual load vectors the instant line of contact will be broken. And the Load Case specifies which instant line of contact on the Contact Pattern is being considered.

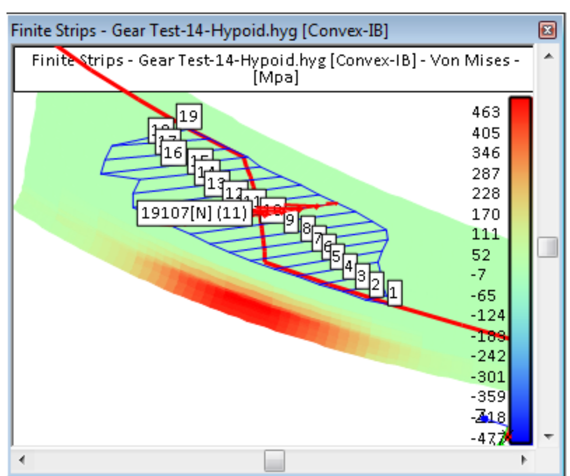
The left figure below should be obtained. Zooming-in gives the right figure and shows how the loads are distributed over the instant line of contact.



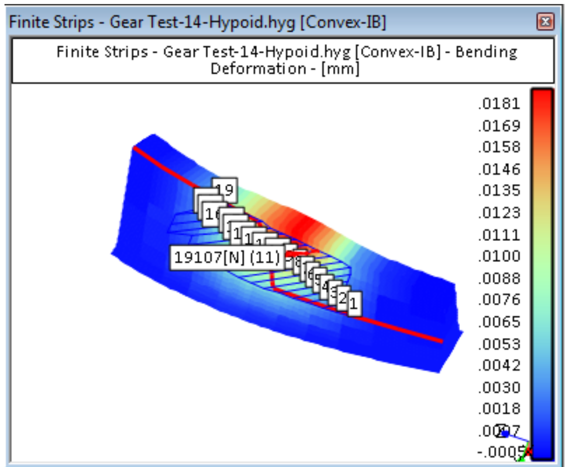


Note :	The applied loads are normally displayed with their values. To improve on the legibility of the display, toggle the "Dims" function button to "NoDi", which will remove the Child window load values.

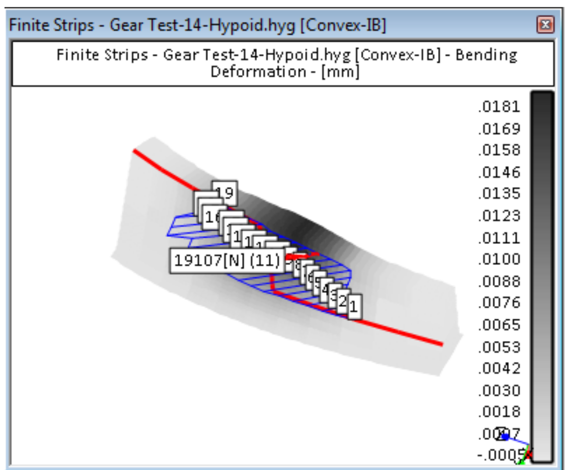
Clicking on the "NoLt" toggles HyGEARS into using the loads calculated from the LTCA at each instant line of contact of the Contact Pattern. As the "NoLt" function button is toggled into "Ltca" and back, the Contact Pattern changes from its unloaded state to that calculated using the LTCA.



By default, the Finite Strips are displayed in Von Mises tooth root stress values; clicking on the “Opt” function button, and selecting “Results -> Deformation” shows the figure below, where tooth deformation and a Color Scale are displayed.

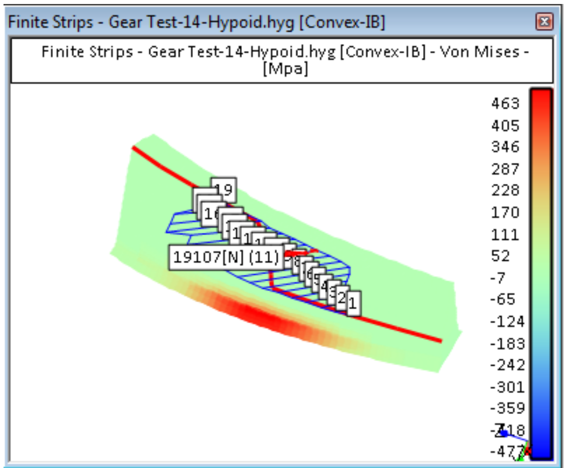


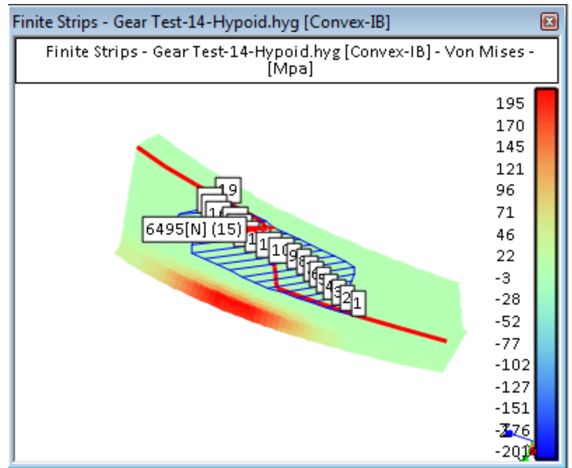
The “Opt” function button offers a display in Grey Scale, which is shown below.



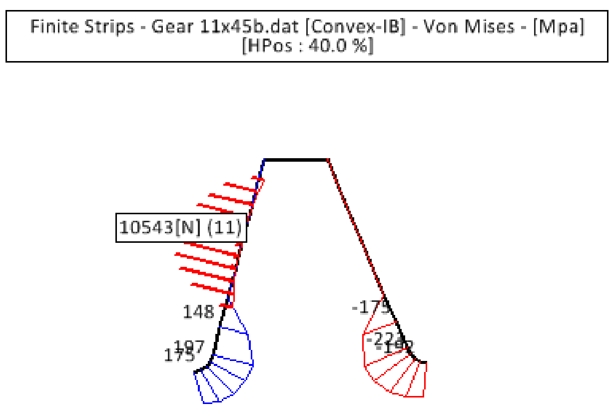
From the “Opt” function button, selecting “Results -. Von Mises” from the proposed results yieds the stress distribution in the tooth. The “+/-“ function key allows to step through the mesh and look for the worst stress case.

The left figures below shows load position at mid-tooth height; where bending stress is on the high side; using the +/- function button, one can move the load above or below this center position to realize that bending stresses diminish; this indicates that the highest bending stress will be at mid-tooth height, a normal behavior.





The next figure shows the tooth section, accessed using the “Sect” function button, that reveals the stress distribution within the tooth at the selected position on the gear tooth flank (HPos: 40.0%), obtained using the HPos function button.



> **Note :** The displayed stresses are indicative. Extensive calibration has been done on the Finite Strips but, as a numerical method, it has its limits and depends on user choices.

18.9 Using Reverse Engineering to Change Cutter Dimensions

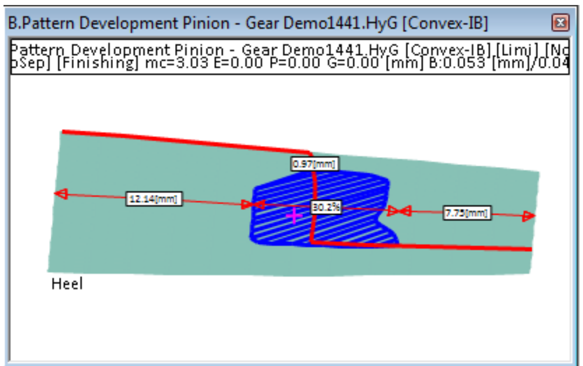
In large production environments, cutter dimensions may be quite varied, which adds cost in terms of inventory overhead and maintenance. Using the Surface Match algorithm., it is possible to reduce the number of cutters if the dimensions are not too different.

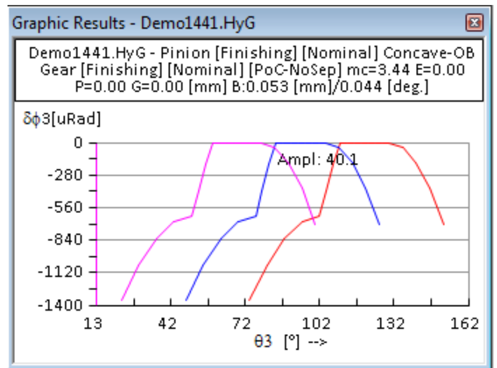
In this section, we will look how, when the cutter diameter and blade angles are changed, HyGEARS can "find" machine settings producing technologically equivalent tooth surfaces. Of course, since we will be using 2nd+ Surface Match, this applies only to Fixed Setting and Modified Roll pinions.

Change in Cutter Diameter

The first test will be to change cutter diameter and see what happens to the Contact Pattern and Transmission Error curve.

Let us use geometry Demo1441.HyG. The Contact Pattern and Transmission Error curve are the following:

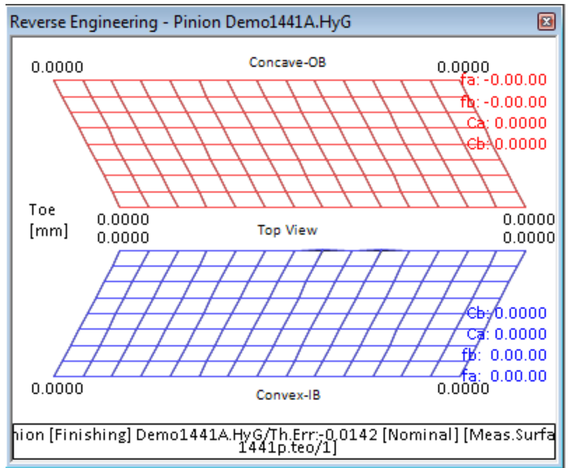




Let us now create a theoretical tooth surface of the pinion (Misc.->Numerical Results; refer to the section "Creating a theoretical Measurement Data File" above), which will be sent to a Text Results window, and call it "1441p.teo" when saving it to disk (File->Save).

Let us also save the current geometry file under a new name, say "Demo1441A.HyG", as we will modify it significantly and we do not want to lose the definition of "Demo1441.HyG".

If we now create a Reverse Engineering Child Window for the pinion using "Demo1441A.HyG" and giving "1441p.teo" as the Measurement data file, we obtain the following:

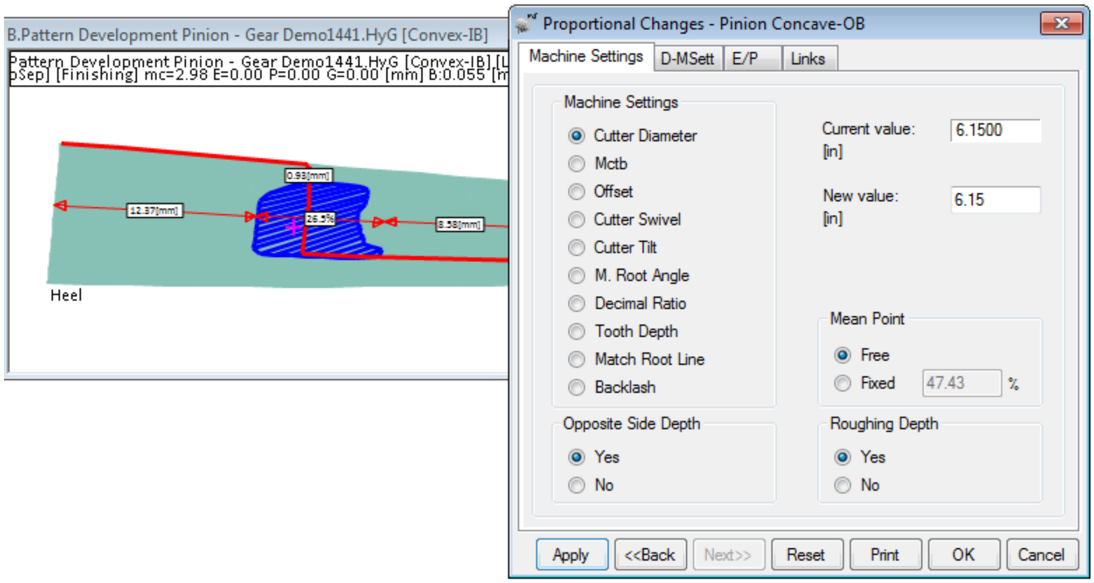


The Pinion O.B. Cutter Diameter is 6.0300 [in]. Suppose that a cutter with a diameter of 6.1500 [in] is available in stock. Is it possible to find a combination of machine settings that will produce a surface equivalent to the one presented above, and with the kinematic characteristics depicted at the beginning of this section ?

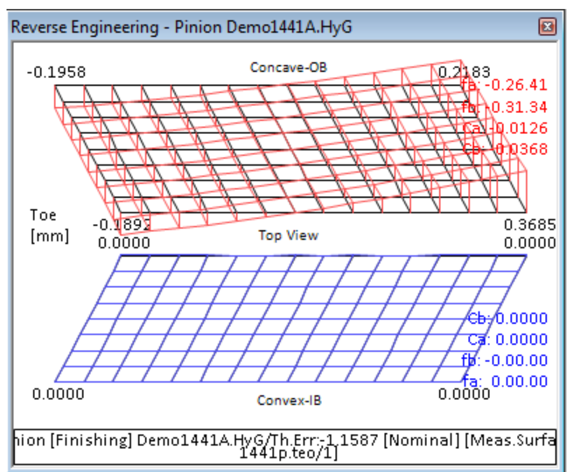
Let us try with the *HyGEARS Reverse Engineering* algorithm ! To do this, the following steps must be done:

Create a Contact Pattern Development Child Window, for the Gear I.B. – Pinion O.B. tooth flank, from which the Cutter Diameter will be changed with proportional changes (“Sett” Function button).

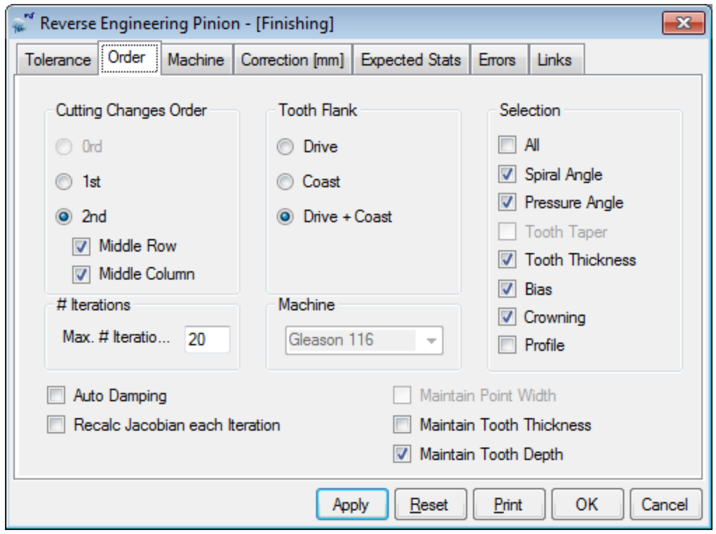
Click on the “Sett” Function button, select the “Cutter Diameter” option, make sure the “Mean Point” option is “Free”, enter the new value for the Cutter Diameter, e.g. 6.1500 [in] and click on the “Apply” button. HyGEARS will calculate the proportional changes and provide a result like the following:

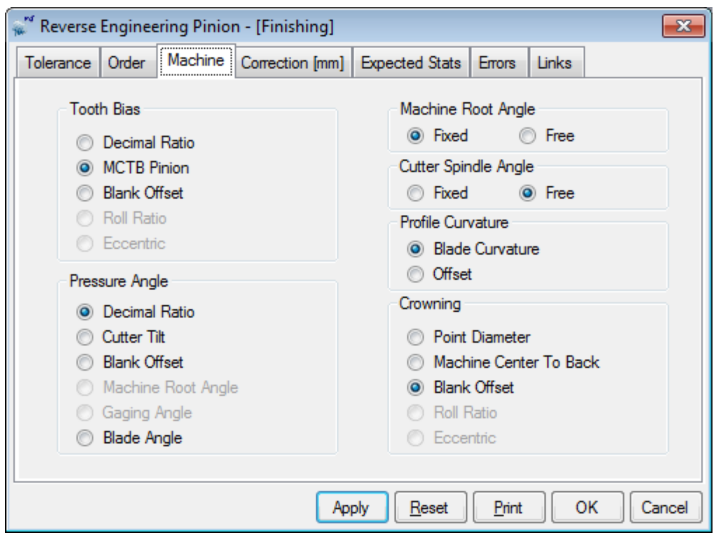


Let us now use the Reverse Engineering window, for the Pinion O.B. tooth flank in 2nd order mode. Before initiating Reverse Engineering, the display should be similar to the following. If not, a Redraw is necessary, which is done by clicking on the redraw Icon of the Tool bar.

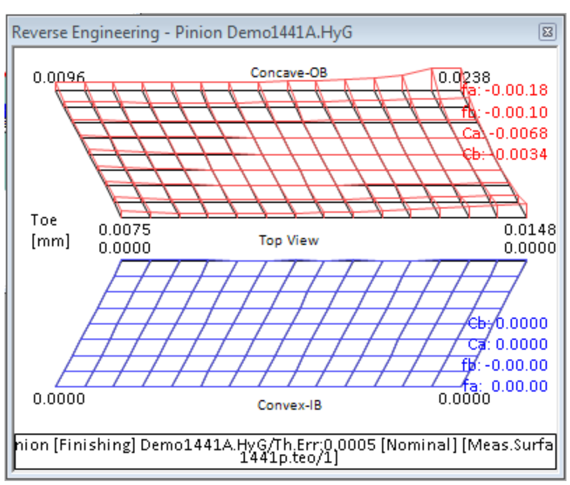


We will now start the Reverse Engineering algorithm with the following constraints:



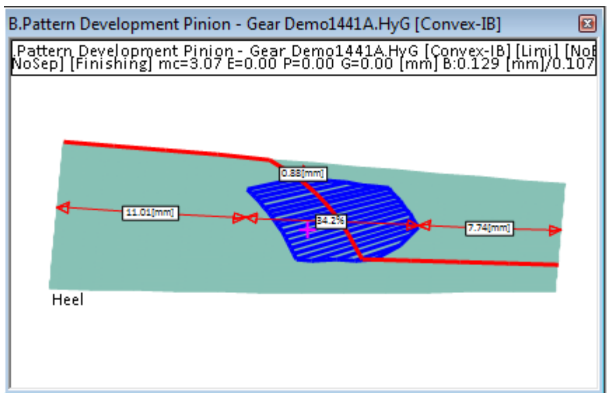


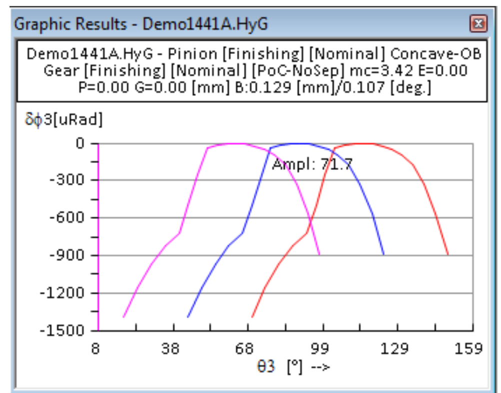
After clicking on the “Apply” button to start the algorithm, the following result should be obtained:



Clearly, the Reverse Engineered surface, in black lines, is almost identical to the target surface, in red dotted lines.

A look at the Contact Pattern and Transmission Error curve (2D Graph), figures below, confirms that the resulting kinematics are almost identical to the original, shown at the beginning of this section.

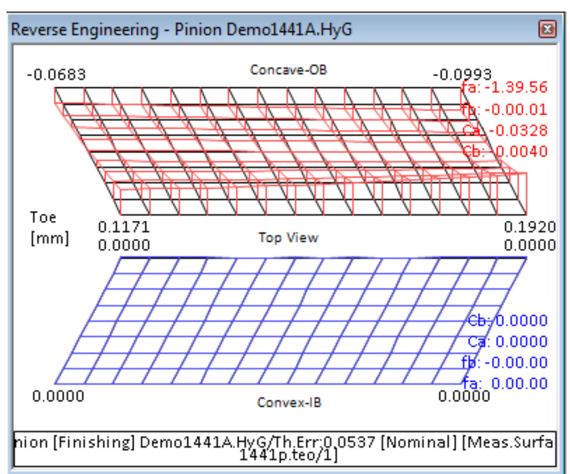




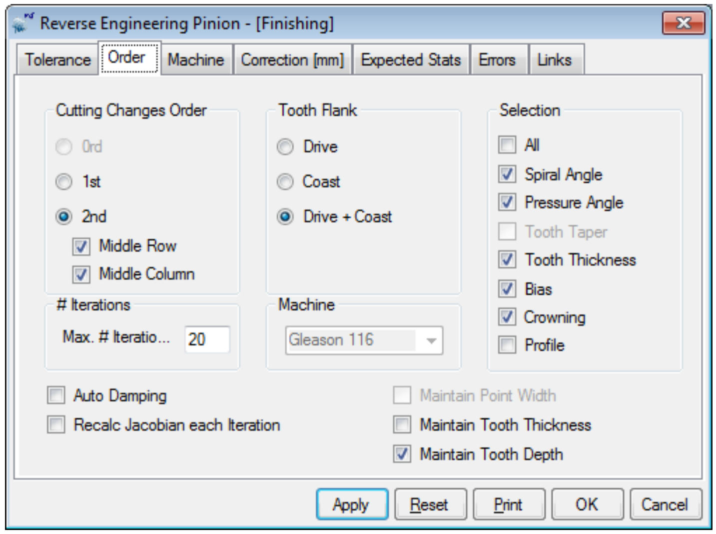
Change in Cutter Blade Angle

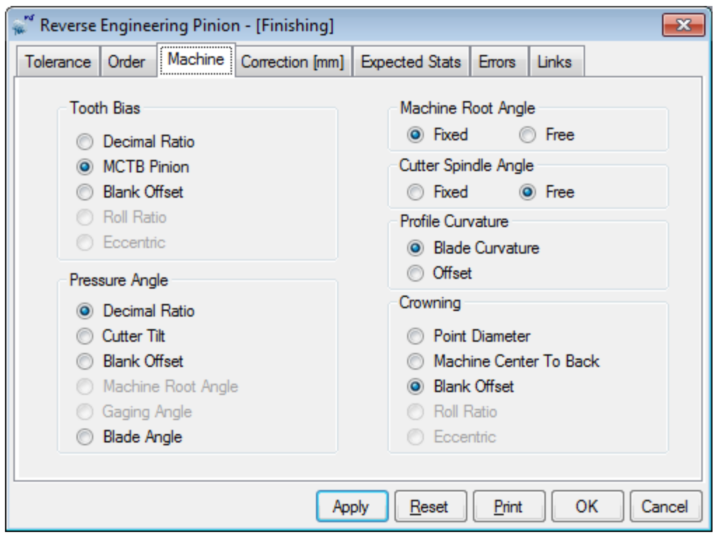
The second test will be to change cutter blade angle and see what happens to the Contact Pattern and Transmission Error curve.

Let us use geometry Demo1441A.HyG, the one used above. Using the Geometry Summary editor, we will change the Pinion O.B. Cutter Blade Angle from 10.00.00 to 12.00.00, and obtain the following surface:

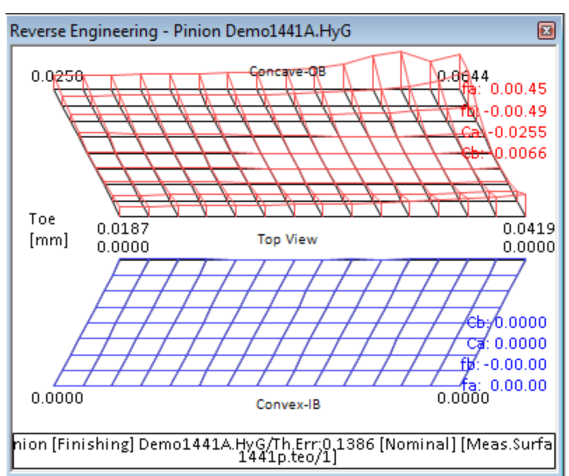


We will now start Reverse Engineering algorithm with the following constraints:



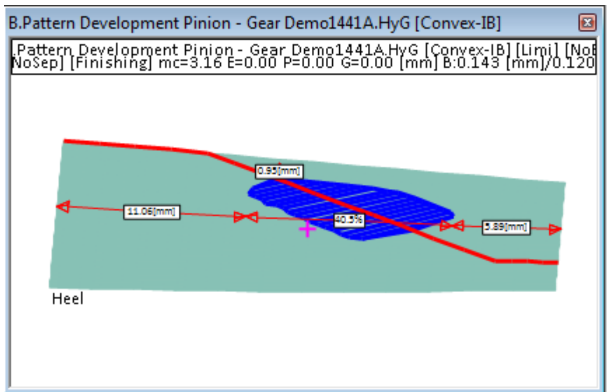


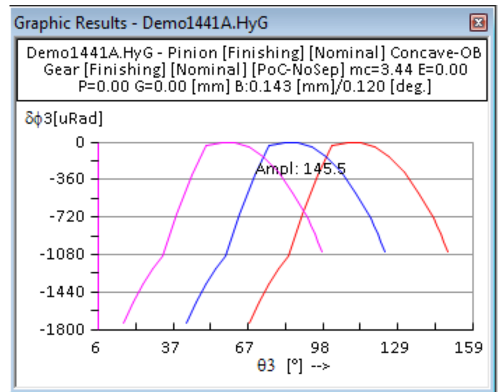
After clicking on the "Apply" button to start the algorithm, the following result should be obtained:



Clearly, the Matched surface, in black lines, again is very similar to the target surface, in red dotted lines, although some deviations in profile curvature has been introduced.

A look at the Contact Pattern and Transmission Error curve (2D Graph), figures below, confirms that the resulting kinematics are very similar to the original, shown before.





Conclusion

One of the many uses of Reverse Engineering is the capability to change cutter dimensions in order to use existing equipment for new designs, or to reduce the number of cutter diameter - blade angle combinations, which may result in reduced costs and maintenance overhead.

18.10 New Fixed Setting Hypoid Gear Set

As an example, we will consider the following requirements for the design of a new Hypoid gear set.

Gear tooth type:	Formate (no Helixform machine available)
Pinion tooth type:	Generated, Fixed Setting
Offset:	38 mm (1,500 in) below center
Pinion Tooth Hand:	Left
Gear Face Width:	30% of outer cone distance
Speed ratio:	Approximately 4:1
Pinion Speed:	1200 RPM
Available diameter space:	About 280 mm (11 in)
Power:	70 kW (93.5 HP)
Application:	Automotive

Preliminary Dimensions

From the considerations of minimum pinion tooth number, available gear diameter space, and non-exact speed ratio, the following combinations may prove usable:

Diametral Pitch [in^{-1}]	Module [mm]	N_p	N_G	m_g
4.3066	5.8979	12	49	4.083
4.0821	6.2222	11	45	4.091
3.7192	**6.8293**	**10**	**41**	**4.100**

The selected values here are a 3.7192 diametral pitch (6.8293 module), with a 10 tooth pinion and a 41 tooth gear, for a speed ratio of 4.1. These values respect the gear diameter space condition.

Using HyGEARS to Obtain an Initial Geometry

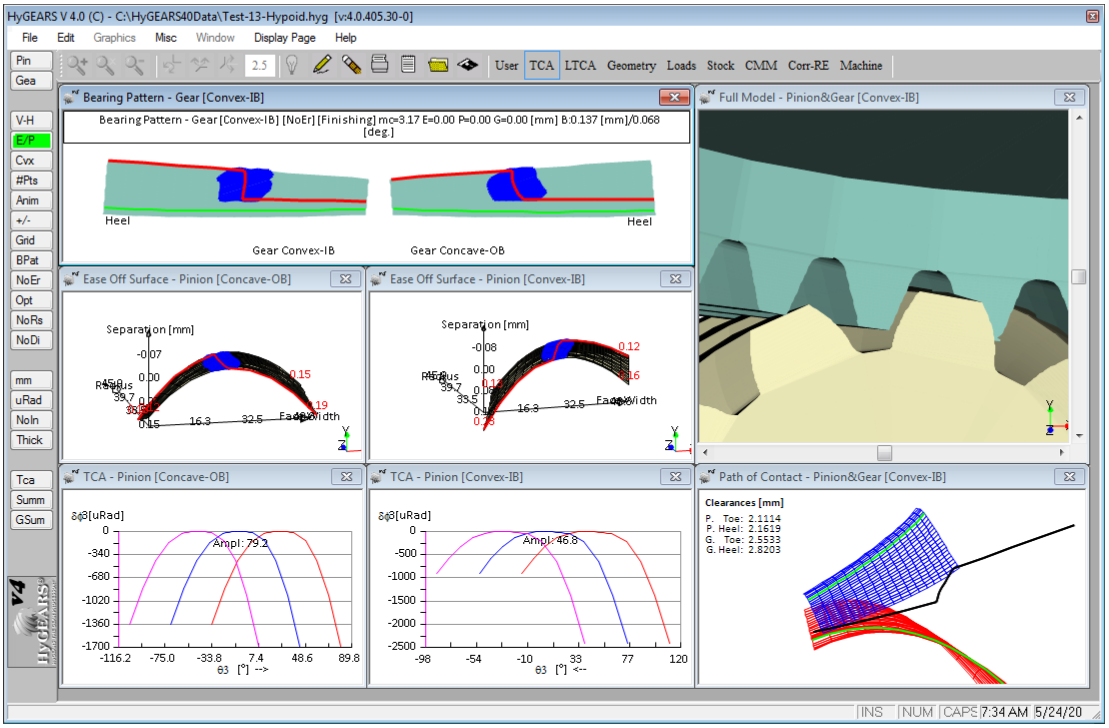
The next step involves using the computer and HyGEARS to create the initial Geometry. Since the gear set to design is not constrained by considerations other than to use standard cutting equipment, we will leave HyGEARS do the work of selecting cutter diameters and blade angles on the first run of the New Geometry Definition, and then rerun the New Geometry Definition function using standard values closest to the values suggested by HyGEARS.

Therefore, the following data will be entered in each New Geometry Definition data page:

General Data Section:		
Geometry Name:	Let HyGEARS provide	
Directory:	Let HyGEARS provide	
Geometry Type:	Hypoid	
Tooth Taper:	Standard	
Material:	4140	
Tooth Hand:	Left	
Tooth Number:	10	41
Tooth Module:	6.8293 [mm]	(25.4 / P, where P = 3.7192)
Tooth Face width:	0	Let HyGEARS calculate.
Shaft Angle:	90.00.00	
Depth Factor	0	Let HyGEARS decide
Addendum Factor	0	Let HyGEARS decide
Clearance Factor	0.0325	
Offset:	38.0 [mm]	
Power:	70 kW	
Speed:	1500 RPM	
Cutter Data Section:		
	Pinion	**Gear**
Machine	Phoenix	Phoenix (based on the selected process below)
Spiral Angle:	50°	
Sum Pressure Angles:	40° (automotive, light duty)	
Stock Allowance:	0.015 [in]	0.015 [in]
Cutter Diameter:	0	Let HyGEARS calculate
Blade Angle:	0	Let HyGEARS calculate
Blade Edge Rad.:	0	Let HyGEARS calculate
Point Width:	0	Let HyGEARS calculate
Mounting Distance:	0	Let HyGEARS calculate
Process:	Fixed Setting	Non Generated

Analysis of the Initial Geometry

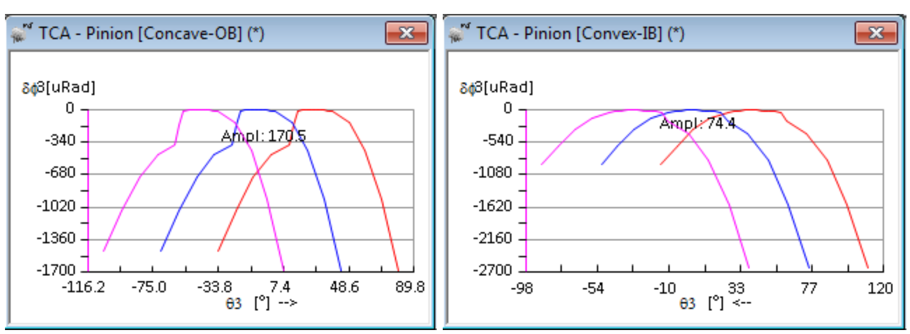
The following paragraphs will comment the initial geometry calculated by HyGEARS, and suggest improvements to be made. The initial Contact Patterns appear as follows, respectively for the Gear Convex-IB and Concave-OB tooth flanks. Both Contact Patterns are well centered, cover ~25% of the tooth flank, and are reasonably bias free.



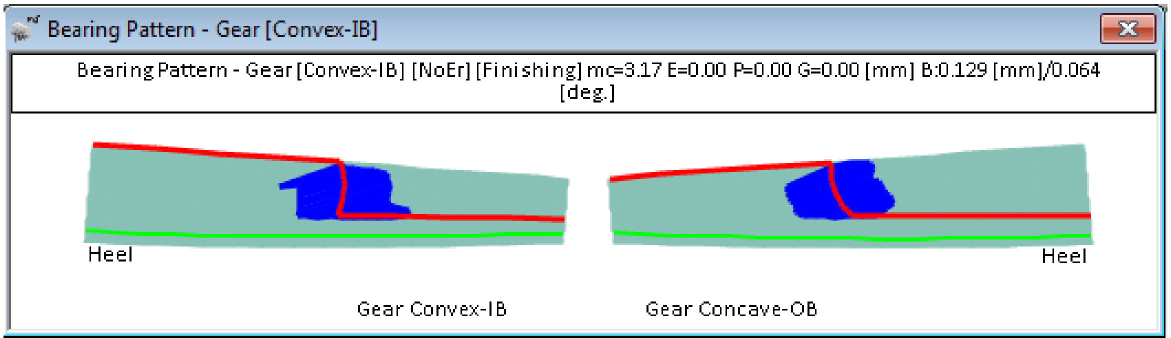
Transmission Error Curves

The Transmission Error curves are convex in shape, overlap one another in the profile section of the tooth flanks, but lack sufficient relief at contact entry (the direction of rotation is indicated by the "->" below the horizontal axis of the T.E. curves).

Therefore, adding TopRem to the pinion cutter blades would be necessary. Selecting TopRem BH, for example, would change the T.E. curves to the following, where it is now clear that relief at contact entry is adequate.



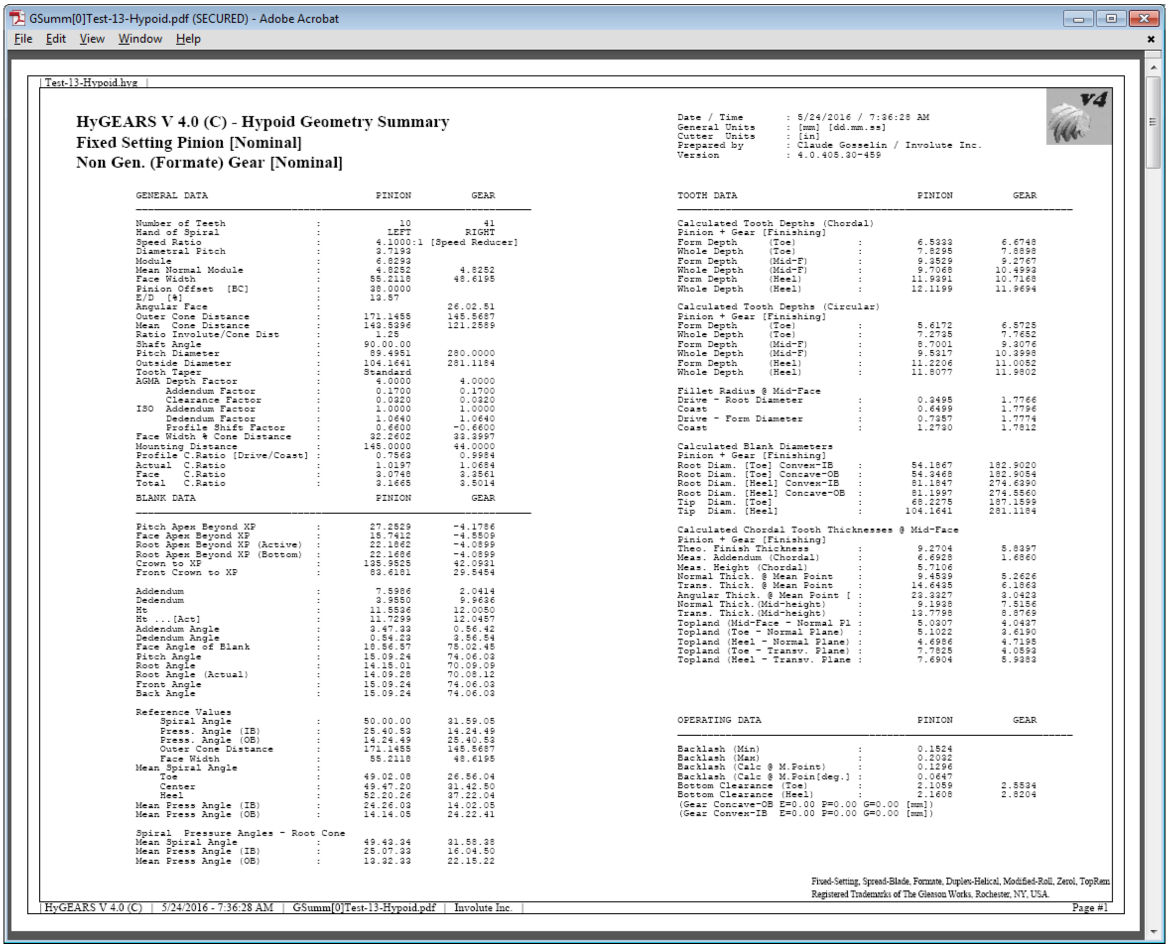
The Contact Pattern now shows a slight gap at the tip of the gear teeth, which is caused by the TopRem on the pinion cutter blade.



Blank Data

The Blank Data section of the Summary gives the main tooth proportions and characteristics. The following points are observed:

- the OD of the gear member is barely above the limit initially imposed on the overall dimension; if additional clearance is needed, the module may be slightly decreased while keeping the other data constant;
- the pinion normal tooth thickness at the mean point is different than that of the gear, which may result in a one of the teeth to be weaker.



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HyGEARS V 4.0 (C) - Hypoid Geometry Summary
Fixed Setting Pinion [Nominal]
Non Gen. (Formate) Gear [Nominal]

Date / Time	: 5/24/2016 / 7:36:28 AM
General Units	: [mm] [dd.mm.ss]
Cutter Units	: [in]
Prepared by	: Claude Gosselin / Involute Inc.
Version	: 4.0.405.30-459

GENERAL DATA		PINION	GEAR
Number of Teeth	:	10	41
Hand of Spiral	:	LEFT	RIGHT
Speed Ratio	:	4.1000:1 [Speed Reducer]	
Diametral Pitch	:	3.7193	
Module	:	6.8293	
Mean Normal Module	:	4.8252	4.8252
Face Width	:	55.2118	48.6195
Pinion Offset [BC]	:	38.0000	
E/D [%]	:	13.57	
Angular Face	:		26.02.51
Outer Cone Distance	:	171.1455	145.5687
Mean Cone Distance	:	143.5396	121.2589
Ratio Involute/Cone Dist	:	1.25	
Shaft Angle	:	90.00.00	
Pitch Diameter	:	89.4951	280.0000
Outside Diameter	:	104.1641	281.1184
Tooth Taper	:	Standard	
AGMA Depth Factor	:	4.0000	4.0000
Addendum Factor	:	0.1700	0.1700
Clearance Factor	:	0.0320	0.0320
ISO Addendum Factor	:	1.0000	1.0000
Dedendum Factor	:	1.0640	1.0640
Profile Shift Factor	:	0.6600	-0.6600
Face Width % Cone Distance	:	32.2602	33.3997
Mounting Distance	:	145.0000	44.0000
Profile C.Ratio [Drive/Coast]	:	0.7563	0.9984
Actual C.Ratio	:	1.0197	1.0684
Face C.Ratio	:	3.0748	3.3561
Total C.Ratio	:	3.1665	3.5014

BLANK DATA		PINION	GEAR
Pitch Apex Beyond XP	:	27.2529	-4.1786
Face Apex Beyond XP	:	15.7412	-4.5509
Root Apex Beyond XP (Active)	:	22.1862	-4.0899
Root Apex Beyond XP (Bottom)	:	22.1686	-4.0899
Crown to XP	:	135.9525	42.0931
Front Crown to XP	:	83.6181	29.5454
Addendum	:	7.5986	2.0414
Dedendum	:	3.9550	9.9636
Ht	:	11.5536	12.0050
Ht ...[Act]	:	11.7299	12.0457
Addendum Angle	:	3.47.33	0.56.42
Dedendum Angle	:	0.54.23	3.56.54
Face Angle of Blank	:	18.56.57	75.02.45
Pitch Angle	:	15.09.24	74.06.03
Root Angle	:	14.15.01	70.09.09
Root Angle (Actual)	:	14.09.28	70.08.12
Front Angle	:	15.09.24	74.06.03
Back Angle	:	15.09.24	74.06.03
Reference Values			
Spiral Angle	:	50.00.00	31.59.05
Press. Angle (IB)	:	25.40.53	14.24.49
Press. Angle (OB)	:	14.24.49	25.40.53
Outer Cone Distance	:	171.1455	145.5687
Face Width	:	55.2118	48.6195
Mean Spiral Angle	:		
Toe	:	49.02.08	26.56.04
Center	:	49.47.20	31.42.50
Heel	:	52.20.26	37.22.04
Mean Press Angle (IB)	:	24.26.03	14.02.05
Mean Press Angle (OB)	:	14.14.05	24.22.41
Spiral Pressure Angles - Root Cone			
Mean Spiral Angle	:	49.43.34	31.58.38
Mean Press Angle (IB)	:	25.07.33	16.04.50
Mean Press Angle (OB)	:	13.32.33	22.15.22

TOOTH DATA		PINION	GEAR
Calculated Tooth Depths (Chordal)			
Pinion + Gear [Finishing]			
Form Depth (Toe)	:	6.5333	6.6748
Whole Depth (Toe)	:	7.8295	7.8898
Form Depth (Mid-F)	:	9.3529	9.2767
Whole Depth (Mid-F)	:	9.7068	10.4993
Form Depth (Heel)	:	11.9391	10.7168
Whole Depth (Heel)	:	12.1199	11.9694
Calculated Tooth Depths (Circular)			
Pinion + Gear [Finishing]			
Form Depth (Toe)	:	5.6172	6.5725
Whole Depth (Toe)	:	7.2735	7.7652
Form Depth (Mid-F)	:	8.7001	9.3076
Whole Depth (Mid-F)	:	9.5317	10.3998
Form Depth (Heel)	:	11.2206	11.0052
Whole Depth (Heel)	:	11.8077	11.9802
Fillet Radius @ Mid-Face			
Drive - Root Diameter	:	0.3495	1.7766
Coast	:	0.6499	1.7796
Drive - Form Diameter	:	0.7357	1.7774
Coast	:	1.2730	1.7812
Calculated Blank Diameters			
Pinion + Gear [Finishing]			
Root Diam. [Toe] Convex-IB	:	54.1867	182.9020
Root Diam. [Toe] Concave-OB	:	54.3468	182.9054
Root Diam. [Heel] Convex-IB	:	81.1847	274.6390
Root Diam. [Heel] Concave-OB	:	81.1997	274.5560
Tip Diam. [Toe]	:	68.2275	187.1599
Tip Diam. [Heel]	:	104.1641	281.1184
Calculated Chordal Tooth Thicknesses @ Mid-Face			
Pinion + Gear [Finishing]			
Theo. Finish Thickness	:	9.2704	5.8397
Meas. Addendum (Chordal)	:	6.6928	1.6860
Meas. Height (Chordal)	:	5.7106	
Normal Thick. @ Mean Point	:	9.4539	5.2626
Trans. Thick. @ Mean Point	:	14.6435	6.1863
Angular Thick. @ Mean Point [	:	23.3327	3.0423
Normal Thick.(Mid-height)	:	9.1938	7.5156
Trans. Thick.(Mid-height)	:	13.7798	8.8769
Topland (Mid-Face - Normal Pl	:	5.0307	4.0437
Topland (Toe - Normal Plane)	:	5.1022	3.6190
Topland (Heel - Normal Plane)	:	4.6986	4.7195
Topland (Toe - Transv. Plane)	:	7.7825	4.0593
Topland (Heel - Transv. Plane	:	7.6904	5.9383

OPERATING DATA		PINION	GEAR
Backlash (Min)	:	0.1524	
Backlash (Max)	:	0.2032	
Backlash (Calc @ M.Point)	:	0.1296	
Backlash (Calc @ M.Poin[deg.]	:	0.0647	
Bottom Clearance (Toe)	:	2.1059	2.5534
Bottom Clearance (Heel)	:	2.1608	2.8204

(Gear Concave-OB E=0.00 P=0.00 G=0.00 [mm])
(Gear Convex-IB E=0.00 P=0.00 G=0.00 [mm])

Fixed-Setting, Spread-Blade, Formate, Duplex-Helical, Modified-Roll, Zerol, TopRem
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HyGEARS V 4.0 (C) | 5/24/2016 - 7:36:28 AM | GSumm[0]Test-13-Hypoid.pdf | Involute Inc. | Page #1

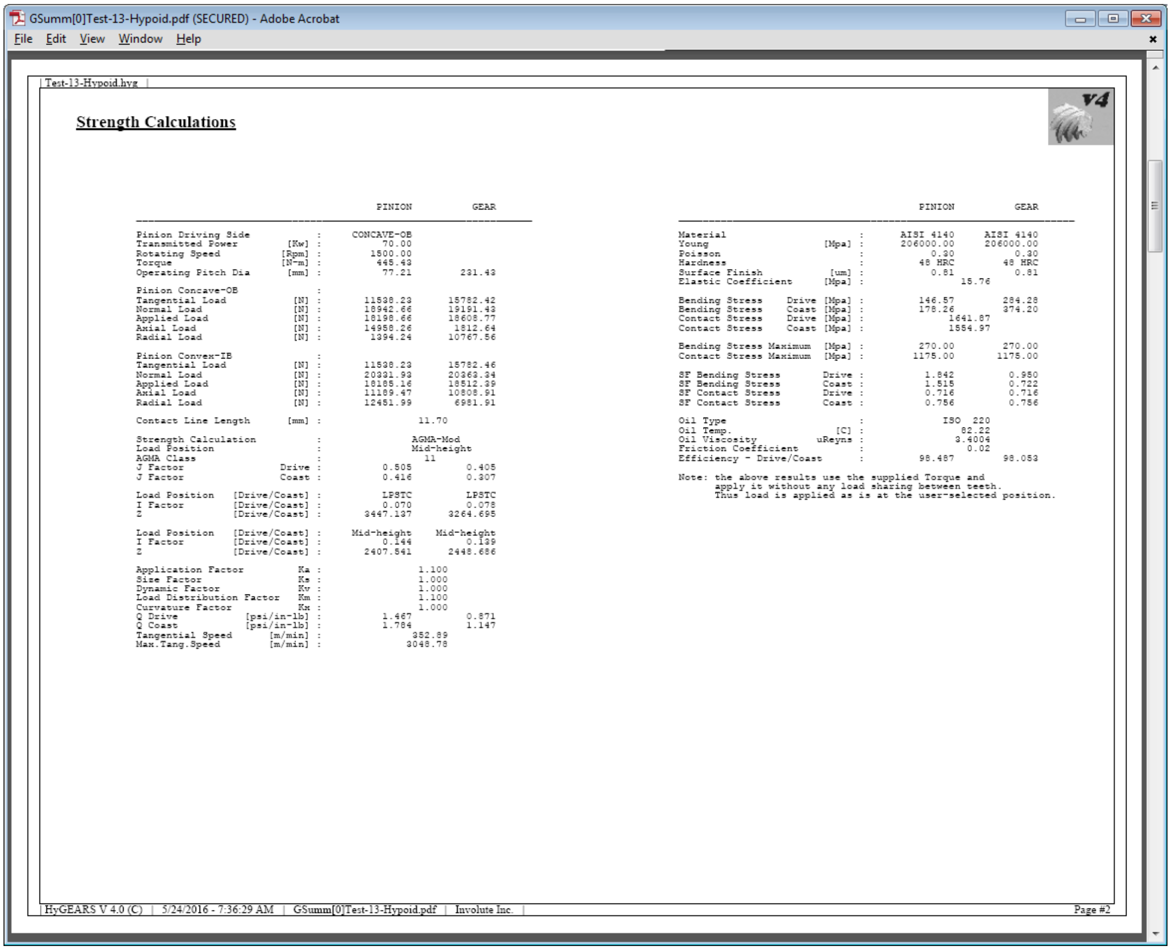
Strength Calculations

The Strength Calculations section of the Summary provide the expected behavior of the teeth under load, as calculated using standard methods. The following points are observed, keeping in mind that the calculated stresses *assume no load sharing* between neighboring teeth:

- the bending stress, calculated at mid-tooth height by default for Spiral Bevel and Hypoid gears, on the pinion member is quite different from that on the gear member, likely because of tooth thickness as noted above; it is also on the high side for the gear, which is likely caused by tooth thickness. HyGEARS assumes an Application Factor Ka equal to 1.1, and an Alignment Factor Km equal to 1.1, which give a margin of safety. If the operating conditions are well known, or past experience suggests otherwise, these values can be changed in the Geometry Summary Editor.

- using the same Application Factors, the calculated contact stresses are high when compared to the normal operating limit for the chosen steel (4140); in practice, gear steel, once hardened, can sustain around 1.7 GPa contact pressures, so in the present case, the contact stress on both flanks would be just below the limit;

In HyGEARS, contact stresses are calculated using Hertz' theory applied to the knowledge of the exact curvatures at the Mean Contact Point, located at mid-tooth height on the gear member tooth flank. Since the pressure angles are different on the gear I.B. and O.B., contact stresses may be different.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Strength Calculations

		PINION	GEAR
Pinion Driving Side	:	CONCAVE-OB	
Transmitted Power	[Kw] :	70.00	
Rotating Speed	[Rpm] :	1500.00	
Torque	[N-m] :	445.43	
Operating Pitch Dia	[mm] :	77.21	231.43
Pinion Concave-OB	:		
Tangential Load	[N] :	11538.23	15782.42
Normal Load	[N] :	18942.66	19191.43
Applied Load	[N] :	18198.66	18608.77
Axial Load	[N] :	14958.26	1812.64
Radial Load	[N] :	1394.24	10767.56
Pinion Convex-IB	:		
Tangential Load	[N] :	11538.23	15782.46
Normal Load	[N] :	20331.93	20363.34
Applied Load	[N] :	18185.16	18512.39
Axial Load	[N] :	11189.47	10808.91
Radial Load	[N] :	12451.99	6981.91
Contact Line Length	[mm] :	11.70	
Strength Calculation	:	AGMA-Mod	
Load Position	:	Mid-height	
AGMA Class	:	11	
J Factor	Drive :	0.505	0.405
J Factor	Coast :	0.416	0.307
Load Position	[Drive/Coast] :	LPSTC	LPSTC
I Factor	[Drive/Coast] :	0.070	0.078
Z	[Drive/Coast] :	3447.137	3264.695
Load Position	[Drive/Coast] :	Mid-height	Mid-height
I Factor	[Drive/Coast] :	0.144	0.139
Z	[Drive/Coast] :	2407.541	2448.686
Application Factor	Ka :	1.100	
Size Factor	Ks :	1.000	
Dynamic Factor	Kv :	1.000	
Load Distribution Factor	Km :	1.100	
Curvature Factor	Kx :	1.000	
Q Drive	[psi/in-lb] :	1.467	0.871
Q Coast	[psi/in-lb] :	1.784	1.147
Tangential Speed	[m/min] :	352.89	
Max.Tang.Speed	[m/min] :	3048.78	

		PINION	GEAR
Material	:	AISI 4140	AISI 4140
Young	[Mpa] :	206000.00	206000.00
Poisson	:	0.30	0.30
Hardness	:	48 HRC	48 HRC
Surface Finish	[um] :	0.81	0.81
Elastic Coefficient	[Mpa] :	15.76	
Bending Stress	Drive [Mpa] :	146.57	284.28
Bending Stress	Coast [Mpa] :	178.26	374.20
Contact Stress	Drive [Mpa] :	1641.87	
Contact Stress	Coast [Mpa] :	1554.97	
Bending Stress Maximum	[Mpa] :	270.00	270.00
Contact Stress Maximum	[Mpa] :	1175.00	1175.00
SF Bending Stress	Drive :	1.842	0.950
SF Bending Stress	Coast :	1.515	0.722
SF Contact Stress	Drive :	0.716	0.716
SF Contact Stress	Coast :	0.756	0.756
Oil Type	:	ISO 220	
Oil Temp.	[C] :	82.22	
Oil Viscosity	uReyns :	3.4004	
Friction Coefficient	:	0.02	
Efficiency - Drive/Coast	:	98.487	98.053

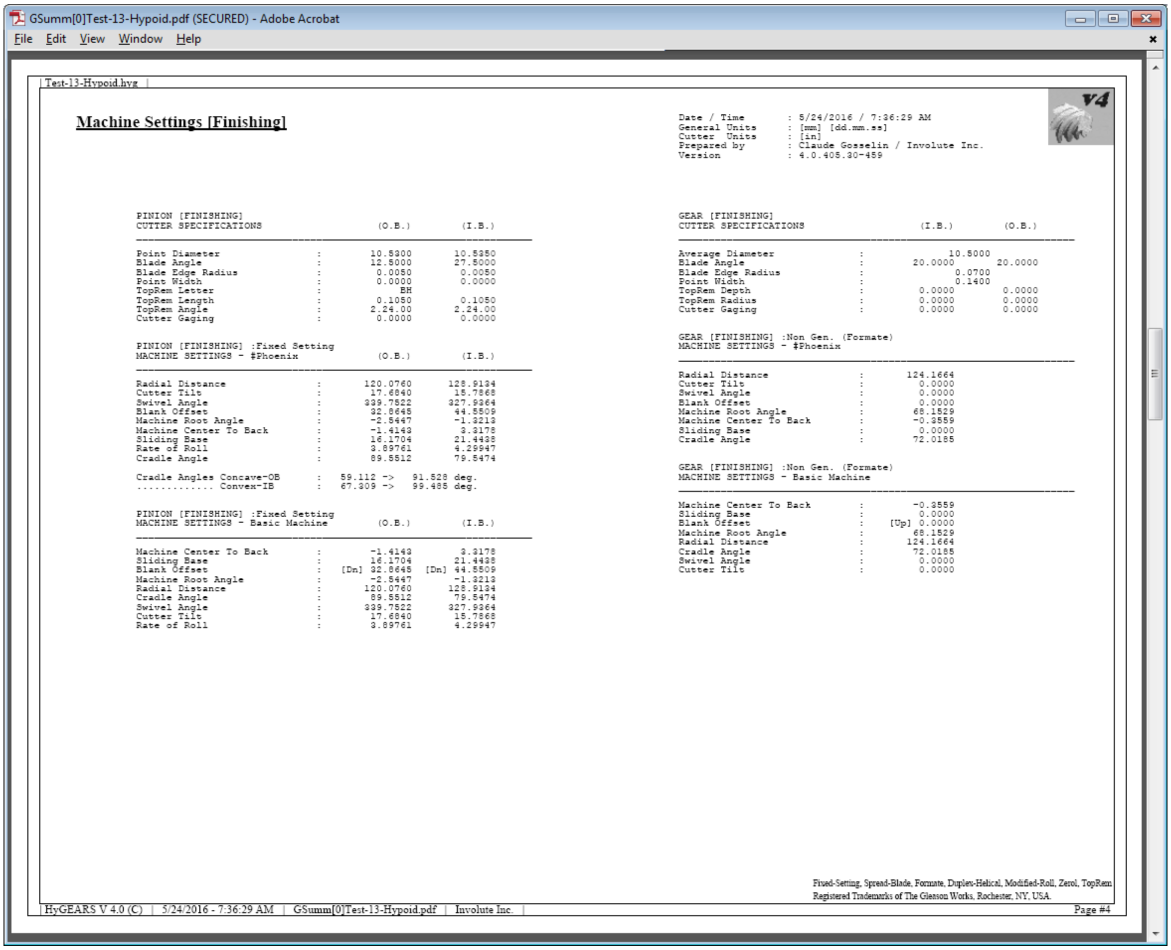
Note: the above results use the supplied Torque and apply it without any load sharing between teeth. Thus load is applied as is at the user-selected position.

HyGEARS V 4.0 (C) | 5/24/2016 - 7:36:29 AM | GSumm[0]Test-13-Hypoid.pdf | Involute Inc. | Page #2

Pinion Machine Settings

The Pinion Machine Settings section of the Summary list the machine setup needed to cut the calculated pinion. We must keep in mind here that we left HyGEARS use default values in the first attempt. It may now be necessary to modify some of these values to match those of available equipment. The following points are observed:

- both the finishing cutter I.B. and O.B. blade angles are not standard, and will be modified in the next iteration;
- the roughing cutter I.B. and O.B. blade angles both are not standard; they will be left as is for the moment;



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Machine Settings [Finishing]

Date / Time : 5/24/2016 / 7:36:29 AM
General Units : [mm] [dd.mm.ss]
Cutter Units : [in]
Prepared by : Claude Gosselin / Involute Inc.
Version : 4.0.405.30-459

PINION [FINISHING] CUTTER SPECIFICATIONS		(O.B.)	(I.B.)
Point Diameter	:	10.5300	10.5350
Blade Angle	:	12.5000	27.5000
Blade Edge Radius	:	0.0050	0.0050
Point Width	:	0.0000	0.0000
TopRem Letter	:	BH	
TopRem Length	:	0.1050	0.1050
TopRem Angle	:	2.24.00	2.24.00
Cutter Gaging	:	0.0000	0.0000

PINION [FINISHING] :Fixed Setting MACHINE SETTINGS - #Phoenix		(O.B.)	(I.B.)
Radial Distance	:	120.0760	128.9134
Cutter Tilt	:	17.6840	15.7868
Swivel Angle	:	339.7522	327.9364
Blank Offset	:	32.8645	44.5509
Machine Root Angle	:	-2.5447	-1.3213
Machine Center To Back	:	-1.4143	3.3178
Sliding Base	:	16.1704	21.4438
Rate of Roll	:	3.89761	4.29947
Cradle Angle	:	89.5512	79.5474
Cradle Angles Concave-OB	:	59.112 ->	91.528 deg.
.... Convex-IB	:	67.309 ->	99.485 deg.

PINION [FINISHING] :Fixed Setting MACHINE SETTINGS - Basic Machine		(O.B.)	(I.B.)
Machine Center To Back	:	-1.4143	3.3178
Sliding Base	:	16.1704	21.4438
Blank Offset	:	[Dn] 32.8645	[Dn] 44.5509
Machine Root Angle	:	-2.5447	-1.3213
Radial Distance	:	120.0760	128.9134
Cradle Angle	:	89.5512	79.5474
Swivel Angle	:	339.7522	327.9364
Cutter Tilt	:	17.6840	15.7868
Rate of Roll	:	3.89761	4.29947

GEAR [FINISHING] CUTTER SPECIFICATIONS		(I.B.)	(O.B.)
Average Diameter	:	10.5000	
Blade Angle	:	20.0000	20.0000
Blade Edge Radius	:	0.0700	
Point Width	:	0.1400	
TopRem Depth	:	0.0000	0.0000
TopRem Radius	:	0.0000	0.0000
Cutter Gaging	:	0.0000	0.0000

GEAR [FINISHING] :Non Gen. (Formate) MACHINE SETTINGS - #Phoenix		
Radial Distance	:	124.1664
Cutter Tilt	:	0.0000
Swivel Angle	:	0.0000
Blank Offset	:	0.0000
Machine Root Angle	:	68.1529
Machine Center To Back	:	-0.3559
Sliding Base	:	0.0000
Cradle Angle	:	72.0185

GEAR [FINISHING] :Non Gen. (Formate) MACHINE SETTINGS - Basic Machine		
Machine Center To Back	:	-0.3559
Sliding Base	:	0.0000
Blank Offset	:	[Up] 0.0000
Machine Root Angle	:	68.1529
Radial Distance	:	124.1664
Cradle Angle	:	72.0185
Swivel Angle	:	0.0000
Cutter Tilt	:	0.0000

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HyGEARS V 4.0 (C) | 5/24/2016 - 7:36:29 AM | GSumm[0]Test-13-Hypoid.pdf | Involute Inc. | Page #4

Gear Machine Settings

The Gear Machine Settings section of the Summary (see above figure) lists the machine setup needed to cut the calculated gear member. Again, we must keep in mind here that we left HyGEARS use default values in the first attempt. The following points are observed:

- the cutter diameter is not standard, and the closest, smaller, value is 9”. We will therefore use this value in the next attempt;
- both the finishing and roughing cutter I.B. and O.B. blade angles are standard, and will therefore be left as calculated;

Modifying the Initial Geometry

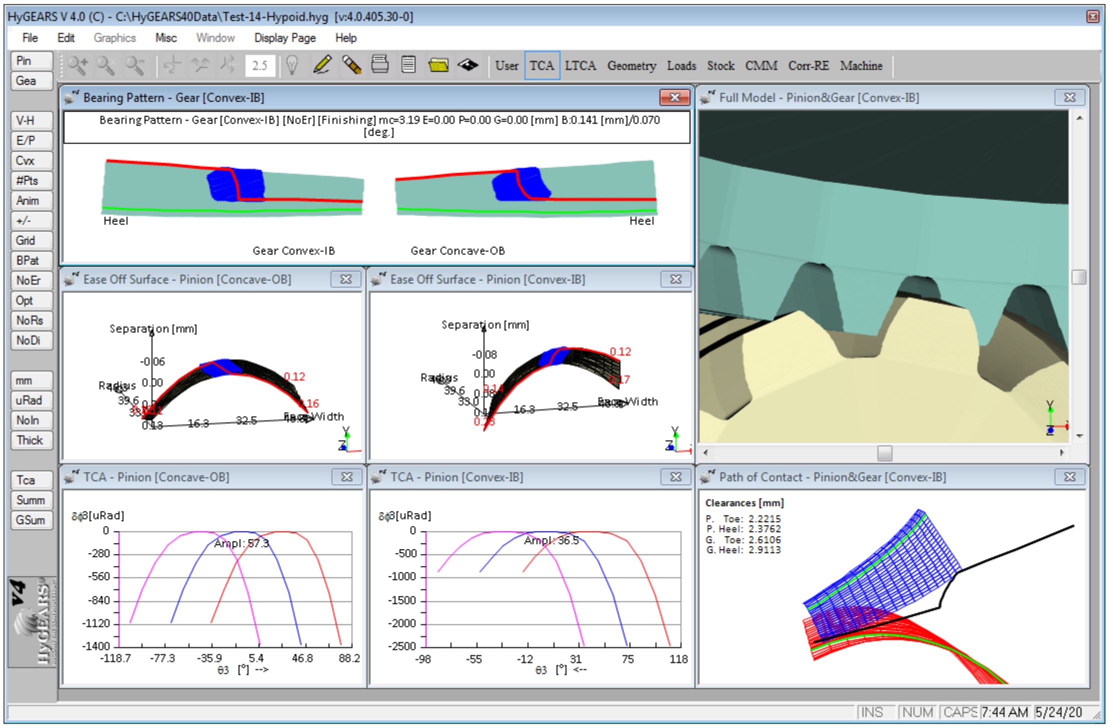
The next step requires modifications to the initial data entered in the New Geometry Definition window. Based on the results from the first attempt, the following data will be entered:

General Data Section:			
Geometry Name:	Let HyGEARS decide		
Directory:	Let HyGEARS decide		
Geometry Type:	Hypoid		
Tooth Taper:	Standard		
Tooth Hand:	Left		
Tooth Number:	10	41	
Tooth Module:	6.8293 [mm]	(25.4 / P, where P = 3.7192)	
Tooth Face width:	0	Let HyGEARS calculate.	
Shaft Angle:	90.00.00		
Depth Factor	0	Let HyGEARS decide	
Addendum Factor	0	Let HyGEARS decide	
Clearance Factor	0.0325		
Offset:	38.0 [mm]		
Power:	70 kW		
Speed:	1500 RPM		

Cutter Data Section:	**Pinion**		**Gear**	
Machine	Phoenix		Phoenix	
Spiral Angle:	50°			
Sum Pressure Angles:	40°	(automotive, light duty)		
Stock Allowance:	0.015 [in]		0.015 [in]	
Cutter Diameter:	0.000		**9.000**	
Blade Angle:	**10.00.00**	**30.00.00**	**20.00.00**	**20.00.00**
Blade Edge Rad.:	Let HyGEARS calculate			
Point Width:	Let HyGEARS calculate			
Mounting Distance:	Let HyGEARS calculate			
Process:	Fixed Setting		Non Generated	

Analysis of the Modified Geometry

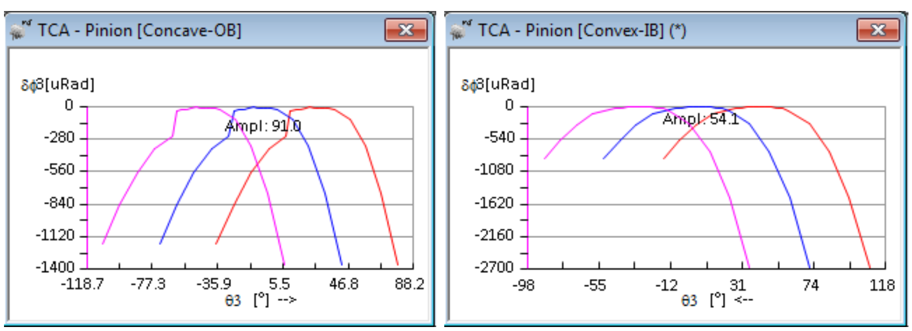
The Bearing Pattens of the modified geometry appear as follows, respectively for the Gear Convex-IB and Concave-OB tooth flanks. Both Contact Patterns are well centered, cover ~25% of the tooth flank, and are reasonably bias free.



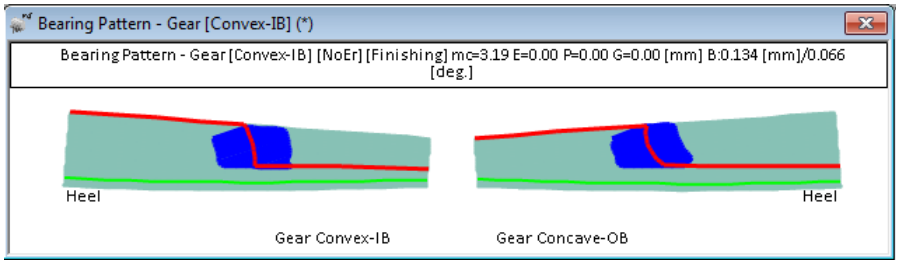
Transmission Error Curves

As for the 1st attempt, the Transmission Error curves are convex in shape, overlap one another in the profile section of the tooth flanks, but lack sufficient relief at contact entry.

Therefore, adding TopRem to the pinion cutter blades would be necessary. Selecting TopRem BH, for example, would change the T.E. curves to the following, where it is clear that relief at contact entry is adequate.

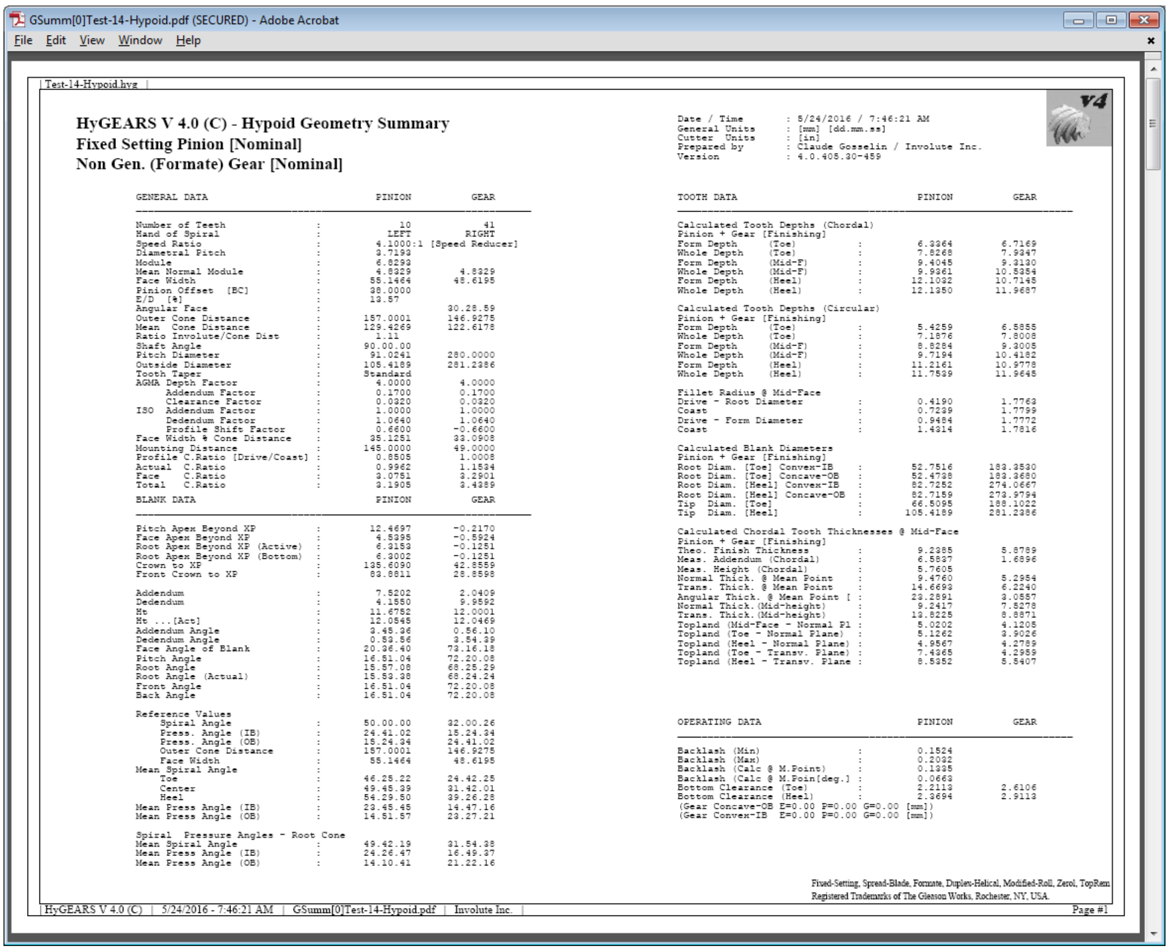


The Contact Pattern now shows a gap at the tip of the gear teeth, which is caused by the TopRem on the pinion cutter blade.



Blank Data

The Blank Data section has changed slightly, as a result of the change in gear cutter diameter. The same remarks as for the initial geometry apply.



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Test-14-Hypoid.hyg

HyGEARS V 4.0 (C) - Hypoid Geometry Summary
Fixed Setting Pinion [Nominal]
Non Gen. (Formate) Gear [Nominal]

Date / Time	: 5/24/2016 / 7:46:21 AM
General Units	: [mm] [dd.mm.ss]
Cutter Units	: [in]
Prepared by	: Claude Gosselin / Involute Inc.
Version	: 4.0.405.30-459

GENERAL DATA		PINION	GEAR
Number of Teeth	:	10	41
Hand of Spiral	:	LEFT	RIGHT
Speed Ratio	:	4.1000:1 [Speed Reducer]	
Diametral Pitch	:	3.7193	
Module	:	6.8293	
Mean Normal Module	:	4.8329	4.8329
Face Width	:	55.1464	48.6195
Pinion Offset [BC]	:	38.0000	
E/D [%]	:	13.57	
Angular Face	:		30.28.59
Outer Cone Distance	:	157.0001	146.9275
Mean Cone Distance	:	129.4269	122.6178
Ratio Involute/Cone Dist	:	1.11	
Shaft Angle	:	90.00.00	
Pitch Diameter	:	91.0241	280.0000
Outside Diameter	:	105.4189	281.2386
Tooth Taper	:	Standard	
AGMA Depth Factor	:	4.0000	4.0000
Addendum Factor	:	0.1700	0.1700
Clearance Factor	:	0.0320	0.0320
ISO Addendum Factor	:	1.0000	1.0000
Dedendum Factor	:	1.0640	1.0640
Profile Shift Factor	:	0.6600	-0.6600
Face Width % Cone Distance	:	35.1251	33.0908
Mounting Distance	:	145.0000	49.0000
Profile C.Ratio [Drive/Coast]	:	0.8505	1.0008
Actual C.Ratio	:	0.9962	1.1534
Face C.Ratio	:	3.0751	3.2901
Total C.Ratio	:	3.1905	3.4389

BLANK DATA		PINION	GEAR
Pitch Apex Beyond XP	:	12.4697	-0.2170
Face Apex Beyond XP	:	4.5395	-0.5924
Root Apex Beyond XP (Active)	:	6.3153	-0.1251
Root Apex Beyond XP (Bottom)	:	6.3002	-0.1251
Crown to XP	:	135.6090	42.8559
Front Crown to XP	:	83.8811	28.8598
Addendum	:	7.5202	2.0409
Dedendum	:	4.1550	9.9592
Ht	:	11.6752	12.0001
Ht ...[Act]	:	12.0545	12.0469
Addendum Angle	:	3.45.36	0.56.10
Dedendum Angle	:	0.53.56	3.54.39
Face Angle of Blank	:	20.36.40	73.16.18
Pitch Angle	:	16.51.04	72.20.08
Root Angle	:	15.57.08	68.25.29
Root Angle (Actual)	:	15.53.38	68.24.24
Front Angle	:	16.51.04	72.20.08
Back Angle	:	16.51.04	72.20.08
Reference Values			
Spiral Angle	:	50.00.00	32.00.26
Press. Angle (IB)	:	24.41.02	15.24.34
Press. Angle (OB)	:	15.24.34	24.41.02
Outer Cone Distance	:	157.0001	146.9275
Face Width	:	55.1464	48.6195
Mean Spiral Angle	:		
Toe	:	46.25.22	24.42.25
Center	:	49.45.39	31.42.01
Heel	:	54.29.50	39.26.28
Mean Press Angle (IB)	:	23.45.45	14.47.16
Mean Press Angle (OB)	:	14.51.57	23.27.21
Spiral Pressure Angles - Root Cone			
Mean Spiral Angle	:	49.42.19	31.54.38
Mean Press Angle (IB)	:	24.26.47	16.49.37
Mean Press Angle (OB)	:	14.10.41	21.22.16

TOOTH DATA		PINION	GEAR
Calculated Tooth Depths (Chordal)			
Pinion + Gear [Finishing]			
Form Depth (Toe)	:	6.3364	6.7169
Whole Depth (Toe)	:	7.8268	7.9347
Form Depth (Mid-F)	:	9.4045	9.3130
Whole Depth (Mid-F)	:	9.9361	10.5354
Form Depth (Heel)	:	12.1032	10.7145
Whole Depth (Heel)	:	12.1350	11.9687
Calculated Tooth Depths (Circular)			
Pinion + Gear [Finishing]			
Form Depth (Toe)	:	5.4259	6.5855
Whole Depth (Toe)	:	7.1876	7.8008
Form Depth (Mid-F)	:	8.8284	9.3005
Whole Depth (Mid-F)	:	9.7194	10.4182
Form Depth (Heel)	:	11.2161	10.9778
Whole Depth (Heel)	:	11.7539	11.9645
Fillet Radius @ Mid-Face			
Drive - Root Diameter	:	0.4190	1.7763
Coast	:	0.7239	1.7799
Drive - Form Diameter	:	0.9484	1.7772
Coast	:	1.4314	1.7816
Calculated Blank Diameters			
Pinion + Gear [Finishing]			
Root Diam. [Toe] Convex-IB	:	52.7516	183.3530
Root Diam. [Toe] Concave-OB	:	52.4738	183.3680
Root Diam. [Heel] Convex-IB	:	82.7252	274.0667
Root Diam. [Heel] Concave-OB	:	82.7159	273.9794
Tip Diam. [Toe]	:	66.5095	188.1022
Tip Diam. [Heel]	:	105.4189	281.2386
Calculated Chordal Tooth Thicknesses @ Mid-Face			
Pinion + Gear [Finishing]			
Theo. Finish Thickness	:	9.2385	5.8789
Meas. Addendum (Chordal)	:	6.5837	1.6896
Meas. Height (Chordal)	:	5.7605	
Normal Thick. @ Mean Point	:	9.4760	5.2954
Trans. Thick. @ Mean Point	:	14.6693	6.2240
Angular Thick. @ Mean Point [	:	23.2891	3.0557
Normal Thick.(Mid-height)	:	9.2417	7.5278
Trans. Thick.(Mid-height)	:	13.8225	8.8871
Topland (Mid-Face - Normal Pl	:	5.0202	4.1205
Topland (Toe - Normal Plane)	:	5.1262	3.9026
Topland (Heel - Normal Plane)	:	4.9567	4.2789
Topland (Toe - Transv. Plane)	:	7.4365	4.2959
Topland (Heel - Transv. Plane	:	8.5352	5.5407

OPERATING DATA		PINION	GEAR
Backlash (Min)	:	0.1524	
Backlash (Max)	:	0.2032	
Backlash (Calc @ M.Point)	:	0.1335	
Backlash (Calc @ M.Poin[deg.]	:	0.0663	
Bottom Clearance (Toe)	:	2.2113	2.6106
Bottom Clearance (Heel)	:	2.3694	2.9113

(Gear Concave-OB E=0.00 P=0.00 G=0.00 [mm])
(Gear Convex-IB E=0.00 P=0.00 G=0.00 [mm])

Fixed-Setting, Spread-Blade, Formate, Duplex-Helical, Modified-Roll, Zerol, TopRem
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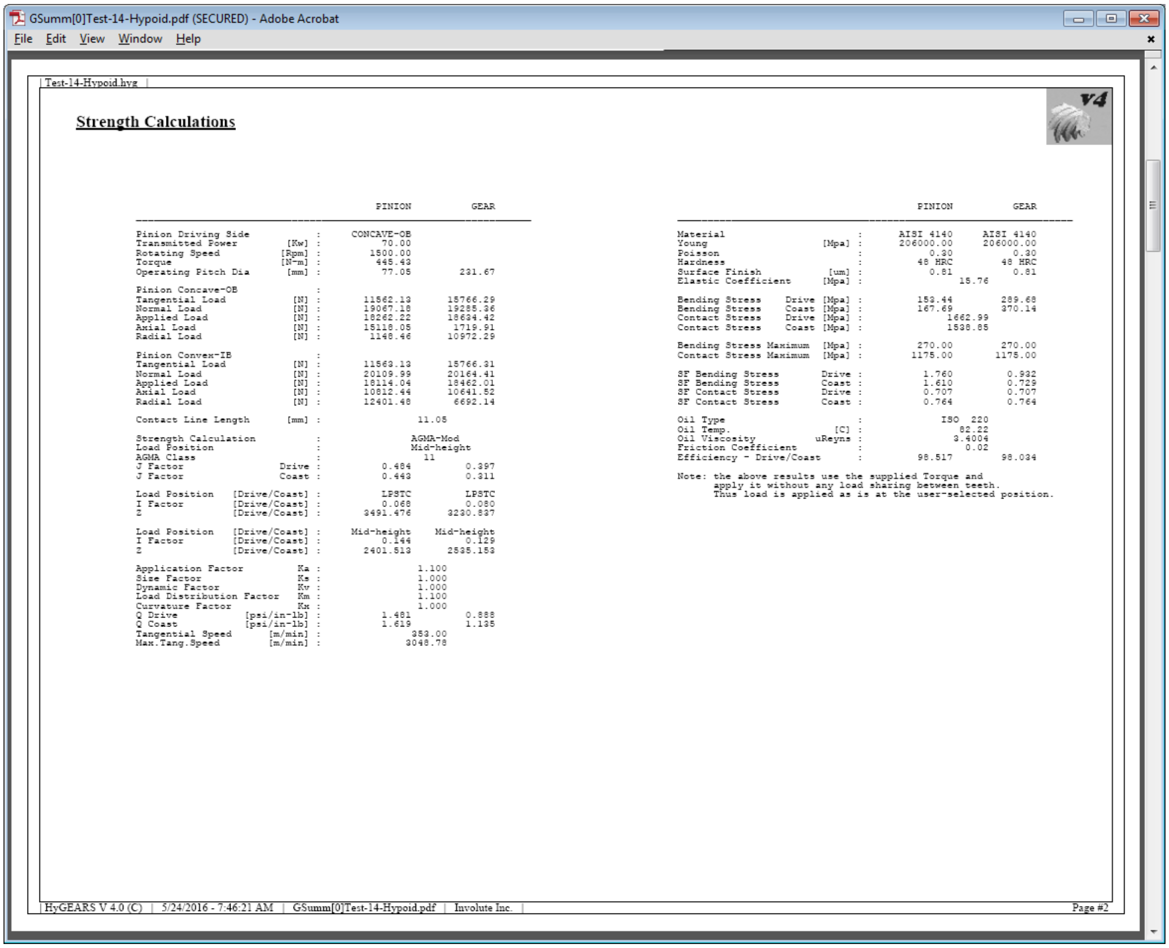
HyGEARS V 4.0 (C) | 5/24/2016 - 7:46:21 AM | GSumm[0]Test-14-Hypoid.pdf | Involute Inc. | Page #1

Strength Calculations

The Strength Calculations section of the Summary have not changed significantly either, such that the remarks for the initial geometry apply.



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Strength Calculations

		PINION	GEAR
Pinion Driving Side	:	CONCAVE-OB	
Transmitted Power	[Kw] :	70.00	
Rotating Speed	[Rpm] :	1500.00	
Torque	[N-m] :	445.43	
Operating Pitch Dia	[mm] :	77.05	231.67
Pinion Concave-OB	:		
Tangential Load	[N] :	11562.13	15766.29
Normal Load	[N] :	19067.18	19285.36
Applied Load	[N] :	18262.22	18634.42
Axial Load	[N] :	15118.05	1719.91
Radial Load	[N] :	1148.46	10972.29
Pinion Convex-IB	:		
Tangential Load	[N] :	11563.13	15766.31
Normal Load	[N] :	20109.99	20164.41
Applied Load	[N] :	18114.04	18462.01
Axial Load	[N] :	10812.44	10641.52
Radial Load	[N] :	12401.48	6692.14
Contact Line Length	[mm] :	11.05	
Strength Calculation	:	AGMA-Mod	
Load Position	:	Mid-height	
AGMA Class	:	11	
J Factor	Drive :	0.484	0.397
J Factor	Coast :	0.443	0.311
Load Position	[Drive/Coast] :	LPSTC	LPSTC
I Factor	[Drive/Coast] :	0.068	0.080
Z	[Drive/Coast] :	3491.476	3230.837
Load Position	[Drive/Coast] :	Mid-height	Mid-height
I Factor	[Drive/Coast] :	0.144	0.129
Z	[Drive/Coast] :	2401.513	2535.153
Application Factor	Ka :	1.100	
Size Factor	Ks :	1.000	
Dynamic Factor	Kv :	1.000	
Load Distribution Factor	Km :	1.100	
Curvature Factor	Kx :	1.000	
Q Drive	[psi/in-lb] :	1.481	0.888
Q Coast	[psi/in-lb] :	1.619	1.135
Tangential Speed	[m/min] :	353.00	
Max.Tang.Speed	[m/min] :	3048.78	

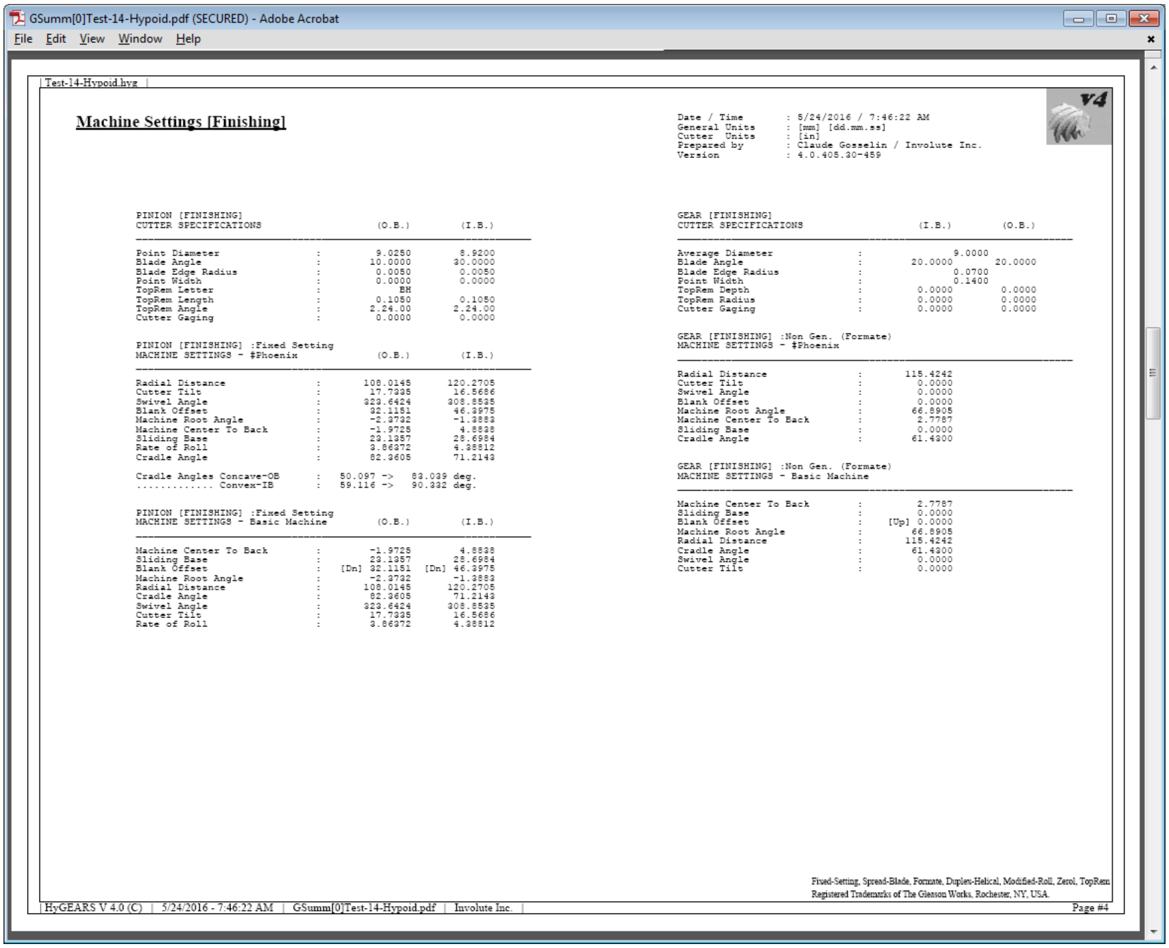
		PINION	GEAR
Material	:	AISI 4140	AISI 4140
Young	[Mpa] :	206000.00	206000.00
Poisson	:	0.30	0.30
Hardness	:	48 HRC	48 HRC
Surface Finish	[um] :	0.81	0.81
Elastic Coefficient	[Mpa] :	15.76	
Bending Stress	Drive [Mpa] :	153.44	289.68
Bending Stress	Coast [Mpa] :	167.69	370.14
Contact Stress	Drive [Mpa] :	1662.99	
Contact Stress	Coast [Mpa] :	1538.85	
Bending Stress Maximum	[Mpa] :	270.00	270.00
Contact Stress Maximum	[Mpa] :	1175.00	1175.00
SF Bending Stress	Drive :	1.760	0.932
SF Bending Stress	Coast :	1.610	0.729
SF Contact Stress	Drive :	0.707	0.707
SF Contact Stress	Coast :	0.764	0.764
Oil Type	:	ISO 220	
Oil Temp.	[C] :	82.22	
Oil Viscosity	uReyns :	3.4004	
Friction Coefficient	:	0.02	
Efficiency - Drive/Coast	:	98.517	98.034

Note: the above results use the supplied Torque and apply it without any load sharing between teeth. Thus load is applied as is at the user-selected position.

HyGEARS V 4.0 (C) | 5/24/2016 - 7:46:21 AM | GSumm[0]Test-14-Hypoid.pdf | Involute Inc. | Page #2

Pinion and Gear Machine Settings

The Pinion and Gear Machine Settings section of the Summary has changed, as a result of the use of specific finishing cutter blade angles and a different gear cutter diameter.



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Machine Settings [Finishing]

Date / Time : 5/24/2016 / 7:46:22 AM
General Units : [mm] [dd.mm.ss]
Cutter Units : [in]
Prepared by : Claude Gosselin / Involute Inc.
Version : 4.0.405.30-459

PINION [FINISHING]
CUTTER SPECIFICATIONS

		(O.B.)	(I.B.)
Point Diameter	:	9.0250	8.9200
Blade Angle	:	10.0000	30.0000
Blade Edge Radius	:	0.0050	0.0050
Point Width	:	0.0000	0.0000
TopRem Letter	:	BH	
TopRem Length	:	0.1050	0.1050
TopRem Angle	:	2.24.00	2.24.00
Cutter Gaging	:	0.0000	0.0000

PINION [FINISHING] :Fixed Setting
MACHINE SETTINGS - #Phoenix

		(O.B.)	(I.B.)
Radial Distance	:	108.0145	120.2705
Cutter Tilt	:	17.7335	16.5686
Swivel Angle	:	323.6424	308.8535
Blank Offset	:	32.1151	46.3975
Machine Root Angle	:	-2.3732	-1.3883
Machine Center To Back	:	-1.9725	4.8838
Sliding Base	:	23.1357	28.6984
Rate of Roll	:	3.86372	4.38812
Cradle Angle	:	82.3605	71.2143

Cradle Angles Concave-OB : 50.097 -> 83.039 deg.
.... Convex-IB : 59.116 -> 90.332 deg.

PINION [FINISHING] :Fixed Setting
MACHINE SETTINGS - Basic Machine

		(O.B.)	(I.B.)
Machine Center To Back	:	-1.9725	4.8838
Sliding Base	:	23.1357	28.6984
Blank Offset	:	[Dn] 32.1151	[Dn] 46.3975
Machine Root Angle	:	-2.3732	-1.3883
Radial Distance	:	108.0145	120.2705
Cradle Angle	:	82.3605	71.2143
Swivel Angle	:	323.6424	308.8535
Cutter Tilt	:	17.7335	16.5686
Rate of Roll	:	3.86372	4.38812

GEAR [FINISHING]
CUTTER SPECIFICATIONS

		(I.B.)		(O.B.)
Average Diameter	:		9.0000	
Blade Angle	:	20.0000		20.0000
Blade Edge Radius	:		0.0700	
Point Width	:		0.1400	
TopRem Depth	:	0.0000		0.0000
TopRem Radius	:	0.0000		0.0000
Cutter Gaging	:	0.0000		0.0000

GEAR [FINISHING] :Non Gen. (Formate)
MACHINE SETTINGS - #Phoenix

Radial Distance	:	115.4242
Cutter Tilt	:	0.0000
Swivel Angle	:	0.0000
Blank Offset	:	0.0000
Machine Root Angle	:	66.8905
Machine Center To Back	:	2.7787
Sliding Base	:	0.0000
Cradle Angle	:	61.4300

GEAR [FINISHING] :Non Gen. (Formate)
MACHINE SETTINGS - Basic Machine

Machine Center To Back	:	2.7787
Sliding Base	:	0.0000
Blank Offset	:	[Up] 0.0000
Machine Root Angle	:	66.8905
Radial Distance	:	115.4242
Cradle Angle	:	61.4300
Swivel Angle	:	0.0000
Cutter Tilt	:	0.0000

Fixed-Setting, Spread-Blade, Formate, Duplex-Helical, Modified-Roll, Zerol, TopRem
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Improving the Contact Pattern

When creating a new geometry, HyGEARS produces a well centered, bias free Contact Pattern covering 25 to 30% of the tooth flank, which ensures that the automated numerical procedures used to design the gear set will not be submitted to excessive tooth surface conformity.

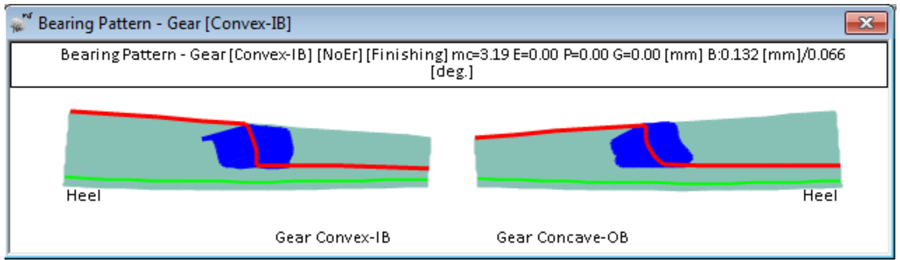
It is therefore the responsibility of the gear designer to modify the Contact Pattern until a satisfactory solution is reached. HyGEARS offers powerful design tools giving full control to the designer to handle this chore in a matter of minutes.

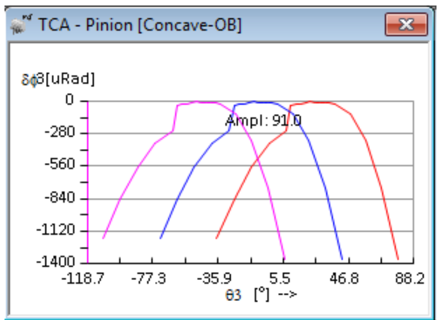
In the following section, we will see how to modify the Bias of the Contact Pattern

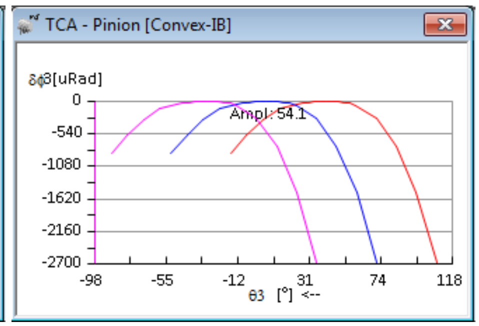
One must also consider the fact that the lapping process will change the tooth surface definition, increasing tooth conformity.

Initial Contact Pattern

The left and right figures below respectively show the gear I.B. and O.B. Contact Patterns, as calculated by HyGEARS, followed by the respective Transmission Error curves.







The following remarks apply:

- both gear I.B. and O.B. Contact Patterns are well positioned, e.g. about 50% or the tooth facewidth, and bias free;
- the Contact Patterns cover 25 to 30% of the tooth facewidth, which may be insufficient if the contact stresses are too large and should then be increased;
- the PoCs on both tooth flanks show slight bias in;
- the pinion tooth edge portions of the PoCs leave sufficient clearance to the gear tooth root;
- the Transmission Error curves for both tooth flanks are convex, and show negligible Transmission Error in the profile portion of the PoC, where the slopes of the curves are horizontal.

Modifying the Contact Pattern

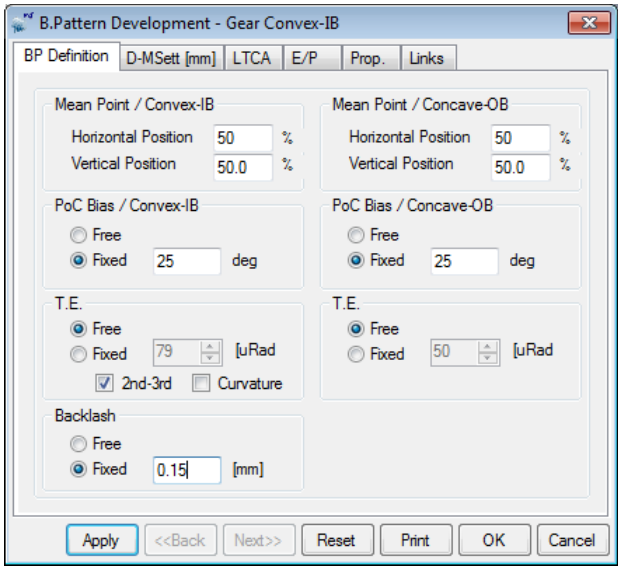
To change the Contact Pattern, the Contact Pattern Development Child Window will be called, and using the “BPat” function button, the following procedure will be used:

- on the gear Convex I.B., input the following requirements for the Contact Pattern definition:

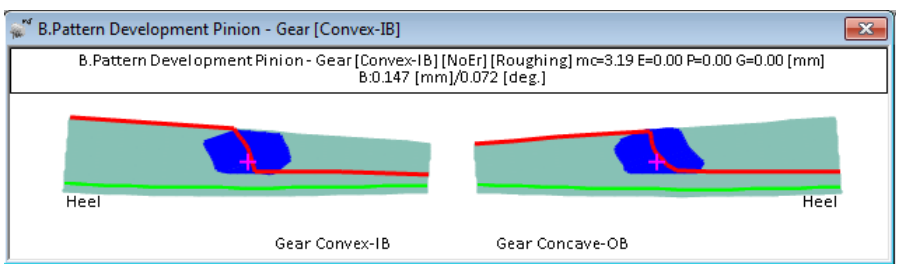
Horizontal Position:	50%
Vertical. Position:	50%
Bias Control:	Fixed, 25°

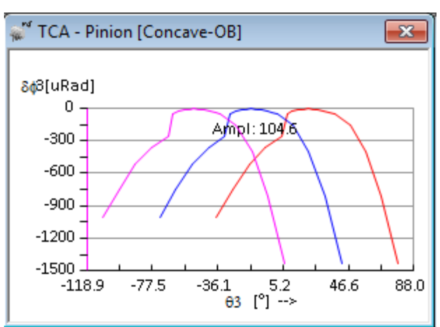
- on the gear Concave O.B., input the following requirements for the Contact Pattern definition:

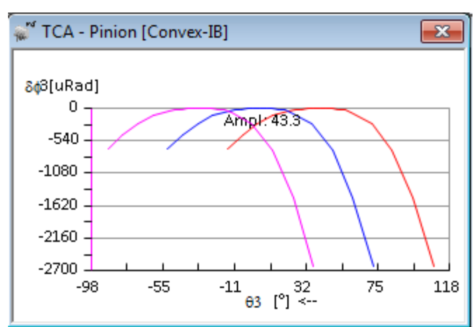
Horizontal Position:	50%
Vertical. Position:	50%
Bias Control:	Fixed, 25°



The above data will ensure adequate PoC and Contact Pattern bias. The following results should be obtained, if the above data was entered.







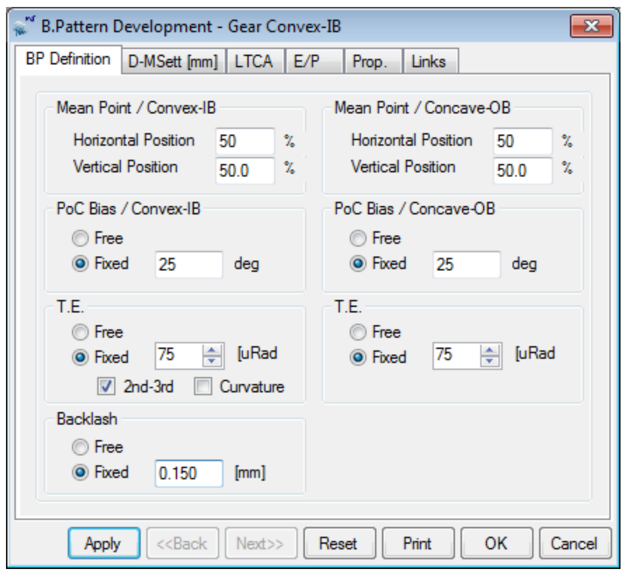
The following remarks apply to the obtained results:

- both gear I.B. and O.B. Contact Patterns are well positioned, e.g. about 50% of the tooth facewidth, and bias free;

- the Contact Patterns cover about 25% of the tooth facewidth;
- the PoCs on both tooth flanks display the requested bias;
- the pinion tooth edge portions of the PoCs leave sufficient clearance to the gear tooth root;
- the Transmission Error curve for the IB tooth flank is convex, and show slight Transmission Error in the profile portion of the PoC, where the slope of the T.E. curve is horizontal. There is adequate profile relief at contact entry, due to the selected TopRem. However, the T.E. curve is rather flat, and could use correction.

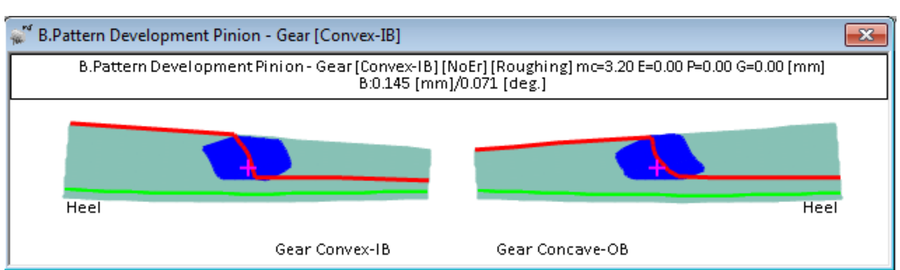
Thus, the Contact Pattern development algorithm will be run a second time, this time to adjust the T.E. To correct the T.E., the desired value can be entered in the respective T.E. fields. By default, the control parameter is "2nd-3rd" which is Modified Roll.

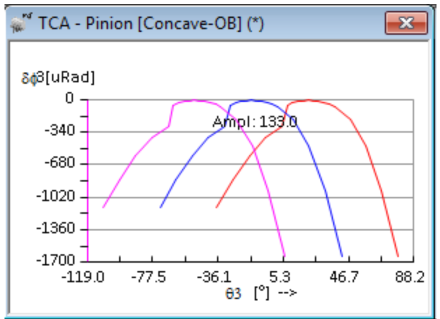
Once the following data is visible in the input form, click on the “Apply” button.

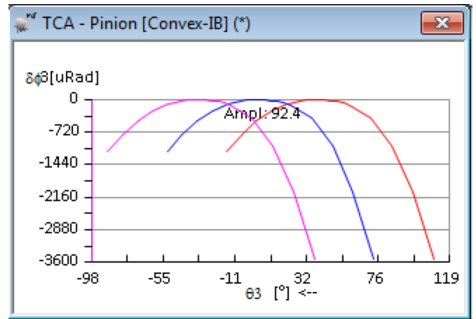


Note: The requested TE will be obtained within 2-3 uRad, *without TopRem,* i.e. HyGEARS temporarily removes TopRem, develops the TE, and then re-installs the TE. However, when TopRem is re-installed, TE is likely to be different from what is obtained without TopRem.

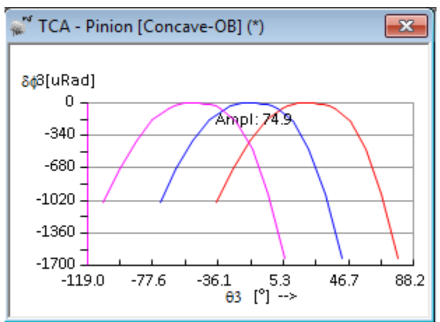
The following results should be obtained, *with TopRem.* As can be seen, TE is above what had been requested.

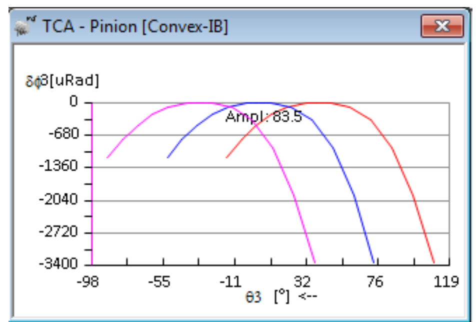






The following results should be obtained, *without TopRem*. As can be seen, TE is just about what had been requested.





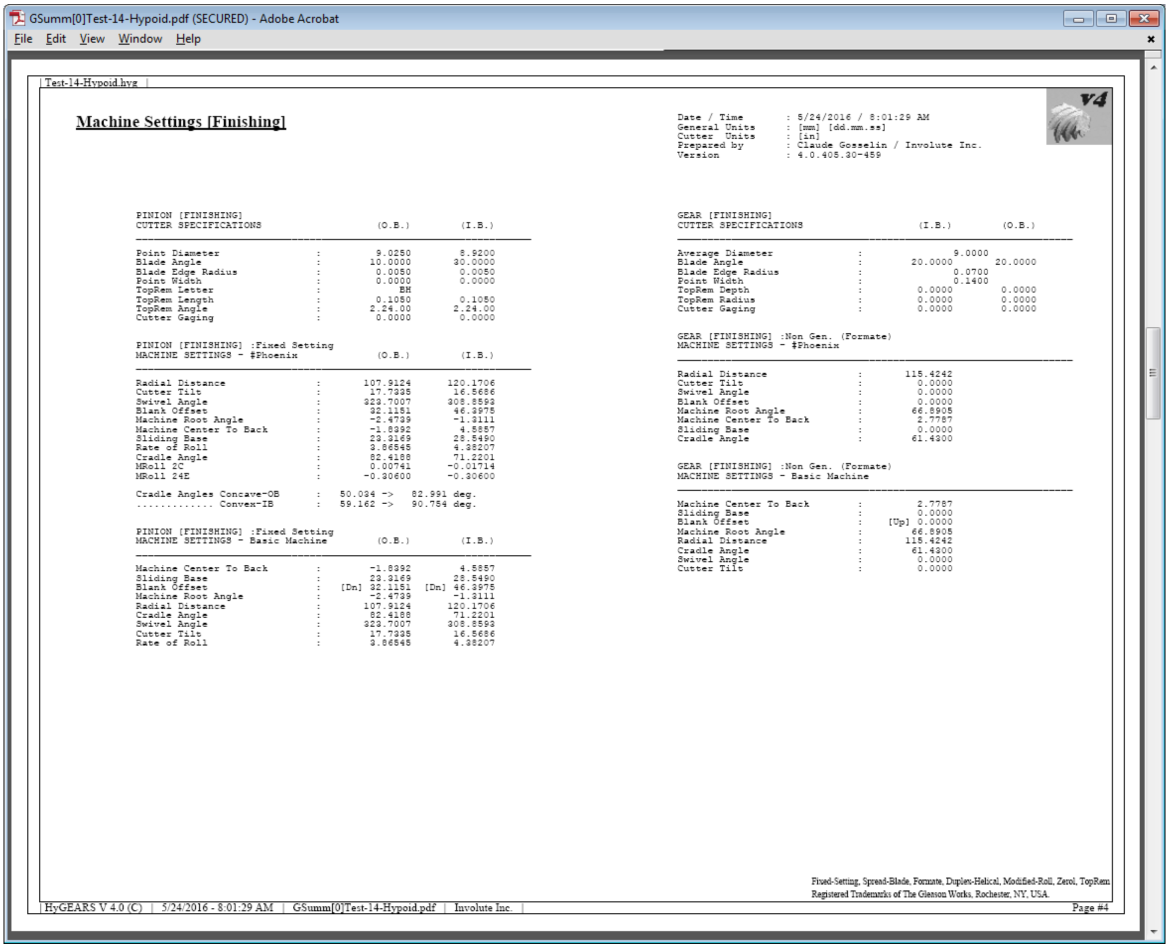
This time, the T.E. curves are adequate on both tooth flanks.

Note 1: The location and size of the Bearing Pattern will affect the value of the J Factors used for bending strength on the Strength Calculations section of the Summary.
In the LTCA algorithm, if the AGMA model is used for Bending Strength, the position of the Bearing Pattern will also affect the J Factor.

Note 2: HyGEARS uses numerical methods to identify the machine settings corresponding to user request. Such numerical methods, although highly flexible, are not bullet-proof.
Therefore, it is a good habit to start with simple a request, such as Horizontal Position. Once this has been obtained, one can add Transmission Error or Bias control, until satisfied with the result.

Note 3: In the above example, we chose to fix the Bias. This choice was dictated by the behavior of the solution under several combinations of constraints. We presented those constraints that produce an adequate result with the given geometry.

The Pinion Finishing Machine Settings appear below. Comparing them to those obtained before Contact Pattern improvement will reveal that about every machine setting has changed.



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Machine Settings [Finishing]

Date / Time : 5/24/2016 / 8:01:29 AM
General Units : [mm] [dd.mm.ss]
Cutter Units : [in]
Prepared by : Claude Gosselin / Involute Inc.
Version : 4.0.405.30-459

PINION [FINISHING]
CUTTER SPECIFICATIONS

		(O.B.)	(I.B.)
Point Diameter	:	9.0250	8.9200
Blade Angle	:	10.0000	30.0000
Blade Edge Radius	:	0.0050	0.0050
Point Width	:	0.0000	0.0000
TopRem Letter	:	BH	
TopRem Length	:	0.1050	0.1050
TopRem Angle	:	2.24.00	2.24.00
Cutter Gaging	:	0.0000	0.0000

PINION [FINISHING] :Fixed Setting
MACHINE SETTINGS - #Phoenix

		(O.B.)	(I.B.)
Radial Distance	:	107.9124	120.1706
Cutter Tilt	:	17.7335	16.5686
Swivel Angle	:	323.7007	308.8593
Blank Offset	:	32.1151	46.3975
Machine Root Angle	:	-2.4739	-1.3111
Machine Center To Back	:	-1.8392	4.5857
Sliding Base	:	23.3169	28.5490
Rate of Roll	:	3.86545	4.38207
Cradle Angle	:	82.4188	71.2201
MRoll 2C	:	0.00741	-0.01714
MRoll 24E	:	-0.30600	-0.30600

Cradle Angles Concave-OB : 50.034 -> 82.991 deg.
.... Convex-IB : 59.162 -> 90.754 deg.

PINION [FINISHING] :Fixed Setting
MACHINE SETTINGS - Basic Machine

		(O.B.)	(I.B.)
Machine Center To Back	:	-1.8392	4.5857
Sliding Base	:	23.3169	28.5490
Blank Offset	:	[Dn] 32.1151	[Dn] 46.3975
Machine Root Angle	:	-2.4739	-1.3111
Radial Distance	:	107.9124	120.1706
Cradle Angle	:	82.4188	71.2201
Swivel Angle	:	323.7007	308.8593
Cutter Tilt	:	17.7335	16.5686
Rate of Roll	:	3.86545	4.38207

GEAR [FINISHING]
CUTTER SPECIFICATIONS

		(I.B.)		(O.B.)
Average Diameter	:		9.0000	
Blade Angle	:	20.0000		20.0000
Blade Edge Radius	:		0.0700	
Point Width	:		0.1400	
TopRem Depth	:	0.0000		0.0000
TopRem Radius	:	0.0000		0.0000
Cutter Gaging	:	0.0000		0.0000

GEAR [FINISHING] :Non Gen. (Formate)
MACHINE SETTINGS - #Phoenix

Radial Distance	:	115.4242
Cutter Tilt	:	0.0000
Swivel Angle	:	0.0000
Blank Offset	:	0.0000
Machine Root Angle	:	66.8905
Machine Center To Back	:	2.7787
Sliding Base	:	0.0000
Cradle Angle	:	61.4300

GEAR [FINISHING] :Non Gen. (Formate)
MACHINE SETTINGS - Basic Machine

Machine Center To Back	:	2.7787
Sliding Base	:	0.0000
Blank Offset	:	[Up] 0.0000
Machine Root Angle	:	66.8905
Radial Distance	:	115.4242
Cradle Angle	:	61.4300
Swivel Angle	:	0.0000
Cutter Tilt	:	0.0000

Fixed-Setting, Spread-Blade, Formate, Duplex-Helical, Modified-Roll, Zerol, TopRem
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| HyGEARS V 4.0 (C) | 5/24/2016 - 8:01:29 AM | GSumm[0]Test-14-Hypoid.pdf | Involute Inc. | Page #4

18.11 New Duplex Helical Hypoid Gear Set

As another example, we will consider the above Hypoid gearset, but this time, we will create a Duplex Helical gearset in order to reduce the number of machines needed in production.

Using HyGEARS to Obtain an Initial Geometry

Therefore, the same data as in the example above will be used, except for the Pinion process:

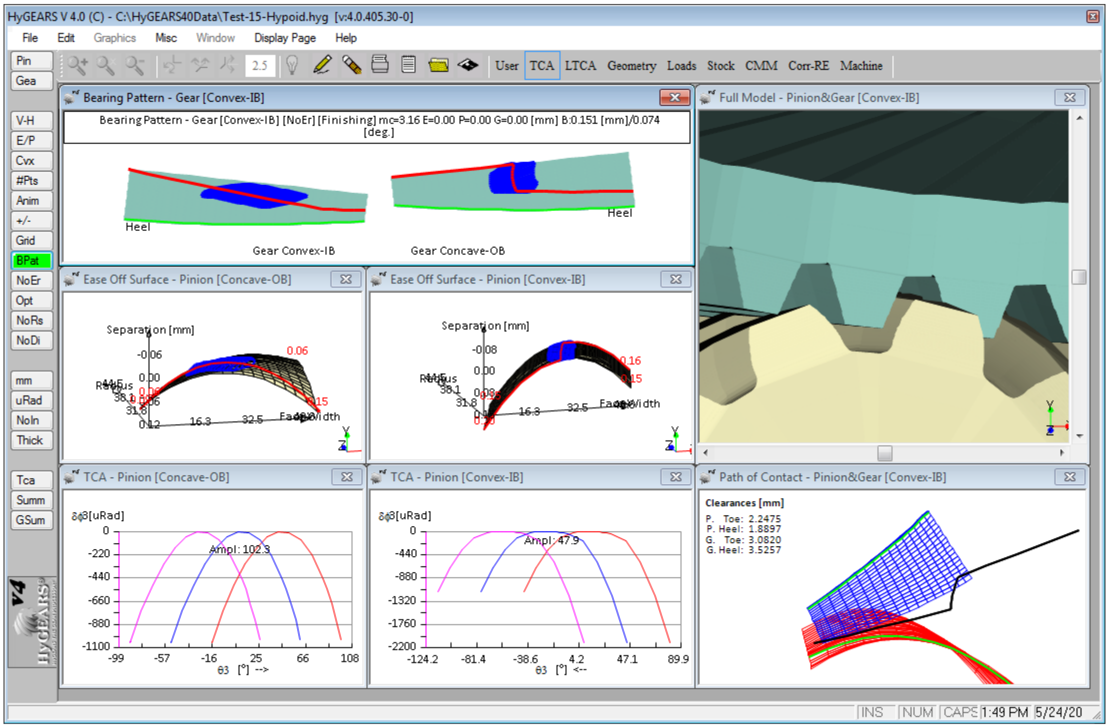
General Data Section:		
Geometry Name:	Let HyGEARS decide	
Directory:	Let HyGEARS decide	
Geometry Type:	Hypoid	
Tooth Taper:	Duplex	
Tooth Hand:	Left	
Tooth Number:	10	41
Tooth Module:	6.8293 [mm]	(25.4 / P, where P = 3.7192)
Tooth Face width:	0	Let HyGEARS calculate.
Shaft Angle:	90.00.00	
Depth Factor	0	Let HyGEARS decide
Addendum Factor	0	Let HyGEARS decide
Clearance Factor	0.0325	
Offset:	38.0 [mm]	
Power:	70 kW	
Speed:	1500 RPM	
Cutter Data Section:		
	Pinion	**Gear**
Machine	Phoenix	Phoenix
Spiral Angle:	50°	
Sum Pressure Angles:	40° (automotive, light duty)	
Stock Allowance:	0.015 [in]	0.015 [in]
Cutter Diameter:	0	Let HyGEARS calculate
Blade Angle:	0	Let HyGEARS calculate
Blade Edge Rad.:	0	Let HyGEARS calculate
Point Width:	0	Let HyGEARS calculate
Mounting Distance:	0	Let HyGEARS calculate
Process:	Duplex Helical	Non Generated

As a first trial, the following Geometry Summary is obtained, the merits of which we will discuss.

Analysis of the Initial Geometry

The figure below shows the initial result produced by HyGEARS. The following points are observed::

- The Contact Pattern on the gear Convex side is shows significant Bias, which should be reduced;
- The Contact Pattern on the Concave side shows some Bias In which could be increased to improve contact ratio;
- The T.E. on both tooth flanks is convex, and of acceptable depth.



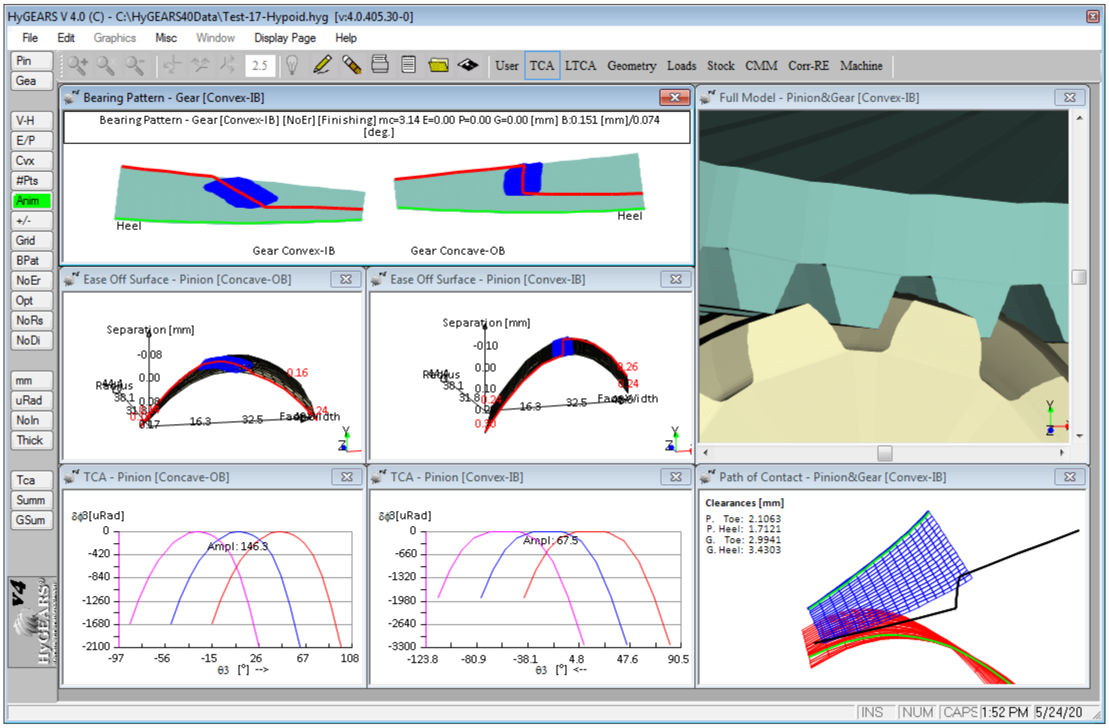
A look at the blade angles for the Gear member ("Gea" function button, to access the Summary Editor; "Cutter" data page) reveals that the IB angle is 28.00.00º while that of the OB side is the complement to 40º, i.e. 12.00.00º.

We will therefore re-create the geometry, this time imposing the blade angles for the Gear member.

When such a situation arises, decreasing the blade angle on the IB while increasing that of the OB normally produces a better Contact Pattern. A change of 2º usually is sufficient to see an improvement.

Improving the Initial Geometry

Using the same parameters as above for input, to the exception of the Gear blade angles: 26.00.00º for the IB and. 14.00.00º for the OB, the geometry is re-created with the result displayed below.

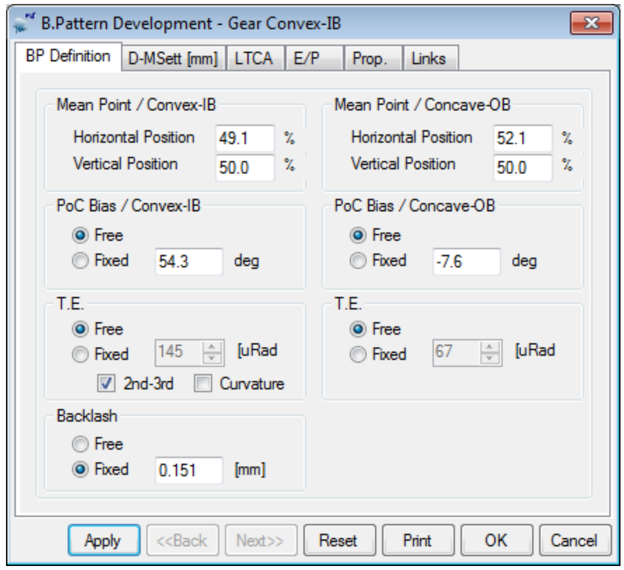


Clearly, the Contact Patterns are located correctly, and the T.E. curves are convex. However, Bias is still significant on the gear Convex flank side We correct this situation using a HyGEARS built in function.

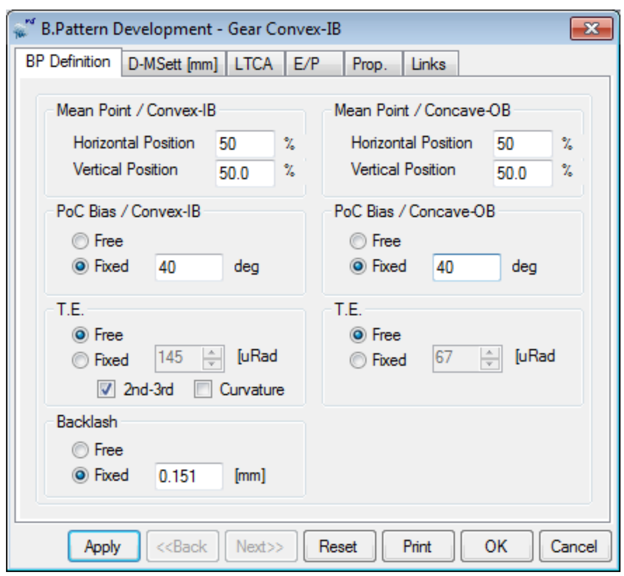
Using HyGEARS to Change Bias

We will now correct the Bias condition on both tooth flanks. To do so, click on the "*BPat*" function button, which will display the Contact Pattern Development selection window, as shown below.

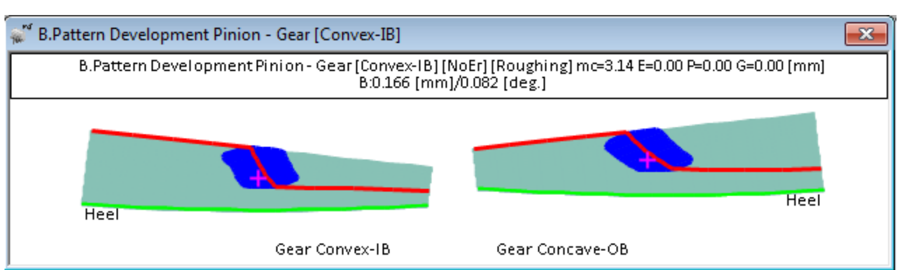
The current location of the Contact Patterns and the current Bias values, for the Drive and Coast tooth flanks, are displayed.



Replace these values by the following, and click on the “Apply” button to initiate the requested modifications:



After a few iterations, HyGEARS displays the following result, where it is now clear that the Contact Patterns have the right shapes and location on the tooth flanks.



18.12 New Duplex Helical Spiral-Bevel Gear Set

As another example, we will consider the following requirements for the design of a new spiral bevel gear set.

Gear tooth type:	Generated
Pinion tooth type:	Generated, Duplex Helical
Pinion Tooth Hand:	Left
Gear Face Width:	~30% of outer cone distance
Speed ratio:	Approximately 1.9:1
Pinion Speed:	1750 RPM
Available diameter space:	About 250 mm (10 in)
Power:	110 kW (~150 HP)
Application:	Automotive

Using HyGEARS to Obtain an Initial Geometry

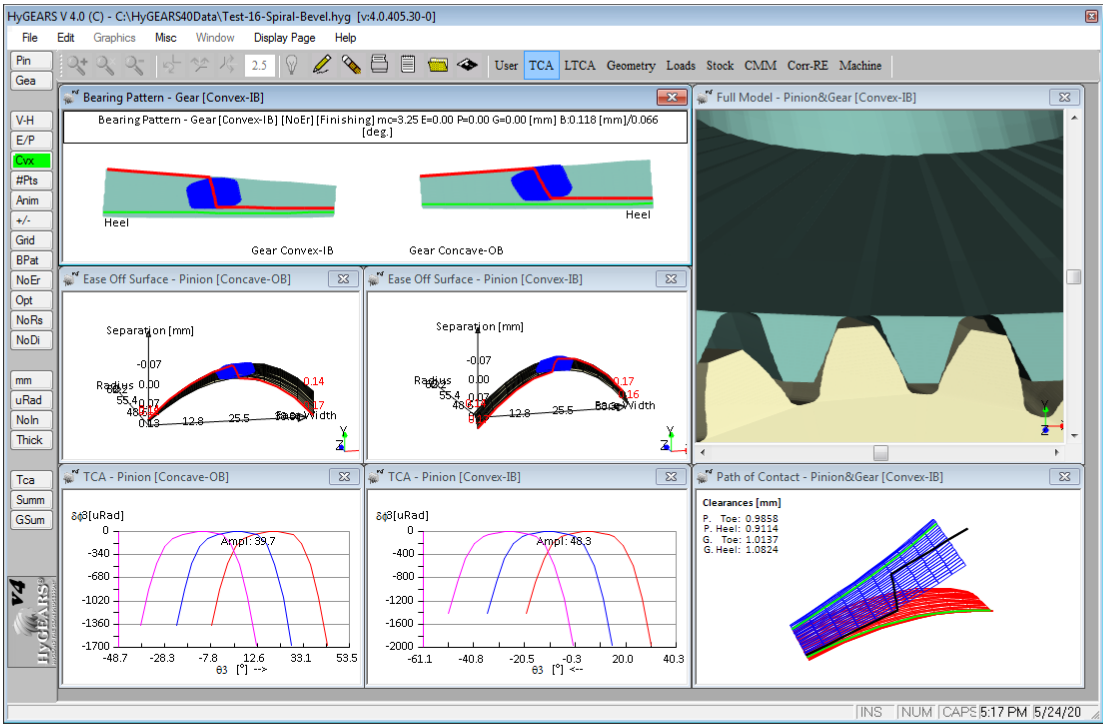
The next step involves using the computer and HyGEARS to create the initial geometry. Since the gear set to design is not constrained by considerations other than to use standard cutting equipment, we will leave HyGEARS do the work of selecting cutter diameters and blade angles on the first run of the New Geometry Definition, and then rerun the New Geometry Definition function using standard values closest to the values suggested by HyGEARS.

Therefore, the following data will be entered in each New Geometry Definition data page:

General Data Section:				
Geometry Name:	Let HyGEARS decide			
Directory:	Let HyGEARS decide			
Geometry Type:	Spiral Bevel			
Tooth Taper:	Duplex Helical			
Material:	4140			
Tooth Hand:	Left			
Tooth Number:	23		44	
Tooth Module:	5.5 [mm]	(25.4 / P, where P = 4.6)		
Tooth Face width:	0	Let HyGEARS calculate.		
Shaft Angle:	90.00.00			
Depth Factor	0	Let HyGEARS decide		
Addendum Factor	0	Let HyGEARS decide		
Clearance Factor	0.125			
Power:	110 kW			
Speed:	1750 RPM			
Cutter Data Section:				
	Pinion		**Gear**	
Machine	Phoenix		Phoenix	
Spiral Angle:	35°			
Sum Pressure Angles:	40°	(light duty)		
Stock Allowance:	0.015 [in]		0.015 [in]	
Cutter Diameter:	0	Let HyGEARS calculate		
Blade Angle:	18.0	22.0	22.0	18.0
Blade Edge Rad.:	0	Let HyGEARS calculate		
Point Width:	0	Let HyGEARS calculate		
Mounting Distance:	0	Let HyGEARS calculate		
Process:	Duplex Helical		Generated	

As a first trial, the following geometry is obtained. Apparently, at first sight, very little needs to be changed to this geometry, unless specific requirements are to be met:

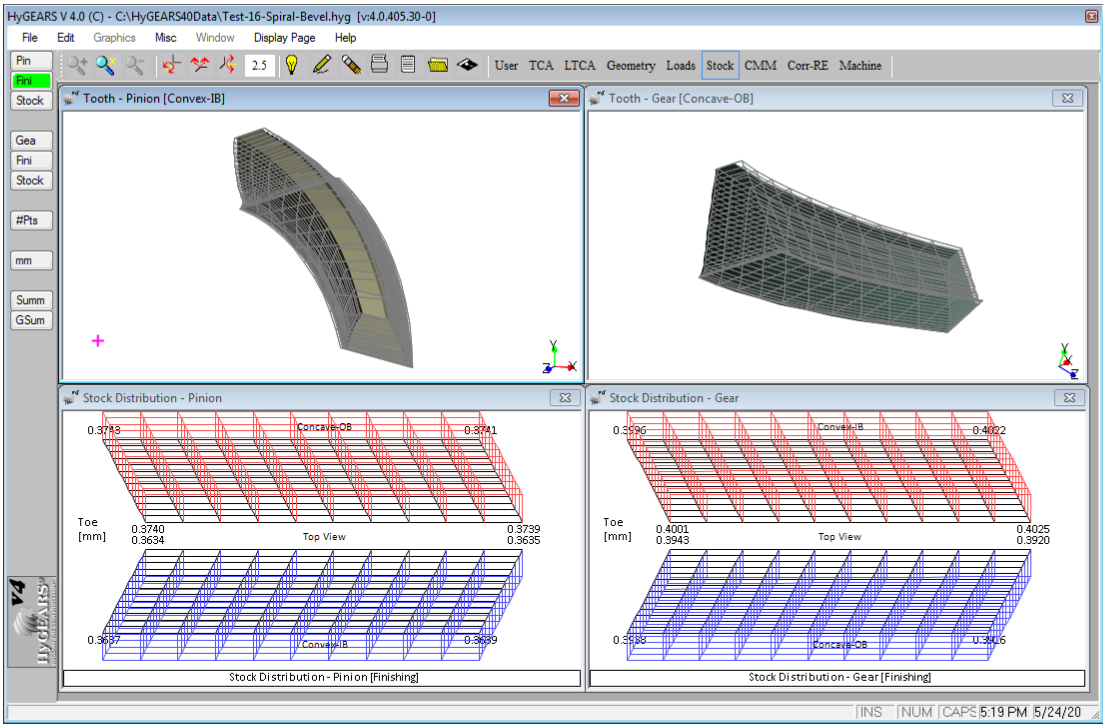
- T.E. is convex, and of adequate depth at ~40 µRad
- The Contact Patterns are well centered on the tooth
- There is adequate relief at Toe and Heel on the Ease Off surfaces.



Stock Distribution (Display Page -> Stock Distribution), figure below, reveals excellent material distribution, in case a Roughing pass is required.

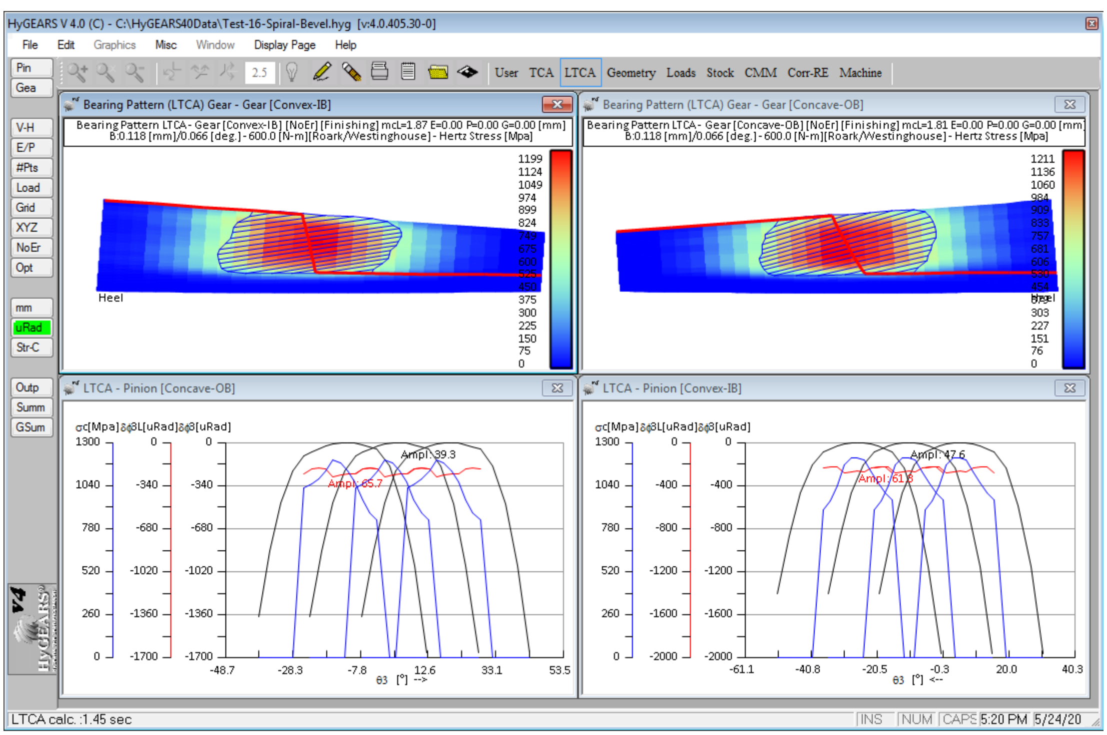
A look at the Stock Distribution

The Duplex Helical process is normally a completing cycle; however, if gears of very high precision are needed, say for instrumentation, or a critical application, or for noise control, the Roughing cut can be followed by a grinding operation. In this case, uniform Stock Distribution, such as the one displayed in the figure below, is a plus as it will extend tool life, and improve the finished product.



A look at the Contact Patterns under Load

Finally, a look at the Contact Pattern under load (Display Page -> BP LTCA) shows that the contact stresses are within acceptable limits.



18.13 New Duplex Helical Spiral-Bevel Gear Set, without Cutter Tilt

As another example, we will consider the re-creating geometry of the previous section, but this time, both the Pinion and Gear cutting machines do not use Cutter Tilt.

This of course reduces the flexibility in controlling the kinematic behavior of the gearset; on the other hand, when no cutter tilt is used, a simple and inexpensive machine such as the Chinese YH-603 can be used, for very economical production.

Gear tooth type:	Generated
Pinion tooth type:	Generated, Duplex Helical
Pinion Tooth Hand:	Left
Gear Face Width:	~30% of outer cone distance
Speed ratio:	Approximately 1.9:1
Pinion Speed:	1750 RPM
Available diameter space:	About 250 mm (10 in)
Power:	110 kW (~150 HP)
Application:	Automotive

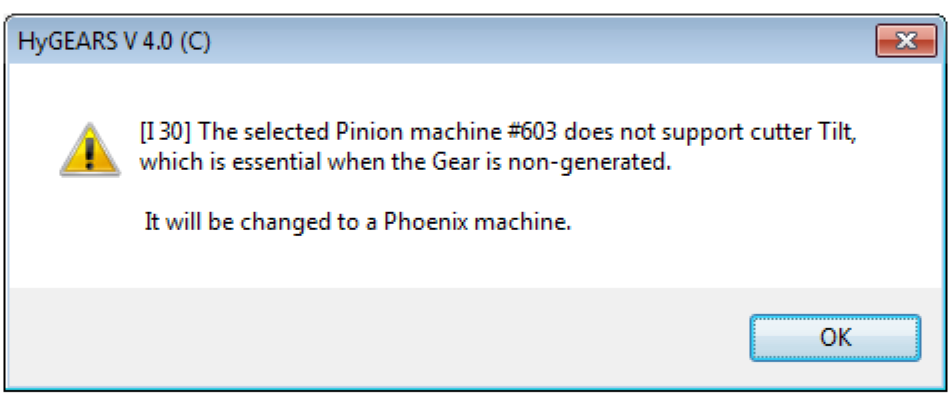
Using HyGEARS to Obtain an Initial Geometry

The next step involves using HyGEARS to create the initial geometry. Since the gear set to design is not constrained by considerations other than to use standard cutting equipment, we will leave HyGEARS do the work of selecting cutter diameters and blade angles on the first run of the New Geometry Definition, and then rerun the New Geometry Definition function using standard values closest to the values suggested by HyGEARS.

Therefore, the following data will be entered in each New Geometry Definition data page:

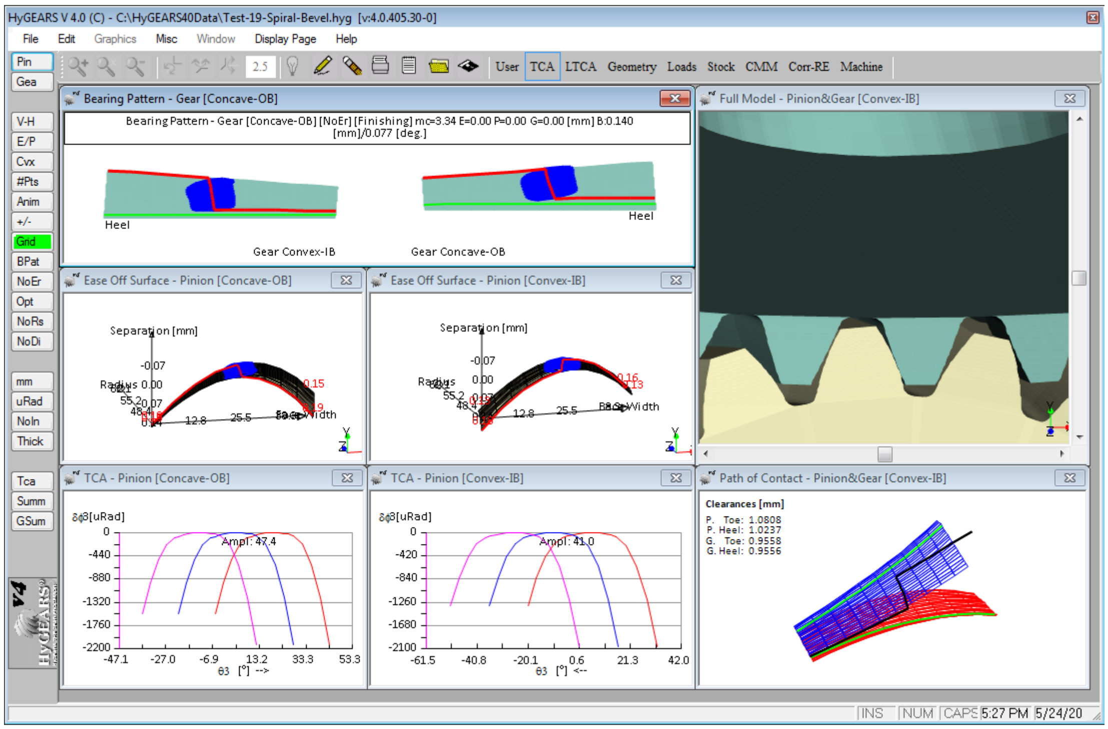
General Data Section:				
Geometry Name:	Let HyGEARS decide			
Directory:	Let HyGEARS decide			
Geometry Type:	Spiral Bevel			
Tooth Taper:	Duplex Helical			
Material:	4140			
Tooth Hand:	Left			
Tooth Number:	23		44	
Tooth Module:	5.5 [mm]	(25.4 / P, where P = 4.6)		
Tooth Face width:	0	Let HyGEARS calculate.		
Shaft Angle:	90.00.00			
Depth Factor	0	Let HyGEARS decide		
Addendum Factor	0	Let HyGEARS decide		
Clearance Factor	0.125			
Power:	110 kW			
Speed:	1750 RPM			
Cutter Data Section:				
	Pinion		**Gear**	
Machine	YH-603		YH-603	
Spiral Angle:	35°			
Sum Pressure Angles:	40°	(light duty)		
Stock Allowance:	0.015 [in]		0.015 [in]	
Cutter Diameter:	0	Let HyGEARS calculate		
Blade Angle:	18.0	22.0	22.0	18.0
Blade Edge Rad.:	0	Let HyGEARS calculate		
Point Width:	0	Let HyGEARS calculate		
Mounting Distance:	0	Let HyGEARS calculate		
Process:	Duplex Helical		Generated	

Note that in the above, the select machine for the Pinion and Gear is the YH-603. When such a choice is made for a non-generated gear set, HyGEARS displays the message shown below to notify the user of the consequences of such a choice.



As a first trial, the following geometry is obtained. Apparently, at first sight, very little needs to be changed to this geometry, unless specific requirements are to be met:

- T.E. is convex, and of adequate depth at ~47 µRad on the Drive side, and 41 µRad on the Coast side;
- The Contact Patterns are well centered on the tooth;
- Slight Bias is visible on both flanks;
- There is adequate relief at Toe and Heel on the Ease Off surfaces.

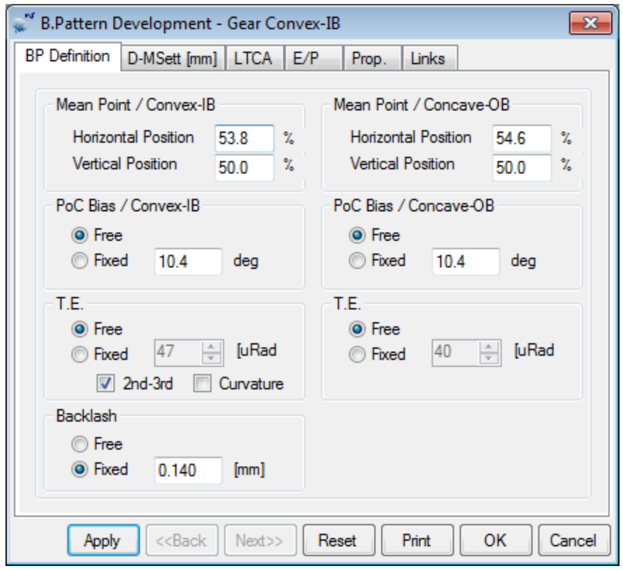


Note that when HyGEARS creates a geometry without Cutter Tilt, the Pinion blade angles are adjusted to compensate for the lack of tilt. Therefore, the Pinion blade angles are likely to be quite different from those of the Gear.

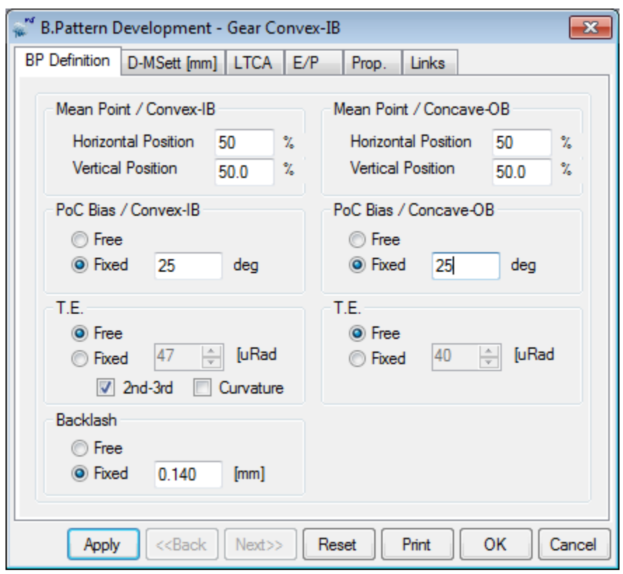
Using HyGEARS to Change Bias

We will now modify the Bias condition on the tooth flanks. To do so, click on the “BPat” function button, which will display the Contact Pattern Development selection window, as shown below.

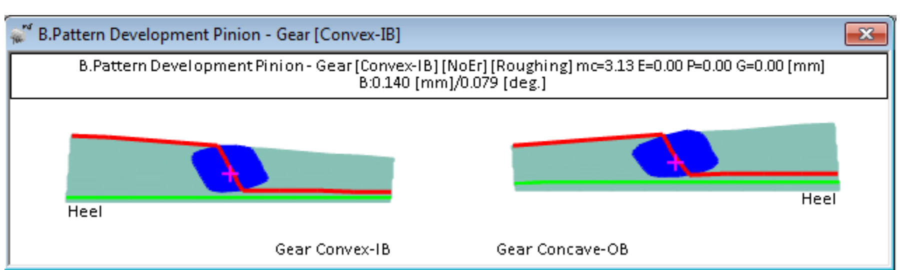
The current location of the Contact Patterns and the current Bias values, for the Drive and Coast tooth flanks, are displayed.



Replace these values by the following, and click on the “Apply” button to initiate the requested modifications:

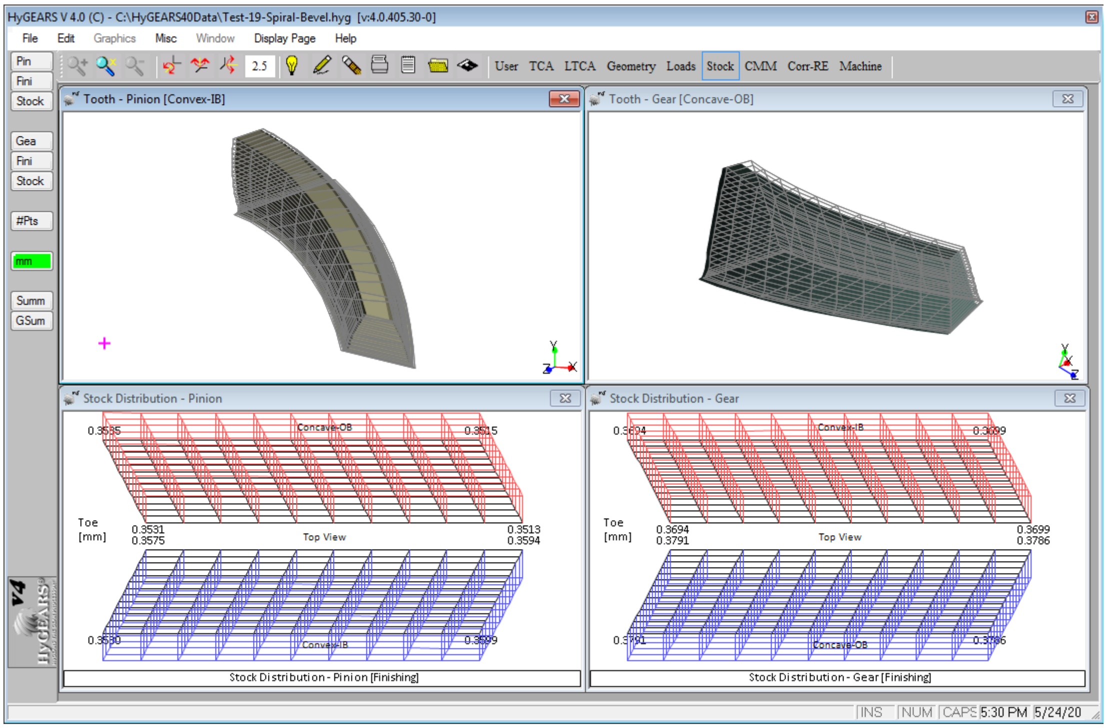


After a few iterations, HyGEARS displays the following result, where it is now clear that the Contact Patterns have the right shapes and location on the tooth flanks.



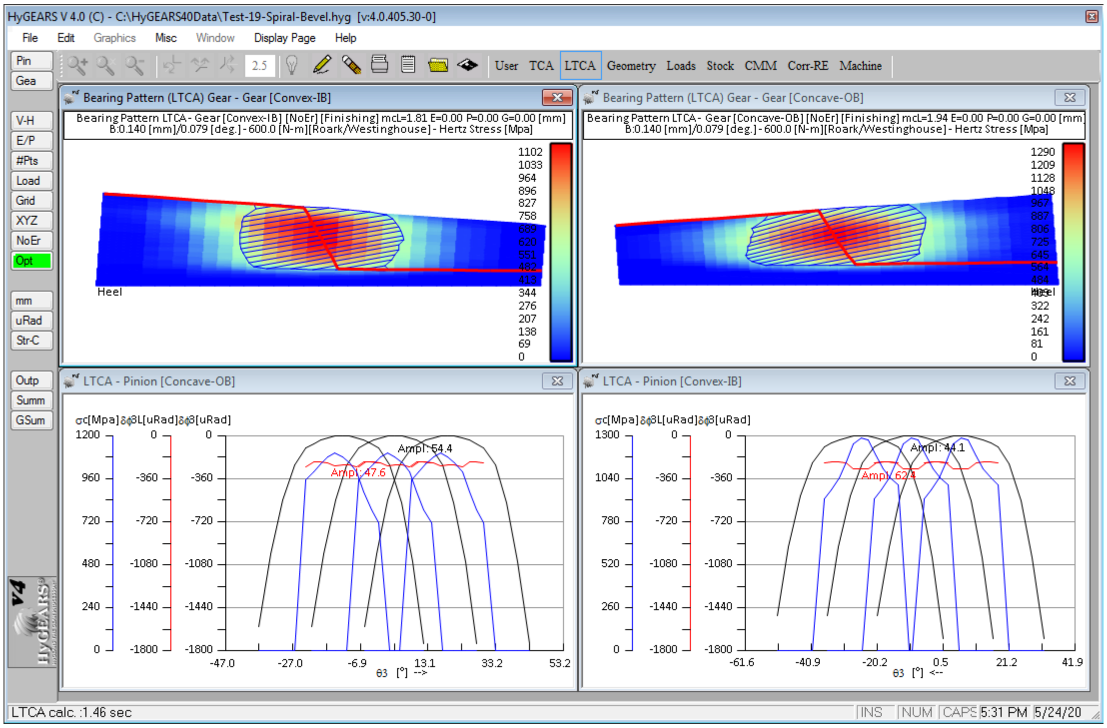
A look at the Stock Distribution

A look at the Stock Distribution (Display Page -> Stock Distribution), figure below, reveals excellent material distribution, in case a Roughing pass is needed.



A look at the Contact Patterns under Load

Finally, a look at the Contact Pattern under load (Display Page -> BP LTCA) shows that the contact stresses are within acceptable limits.



18.14 New Straight-Bevel Gear Set

As another example, we will consider the following requirements for the design of a new Straight-Bevel gear set to be used in a small angle grinder.

It is assumed the gears will be forged in order to reduce costs.

Gear tooth type:	Generated
Pinion tooth type:	Generated
Pinion Tooth Hand:	Left (in fact, it is unused)
Gear Face Width:	30% of outer cone distance
Speed ratio:	Approximately 3.5:1
Pinion motor speed:	3000 RPM
Available gear diameter:	About 50.0 mm (~2 in)
Power:	1.1 kW (1.5 HP)
Application:	Hand power tool
Material:	Sintered (powder metallurgy) use

Preliminary Dimensions

From the considerations of minimum pinion tooth number, available gear diameter space, and non-exact speed ratio, the following value range may prove useable:

- 19 to 20 diametral pitch ;
- 9 to 11 tooth pinion ;
- 35 to 38 tooth gear;
- speed ratio of ~3.5.

These values should respect the gear diameter space condition, a speed ratio which is not an exact number, and an uneven pinion tooth number.

Using HyGEARS to Obtain an Initial Geometry

The next step involves using the computer and HyGEARS to create the initial geometry. Since the gear set to design is not constrained by considerations other than to use standard cutting equipment, we will leave HyGEARS do the work of selecting the Facewidth on the first run of the New Geometry Definition, and then modify the New Geometry Definition using different values if needed.

Therefore, the following data will be entered in each New Geometry Definition data page:

General Data Section:		
Geometry Name:	Let HyGEARS decide	
Directory:	Let HyGEARS decide	
Geometry Type:	Straight Bevel (Generated)	
Material:	AGMA A-3	
	Pinion	**Gear**
Tooth Number:	11	38
Module:	1.55 [mm] (25.4 / P, where P = 16.38)	
Tooth Face width:	0 Let HyGEARS calculate.	
Shaft Angle:	90.00.00	
Depth Factor:	0 Leave HyGEARS use default value.	
Addendum Factor:	0 Leave HyGEARS use default value.	
Clearance Factor:	0 Leave HyGEARS use default value.	
Power:	1.1 kW	
Speed:	3000 RPM	
Cutter Data Section:		
	Pinion	**Gear**
Helix Angle:	0	
Pressure Angle:	22.30.00	22.30.00
Backlash:	0.05 mm	

As a first trial, the following Geometry Summary is obtained, the merits of which we will discuss. Note that above, a large Pressure Angle was selected to limit undercutting on the pinion, given the low number of teeth in the Pinion.

Analysis of the Initial Geometry

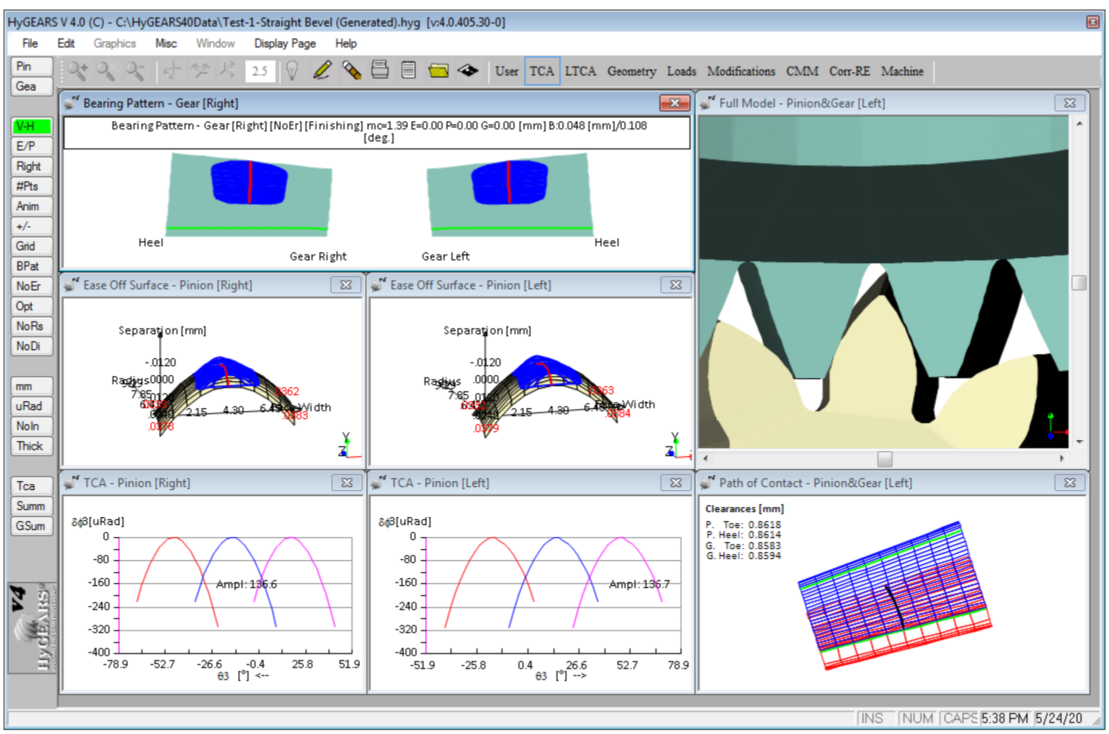
HyGEARS can produce a “net shape” tooth for Straight Bevel gears, i.e., a tooth that is applicable to forging.

This tooth geometry uses:

- Crowning on the Gear member to center the contact along the facewidth;
- Modified Roll to control the Transmission Error;
- Tip relief on the Pinion and Gear cutter blades.

Therefore, such gears cannot be manufactured by existing Straight Bevel gear machines, but may be forged since the topography of the teeth is known and can be used to manufacture dies.

Using the above entered data, HyGEARS produces the result displayed below.



The following comments apply:

- The Contact Patterns are centrally located, and cover about 50% of the tooth flanks;

- The T.E. curves are convex, and exhibit some transmission error (~ 135 µRad) at the transfer point; contact ratio is 1.39, and sufficient for the application, although higher contact ratio is always preferable (a spiral-bevel gearset would provide this);
- The root clearance appears sufficient on both the Pinion and Gear.

Overall, the gearset kinematics appear Ok at this early stage.

Strength Calculations

The Strength Calculations section of the Summary provide the expected behavior of the teeth under load, as calculated using standard methods.

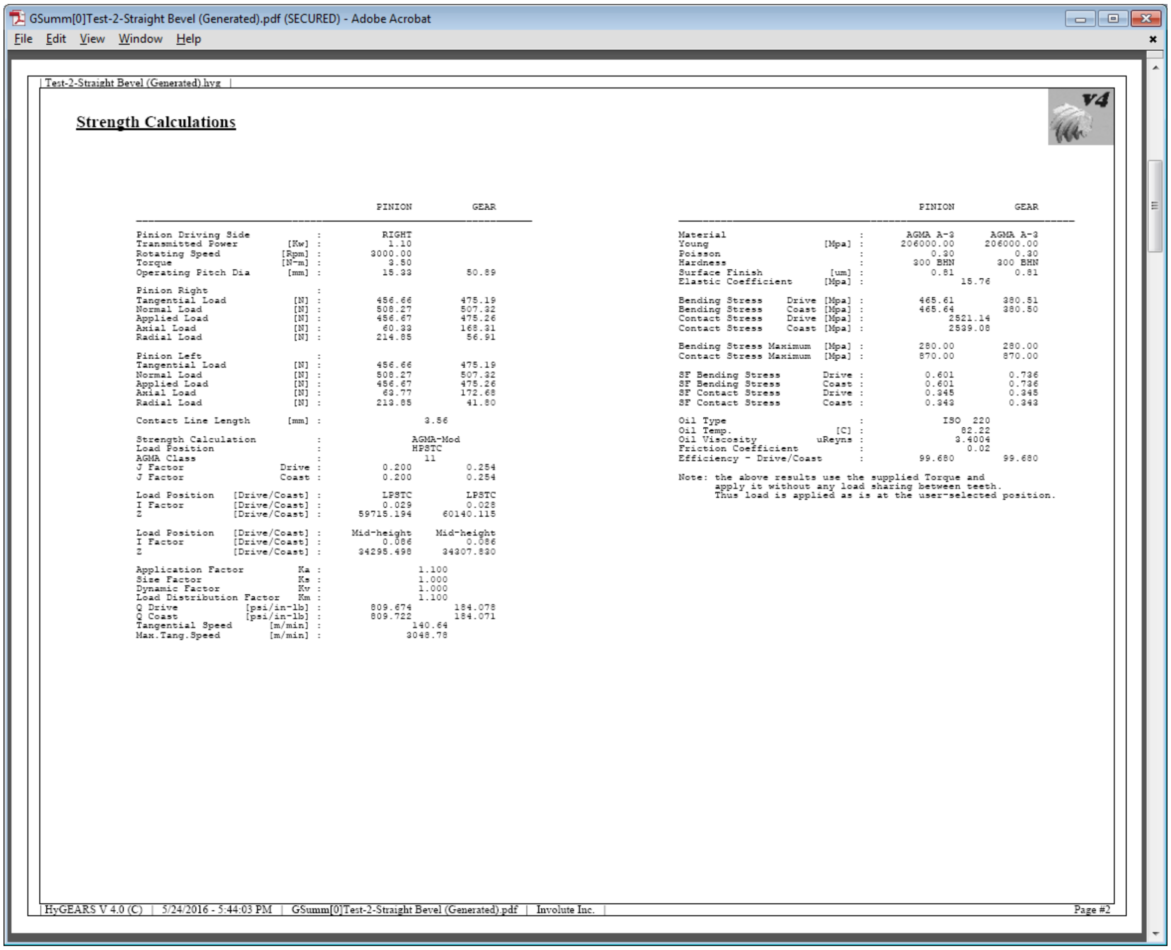
In HyGEARS, the following are the default values:

- Bending stresses are to be calculated at the HPSTC for Straight Bevel gears;
- Load Application factor Ka = 1.1
- Load distribution factor Km = 1.1
- Size factor Kx is calculated by HyGEARS
- Dynamic facor Kv is calculated by HyGEARS

The following points are observed:

· the bending stress, calculated at the HPSTC (highest point of single tooth contact) on the pinion member is slightly larger than that on the gear member; it is also below the maximum for the selected material;

· using the same Application Factors, the calculated contact stresses are significantly above the maximum for the material. However, the maximum contact stress given in the Material file does not account for hardening; depending on the hardening process used, the maximum contact stress could be significantly higher.


GSumm[0]Test-2-Straight Bevel (Generated).pdf (SECURED) - Adobe Acrobat

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Test-2-Straight Bevel (Generated).hyg

Strength Calculations

		PINION	GEAR
Pinion Driving Side	:	RIGHT	
Transmitted Power	[Kw] :	1.10	
Rotating Speed	[Rpm] :	3000.00	
Torque	[N-m] :	3.50	
Operating Pitch Dia	[mm] :	15.33	50.89
Pinion Right	:		
Tangential Load	[N] :	456.66	475.19
Normal Load	[N] :	508.27	507.32
Applied Load	[N] :	456.67	475.26
Axial Load	[N] :	60.33	168.31
Radial Load	[N] :	214.85	56.91
Pinion Left	:		
Tangential Load	[N] :	456.66	475.19
Normal Load	[N] :	508.27	507.32
Applied Load	[N] :	456.67	475.26
Axial Load	[N] :	63.77	172.68
Radial Load	[N] :	213.85	41.80
Contact Line Length	[mm] :	3.56	
Strength Calculation	:	AGMA-Mod	
Load Position	:	HPSTC	
AGMA Class	:	11	
J Factor	Drive :	0.200	0.254
J Factor	Coast :	0.200	0.254
Load Position	[Drive/Coast] :	LPSTC	LPSTC
I Factor	[Drive/Coast] :	0.029	0.028
Z	[Drive/Coast] :	59715.194	60140.115
Load Position	[Drive/Coast] :	Mid-height	Mid-height
I Factor	[Drive/Coast] :	0.086	0.086
Z	[Drive/Coast] :	34295.498	34307.830
Application Factor	Ka :	1.100	
Size Factor	Ks :	1.000	
Dynamic Factor	Kv :	1.000	
Load Distribution Factor	Km :	1.100	
Q Drive	[psi/in-lb] :	809.674	184.078
Q Coast	[psi/in-lb] :	809.722	184.071
Tangential Speed	[m/min] :	140.64	
Max.Tang.Speed	[m/min] :	3048.78	

		PINION	GEAR
Material	:	AGMA A-3	AGMA A-3
Young	[Mpa] :	206000.00	206000.00
Poisson	:	0.30	0.30
Hardness	:	300 BHN	300 BHN
Surface Finish	[um] :	0.81	0.81
Elastic Coefficient	[Mpa] :	15.76	
Bending Stress	Drive [Mpa] :	465.61	380.51
Bending Stress	Coast [Mpa] :	465.64	380.50
Contact Stress	Drive [Mpa] :	2521.14	
Contact Stress	Coast [Mpa] :	2539.08	
Bending Stress Maximum	[Mpa] :	280.00	280.00
Contact Stress Maximum	[Mpa] :	870.00	870.00
SF Bending Stress	Drive :	0.601	0.736
SF Bending Stress	Coast :	0.601	0.736
SF Contact Stress	Drive :	0.345	0.345
SF Contact Stress	Coast :	0.343	0.343
Oil Type	:	ISO 220	
Oil Temp.	[C] :	82.22	
Oil Viscosity	uReyns :	3.4004	
Friction Coefficient	:	0.02	
Efficiency - Drive/Coast	:	99.680	99.680

Note: the above results use the supplied Torque and apply it without any load sharing between teeth. Thus load is applied as is at the user-selected position.

HyGEARS V 4.0 (C) | 5/24/2016 - 5:44:03 PM | GSumm[0]Test-2-Straight Bevel (Generated).pdf | Involute Inc. | Page #2

In HyGEARS, contact stresses are calculated using Hertz' theory applied to the knowledge of the exact curvatures at the Lowest Point of Single Tooth Contact (LPSTC) on the Pinion tooth flank.

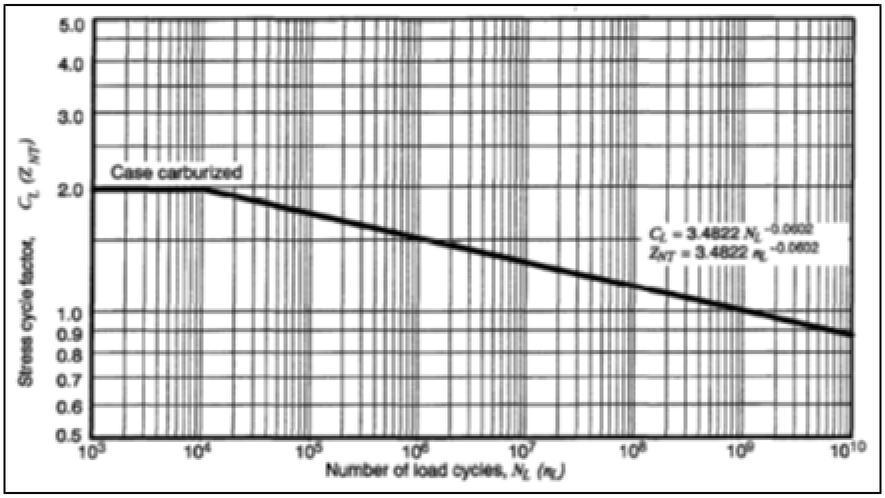
At first sight, the calculated contact stresses at ~1.7 GPa do not seem to provide sufficient capacity for the select material, which suggests 0.87 GPa (in unhardened state).

However, gears in hand tools are not designed for an infinite life and therefore do not accumulate the same number of cycles as gears in normal duty.

For example, if the above angle grinder was designed for a 50 hour life, it would accumulate 9,000,000 cycles on the pinion, and 2,600,000 on the gear; thus, on the pinion, according to the figure below, acceptable contact stresses on the material could be increased by about 50%.

In addition, angle grinders are not always operated at full power; therefore, knowing the duty cycle would allow to further define the actual life expectancy for contact stresses.

The following graph shows the Life Cycle factor for contact stresses, as a function of the number of cycles; it is clear that for a low number of cycles, such as what is experienced in hand power tools gears, the contact stresses may be much higher.



A Look at the Contact Pattern under Load

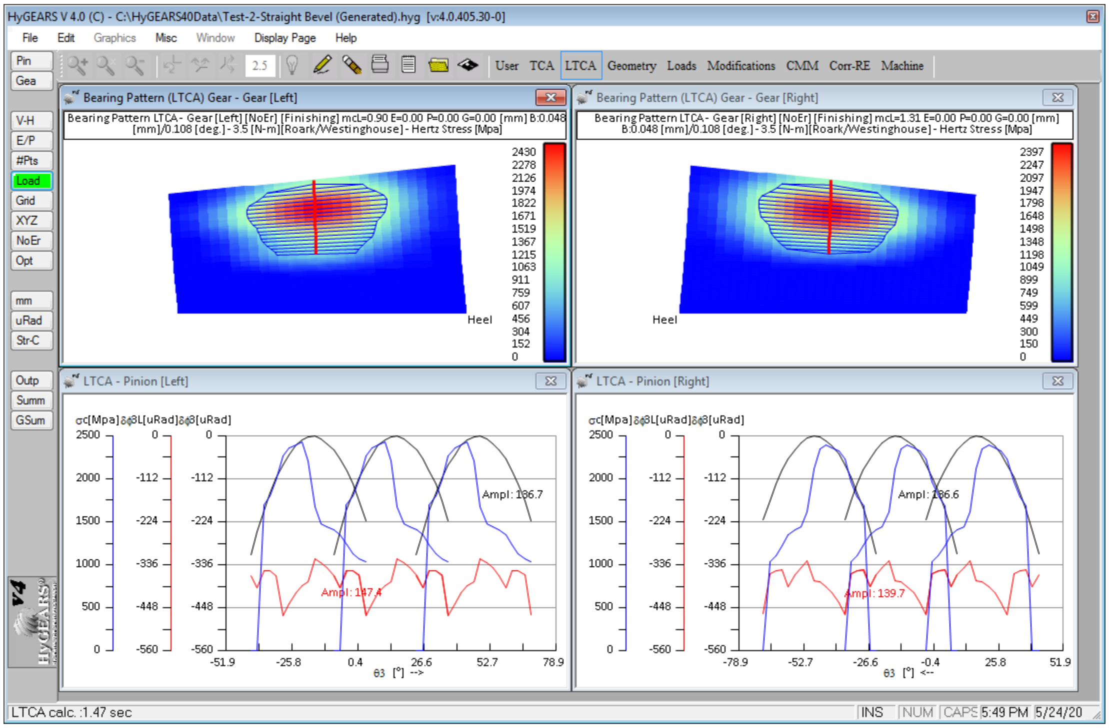
The operations performed before led to the design of a gear set with adequate Contact Pattern when operated without load. We will now look at the shape of the gear Bearing under full load, and the corresponding Transmission Error curves.

The figures below respectively show the gear Contact Patterns when the full torque is applied to the gear set. In the following, the Westinghouse formula is used as the Stiffness model.

It is readily apparent that no toe or heel edge contact occurs, thanks to the crowning on the gear tooth. Maximum contact stresses, at ~2.4 GPa, are comparable to what is given in the Strength Calculations of the Summary; since the max. contact stress occurs at pinion fillet, therefore at contact entry, some measure of load sharing happens, although with a contact ratio of 1.35, not much in terms of load sharing is really going on.

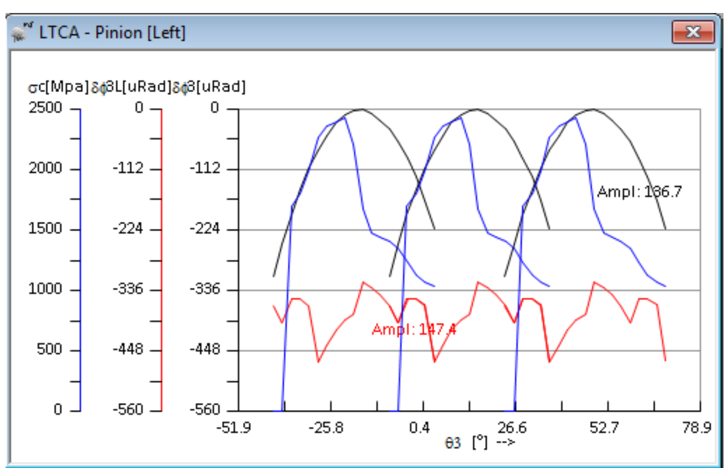
In the Strength Calculations, the contact stress is calculated at the LPSTC, accounting for local curvatures on the pinion and gear teeth; in addition, the application factors Ka, Ks, Km, Kv are used; in the present case, the size factor Ks = 0.5, such that the calculated contact stressshould be *diminished* when compared to the raw value; but no load sharing is accounted for, and therefore the calculated stress should be somewhat higher.

In the display below, load sharing between neighbouring teeth is established, and then the calculated tooth load is applied to the local curvatures to determine the contact stress, *without any application factor.*



The figure below shows the Transmission Error curves, without load (black lines) and under full torque (red lines).

This graph reveals that the Transmission Error curve under full load, $\delta\phi_{3L}$ (red curve), is *below* the unloaded Transmission Error ($\delta\phi_3$) level at contact entry, which means that contact will occur in the contact entry and exit area of the tooth, a detrimental situation especially since contact stresses are usually higher at the bottom of the tooth where radius of curvature is minimum.

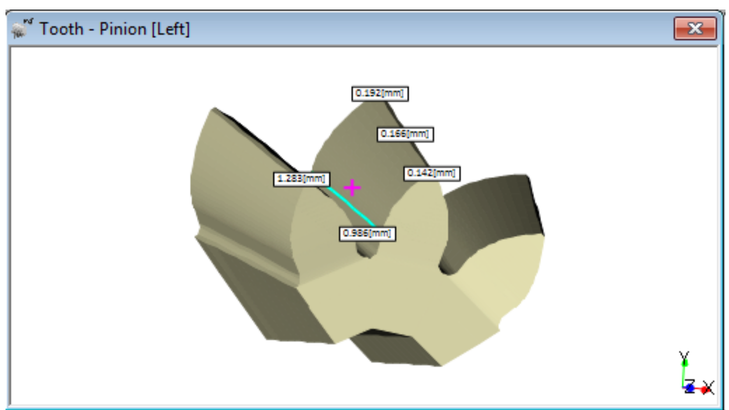


Reducing the Contact Stresses in Straight Bevel Gear Teeth

In order to reduce contact stresses in Straight-Bevel gear teeth, several approaches may be used:

- Reduce the specific load, i.e. decrease torque or increase module;
- Reduce crowning, such as to have a less localized contact pattern; this may be detrimental if significant misalignment is expected under load, as contact can reach toe or heel tooth edge and produce localized stress concentration; in HyGEARS, crowning defaults to Module / 50 [mm];
- Increase the crowning order, from the default value of 2 to 3; this results in a longer tooth area that is linear, and concentrates the relief closer to the toe and heel edges;
- Increase profile relief at tooth fillet; to be effective, contact ratio should be at least 1.5 to 1.6; here we have ~1.3, which is insufficient for profile relief to show any significant effect.

However, this is highly dependent on the number of teeth in the pinion; in the current case, with 11 teeth, the pinion is clearly at the undercutting limit, as shown in the figure below where the light blue line is at the fillet limit. Therefore, the profile radius of curvature is not affected by changes in crowning, and a reduction in contact stress cannot be obtained otherwise than by reducing the applied load.



18.15 New External Helical Gear Set

As a further example, we will consider the following requirements for the design of an external helical gear set to be used in a power generator.

Gear tooth type:	Generated
Pinion tooth type:	Generated
Pinion Tooth Hand:	Right
Gear Face Width:	160 mm (based on previous experience)
Speed ratio:	Approximately 3:1
Pinion speed:	600 RPM

Available gear diameter:	About 900.0 mm (~35.5 in)
Power:	1,200 kW (1600 HP)
Application:	Power generation
Material:	4340

Preliminary Dimensions

From the considerations of minimum pinion tooth number, available gear diameter space, transmitted power, and non-exact speed ratio, the following value range may prove useable:

- 1.9 to 2.0 diametral pitch ;
- 19 to 21 tooth pinion ;
- 56 to 61 tooth gear;
- speed ratio of ~3.0:1

These values should respect the gear diameter space condition, a speed ratio which is not an exact number, and an uneven pinion tooth number.

Using HyGEARS to Obtain an Initial Geometry

The next step involves using the computer and HyGEARS to create the initial geometry. Since the gear set to design is not constrained by considerations other than to use standard cutting equipment, we will leave HyGEARS do the work of selecting the Facewidth on the first run of the New Geometry Definition, and then modify the New Geometry Definition using different values if needed.

Therefore, the following data will be entered in each New Geometry Definition data page:

General Data Section:

Geometry Name:	Let HyGEARS decide	
Directory:	Let HyGEARS decide	
Geometry Type:	Ext. Spur-Helical	
Material:	AISI 4340	
Pinion Tooth Hand:	Right	
Epicyclic Gear:	No	
	Pinion	**Gear**
Tooth Number:	19	56
Module:	14 [mm] (25.4 / P, where P = 1.8)	
Tooth Face width:	160 [mm]	
Number of Planets:	0	
Shaft Angle:	0.00.00	
Power:	1500 kW	
Speed:	600 RPM	

Cutter Data Section:

	Pinion	**Gear**
Helix Angle:	22.00.00 (to have as high a contact ratio as possible)	
Pressure Angle:	20.00.00	20.00.00
X Factor:	0	0
Addendum Factor:	1.00	1.00
Dedendum Factor:	1.25	1.25
Fillet Factor:	0.25	0.25

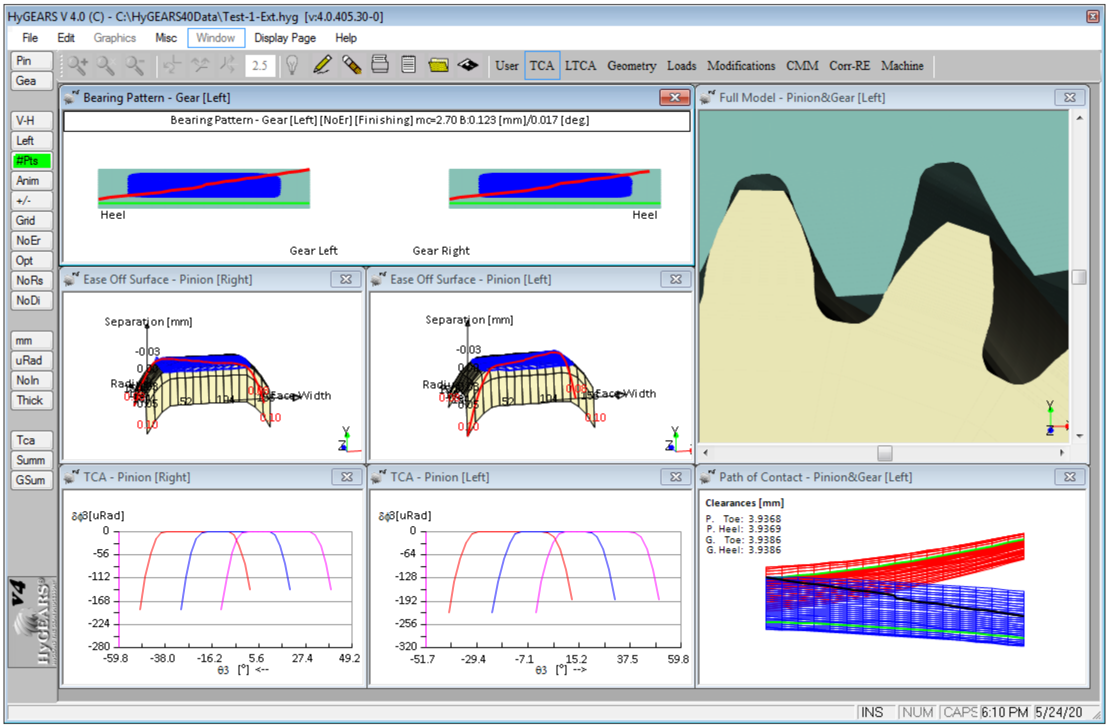
As a first trial, the following Geometry Summary is obtained, the merits of which we will discuss.

Analysis of the Initial Geometry

HyGEARS produces a gear set with the following characteristics, by default:

- Crowning on the Gear member to center the contact along the facewidth; crowning amounts to Module / 200 [mm]
- Tip relief on the Pinion and Gear cutter blades; relief amounts to 10% of tooth height.

Using the above entered data, HyGEARS produces the result displayed below.



The following comments apply:

- The Contact Patterns are centrally located, and cover about 80% of the tooth flanks;
- The T.E. curves are convex, and exhibit no transmission error in the center of the tooth; relief, produced by Crowning and Blade tip relief, is clearly visible in the Transmission error curve and on the Ease Off surfaces;
- The Pinion fillet area, below the green line, appears rather high when compared to that of the gear; this will reduce tooth bending strength and therefore, if would be wise to redesign this gear set with profile shift factors (X Factor in the input);
- The root clearance appears sufficient on both the Pinion and Gear;
- Contact Ratio, at 2.70, is sufficient; it would be nice to have an integer Contact Ratio, but this means either increasing the Facewidth, thus the space used, or the Helix angle, and therefore the reactions at the bearings. In absence of more data, we will leave the Facewidth as is at this time.

Otherwise, the gearset kinematics appear Ok at this early stage.

Redesign of the Initial Geometry

We will re-enter the previous data, but this time we include a profile-shift factor, or X Factor, of 0.3 on the Pinion and -0.3 on the Gear, such as not to change the Center Distance.

General Data Section:

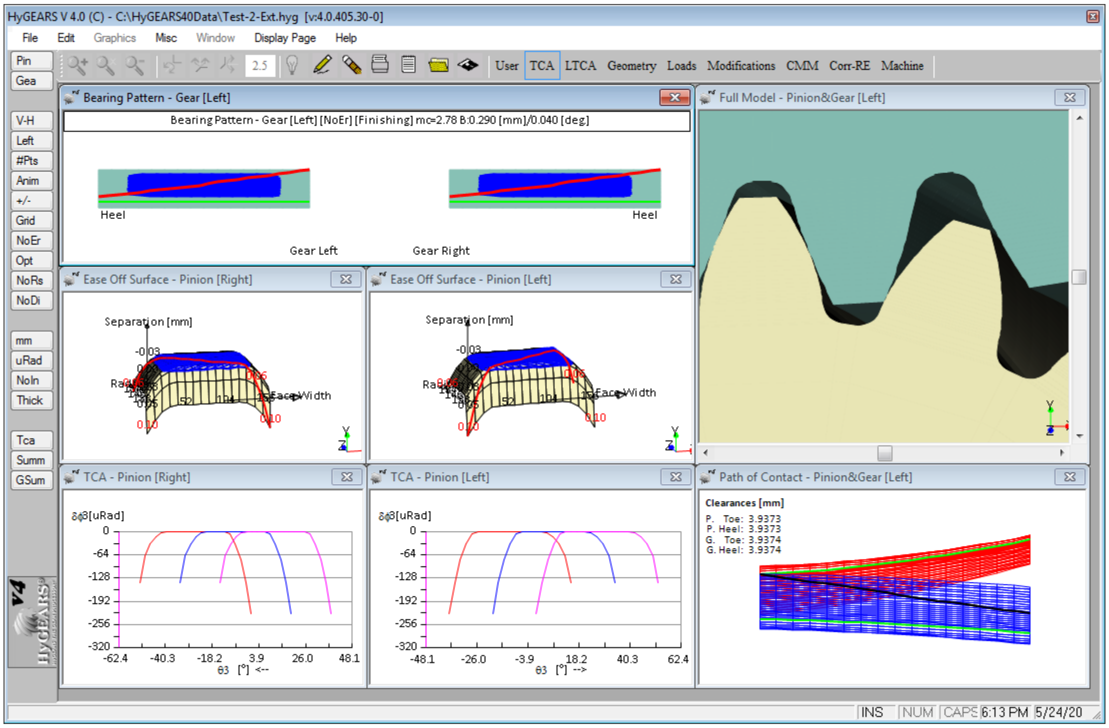
Geometry Name:	Let HyGEARS decide	
Directory:	Let HyGEARS decide	
Geometry Type:	Ext. Spur-Helical	
Material:	AISI 4340	
Pinion Tooth Hand:	Right	
Epicyclic Gear:	No	
	Pinion	**Gear**
Tooth Number:	19	56
Module:	14 [mm]	(25.4 / P, where P = 1.8)
Tooth Face width:	160 [mm]	
Number of Planets:	0	
Shaft Angle:	0.00.00	
Power:	1500 kW	
Speed:	600 RPM	

Cutter Data Section:

	Pinion	**Gear**
Helix Angle:	22.00.00 (to have as high a contact ratio as possible)	
Pressure Angle:	20.00.00	20.00.00
X Factor:	0.3	-0.3
Addendum Factor:	1.00	1.00
Dedendum Factor:	1.25	1.25
Fillet Factor:	0.25	0.25

The following Geometry Summary is obtained.

The following Geometry Summary is obtained.



It is clear that the fillet area of the Pinion tooth is now much shallower, and should not influence tooth strength adversely.

Otherwise, the tooth dimensions and kinematics appear Ok at first sight.

Strength Calculations

The Strength Calculations section of the Summary provide the expected behavior of the teeth under load, as calculated using standard methods.

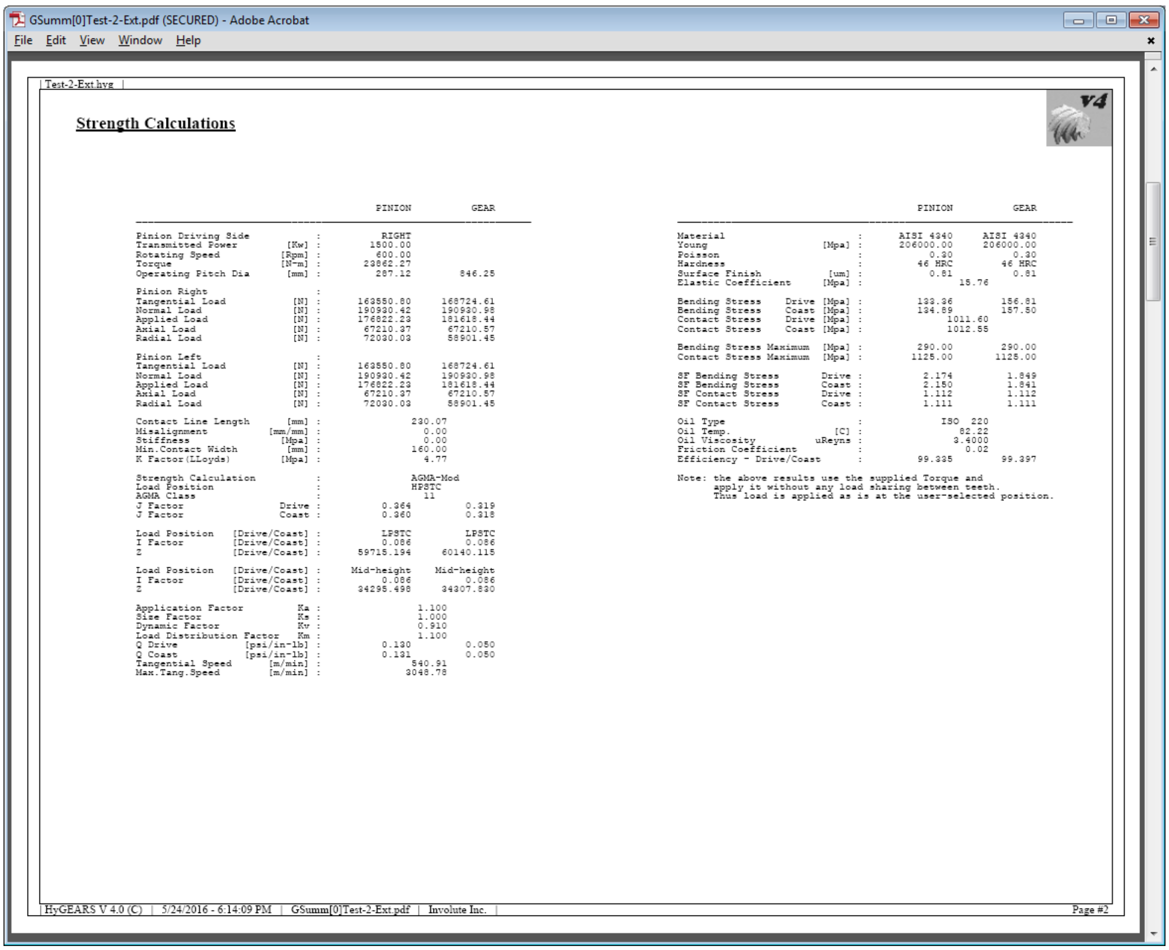
In HyGEARS, the following are the default values:

- Bending stresses are to be calculated at the HPSTC for Spur and Helical gears;
- The Load Application factor Ka = 1.1
- The Load distribution factor Km = 1.1
- The Size factor Ks defaults to 1.0
- The Dynamic facor Kv is calculated by HyGEARS

The following points are observed:

- the bending stress, calculated at the HPSTC (highest point of single tooth contact) on the pinion member are lower than on the gear; this is Ok since the pinion teeth will see 3 times as many cycles as those of the gear;

- the bending stresses on the pinion and gear are substantially lower than the maximum for the selected material; therefore, there is a good margin of safety;
- using the same Application Factors as for bending, the calculated contact stresses are below the maximum for the material. However, the maximum contact stress given in the Material file does not account for hardening; depending on the hardening process used, the maximum allowable contact stress could be significantly higher;
- no load sharing calculation has been performed in the above; given the large overlap produced by the helix angle, it is possible that the maximums shown here become lower with a Loaded Tooth Contact Analysis (next section).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Strength Calculations

			PINION	GEAR
Pinion Driving Side		:	RIGHT	
Transmitted Power	[Kw]	:	1500.00	
Rotating Speed	[Rpm]	:	600.00	
Torque	[N-m]	:	23862.27	
Operating Pitch Dia	[mm]	:	287.12	846.25
Pinion Right		:		
Tangential Load	[N]	:	163550.80	168724.61
Normal Load	[N]	:	190930.42	190930.98
Applied Load	[N]	:	176822.23	181618.44
Axial Load	[N]	:	67210.37	67210.57
Radial Load	[N]	:	72030.03	58901.45
Pinion Left		:		
Tangential Load	[N]	:	163550.80	168724.61
Normal Load	[N]	:	190930.42	190930.98
Applied Load	[N]	:	176822.23	181618.44
Axial Load	[N]	:	67210.37	67210.57
Radial Load	[N]	:	72030.03	58901.45
Contact Line Length	[mm]	:	230.07	
Misalignment	[mm/mm]	:	0.00	
Stiffness	[Mpa]	:	0.00	
Min.Contact Width	[mm]	:	160.00	
K Factor(LLoyds)	[Mpa]	:	4.77	
Strength Calculation		:	AGMA-Mod	
Load Position		:	HPSTC	
AGMA Class		:	11	
J Factor	Drive	:	0.364	0.319
J Factor	Coast	:	0.360	0.318
Load Position	[Drive/Coast]	:	LPSTC	LPSTC
I Factor	[Drive/Coast]	:	0.086	0.086
Z	[Drive/Coast]	:	59715.194	60140.115
Load Position	[Drive/Coast]	:	Mid-height	Mid-height
I Factor	[Drive/Coast]	:	0.086	0.086
Z	[Drive/Coast]	:	34295.498	34307.830
Application Factor	Ka	:	1.100	
Size Factor	Ks	:	1.000	
Dynamic Factor	Kv	:	0.910	
Load Distribution Factor	Km	:	1.100	
Q Drive	[psi/in-lb]	:	0.130	0.050
Q Coast	[psi/in-lb]	:	0.131	0.050
Tangential Speed	[m/min]	:	540.91	
Max.Tang.Speed	[m/min]	:	3048.78	

			PINION	GEAR
Material		:	AISI 4340	AISI 4340
Young	[Mpa]	:	206000.00	206000.00
Poisson		:	0.30	0.30
Hardness		:	46 HRC	46 HRC
Surface Finish	[um]	:	0.81	0.81
Elastic Coefficient	[Mpa]	:	15.76	
Bending Stress	Drive [Mpa]	:	133.36	156.81
Bending Stress	Coast [Mpa]	:	134.89	157.50
Contact Stress	Drive [Mpa]	:	1011.60	
Contact Stress	Coast [Mpa]	:	1012.55	
Bending Stress Maximum	[Mpa]	:	290.00	290.00
Contact Stress Maximum	[Mpa]	:	1125.00	1125.00
SF Bending Stress	Drive	:	2.174	1.849
SF Bending Stress	Coast	:	2.150	1.841
SF Contact Stress	Drive	:	1.112	1.112
SF Contact Stress	Coast	:	1.111	1.111
Oil Type		:	ISO 220	
Oil Temp.	[C]	:	82.22	
Oil Viscosity	uReyns	:	3.4000	
Friction Coefficient		:	0.02	
Efficiency - Drive/Coast		:	99.335	99.397

Note: the above results use the supplied Torque and apply it without any load sharing between teeth. Thus load is applied as is at the user-selected position.

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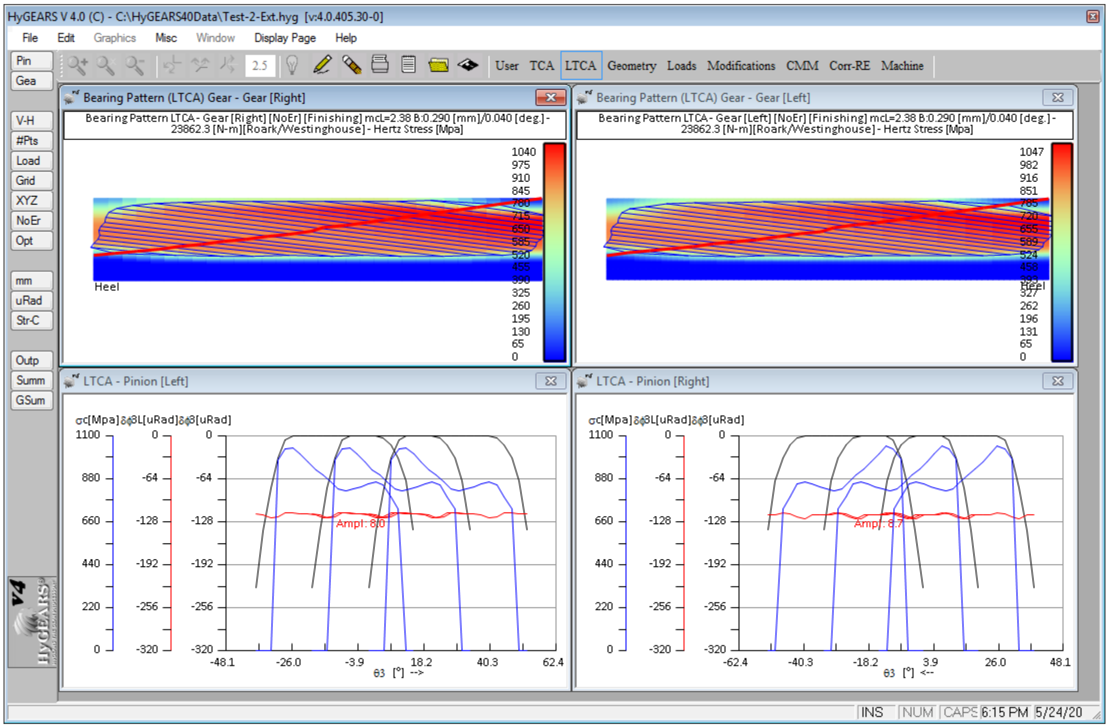
A Look at the Contact Pattern under Load

The operations performed before led to the design of a gear set with adequate Contact Pattern when operated without load. We will now look at the shape of the gear Bearing under full load, and the corresponding Transmission Error curves.

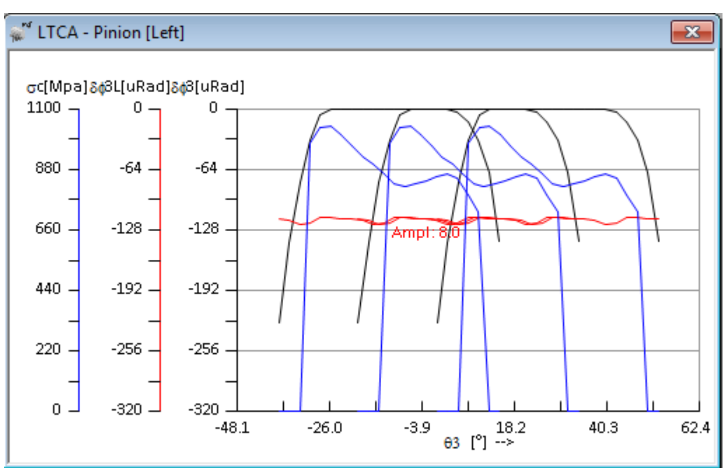
The figures below respectively show the gear Contact Patterns when the full torque is applied to the gear set. In the following, the Westinghouse formula is used as the Stiffness model.



It is readily apparent that no edge contact occurs, thanks to the crowning on the gear tooth. Maximum contact stresses, at ~1 to 1.1 GPa, are almost identical to the 1 Gpa displayed in the Strength Calculations section.

This is natural, since in the LTCA analysis, load sharing between neighboring teeth is established and the maximum contact stress is obtained from the loads applied on each individual tooth pair whereas in the Strength Calculations, the full load is applied at the LPSTC where curvatures are normally highest.

The figure below shows the Transmission Error curves, without load (black) and under full torque (red), and the contact stress (blue, for one tooth flank.



What this graph reveals is that the Transmission Error curve under full load, $\delta\phi_{3L}$ (red curve), is *barely above* the unloaded Transmission Error ($\delta\phi_3$) level at contact exit (the “->” at the bottom of the graphs gives contact direction, i.e. from pinion fillet to tip), which means that contact will occur in the contact exit area of the tooth, a detrimental situation especially since contact stresses are usually higher at the bottom of the tooth where radius of curvature is minimum.

The blue curve shows that the contact stress is maximum at contact entry, and progressively decreases as contact moves up on the pinion tooth flank. It is sometimes possible to remove the contact stress peak at contact entry by modifying the gear tooth tip relief default values.

18.16 New Spur Gear Set

As another example, we will design of a spur gear set based on the same requirements as the helical gear set of the previous example, to the difference that the helix angle will now be null.

Using HyGEARS to Obtain an Initial Geometry

The next step involves using HyGEARS to create the initial geometry. Since the gear set to design is not constrained by considerations other than to use standard cutting equipment, we will leave HyGEARS do the work of selecting the Facewidth on the first run of the New Geometry Definition, and then modify the New Geometry Definition using different values if needed.

Therefore, the following data will be entered in each New Geometry Definition data page:

General Data Section:		
Geometry Name:	Let HyGEARS decide	
Directory:	Let HyGEARS decide	
Geometry Type:	Ext. Spur-Helical	
Material:	AISI 4340	
Pinion Tooth Hand:	Right	
Epicyclic Gear:	No	
	Pinion	**Gear**
Tooth Number:	19	56
Module:	14 [mm]	(25.4 / P, where P = 1.8)
Tooth Face width:	160 [mm]	
Number of Planets:	0	
Shaft Angle:	0.00.00	
Power:	1500 kW	
Speed:	600 RPM	
Cutter Data Section:		
	Pinion	**Gear**
Helix Angle:	0	
Pressure Angle:	20.00.00	20.00.00
X Factor:	0.3	-0.3
Addendum Factor:	1.00	1.00
Dedendum Factor:	1.25	1.25
Fillet Factor:	0.25	0.25

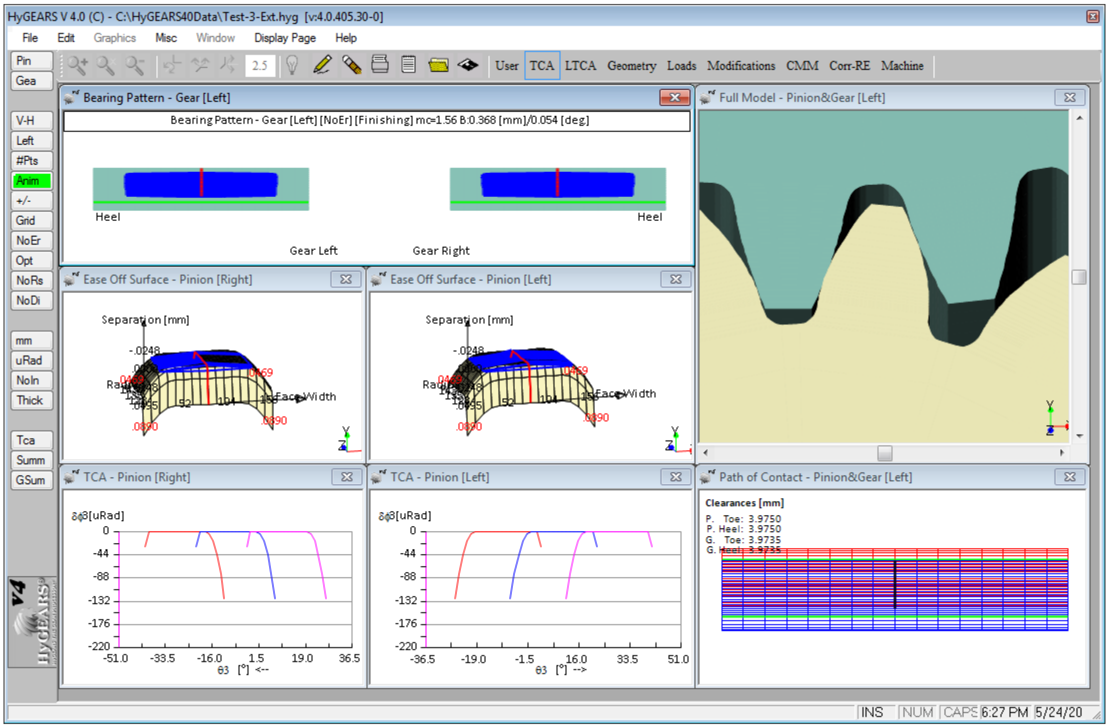
The following Geometry is obtained, the merits of which we will discuss.

Analysis of the Initial Geometry

HyGEARS produces a gear set with the following characteristics, by default:

- Crowning on the Gear member to center the contact along the facewidth; crowning amounts to Module / 200 [mm]
- Tip relief on the Pinion and Gear cutter blades; relief amounts to 10% of tooth height.

Using the above entered data, HyGEARS produces the result displayed below.



The following comments apply:

- The Contact Patterns are centrally located, and cover about 80% of the tooth flanks;
- The T.E. curves are convex, and exhibit no transmission error in the center of the tooth; relief, produced by Crowning and Blade tip relief, is clearly visible in the Transmission error curve and on the Ease Off surfaces;
- The root clearance appears sufficient on both the Pinion and Gear;
- Contact Ratio, at 1.56, is sufficient;.

Otherwise, the gearset kinematics appear Ok at this stage.

When compared to the previous helical gear set, the overlap of the Transmission Error curves is significantly less, because of the lack of helix angle.

Strength Calculations

The Strength Calculations section of the Summary provide the expected behavior of the teeth under load, as calculated using standard methods.

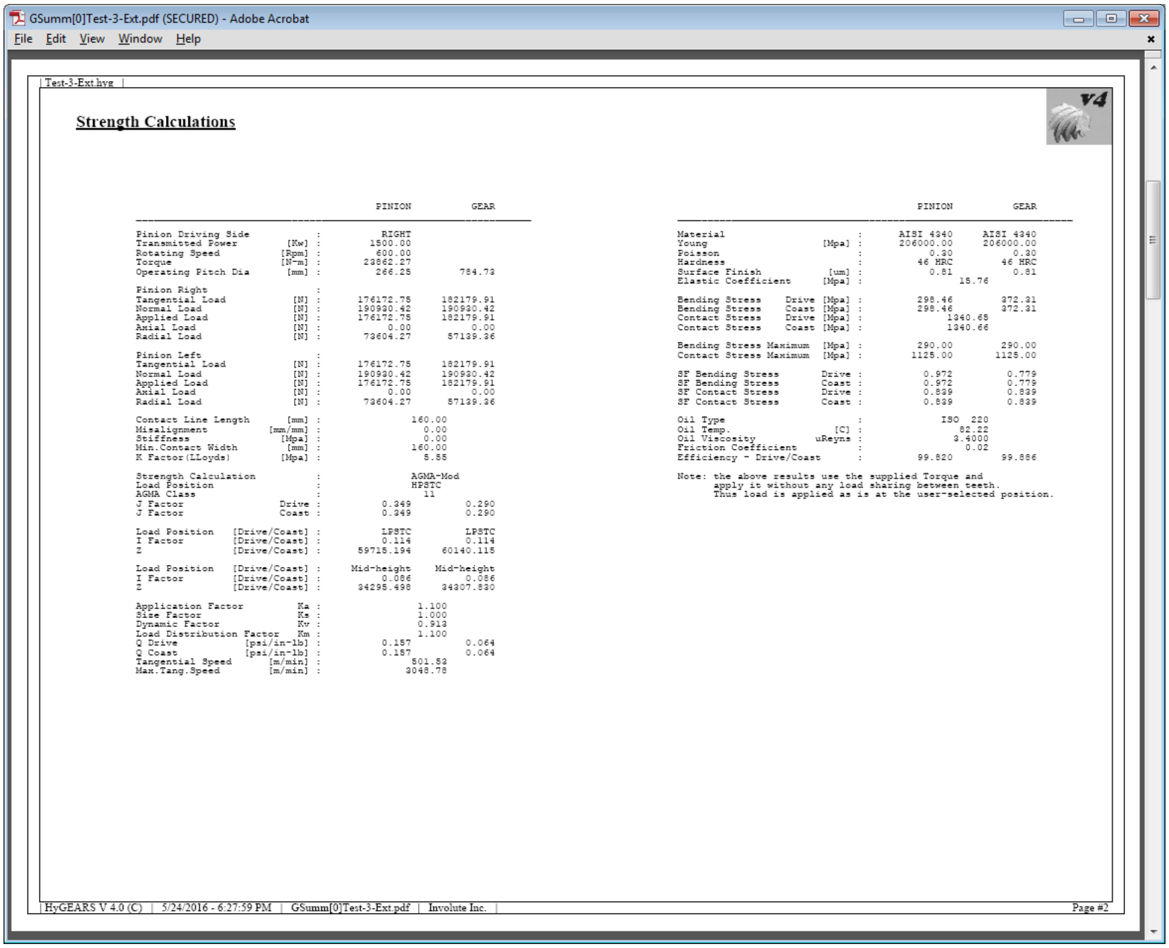
In HyGEARS, the following are the default values:

- Bending stresses are to be calculated at the HPSTC for Spur and Helical gears;
- The Load Application factor Ka = 1.1
- The Load distribution factor Km = 1.1

- The Size factor Ks defaults to 1.0
- The Dynamic facor Kv is calculated by HyGEARS

The following points are observed:

- the bending stresses, calculated at the HPSTC (highest point of single tooth contact) on the pinion member are lower than on the gear; this is Ok since the pinion teeth will see 3 times as many cycles as those of the gear;
- the bending stresses on the pinion and gear are lower than the maximum for the selected material; therefore, there is a good margin of safety; they are also significantly higher that those on the previous helical gear set because of the lack of overlapping in the spur gear set;
- using the same Application Factors as for bending, the calculated contact stresses are below the maximum for the material;
- the calculated contact stresses are also somewhat higher than those calculated on the previous helical gear set, again because of lesser load sharing caused by the lack of helix angle;
- no load sharing calculation has been performed in the above; thus it is possible that the maximums shown here become lower with a Loaded Tooth Contact Analysis (next section).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Strength Calculations

```
                                          PINION         GEAR
------------------------------------------------------------------
Pinion Driving Side                :       RIGHT
Transmitted Power          [Kw]    :     1500.00
Rotating Speed            [Rpm]    :      600.00
Torque                    [N-m]    :    23862.27
Operating Pitch Dia        [mm]    :      266.25        784.73

Pinion Right                       :
Tangential Load             [N]    :   176172.75     182179.91
Normal Load                 [N]    :   190930.42     190930.42
Applied Load                [N]    :   176172.75     182179.91
Axial Load                  [N]    :        0.00          0.00
Radial Load                 [N]    :    73604.27      57139.36

Pinion Left                        :
Tangential Load             [N]    :   176172.75     182179.91
Normal Load                 [N]    :   190930.42     190930.42
Applied Load                [N]    :   176172.75     182179.91
Axial Load                  [N]    :        0.00          0.00
Radial Load                 [N]    :    73604.27      57139.36

Contact Line Length        [mm]    :            160.00
Misalignment            [mm/mm]    :              0.00
Stiffness                 [Mpa]    :              0.00
Min.Contact Width          [mm]    :            160.00
K Factor(LLoyds)          [Mpa]    :              5.55

Strength Calculation               :            AGMA-Mod
Load Position                      :            HPSTC
AGMA Class                         :             11
J Factor                  Drive    :       0.349         0.290
J Factor                  Coast    :       0.349         0.290

Load Position    [Drive/Coast]     :       LPSTC         LPSTC
I Factor         [Drive/Coast]     :       0.114         0.114
Z                [Drive/Coast]     :   59715.194     60140.115

Load Position    [Drive/Coast]     :  Mid-height    Mid-height
I Factor         [Drive/Coast]     :       0.086         0.086
Z                [Drive/Coast]     :   34295.498     34307.830

Application Factor           Ka    :             1.100
Size Factor                  Ks    :             1.000
Dynamic Factor               Kv    :             0.913
Load Distribution Factor     Km    :             1.100
Q Drive            [psi/in-lb]     :       0.157         0.064
Q Coast            [psi/in-lb]     :       0.157         0.064
Tangential Speed        [m/min]    :            501.53
Max.Tang.Speed          [m/min]    :           3048.78
```

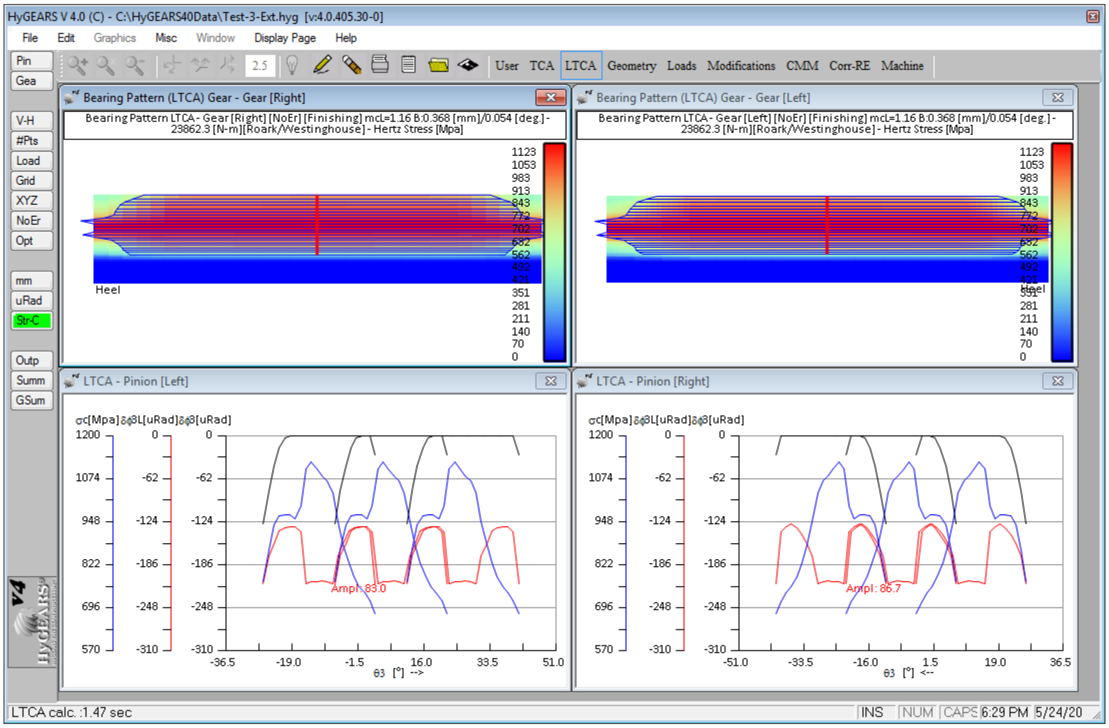
```
                                          PINION         GEAR
------------------------------------------------------------------
Material                           :   AISI 4340     AISI 4340
Young                     [Mpa]    :   206000.00     206000.00
Poisson                            :        0.30          0.30
Hardness                           :      46 HRC        46 HRC
Surface Finish             [um]    :        0.81          0.81
Elastic Coefficient       [Mpa]    :             15.76

Bending Stress     Drive  [Mpa]    :      298.46        372.31
Bending Stress     Coast  [Mpa]    :      298.46        372.31
Contact Stress     Drive  [Mpa]    :           1340.65
Contact Stress     Coast  [Mpa]    :           1340.66

Bending Stress Maximum    [Mpa]    :      290.00        290.00
Contact Stress Maximum    [Mpa]    :     1125.00       1125.00

SF Bending Stress         Drive    :       0.972         0.779
SF Bending Stress         Coast    :       0.972         0.779
SF Contact Stress         Drive    :       0.839         0.839
SF Contact Stress         Coast    :       0.839         0.839

Oil Type                           :            ISO  220
Oil Temp.                   [C]    :             82.22
Oil Viscosity            uReyns    :            3.4000
Friction Coefficient               :              0.02
Efficiency - Drive/Coast           :      99.820        99.886

Note: the above results use the supplied Torque and
      apply it without any load sharing between teeth.
      Thus load is applied as is at the user-selected position.
```

HyGEARS V 4.0 (C) | 5/24/2016 - 6:27:59 PM | GSumm[0]Test-3-Ext.pdf | Involute Inc. | Page #2

A Look at the Contact Pattern under Load

The operations performed before led to the design of a gear set with adequate Contact Pattern when operated without load. We will now look at the shape of the gear Bearing under full load, and the corresponding Transmission Error curves.

The figures below respectively show the gear Contact Patterns when the full torque is applied to the gear set. In the following, the Westinghouse formula is used as the Stiffness model.

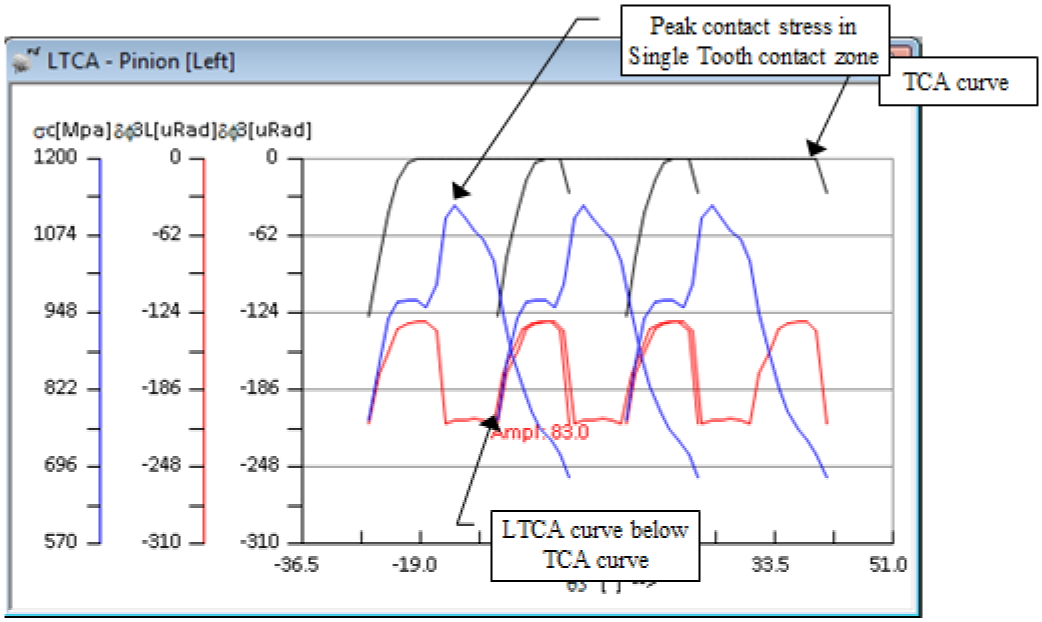


It is readily apparent that no edge contact occurs, thanks to the crowning on the gear tooth. Maximum contact stresses, at 1.1 GPa, are a bit higher than the 1 GPa displayed in the Strength Calculations section, as expected.

This is natural, since in the LTCA analysis, load sharing between neighboring teeth is established and the maximum contact stress is obtained from the loads applied on each individual tooth pair. No application factor is used here.

We can also see that the Contact Pattern is quite localized on the tooth flank; if the operating conditions are well known, it may be possible to reduce crowning and therefore spread the contact areas over a larger portion of the tooth flank, thereby reducing both contact and bending stresses.

The figure below shows the Transmission Error curves, without load (black) and under full torque (red), and the contact stress (blue, for one tooth flank.



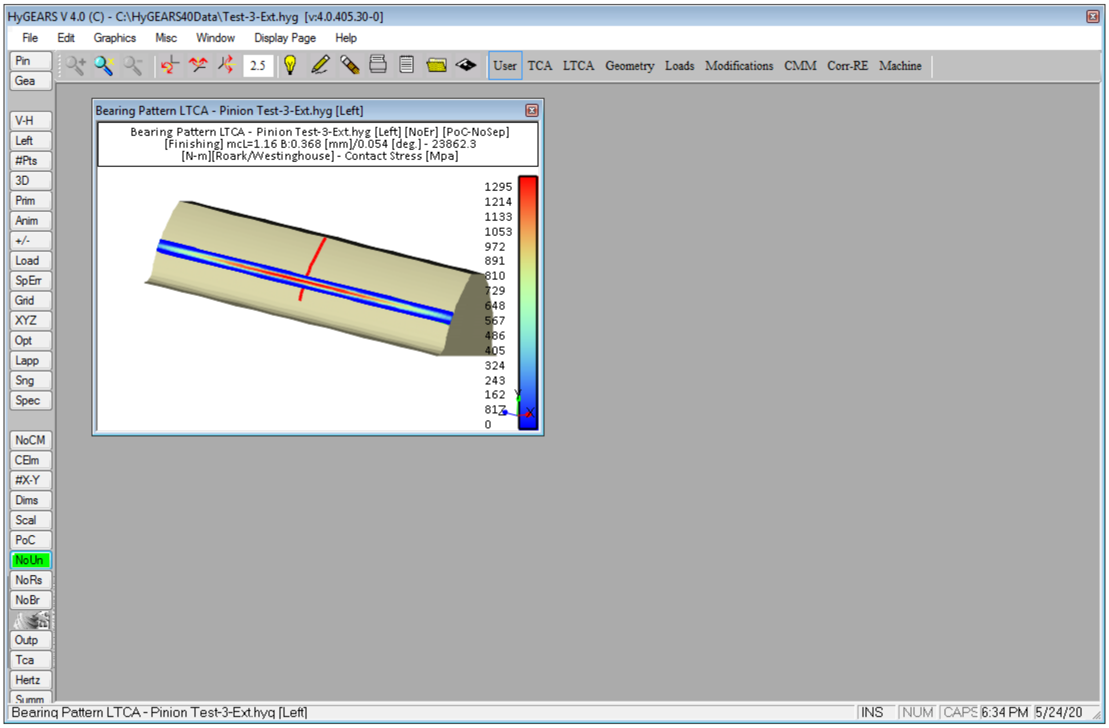
What this graph reveals is that the Transmission Error curve under full load, df3L (red curve), is *below* the unloaded Transmission Error (df3) level at contact entry (the "->" at the bottom of the graphs gives contact direction, i.e. from pinion fillet to tip) , which means that contact will occur in the contact entry area of the tooth, a detrimental situation especially since contact stresses are usually higher at the bottom of the tooth where radius of curvature is minimum.

The blue curve indeed shows that the contact stress is maximum at contact entry, and progressively decreases as contact moves up on the pinion tooth flank.

In this case, it is not possible to reduce contact stresses at contact entry since they peak immediately at the beginning of the Single Tooth contact zone, as shown in the above figure.

Thus, in order to reduce contact stresses at contact entry, it is necessary to increase load sharing in this portion of the mesh, which means an increase in contact ratio. A smaller module gearset, with a larger number of teeth, could achieve this but only marginally.

The optional Contact Element, at gear tooth tip / pinion tooth fillet, shows 1.3 GPa, a value slightly above that obtained in the above LTCA display.



Note : Many of the tools provided in HyGEARS should not be considered as a definite answer to a given strength or reliability problem, but rather as a guide as to what may be happening.

Recognized formulations have been used to develop these tools but, as usual, these should be used in perspective to one's own experience and knowledge.

19 Calculations Tracing

HyGEARS uses many numerical procedures to establish the boundaries of the teeth which are seen in the Child Windows graphics displays, and then from such boundaries, the Path of Contact is calculated.

Although these numerical procedures have been in use for close to ten years, and have proven to be extremely stable under a large number of conditions, it is still possible that exceptional cases happen.

In such instances, the Parent Window Menu Calculation Trace may be set "On" to produce a trace of all calculations taking place and send this trace to a Text Results window whose contents should be printed or saved to a file for analysis.

This section explains the output of the two main calculations tracings which may be made in HyGEARS:

- Digitization Process;
- Path of Contact,
- Surface Matching Algorithm,
- Contact Pattern Development Algorithm.

19.1 Tracing the Digitization Process

Applies to: Tooth
Blank
Diameter over Balls
Full Model

Tracing the Digitization Process is activated by setting the Trace Property On (^ T keyboard shortcut). Because of the tracing, the calculation time will be somewhat longer. The Trace is sent to a Text Results window.

The Digitization Process trace is made of several different parts, as follows:

1- The first part displays the **initial cutter angles**, which may be visualized in the Cutting Machine Child Window, when the "NoAn" function button is toggled to "Ang".

The initial cutter angles routine, "AlfcInit", locates the Cutter Center, a point D3 on the cutter body, the tooth end (toe or heel), and from these, calculates a first trial cutter angle AlfcIn, which is then refined to a final value Alfc.

Initial roll angle values Angl3 and DAngl3 are also calculated if the digitized member is generated.

Finally, the approximate Spiral Angle at either tooth end, toe or heel, is calculated.

This process is repeated for both the IB and OB tooth flanks.

```
AlfcInit Pinion Convex-IB                (Toe)
 Cutter Center          1.095    -4.172     0.984
 Cutter Point D3        0.808    -0.168     2.802
 Tooth Point            1.053    -1.281     3.371
 AlfcIn, Alfc          15.425    11.425
 Angl3, DAngl3        712.006    34.754
 Spiral Angle          40.678

AlfcInit Pinion Convex-IB                (Heel)
 Cutter Center          1.095    -4.172     0.984
 Cutter Point D3        0.808    -0.168     2.802
 Tooth Point            1.758    -1.281     5.199
 AlfcIn, Alfc          32.998    39.998
 Angl3, DAngl3        632.018   -23.628
 Spiral Angle          45.064
```

2- The second part displays the **initial roll angles** calculated by the "Rolext" routine between the above calculated toe and heel initial cutter angles. The printout includes:

Angl3: the roll angle; if the digitized member is not generated, this value is zero;
Alfc: the cutter angle;
S: the position along the cutter blade edge which is "cutting" the work; when Condition equals 1, S is zero (tooth root), otherwise, it is larger than zero (tooth tip).

```
Rolext:  Condition, Flank    1 Pinion-Convex-IB
    Angl3   -   Alfc   -    S
   712.006    11.425     0.000
   722.003    11.425     0.000
   722.003    16.187     0.000
   704.760    16.187     0.000
   704.760    20.949     0.000
   689.058    20.949     0.000
       ...

Rolext:  Condition, Flank    2 Pinion-Convex-IB
    Angl3   -   Alfc   -    S
   712.006    11.425     0.353
   662.984    11.425     0.353
```

```
  662.984    16.187     0.385
  650.394    16.187     0.385
  650.394    20.949     0.417
      ...
```

3- The third part displays, for each profile point of the tooth boundary, the **initial roll and cutter angles**, respectively Angl3 and Alfc, when the “Profile” routine is called; this routine then searches iteratively for a point which answers to a specific radial and axial position.

The “End Cond.” and “Cone Cond.” show how close the initial value is from the solution, when these values should be zero.

The iteration number is given by “Iter.” and the determinant of the Jacobian matrix si given by “Determinant”. Normally, two to three iterations are sufficient.

```
*** Profile:  ICond, Flank, End = 1  Pinion-Convex-IB  0
 Angl3, Alfc    =   722.00   11.43
 End Cond.  -  Cone Cond. - Iter. - Determinant
   -0.059       0.000       1      -1.481
    0.000       0.000       2      -1.524
 Angl3, Alfc, S =   718.96   12.23    0.00

*** Profile:  ICond, Flank, End = 2  Pinion-Convex-IB  0
 Angl3, Alfc    =   662.98   11.43
 End Cond.  -  Cone Cond. - Iter. - Determinant
    0.022       0.176       1      -2.345
   -0.008       0.012       2      -2.097
 Angl3, Alfc, S =   680.80   11.12    0.25

*** Profile:  ICond, Flank, End = 1  Pinion-Convex-IB  1
 Angl3, Alfc    =   632.85   40.80
 End Cond.  -  Cone Cond. - Iter. - Determinant
    0.032       0.017       1      -3.070
    0.000       0.000       2      -3.072
 Angl3, Alfc, S =   635.41   40.19    0.00

.....
```

4- The fourth part displays a message for each **profile point** of the tooth within the boundaries. The “ICond” entry, equal to 3, indicates a point within the tooth boundaries, and the “End” entry indicates where along the tooth, from 0 to 1, the point is located. If the number of iterations exceeds a given limit, a message will be added on the corresponding line were the error occurred.

```
*** Profile:  ICond, Flank, End = 3  Pinion-Convex-IB  0

*** Profile:  ICond, Flank, End = 3  Pinion-Convex-IB  0

*** Profile:  ICond, Flank, End = 3  Pinion-Convex-IB  0
```

```
*** Profile:  ICond, Flank, End = 3  Pinion-Convex-IB  0

*** Profile:  ICond, Flank, End = 3  Pinion-Convex-IB  0
```

5- The above process is repeated for the other tooth flank.

6- The last part displays a message for each **fillet point** of the tooth, for each tooth flank. If the number of iterations exceeds a given limit, a message will be added on the corresponding line were the error occurred.

```
*** Fillet:  Pinion Convex-IB

*** Fillet:  Pinion Convex-IB

*** Fillet:  Pinion Convex-IB

*** Fillet:  Pinion Convex-IB
```

19.2 Tracing the Path of Contact Calculation

Applies to: Path of Contact
Contact Pattern
Contact Pattern Development
Contact Pattern LTCA
Sliding Speeds

Tracing the Path of Contact Calculation is activated by setting the Trace Property On (^ T keyboard shortcut). The trace is sent to a Text Results window.

The Path of Contact Calculation trace is made of several different parts, as follows:

1- The first part **identifies the Geometry name** and which pinion tooth flank is being traced.

```
>>> 11x45c.dat Pinion Concave-OB <<<
>>> Scanning Tooth Flank <<<
```

2- The second part **scans all the gear tooth points** above the pitch cone, and tries to find a corresponding point on the pinion tooth flank; the upper part of the pinion tooth flank is then scanned to find contact points on the gear tooth flank. The "Contac" function is used to find the requested contact points.

The "Contac" function parameters are given, namely "Ninc", which is the number of unknowns being searched, "ICond" which identifies which unknowns are to be searched, and "Ig", indicating either the Pinion or Gear.

Each time the "Contac" function is called, the pinion and gear tooth surface variables, respectively A3 (pinion roll angle), Ac (pinion cutter angle), Sg (position along gear cutter edge) and Ac (gear cutter angle), and the pinion and gear angular positions T3 (pinion angular position Theta3) and P3 (gear angular position Phi3) are recorded and printed.

The Newton-Raphson algorithm then searches for a contact point between the pinion and gear tooth, and the "Iter, Fi ..." entry shows how the convergence evolves: "Iter" is the iteration number, whereas "Fi" are the functions to satisfy for a contact point, are should be zero when the solution si reached. Normally, 3 iterations are sufficient.

Upon exiting the "Contac" function, the final values of the surface and orientation variables are printed. These should normally be quite close to the inital values printed when the function was called.

```
*** Contac:  Ninc, ICond, Ig =    4  1 Gear
T3 A3 Ac P3 Sg Ac:   344.27   704.27    20.68    23.25    0.188   300.77
Iter, Fi ... = :    1  -0.0740   0.4974   0.2114  -0.0891
                    2   0.0047  -0.0111   0.0285  -0.0087
                    3   0.0001   0.0000   0.0000   0.0000
T3 A3 Ac P3 Sg Ac:   345.24   708.21    21.33    16.32    0.188   300.77

>>> Posn Iap3, Iac     :   20    1
*** Contac:  Ninc, ICond, Ig =    4  1 Gear
T3 A3 Ac P3 Sg Ac:   359.17   722.14    10.49    19.72    0.320   292.59
Iter, Fi ... = :    1  -0.0692   0.1432  -0.1434  -0.0080
                    2  -0.0014   0.0019   0.0021  -0.0006
T3 A3 Ac P3 Sg Ac:   350.48   714.21    13.43    17.52    0.320   292.59

>>> Posn Iap3, Iac     :   20    2
*** Contac:  Ninc, ICond, Ig =    4  1 Gear
T3 A3 Ac P3 Sg Ac:   336.63   699.59    17.82    14.21    0.349   296.73
Iter, Fi ... = :    1  -0.0010  -0.0069   0.0112  -0.0053
                    2   0.0001   0.0001   0.0000   0.0000
T3 A3 Ac P3 Sg Ac:   337.50   700.74    17.65    14.38    0.349   296.73
```

3- The third part prints the pinion to gear tooth to "**Tooth Separation**", the location of the contact points along the Z3 axi, and the "Differences between Normals" in the Z3 direction, for every tooth flank point. Values can be positive or negative. Contact will occur where the values are minimum along a line.

```
Tooth Separation ... Flank  Concave-OB
  .00000  .00197  .00224  .00134 -.00020
  .00000  .00229  .00275  .00192  .00029
  .00000  .00254  .00313  .00231  .00060
  .00000  .00274  .00343  .00262  .00083
  .00000  .00292  .00369  .00286  .00099



Z3 Concave-OB
   3.653   4.089   4.522   4.955   5.387
   3.591   4.019   4.444   4.868   5.291
   3.537   3.959   4.379   4.798   5.216
   3.487   3.903   4.318   4.733   5.147
   3.441   3.851   4.261   4.671   5.082



Differences between Normals(3) ... Flank  Concave-OB
  -.0035  -.0012   .0003   .0012   .0015
  -.0037  -.0012   .0005   .0015   .0020
  -.0040  -.0013   .0005   .0017   .0022
  -.0042  -.0015   .0005   .0018   .0024
  -.0045  -.0016   .0004   .0018   .0025
    ...
```

4- Once approximate values have been found for the lengthwise positions of the contact points along the PoC, the **final values are calculated** one by one by calling the “Contac” function once again.

```
>>> Searching single contact points <<<

>>> Posn Iap3         :   18
*** Contac:  Ninc, ICond, Ig =   4  1 Gear
T3 A3 Ac P3 Sg Ac:   307.47   669.66    28.11     7.06    0.407   307.03
T3 A3 Ac P3 Sg Ac:   307.47   669.66    28.11     7.06    0.407   307.03

>>> Posn Iap3         :   17
*** Contac:  Ninc, ICond, Ig =   4  1 Gear
T3 A3 Ac P3 Sg Ac:   316.38   678.74    26.51     9.26    0.357   305.54
Iter, Fi ... = :    1  -0.0001   0.0000   0.0000   0.0000
T3 A3 Ac P3 Sg Ac:   316.40   678.76    26.51     9.27    0.357   305.54

>>> Posn Iap3         :   16
*** Contac:  Ninc, ICond, Ig =   4  1 Gear
T3 A3 Ac P3 Sg Ac:   325.30   687.76    25.72    11.45    0.287   304.93
Iter, Fi ... = :    1  -0.0002  -0.0001   0.0000   0.0000
T3 A3 Ac P3 Sg Ac:   325.32   687.79    25.72    11.46    0.287   304.93

....
```

19.3 Tracing the Surface Matching Algorithm

Applies to: Corrective Machine Settings (Closed Loop)
Reverse Engineering
Stock Distribution

Tracing the Surface Matching Algorithm is activated by clicking on the "Calculation Trace" check box of the Corrective Machine Settings (Closed Loop) / Reverse Engineering Selection Window. The Trace Output is sent to the Trace data page, from where it can be selected using the mouse, annotated, or copied to the Windows Clipboard.

Whenever Corrective Machine Settings (Closed Loop) or Reverse Engineering are performed, the same numerical algorithm is used, what is called the Surface Matching Algorithm.

This numerical process goes through a series of steps that can be traced to see how the results evolve with time.

The Surface Matching Algorithm trace is made of several different parts, as follows:

1- The first part **displays the identification** of the Pinion/Gear member being treated, the Finishing or Roughing state, and the tooth flank, as follows:

```
PINION [FINISHING] CONCAVE-OB
_____________________________
```

2- The second part displays the **contents of the Jacobian matrix** and its damping factor, and identifies the objective functions and the control parameters.

The Surface Matching Algorithm uses a numerical technique to find the combination of machine settings that will minimize the tooth surface error. This numerical technique, also known as Newton Raphson, uses the 1st order derivatives of the objective functions relative to the control parameters in matrix form, and solves this matrix in combination with the current objective function values to find the increment in machine settings that will enable reaching the sought objective functions.

Because it is a numerical technique, the system must be dampened in order to stabilize the convergence and thus prevent numerical divergence. Therefore, a damping factor is used to multiply all the derivative values of the Jacobian matrix. This damping factor varies with the number of objective functions as follows:

Number of Objective Functions	Damping Factor
1	2.0
2	2.0
3	5.0
4	5.0
5	5.0

The Jacobian matrix is presented as follows:

```
Jacobian    : Pinion [Finishing] Concave-OB
Damping     :     5.00
     7.15619  -0.68746   1.43469   0.91671   1.47220     Spiral Angle
    13.84348  -5.95703   8.32097  -2.28969  -2.68108     Pressure Angle
     0.07161   0.02845  -0.08051  -0.14680   0.18329     Crowning
    -0.11176  -0.61856   0.68998   0.16308  -0.18917     Bias
    -0.43154   0.15679  -0.32693   0.15162   0.15446     Profile Curvature
1:   Spiral Angle
2:   Swivel Angle
3:   Blank Offset
4:   Machine Center To Back
5:   Decimal Ratio
```

In the above, each line represents an Objective Function, which is identified at the end of the line (Spiral Angle, Pressure Angle, etc.).

Each column represents a control parameter, which is identified just below the Jacobian matrix (1: Spiral Angle; 2: Swivel Angle; etc.).

Thus, the numbers in the Jacobian matrix represent the derivative of an Objective Function relative to a given control parameter. The larger the value, the more sensitive the Objective Function is to a change in a given control parameter.

3- The third part displays the **evolution of the surface statistics** with the iteration number and time to solution, as follows. In the following, the Lengthwise Crowning (Crowning) and Profile Curvature (Profile) errors are in linear units [mm], while the Pressure (Press), Spiral (Spiral), Total Bias (BiasTot), Bias at tooth toe (BiasToe) and at heel (BiasHeel) are given in Degree.Decimal units.

If a Spread Blade, Formate, Helixform, Duplex Helical or face Hobbing process is used, the Taper statistic, which is the difference in spiral angle between the I.B. and O.B. tooth flanks, is added at the end of the line. For Fixed Setting and Modified Roll, Taper has no meaning.

```
Units :Deg.Dec / [mm]
#Iter.    Press.   Spiral  Crowning   Profile   BiasTot   BiasToe  BiasHeel
Time(sec)
    1    0.2563    0.0925    0.0008   -0.0005    0.0896    0.1052   -0.0156
     7
    2    0.1198    0.0417    0.0007    0.0004    0.0718    0.0948   -0.0230
     9
    3    0.0564    0.0187    0.0006    0.0008    0.0603    0.0880   -0.0277
    11
    4    0.0274    0.0092    0.0005    0.0009    0.0527    0.0838   -0.0311
    13
    5    0.0131    0.0042    0.0005    0.0010    0.0462    0.0806   -0.0344
    15
    6    0.0061    0.0011    0.0005    0.0009    0.0403    0.0776   -0.0373
    17
    7    0.0065   -0.0039    0.0005    0.0004    0.0390    0.0774   -0.0384
    20
    8    0.0064   -0.0036    0.0005    0.0003    0.0352    0.0755   -0.0403
    21
    9    0.0068   -0.0024    0.0004    0.0003    0.0320    0.0738   -0.0418
    22
   10    0.0058   -0.0031    0.0004    0.0003    0.0281    0.0716   -0.0435
    23
   11    0.0055   -0.0029    0.0004    0.0003    0.0251    0.0699   -0.0448
    24
   12    0.0059   -0.0017    0.0003    0.0002    0.0231    0.0688   -0.0457
    26
   13    0.0049   -0.0025    0.0003    0.0002    0.0202    0.0672   -0.0470
    28
   14    0.0054   -0.0014    0.0002    0.0002    0.0187    0.0666   -0.0478
    29
   15    0.0050   -0.0013    0.0002    0.0002    0.0167    0.0652   -0.0485
    30
   16    0.0051   -0.0019    0.0002    0.0001    0.0140    0.0640   -0.0501
    31
   17    0.0055   -0.0015    0.0002    0.0001    0.0124    0.0631   -0.0508
    32
   18    0.0057   -0.0012    0.0002    0.0001    0.0109    0.0623   -0.0515
    33
```

Index

- # -

- _ -

- + -

- > -

- 0 -

- 2 -

- 3 -

- 5 -

- A -

- B -

- C -

- D -

- E -

- F -

- G -

- H -

- I -

- K -

- L -

- M -

- N -

- O -

- P -

- R -

- S -

- T -

- U -

- V -

- W -

- X -