CnC 5Axis Manufacturing of Gears

with

HyGEARS ™ V 5.0

An Overview

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October 2021

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Introduction

*HyGEARS V 5.0 covers **all major gear types found in the gear industry**.*

*The HyGEARS integrated **5Axis CnC Post-Processor** generates, from the **exact tooth definition** and without any interpolation, the CnC machine part programs needed to manufacture **every supported gear type** on **any 5Axis CnC machine** available on the market: the resulting tooth flank topography is the same whether Face Mill, CoSIMT, End Mill or Ball Mill tools are used.*

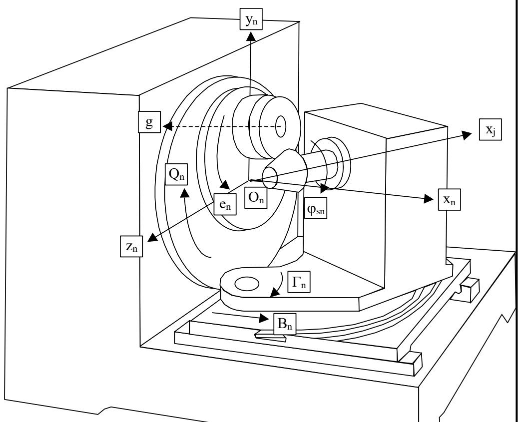
In one single stand alone software, HyGEARS allows :

- *to **design gear sets**: face milled spiral-bevel, hypoid, straight bevel, Cyclo-Palloid spiral-bevel gears, Coniflex ™, spur, helical, Beveloid, herringbone and Face gears;*
- *to **analyze the kinematics**, unloaded and loaded: TE, Contact Pattern, LTCA, FFT, Bending and Contact stresses, and more, are all but one click away;*
- *to **develop and optimize the kinematic characteristics** of gear pairs, through specialized functions, in order to improve load carrying capacity and smoothness of operation;*
- *to **assess the manufacturing quality** through an export/import interface to common CMMs;*
- *to **cut gears on conventional and 5 Axis CnC machines** using Face Mill, Dish type cutter (for Coniflex gears), Conical Side Milling Tool (or CoSIMT, such as made by Ingersoll Rand, Sandvik, PTR-TEC), End Mill and Ball Mill tools;*
- *to use the **integrated Closed Loop**, i.e. seamless use of CMM output to obtain machine corrections such that manufactured parts are within set tolerances when compared to the design.*

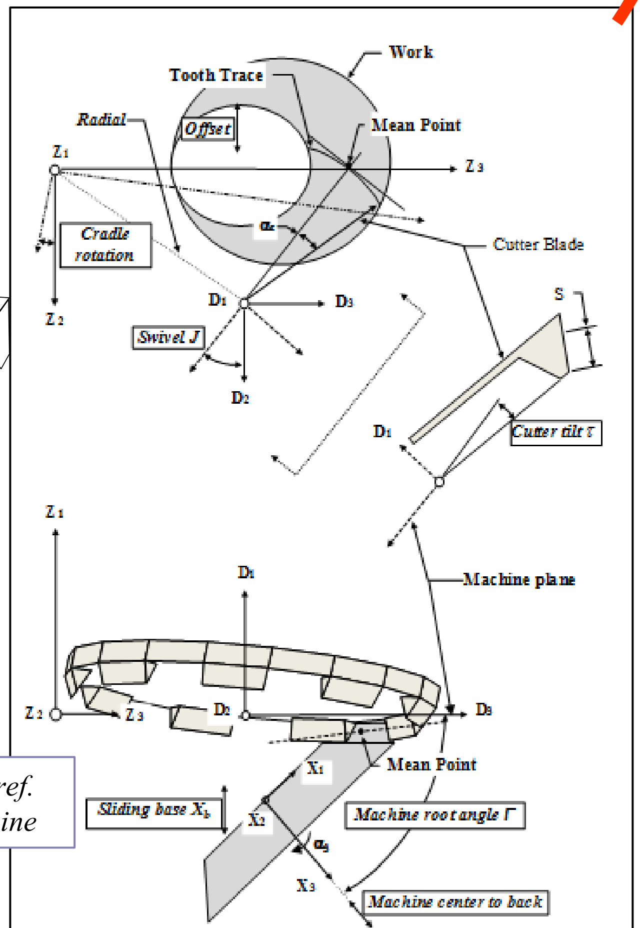
Read on for a brief overview of HyGEARS.

HyGEARS™ is built on Vector Simulation

In Vector Simulation, a theoretical gear generator is simulated by translations and rotations applied to reference frames that determine the relations between cutting tool and machine.

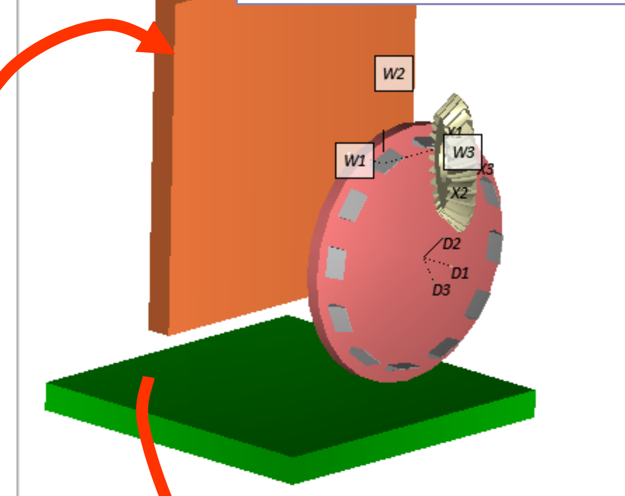


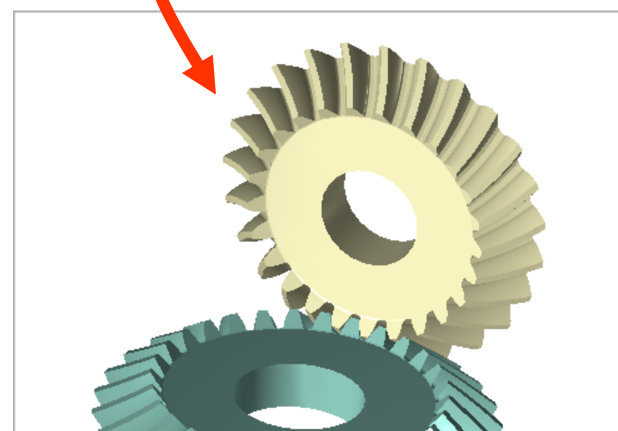
***1:** The reference machine is discretized in a series of ref. frames*



***2:** The Vector Model uses the ref. frames of the discretized machine*

***3:** A Numerical machine is created from the Vector Model*





***4:** A Numerical gear set is created with the Numerical machine.*

HyGEARS™ The Vector Model

The coordinates and normal vectors at any point on the tooth flanks are obtained by applying machine specific rotations and translations to cutter definition.

Point on tooth flank:

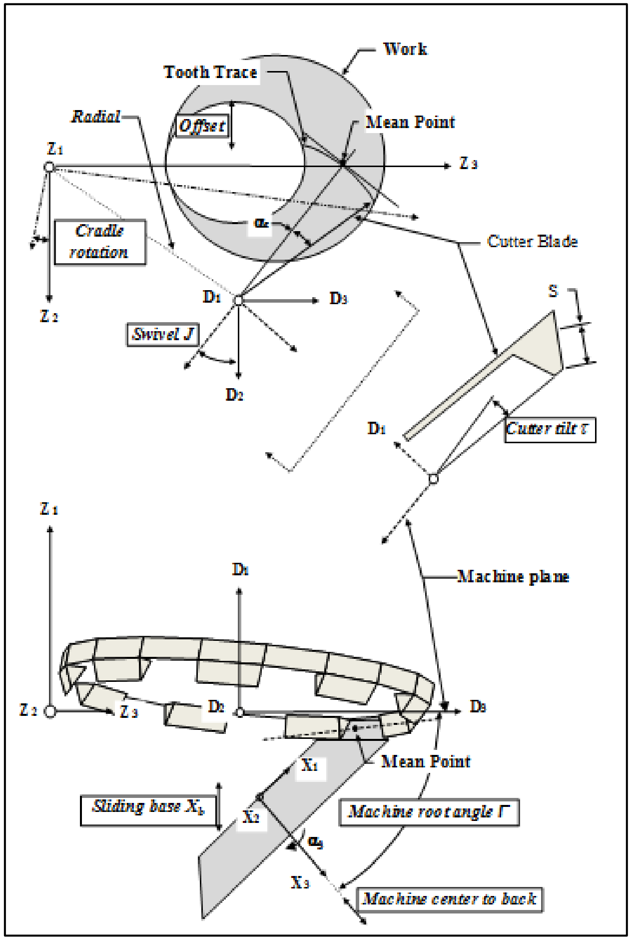
$$D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha c) & \sin(\alpha c) \\ 0 & -\sin(\alpha c) & \cos(\alpha c) \end{bmatrix} \begin{bmatrix} S\cos(\phi) \\ 0 \\ (R \pm S\sin(\phi)) \end{bmatrix}$$

$$\boldsymbol{X} = \boldsymbol{D}\ [\tau]^3\ [k]^1\ [Radial]\ [L_1]^3 [Dist]\ [\gamma_m]^2 [\theta_3]^3$$

Normal on tooth flank:

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

$$\boldsymbol{N_x} = \boldsymbol{N}\ [\tau]^3\ [k]^1\ [L_1]^3\ [\gamma_m]^2 [\theta_3]^3$$



HyGEARS™ The Vector Model

Higher order changes, up to 6th order, are superimposed to tool and work piece movements in order to achieve specific kinematic behavior.

Example 1) Modified Roll higher order changes:

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

where:	L_{1m}:	modified cradle angle
	α_3:	work piece roll angle
	R_r:	ratio of roll, cradle to work piece
	C_r:	cradle ref. position
	2C:	2nd Order parameter (Gleason notation)
	6D:	3rd Order parameter
	24E:	4th Order parameter
	120F:	5th Order parameter
	720G:	6th Order parameter

Example 2) Helical Motion higher order changes:

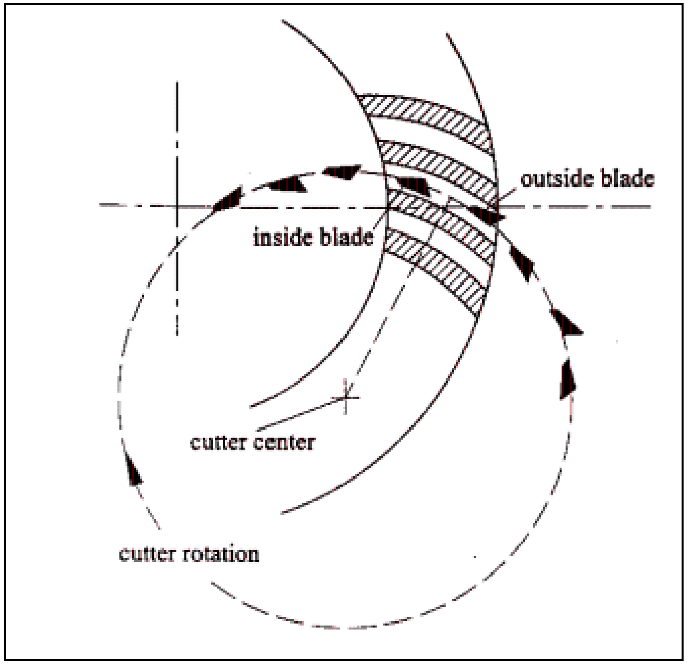
$$X_{bm} = X_b + 1_{st} \, (C_r - \alpha_3 \, R_r)^{\square} + 2_{nd} \, (C_r - \alpha_3 \, R_r)^2 + 3_{rd} \, (C_r - \alpha_3 \, R_r)^3 + 4_{th} \, (C_r - \alpha_3 \, R_r)^4 + 5_{th} \, (C_r - \alpha_3 \, R_r)^5 + 6_{th} \, (C_r - \alpha_3 \, R_r)^6$$

where:	X_{bm}:	modified sliding base
	α_3:	work piece roll angle
	R_r:	ratio of roll, cradle to work piece
	C_r:	cradle ref. position
	1st :	1st Order parameter
	2nd :	2nd Order parameter
	3rd :	3rd Order parameter
	4th :	4th Order parameter
	5th :	5th Order parameter
	6th :	6th Order parameter

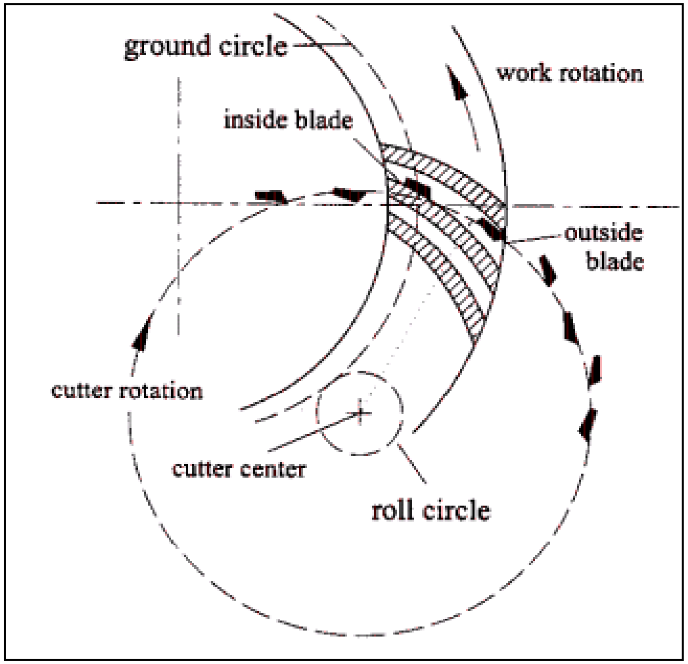
HyGEARS™

Face Milling and Face Hobbing

Both the Face Milling and Face Hobbing processes are supported for all Spiral Bevel type gears.



Face Milling (single indexing)



Face Hobbing (continuous indexing)

HyGEARS™ **Calibration**

HyGEARS has been extensively calibrated against Gleason's CAGE and Klingelnberg's KIMoS softwares for tooth flank coordinates, Contact Pattern and Transmission Error, CMM output, Corrective Machine Settings (Closed Loop), LTCA Contact Stresses, etc.

Some important milestones:

1993-1994:	*Machine Calibration (Gleason and Yutaka machines)*
1994:	*Closed Loop 1st Order*
1995:	*Closed Loop 2nd Order*
1996:	*Experimental TE*
1997:	*Experimental LTCA*
1998:	*Fillet Stress (against FEA)*
2001:	*Contact Stress (against Gleason)*
2004:	*Bending and Contact Stress – Face Hobbing – (against Gleason)*
2006:	*Lapping Prediction (with AAM)*
2011:	*First 5Axis CnC Interface*

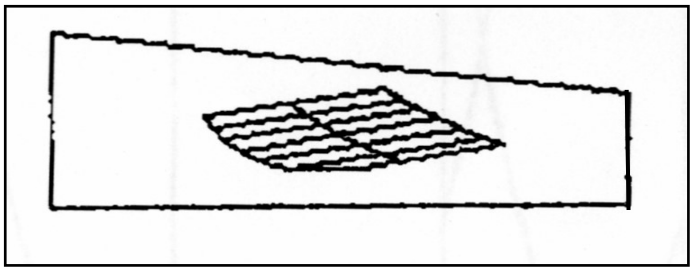
Consistently equivalent results are obtained, as is shown in the following pages.

HyGEARS™ **Calibration**

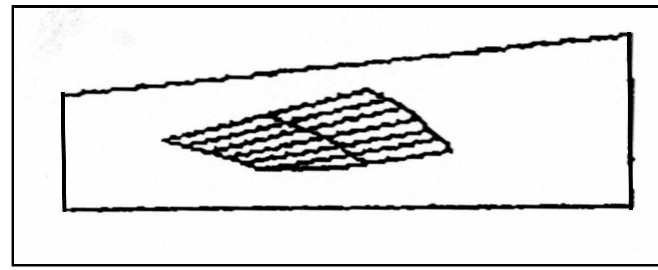
Contact Pattern Comparison: *Gleason TCA* vs *HyGEARS TCA*

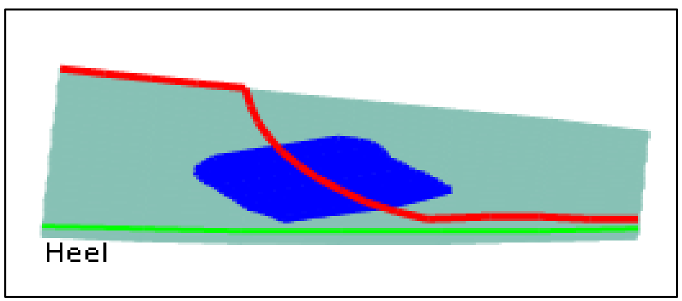
13x24 Face Milled Spiral Bevel gear set

Drive Side | *Coast Side*

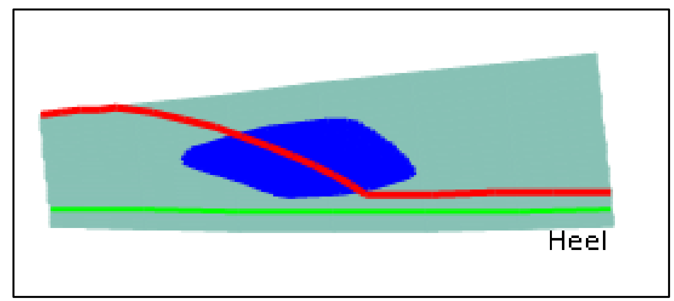


Gleason





HyGEARS

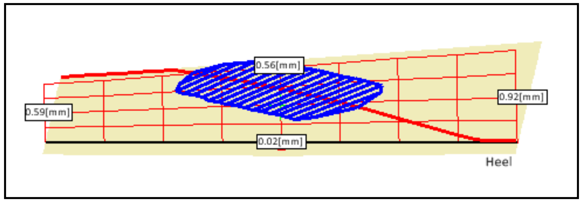


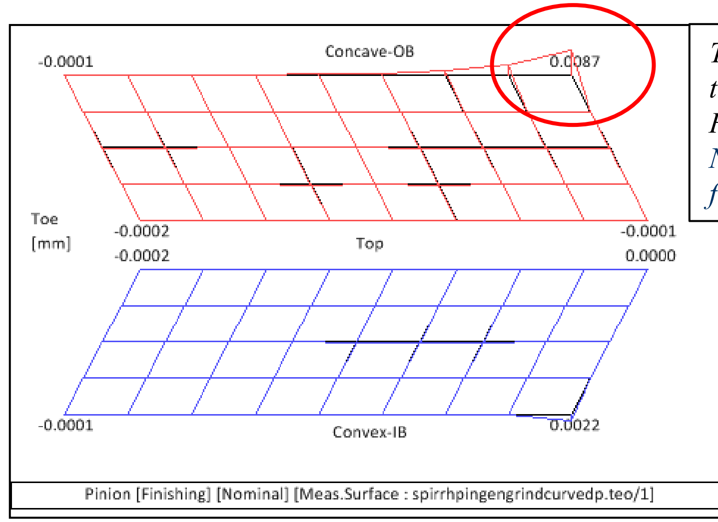
HyGEARS™ Calibration

Tooth Flank Topography Comparison: *Gleason and Klingelnberg* vs *HyGEARS*

*8x39 **Face Milled** Spiral Bevel gear set: comparing Nominals using the same machine settings*

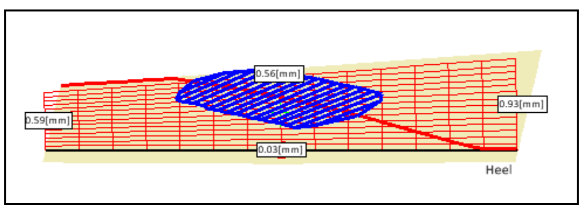
HyGEARS vs. Gleason Nominal

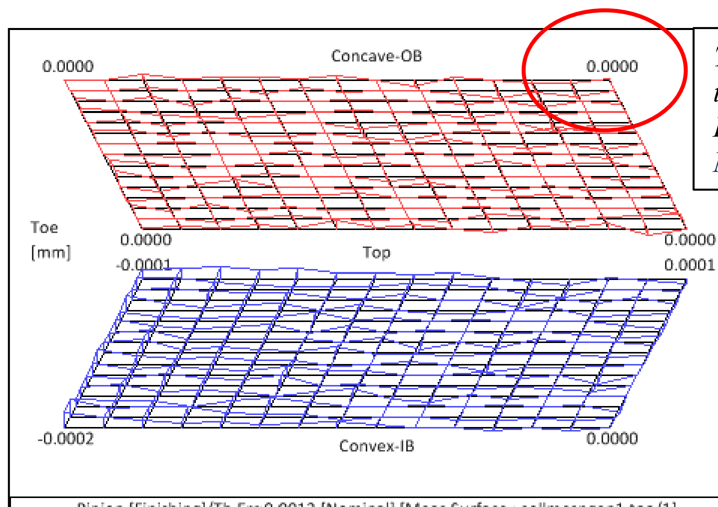




The colored lines are the Gleason nominal; HyGEARS is in black
Note the deviation at fillet, Heel-OB

HyGEARS vs. KIMoS Nominal





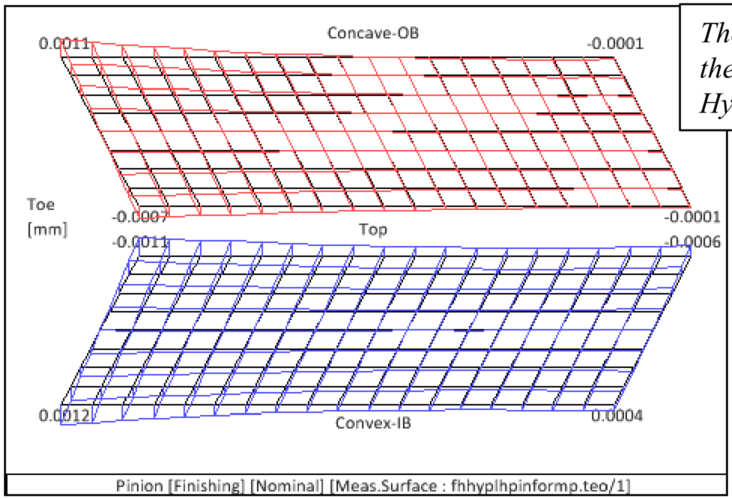
The colored lines are the KIMoS nominal; HyGEARS is in black
No deviation here !

HyGEARS™ Calibration

Tooth Flank Topography Comparison: *Gleason and Klingelnberg* vs *HyGEARS*

8x39 ***Face Hobbed*** *Hypoid gear set: comparing Nominals using the same machine settings*

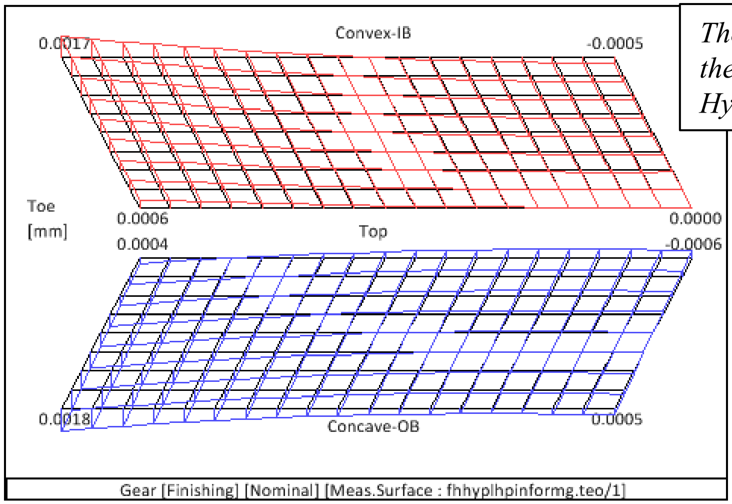
HyGEARS vs. Gleason - Pinion



The colored lines are the Gleason nominal; HyGEARS is in black.

Typical differences are less than 1 µm

HyGEARS vs. Gleason - Gear



The colored lines are the Gleason nominal; HyGEARS is in black.

HyGEARS™

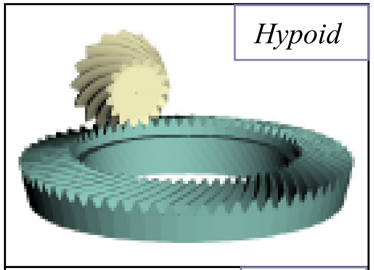
Supported Gear Types

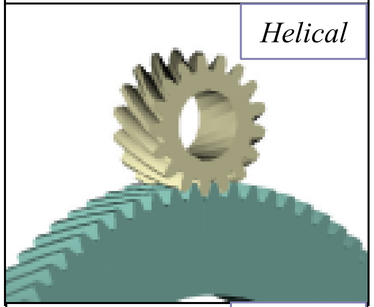
The most popular gear types are supported by HyGEARS.
All can be cut on any CnC machine.

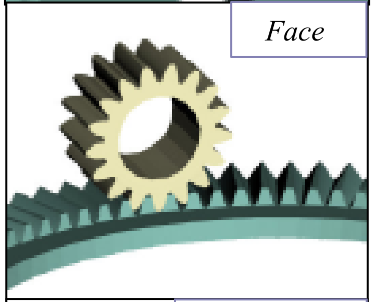
- *Spur/Helical*
- *Herringbone*
- *Spiral Bevel: Face Milled, Face Hobbed, Cyclo-Palloid*
- *Hypoids, both conventional and High Ratio (HRH)*
- *Straight Bevels*
- *Coniflex (™ The Gleason Works)*
- *Beveloid*
- *Face Gears*
- *Spiral Bevel Face Clutches*

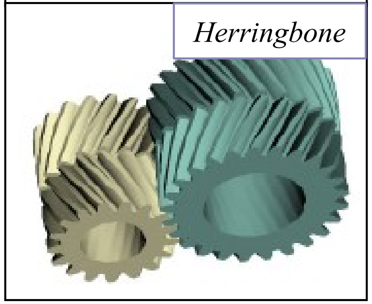
Spiral-Bevel/Hypoid cutting processes:

- *Fixed Setting (i.e. the old 5 cut system);*
- *Non Generated (i.e. Formate ®)*
- *Spread Blade*
- *Modified Roll*
- *Duplex Helical*
- *Semi-Completing*
- *Face Hobbed*
- *Cyclo-Palloid*



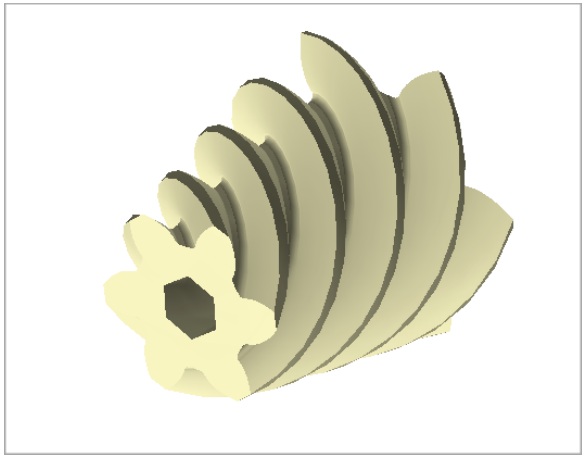




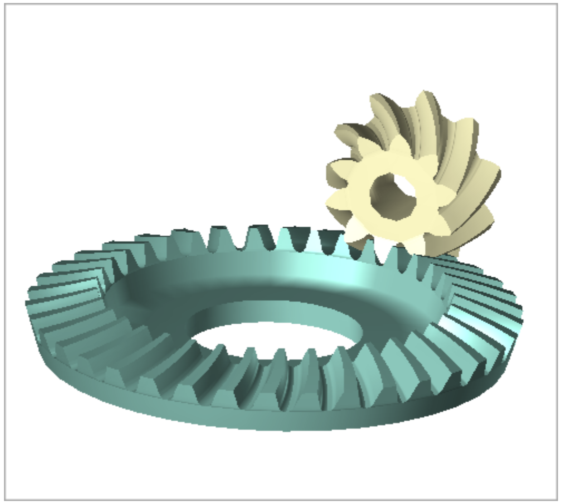


Fixed Setting Hypoid Pinion

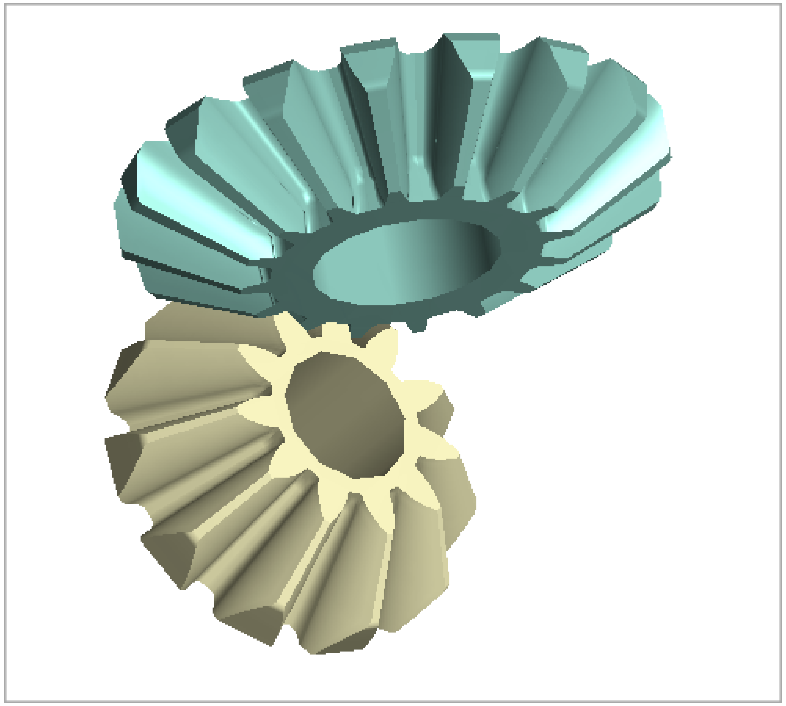
Duplex Helical Hypoid Pinion



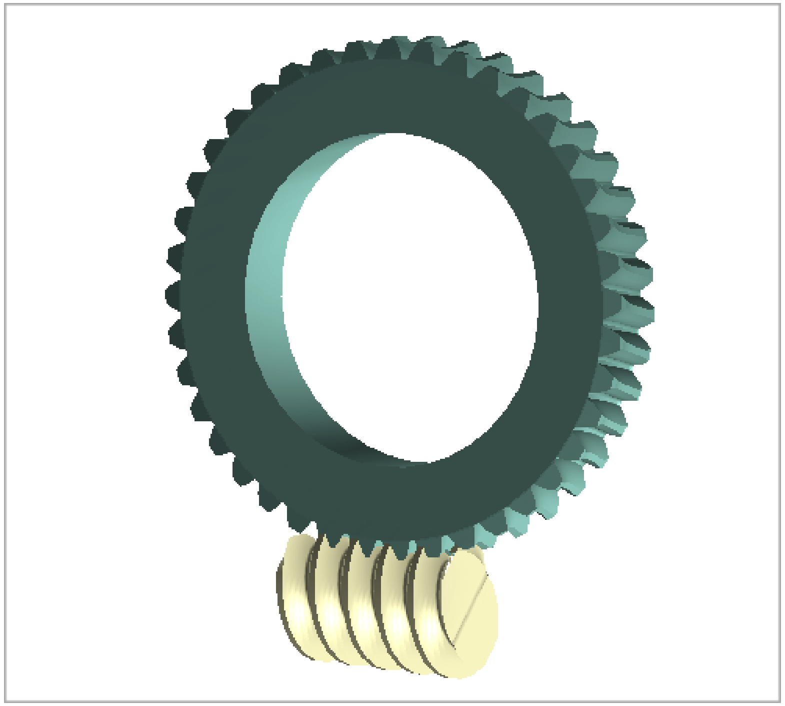
Cyclo Palloid Gear Set



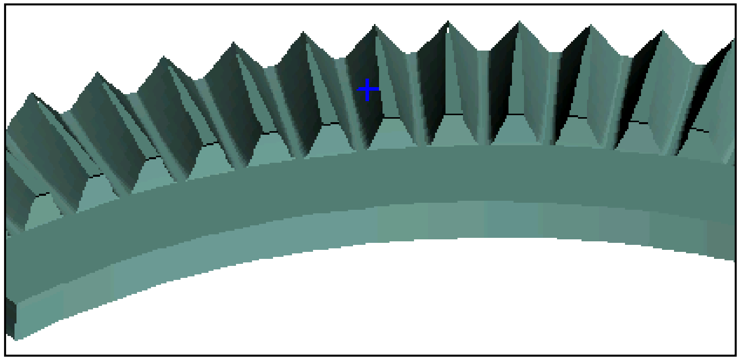
Differential Straight Bevel Gears

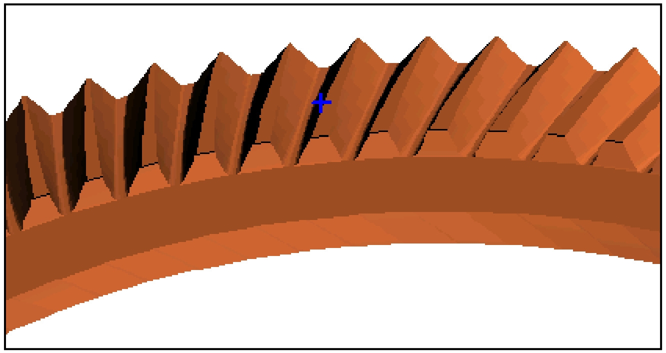


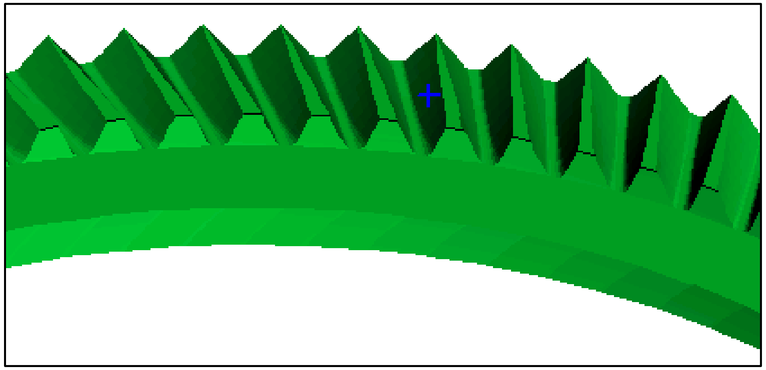
Worm Gears



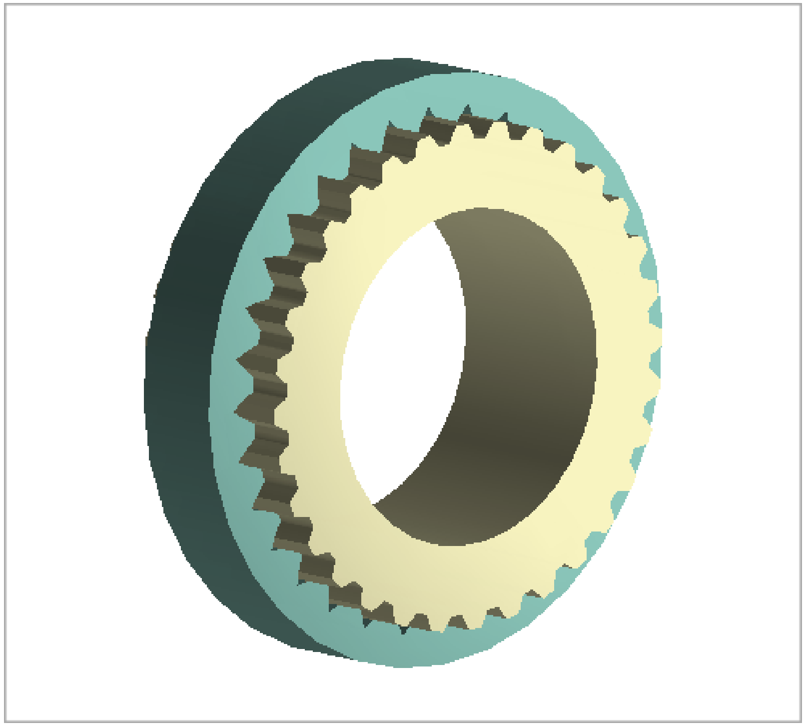
Face Gears



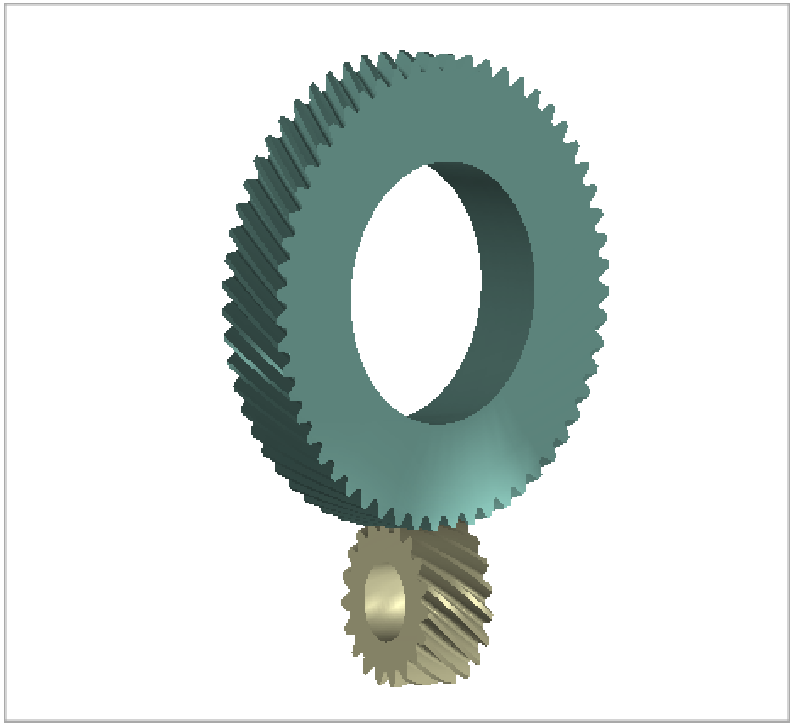




Splines/Internal Gears

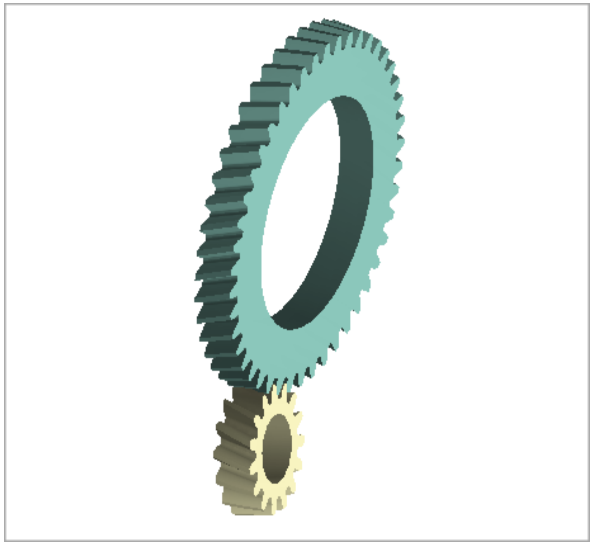


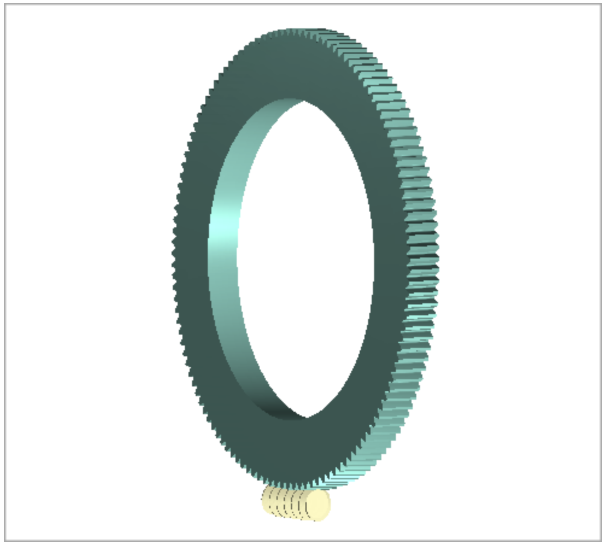
Crossed Axis Helical Gears

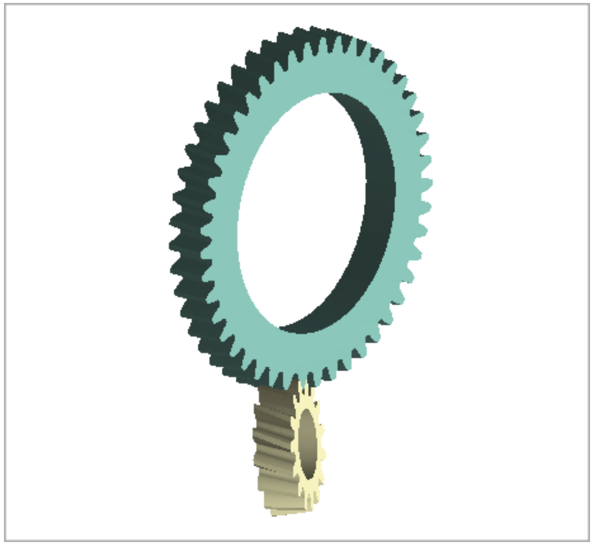


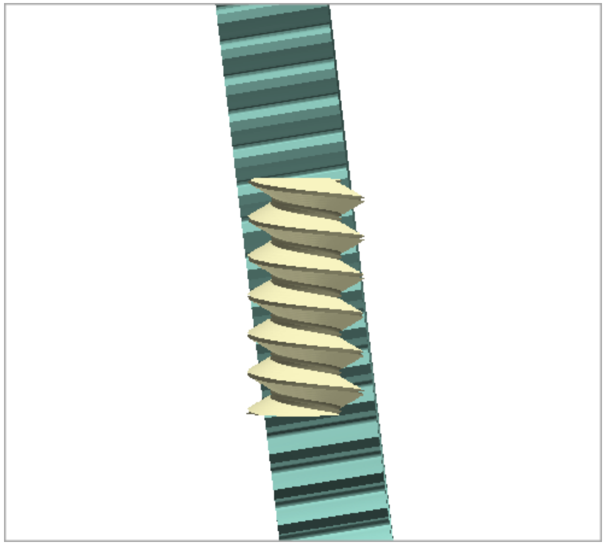
Beveloid Gears

Worm & Helical Gears



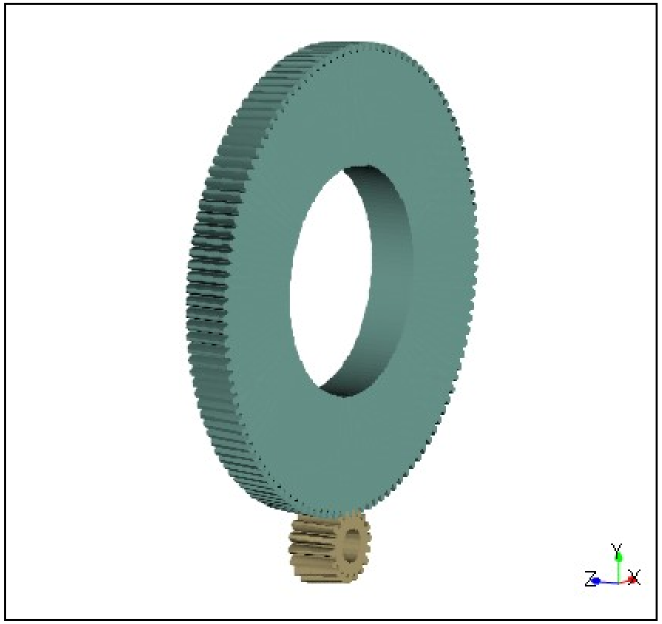


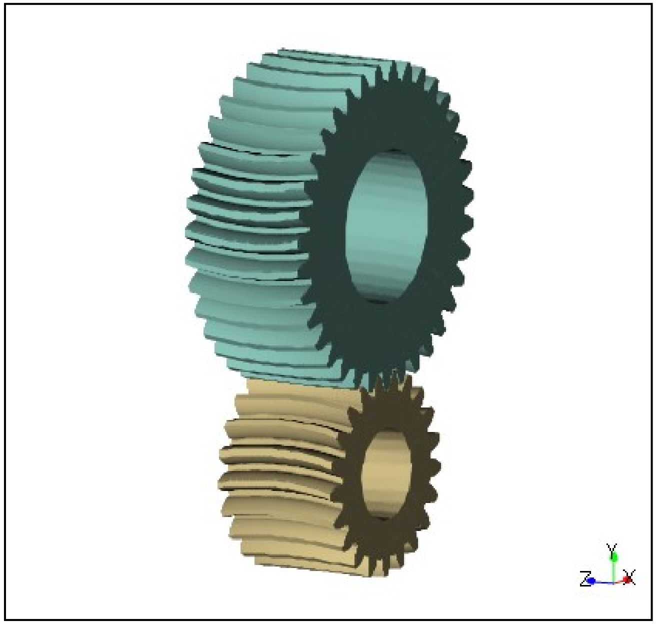


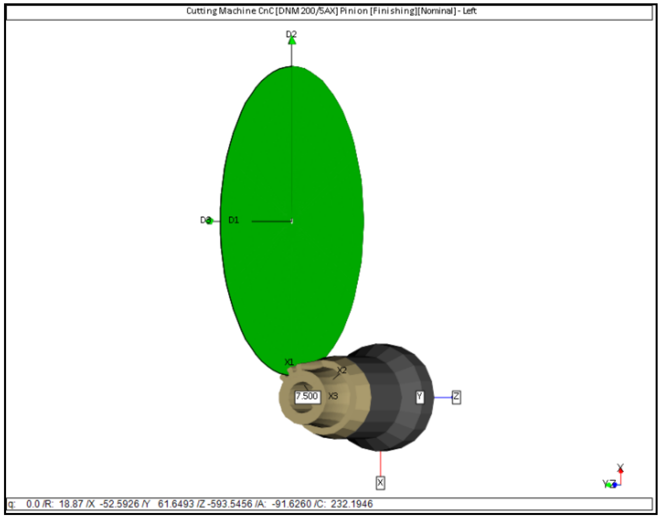


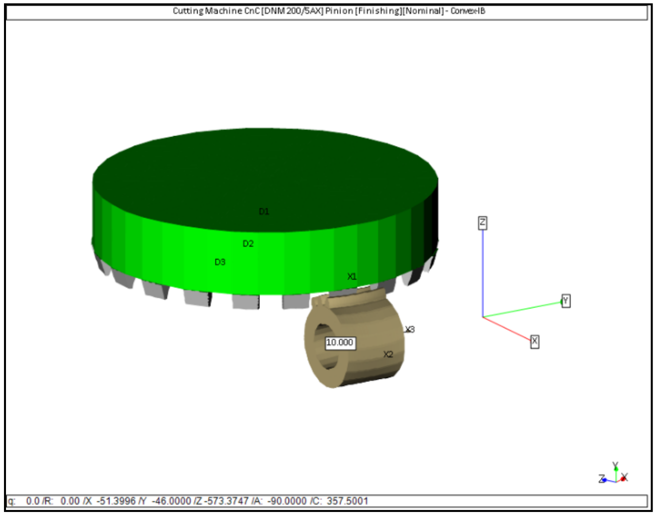
Spurniflex Gears

Spurved Gears

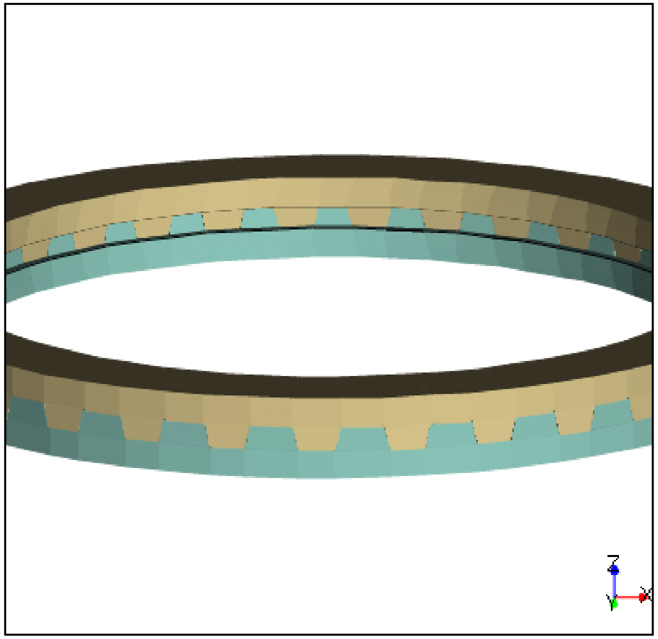


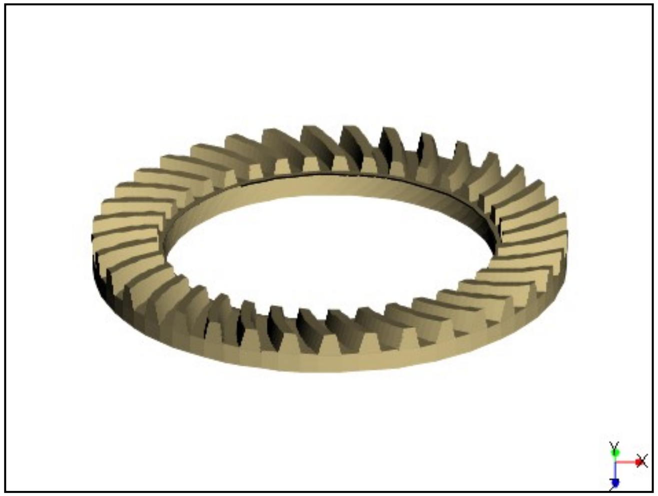




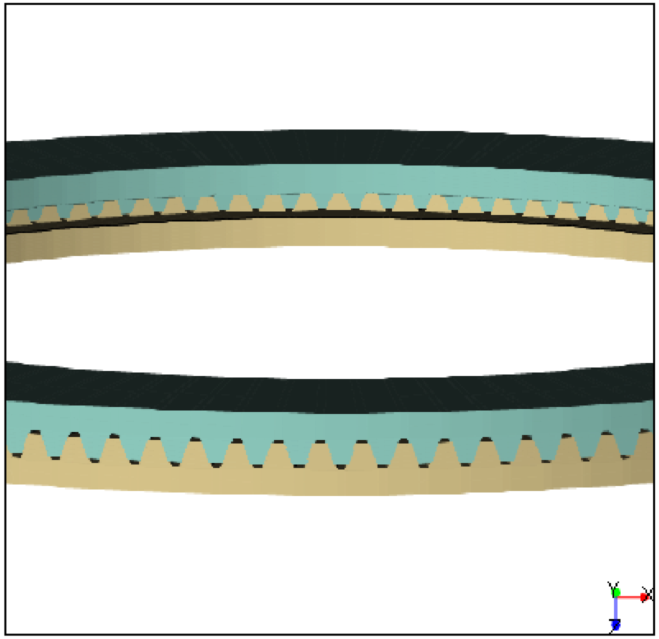


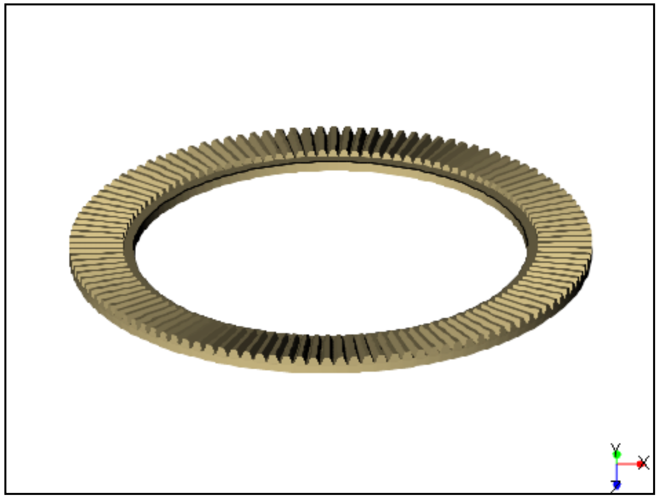
Spiral Face Clutch





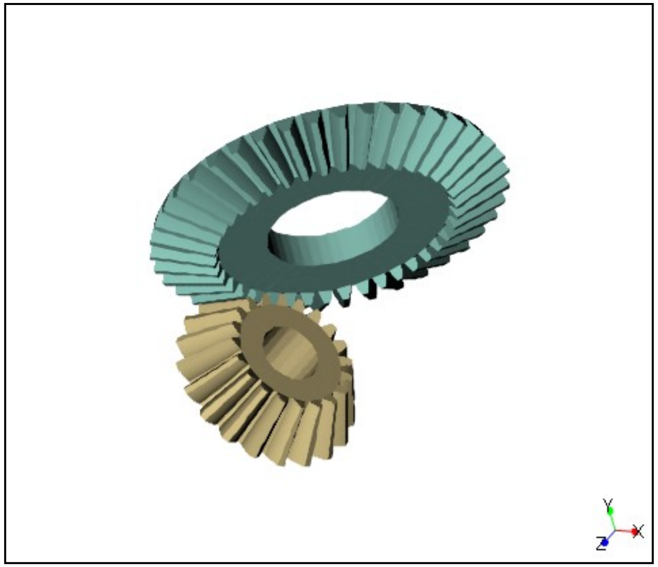
Hirth Coupling

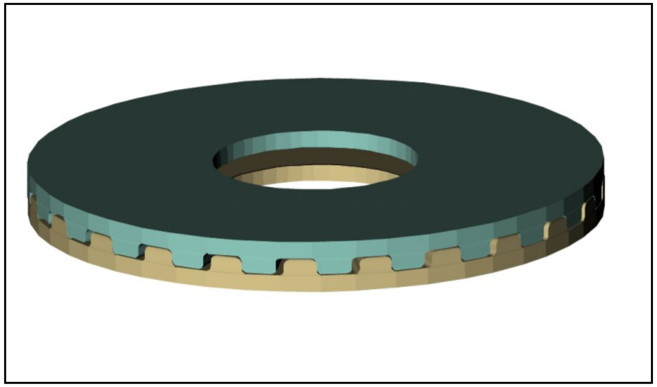


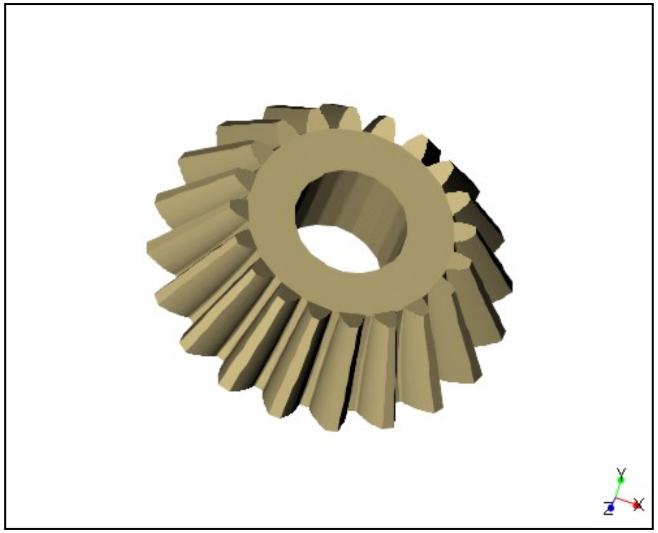


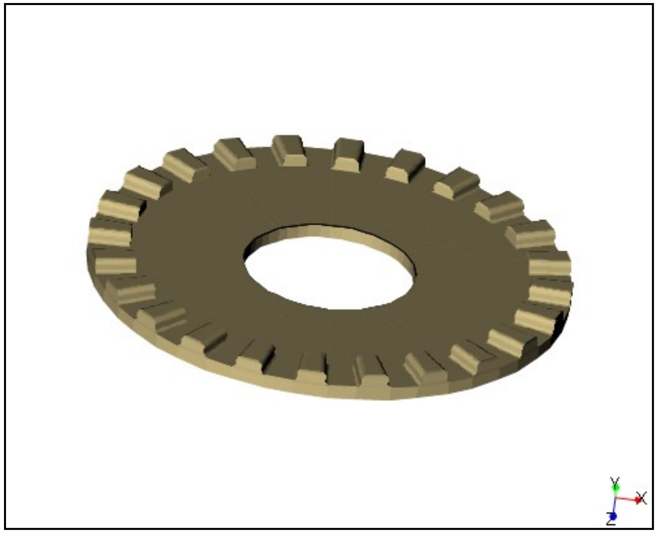
Coniflex Bevel Gears

Cogged Teeth Coupling









The HyGEARS™ 5 Axis CnC Post-Processor

Overview:

HyGEARS integrates a ***Post-Processor*** *which generates CnC part programs to cut* ***any HyGEARS supported gear type on any 3, 4 and 5 Axis CnC machine using any tool****.*

The part programs are based on the exact tooth definition, ***need no user intervention*** *and can be uploaded directly to any 3, 4 and 5Axis CnC machine.*

Tool and machine movements are displayed in 3D*, can be rotated in any direction for viewing, and can be animated or single stepped to allow visualization and collision detection throughout the tool path.*

The use of the Post-processor is easy, intuitive, and reflects the actual work done on the shop floor.

The Post-processor supports horizontal lathe and vertical milling center machine architectures.

Other architectures are supported through workpiece coordinates in Traori/TCP/TCPM/TCPC mode

Specific machines can be created and saved for later use: the translation and rotation axes can be renamed, and their positive direction can be inverted.

Typical tools include Face Milling, Coniflex™ dish, CoSIMT (i.e. Conical Side Milling Tool), End Mill and Ball Mill cutters. A tool box for each tool type can be created by the users to suit their needs.

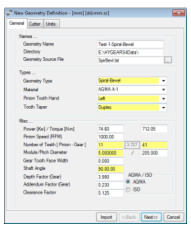
The HyGEARS™ 5 Axis CnC Post-Processor

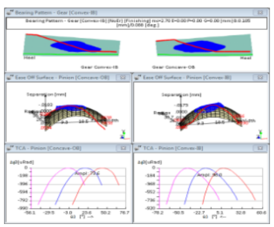
Navigation: *all steps are integrated; no outside software support required.*

1- Design *and* optimize gear sets using HyGEARS V 5.0 tools :

- Spiral bevel / hypoid / Zerol
- Spur/helical/herringbone
- Face gears
- Straight bevel/Coniflex
- Beveloid

Contact Pattern location and TE can be modified to user's desire in a few steps.

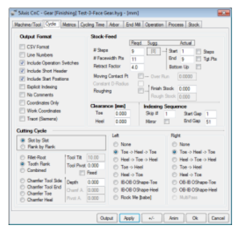


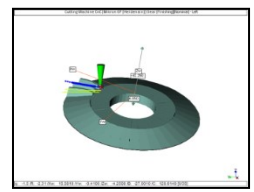


2- Create *machine ready* part programs in a few steps *using any cutting tool* :

- Face Mill cutters
- Coniflex cutters
- End Mill, Ball Mill cutters
- CoSIMT (conical side milling tool)

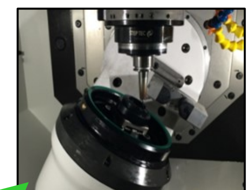
Part program definitions are *parametric and saved as re-usable Operations.*





3- Cut the part on the *selected* CnC machine.

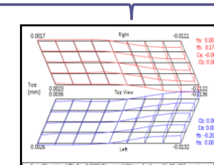
Part programs can be in Machine or Work piece coordinates.



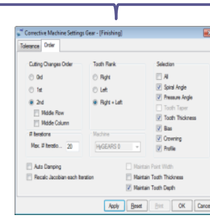
Closed Loop

7- Re-cut: *only if needed* !

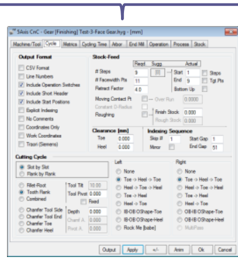
4- Measure the part on *any CMM* (Klingelnberg, Gleason, Zeiss, Leitz, MdM, Mitutoyo, etc.)



5- *Integrated* Closed Loop: from CMM output, get changes in machine settings to *offset tool and machine errors.*



6- Re-generate: *re-use* the Operation in 2. to generate a new part program *with the modified Machine Settings.*



The HyGEARS™ 5 Axis CnC Post-Processor

User Interface: *simple switch selection from a single window; instant display;*

Expected Cycle Time breakdown

Workpiece Support definition

Expected Surface Quality metrics

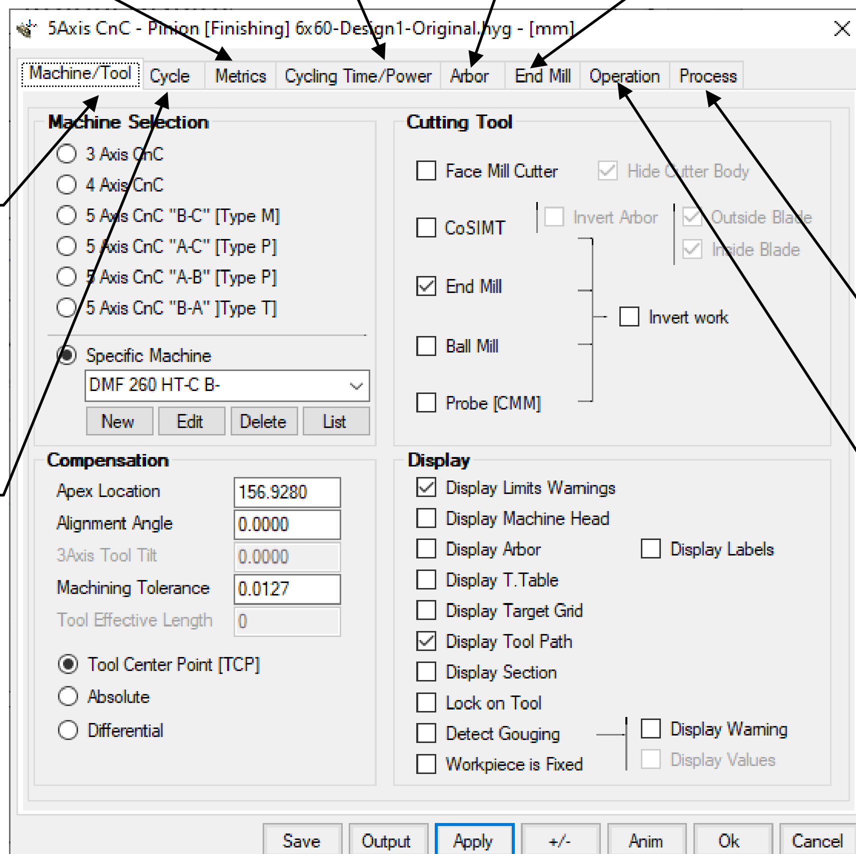
Tool definition

Machine – Tool - Display selection

Process definition

Cutting Cycle - Output selection

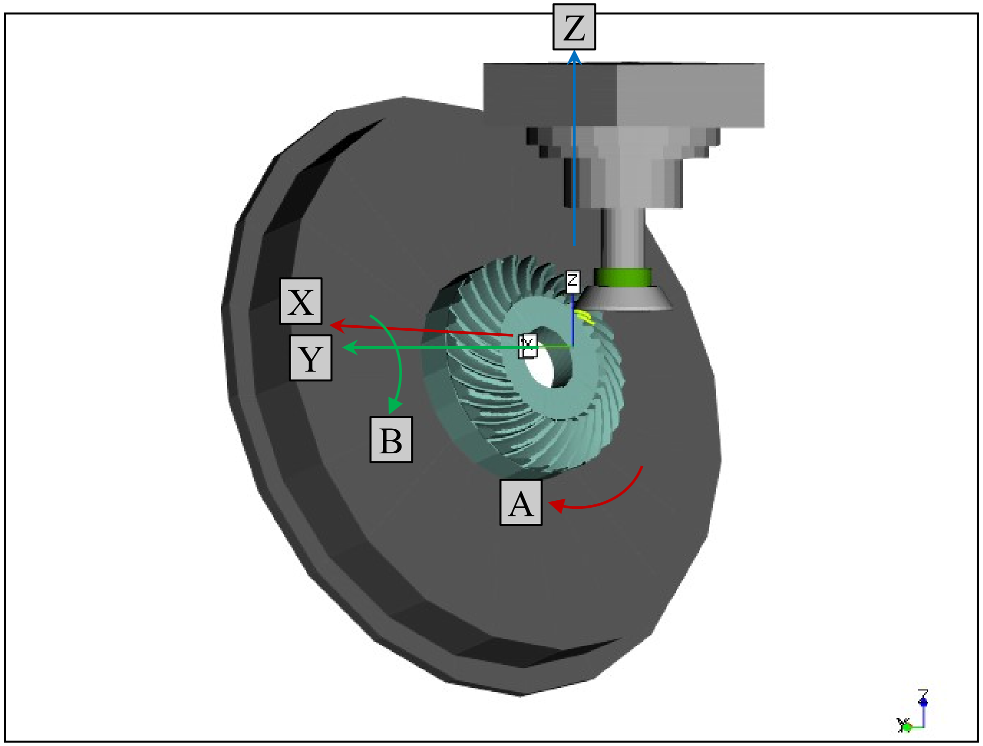
Operation definition



The HyGEARS™ 5 Axis CnC Post-Processor

***A-B* VMC machine architecture**:

- X, Y, Z translations (tool and/or work piece)
- Work tilt about Y axis: angle B
- Work rotation : angle A

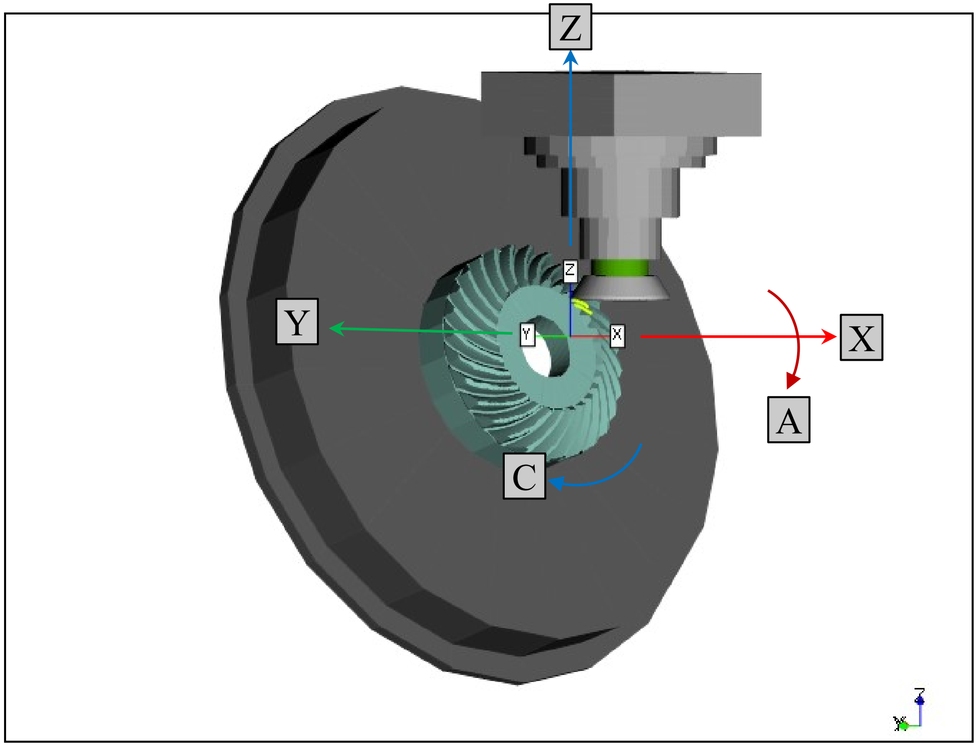


The HyGEARS™ 5 Axis CnC Post-Processor

***A-C* VMC machine architecture**:

- X, Y, Z translations (tool and/or work piece)
- Work tilt about X axis: angle A
- Work rotation : angle C

Note: corresponds to an A-B machine pivoted 90 deg. around the tool spindle axis.

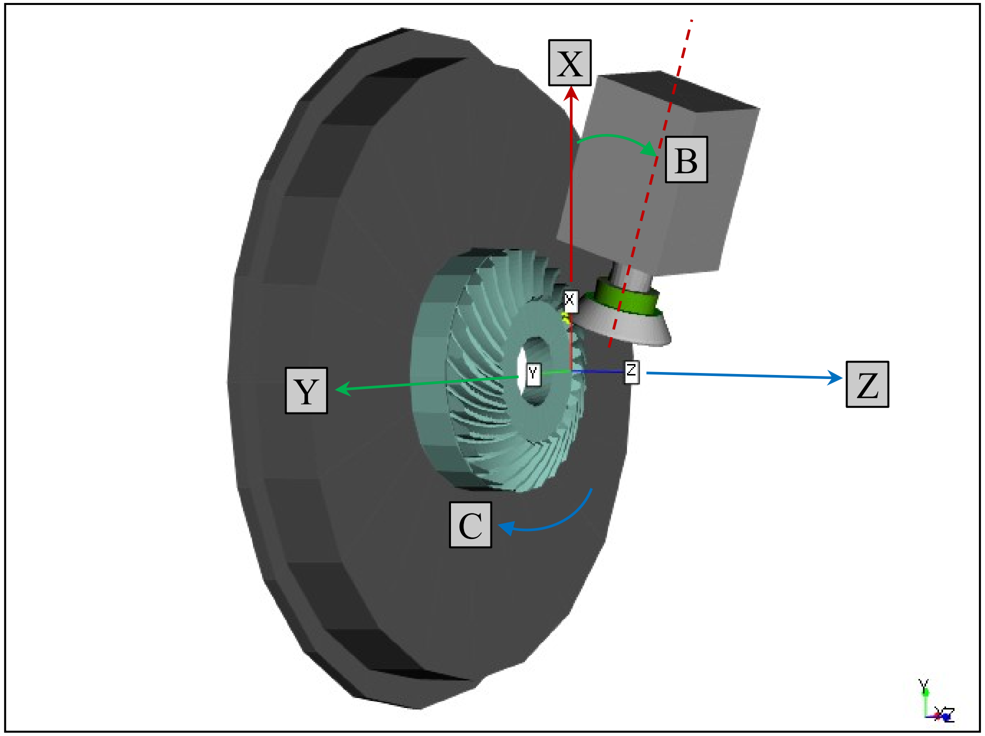


The HyGEARS™ 5 Axis CnC Post-Processor

***B-C* Horizontal Lathe machine architecture**:

- X, Y, Z translations (tool and/or work piece)
- Tool tilt about Y axis: angle B
- Work rotation : angle C

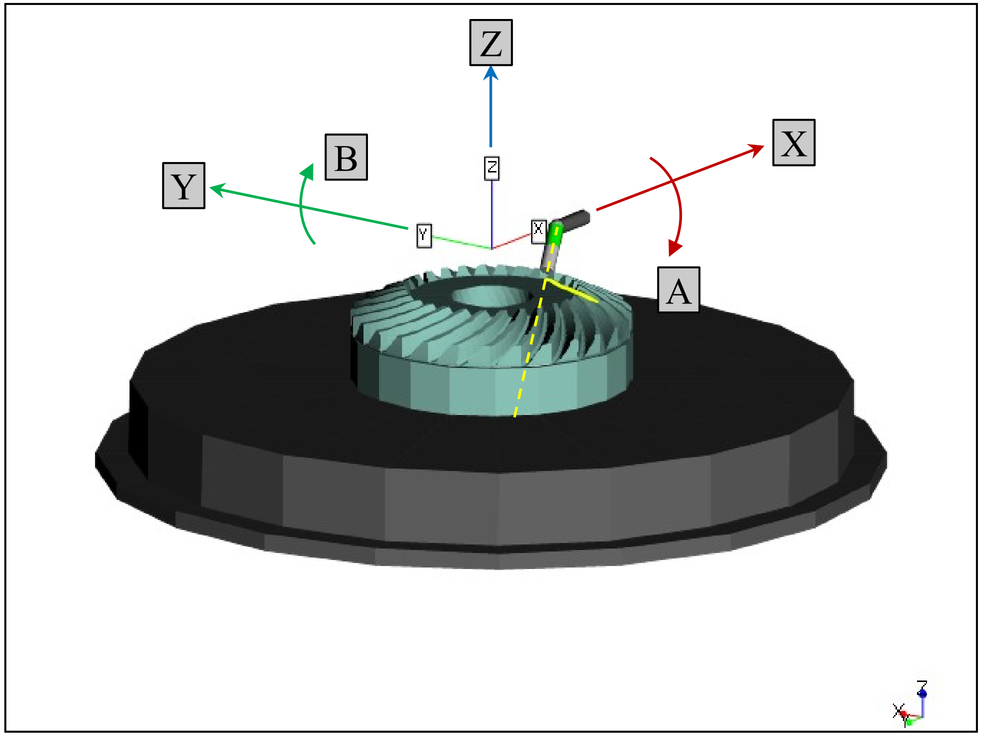
Note: the turntable axis may be horizontal or vertical



The HyGEARS™ 5 Axis CnC Post-Processor

***B-A* machine architecture**:

- X, Y, Z translations (tool and/or work piece)
- Tool swivel about X axis: angle A
- Tool tilt about Y axis: angle B



The HyGEARS™ 5 Axis CnC Post-Processor

Main features of the Post-Processor:

- *supports "AB", "AC", "BA" and "BC" architecture machines;*
- *supports GCodes, Heidenhain, Siemens, Okuma, Fanuc and Mazak controllers;*
- *supports Traori (Siemens), TCPM (Heidenhain), TCPC (Okuma) and TCP (Fanuc);*
- *allows creation of specific 3, 4 and 5Axis machines from 4 basic architectures; specific machines can be fully customized by the user to reproduce the exact implementation of any machine;*
- *offers 14+ pre-defined cutting cycles for CoSIMT, End Mill and Ball Mill tools; and 6 pre-defined cutting cycles for Face Mill tools (single roll/double roll);*
- *CoSIMT and End Mill cutting edges can be linear or circular (to cut a Face Gear for example);*
- *allows single pass and multi-pass roughing/semi-finishing/finishing for CoSIMT, End Mill and Ball Mill tools;*
- *allows the generation of a negative protuberance in the fillet;*
- *the tool path is easily customized by the user in order to optimize both cycle time and product quality;*
- *allows automated / single stepping animation of the tool and work piece through the cutting cycle;*
- *allows the display of the supporting arbor and the machine head to detect potential collisions;*
- *allows the creation of "Operations" which define a given task; Operations can be re-used on different parts;*
- *allows the creation of "Processes" which are a series of "Operations" in a specific order; Processes can thus generate a complete program sequence including roughing and semi-finishing of the tooth flank and fillet using different tools.*

Part Programs:

- *can be in CSV (comma separated values) format for import in Excel;*
- *can include or exclude comments describing the logic and operations performed;*
- *can be for Face Milling cutters (spiral bevel gears), Dish type cutters (Coniflex - ™ The Gleason Works - gears), CoSIMT (such as made by Ingersoll Rand, Sandvik), End Mill, Ball Mill cutters.*

The HyGEARS™ 5 Axis CnC Post-Processor

Conversion: *To generate a part program, HyGEARS converts the movements of the conventional cutter (in a conventional machine) into movements of a Face Mill, Coniflex™ dish, CoSIMT, End Mill or a Ball Mill tool in a 5Axis CnC machine where:*

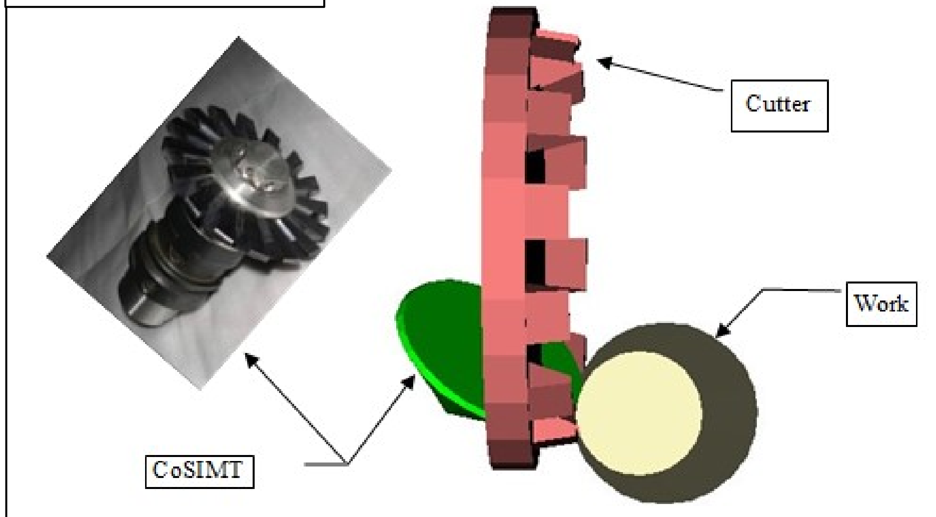
- the relative orientation between the ref. frames of tool and work in the conventional machine are maintained in the CnC machine;
- the relative position between the ref. frames of tool and work in the conventional machine are maintained in the CnC machine.

The figure to the right shows a Face Mill cutter (pink) and a CoSIMT (green) with coincident cutting edges.

The HyGEARS Post Processor tracks the movements of the Face Mill cutter in the conventional machine and converts them to CoSIMT movements in a 5Axis CnC machine.

The same approach is applied to all tools and gear types.

Photo courtesy of PTR-TEC.de

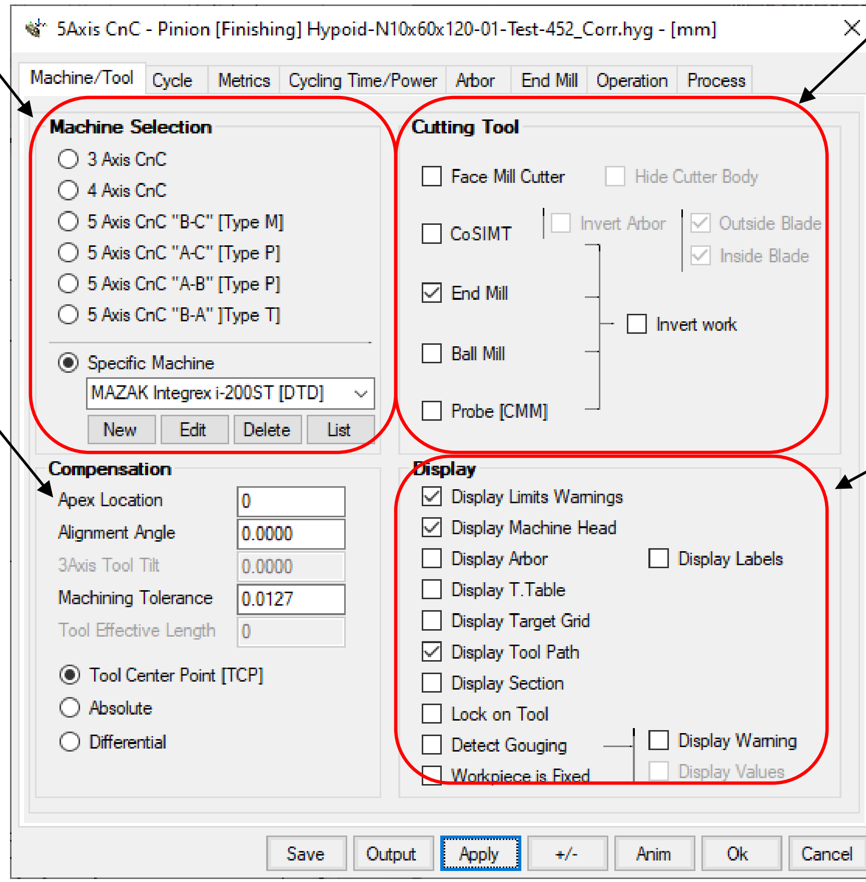


The HyGEARS™ 5 Axis CnC Post-Processor

***Machine/Tool**: Machine and Tool selection; display options*

Machines are optional;
- Generic type
- Specific type

Apex Location: used in "Machine" coordinates



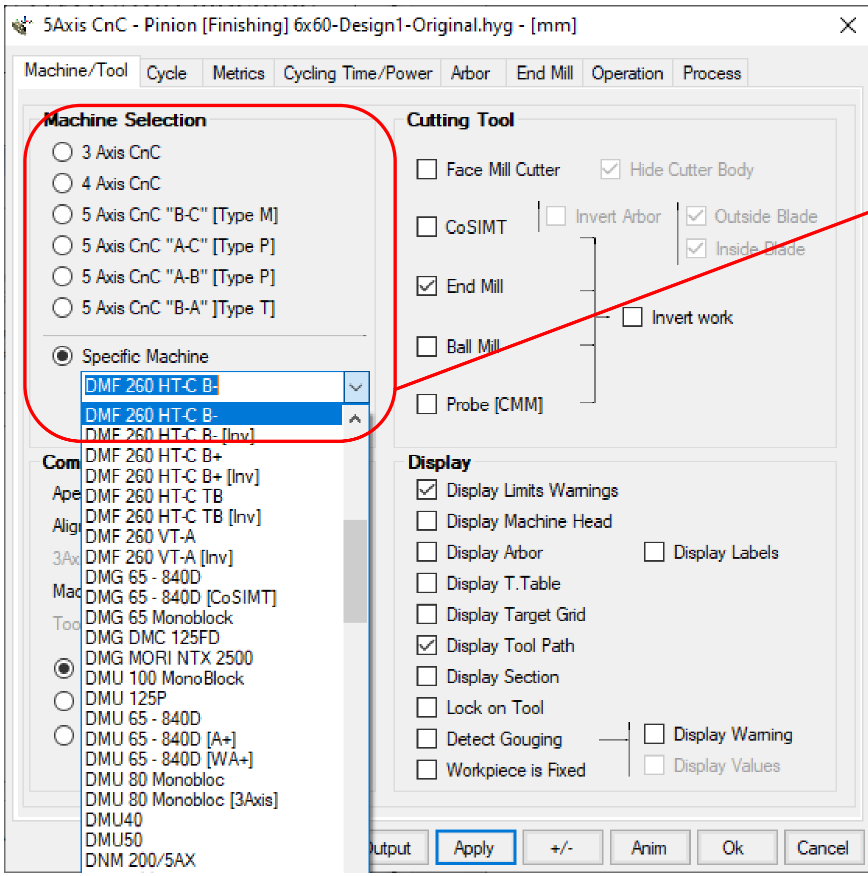
Cutting Tools are optional; they are user defined.

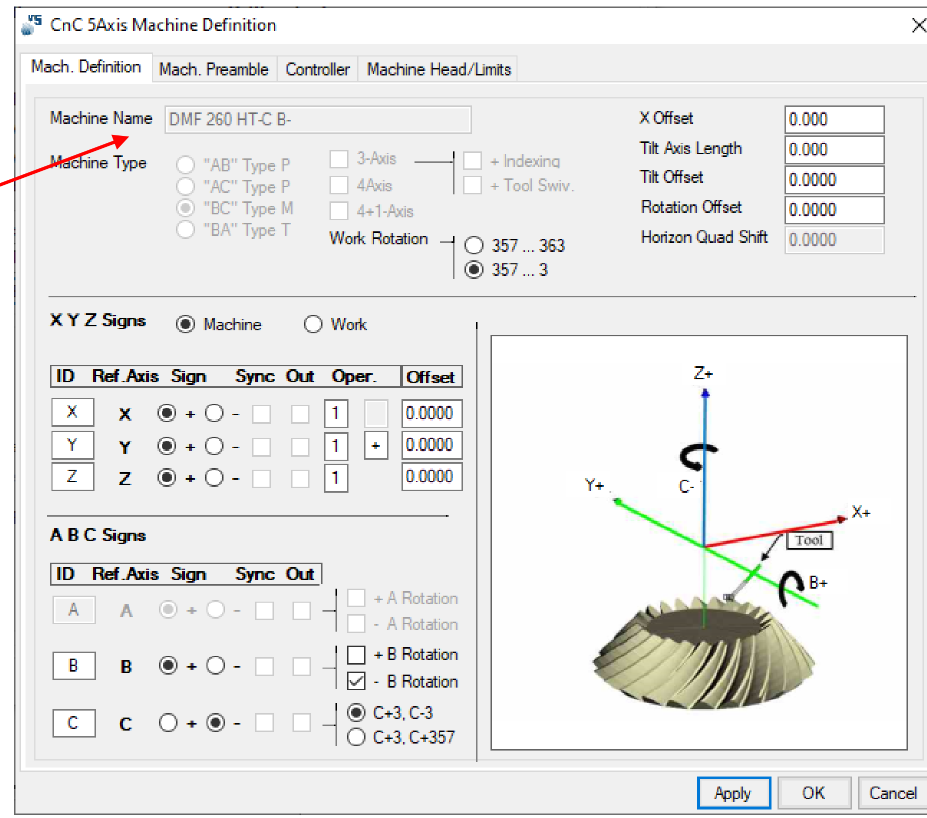
Display switches control what is shown on screen.

The HyGEARS™ 5 Axis CnC Post-Processor

***Machines**: 4 basic CnC machine architectures are available: AB, AC, BA and BC.*

Any specific machine can be derived from the basic types using the HyGEARS machine editor (bottom right figure).





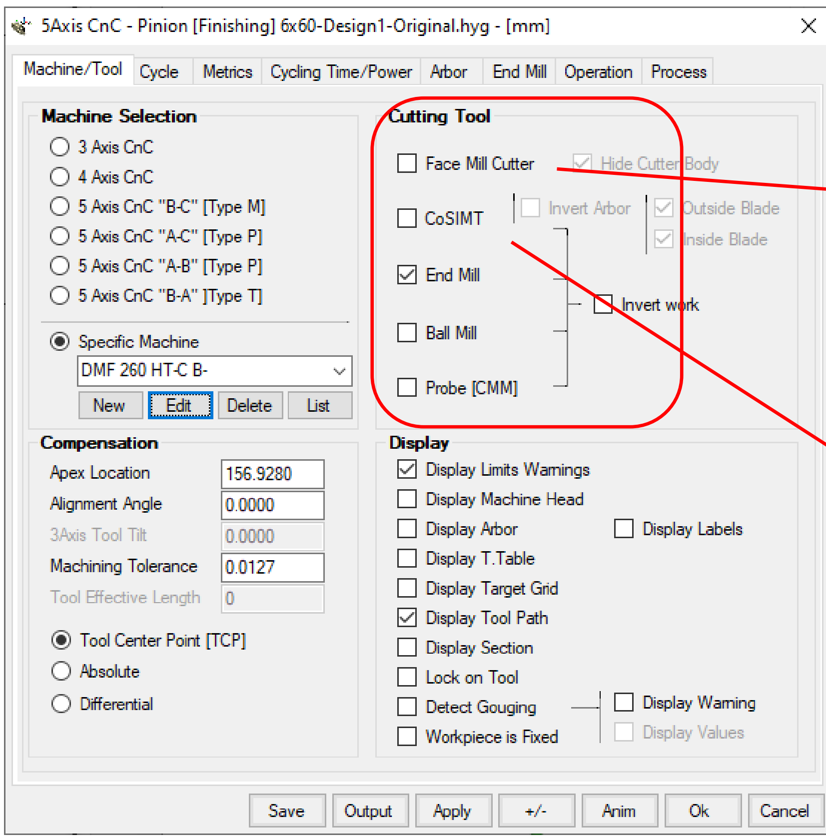
Machine Selection

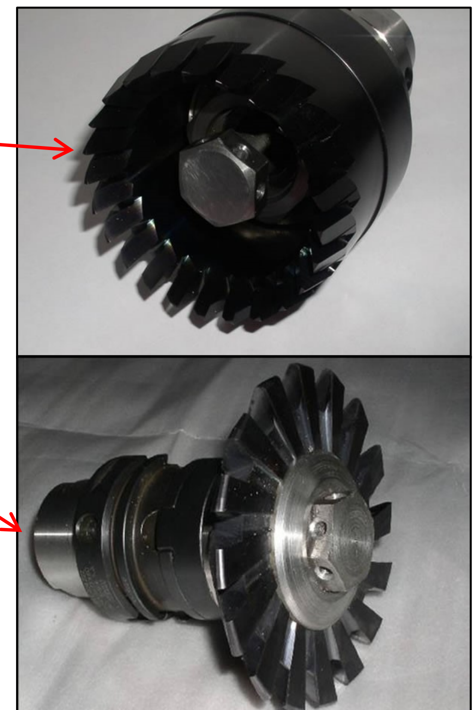
Machine Editor

The HyGEARS™ 5 Axis CnC Post-Processor

***Tools:** HyGEARS offers 6 different tools:*

Face Mill cutter	*(spiral bevel, Zerol, hypoid gears)*
Dish cutter	*(Coniflex™ gears)*
CoSIMT	*(all gear types)*
End Mill	*(all gear types)*
Ball Mill	*(all gear types)*
Probe (CMM)	*(all gear types; for measurement)*



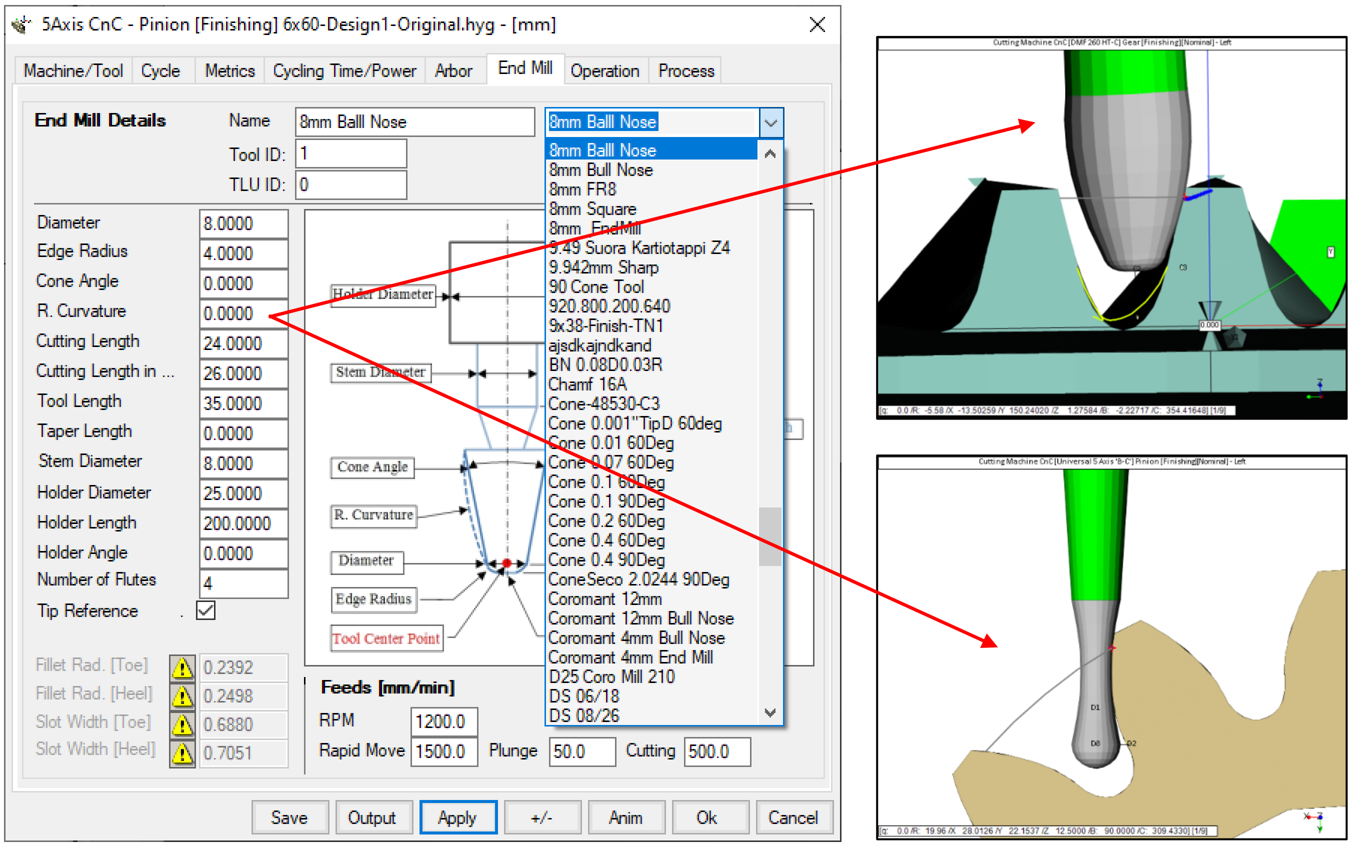


Photos courtesy of PTR-TEC.de

The HyGEARS™ 5 Axis CnC Post-Processor

Tools: *Each tool is described in a dedicated data page where the defining dimensions are entered by the user. The 30 character-long tool name is user defined.*

The tools can be saved for re-use and are specific to users, i.e. they are not distributed with HyGEARS. Hence, proprietary information remains proprietary.

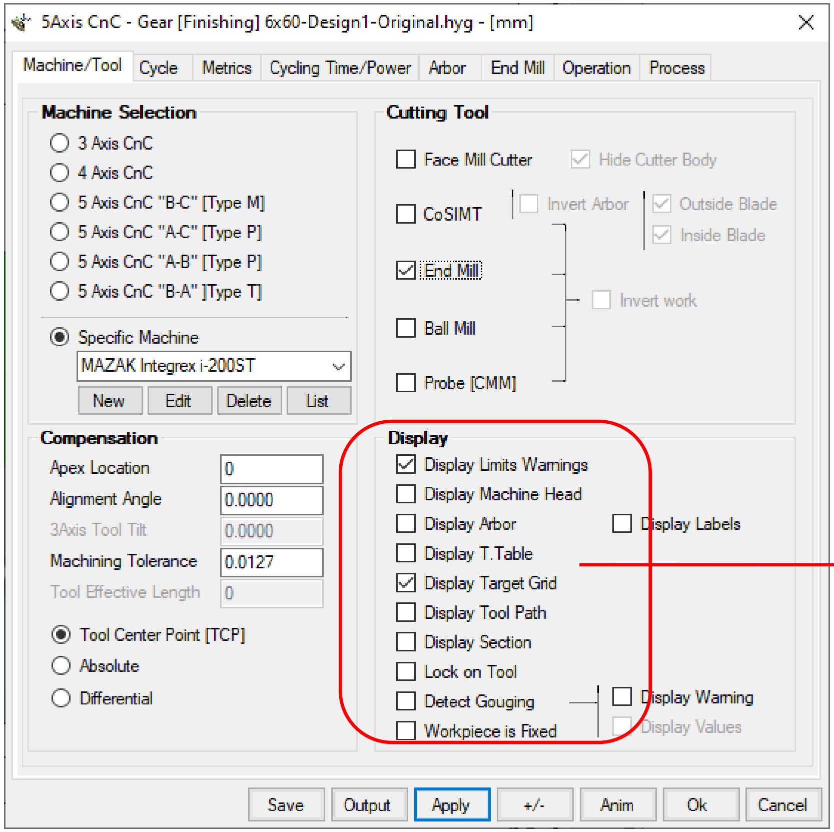


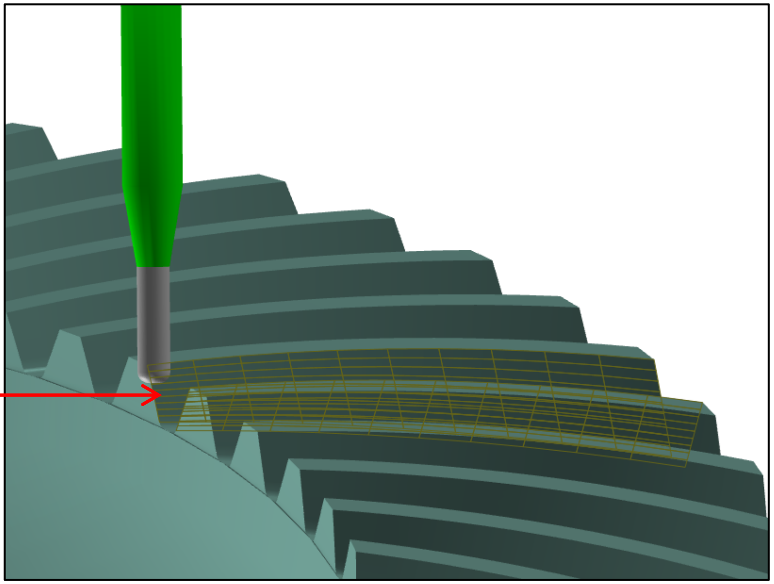
Definition of an 8mm Bull Nose

The HyGEARS™ 5 Axis CnC Post-Processor

Display: *Several options allow selective information display. These include:*

- *the Machine Head,*
- *the Machine Turn Table*
- *the Work Arbor and support,*
- *the Target Grid, where the target coordinates are displayed in wire frame mesh,*
- *the Tool Path.*

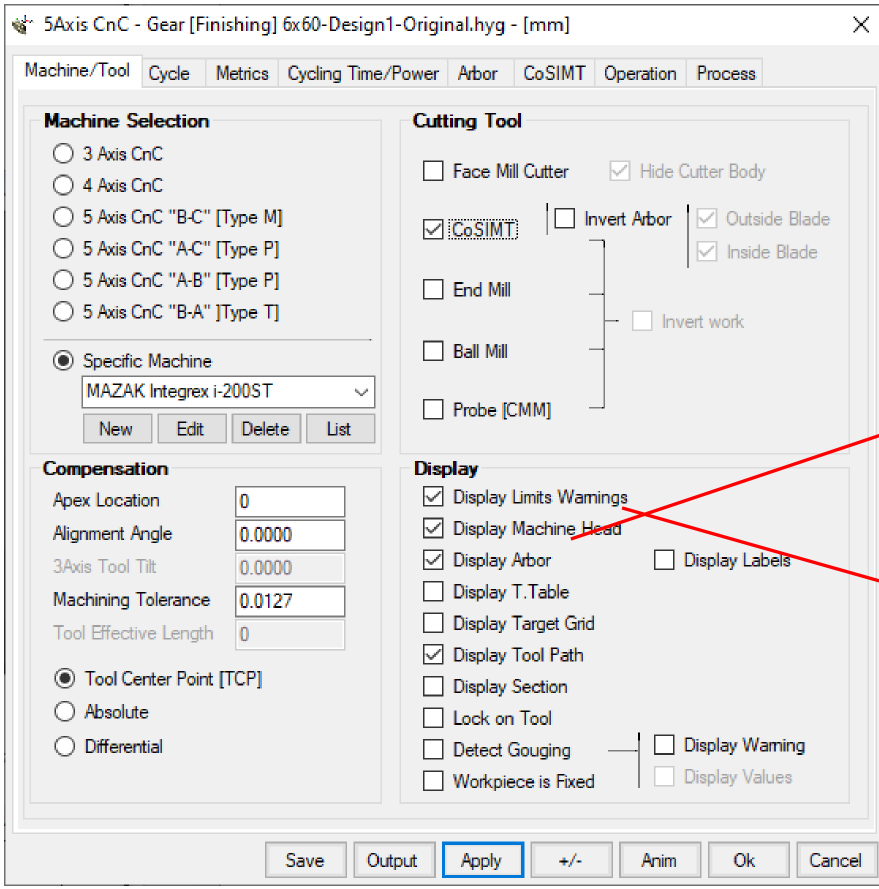


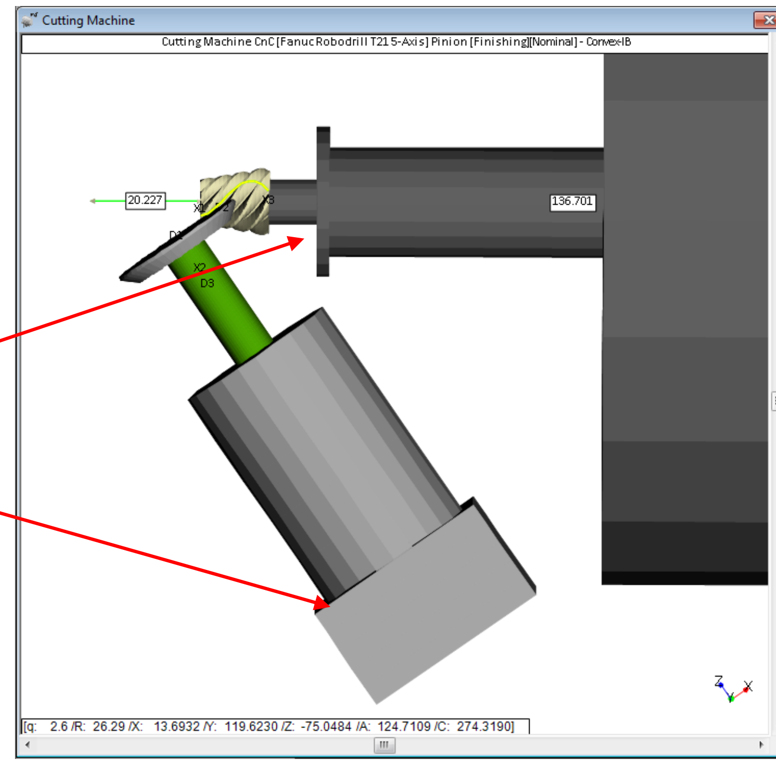


Display of the Target Grid (beige)

The HyGEARS™ 5 Axis CnC Post-Processor

Display: *Example of Tool Holder and Work Arbor with CoSIMT and 1.2 mm module hypoid pinion.*

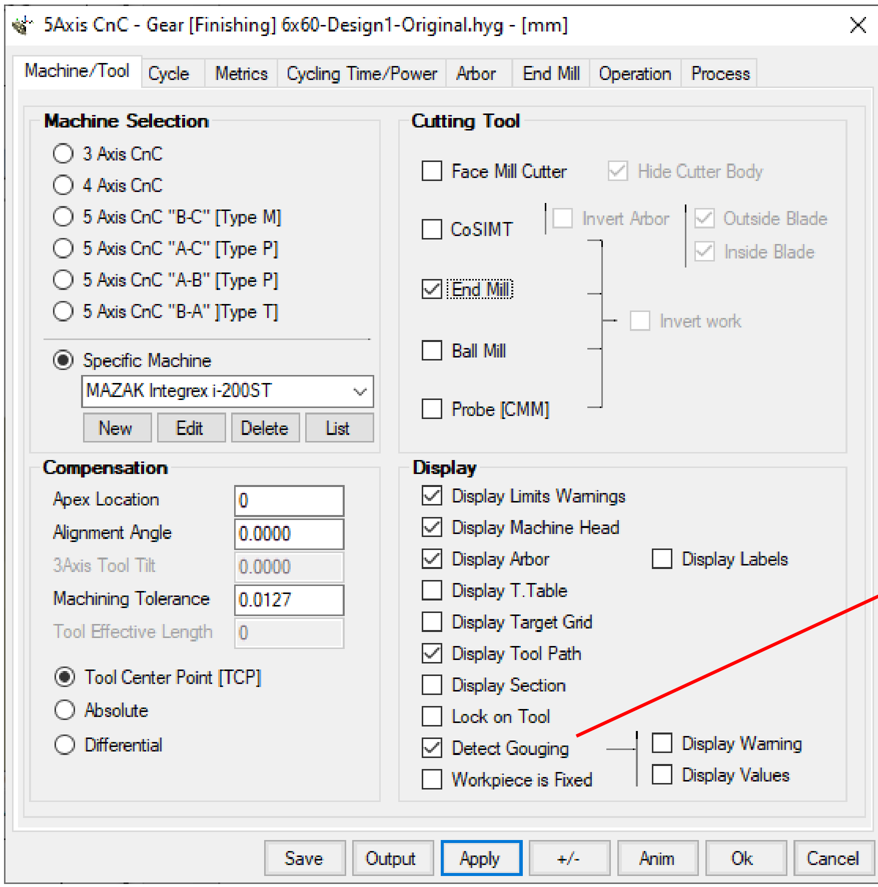


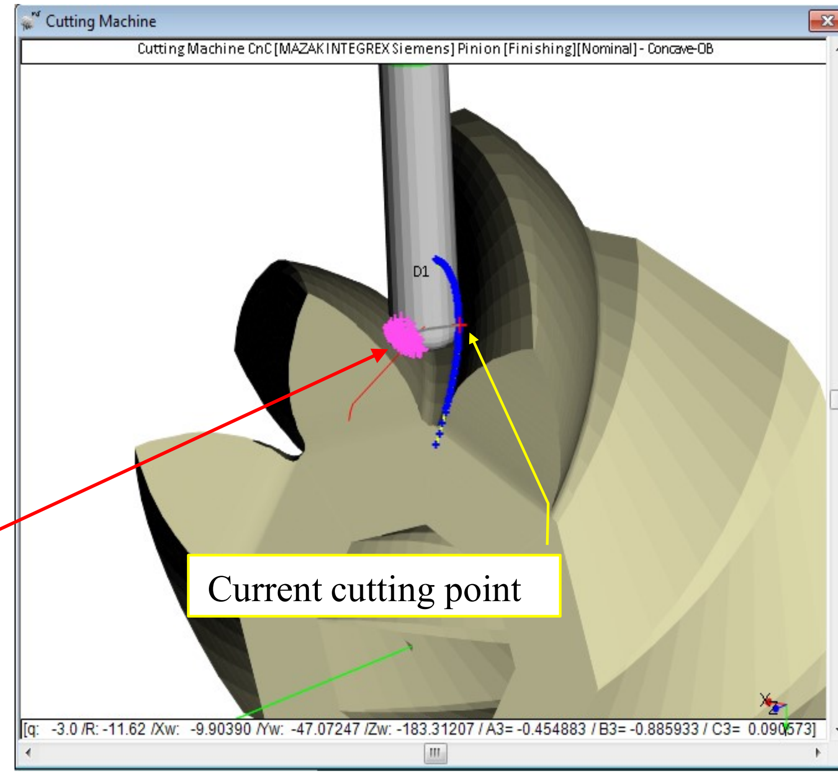


Display of the Arbor and Tool Holder

The HyGEARS™ 5 Axis CnC Post-Processor

Display: *Detection of Gouging interference (tool back side contact with opposite tooth flank): HyGEARS can determine, and display where, if any Gouging occurs such as to alert the user of potential profile mutilation; valid for CoSIMT, End Mill, Ball Mill tools.*





Display of Gouging points with Pink crosses

The HyGEARS™ 5 Axis CnC Post-Processor

***Cycle**: Selection of Output, Stock, Feed, Clearances, Tooth area, and Cutting Cycle*

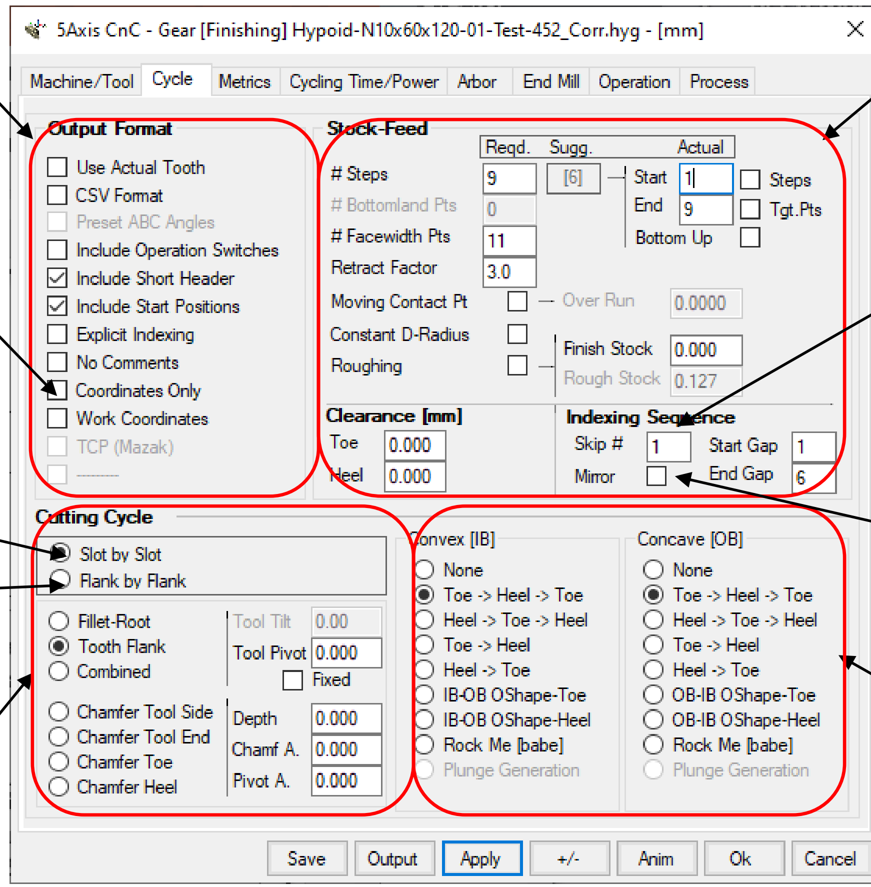
Output Format: allows selecting wanted or unwanted features

- •Machine: XYZ ABC
- •Work: XwYwZw ABC
- •Traori: XwYwZw ijk

Cuts the Complete Gap
or
Cuts all the Convex flanks and then cuts all the Concave flanks.

Targeted tooth region:

- Fillet,
- Flank,
- Combined,
- Chamfering



Controls step depth, cycle coarseness, Toe and Heel clearances, gap indexing.

Gaps skipped between 2 cuts. If "/X" where X = 1, 2, …, n, then

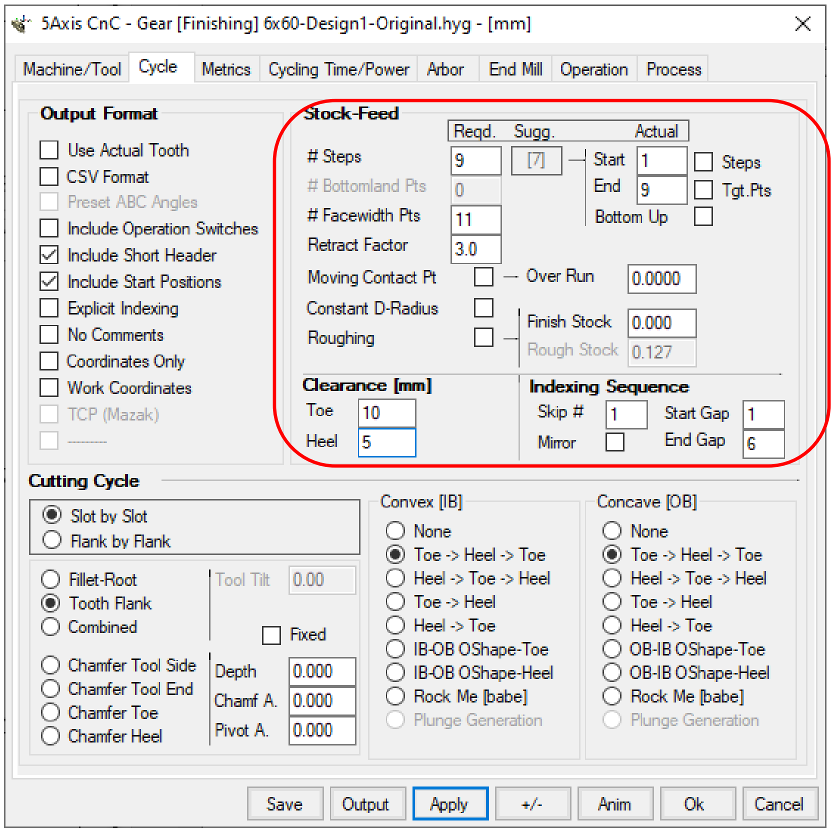
- Start Gap = 1
- End Gap = Z

Distributed about one central tooth gap

Tool movement types during cutting cycle

The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Cutting cycles can be extensively tailored to user preferences, depending on tool choice.*



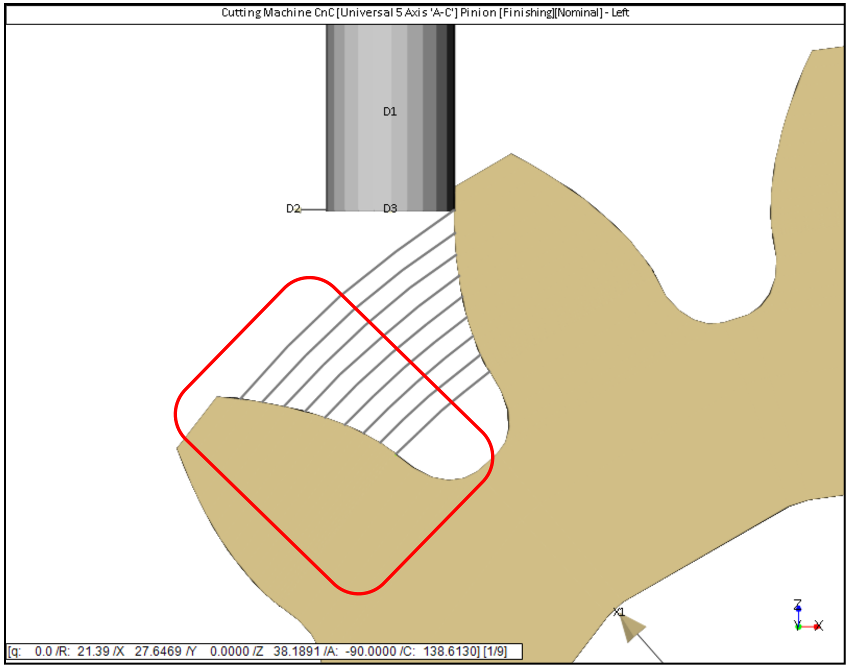
Cycle Options for CoSIMT, End Mill and Ball Mill tools

- *Stock-Feed along the face width (#Facewidth Pts) and tooth depth (#Steps)*
- *When cutting starts and ends (Start / End)*
- *Tool retraction at end of cycle (Retract Factor, based on Heel tooth depth)*
- *Whether the tooth description is with constant roll angles or constant radius (Constant D-Radius)*
- *Whether the contact point moves, or does not move, along the tool's cutting edge (Moving Contact Pt)*
- *Roughing and Finishing cycles*
- *Toe and Heel clearances*
- *Tip, Toe and Heel chamfering*
- *Indexing sequence in order to spread tool wear and thermal load over non sequential teeth (Skip#).*

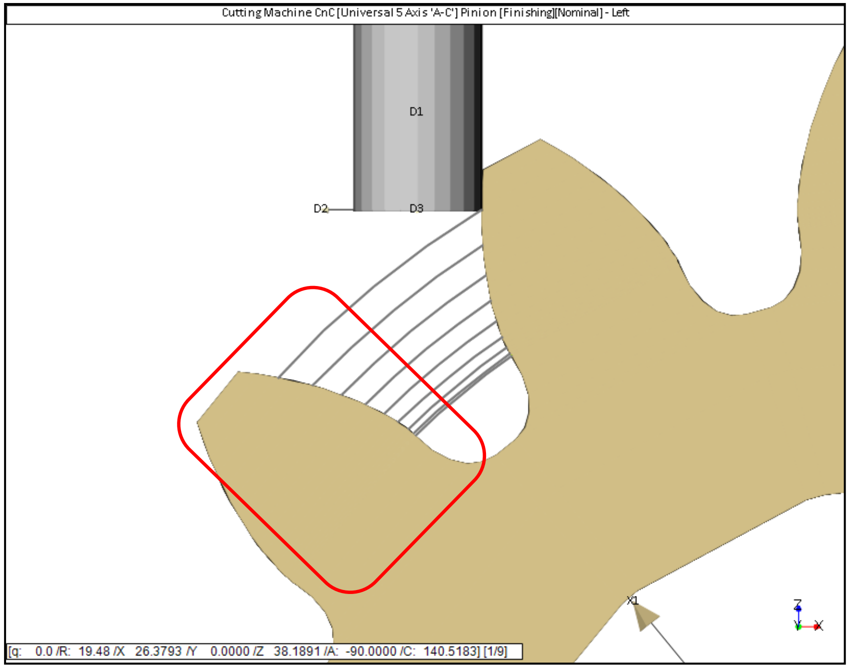
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Constant D-Radius:* *checked:* *constant radial steps; insensitive for Z > ~25*

un-checked: *constant roll-angle steps – improved surface near fillet better for Z < ~20*



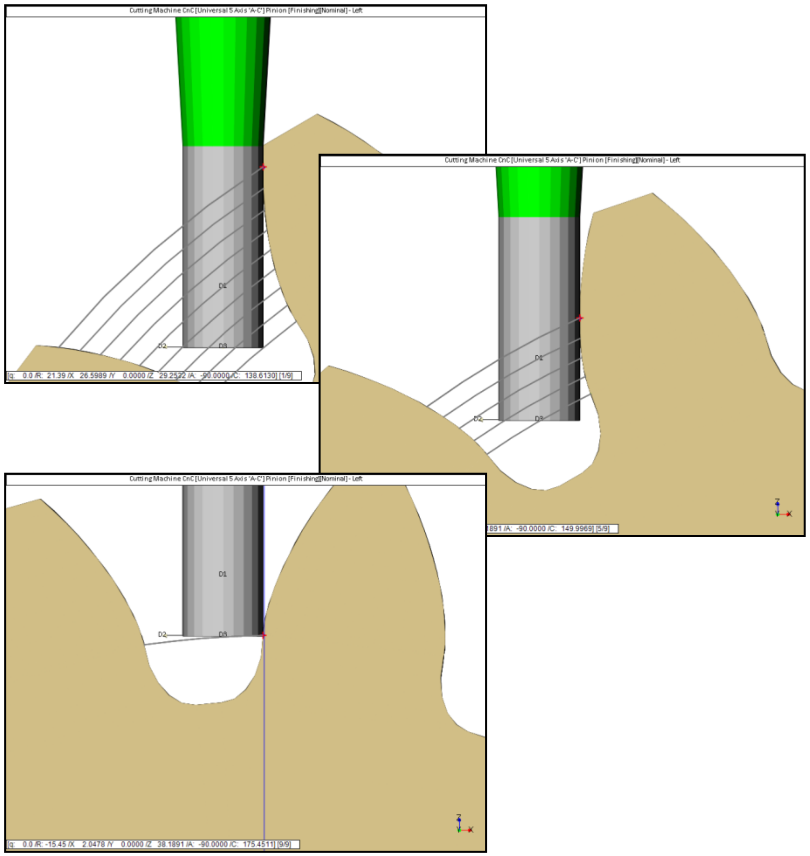
Constant D-Radius



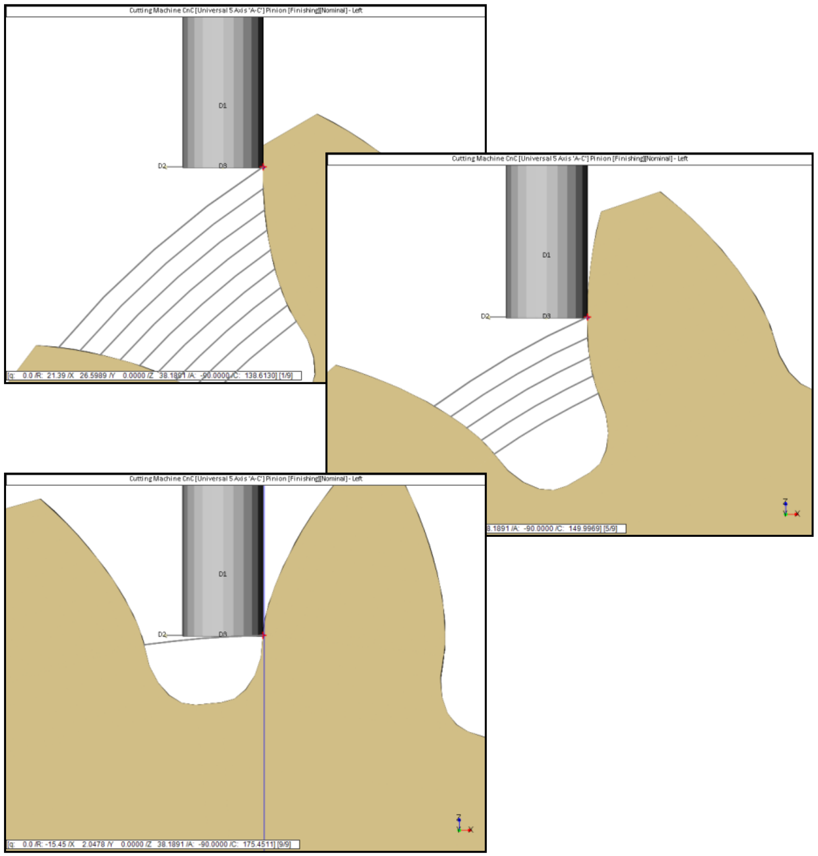
Constant D-Roll

The HyGEARS™ 5 Axis CnC Post-Processor

Cycles:	*Moving Contact Pt:*	*checked:*	*contact point moves along tool edge; better Finish and reduced tool wear;*
		un-checked:	*contact point always at tool tip: more tool wear*



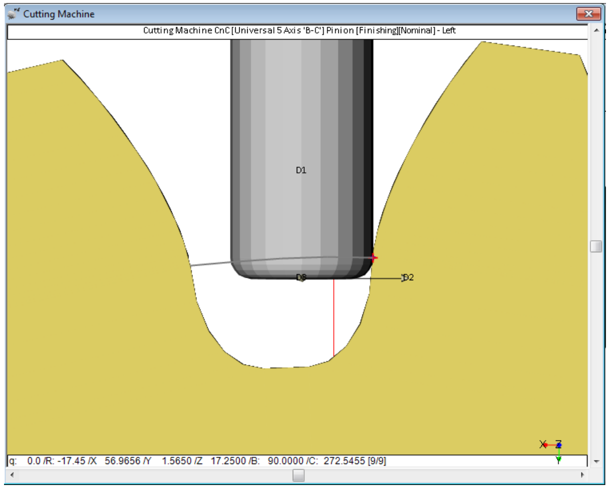
Moving Contact Pt: Finishing



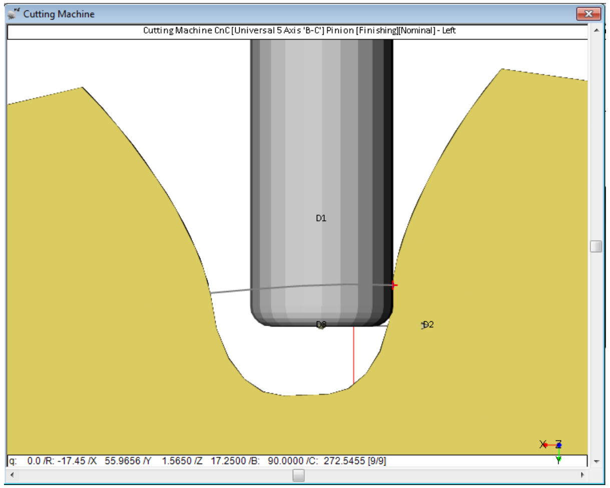
Fixed Contact Pt: Roughing

The HyGEARS™ 5 Axis CnC Post-Processor

Cycles:	*Over Run:*	*= 0:*	*End Mill stops at Fillet Line*
		> 0:	*End Mill extends below the Fillet Line: prevents lip forming in the fillet when negative stock is used on the flank*



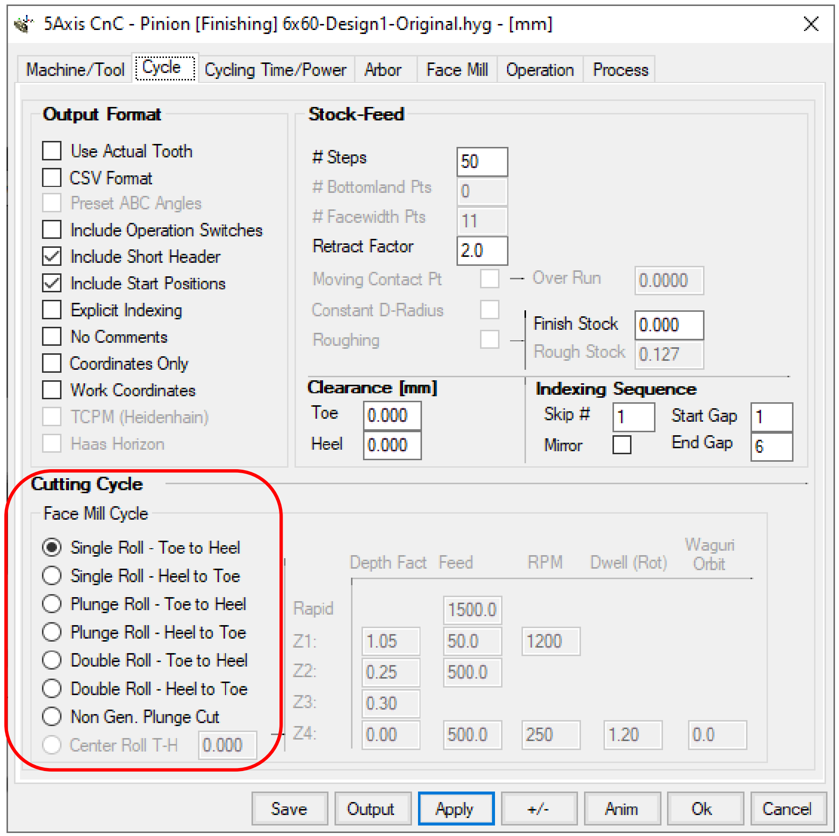
Over Run: 0

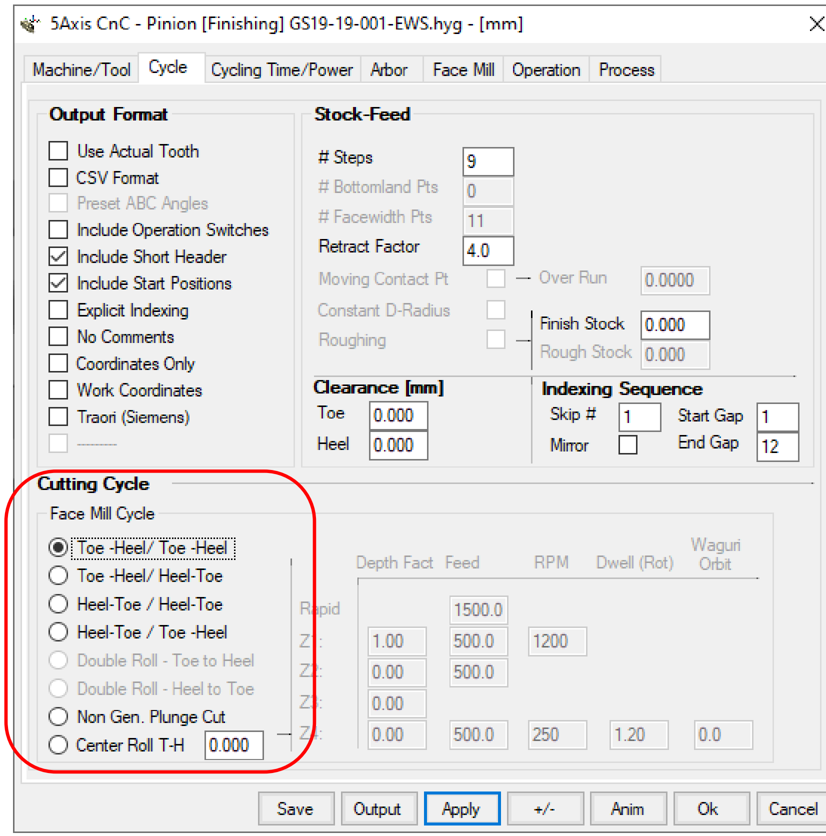


Over Run > 0

The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *HyGEARS offers 7 cycles for Face Mill cutters and 1 cycle for the Coniflex™ dish cutter.*



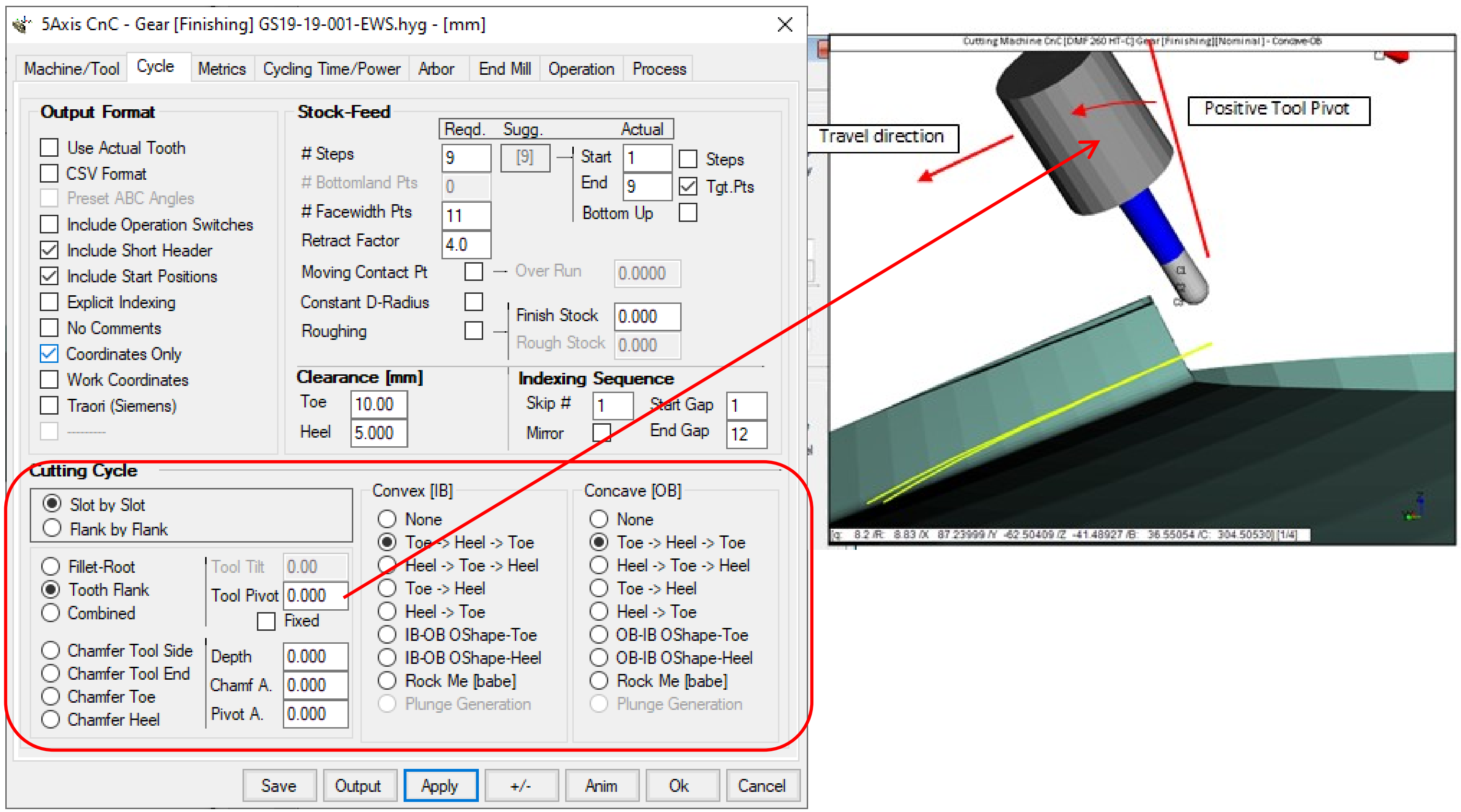


Cycles for Face Mill cutters / Completing

Cycles for Face Mill cutters / Fixed Setting - Semi-Completing

The HyGEARS™ 5 Axis CnC Post-Processor

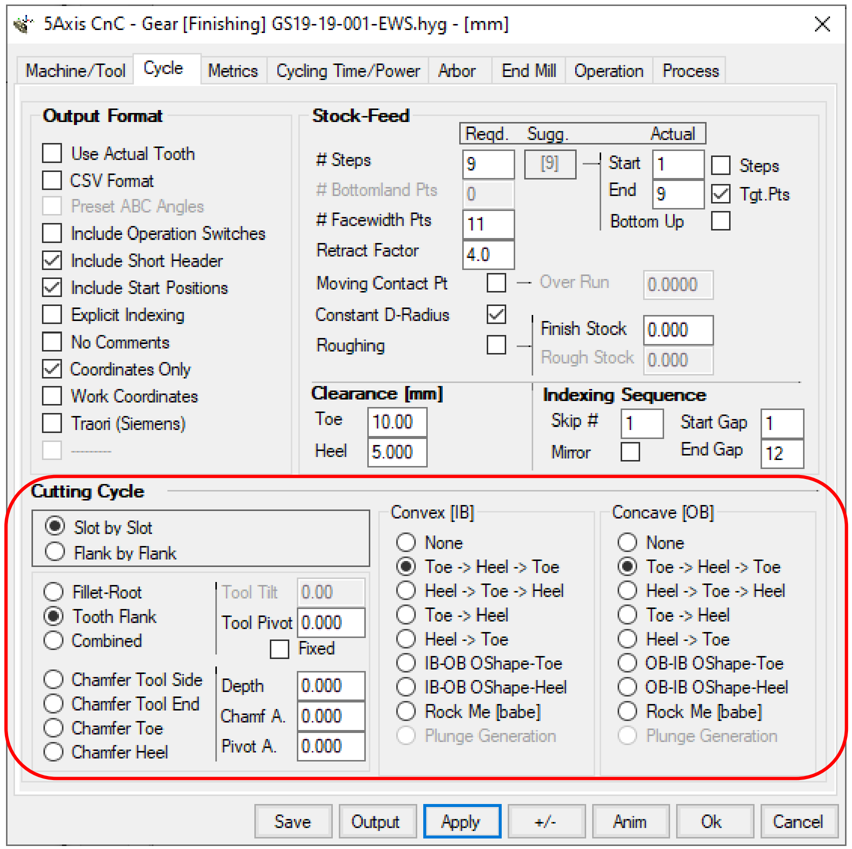
Cycles: *HyGEARS offers 14+ different cutting cycles for End Mill and Ball Mill tools, and 15 for CoSIMT tools. Tool can be Pivoted to improve cutting conditions.*



Cycles for CoSIMT, End Mill and Ball Mill tools

The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Finishing cycles for CoSIMT, End Mill and Ball Mill tools.*

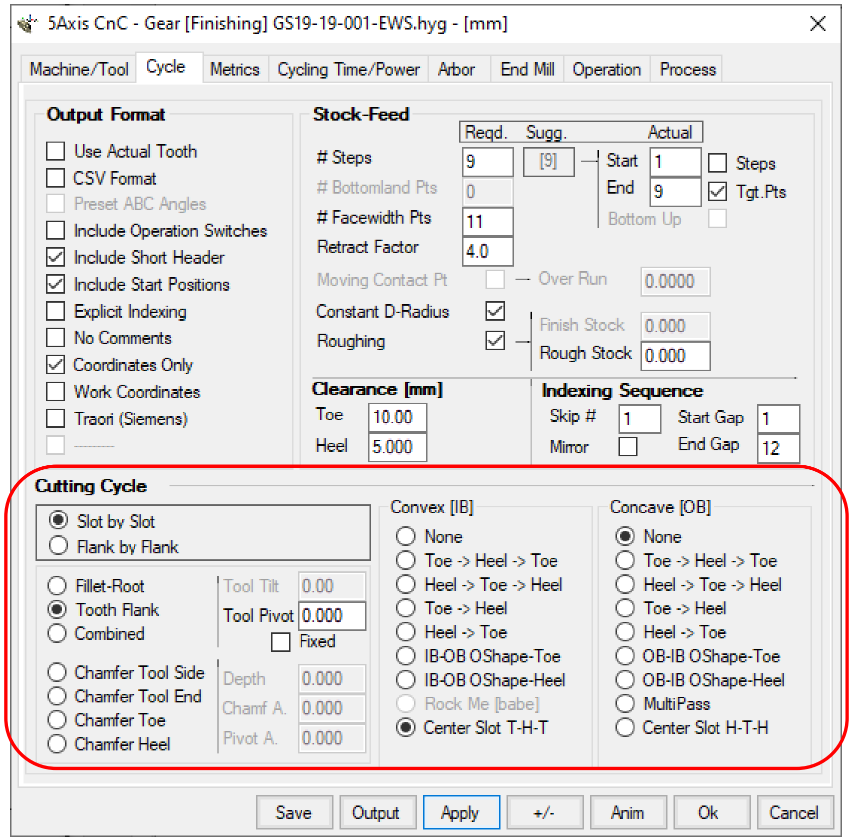


Finishing Cycles for CoSIMT, End Mill and Ball Mill tools

- *Fillet/Root, Tooth Flank, Toe, Heel and Tip Chamfer (Deburring) are different operations;*
- *They can be cut Slot by Slot or Flank by Flank, depending on machine selection, work size, and how much travel is required by the machine or tool between tooth flanks;*
- *Finishing cycles can be different on each tooth flank.*

The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Roughing cycles for End Mill and Ball Mill tools.*

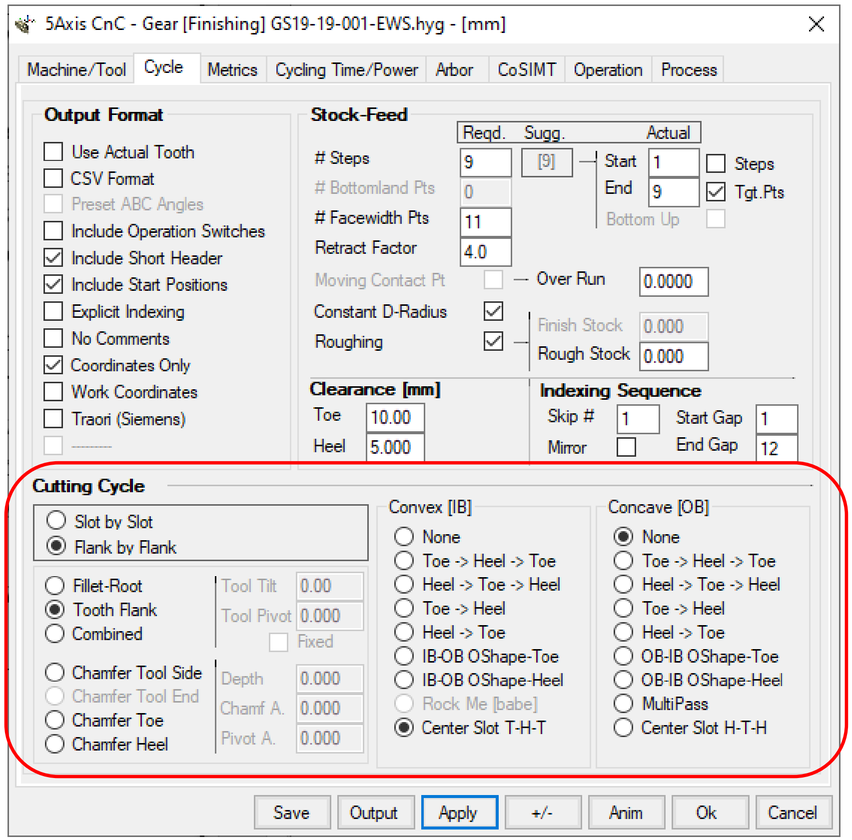


Roughing Cycles for End Mill and Ball Mill tools

- *Fillet/Root and Tooth Flank are different operations;*
- *They can be cut Slot by Slot or Flank by Flank, depending on machine selection, work size, and how much travel is required by the machine or tool between tooth flanks;*
- *Roughing cycles need not be the same on both tooth flanks;*
- *Center Slot cuts a through in the center of the gap; may start at Toe or Heel;*
- *MultiPass is a Slot by Slot operation; it makes an even number of passes per Step, based on slot width and tool diameter; the number of passes is calculated at each Step; allows greater tool feeds over Center Slot because the tool is never captive in a through.*

The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Roughing cycles for CoSIMT tools.*

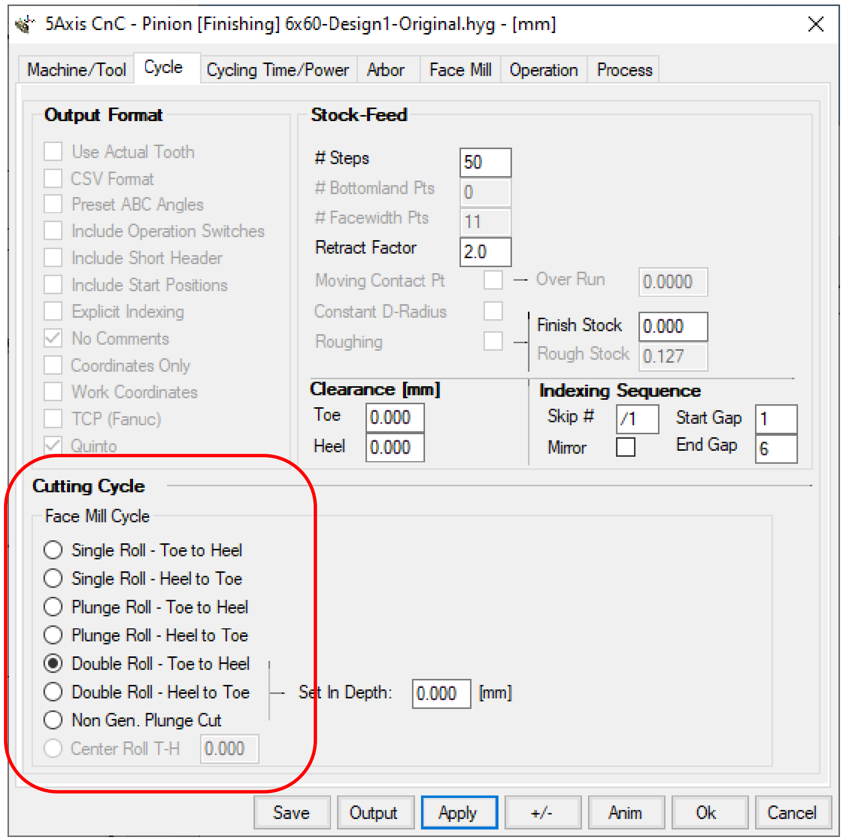


Roughing Cycles for CoSIMT tools

- *Fillet/Root and Tooth Flank are different operations;*
- *They can be cut Slot by Slot or Flank by Flank, depending on machine selection, work size, and how much travel is required by the machine or tool between tooth flanks;*
- *Center Slot cuts a through in the center of the gap; may start at Toe or Heel;*
- *MultiPass is a Slot by Slot operation; it makes an even number of passes per Step, based on slot width and tool diameter, the number of passes is calculated at each Step; allows greater tool feeds when compared to Center Slot;*

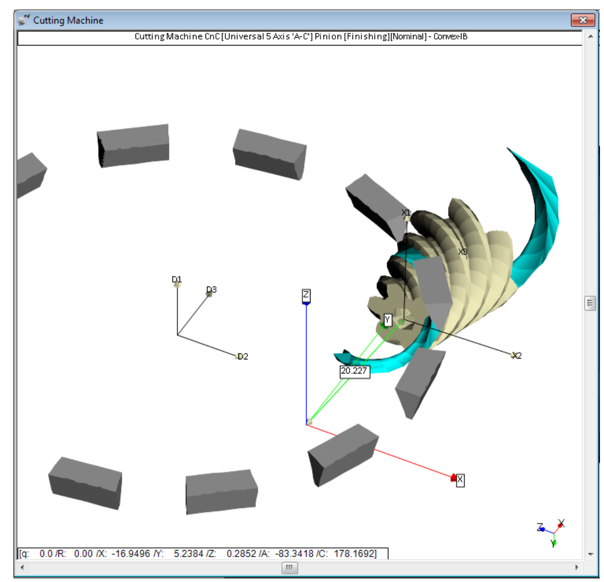
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Face Mill Cutter – Completing cutting processes*



Cycles for Face Mill cutters

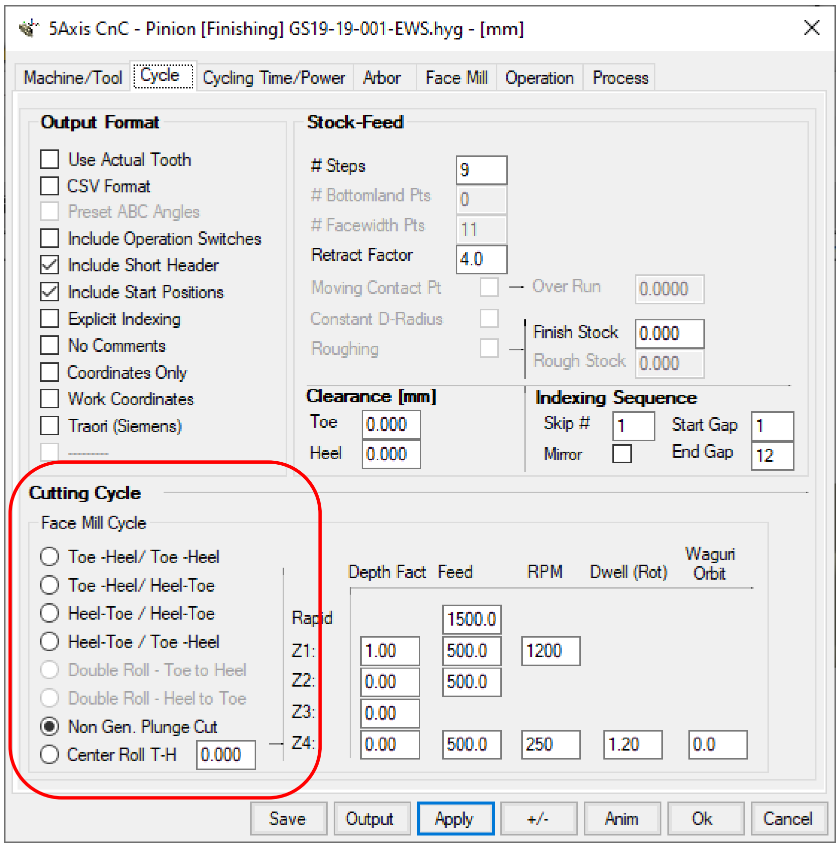
- *can be Single Roll/Double Roll;*
- *Double Roll plunges the cutter to full depth between the start and end of the 1st roll, and then generates full depth on the 2nd roll;*
- *can be Toe to Heel or Heel to Toe;*
- *the use of Toe/Heel clearances allows progressive cutter entry/retract for better tool life (see the Target Volume in light blue below);*
- *the Indexing Sequence allows spreading tool wear and thermal load over non-consecutive tooth slots.*



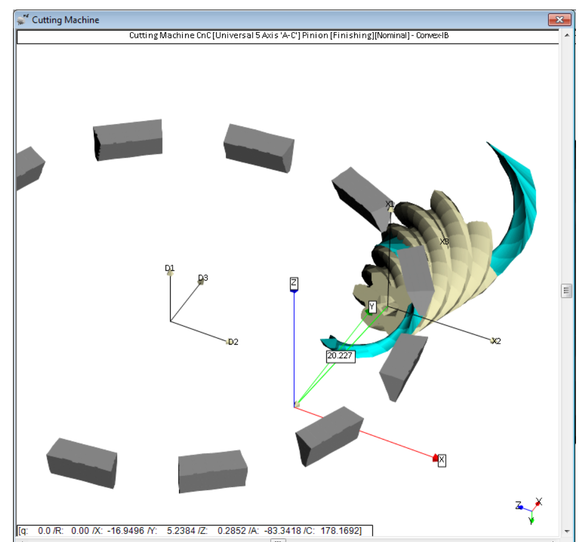
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Face Mill Cutter – Fixed Setting / Semi-Completing cutting processes*

- *xx / yy: 1st part is Convex flank; 2nd part is Concave flank*
- *the use of Toe/Heel clearances allows progressive cutter entry/retract for better tool life (see the Target Volume in light blue below);*
- *Negative Finish stock pushes the cutter In such as to compensate for tool wear;*
- *the Indexing Sequence allows spreading tool wear and thermal load over non-consecutive tooth slots.*



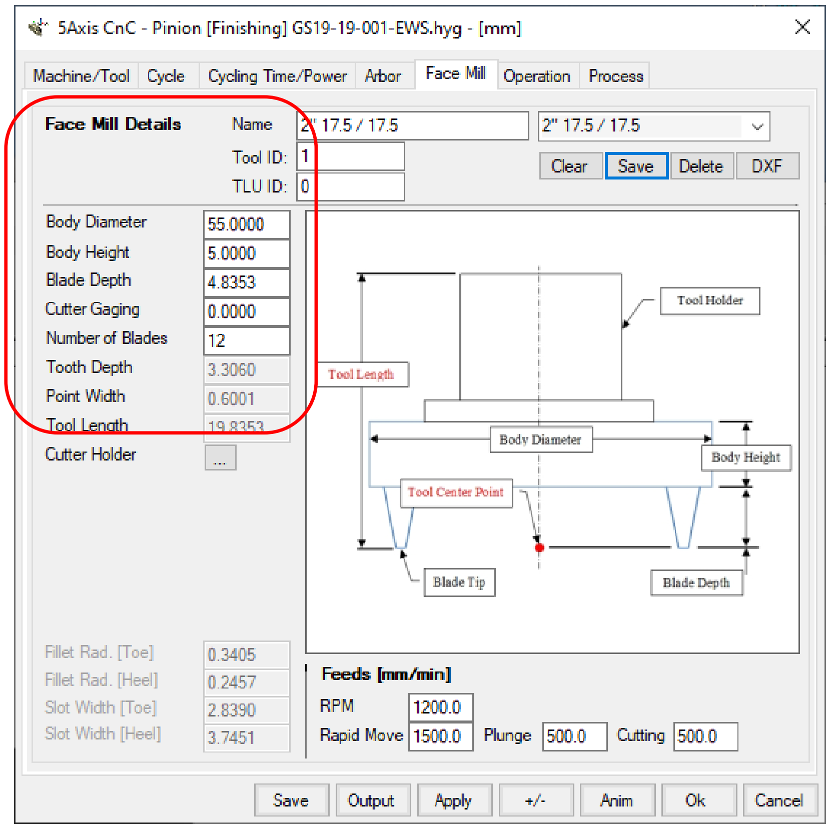
Cycles for Face Mill cutters

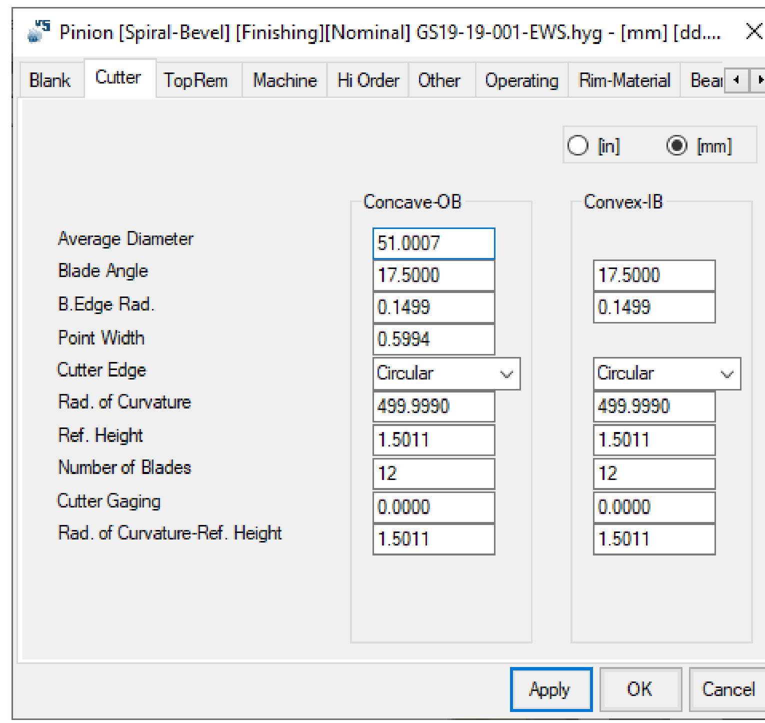


The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Face Mill Cutter*

- *the Face Mill cutter used on the 5Axis CnC machine can be defined and saved;*
- *cutter Diameter, Blade angles, Edge Radii, and Point Width are those described in the Summary Editor (see below).*

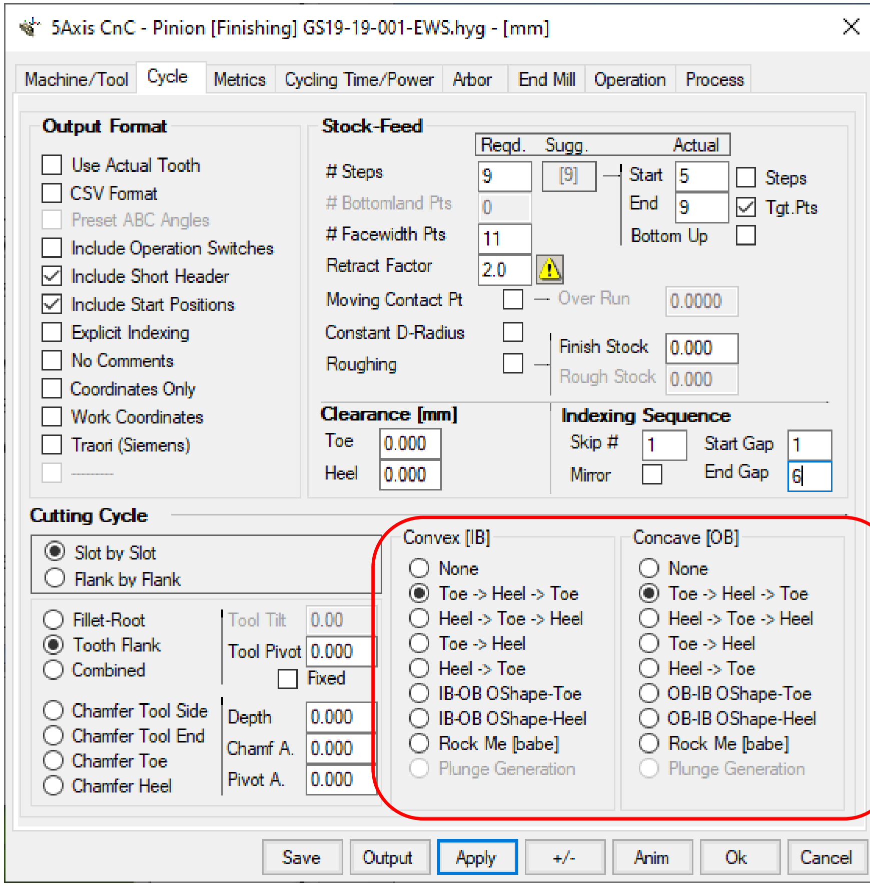




Face Mill cutter definition

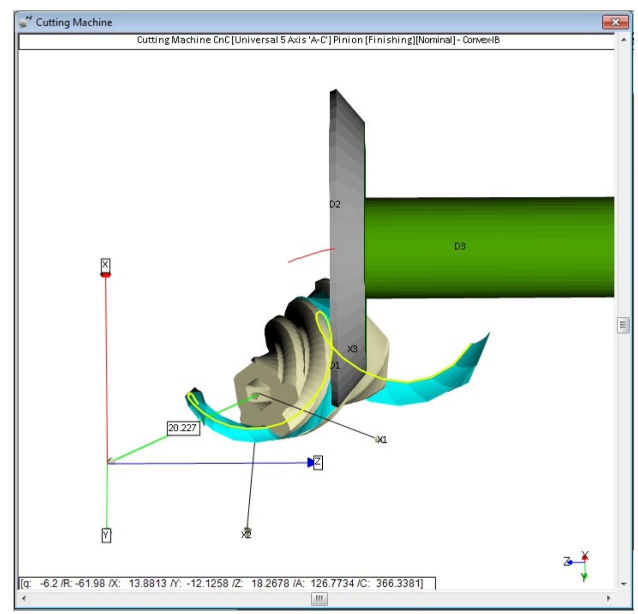
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *CoSIMT, End Mill, Ball Mill*



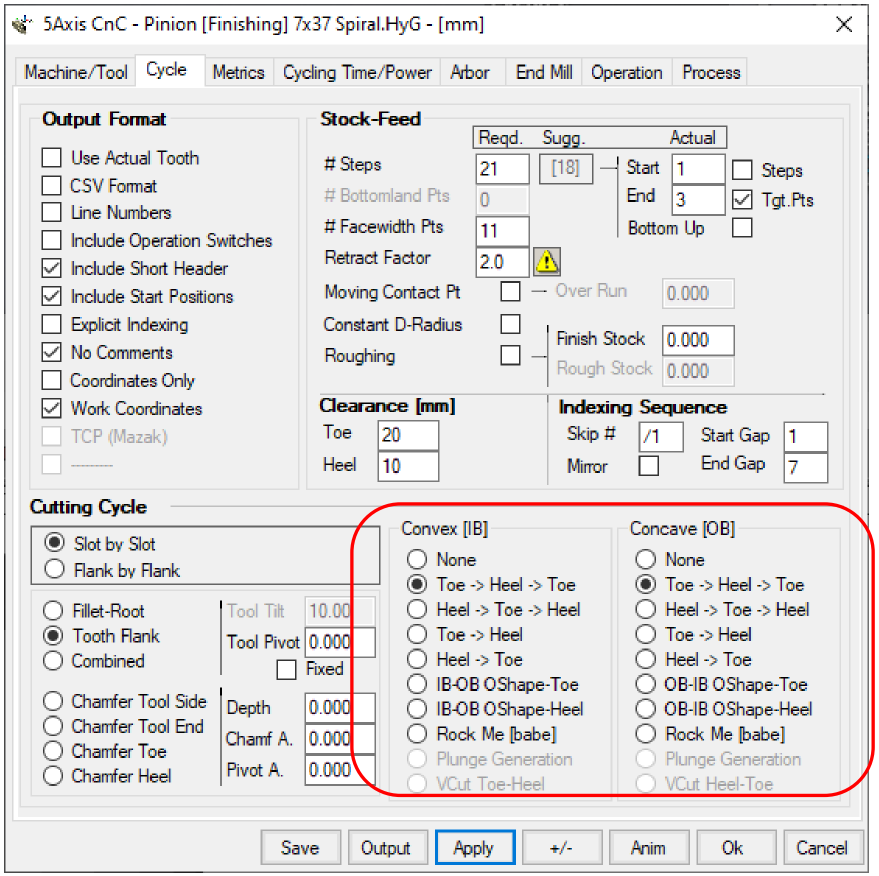
Cycles for CoSIMT, End Mill and Ball Mill tools

- *CoSIMT, End Mill and Ball Mill tools can **rough** and **finish** tooth flanks and fillet;*
- *CoSIMT, Bull Nose End Mill and Ball Mill tools can finish the fillet, and a protuberance can be imposed in the form of negative Stock;*
- *End Mill and Ball Mill can Chamfer (i.e. deburring) tooth Tip;*
- *Positive and Negative stock can be used;*
- *Toe and Heel clearances can be imposed;*
- *The Indexing Sequence can be selected.*



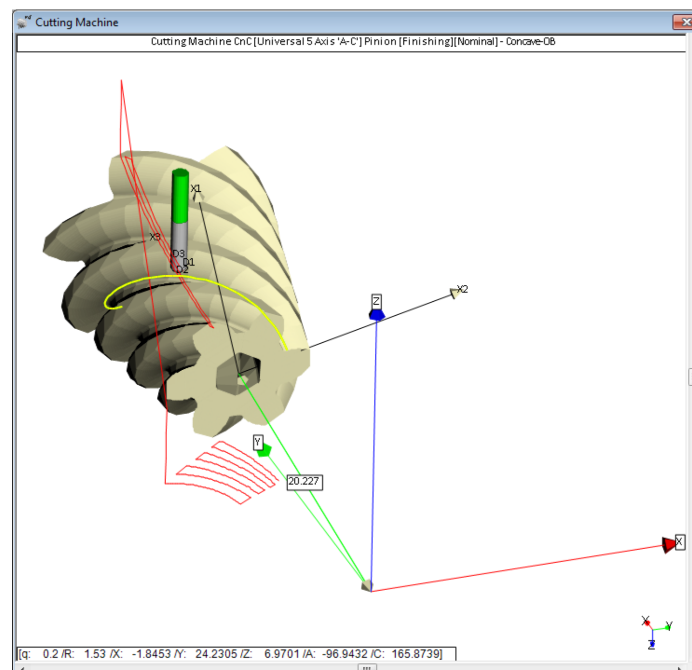
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Example: End Mill tool, Toe-Heel-Toe (IB-Side) / Heel-Toe-Heel (OB-Side)*



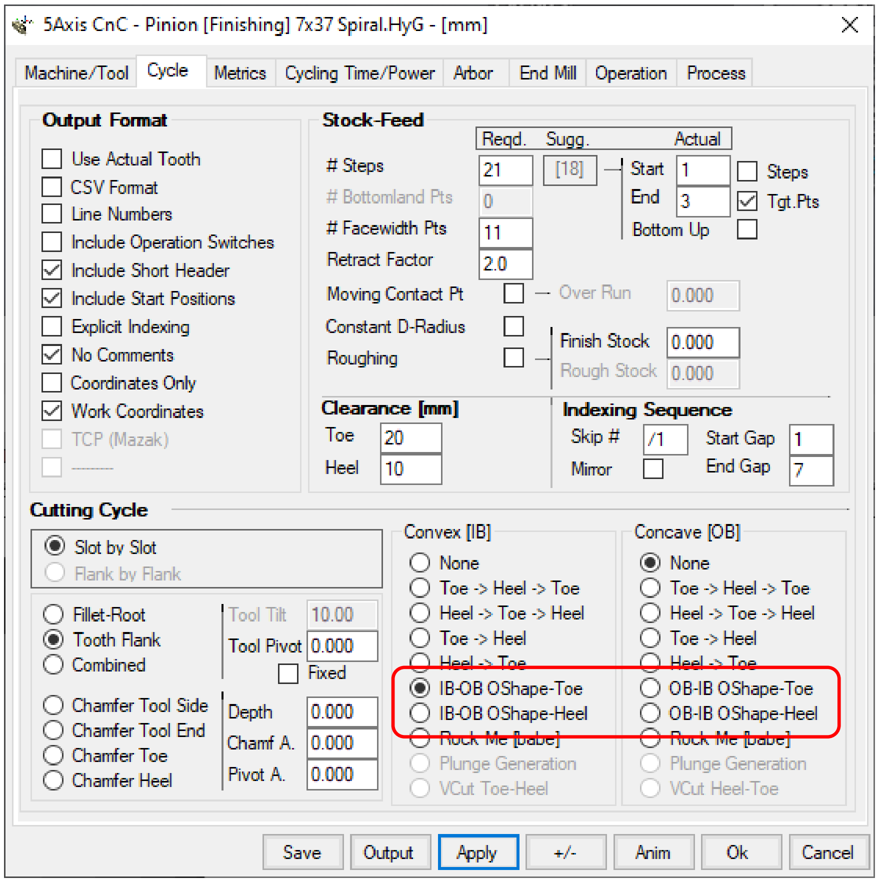
End Mill cycles

- *Cutting cycles can be different for each tooth flank (IB-OB, Left-Right);*
- *a cutting cycle may start on the IB and finish on the OB (Left-Right for non spiral-bevels);*
- *for example, with the selections made in the left figure, given the IB cycle ends at Heel, unless otherwise dictated it could make sense to start the OB cycle at Heel to reduce cycle time (the tool path is the red line in the figure below).*



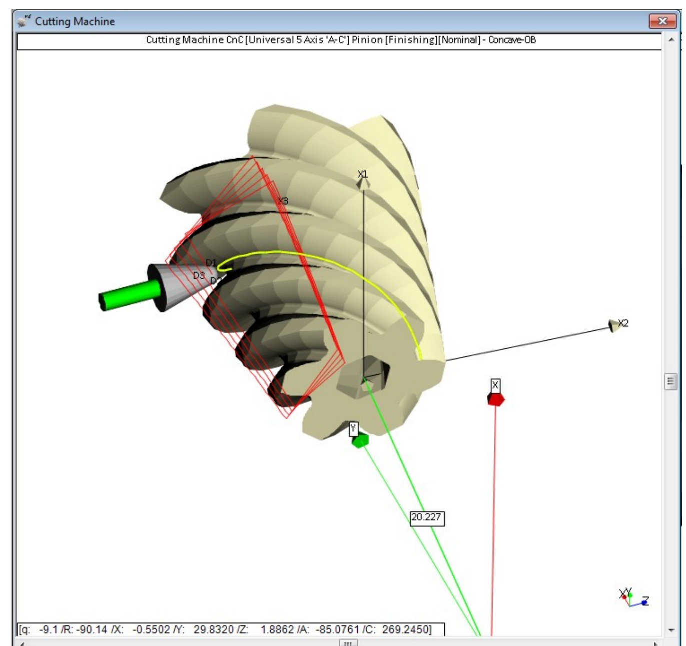
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Example: tapered End Mill tool, O-Shaped cycles*



O-Shaped cycles

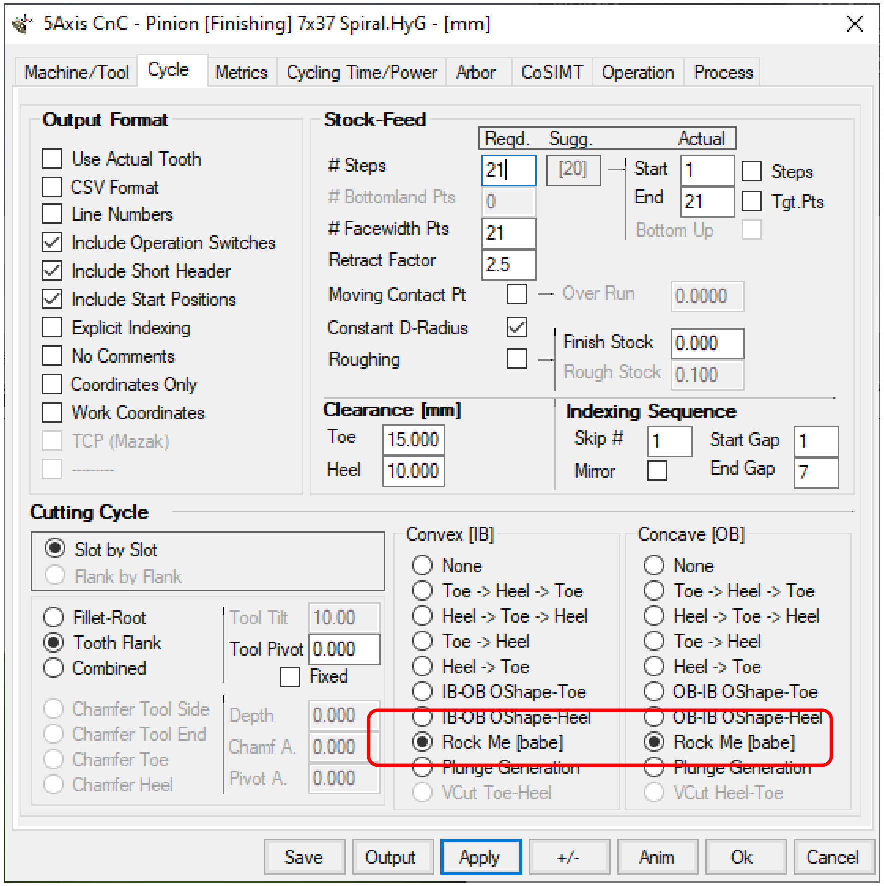
- *one starting flank – IB / OB - and tooth end – Toe / Heel - is selected, the other being slave;*
- *for O-Shaped cycles, the cutting cycle takes a pass along the face width on the one flank and switches to the opposite flank for return; the cycle then switches back to the starting and takes one step depth wise before starting over again;*
- *can be a real time saver when used with a Tapered End Mill or a CoSIMT.*



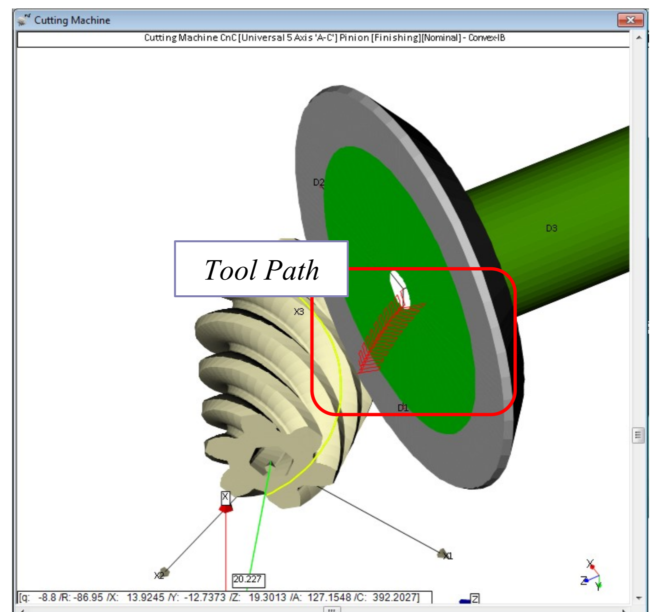
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Example: CoSIMT tool, Rock-Me (babe)*

- *the cycle starts at IB Toe-Tip, generates depth wise to the Fillet, switches to the OB and generates from Fillet to Tip, advances along the OB face width, generates depth wise along the OB side to the Fillet, switches to the IB and generates till Tip, advances along the IB face width, and starts over until Heel is reached;*
- *may be done individually for each flank;*
- *this process is well suited to CoSIMT and finishing in one operation.*

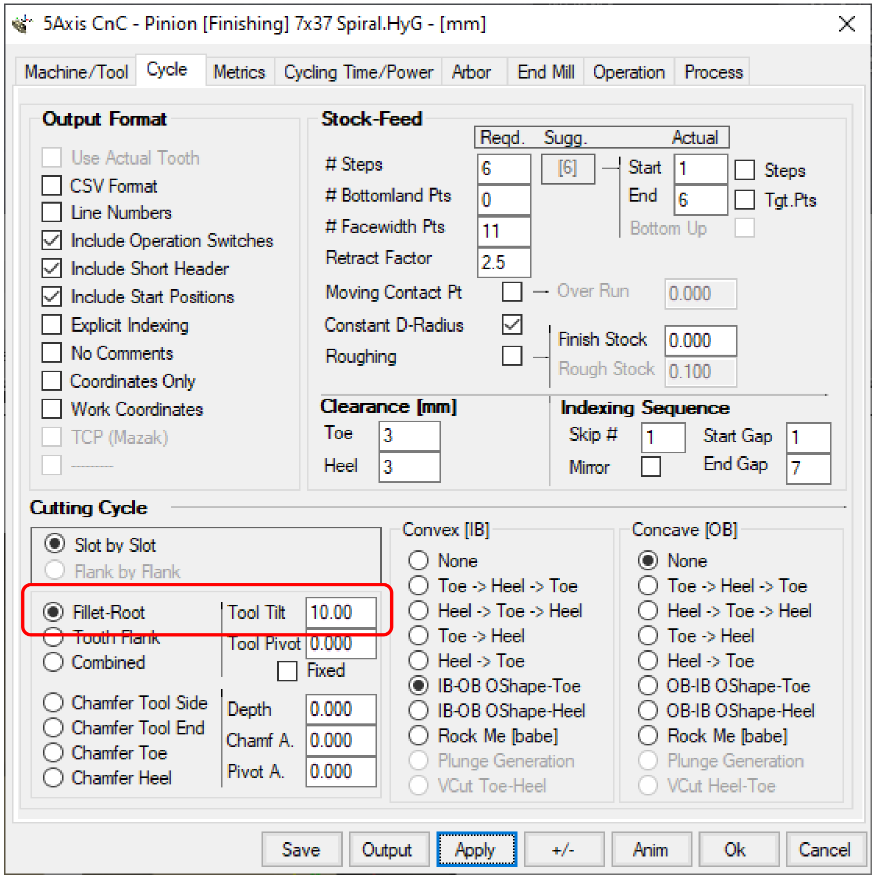


Rock Me (babe) cycle



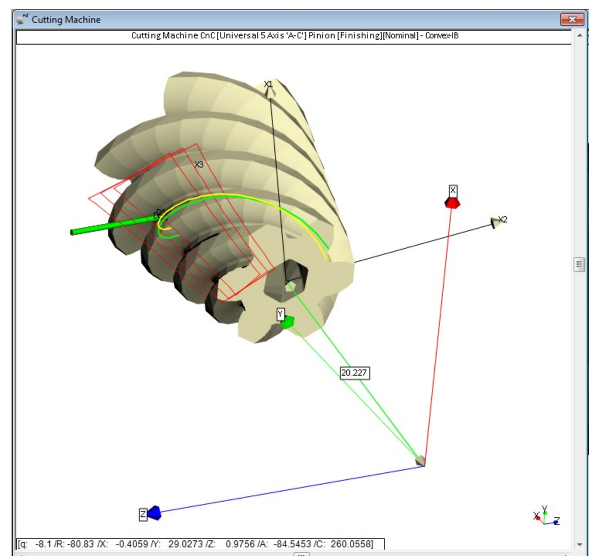
The HyGEARS™ 5 Axis CnC Post-Processor

Cycles: *Example: End Mill tool, Fillet*



Fillet cycles

- *Fillet finishing is integral to tooth flank finishing when using a Face Mill cutter since the tool sweeping movement generates the fillet;*
- *Fillet finishing is done in a distinct operation when using CoSIMT, End Mill or Ball Mill tools;*
- *negative Stock can be imposed to produce a protuberance;*
- *End Mill and Ball Mill tools can be tilted away from the tooth to avoid interference;*
- *Fillet finishing uses the same cycles as for Flank finishing.*



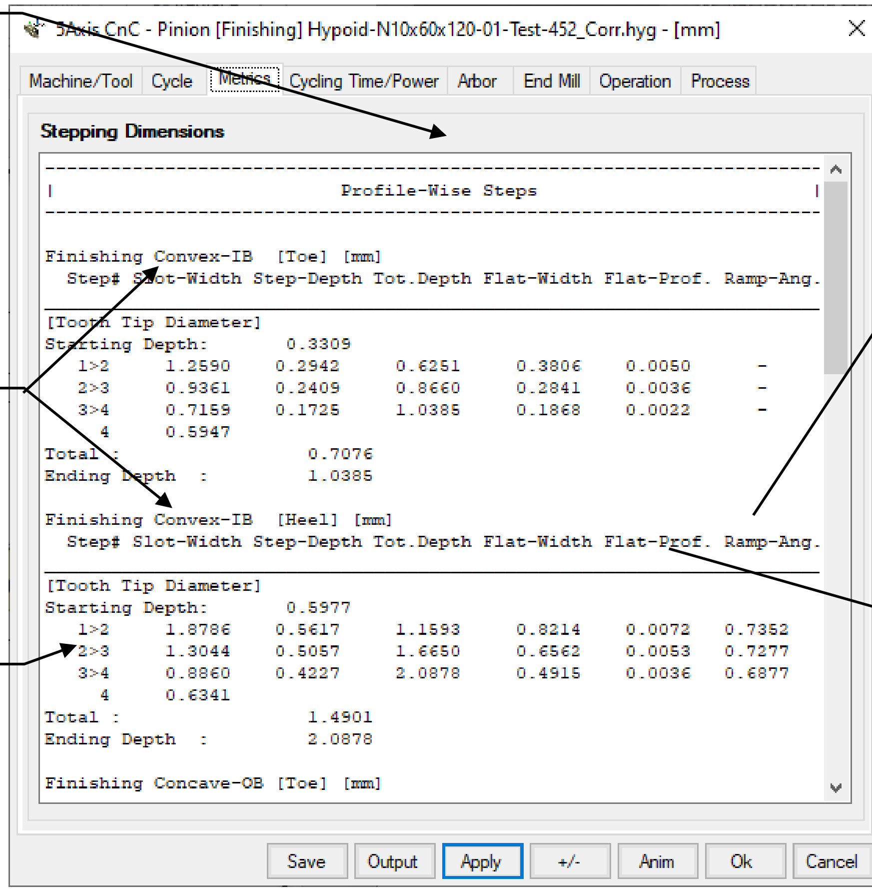
The HyGEARS™ 5 Axis CnC Post-Processor

***Metrics**: Profile-wise step depth, slot width, expected surface quality*

Profile-wise Steps

Considered Tooth flank

Step by step breakdown

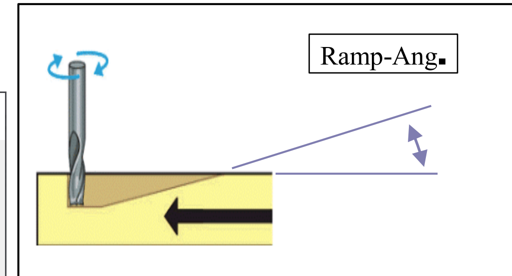

5Axis CnC - Pinion [Finishing] Hypoid-N10x60x120-01-Test-452_Corr.hyg - [mm]

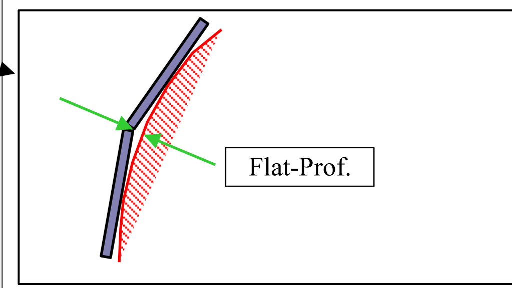
Machine/Tool | Cycle | Metrics | Cycling Time/Power | Arbor | End Mill | Operation | Process

Stepping Dimensions

```
-----------------------------------------------------------------------
|                          Profile-Wise Steps                          |
-----------------------------------------------------------------------

Finishing Convex-IB  [Toe] [mm]
  Step# Slot-Width Step-Depth Tot.Depth Flat-Width Flat-Prof. Ramp-Ang.
-----------------------------------------------------------------------
[Tooth Tip Diameter]
Starting Depth:        0.3309
   1>2     1.2590    0.2942     0.6251     0.3806     0.0050      -
   2>3     0.9361    0.2409     0.8660     0.2841     0.0036      -
   3>4     0.7159    0.1725     1.0385     0.1868     0.0022      -
     4     0.5947
Total   :                0.7076
Ending Depth   :         1.0385

Finishing Convex-IB  [Heel] [mm]
  Step# Slot-Width Step-Depth Tot.Depth Flat-Width Flat-Prof. Ramp-Ang.
-----------------------------------------------------------------------
[Tooth Tip Diameter]
Starting Depth:        0.5977
   1>2     1.8786    0.5617     1.1593     0.8214     0.0072    0.7352
   2>3     1.3044    0.5057     1.6650     0.6562     0.0053    0.7277
   3>4     0.8860    0.4227     2.0878     0.4915     0.0036    0.6877
     4     0.6341
Total   :                1.4901
Ending Depth   :         2.0878

Finishing Concave-OB [Toe] [mm]
```

Save | Output | Apply | +/- | Anim | Ok | Cancel





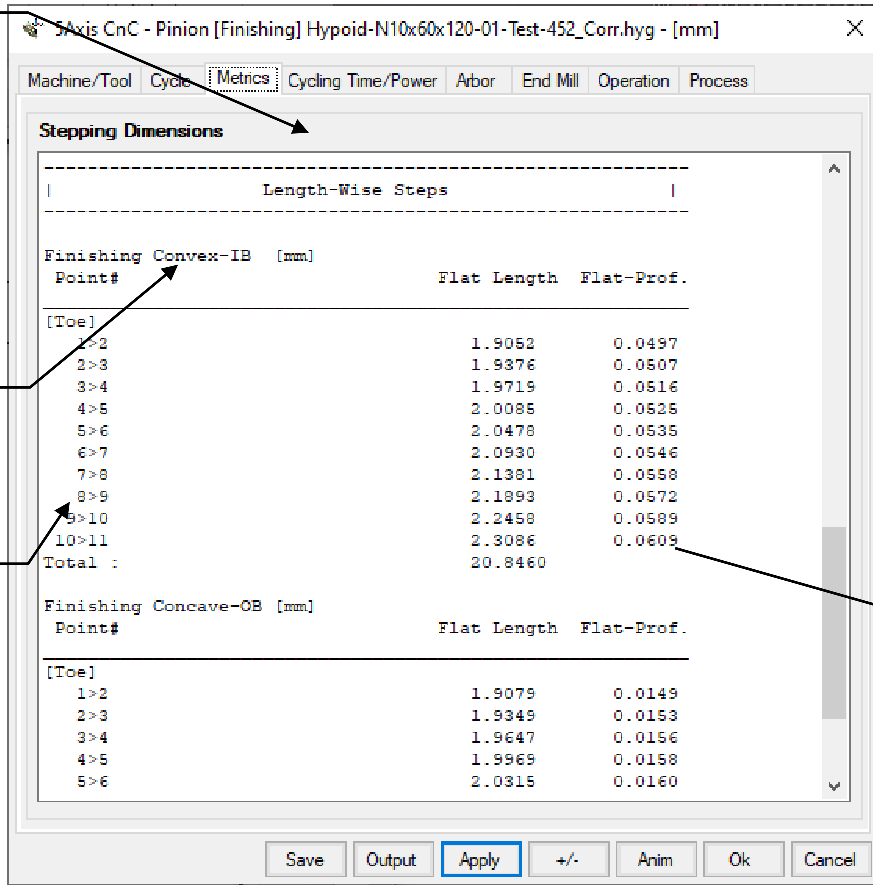
The HyGEARS™ 5 Axis CnC Post-Processor

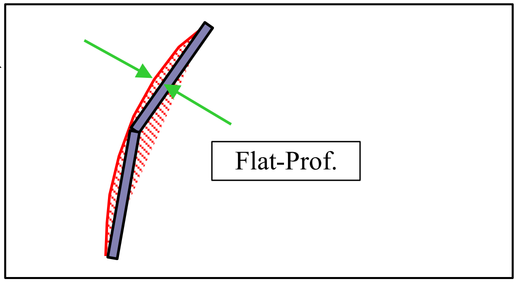
***Metrics**: Length-wise step depth, slot width, expected surface quality*

Length-wise Steps

Considered Tooth flank

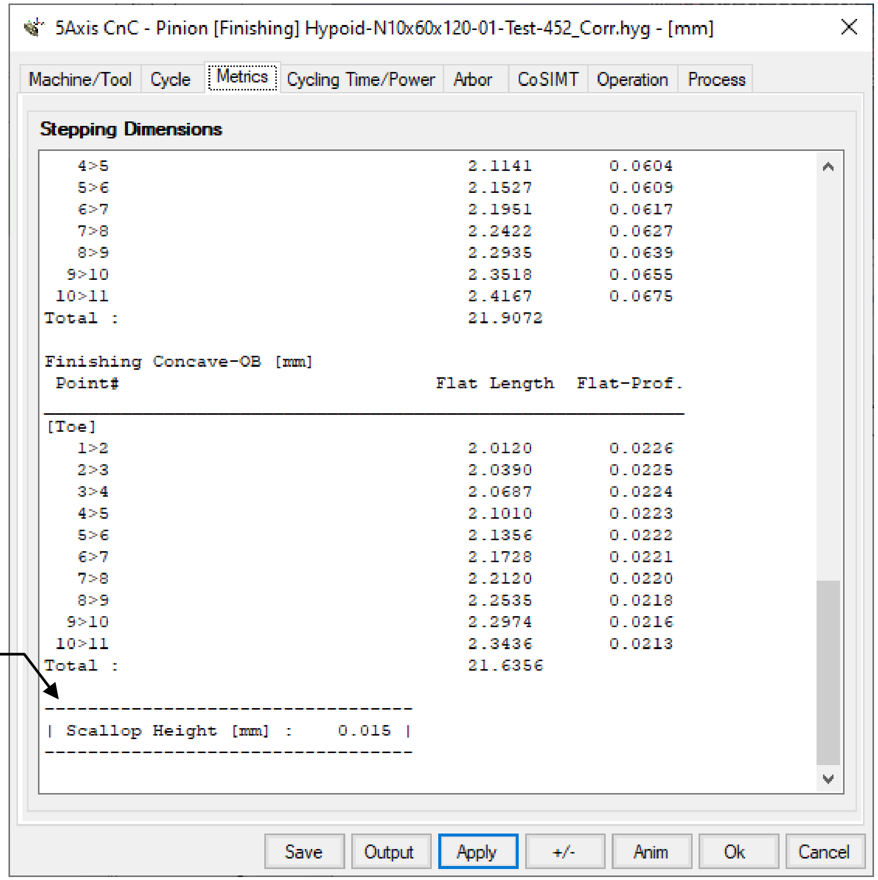
Step by step breakdown



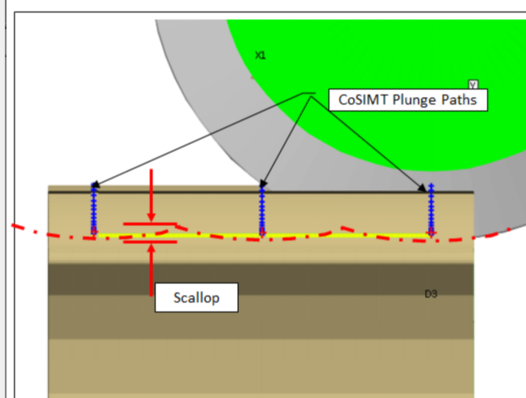


The HyGEARS™ 5 Axis CnC Post-Processor

***Metrics**: Scallop height: for Plunge Generation with CoSIMT*

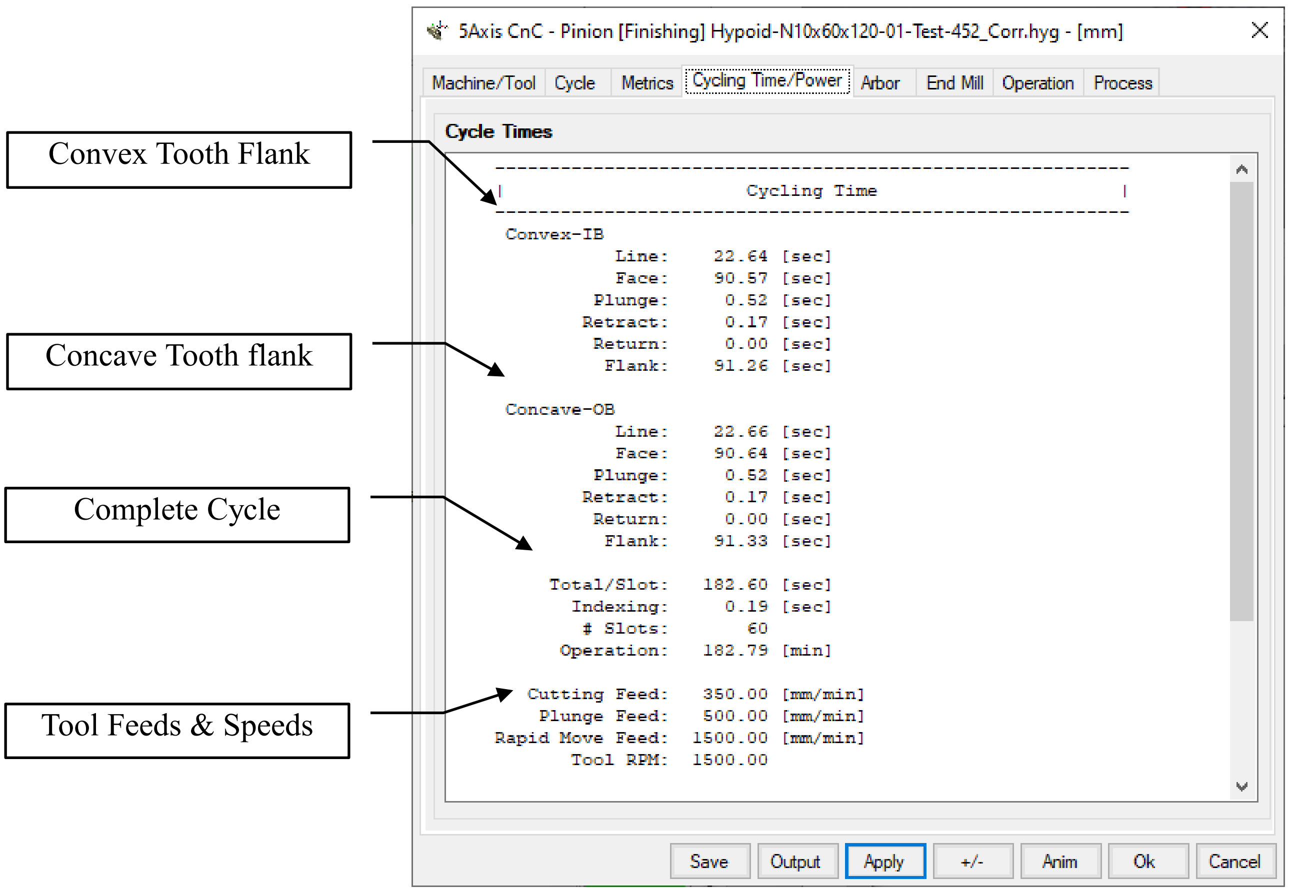


Scallop Height



The HyGEARS™ 5 Axis CnC Post-Processor

***Cycling Time**: Flank by flank operation Cycling time breakdown*



For Each Tooth Flank

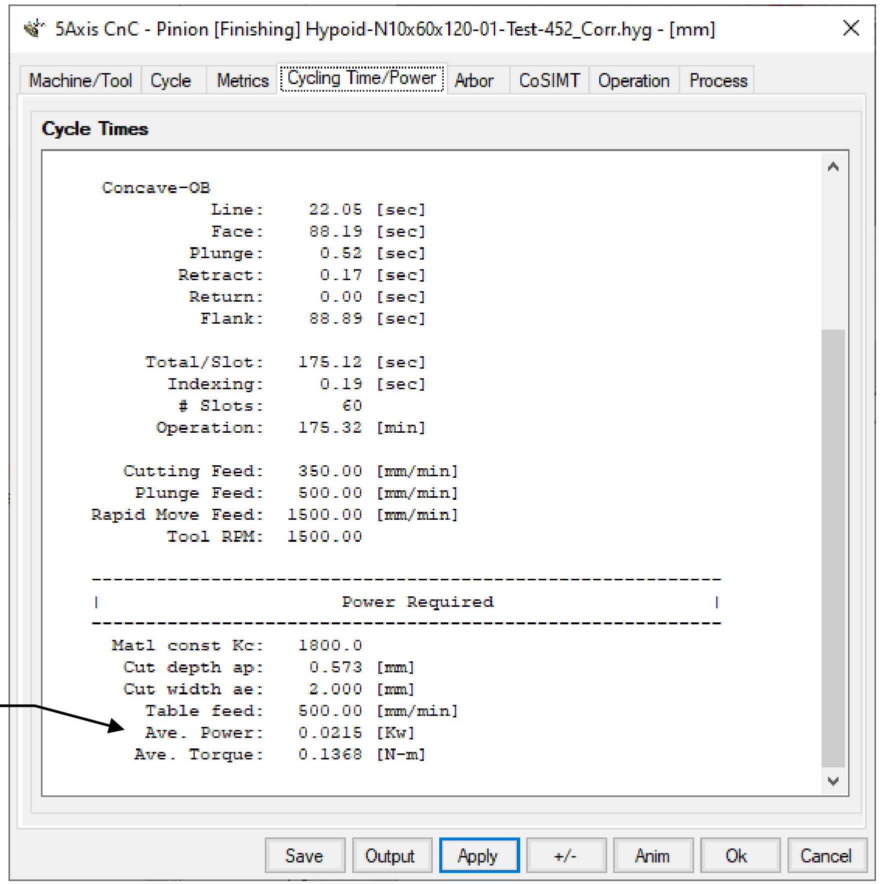
- *Line: each line in the face width direction*
- *Face: the complete tooth flank*
- *Plunge/Retract: time needed to go in and out of the slot;*
- *Return: return trip time (when applicable)*

For the current cycle

- *Total/Slot: total time per slot*
- *Indexing: indexing time*
- *Operation: time needed to complete the operation*

The HyGEARS™ 5 Axis CnC Post-Processor

***Power Required**: Estimate of average cutting torque required from tool*



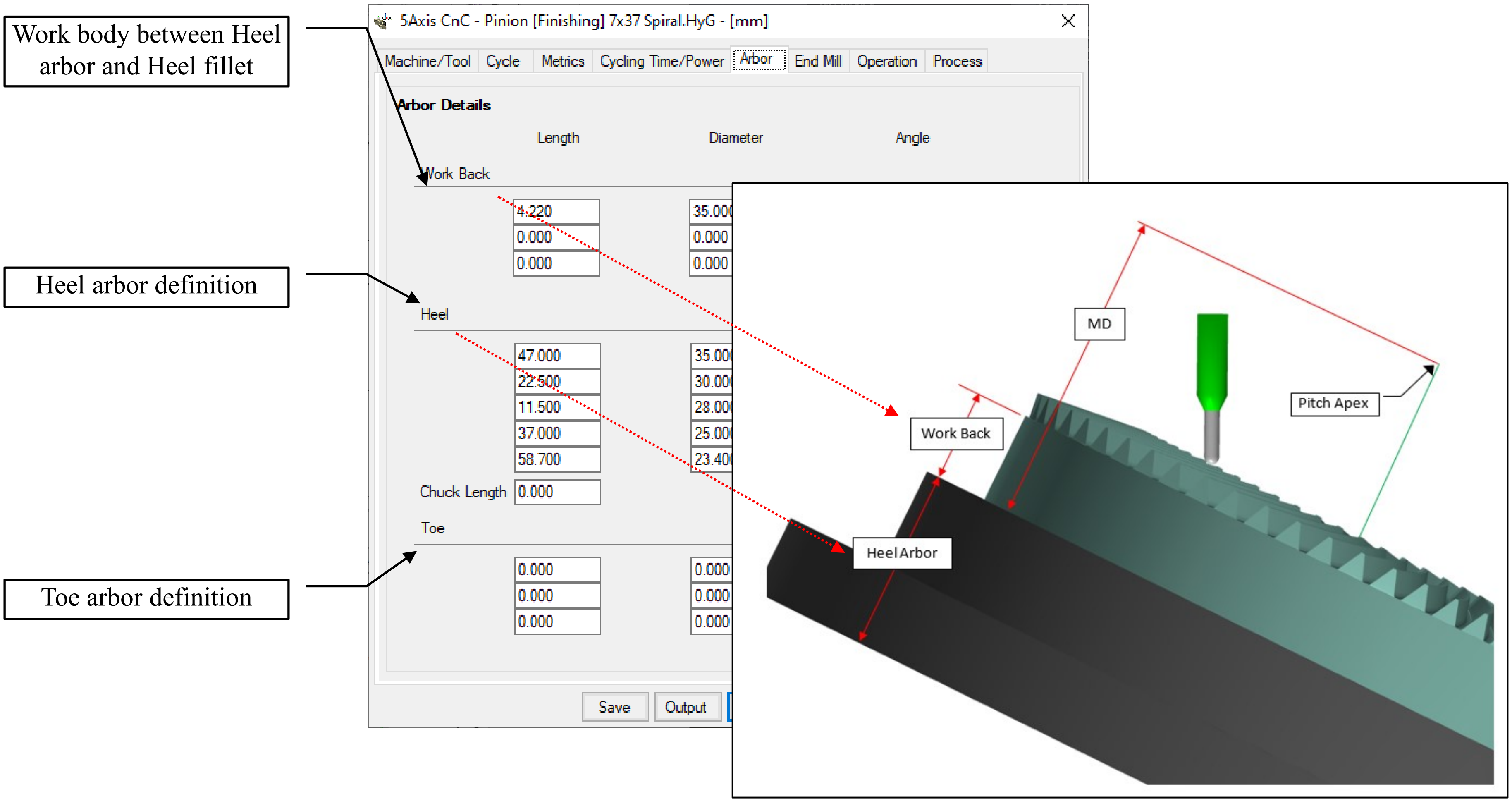
Power required

CoSIMT, End Mill Ball Mill: 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 based on material *Kc* value.

Face Mill / Coniflex: 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.

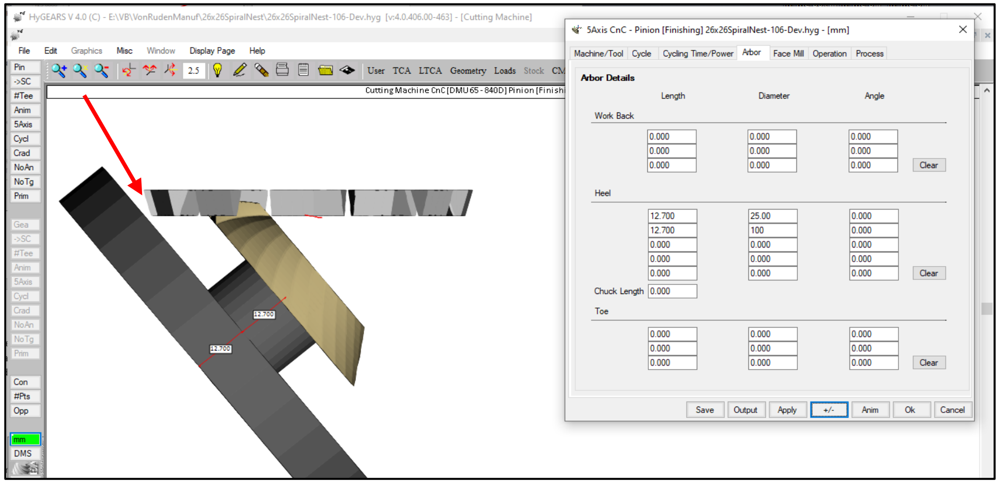
The HyGEARS™ 5 Axis CnC Post-Processor

***Arbor**: Blank supports on the machine.*



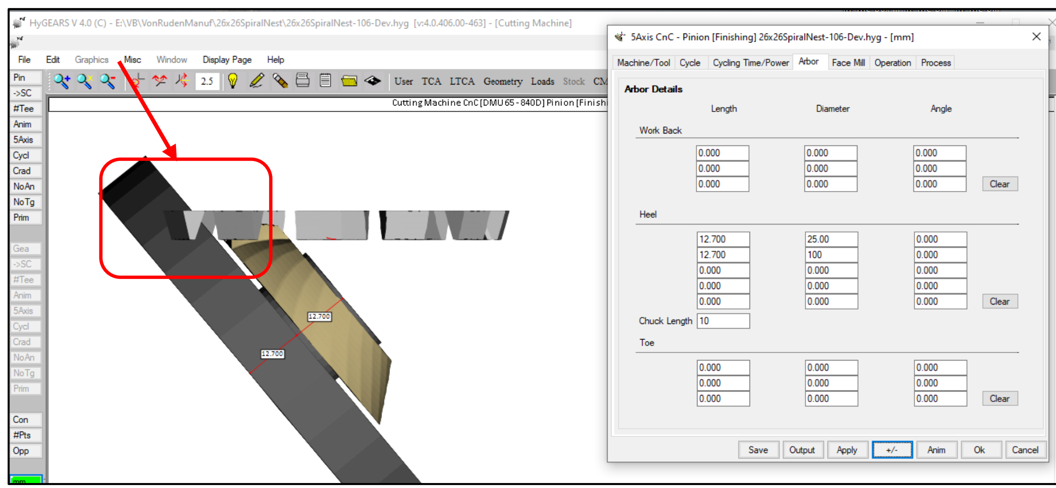
The HyGEARS™ 5 Axis CnC Post-Processor

Arbor: *Chuck Length.:* moves the workpiece relative to the 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, 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 that the Face Mill cutter will hit the support and an alternative approach must be found.



The HyGEARS™ 5 Axis CnC Post-Processor

***Tool Definition**: Tool dimensions, reference (tools are user defined).*

Tool name & ID

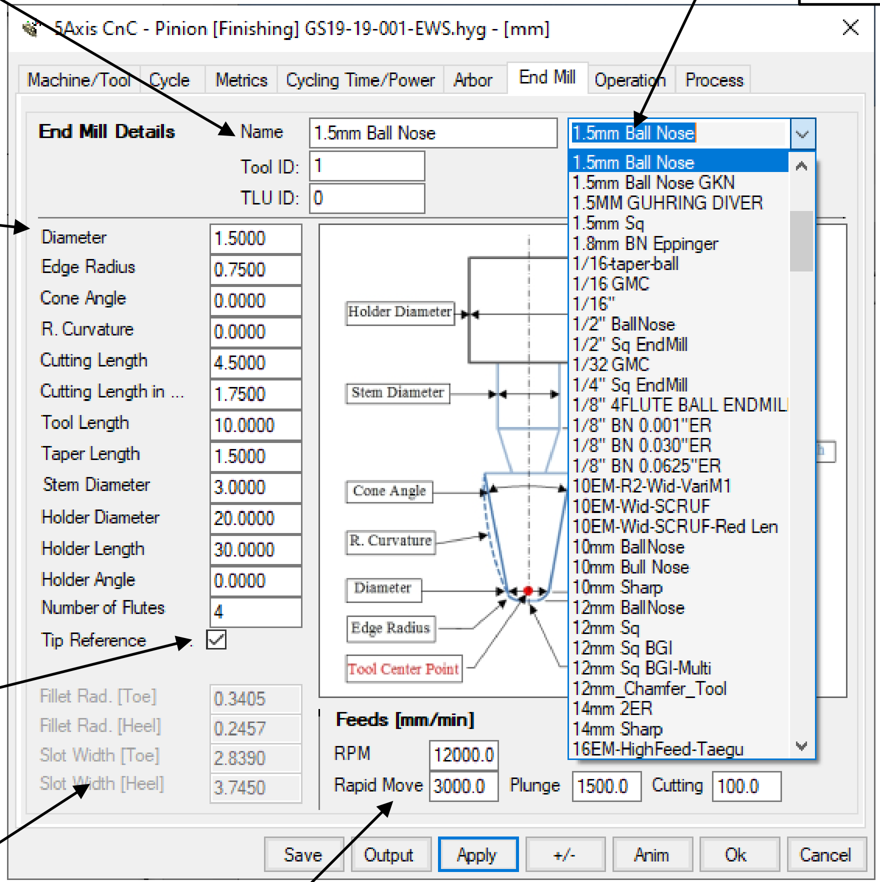
Tool list

Tool dimensions

Tip reference warning

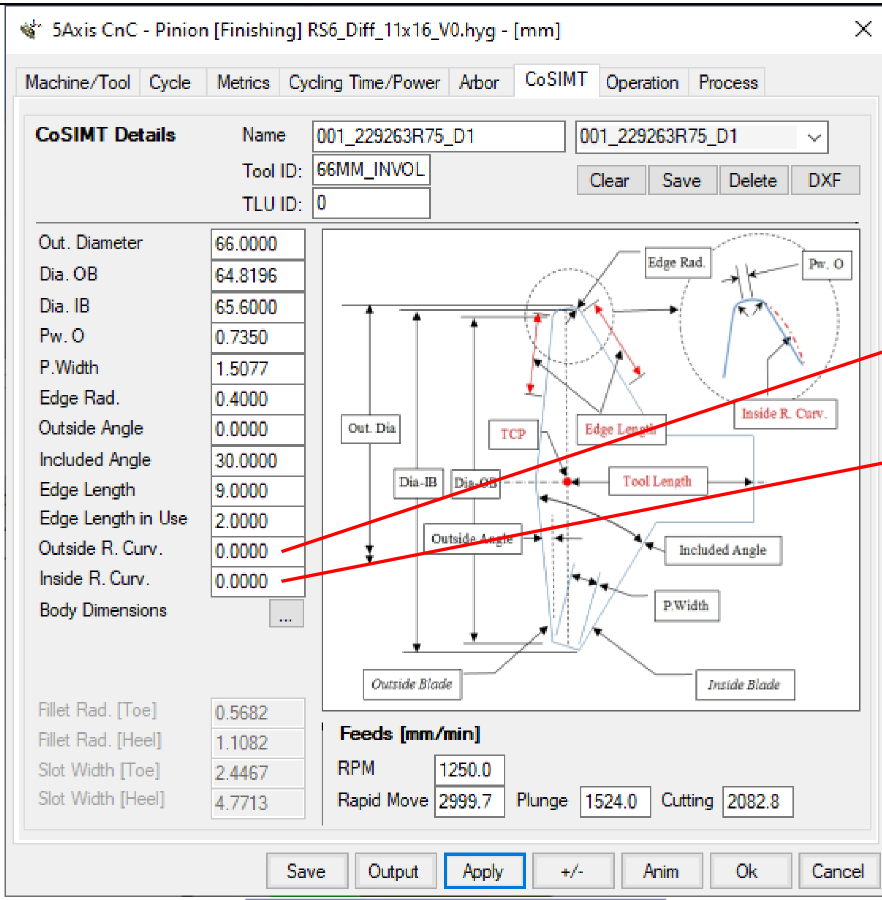
Tooth reference dims.

Tool feeds & speeds

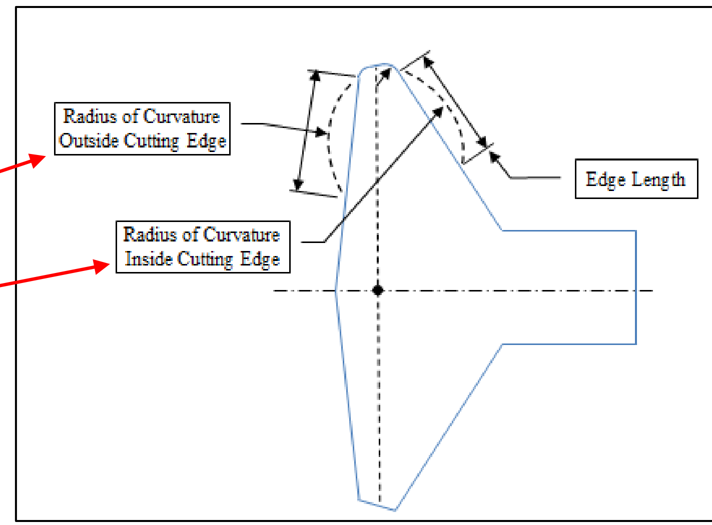


The HyGEARS™ 5 Axis CnC Post-Processor

Tools: *CoSIMT tools (or Conical Side Milling Tool; same as Sandvik's InvoMill and Gleason's UpGear) can have circular cutting edges which allow the generation of tooth profiles with concave profile curvature, such as Face Gears. Blade angles are totally flexible.*



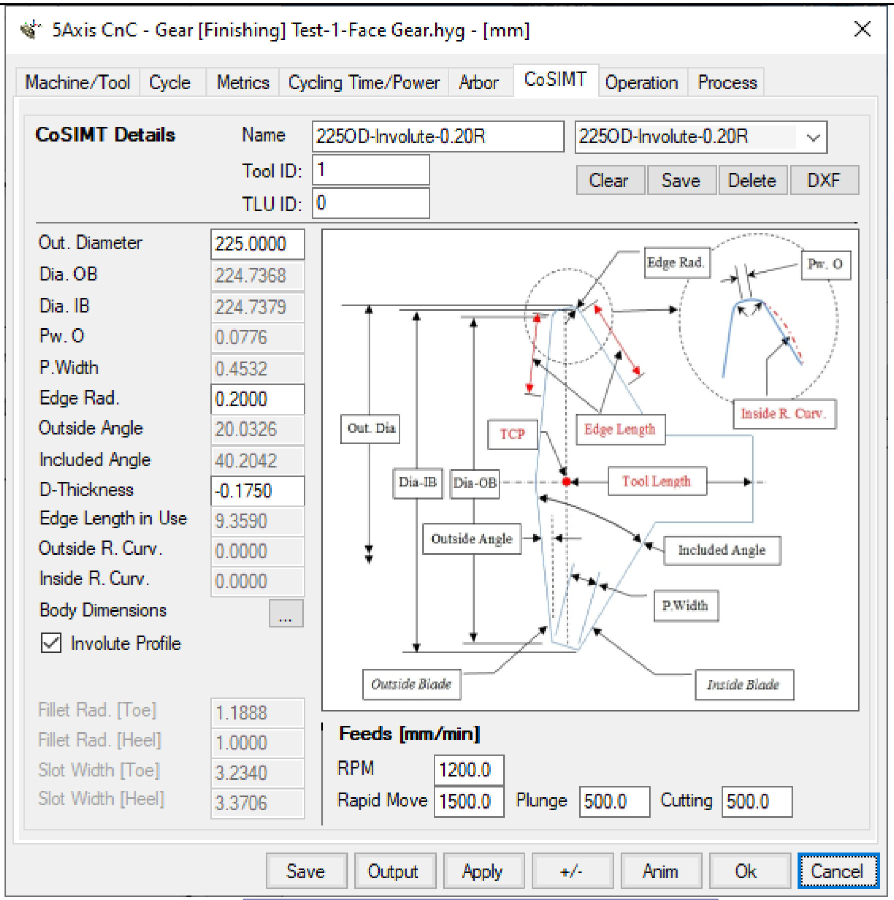
Definition of a CoSIMT



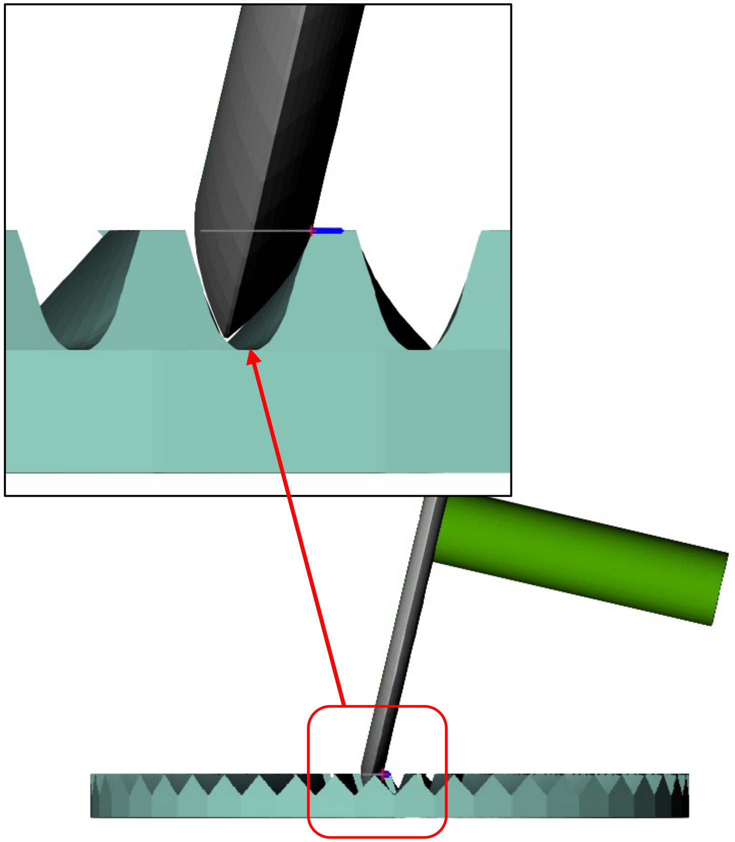
Spherical Cutting Edge

The HyGEARS™ 5 Axis CnC Post-Processor

Tools: *CoSIMT tools can also have an Involute profile such as to allow grinding Face Gears.* When doing so, the same Involute profile as defined for the reference shaper is used on the CoSIMT, but the profile is shifted radially such as to satisfy the entered OD.



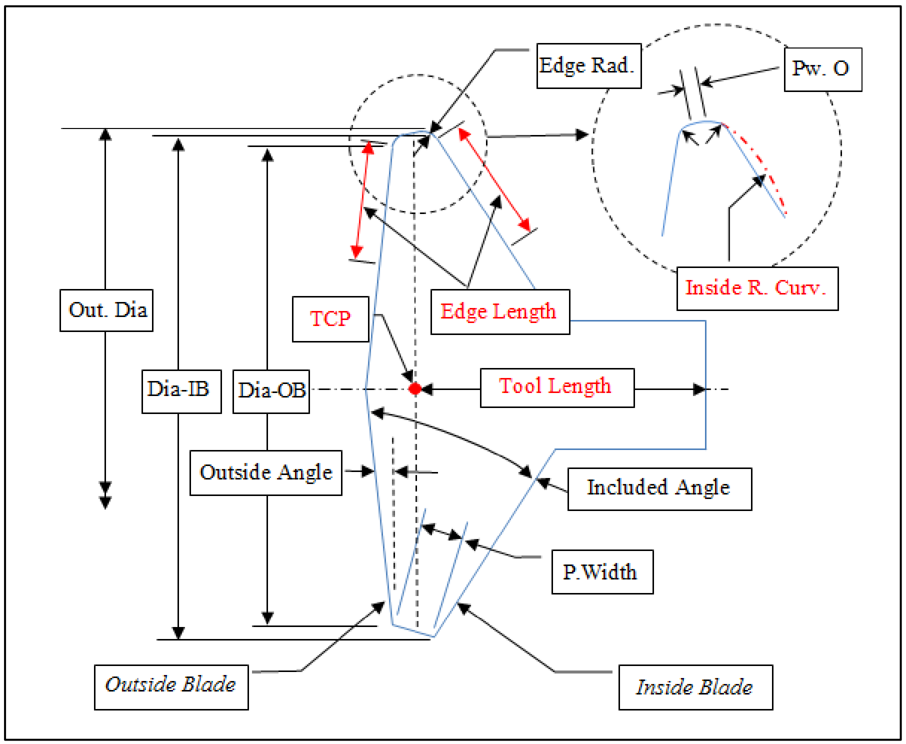
Definition of an Involute CoSIMT



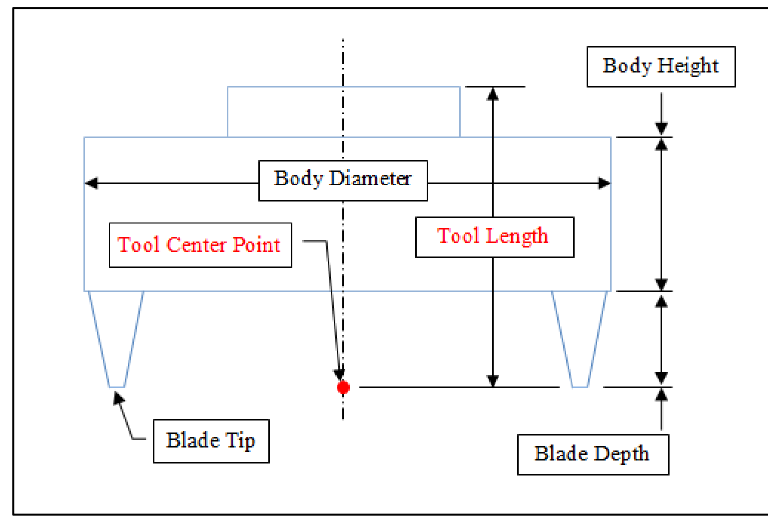
Involute Cutting Edge

The HyGEARS™ 5 Axis CnC Post-Processor

Tool Reference Point: *the Tool Length to be entered in the 5Axis machine controller depends on the location of the Tool Center Point (TCP), as follows.*



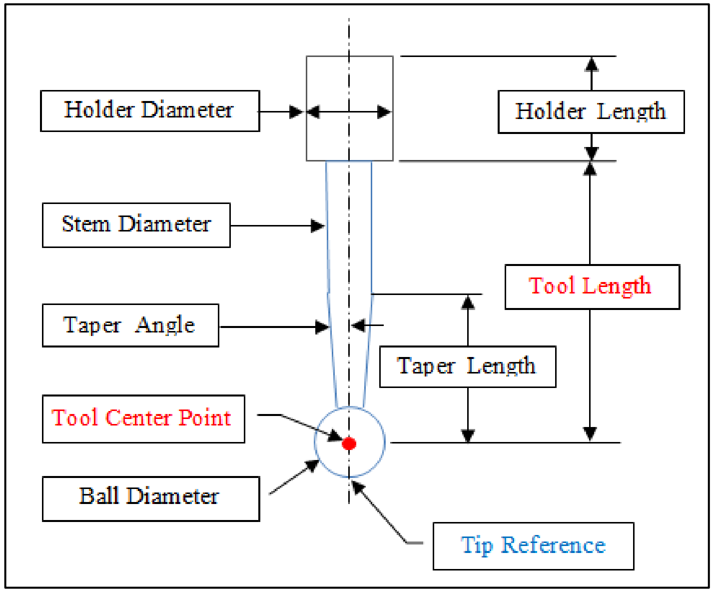
CoSIMT : TCP (located @ mid P.Width)



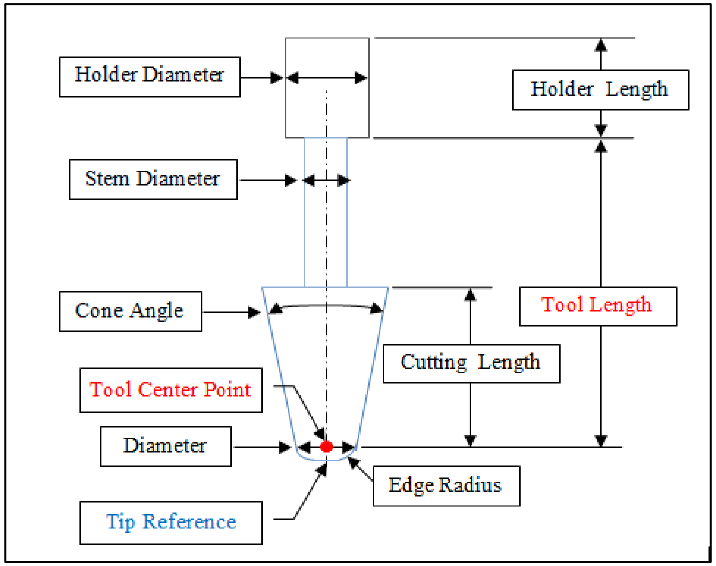
Face Mill Cutter: TCP (in the plane of blade tips)

The HyGEARS™ 5 Axis CnC Post-Processor

Tool Reference Point: *End Mill / Ball Mill tools: reference can be given at TCP or Tip.*



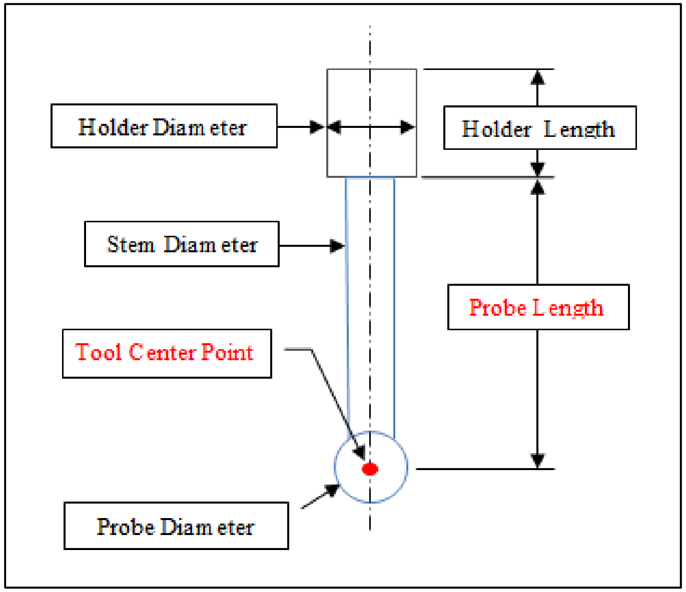
Ball Mill : TCP and Tip



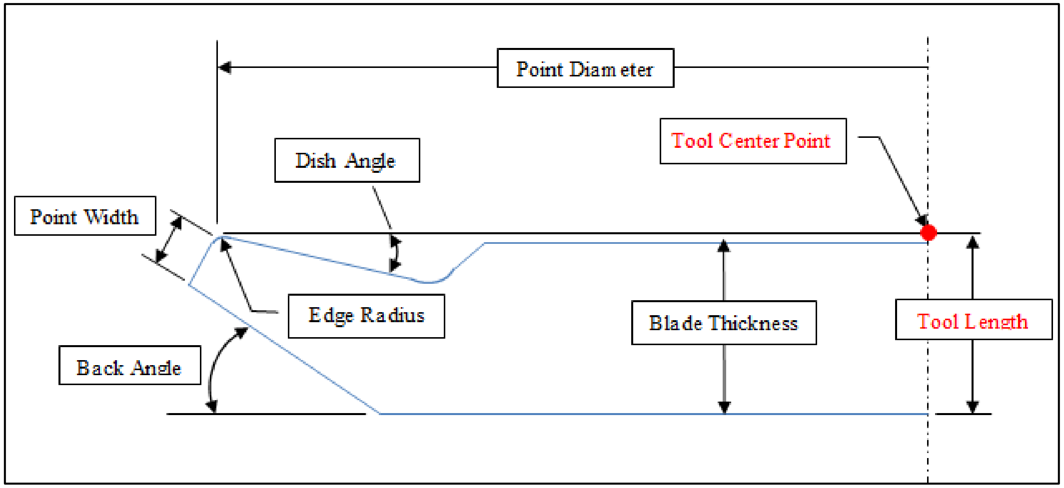
End Mill: TCP and Tip

The HyGEARS™ 5 Axis CnC Post-Processor

Tool Reference Point: *Probe and Coniflex™ dish type cutter: TCP.*



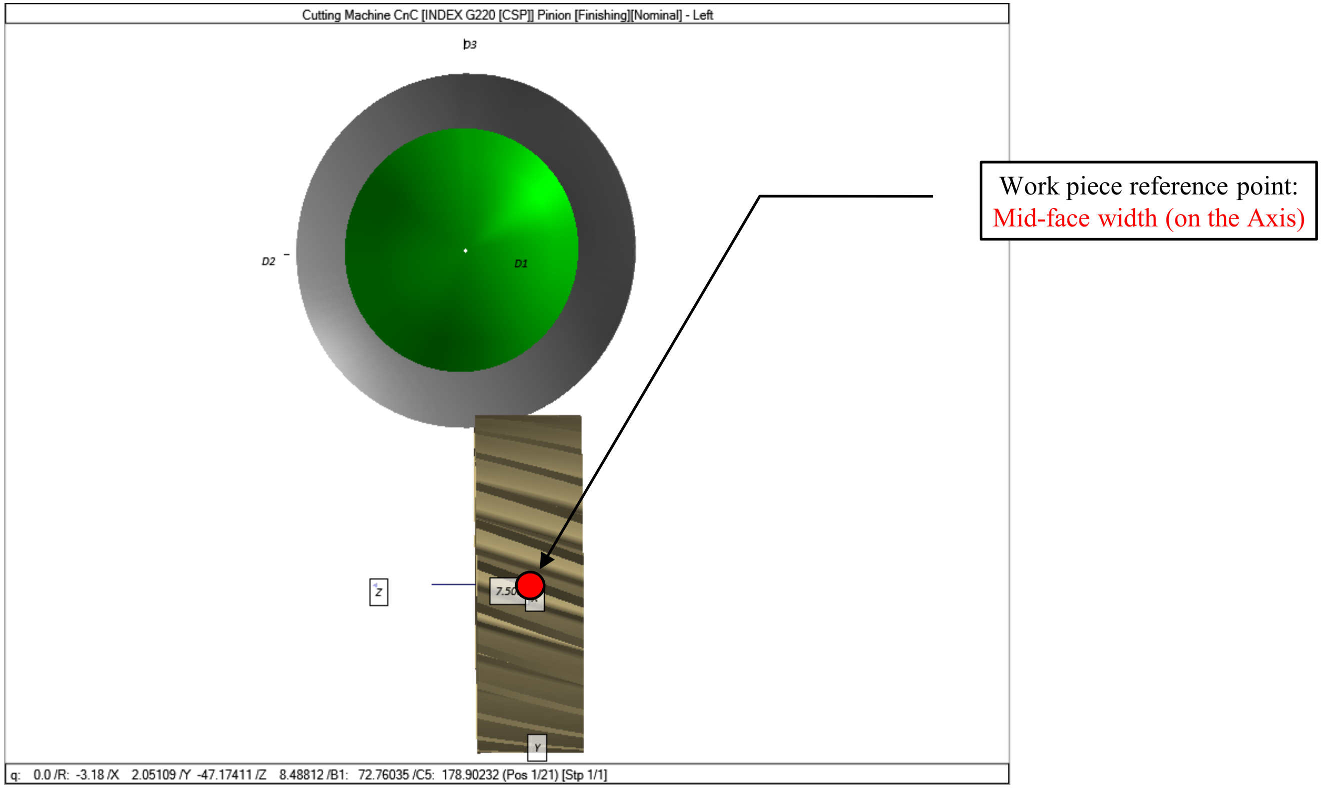
Probe: TCP



Coniflex Dish Reference Point

The HyGEARS™ 5 Axis CnC Post-Processor

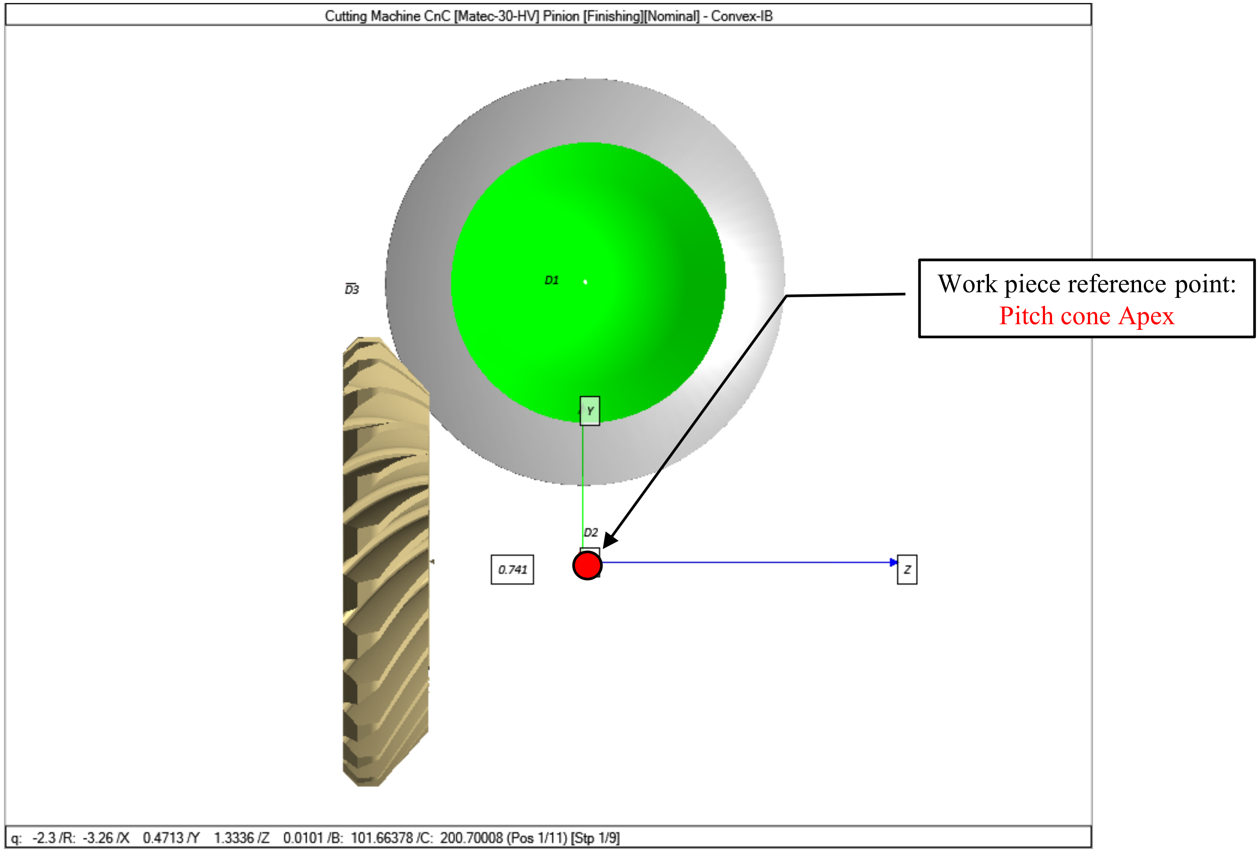
Part Reference Point:	*The reference point on the work piece changes with geometry type; it is tool independent.*



Spur/Helical/Beveloid/Herringbone gears

The HyGEARS™ 5 Axis CnC Post-Processor

Part Reference Point: *Straight Bevel / Spiral Bevel / Zerol / Coniflex gears.*

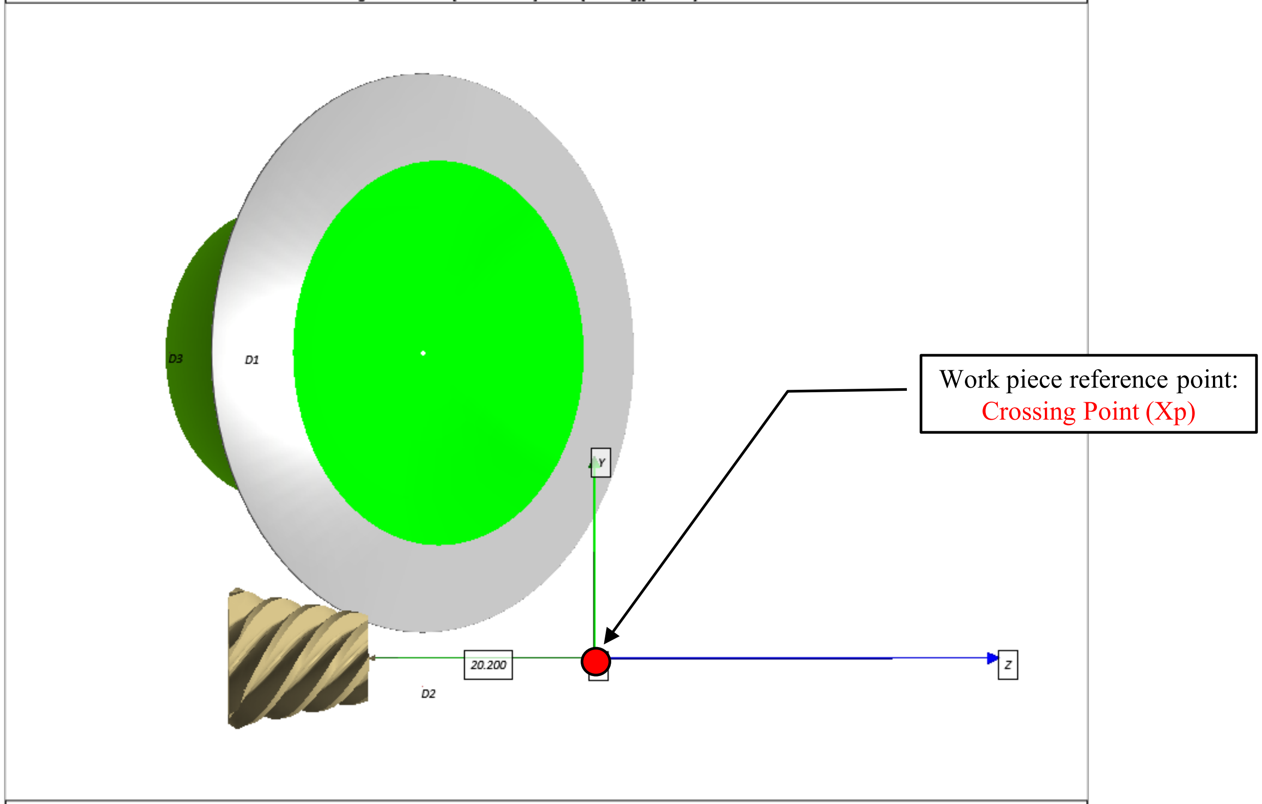


Straight Bevel/Spiral Bevel/Zerol/Coniflex gears

The HyGEARS™ 5 Axis CnC Post-Processor

Part Reference Point: *Hypoid gears.*

Cutting Machine CnC [Matec-30-HV] Pinion [Finishing][Nominal] - Convex-IB

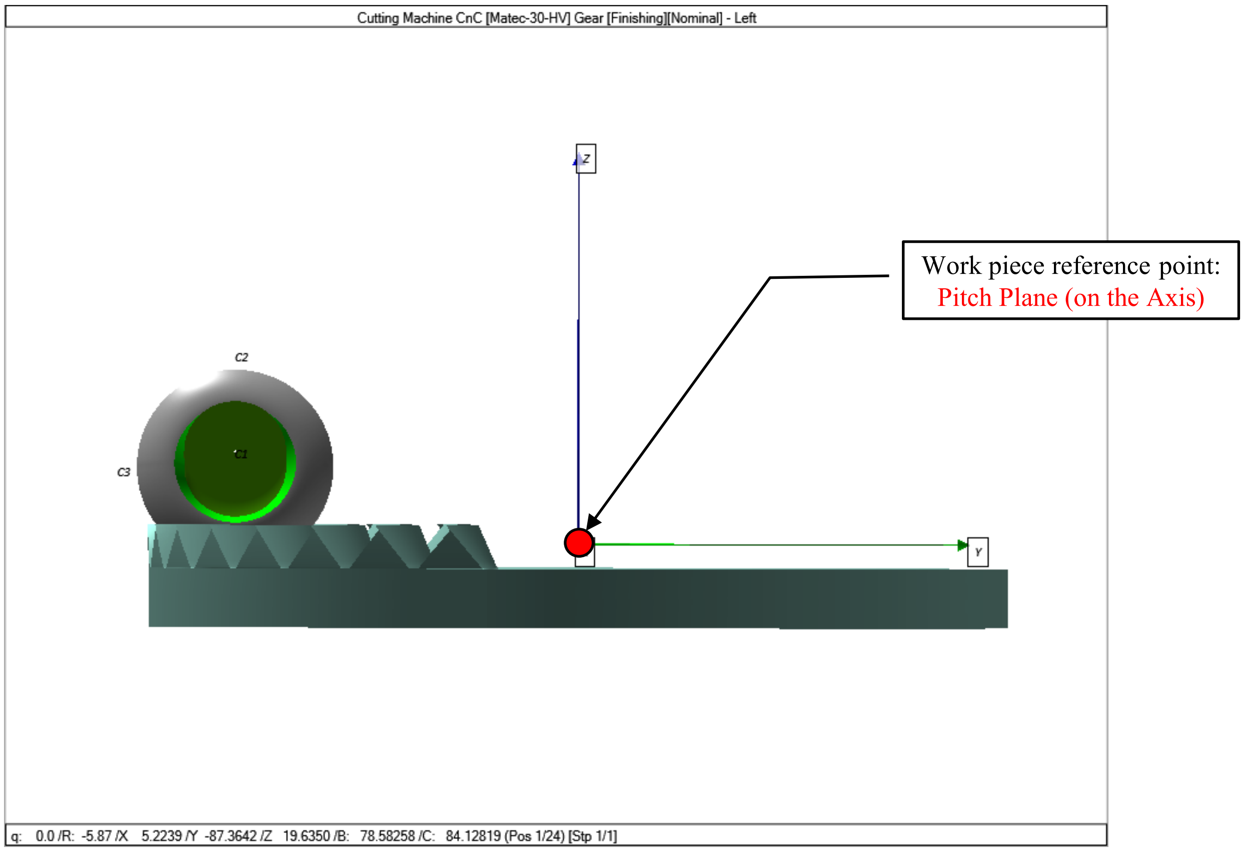


q: 6.1 /R: 60.20 /X 6.4219 /Y 27.2941 /Z -15.2566 /B: 130.17260 /C: 132.55451 (Pos 1/11) [Stp 1/9]

Hypoid gears

The HyGEARS™ 5 Axis CnC Post-Processor

Part Reference Point: *Face gears.*



Face gears

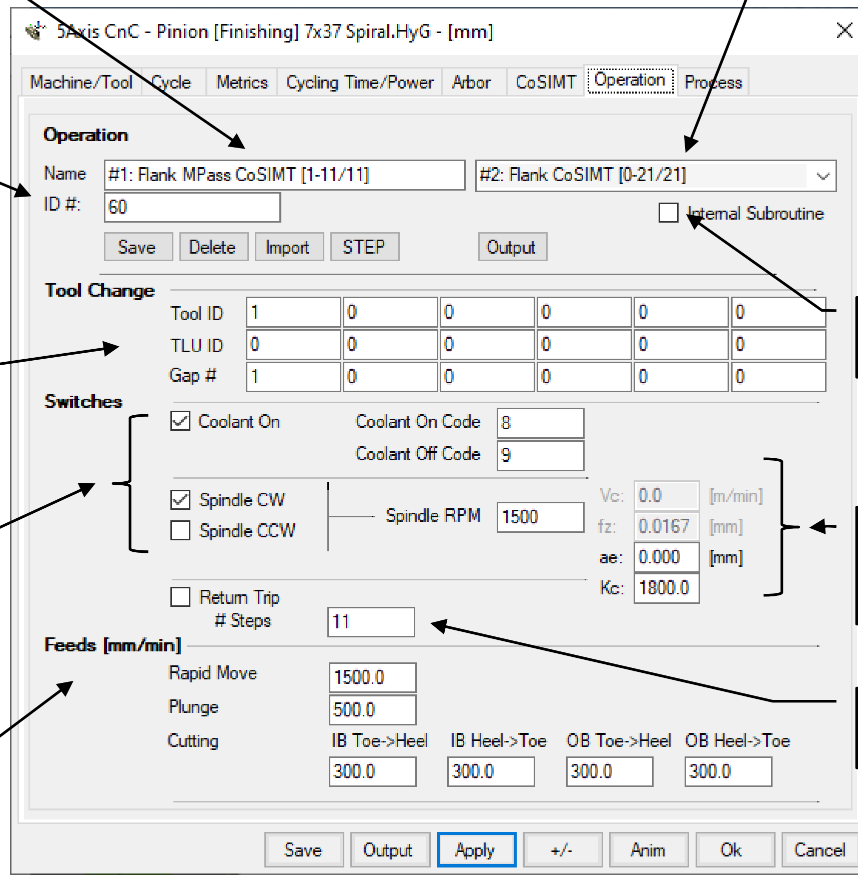
The HyGEARS™ 5 Axis CnC Post-Processor

***Operation**: Saves all switches and choices such as to be reusable.*

Operation name

Operation list

Operation ID
Used for the name of the part program and sub- programs



Main and sub programs in same file

Programmed tool change
If 1st Gap = 0, then no Tool change occurs.

Operation switches
May be turned On/Off in the Output Format

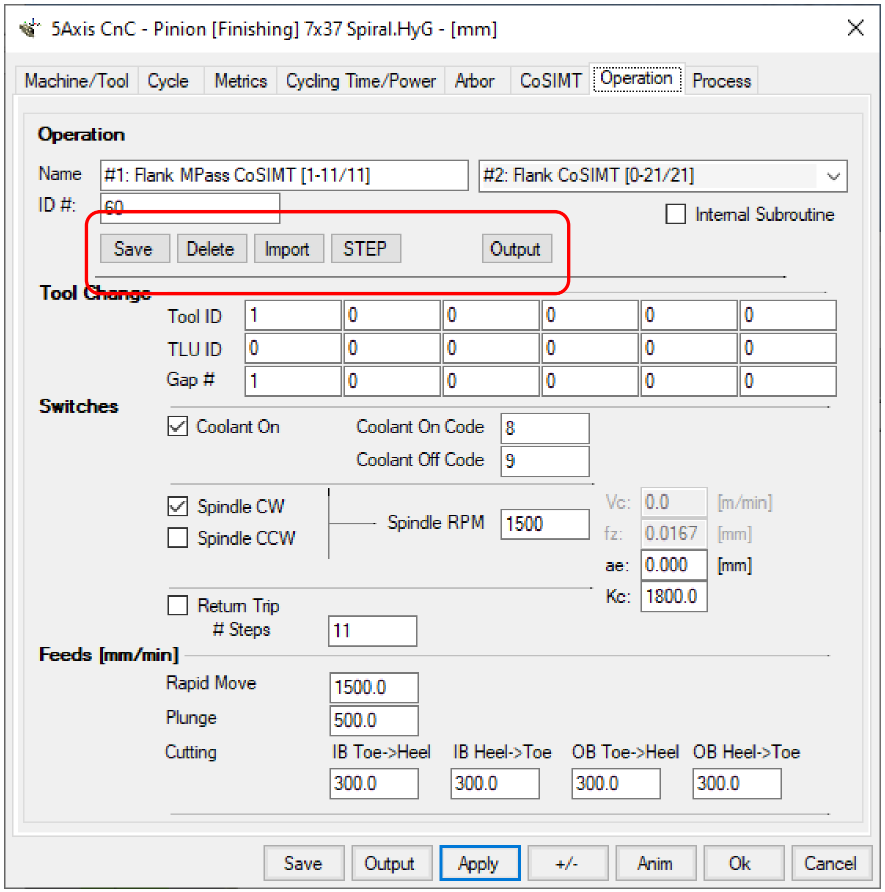
Tool cutting torque; used to estimate required torque & power.

Imposes the tool return path

Tool feeds & speeds
Origin from tool, and are overridden here.

The HyGEARS™ 5 Axis CnC Post-Processor

Operations: *The Operations page allows saving combinations of Machine, Tool and Cutting Cycle selections, for the current geometry, under one identifier such as to be able to use the same combinations with different geometries, or when defining Processes.*

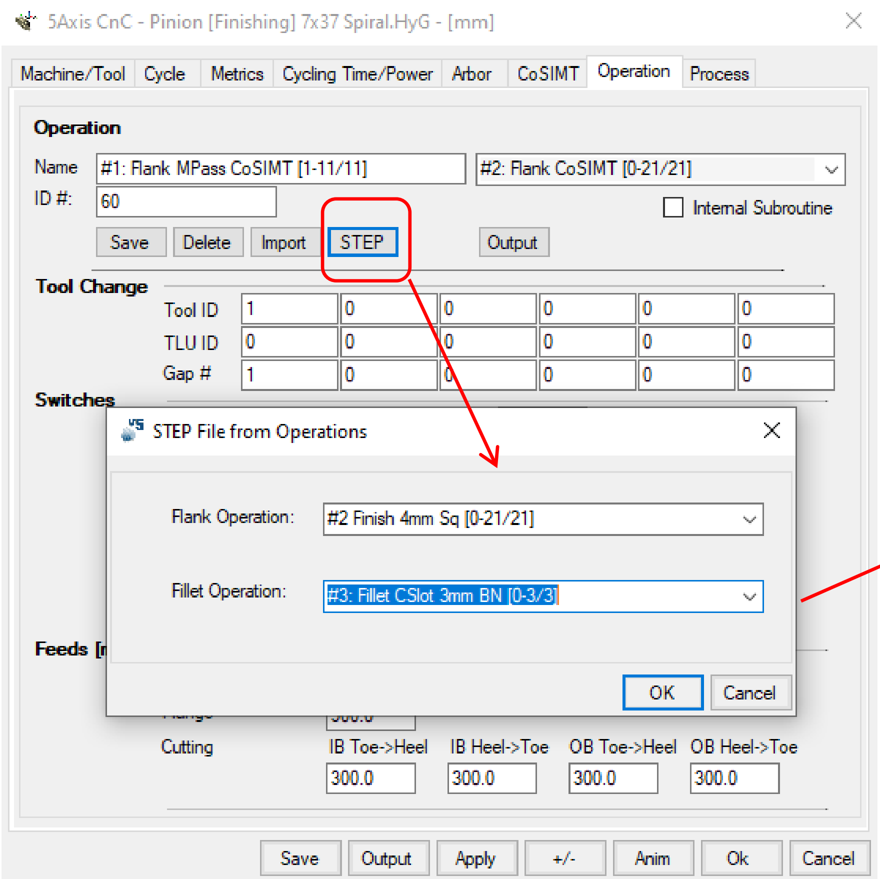


Operations Tab

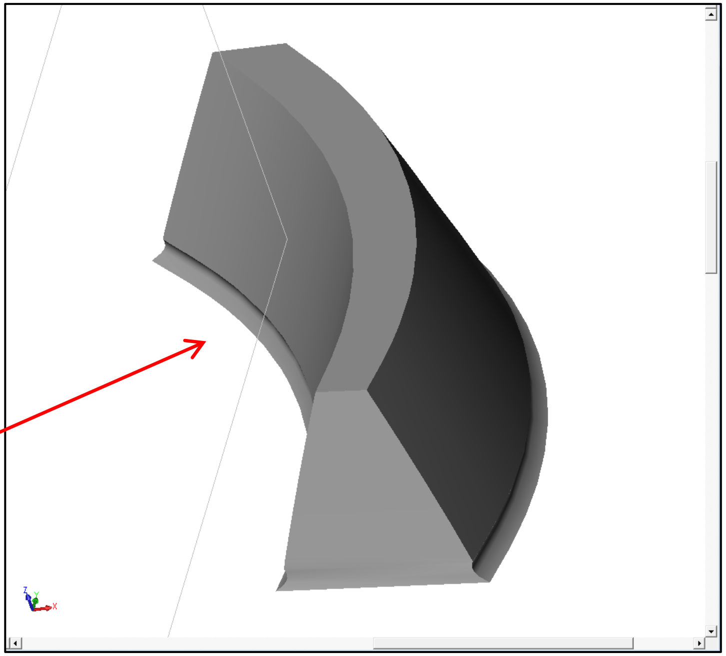
- *an Operation is specific to a geometry, i.e. it is saved in the "Operations.fil" file stored in a geometry's folder;*
- *the **Save / Delete** buttons conserve and erase the selected operation;*
- *the **Import** button allows importing Operations from other geometries; thus, Operations can be re-used;*
- *the **Output** button generates the part program for the selected Operation;*
- ***Tool Changes** can be imposed at specified tooth gaps;*
- *Several **Switches** can be imposed to any given operation.*

The HyGEARS™ 5 Axis CnC Post-Processor

Operations: *The STEP button displays a selection window where one Flank and one Fillet operation are selected, and then combines the selected operations in one STEP file which can be read by any CAD-CAM software, such that the actual shape of the tooth can be exported for assessment at any intermediate manufacturing step.*



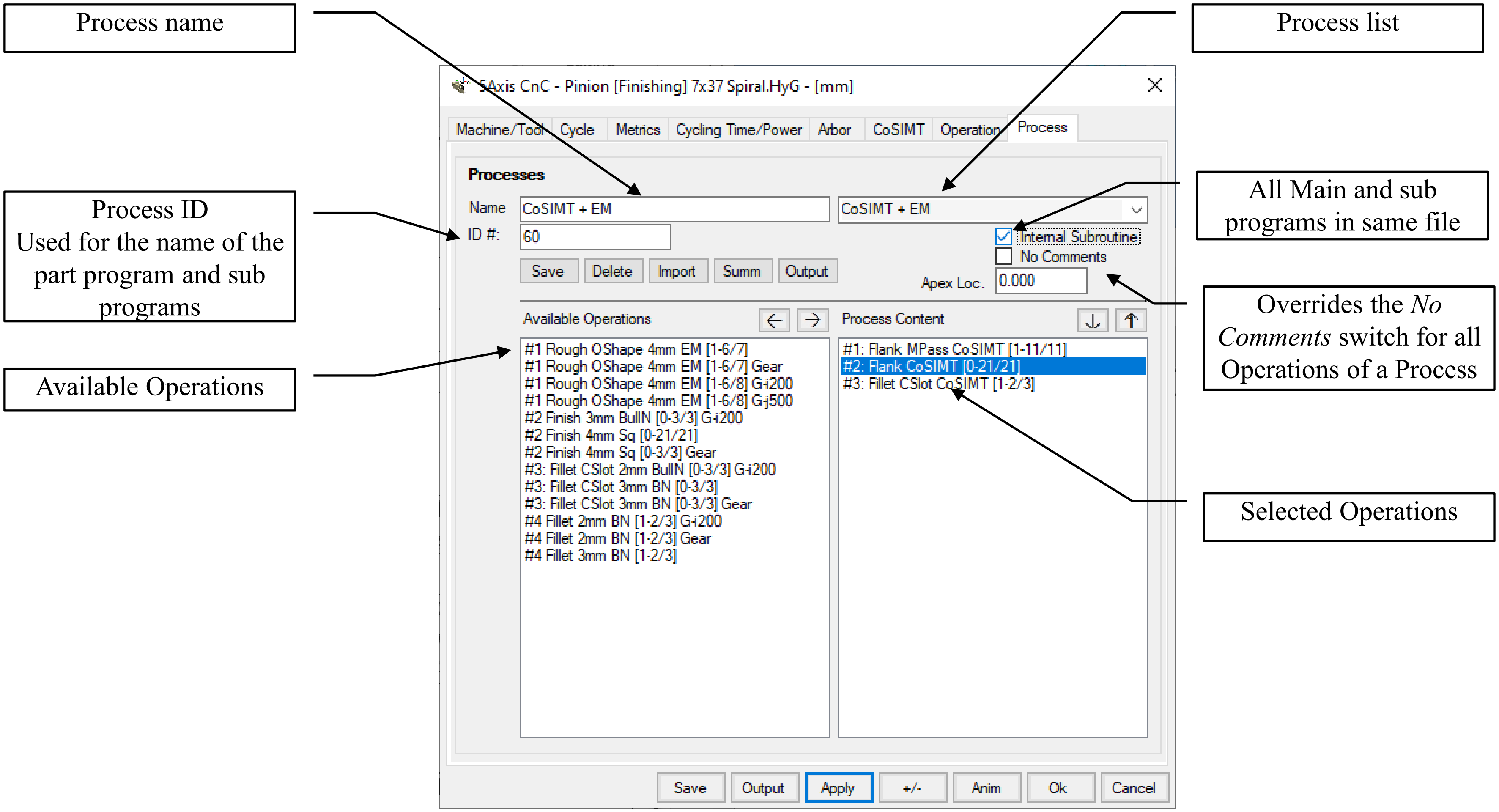
Operations: STEP output



Final tooth: 0 Flank Stock, -1.5 mm Fillet Stock

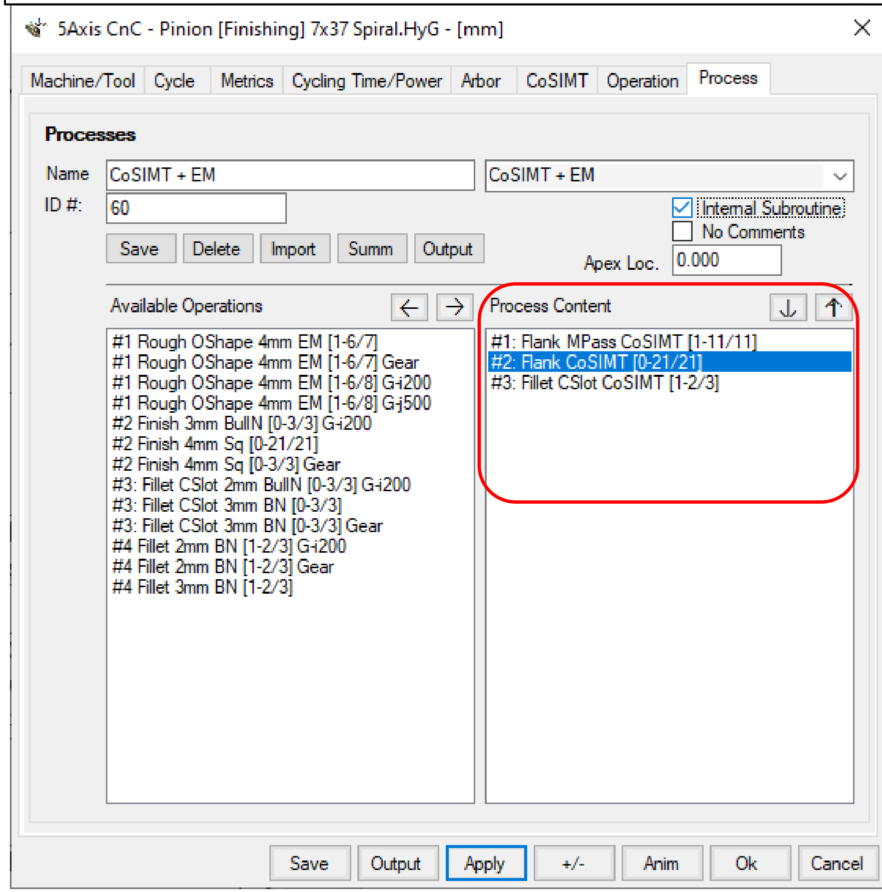
The HyGEARS™ 5 Axis CnC Post-Processor

***Process**: Organizes Operations in a user defined sequence.*



The HyGEARS™ 5 Axis CnC Post-Processor

Process: *A Process is an ordered sequence of Operations in which a Main, or Calling, program is generated which calls the selected Operations in the requested order.*
For example, right column in the figure below, the Main program would call Operation "Rough MPass" first, and then Operation "Rough Fil-MPass"

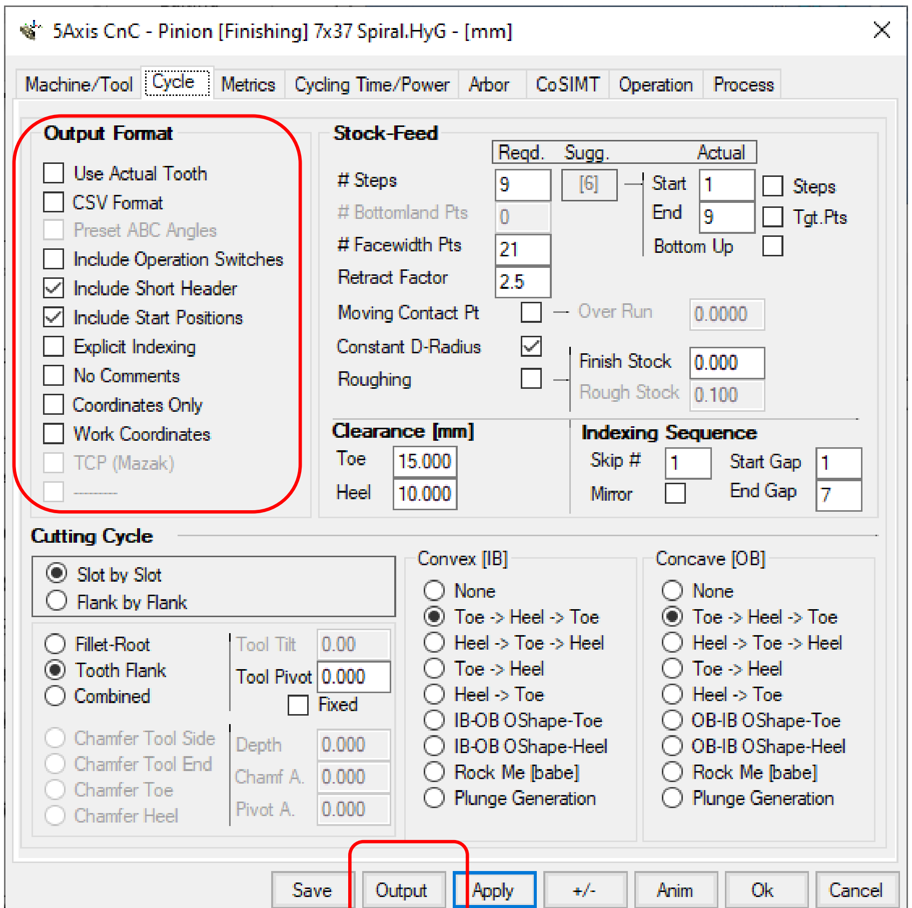


Processes Tab

- *A Process is specific to a geometry, i.e. it is saved in the "Processes.fil" file stored in a geometry's folder;*
- *A Process can contain any number of operations – the controller's memory being the practical limit;*
- *the* ***Save / Delete*** *buttons conserve and erase the selected Process;*
- *the* ***Import*** *button allows importing Processes from other geometries;*
- *the* ***Output*** *button generates the complete part program for the selected Process;*
- *All* ***Switches*** *imposed in any given operation appear in each step of the Process.*

The HyGEARS™ 5 Axis CnC Post-Processor

Output: *The Output button instructs HyGEARS to read the selected user choices, generate the part program and send the output to a Text Results window.*



Part program Output

A part program comprises:

- *a **Header**, in which user selections, machine settings and tool definition are listed; this is optional at output time using the "No comment lines" switch;*
- *a **Preamble**, specific to the selected machine, where machine code desired by the operator is added automatically;*
- *the **Indexing Sequence**, where each tooth slot calls the actual cutting program in the specified sequence order;*
- *the actual cutting program with tool path coordinates;*
- *Work Coordinates indicate that X, Y and Z are in work piece coordinates, and that angles A, B, C are machine angles;*
- *Traori, TCPM, TCP and TCPC indicate that the unit vector of the tool axis is provided along with X, Y and Z in work piece coordinates.*

The HyGEARS™ 5 Axis CnC Post-Processor

Output: *the Header lists user selections, machine settings and tool definition.*

Part Program for : Gear [Finishing] 13x33d400_final_REG.hyg

File Edit

```
;****************************************
;PROGRAM NAME       : #2 Finish Moving Contace [1-10/10]
;PROGRAM DATE       : 07-21-2015
;SUMMARY VERSION    : [Nominal]
;TOOL ID            : 120121 27588 367
;TOOL DIAMETER      : 6.00[mm]
;TOOL LENGTH        : 40.00[mm]
;****************************************
           ; Date / Time       : 21/07/2015 / 6:13:44 PM
           ; General Units     : [mm] [dd.mm.ss]
           ; Cutter  Units     : [mm]
           ; Prepared by       : Claude Gosselin
           ; Version           : 4.0.404.60-457
           ;
           ; ----------------- Start Header --------------------
           ; HyGEARS V 4.0 © ®
           ;
           ; Part Program       : 13x33d400_final_REG.hyg
           ;
           ; Machine            : CnC [Ultrix] - [Finishing][Nominal]
           ;
           ; Operation          : #2 Finish Moving Contace [1-10/10]
           ;
           ; Member            :                          Gear
           ; Controller        :                       Siemens
           ; Coordinates       :                    Work Piece
           ; Indexing          :               Controller code
           ; Contact Point     :                         Fixed
           ; Tooth line sep.   :                    Cst D-Roll
           ; Stock left        :                       -0.5000
           ; Tool Length       :                        40.000
           ; Apex Location     :                         0.000
           ; # Gaps            :                            33
           ;   Start           :                             1
           ;   End             :                            33
           ;   Increment       :                             1
           ; # Steps           :                             6
           ;   Start           :                             1
           ;   End             :                             6
           ; # Points width    :                            11
           ; Tool Tilt Angle   :                        10.000
           ; Retract factor    :                           2.0
           ; Toe Clear.  [#pts] :                    50.000[3]
           ; Heel Clear. [#pts] :                    20.000[3]
           ; Compensation      :             Tool Center Point
           ; Cutting Cycle     :                  Slot by Slot
           ; Target            :                   Fillet Area
           ; IB/Left Cycle     :                  Toe-Heel-Toe
           ; OB/Right Cycle    :                  Toe-Heel-Toe
           ; ---------------------------------------------------
           ;
```

Output: Header – 1st part

Part Program for : Gear [Finishing] 13x33d400_final_REG.hyg

File Edit

```
; GEAR [FINISHING]
; CUTTER SPECIFICATIONS                            [I.B.]        [O.B.]
;
; Average Diameter              :              304.8000
; Blade Angle                   :         28.4178       11.4156
; Blade Edge Radius             :                4.1910
; Point Width                   :                6.1112
; Rad. of Curvature             :       6350.0000     6350.0000
; Rad. of Curvature-Ref. Height :          0.0000        0.0000
; TopRem Depth                  :          0.0000        0.0000
; TopRem Radius                 :         88.9000        0.0000
; Cutter Gaging                 :          0.0000        0.0000


; GEAR [FINISHING] :Spread Blade
; MACHINE SETTINGS - #175-S
;

; Radial Distance               :        148.9870
; Cutter Tilt                   :          6.1644
; Swivel Angle                  :        197.3272
; Blank Offset                  :          0.0000
; Machine Root Angle            :         64.5626
; Machine Center To Back        :          0.0947
; Sliding Base                  :         13.7400
; Rate of Roll                  :         1.07255
; Cradle Angle                  :         54.3272

; WORKPIECE DIMENSIONS
;
; # Teeth               :                     33
; Module                :                 12.121
; Face Angle            :                 69.746
; Face Width            :                 78.749
; Front Crown to Xp     :                 49.047
; OD Toe                :                266.512
; OD Heel               :                400.036
;
; END MILL TOOL DEFINITION
;
; Name                  :
; Diameter              :                  6.000
; Edge Radius           :                  3.000
; Cone Angle            :                  0.000
; Cutting Length        :                 30.000
; Cutting Length in Use:                  30.000
; Tool Length           :                 40.000
; Stem Diameter         :                  8.000
; Holder Diameter       :                  0.000
```

Output: Header – 2nd part

The HyGEARS™ 5 Axis CnC Post-Processor

Output: *Indexing Sequence: indexes the work piece axis in the specified sequence.*

Part Program for : Gear [Finishing] 13x33d400_final_REG.hyg

File Edit

```
          ;  -----------   Start of Program   ----------
SEQINDEX[1] = 1
SEQINDEX[2] = 2
SEQINDEX[3] = 3
SEQINDEX[4] = 4
SEQINDEX[5] = 5
SEQINDEX[6] = 6
SEQINDEX[7] = 7
SEQINDEX[8] = 8
SEQINDEX[9] = 9
SEQINDEX[10] = 10
SEQINDEX[11] = 11
SEQINDEX[12] = 12
SEQINDEX[13] = 13
SEQINDEX[14] = 14
SEQINDEX[15] = 15
SEQINDEX[16] = 16
SEQINDEX[17] = 17
SEQINDEX[18] = 18
SEQINDEX[19] = 19
SEQINDEX[20] = 20
SEQINDEX[21] = 21
SEQINDEX[22] = 22
SEQINDEX[23] = 23
SEQINDEX[24] = 24
SEQINDEX[25] = 25
SEQINDEX[26] = 26
SEQINDEX[27] = 27
SEQINDEX[28] = 28
SEQINDEX[29] = 29
SEQINDEX[30] = 30
SEQINDEX[31] = 31
SEQINDEX[32] = 32
SEQINDEX[33] = 33

TEETH_ANGLE = (360/TOTAL_TEETH)
TEETH_ANGLE = (ROUND(TEETH_ANGLE*100000)/100000)
TRAORI
ORIAXES
          ;  ----------   Start of Cycle   -------------
          ;                Section  1

T120121 M6

          ;  --------   Tooth Space #  1  --------------
RESTART_TEETH=1
TRANS C=(TEETH_ANGLE*SEQINDEX[(RESTART_TEETH)])
STOPRE
EXTCALL "PROC1"
          ;  --------   Tooth Space #  2  --------------
RESTART_TEETH=2
```

Output: Header – Indexing Sequence

The HyGEARS™ 5 Axis CnC Post-Processor

Output: *Tool path coordinates: the actual tooth flank cutting commands.*

Part Program for : Gear [Finishing] 13x33d400_final_REG.hyg

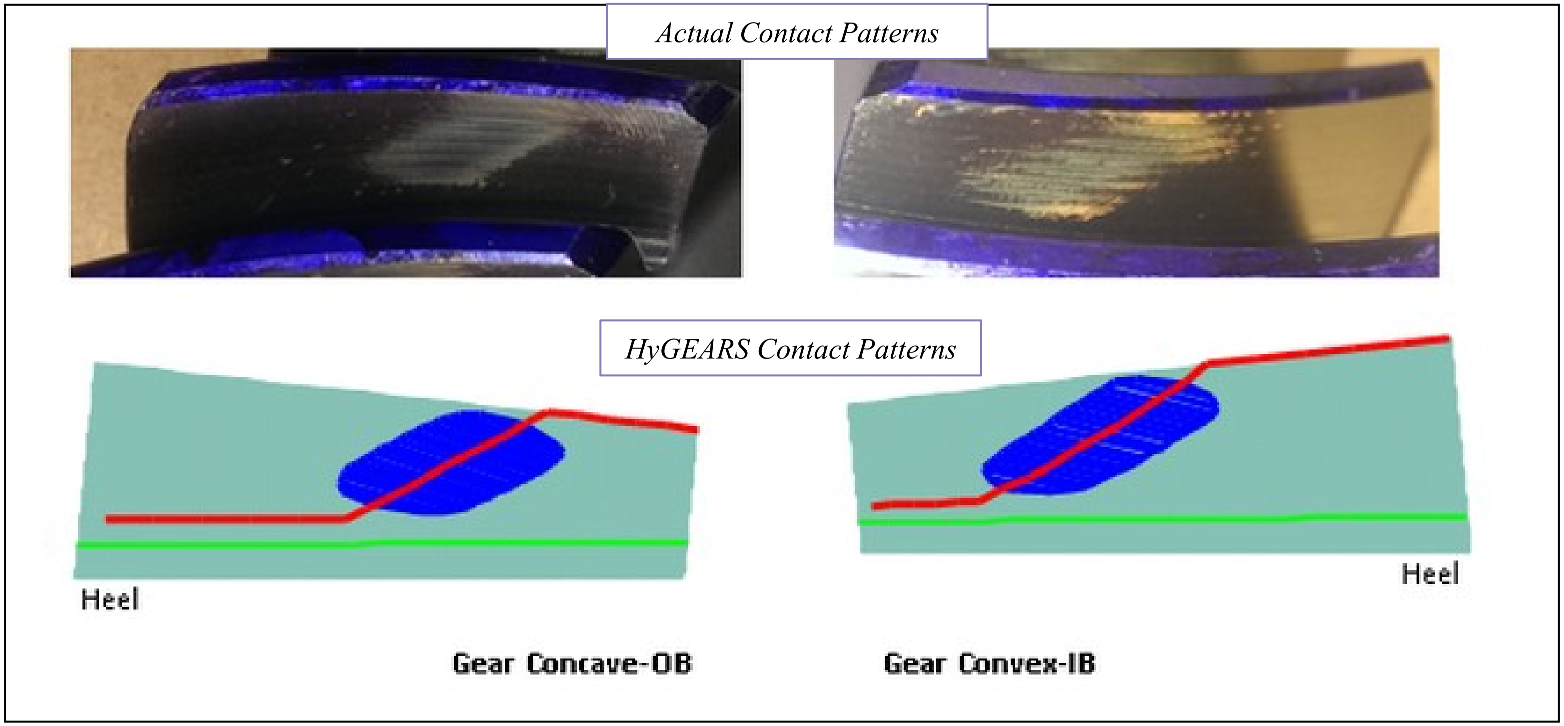
File Edit

```
          ;  ----------    Cutting Cycle    ------------
START1:
TRANS C=(TEETH_ANGLE*SEQINDEX[(RESTART_TEETH)])
STOPRE

          ;  ------------------- Convex  ---------------
          ;  ------------------  Toe  ------------------
F=HYG_RMOVE_FEED
G1 X43.53071 Y110.61900 Z-3.74949 A35.756273 C=DC(400.152521)
F=HYG_PLUNGE_FEED

G1 X26.06661 Y89.91821 Z-41.36221 A35.756273 C=DC(400.152521)
F=HYG_CUT_FEED
G1 X25.26790 Y103.03668 Z-47.52692 A36.029326 C=DC(397.961522)
G1 X22.55098 Y116.12572 Z-53.68882 A36.265516 C=DC(395.416752)
G1 X17.92101 Y129.18801 Z-59.84734 A36.460072 C=DC(392.519123)
G1 X14.29067 Y136.78683 Z-63.44583 A36.550894 C=DC(390.645807)
G1 X10.10552 Y144.30330 Z-66.99599 A36.625650 C=DC(388.695267)
G1 X5.34714 Y151.70683 Z-70.49853 A36.680815 C=DC(386.646779)
G1 X-0.00629 Y158.96533 Z-73.95076 A36.716033 C=DC(384.496324)
G1 X-5.97993 Y166.04370 Z-77.34803 A36.731920 C=DC(382.244733)
G1 X-12.60486 Y172.90406 Z-80.68036 A36.732909 C=DC(379.913287)
G1 X-19.90785 Y179.49789 Z-83.95180 A36.709655 C=DC(377.447298)
G1 X-27.93179 Y185.77627 Z-87.14607 A36.670126 C=DC(374.886054)
G1 X-36.71690 Y191.67622 Z-90.26119 A36.607962 C=DC(372.189166)
G1 X-46.31630 Y197.12535 Z-93.28604 A36.523252 C=DC(369.350248)
G1 X-54.77268 Y201.37599 Z-95.73668 A36.434894 C=DC(366.904596)
G1 X-63.87406 Y205.45836 Z-98.18585 A36.327558 C=DC(364.320003)
G1 X-73.61161 Y209.37427 Z-100.63336 A36.199903 C=DC(361.595406)
          ;  ------------------  Heel ------------------

G1 X-73.08370 Y209.26241 Z-100.84835 A34.528885 C=DC(360.289059)
G1 X-63.34294 Y205.30060 Z-98.40175 A34.664243 C=DC(362.902380)
G1 X-54.24202 Y201.17677 Z-95.95369 A34.780279 C=DC(365.378343)
G1 X-45.78994 Y196.88897 Z-93.50434 A34.878262 C=DC(367.718440)
G1 X-36.23343 Y191.41968 Z-90.49238 A34.975347 C=DC(370.418916)
G1 X-27.48794 Y185.50425 Z-87.38904 A35.051837 C=DC(372.984634)
G1 X-19.50004 Y179.21428 Z-84.20582 A35.106547 C=DC(375.413710)
G1 X-12.23398 Y172.61331 Z-80.94058 A35.150797 C=DC(377.779319)
G1 X-5.64100 Y165.74836 Z-77.61518 A35.169069 C=DC(379.990188)
G1 X0.29936 Y158.66957 Z-74.21937 A35.178710 C=DC(382.154580)
G1 X5.62143 Y151.41360 Z-70.76635 A35.171167 C=DC(384.222515)
G1 X10.35029 Y144.01533 Z-67.26063 A35.146073 C=DC(386.193376)
G1 X14.50776 Y136.50658 Z-63.70516 A35.103886 C=DC(388.071190)
G1 X18.11037 Y128.91874 Z-60.09715 A35.051995 C=DC(389.902054)
G1 X22.66829 Y115.94751 Z-53.94874 A34.929071 C=DC(392.726020)
G1 X25.31506 Y102.97743 Z-47.79827 A34.774315 C=DC(395.238174)
G1 X26.04511 Y90.00484 Z-41.64624 A34.591863 C=DC(397.436114)
          ;  ------------------  Toe  ------------------

G1 X26.12023 Y89.98651 Z-41.91066 A33.485440 C=DC(394.572169)
```

Output: Tool path coordinates (with comments)

The HyGEARS™ 5 Axis CnC Post-Processor

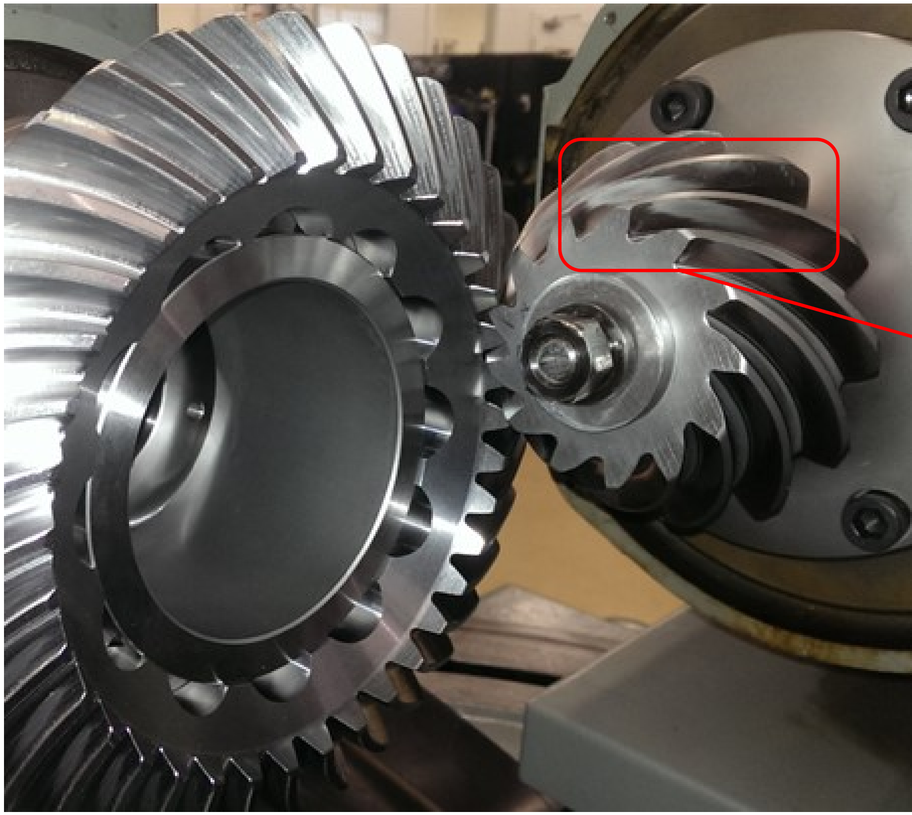
Sample Result 1:	*13x37 6.5 mm module, Face Milled hypoid gear set: **soft-finish**.* *Contact Pattern checks show perfect agreement with HyGEARS' prediction.*



The HyGEARS™ 5 Axis CnC Post-Processor

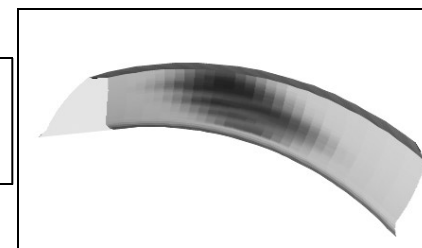
Sample Result 1: *13x37 6.5 mm module, Face Milled hypoid gear set:* ***hard-finish****.*
Contact Pattern check shows perfect agreement with HyGEARS' prediction.

- *Pinion Fixed Setting – Generated*
- *Gear Spread Blade – Generated*
- *Cut on DMU65 Monoblock (AC type machine)*
- *Roughing : CoSIMT*
- *Pre-Finishing : Bull Nose End Mill*
- *Hard finish : Tapered End Mill*



13x37 hypoid gear pair on the VH tester

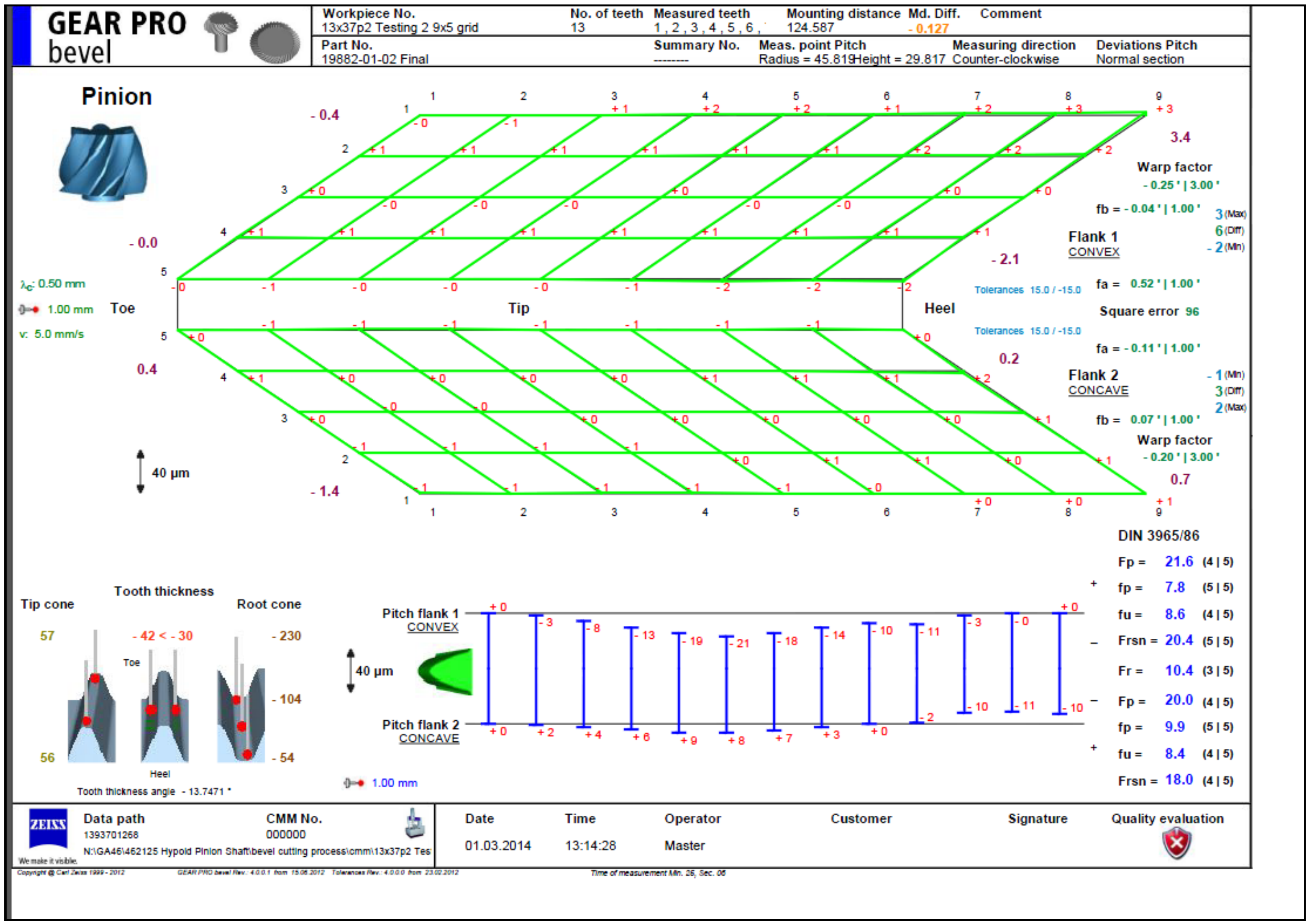
Actual Contact Pattern Pinion OB



HyGEARS' Predicted Contact Pattern Pinion OB

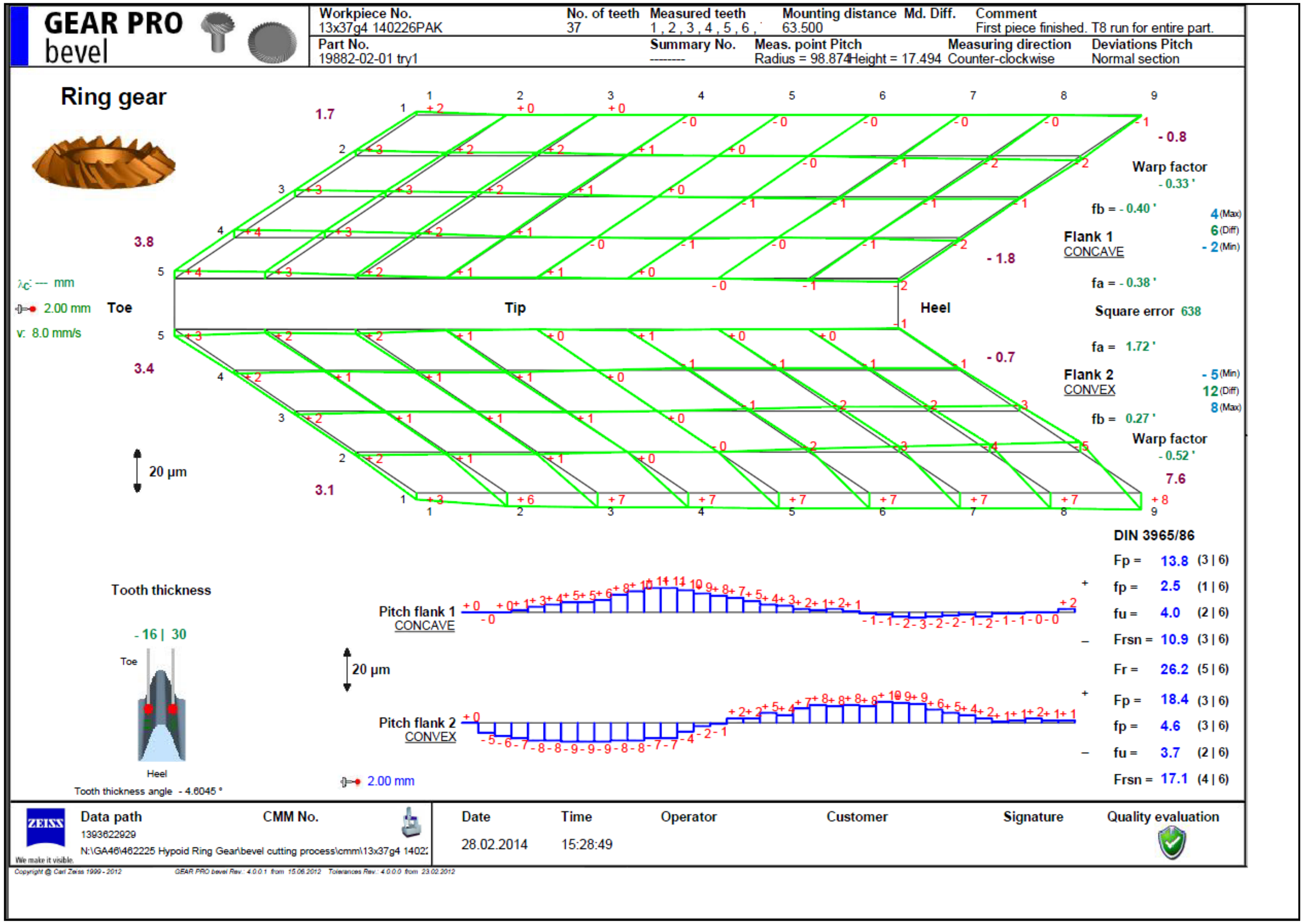
The HyGEARS™ 5 Axis CnC Post-Processor

Sample Result 1:	*13x37 6.5 mm module, Face Milled hypoid gear set: Pinion CMM output after hard-finish shows negligible deviations between actual and HyGEARS' theoretical.*



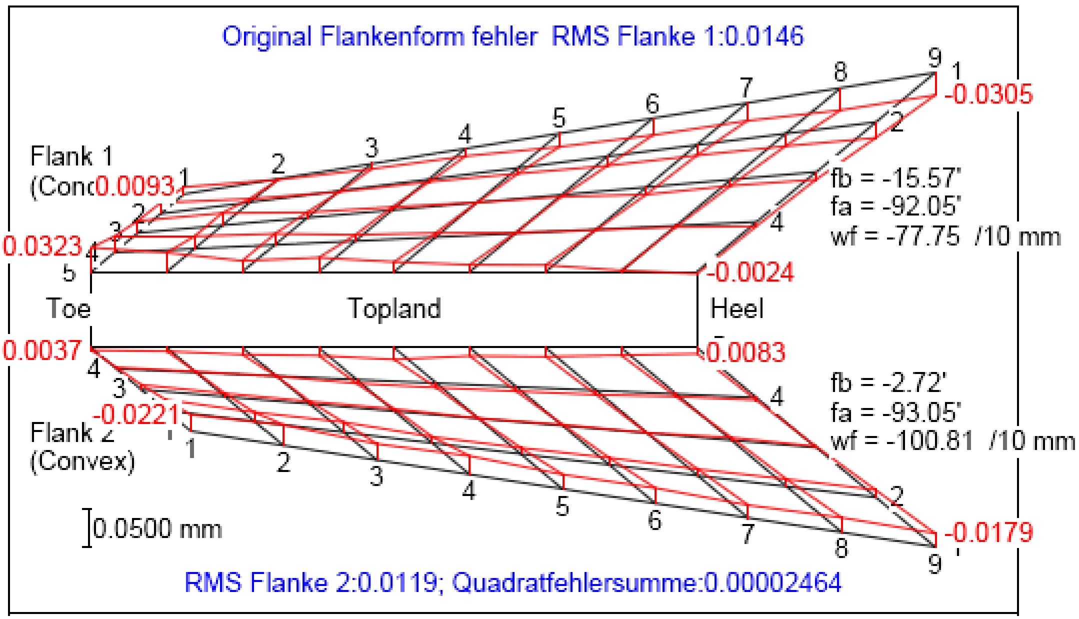
The HyGEARS™ 5 Axis CnC Post-Processor

Sample Result 1:	*13x37 6.5 mm module, Face Milled hypoid gear set: Gear CMM output after hard-finish shows negligible deviations between actual and HyGEARS' theoretical.*



The HyGEARS™ 5 Axis CnC Post-Processor

Sample Result 2:	*26x26, 1.5 mm module, duplex helical spiral-bevel pinion cut using a Face Mill cutter.* *Pinion CMM output after soft cut show a combination of pressure and spiral angle errors, plus some surface bias and lengthwise crowning.*



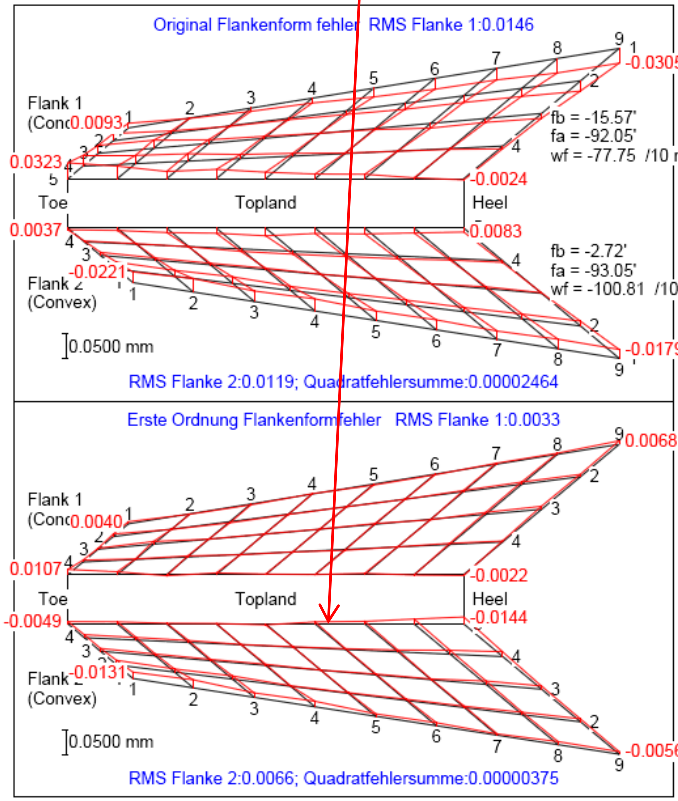
Sample Result 2: *GAGE's calculated Correction data and expected residual errors after re-cut show negligible pressure and spiral angle errors, but crowning will remain on the Concave tooth flank.*

GLEASON Maschinenkorrekturen

Flankformmessung bezogen auf modifizierte Solldaten - 11/26/2014/13:10:14
275HC Summarydaten- Änderungen (991801)
Nullte Ordnung
Erste Ordnung: Kreuztragend Lahmtragend Zehe/Ferse Kopf/Fuß
Ritzel - Spreizmesser

Radialabstand	0.0735mm
Neigungswinkel	-0.0129°
Schwenkwinkel	-0.0603°
Maschinengrundwinkel	-0.0108°
Schlittenplatte	-0.1921mm
Wälzverhältnis	0.017765
Wälzmitte	-0.1579°
A.M. Eingriffswinkel	0.0000°
I.M. Eingriffswinkel	0.0000°
Zahndickenfehler	0.1805mm
Quadratfehlersumme (original)	0.00002464
Quadratfehlersumme (nach 1st)	0.00000375

Mittlerer Fehler	Konkav Flanke	Konvex Flanke
Eingriffswinkel	-92.05´	-93.05´
Spiralwinkel	-15.57´	-2.72´
Verwindungsfaktor	-77.75´ /10 mm	-100.81´ /10 mm
RMS Fehler (Original)	0.0146mm	0.0119mm
RMS Fehler (nach 1st)	0.0033mm	0.0066mm



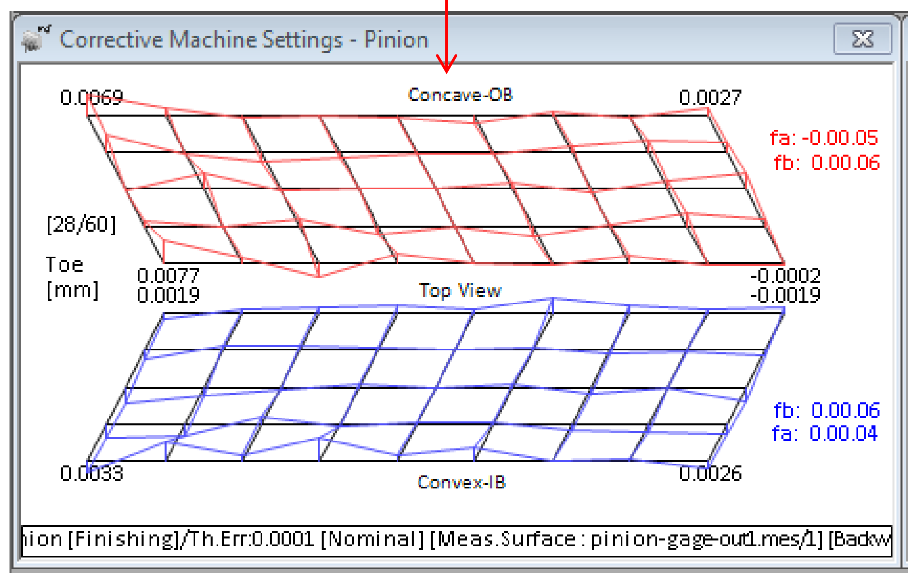
The HyGEARS™ 5 Axis CnC Post-Processor

Sample Result 2: *HyGEARS' calculated Correction data and expected residual errors after re-cut show negligible pressure and spiral angle errors, and crowning on the Concave tooth flank disappears.*

Corrective Machine Settings

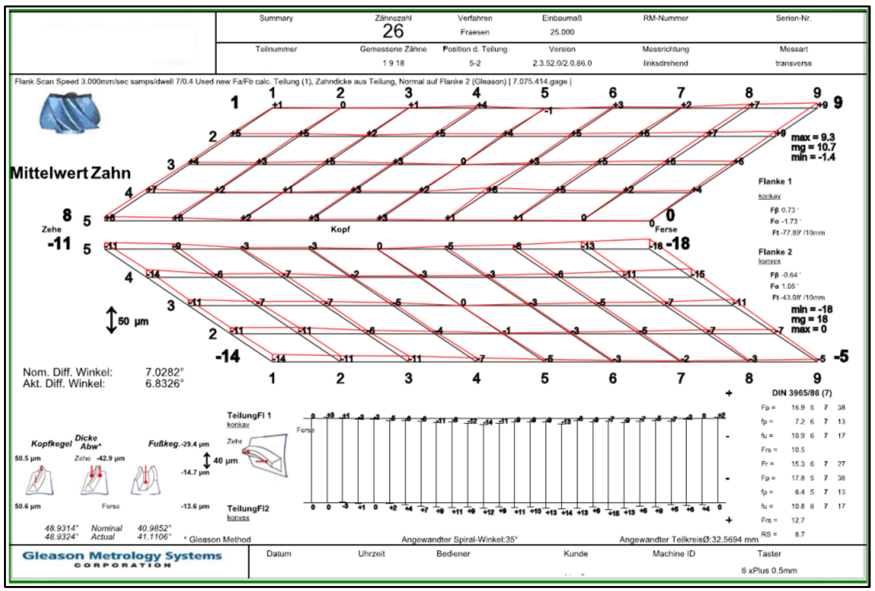
Machine Setting Changes
175U - Meas.Surface : pinion-gage-out1.mes/1
Pinion [Finishing] [2/2] [Backward]

2nd Order Changes		(O.B.)	(I.B.)
Radial Distance	:	0.1969	
Cutter Tilt	:	0.2661	
Swivel Angle	:	-0.8929	
Blank Offset	:	0.2178	
Machine Root Angle	:	-360.0001	
Machine Center To Back	:	-0.3698	
Sliding Base	:	-0.0545	
Rate of Roll	:	0.01307	
Cradle Angle	:	-0.8929	
Blade Angle	:	0.0000	0.0000
Average Diameter	:	0.0000	
Point Width	:	0.0000	
Modified Roll			
Helical Motion			

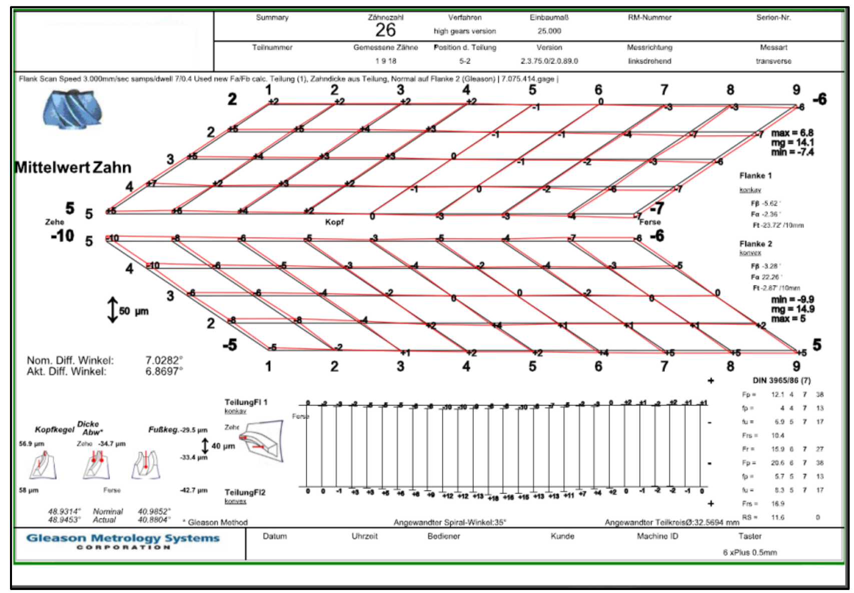


The HyGEARS™ 5 Axis CnC Post-Processor

Sample Result 2:	*CMM results after the 1st corrective cycle appear below. As expected, crowning remains in the GAGE corrected tooth while it is not visible in the HyGEARS corrected tooth.* *In both the GAGE and HyGEARS corrected teeth, spiral and pressure angle errors have been eliminated.*



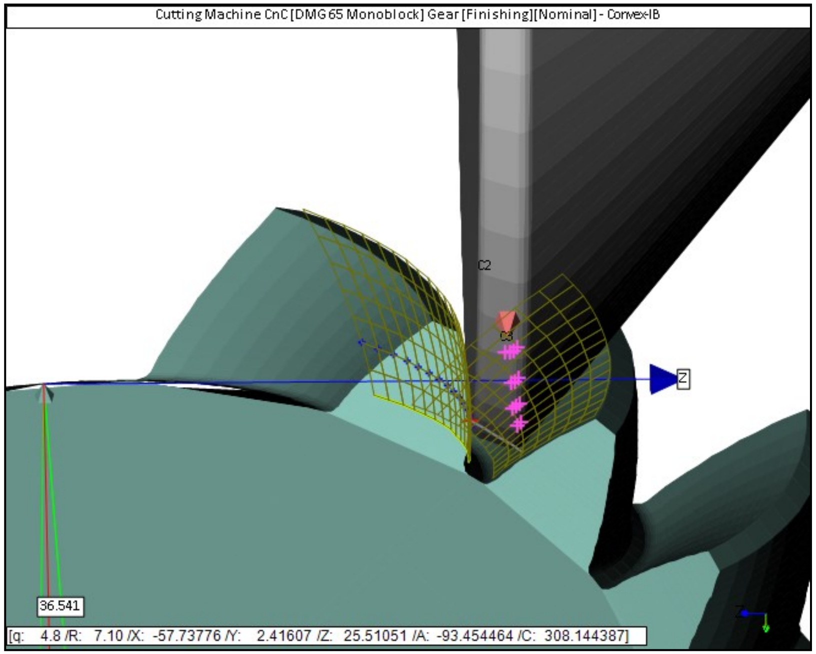
GAGE correction



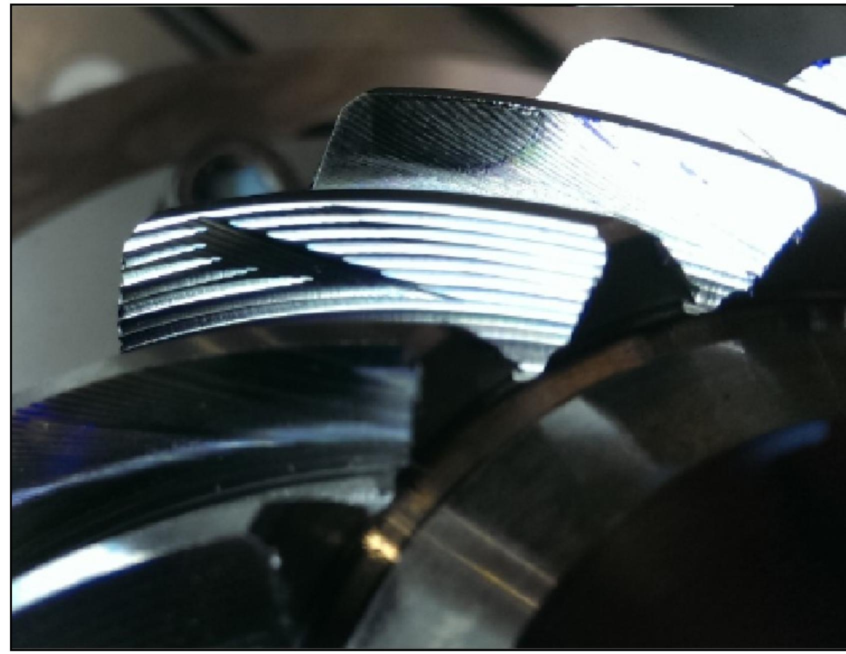
HyGEARS correction

The HyGEARS™ 5 Axis CnC Post-Processor

Sample Result 3: *Gouging detection is a desirable feature to prevent the mutilation of the tooth flank opposite that being cut by the back face of the tool.*
The left figure below shows the HyGEARS detected gouging points (pink crosses) on the concave side while the convex side is being cut. The right figure shows what happened in practice. The correlation is obvious.



HyGEARS predicted gouging on OB



Actual gouging on OB

Summary

1. *HyGEARS' tooth flank generation and TCA calculations match Gleason's CAGE and Klingelnberg's KIMoS; therefore, the* ***reference topography*** *in HyGEARS is the* ***exact tooth definition****;*
2. ***HyGEARS designs gear set geometries****, i.e. the Dimension sheet and Machine settings for all HyGEARS supported geometries are calculated and a Summary is created;*
3. *Geometries can be* ***imported from Gleason SPA, KIMoS ND*** *and* ***BECAL ND*** *files;*
4. *Spiral bevel cutting processes such as Face Milling and Face Hobbing are* ***integral to HyGEARS****;*
5. *Geometry kinematics can be* ***analyzed unloaded and loaded*** *for contact and tooth fillet stresses;*
6. ***5Axis CnC machine Post-Processing****, i.e. the generation of a part program "machine ready", is integral to HyGEARS;*
7. *Part programs are* ***generated in reference to the exact tooth surface*** *definition (rather than an interpolated surface as is the case with other CAM softwares);*
8. *Part program generation is* ***based on a wide range of user selected cycle features****;*
9. *Any* ***5Axis CnC machine architecture*** *can be accommodated; current architectures include "AB", "AC", "BA" and "BC";* ***any controller can be accommodated****; current controllers include GCodes, Siemens, Heidenhain, Okuma, Fanuc and Mazak;*
10. *Part programs can be in* ***Machine coordinates, Work piece coordinates*** *with axis angles, or Work piece coordinates with tool axis vector (****Traori, TCPM, TCP and TCPC****);*

Summary

11. *Users can **define their own tool box** for Face Mill, CoSIMT, End Mill, Ball Mill and Probe tools;*
12. *Cutting Cycles include **Slot by Slot** and **Flank by Flank**, both for tooth flank and fillet; Toe, Heel and Tip chamfering is available;*
13. ***Animations and single stepping** allow the visualization of tool movements and the verification of tool paths and possible interference;*
14. *A "Metrics" function gives an **estimate of the deviations** between the theoretical tooth flank and the "flats" and "peaks" created by the discrete movements of the tool; thus, the # of depth wise and face width steps can be adjusted to **optimize quality and cycle time**;*
15. ***Toe and Heel clearances** allow smooth tool entry and exit, and full speed tool plunge;*
16. ***"Stock" allowance** is available for roughing and finishing;*
17. *The **"Roughing mode"** allows to quickly remove material before the finishing operation;*
18. ***"Operations"**, including all user selections for a given task, may be saved for later re-use; **"Processes"** allow the organization of several Operations in 1 file;*
19. ***Closed Loop** (i.e. Corrective Machine Settings) is **integral to HyGEARS** and allows the seamless manufacture of gears to the **required topography and tolerances**.*
20. *The **HyGEARS** Closed Loop corrections match (and in some respect are better than) those of Gleason's GAGE.*

HyGEARS covers just about all your needs for the design and manufacture of gears.