# Design, Analysis and Manufacturing of Gears

# HyGEARS V 5.0 Training

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# What You See Is What You Get

HyGEARS, THE GEAR PROCESSOR, was developed to help Spiral-Bevel and Hypoid gear designers and manufacturers reduce production time while increasing the quality of their products.

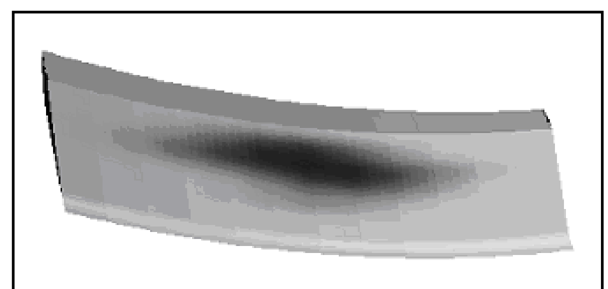
HyGEARS may also be used for the analysis of internal and external Spur and Helical gears, Straight bevel gears, Coniflex bevel gears, Hirth couplings, and Face gears.

HyGEARS is built around an advanced Graphic User Interface, which simplifies the operations and the understanding of the results.

All results are given in WYSIWYG mode which means that, in HyGEARS, *what you see is what you get.*

Measured Contact Pattern

HyGEARS' Simulation



# Training Outline

- General presentation of HyGEARS
- Vector simulation of gear manufacturing processes
- Tooth Contact Analysis (TCA)
    - Ease Off Surface
    - TCA, Transmission Error and the Contact Pattern
- Numerical Contact Pattern development
- Cutting processes and machines
- Software calibration
- HyGEARS Graphic User Interface (GUI):
    - Starting HyGEARS
    - Parent Window
    - Display Modes
    - Child Windows
    - Graphic controls
    - Context sensitive Help
    - Geometry Summary editor
    - V-H Settings
- Creating a New Geometry; Spiral bevel / hypoid, Coniflex Spur. Helical, Face gear, Beveloid, Straight bevel
- Production Control: Corrective Machine Settings (Closed Loop) / Reverse Engineering
- 5Axis CnC Manufacturing
- Graphic Display Functions
    - Teeth and Machines: geometry, 5 Axis CNC manufacturing
    - Kinematics: TCA, LTCA
    - Measurement: target file, analysis, Corrective machine settings, Reverse engineering
    - 2D Graphs:
    - FEA meshing; Finite Strips meshing
- Addendums

# Strengths and limitations

**Main HyGEARS features …**

- 3D displays throughout;
- Internal architecture flexibility allows expansions;
- Many different ways to arrive at a given goal;
- Fast and easy to use.

**Some HyGEARS limitations …**

- Design of face-milled hypoid gears limited to 90° shaft angle;
- Design of face-milled spiral-bevel gears limited to ~ 25-140° shaft angle;
- Design of face-hobbed hypoid and spiral-bevel gears not allowed at this time (import of existing summaries allowed);

# HyGEARS Customers

*1994-2004*

**Japan**:
- Yutaka Seimitsu Kogyo
- Mitsubishi Motors
- Toyota Motor Corp.
- Subaru Motors Corp.
- Subaru Central Labs (Tokyo)
- Hino Trucks
- Honda Motors
- Showa Gears
- Daihatsu

**Korea**:
- KIA Motors
- KIA Heavy Industries

**Europe**:
- Romax Technology (UK)

**USA**:
- DANA Corp.
- American Axle and Manufacturing
- GM
- Linamar

*From 2013 -*

**China**:
- SEW Eurodrive (Tianjin)
- miniGears (Suzhou)
- Harbin Marine Boiler TRI

**Europe**:

| | |
|---|---|
| Drive System Design | (UK) |
| Reliance Precision Ltd | (UK) |
| Spirotec | (France) |
| Robert Bosch GmbH | (Germany) |
| Neugart GmbH | (Germany) |
| PTR-TEC | (Germany) |
| BMW | (Germany) |
| EWS Weigele GmbH | (Germany |
| DEPRAG | (Germany) |
| FZG | (Germany) |
| ZG Hypoid | (Germany) |
| Hoer Innovativ | (Germany) |
| MAN Trucks & Bus | (Germany) |
| Haas-Multigrind | (Germany) |
| ZG Hypoid | (Germany) |
| Eppinger Gears | (Germany) |
| EWS Weigele | (Germany) |
| Sandvik GmbH | (Austria) |
| GB Ricambi | (Italy) |
| Breton Spa | (Italy) |
| GB Gearboxes | (Italy) |
| MdM Mecatronics | (Italy) |
| Tecnogear | (Italy) |
| Kumera Drives | (Finland) |
| GKN Driveline | (Sweden) |

**USA**:
- EMCO Gears
- Dynamic Engineering
- Rexnord Geared Products
- GMT Gears
- DTD Precision
- Perry Technology Corp
- Afton Chemical

**India**:
- Bevel Gears India
- Shivam Autotech
- Eppinger Tools
- Bharat Forge Limited

**Israel**:
- Precision Products

**Japan**:
- Takeda Trade Co.

**Canada**:
- Usimax Inc

# HyGEARS currently defined CnC machines

| |
|---|
| DEPO |
| DMC 65H DuoBlock |
| DMC 125FD |
| DMF 260 HT-C |
| DMG CTXBeta-1250TC |
| DMG CTXBeta-2000TC |
| DMG CTXBeta-3000TC |
| DMG 65 - 840D |
| DMG 65 MonoBlock |
| DMG MORI NTX 2500 |
| DNM 200 (Doosan) |
| DMU 65 - 840D |
| DMU 50 |
| DMU 100 MonoBlock |
| DMU 125P |
| EMCO Hyperturn 65 |
| Fanuc Robodrill T21 |
| Fanuc V-8D |
| Fryer TR-60 |
| GroB 350 |
| Haas Horizon |
| Haas Multigrind CB |
| Haas VF3 |
| Heller MC 16 |
| Hermle C22U |
| Hermle C30U |
| Hermle C40U [Siemens] |
| Index G220 |
| Juaristi TXH5K-MGX12 |
| Kitamura Mytrunnion 5 |
| MAG NBV700 |
| Makino DA300 |
| Makino PS95 |
| Matec 30-HV |
| Maxima 1600 [Breton] |
| Mazak IG e-500H |
| Mazak Integrex i-500S |
| Mazak Integrex i200 |
| Mazak Integrex i200ST |
| Mazak Variaxis j500 |
| Mazak Variaxis 630-5X II T |
| Mazak Integrex I-630V/6S AG |
| Mikron GF |
| Mitsui HU63A-5X |
| Mori NT3100-BC |
| Mori NT4200 |
| Mori NT4250 / C1 |
| Multus B400 |
| NMV 3000-AC |
| Okuma MU-500VA |
| Okuma MU 4000V |
| Okuma MU 5000V |
| Okuma MU 6300V |
| PAMA SPEEDRAM 2000 |
| Phoenix 175-HC |
| Phoenix 250-HC |
| Phoenix 250-HC [TGSN] |
| Rafaello R5A.6 |
| Reiden BFR22 |
| Schneeberger NGM |
| SMX2600S (Doosan) |
| Spinner U5 1530 |
| Ultrix [Breton] |

Machines are easily added if the requested one is not already in the list.

Besides, an existing machine may be modified to suit a specific user's needs and then a machine variant is created with a different name.

The supported controllers are:

- Fanuc
- Okuma
- Siemens
- Heindehein
- Mazak

# Short HyGEARS history – the Early Days

1983-1985: Master's Thesis – Development of a 3D CAD package to analyze spiral-bevel gears

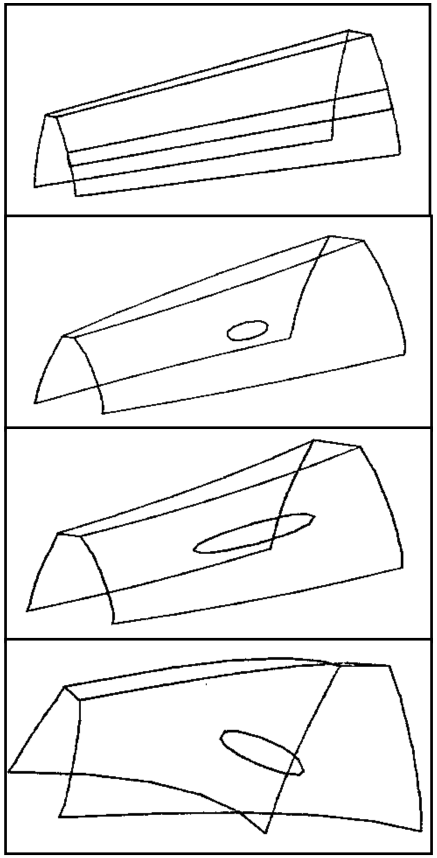
1985-1987: PhD Thesis – Optimization of the kinematics of spiral-bevel gears

1989: DEC VAX-Station Version

1991: ***1st Windows 3.1 Version*** (VB3 + Fortran)

1992: LTCA – Loaded Tooth Contact Analysis

1993: 1st Meeting with Yutaka Seimitsu, Japan; Calibration on Yutaka and Gleason machines



# Short HyGEARS history – Coming of Age

1994: 1st order Corrective machine settings; JIMTOF

1995: ***HyGEARS V 1.0*** Single precision

1996: Reverse Engineering

1997: 2nd and 2nd+ order Corrective Machine Settings

1999: ***HyGEARS V 2.0*** Single+double precision

2000: Contact Elements, Grid output, Spur/Helical, …

2003: Face Hobbing Simulation

2006: Lapping Simulation and Prediction

2007: ***HyGEARS V 2.5***

2010: Net-shape Straight Bevel Gears

2011: ***HyGEARS V 3.0*** Coniflex

Universal 5 Axis CnC Interface

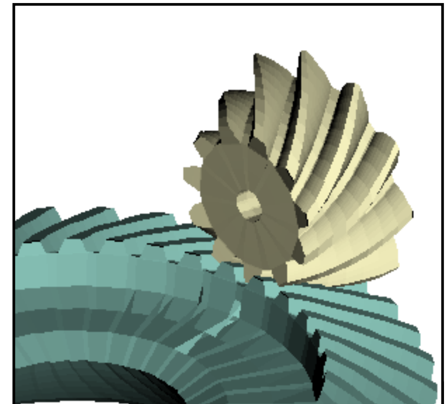
2012: ***HyGEARS V 4.0*** Double precision

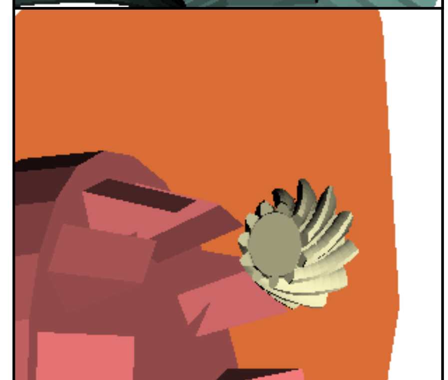
VS 2010 + .NET 4.0

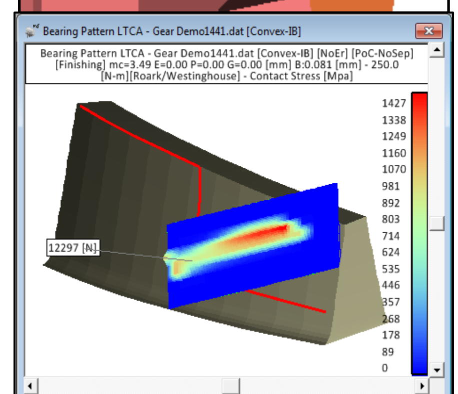
~390,000 lines of code

2021: ***HyGEARS V 5.0*** 64 Bits; GPU 3D graphics

VS 2019 + .NET 4.7

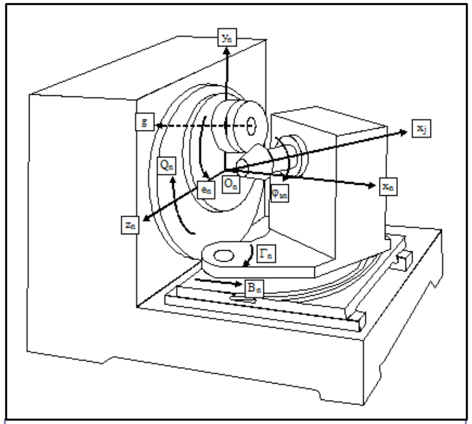




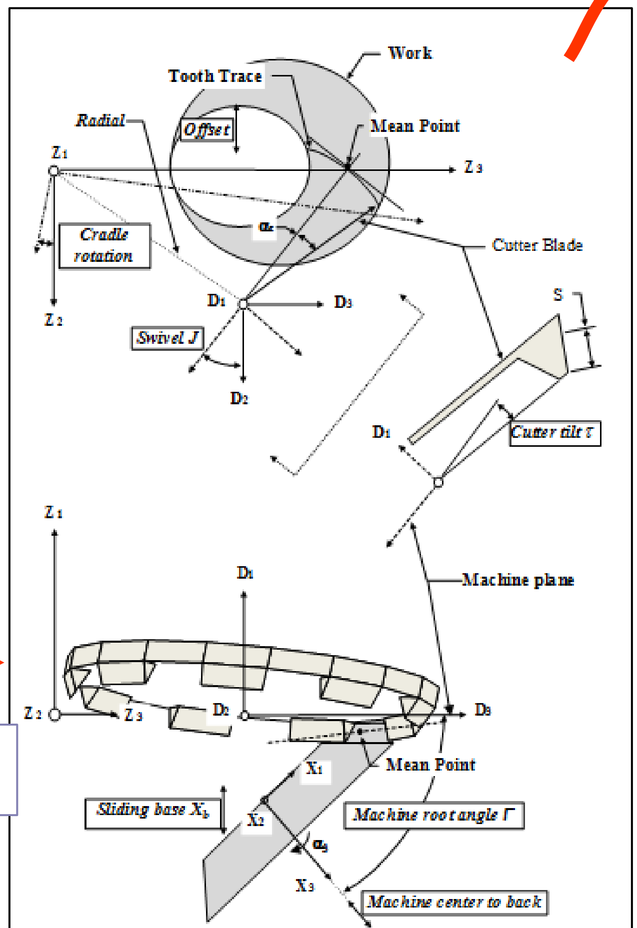


# Vector Simulation – A Short Primer

*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.*

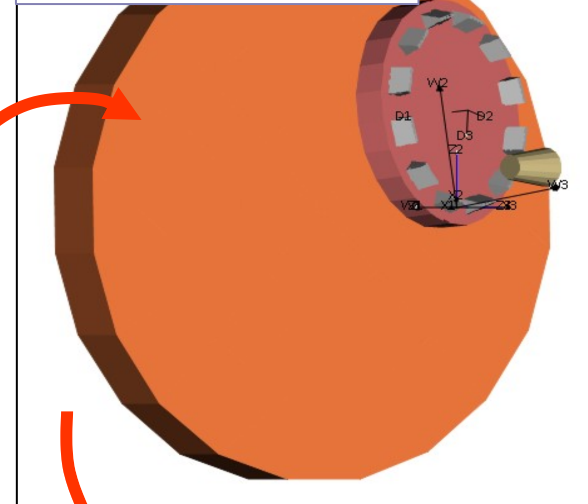


***1:** The reference machine is discretized in a series of ref. frames*

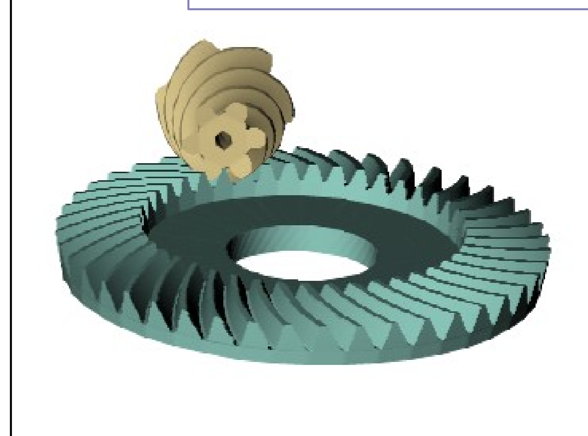



***2:** The Vector Model uses the ref. frames of the discretized machine*

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



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



# HyGEARS Vector Model

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

Point on tooth flank:

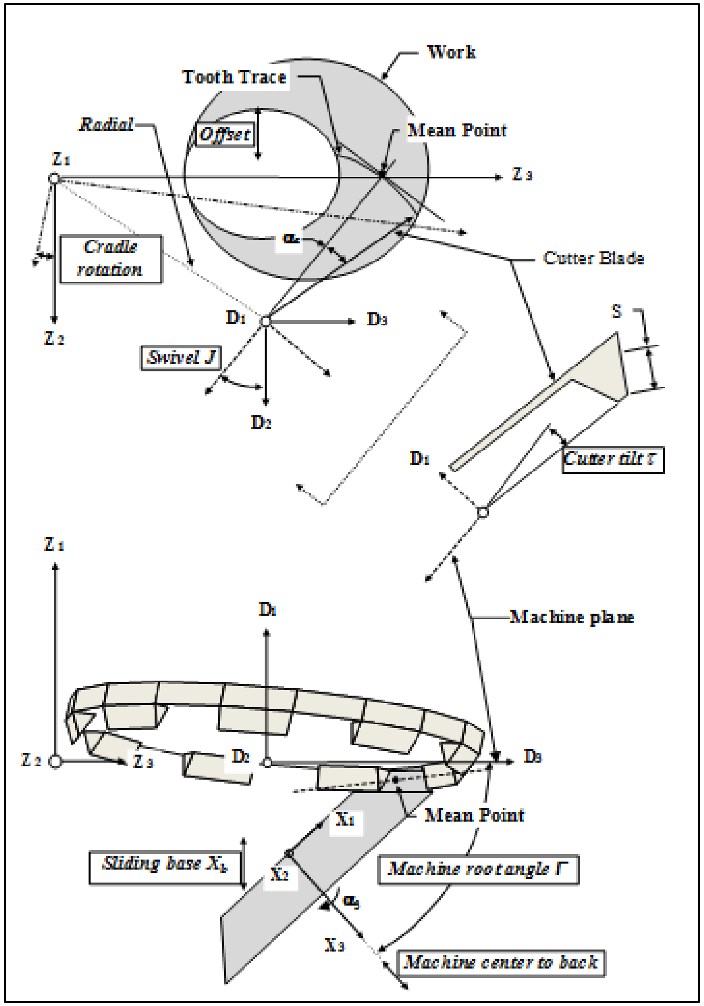
$$D = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha c) & \sin(\alpha c) \\ 0 & -\sin(\alpha c) & \cos(\alpha c) \end{bmatrix} \begin{bmatrix} S\cos(\phi) \\ 0 \\ (R \pm S\sin(\phi)) \end{bmatrix}$$

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

Normal vector 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 Vector Model

*Higher order changes can be superimposed to the tool and work piece movements in order to achieve specific kinematic behavior.*

## *Higher order cutting changes*:

- Modified Roll

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

| | | |
|---|---|---|
| where: | $L_{1m}$: | modified cradle angle |
| | $\alpha_3$: | 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 (Gleason notation) |
| | 24E: | 4th Order parameter (Gleason notation) |
| | 120F: | 5th Order parameter (Gleason notation) |
| | 720G: | 6th Order parameter (Gleason notation) |

# HyGEARS Vector Model

*Higher order cutting changes*:

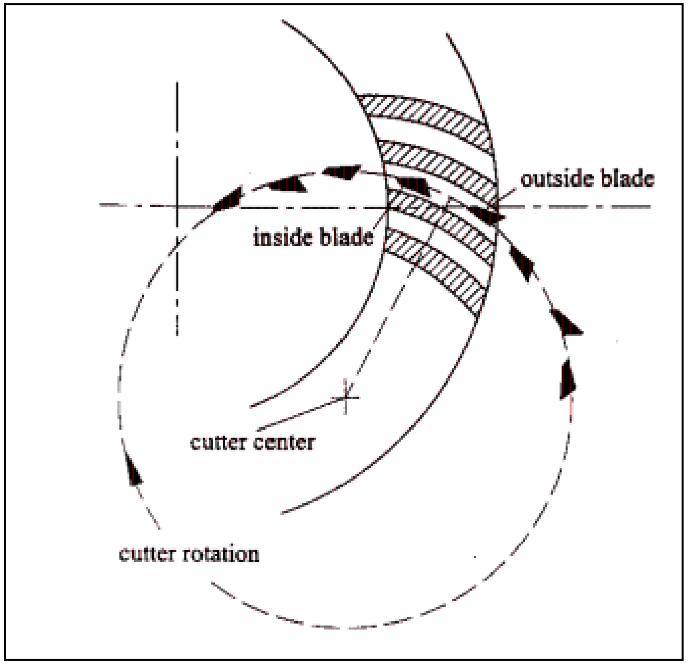
- Helical Motion

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

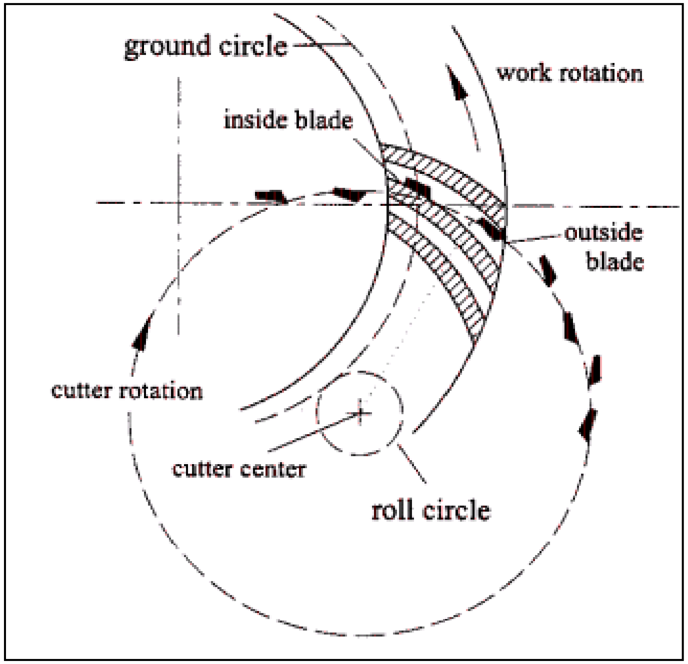
| | | |
|---|---|---|
| where: | $X_{bm}$: | modified sliding base |
| | $\alpha_3$: | work piece roll angle |
| | $R_r$: | ratio of roll, cradle to work piece |
| | $C_r$: | cradle ref. position |
| | 1st : | 1st Order parameter |
| | 2nd : | 2nd Order parameter |
| | 3rd : | 3rd Order parameter |
| | 4th : | 4th Order parameter |
| | 5th : | 5th Order parameter |
| | 6th : | 6th Order parameter |

# HyGEARS Vector Model – Face Milling and Face Hobbing

*Simulation of Face Milling and Face Hobbing processes supported for Spiral Bevel gears.*




*Face Milling (single indexing)*

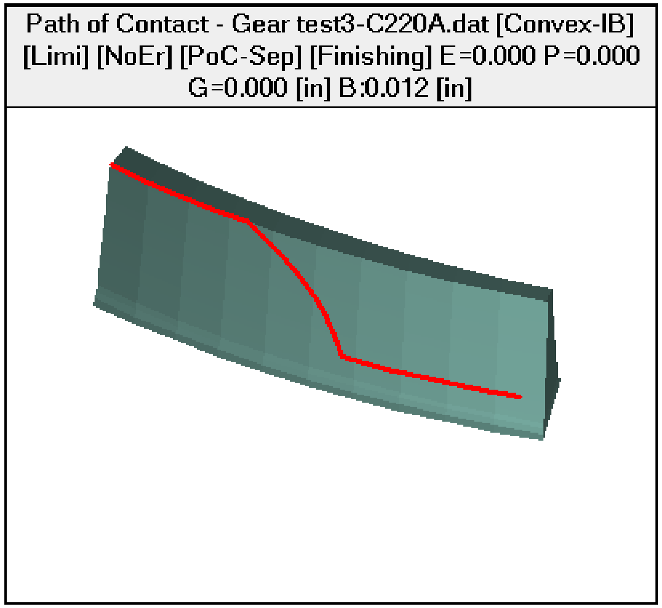


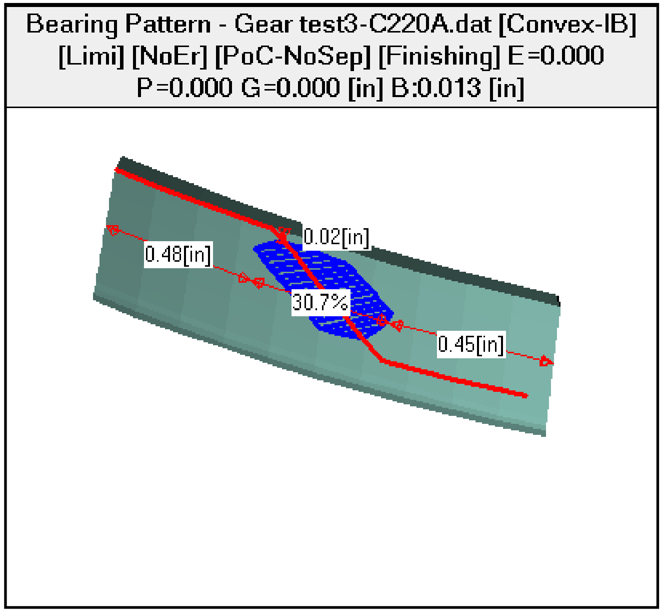

*Face Hobbing (continuous indexing)*

# Tooth Contact Analysis (TCA)

The basis of all kinematics in HyGEARS is the Tooth Contact Analysis, or TCA, whereby the location of the Path of Contact is calculated, red line - left figure below, which leads to the Contact Pattern, blue patch - right figure below.

The location and dimensions of the Contact Pattern can be viewed in several ways, and may be optimized according to the user's wishes using the Contact Pattern Development functions. ("CPat" function button)

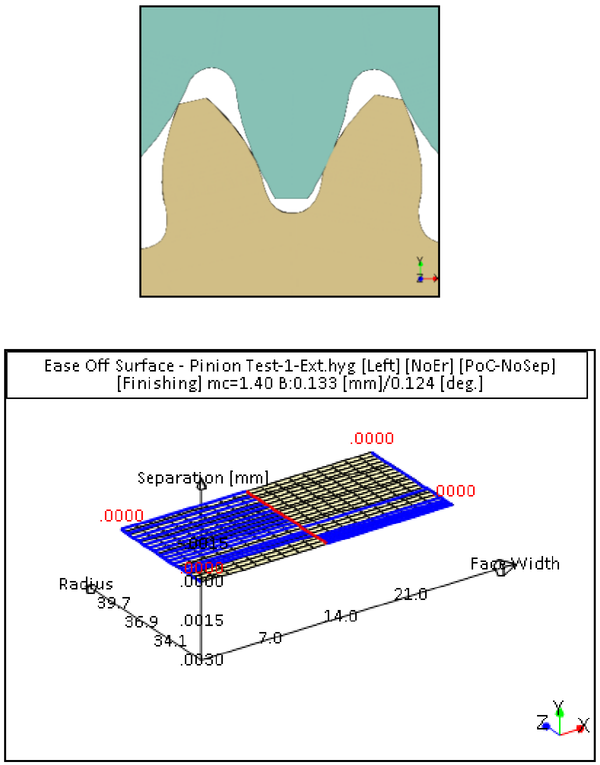


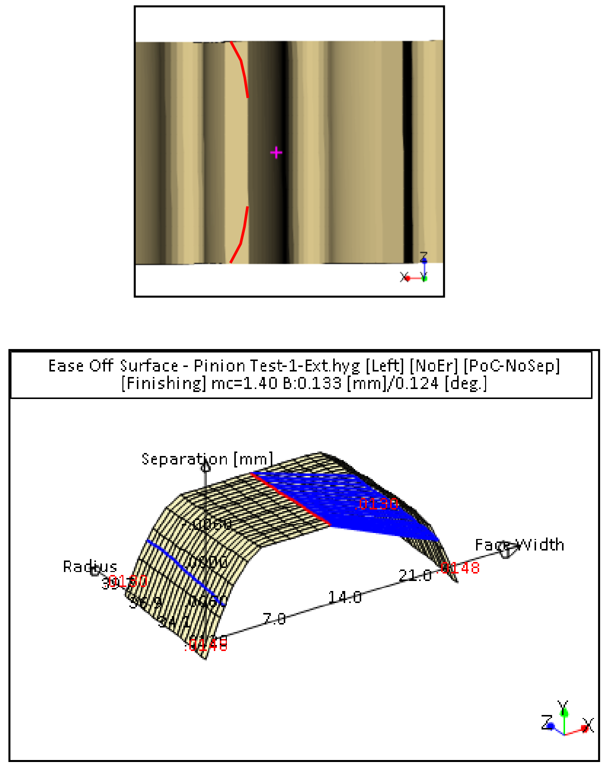
# The *Ease Off* Surface

The Ease Off Surface represents tooth to tooth separation as meshing proceeds.

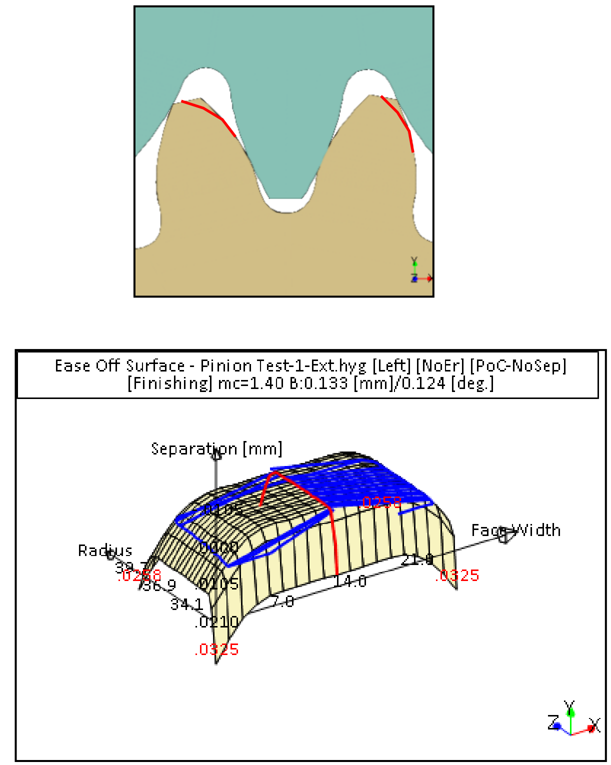
It can be seen as a measure of the ***discrepancy in conjugacy*** between 2 meshing surfaces.




**1) Spur gear pair – basic**




**2) + crowning**



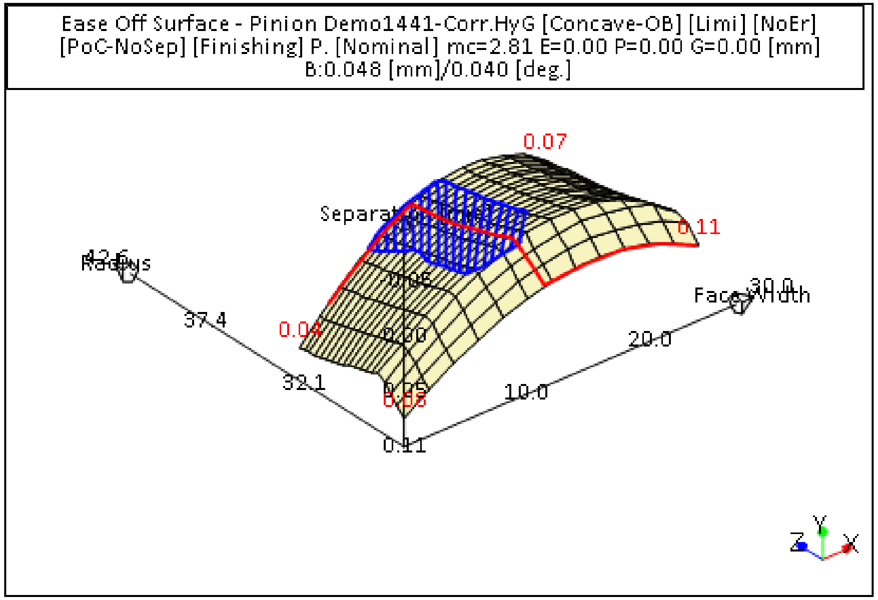

**3) + profile modification**

# The *Ease Off* Surface / 2

1. The *Ease Off* is displayed in ref. to the Pinion tooth:

   The displayed elements are:

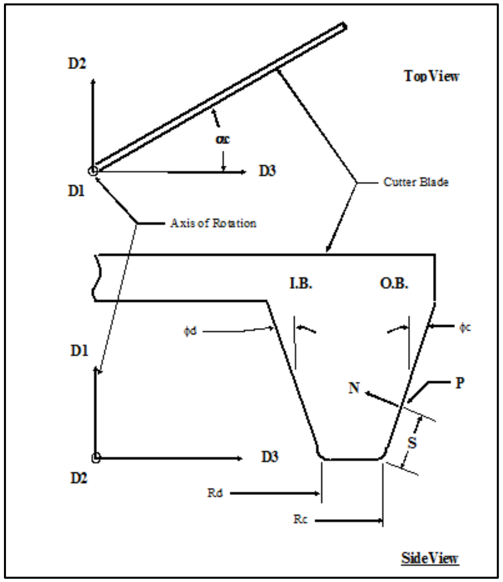
   - Contact Separation Axis
   - Face Width Axis
   - Radial Axis
   - *Ease Off* surface, or discrepancy in *conjugacy*
   - Path of Contact (PoC – red line)
   - Contact Pattern (Blue patch)
   - Edge values (0.11, 0.07, etc.)



# The *Ease Off* Surface / 3

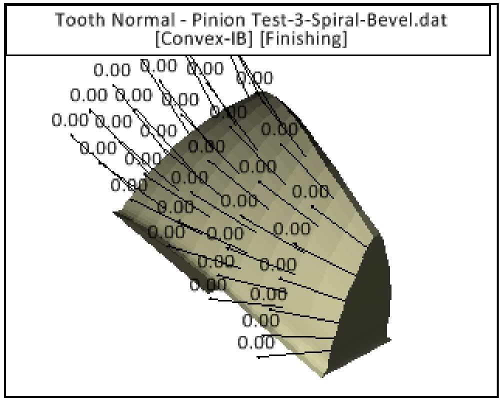
2. The pinion and gear tooth surfaces are digitized, i.e. the *implicit* surface equations are solved; therefore, on each tooth several points are known by:

   – Surface parameters αc, S, α3
     - αc: cutter blade angular position
     - S: position of a cutter blade to work contact point
     - α3: work piece roll angle




   – Coordinates      X, Y, Z

   – Normal vector    Nx, Ny, Nz

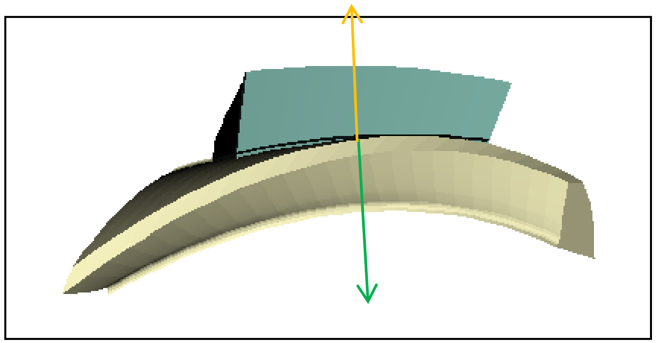


# The *Ease Off* Surface / 4

3. Contact points are calculated at each tooth flank coordinate;

   – A contact point is obtained when:
     - The pinion and gear *Coordinates* are equal in a common ref. frame;
     - The pinion and gear *Normal* are equal and opposed in a common ref. frame;

   – The following are obtained at each contact point,
     - coordinates,
     - normal components,
     - tooth surface parameters (αc, S, α3) and
     - tooth rotation (θ3, ϕ3);



# The *Ease Off* Surface / 5

- An image of the *Ease Off* or *tooth to tooth meshing separation* is obtained by scanning the pinion and gear teeth for contact points;

- Using 1 ref. point, tooth separation is calculated as function of the T.E. multiplied by the contact radius on the gear at each contact point;

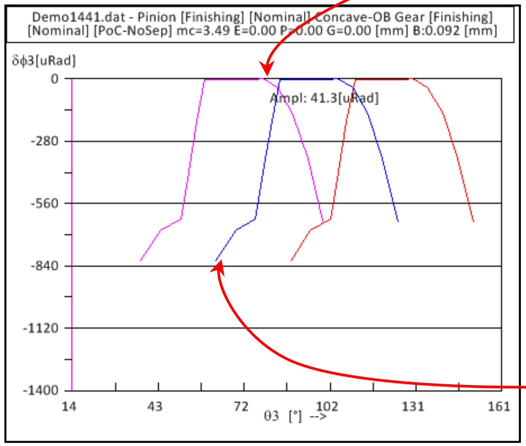
- T.E. is defined as : $\boxed{\delta\phi_3 = \phi_3 - \theta_3 m_g}$

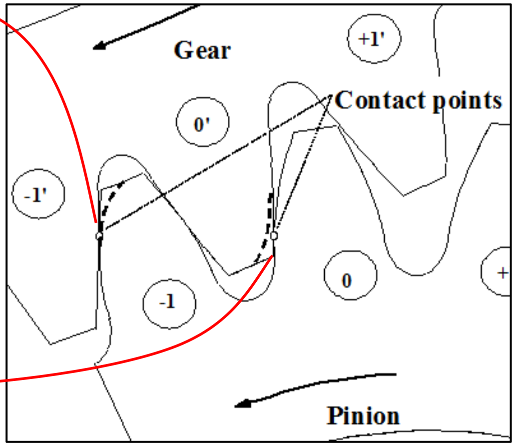
where: $\delta\phi_3$: T.E.

$\phi_3$: angular position of the Gear

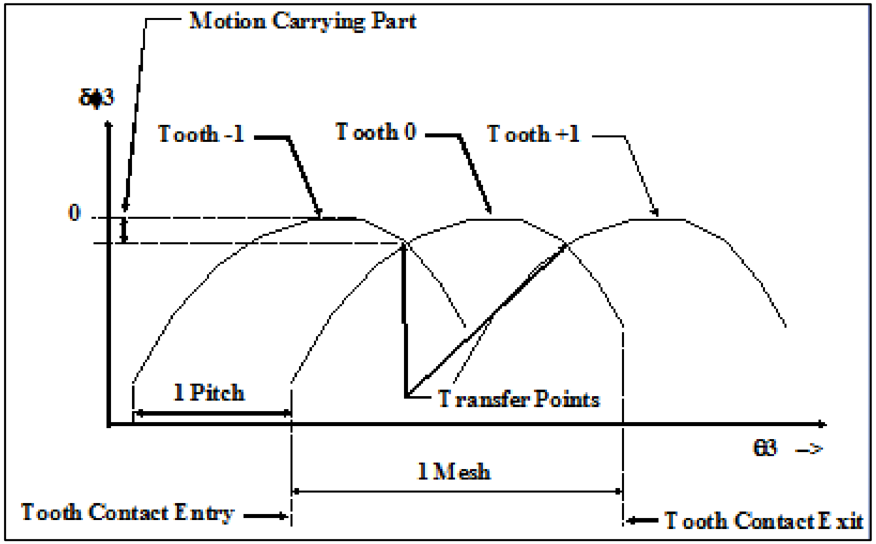
$\theta_3$: angular position of the Pinion

$m_g$: gear ratio



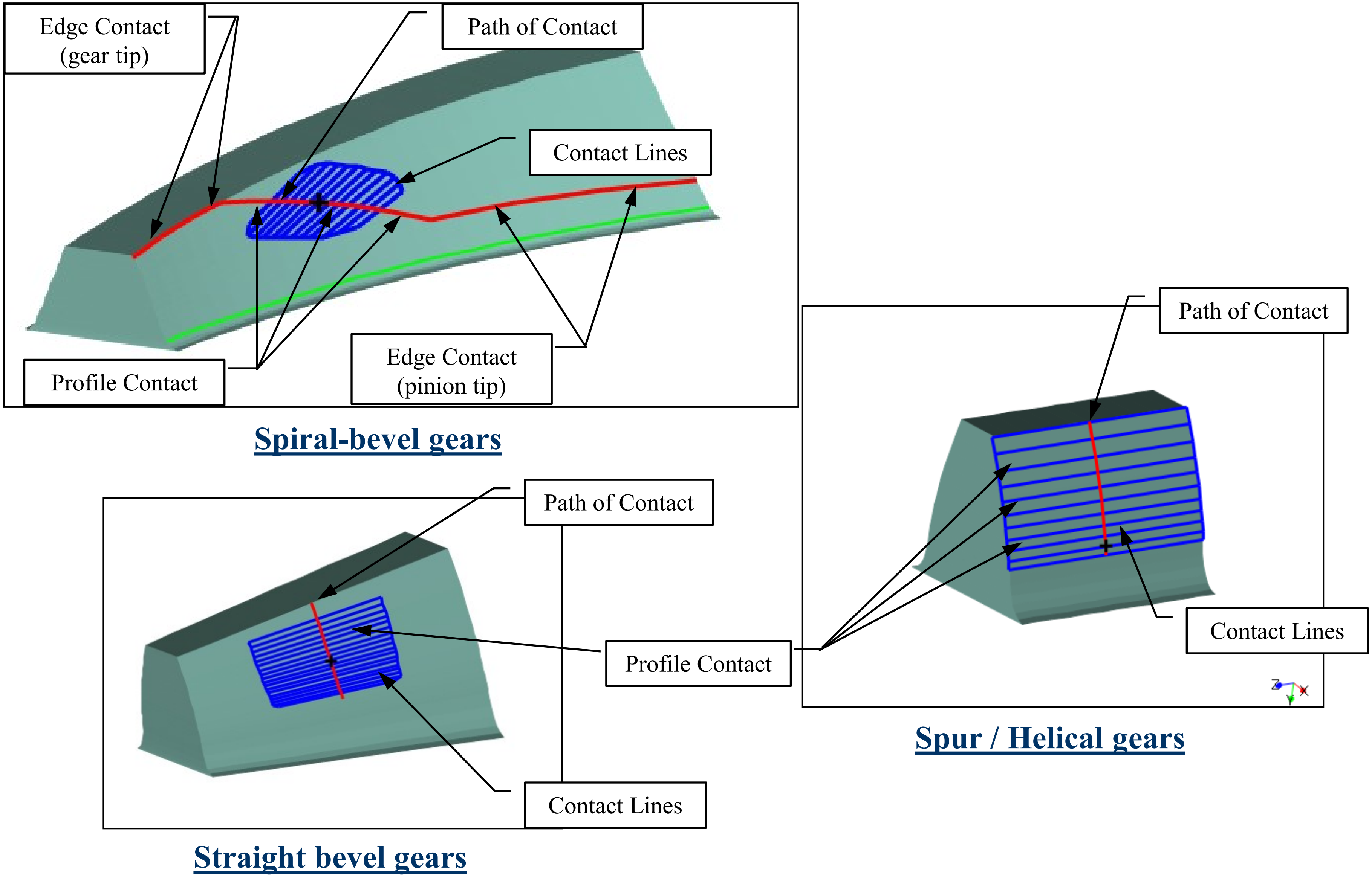
# TCA and Transmission Error



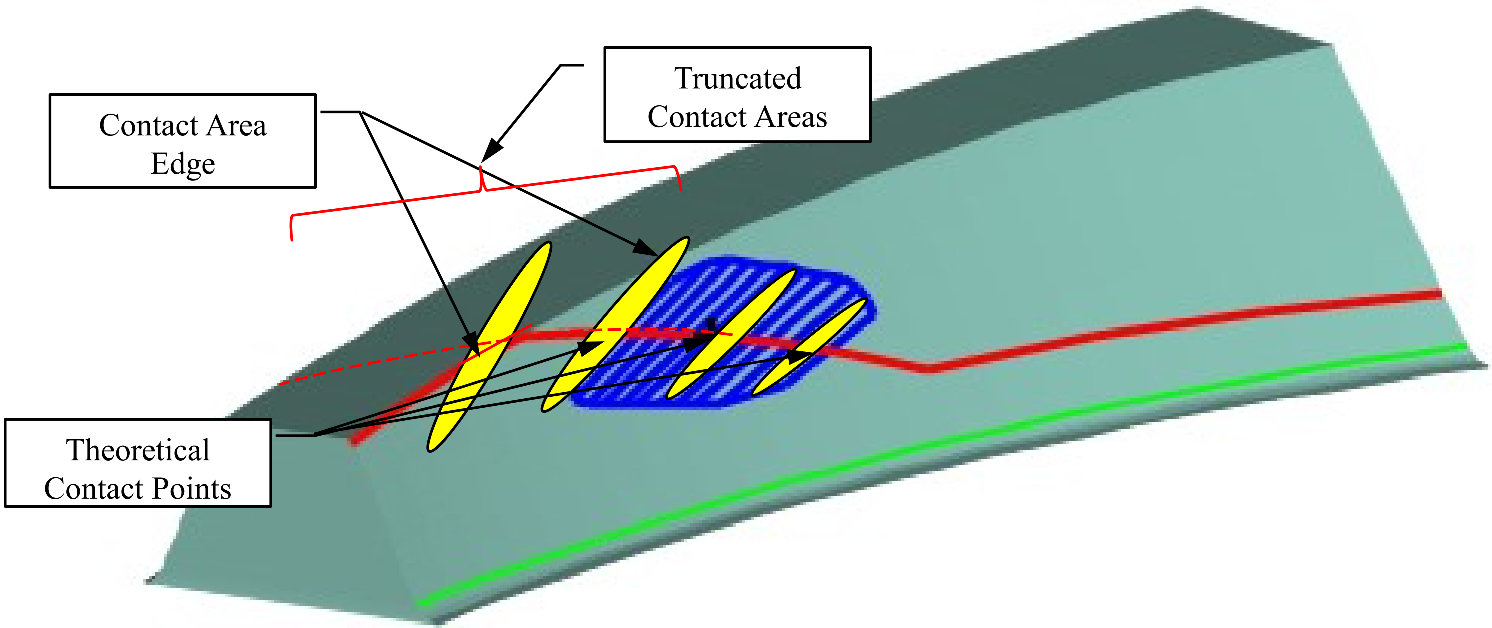

$$\delta\phi_3 = \phi_3 - \theta_3 m_g$$

| | |
|---|---|
| $\delta\varphi_3$ | is the gear angular position error, or Transmission Error (TE) 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. |

# TCA and Transmission Error / 2

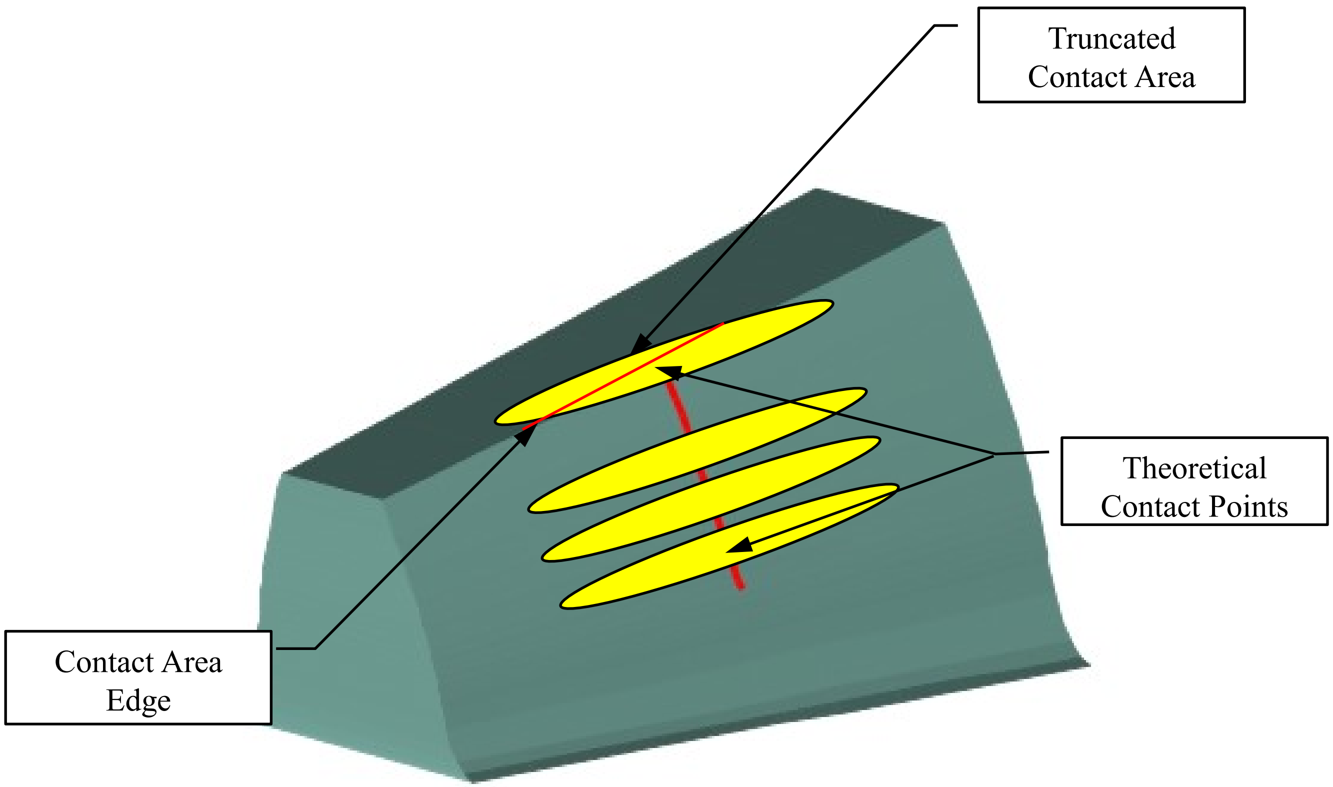


# TCA and Transmission Error / 3



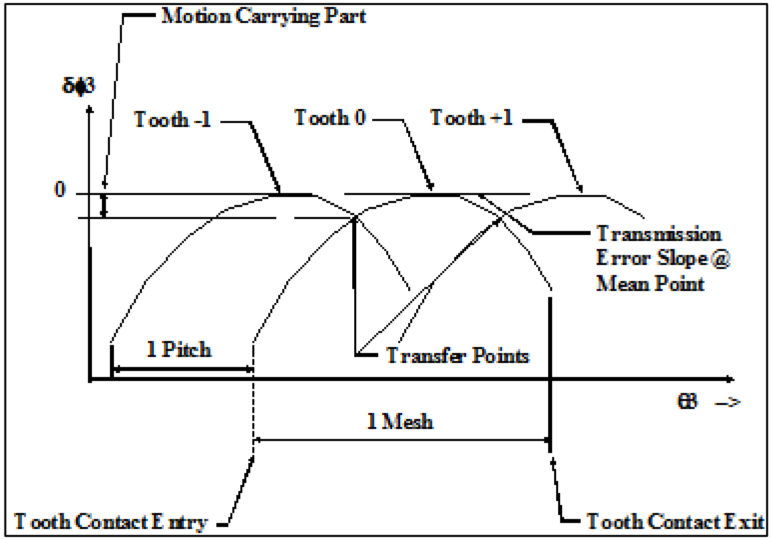

Tip Edge Contact: to be avoided

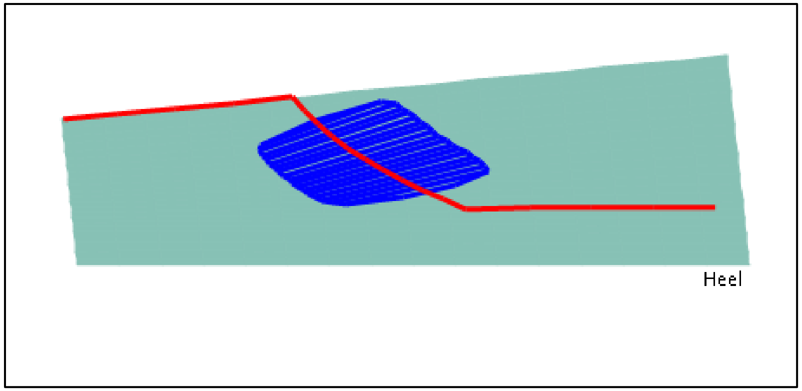
# TCA and Transmission Error / 4

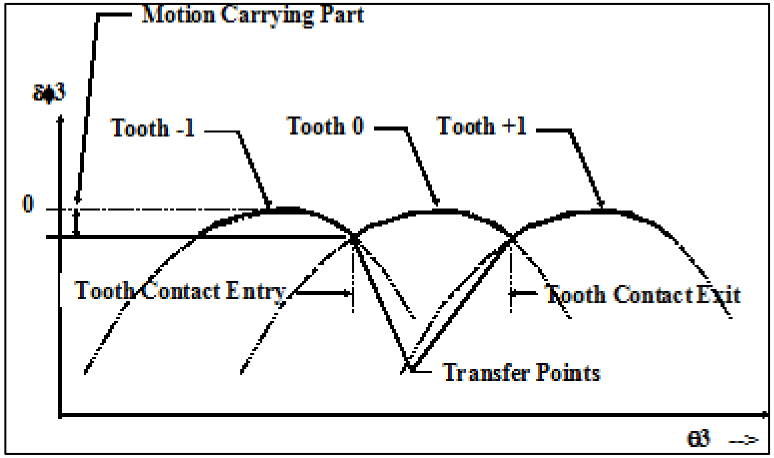



Tip Edge Contact: to be avoided

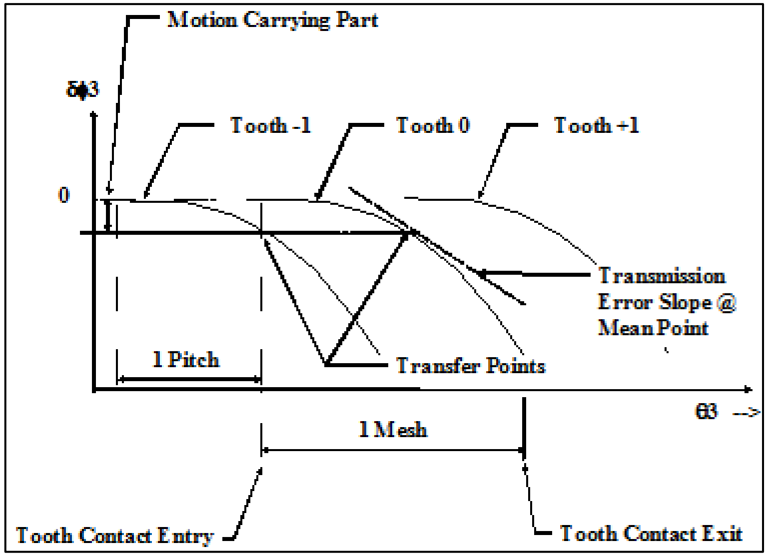
# TCA and Transmission Error / 5: Center CP

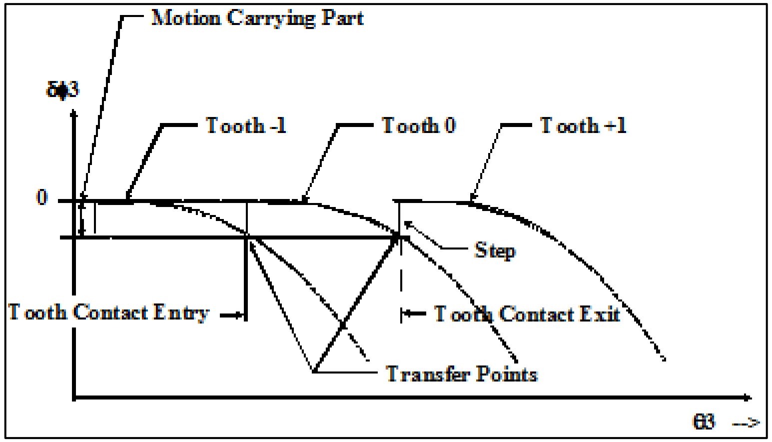


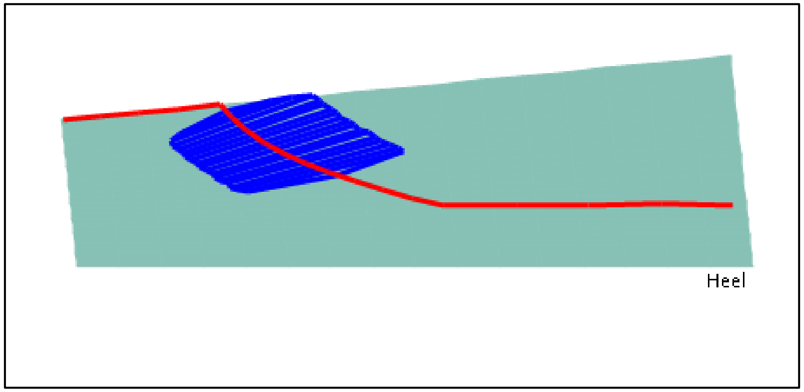



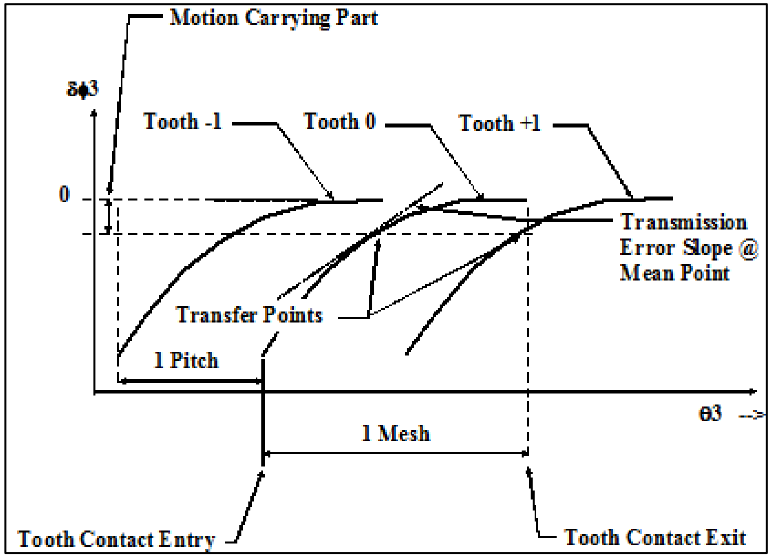
# TCA and Transmission Error / 6: High CP

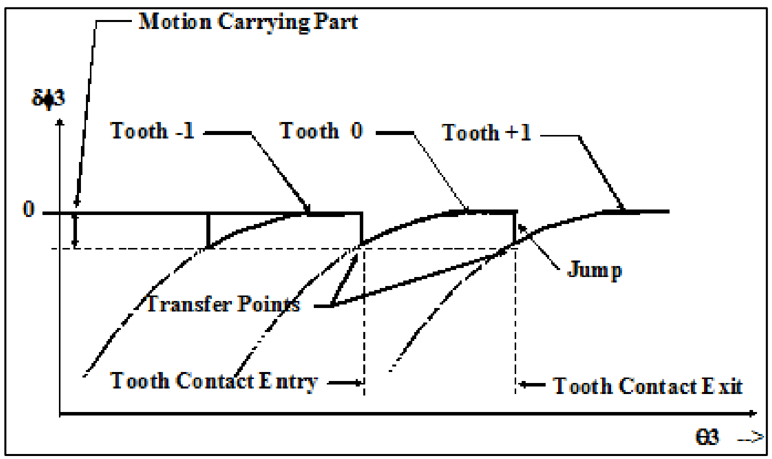


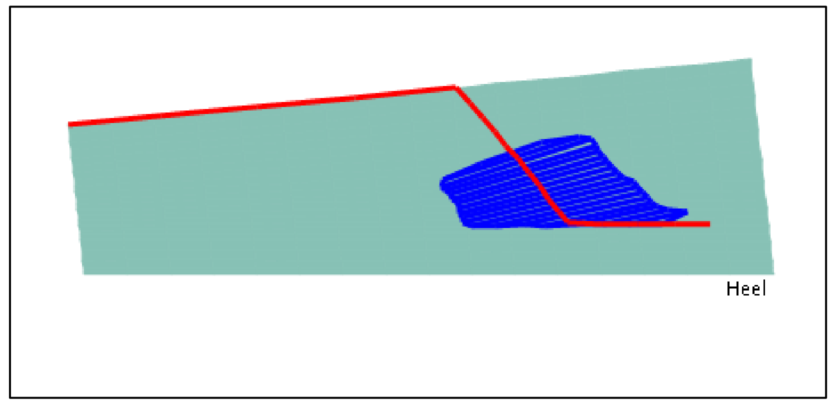



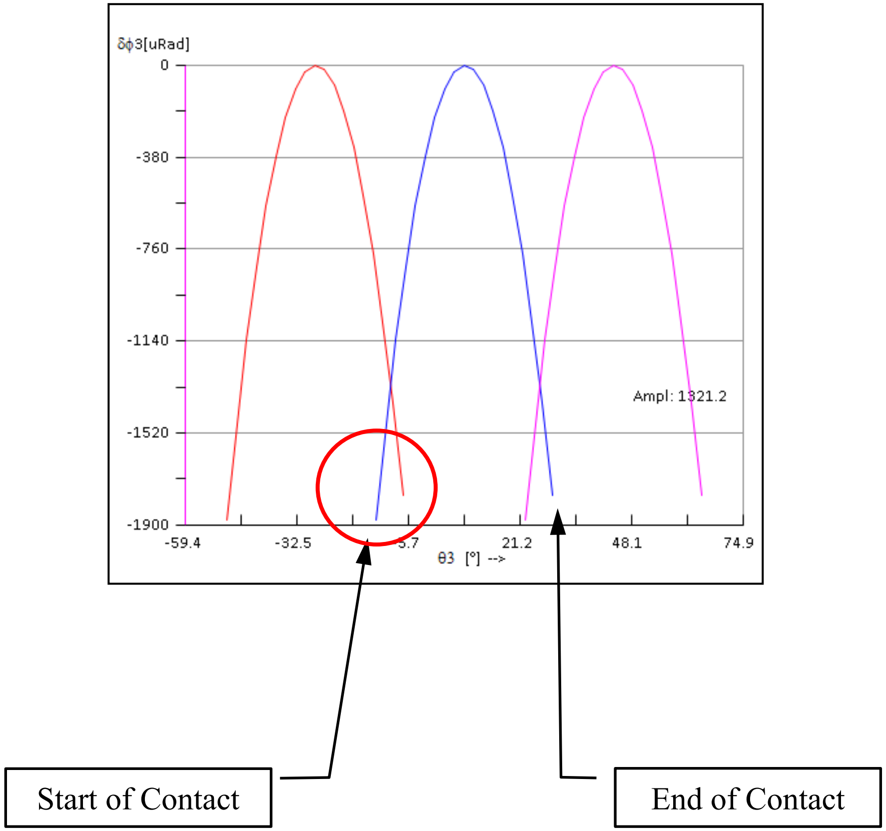
# TCA and Transmission Error / 7: Low CP

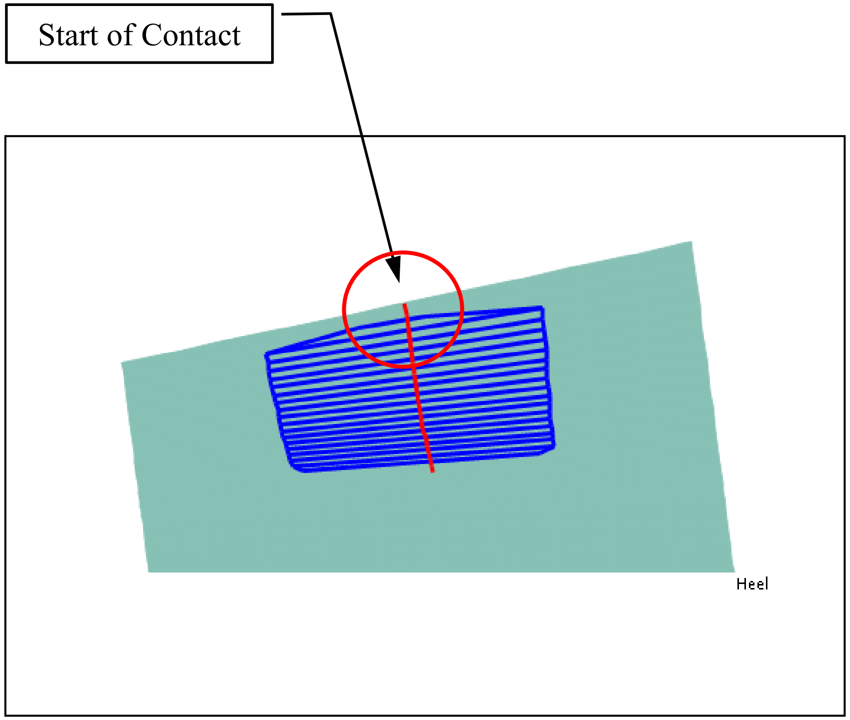


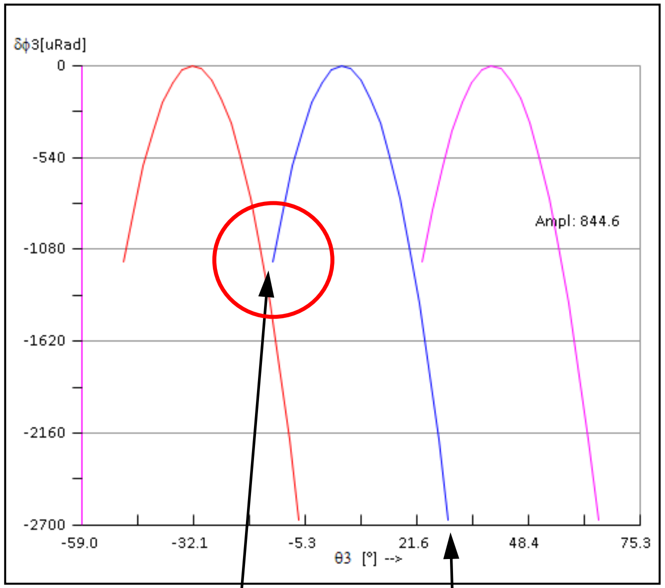
# TCA and Transmission Error / 8: Center CP

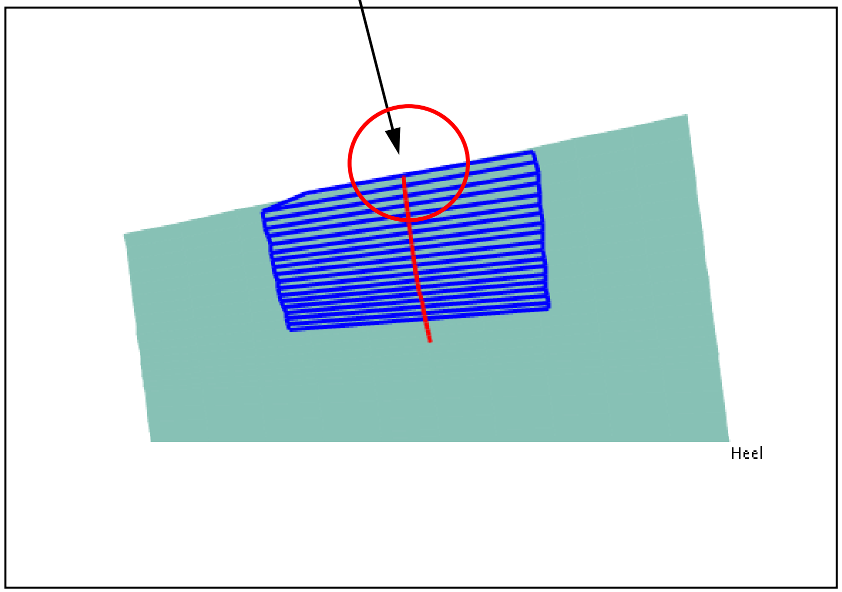


# TCA and Transmission Error / 9: High CP

Start of Contact



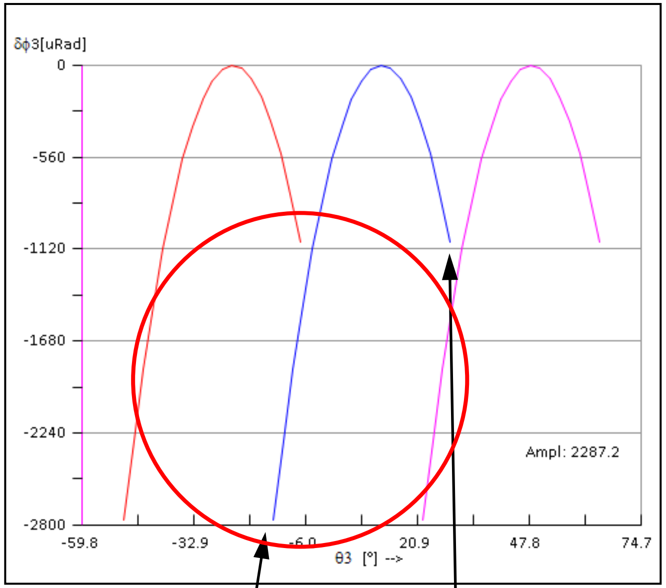



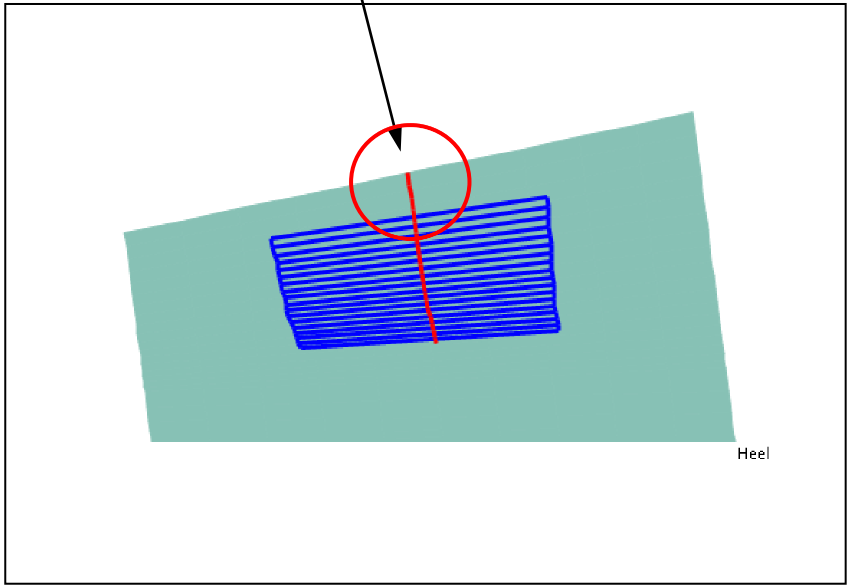

Start of Contact

End of Contact

# TCA and Transmission Error / 10: Low CP

Start of Contact

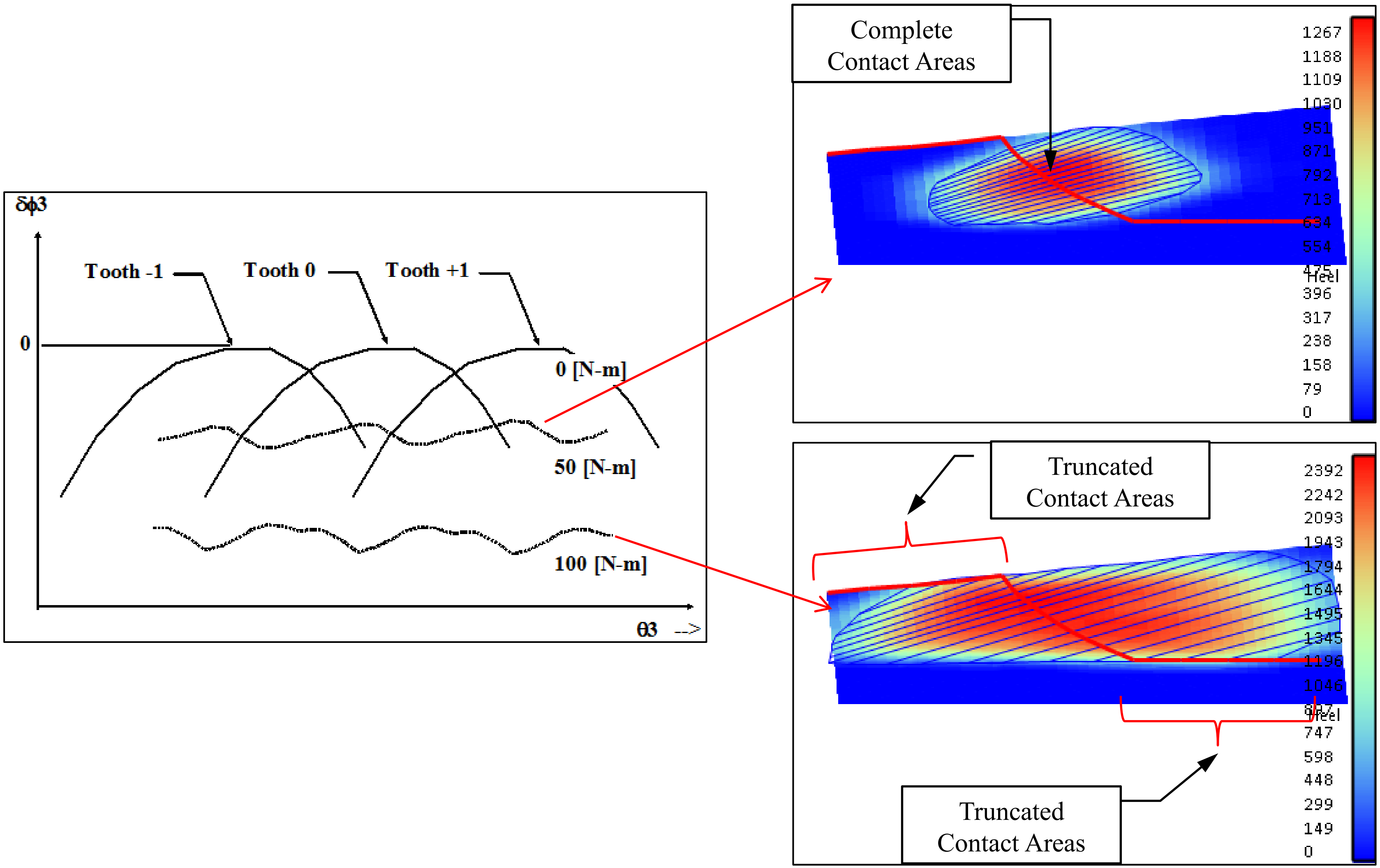


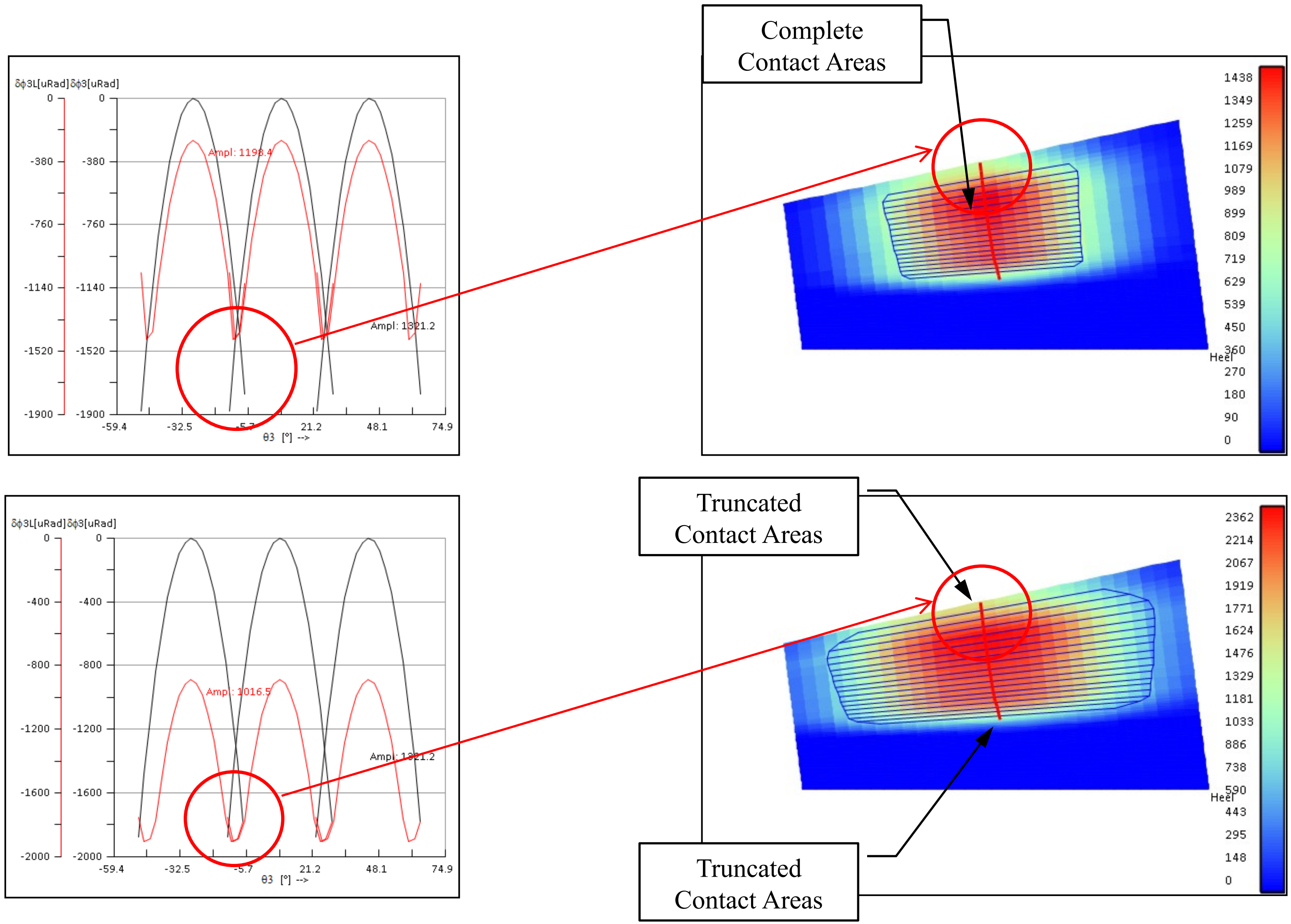

Start of Contact

End of Contact

# LTCA and Transmission Error: Shift in TE curve

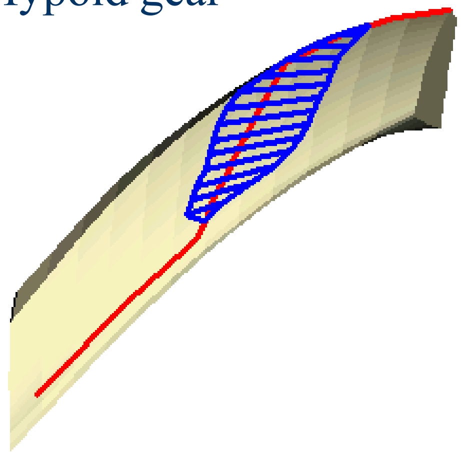


# LTCA and Transmission Error: Shift in TE curve

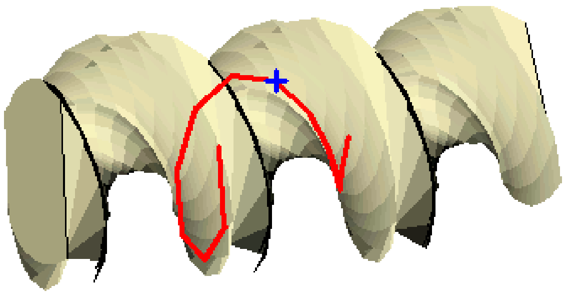


# Contact Pattern: Examples

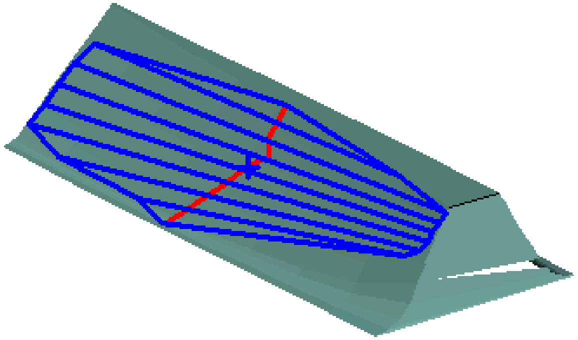
Hypoid gear



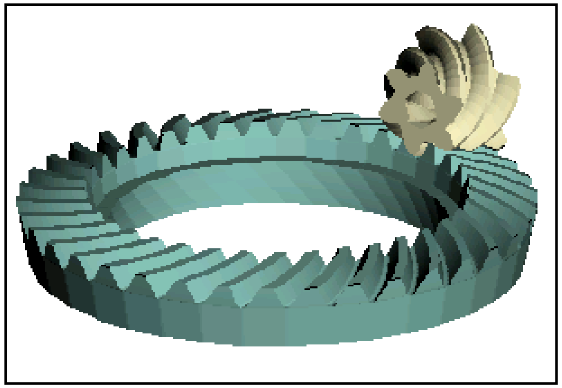
Worm gear

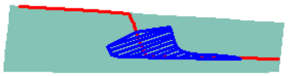
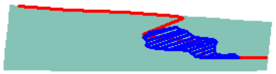
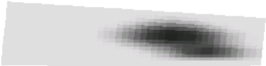
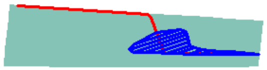
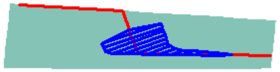
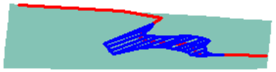
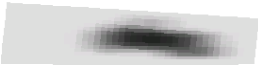
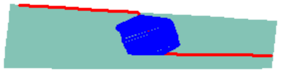
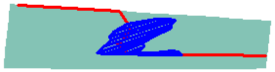
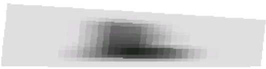
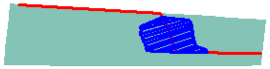
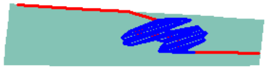
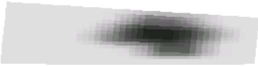
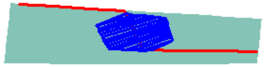
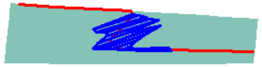


Face gear



# Example: Contact Patterns of an Existing Gear Set



| Tooth Pair | Measured | Simulated 1 (R.E.) | Simulated 2 (R.E. + ErrS) | Simulated 3 (R.E. + ErrS + Diff.) |
|---|---|---|---|---|
| P01-G01 |  |  |  |  |
| P01-G19 |  |  |  |  |
| P01-G33 |  |  |  |  |
| P04-G01 |  |  |  |  |
| P04-G19 |  |  |  |  |
| P04-G33 |  |  |  |  |

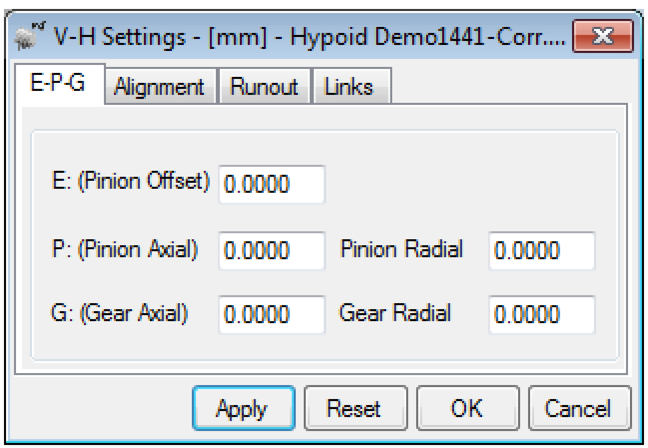
# EPG, Alignment, Shaft Angle Errors

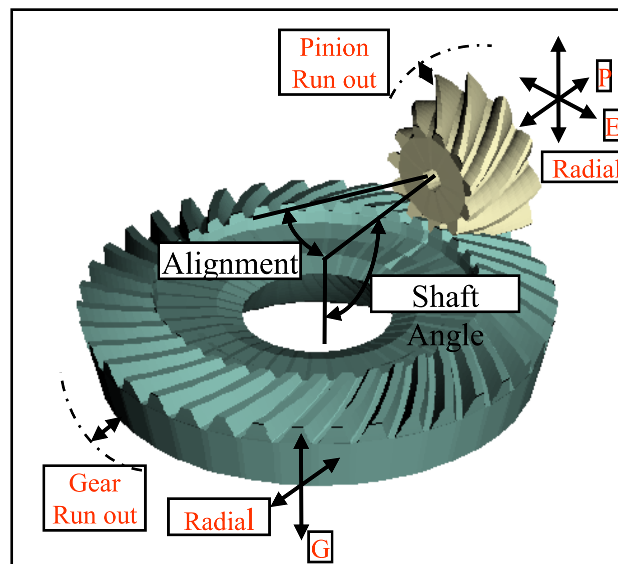
In TCA and LTCA, HyGEARS can account for positional errors in three directions: *pinion Offset "E", pinion MD "P" and gear MD "G"*.  Additionally, pinion and gear Radial may be used directly.

This feature is available for all HyGEARS supported gear types.

*Alignment, shaft angle error,  and gear eccentricity* can also be introduced to predict the behavior under load or in an actual gearbox.

The effects on TE, Contact Pattern and Load Sharing, may be investigated using the convenient V-H Settings Editor .



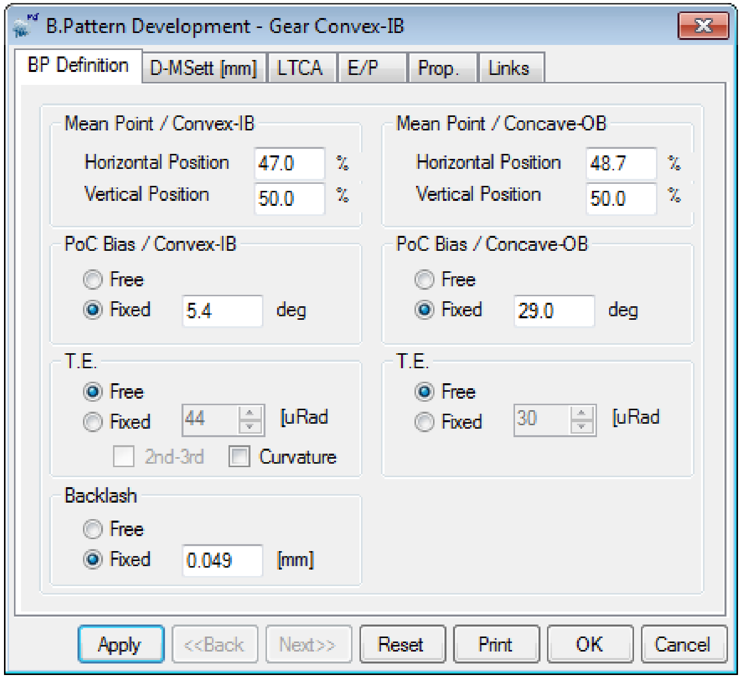
# Numerical Contact Pattern Development

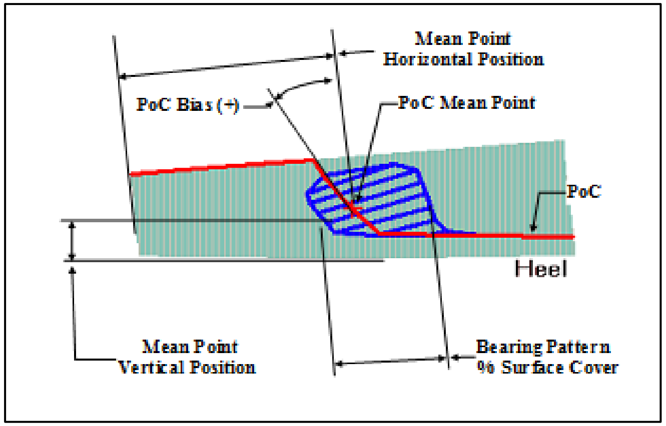
To develop a Contact Pattern, HyGEARS offers sophisticated functions where the *location and bias of the Contact Pattern can be specified.*

The amplitude of the TE curve can also be modified to accommodate specific operating conditions.

Contact Pattern Development can be done on

- Fixed Setting spiral-bevel gears,
- Modified Roll spiral-bevel gears,
- Duplex Helical spiral-bevel gears,
- SimplexT spiral-bevel gears,
- Cyclo-Palloid spiral-bevel gears,
- Face Hobbed spiral-bevel gears,
- Straight bevel gears,
- Coniflex bevel gears

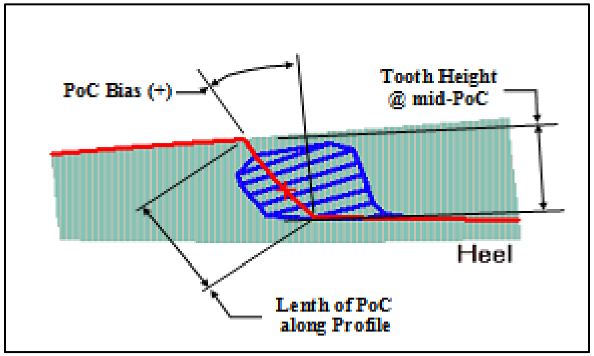


# Numerical Contact Pattern Development

Contact Pattern development is done in several steps:

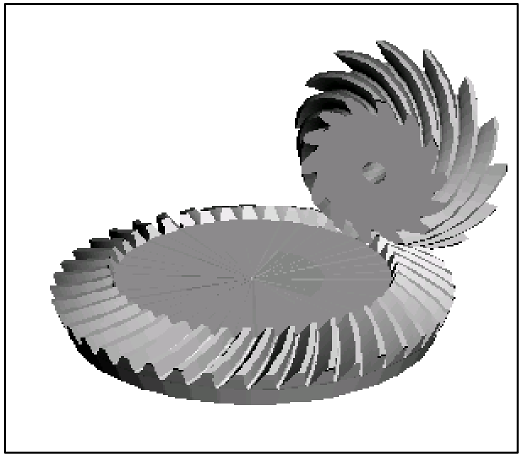
- The *Ease Off* surface is modified through changes in Pinion machine settings;
- The Gear member is either conjugate to the Generating Gear, for a generated gear set, or is the Generating Gear for a non generated gear set; changes to the *Ease Off* come from the Pinion;
- In practice, the R.E. algorithm is applied using *deviations in ref. to the current pinion surface,* which are reflected in the *Ease Off;*
- CP is centered where requested by the user;
- Bias is modified until user request is reached;
- Bias is calculated between the 1st and last points of the PoC along the profile;

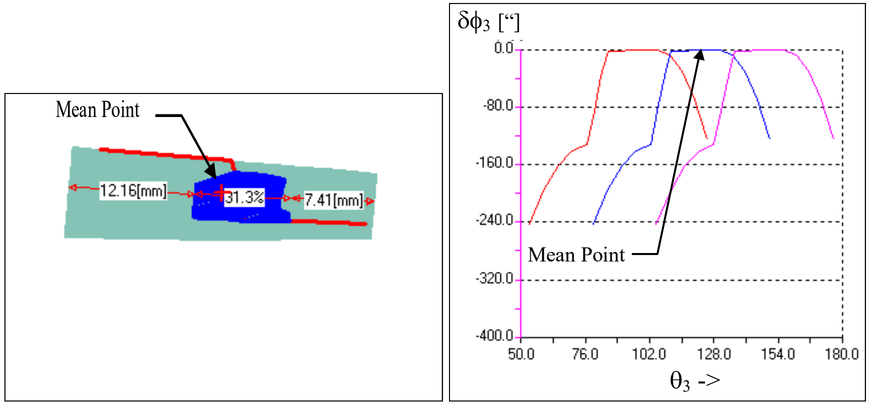


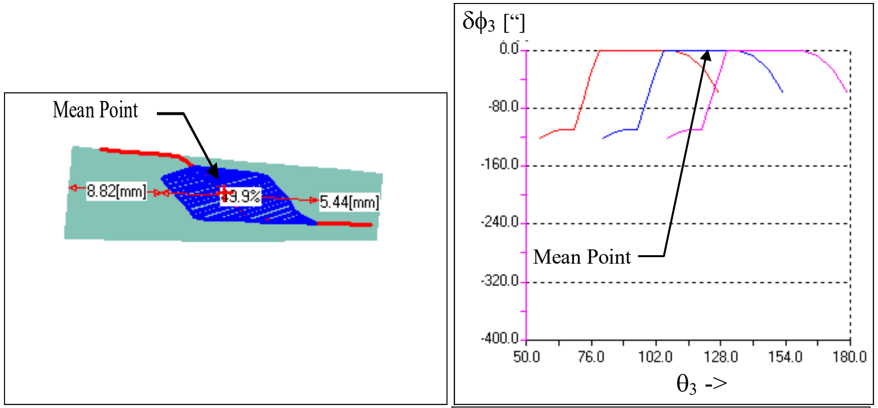

- No undercutting check;
- Tooth depth is maintained at mid-face width;

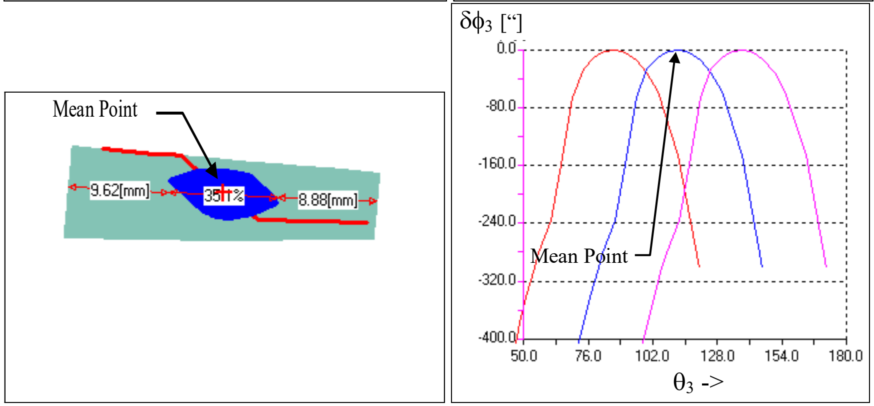
# Numerical Contact Pattern Development

## Helixform Gear Set



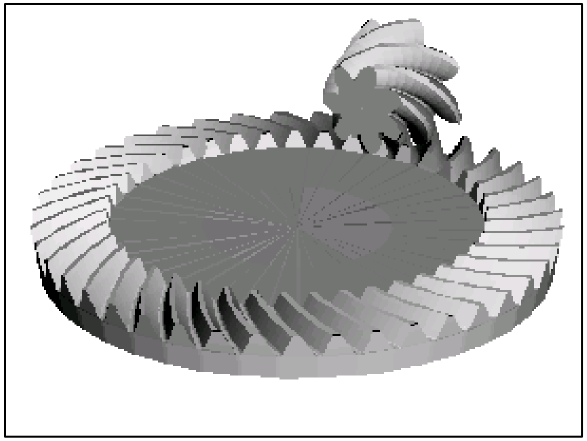


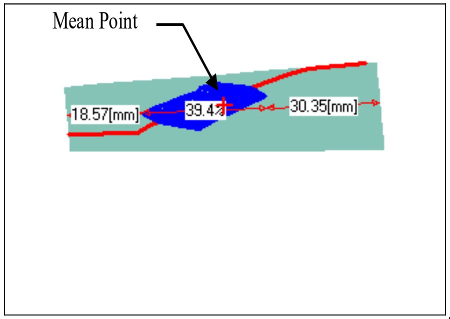



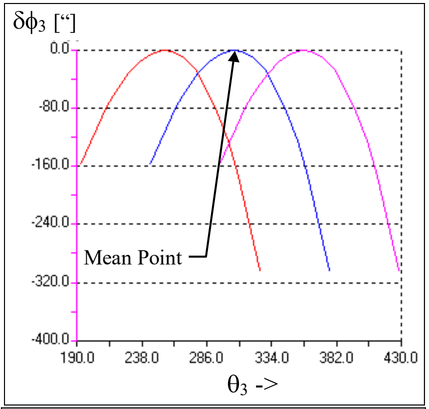



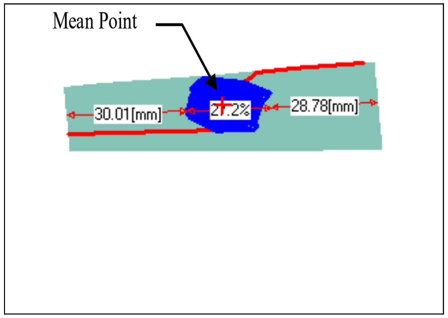
# Numerical Contact Pattern Development

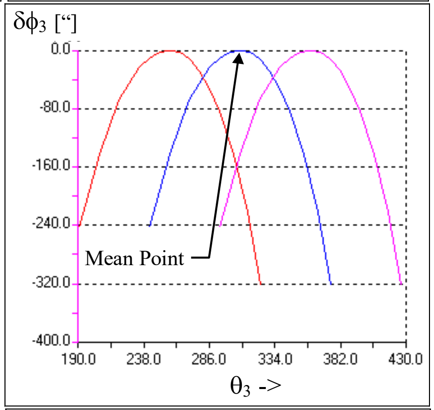
## Modified Roll Gear Set

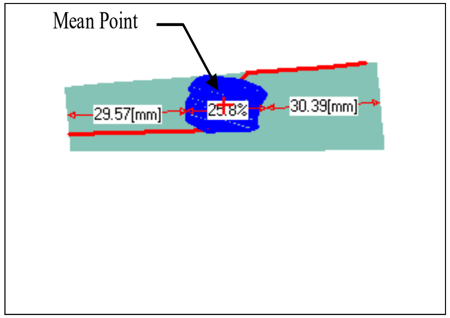


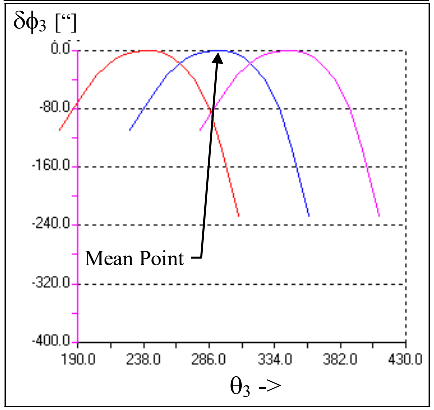


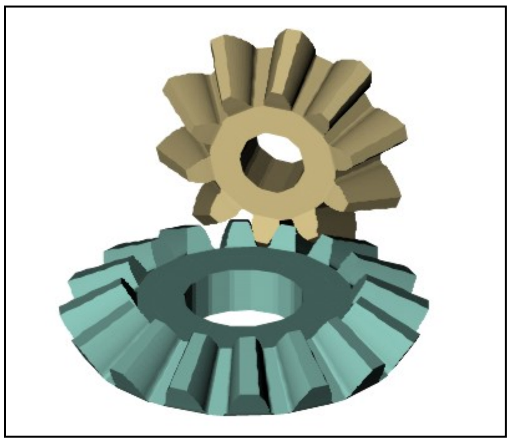



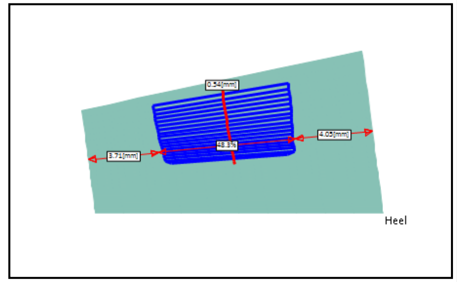



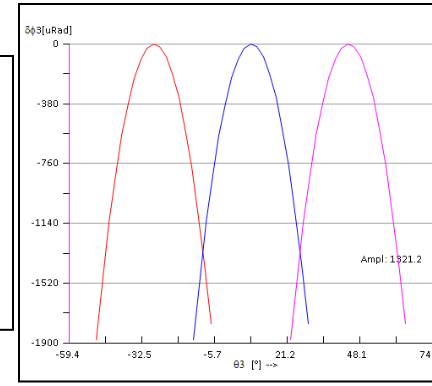



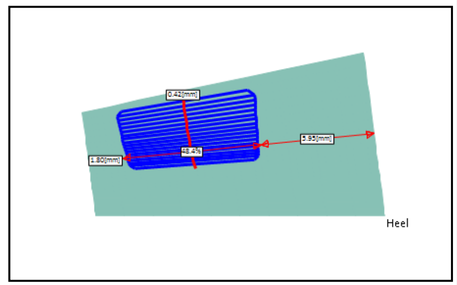
# Numerical Contact Pattern Development

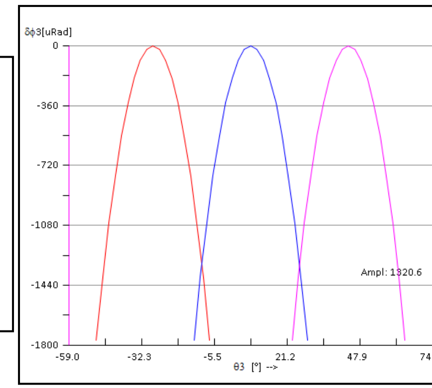
## Straight Bevel Gear Set

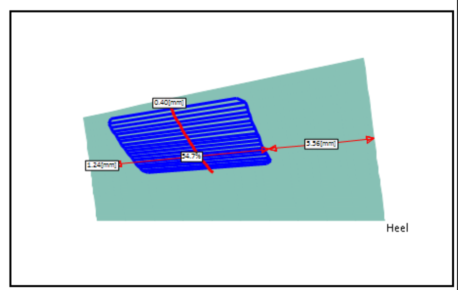


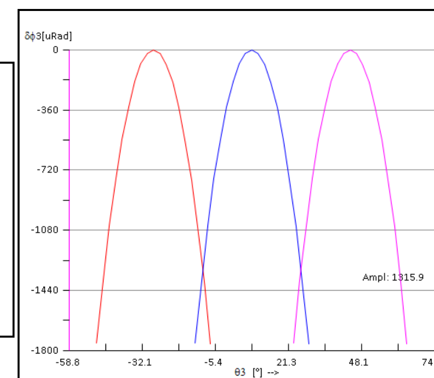


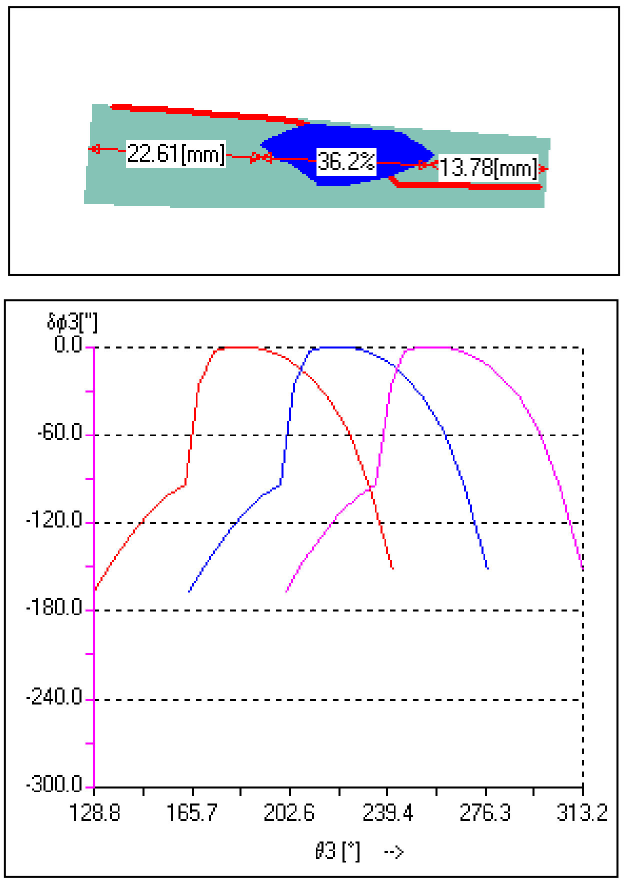



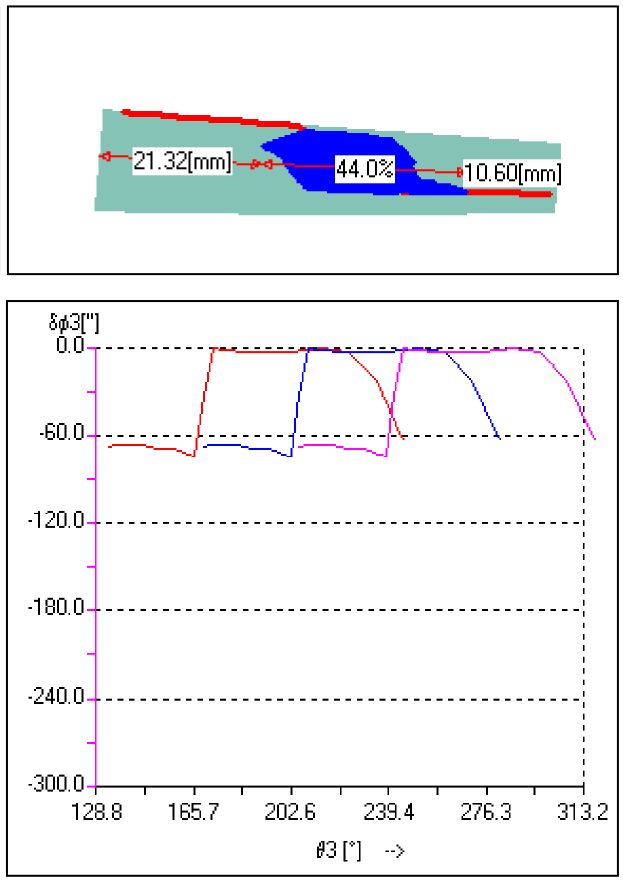



# Numerical Contact Pattern Development Optimization for Gear Noise

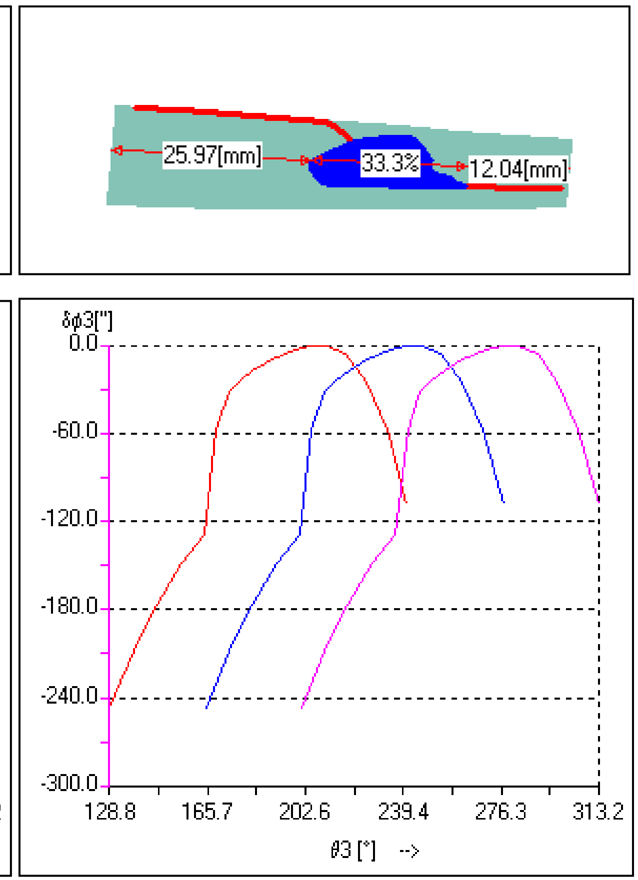
Change in CP bias and TE shape/amplitude




High CP/TE=20 arc-sec




Mid CP/TE=0 arc-sec

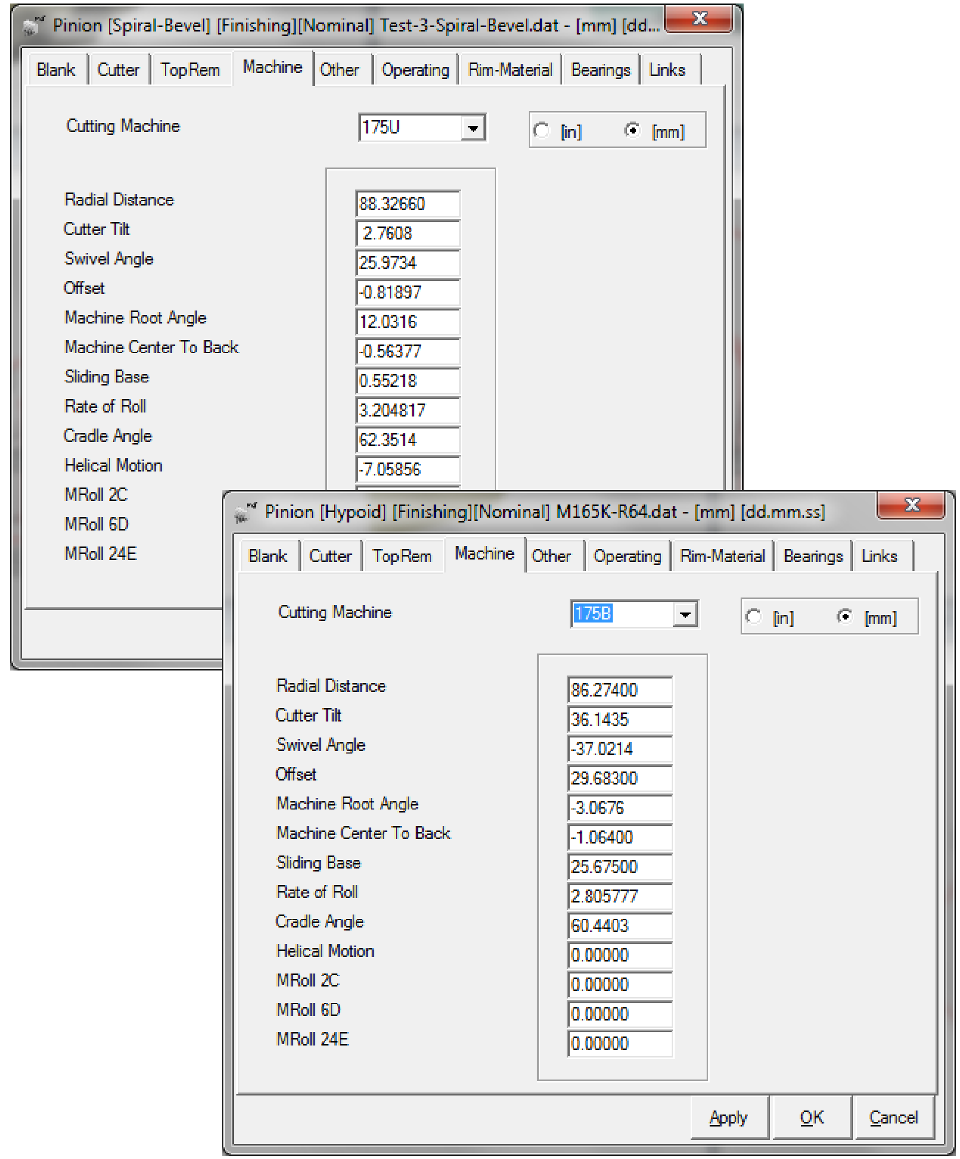



Low CP/TE=20 arc-sec

# Zerol, Spiral-Bevel, Hypoid Cutting Processes

HyGEARS supports most popular cutting processes, such as :

- Fixed Setting ®
- Modified Roll ®
- Duplex Helical ®
- Spread Blade ®
- Semi-Completing
- Formate ®
- Helixform ®
- Face Hobbing
- Cyclo-Palloid

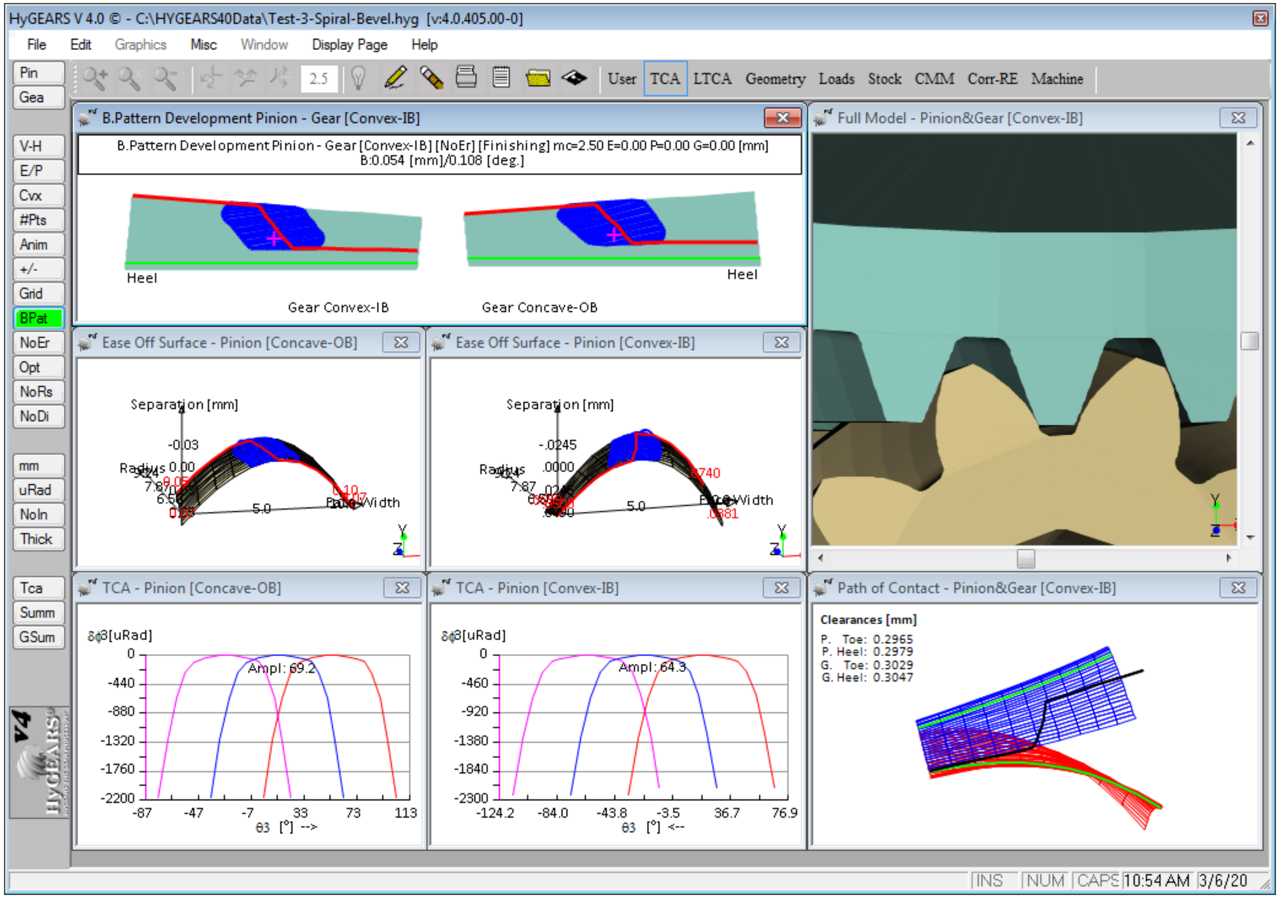



® The Gleason Works, Rochester, N.Y.

+ SimplexT
(Involute Inc.)

# DH vs SimplexT Spiral-Bevel Gears

**Duplex Helical:**
- Tilted spread blade pinion cutter
- Tilted spread blade gear cutter
- Helical motion
- Different pinion and gear cutters



# DH vs SimplexT Spiral-Bevel Gears

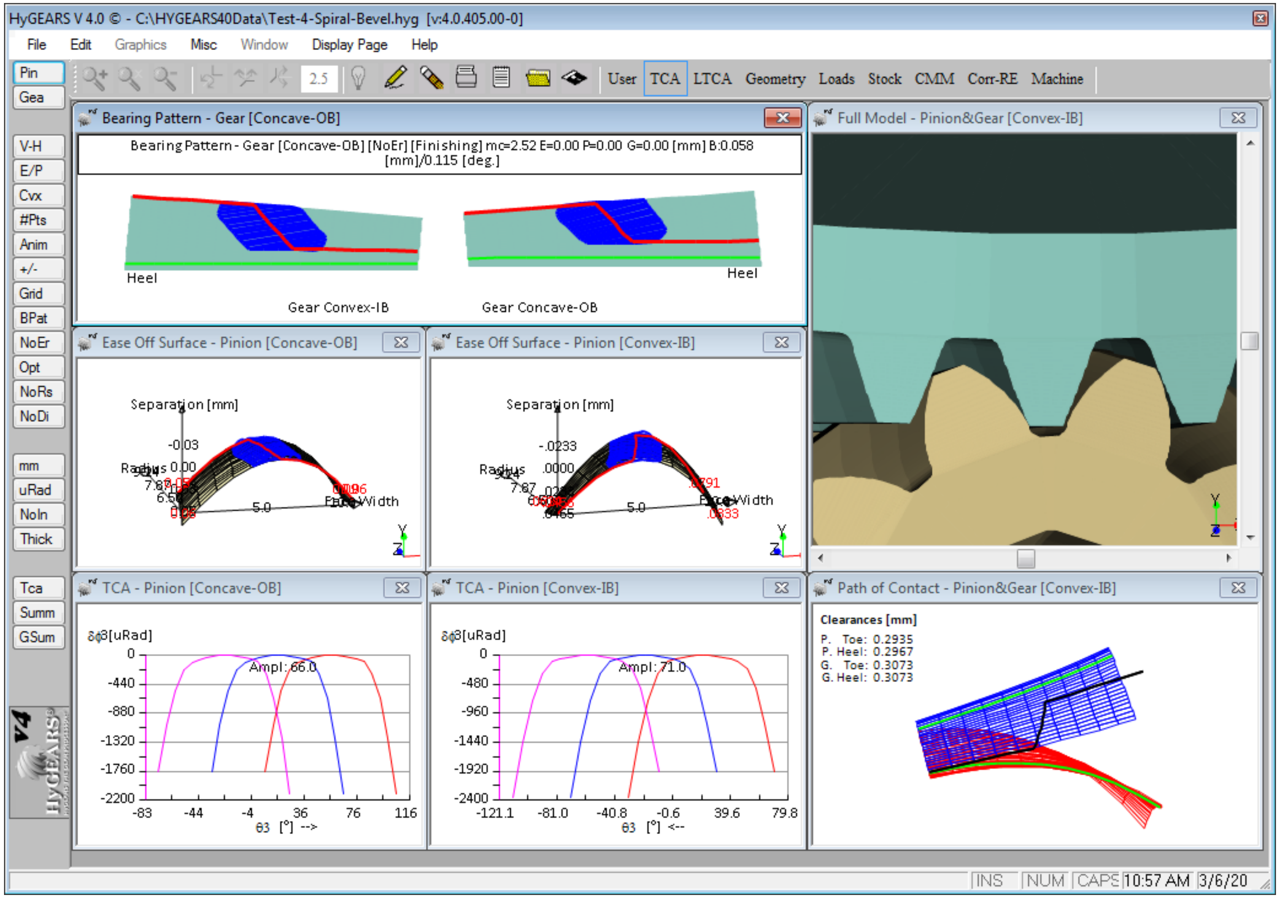
SimplexT:

Tilted spread blade pinion cutter

Non-tilted spread blade gear cutter

No helical motion

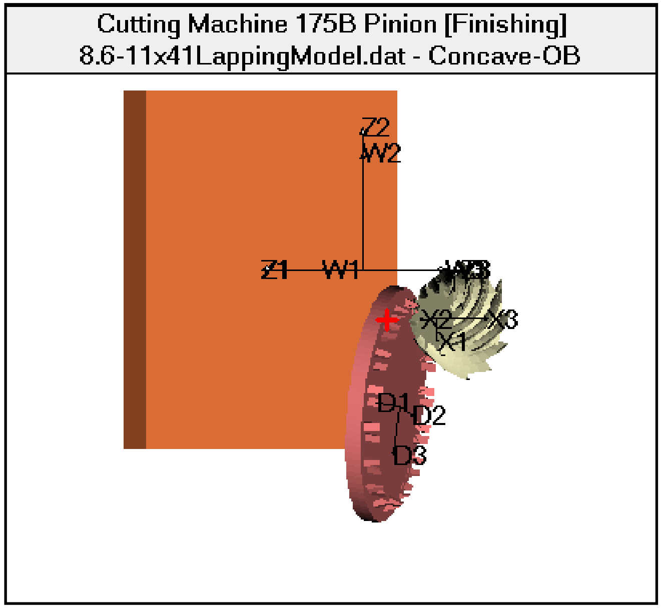
Identical pinion and gear cutters



# Zerol, Spiral-Bevel, Hypoid Cutting Machines

HyGEARS supports most popular cutting machines:

Gleason: 7A
16
26
102, 106, 108
116, 118, 122
606, 607
613, 631, 641
645, 650, 655, 675
Phoenix (i.e. 175)
Basic (YH 603)




A *Machine Converter*, included in the Geometry Summary Editor, allows machine conversion.

Klingelnberg: Neutral

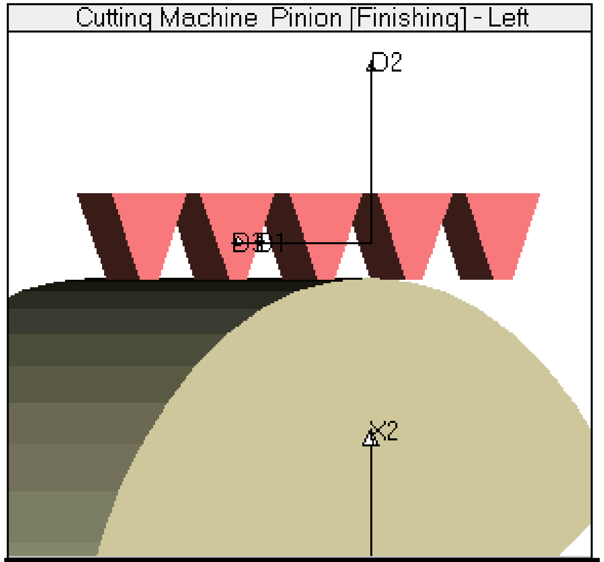
5Axis CNC machines:
“AC”, “BC”, “BA” Types

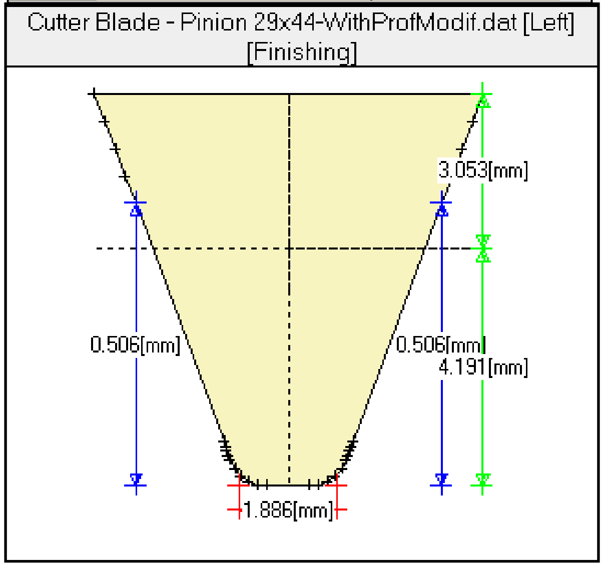
# Spur/Helical Cutting Processes

For Spur and Helical gears, HyGEARS supports *Rack* and *Shaping* tools and movements.

Profile modifications may be introduced, up to the 4th order, as well as crowning.

Modules down to 0.1 [mm] and as large as 30 [mm] are easily accommodated by HyGEARS.



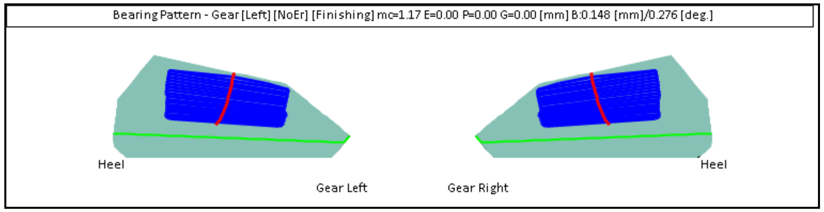



# Straight Bevel Cutting Processes

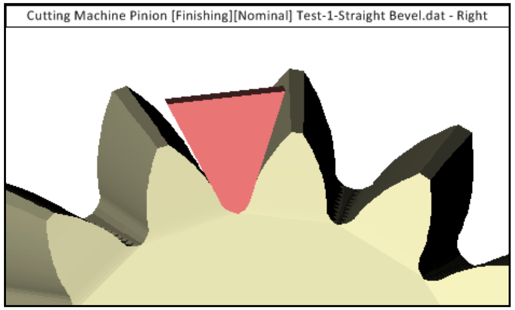
Straight Bevel gears are traditionally cut on a 2-tool generator. In HyGEARS, with or without lengthwise crowning, these are referred to as Straight Bevel gears to distinguish with Coniflex.

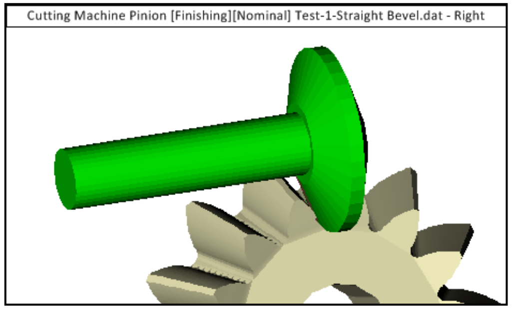
HyGEARS supports:

- Tooth shape for gear box differentials: 2-tool generator type machine; straight edge blade; + M.Roll; often aimed to *forging*.




- Standard tooth shape: 2-tool generator type machine; straight edge blade; M.Roll can be used on CnC machines.
- Both variants can be cut on CnC machines using; *CoSIMT, Ball-Mill and End-Mill tools*.



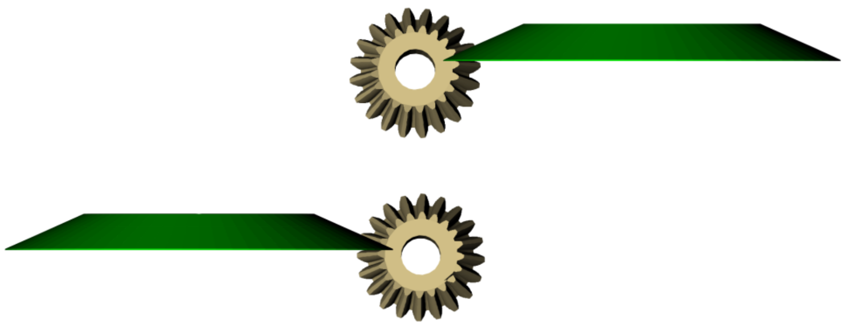



# Coniflex Straight Bevel

In HyGEARS, Coniflex® refers to the cutting process using a dish-type face mill cutter.

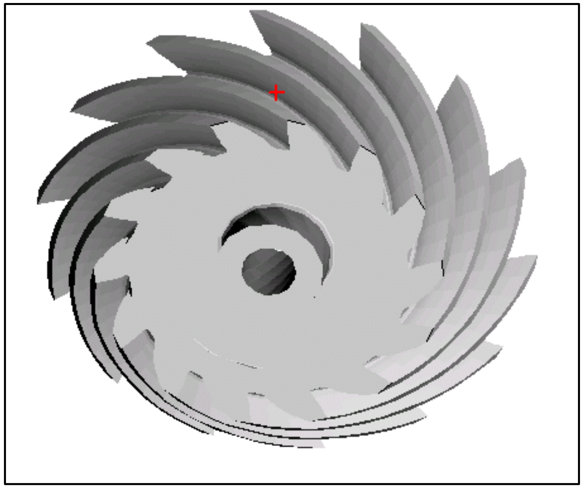
Gleason machines 102, 104, 114 and 134 are supported in native mode. Coniflex® gears can also be cut on 5Axis CnC machines where each side of a tooth is generated using the same cutter on opposite sides of the work piece.

Gleason Coniflex Generator

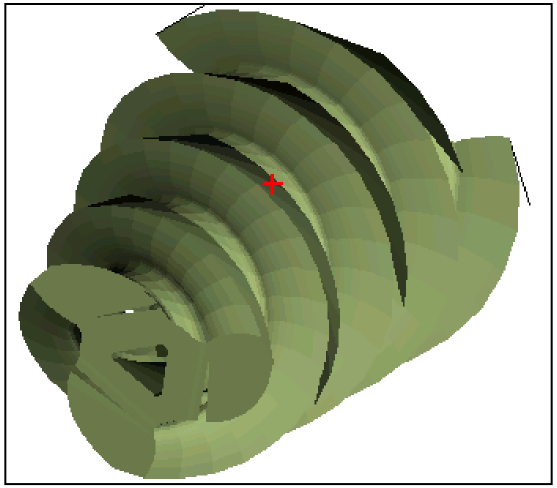


5Axis CnC Machine

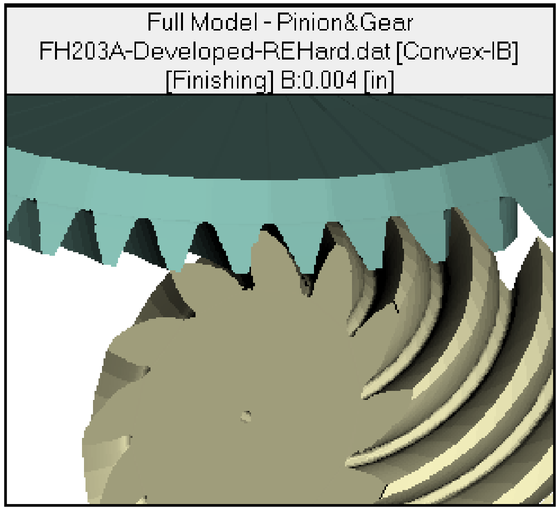
Fixed Setting Hypoid Pinion



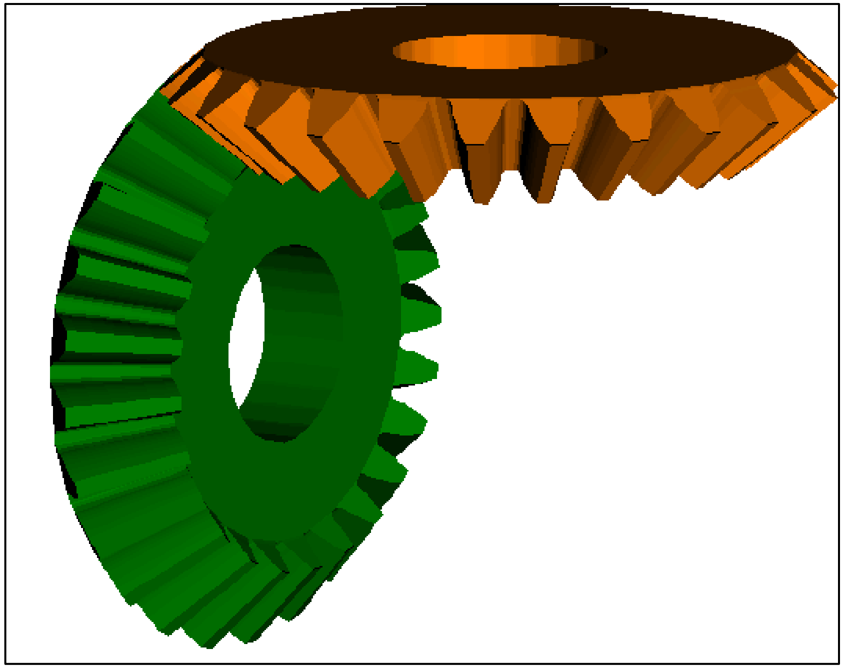
Duplex Helical Hypoid Pinion



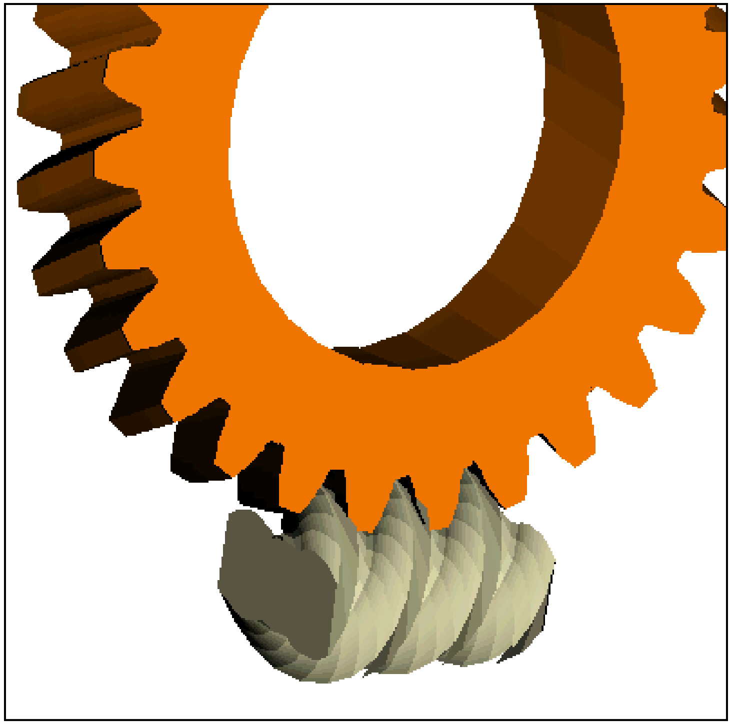
Face Hobbed Gear Set



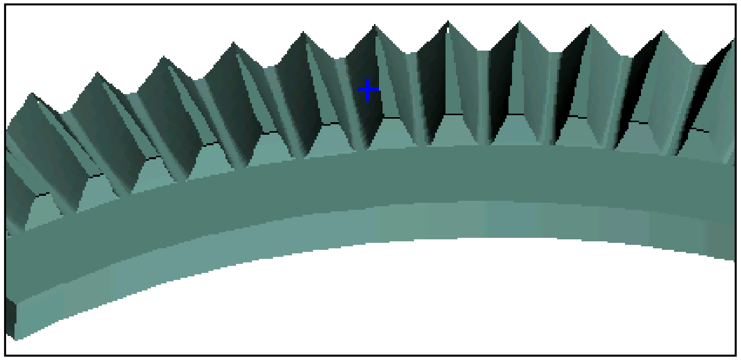
## Straight Bevel Gears

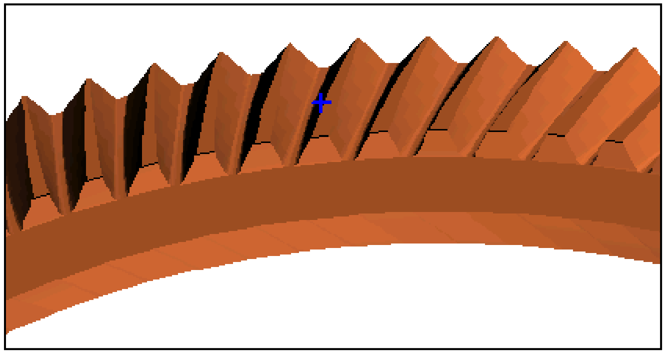


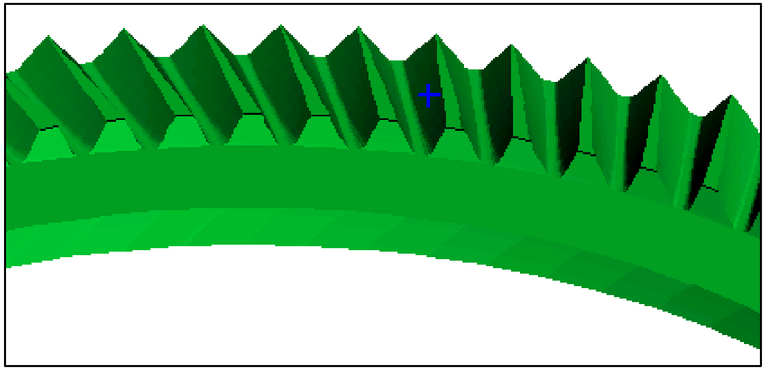
## Worm Gears



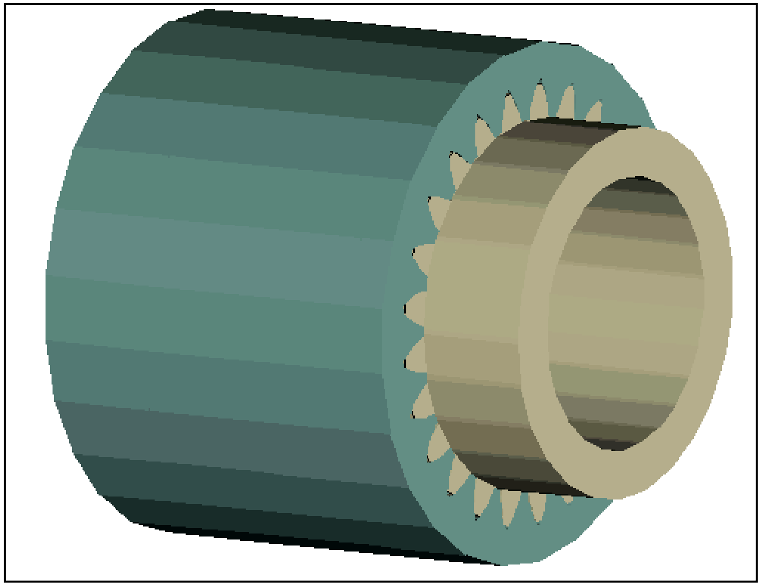
# Face Gears



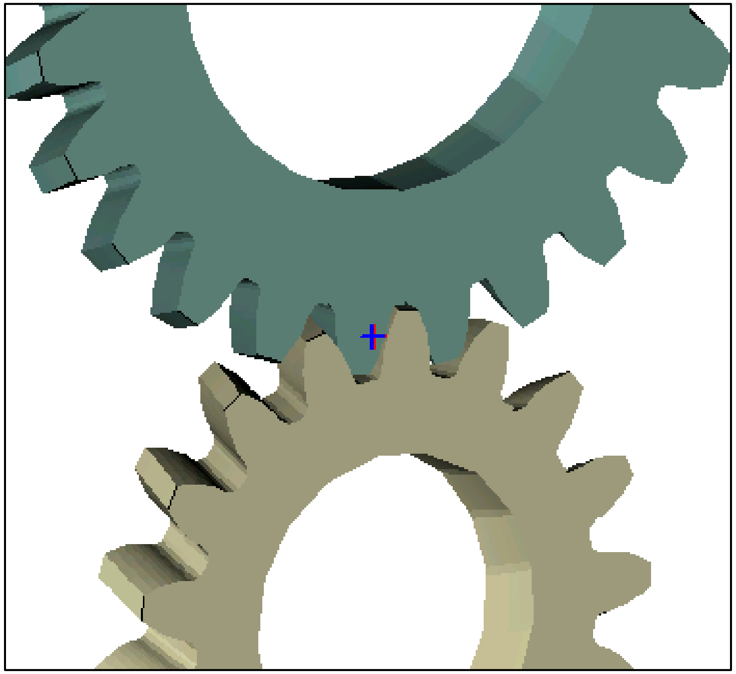




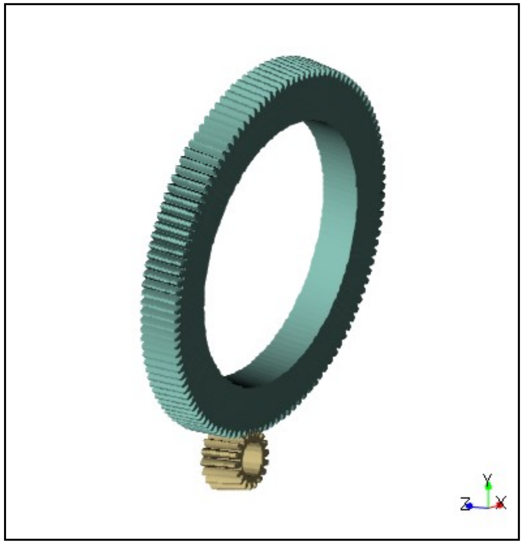
## Splines/Internal Gears



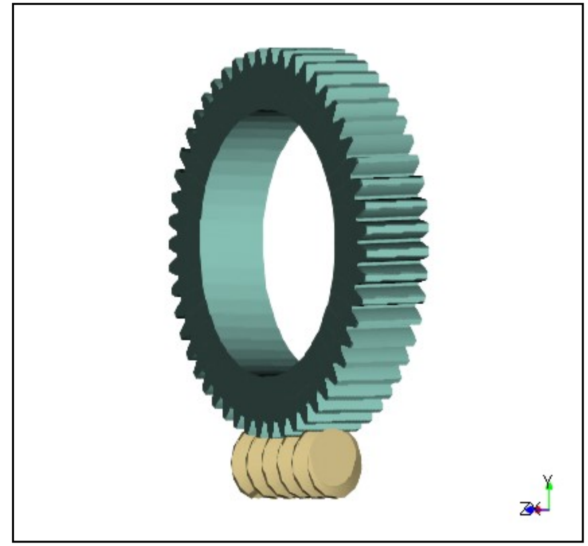
## Helical Gears

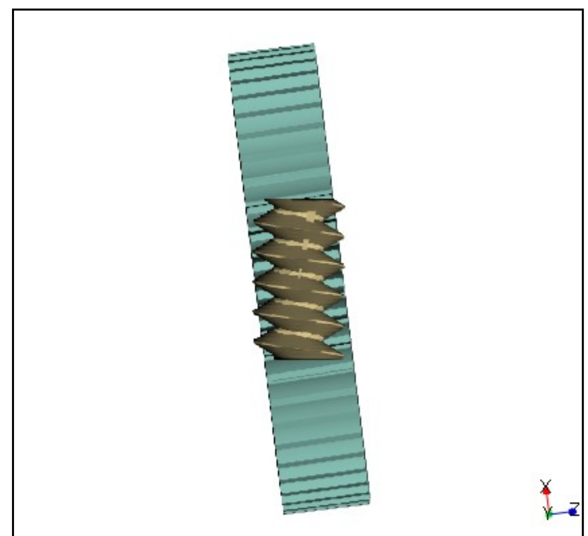


## Beveloid Gears

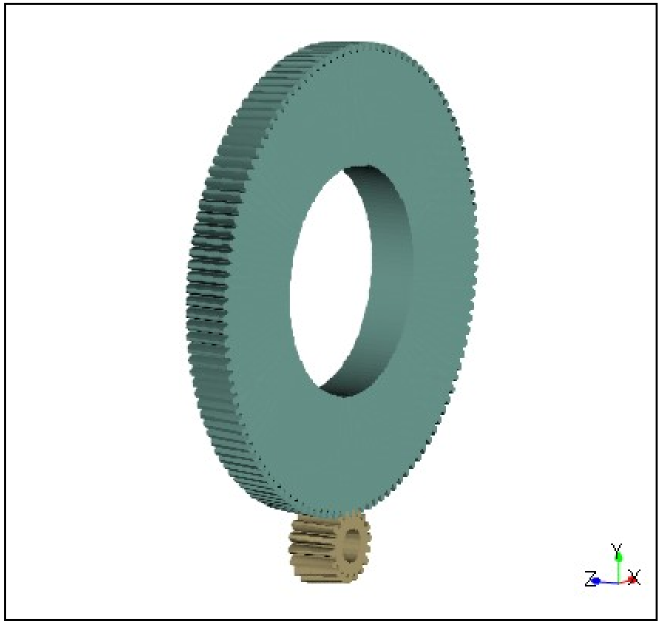


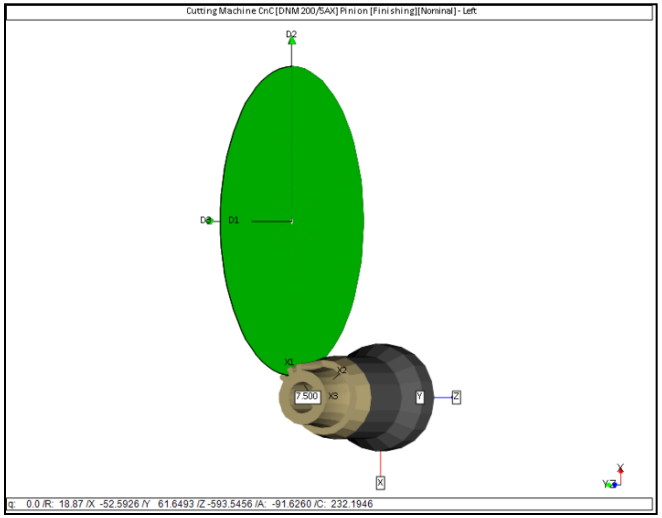
## Worm & Helical Gears



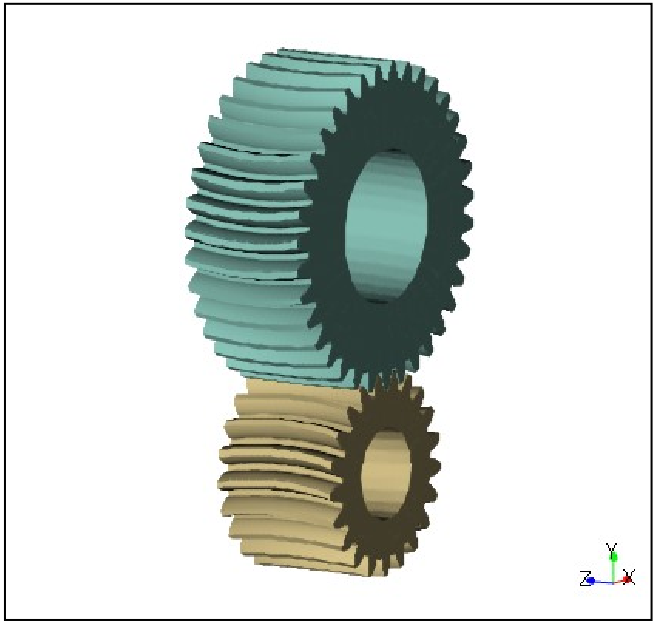


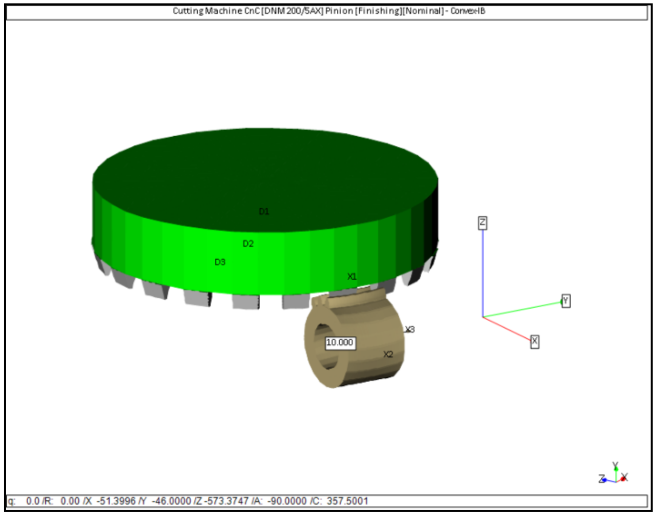
# Spurniflex Gears



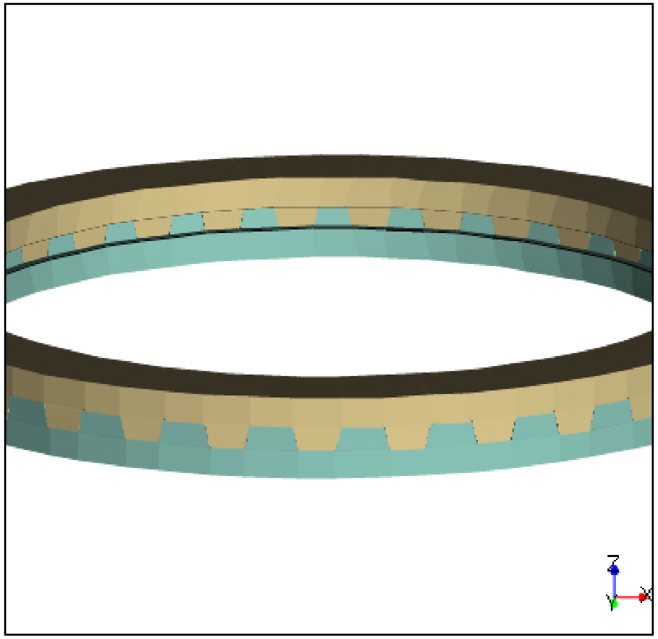


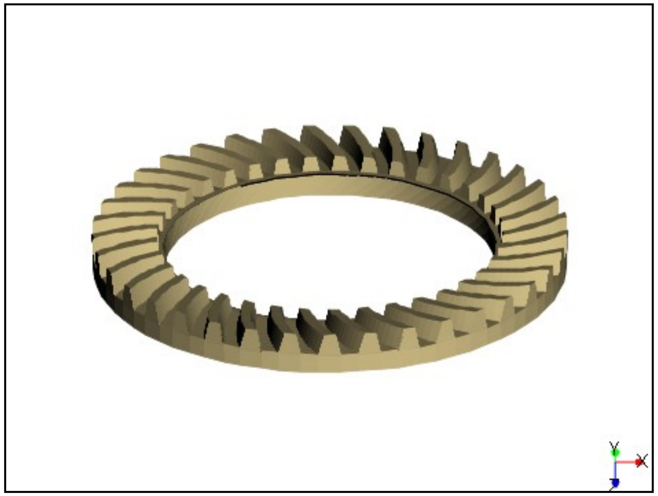

# Spurved Gears



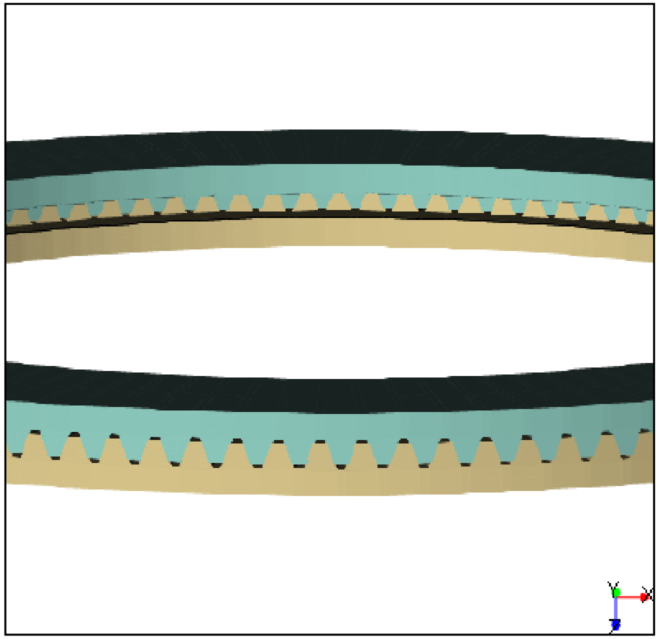


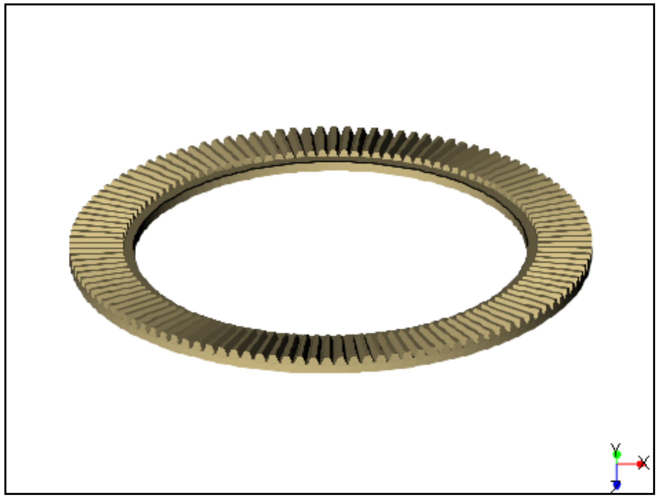
## Spiral Face Clutch





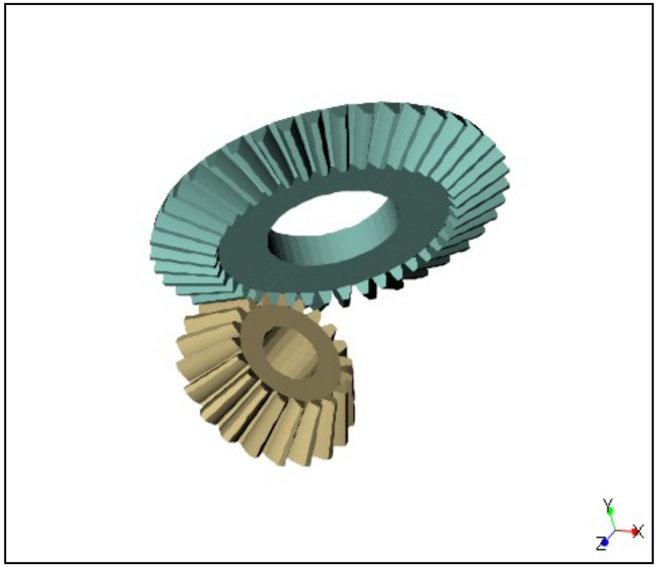
## Hirth Coupling

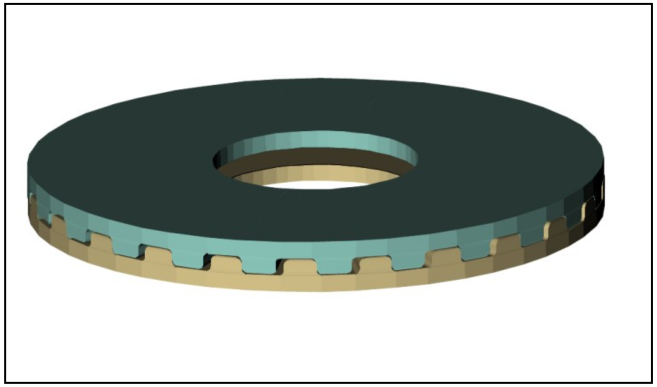


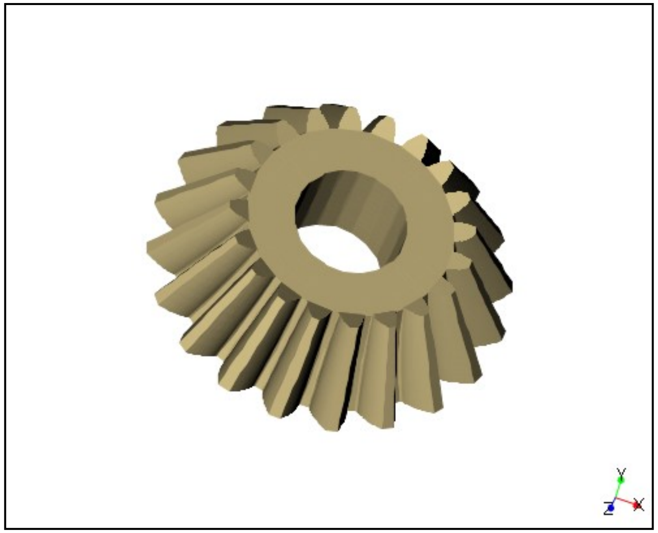


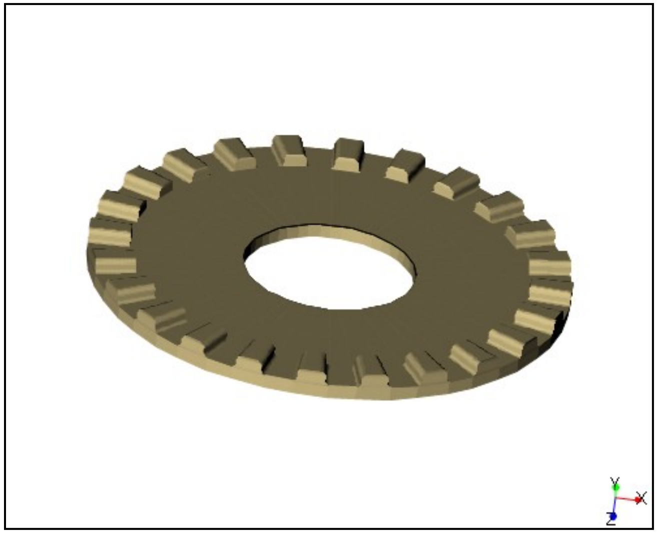
## Coniflex Bevel Gears

## Cogged Teeth Coupling

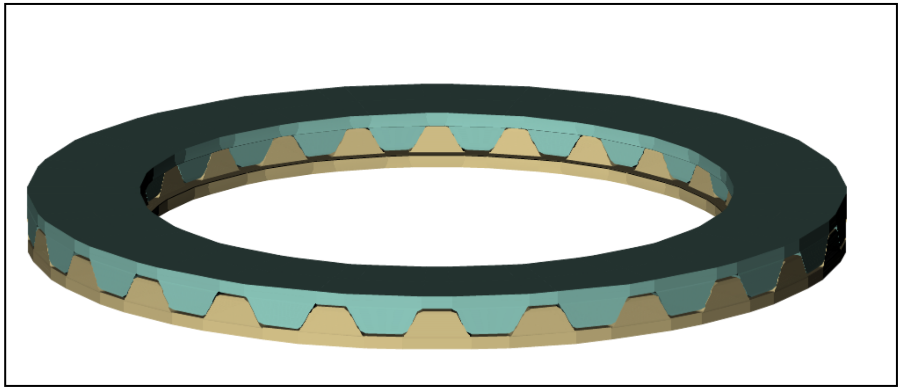


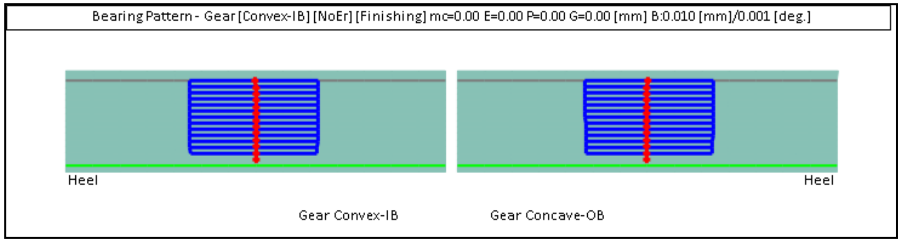


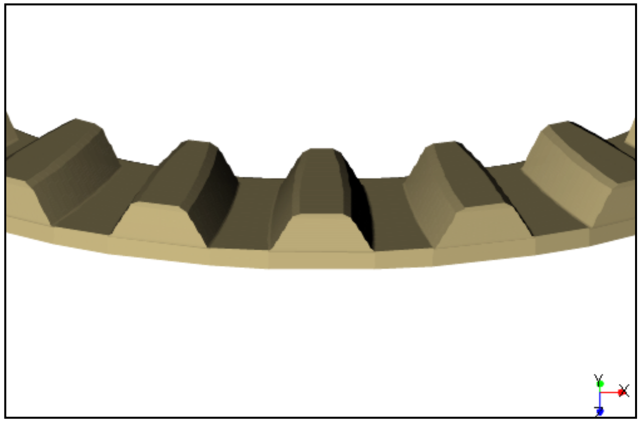


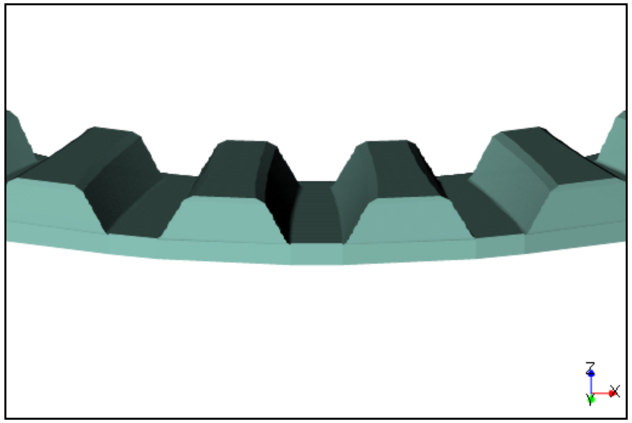


# Curvic Coupling







# Software Calibration

HyGEARS was calibrated against Gleason's and KIMoS TCA (CP and TE), CMM control, Corrective Machine Settings, LTCA Contact Stresses, etc.

1993: Machine Calibration (Gleason and Yutaka machines)

1994: Corrective M/C (Closed Loop vs Gleason's GAGE)

1996: Experimental TE

1997: Experimental LTCA

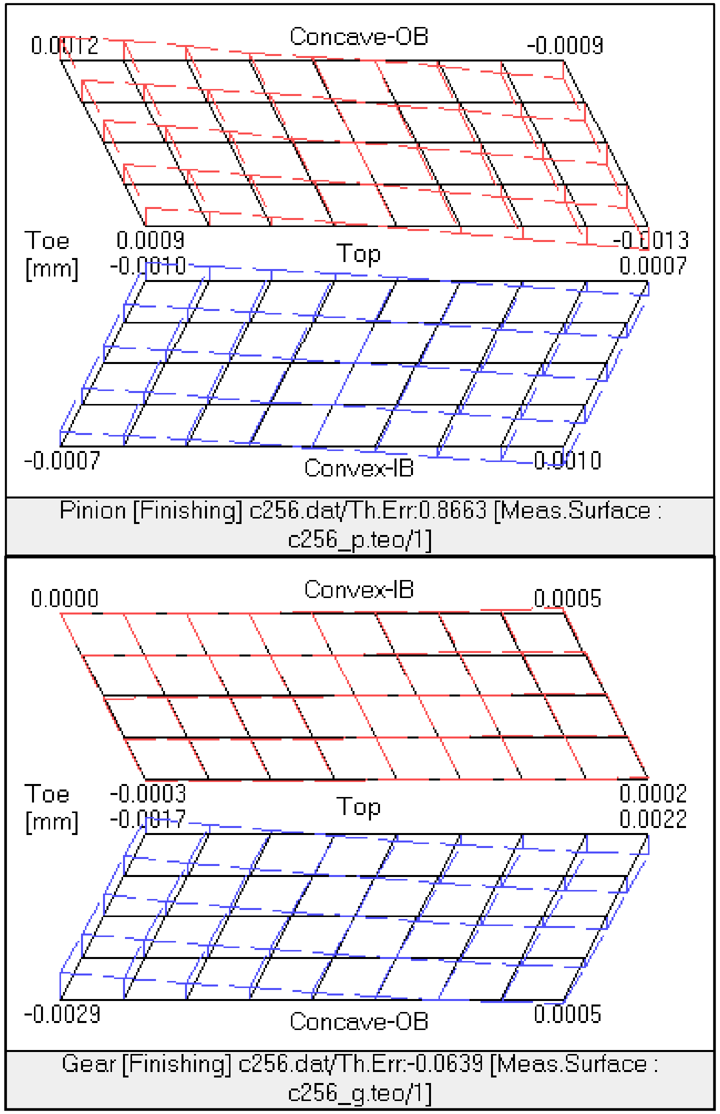
1998: Fillet Stress (against FEA)

2001: Contact Stress (against Gleason's LTCA)

2004: Bending and Contact Stress – Face Hobbing – (against Gleason's LTCA)

2006: Lapping Prediction (with AAM)

*Consistently equivalent results are obtained.*

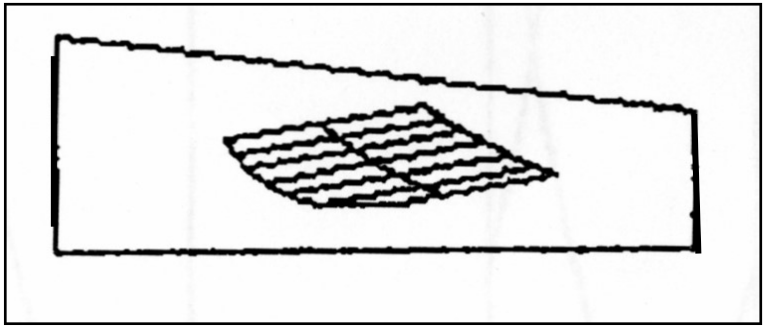
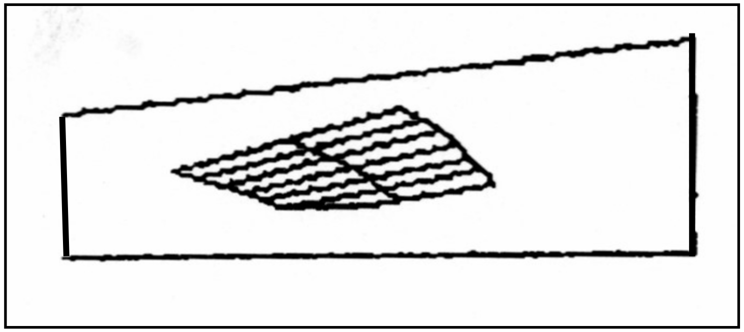


# Software Calibration

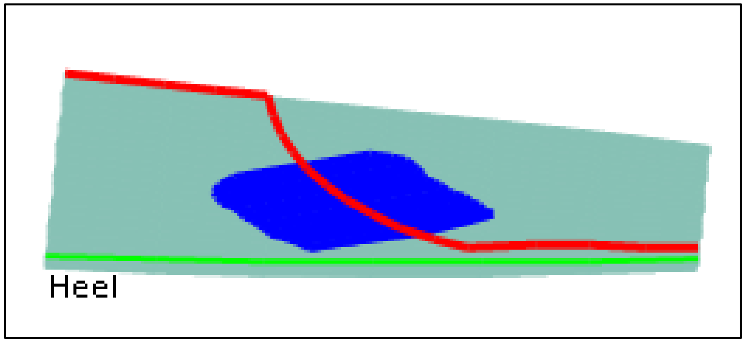
13x24 Face Milled Spiral Bevel gear set

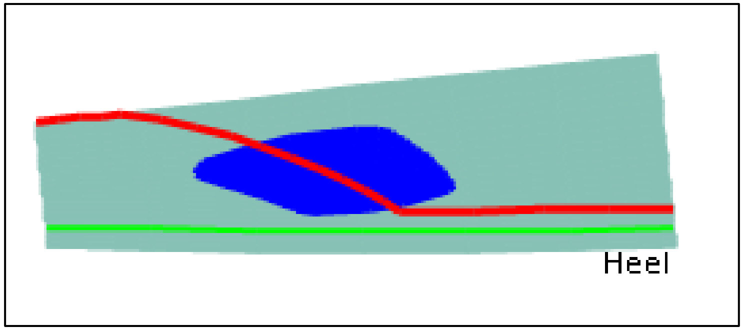
Drive Side

Coast Side

**Gleason**



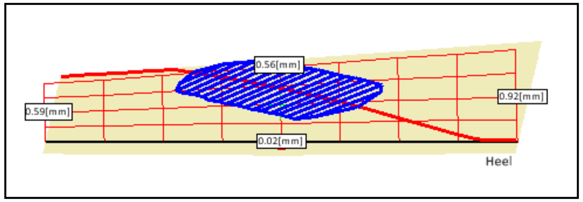


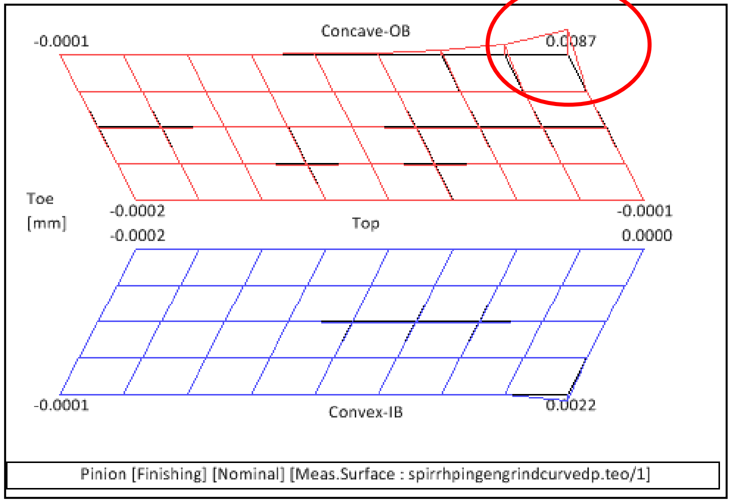

**HyGEARS**

# Software Calibration

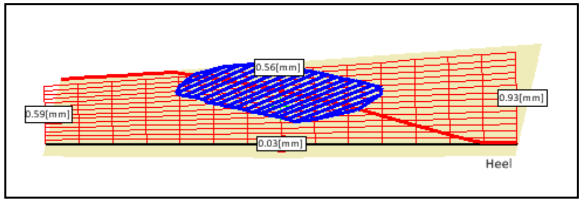
8x39 Face Milled Spiral Bevel gear set

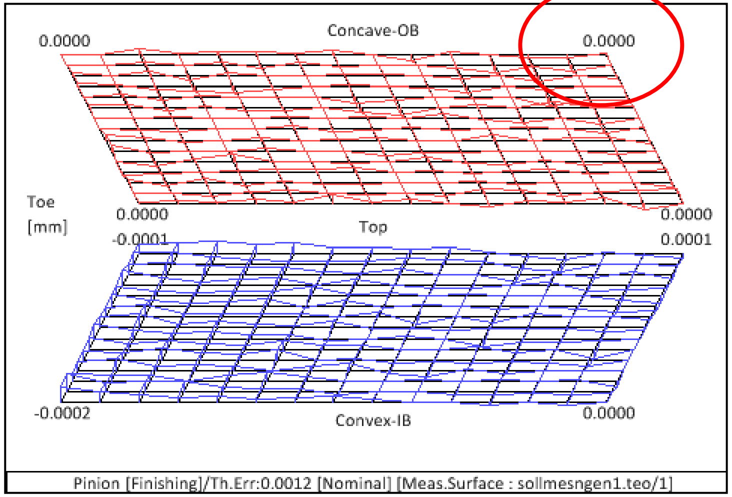
HyGEARS vs. Gleason Nominal




HyGEARS vs. KIMOS Nominal

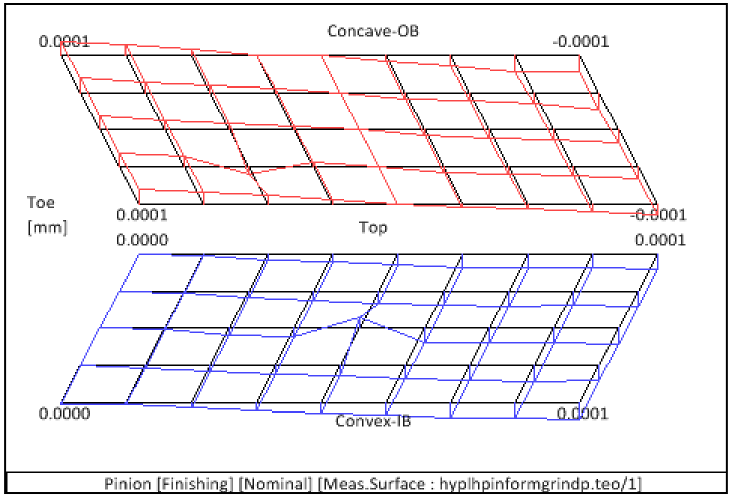


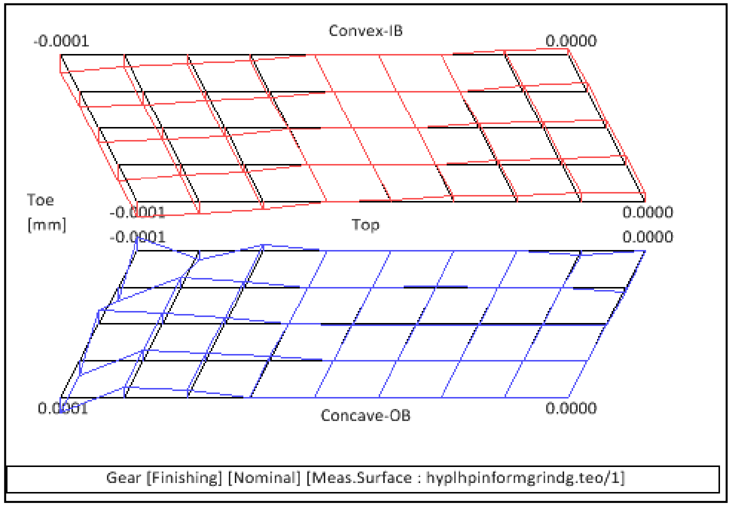
# Software Calibration

8x39 Face Milled Hypoid gear set

HyGEARS vs. Gleason - Pinion



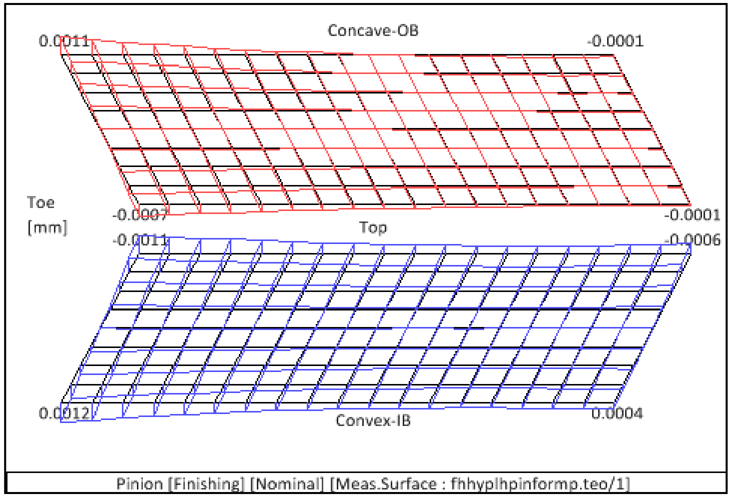

HyGEARS vs. Gleason - Gear



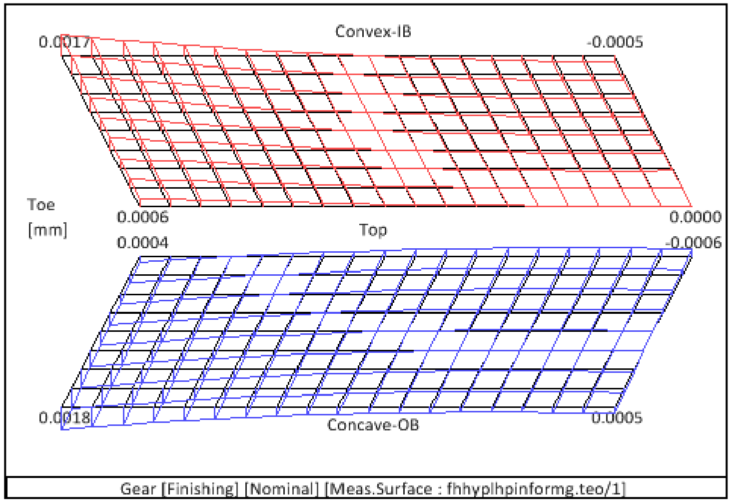
# Software Calibration

8x39 Face Hobbed Hypoid gear set

HyGEARS vs. Gleason - Pinion

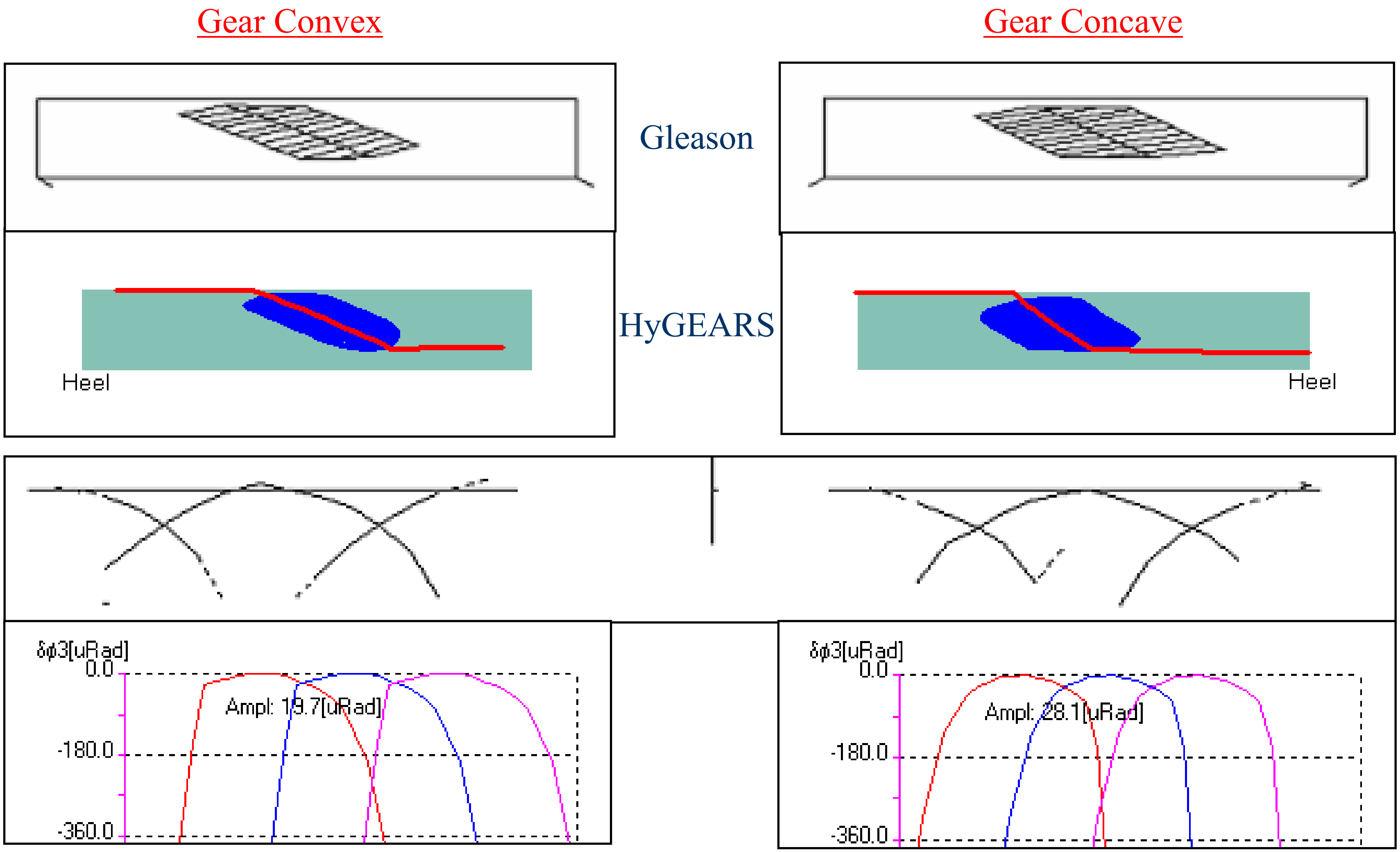



HyGEARS vs. Gleason - Gear

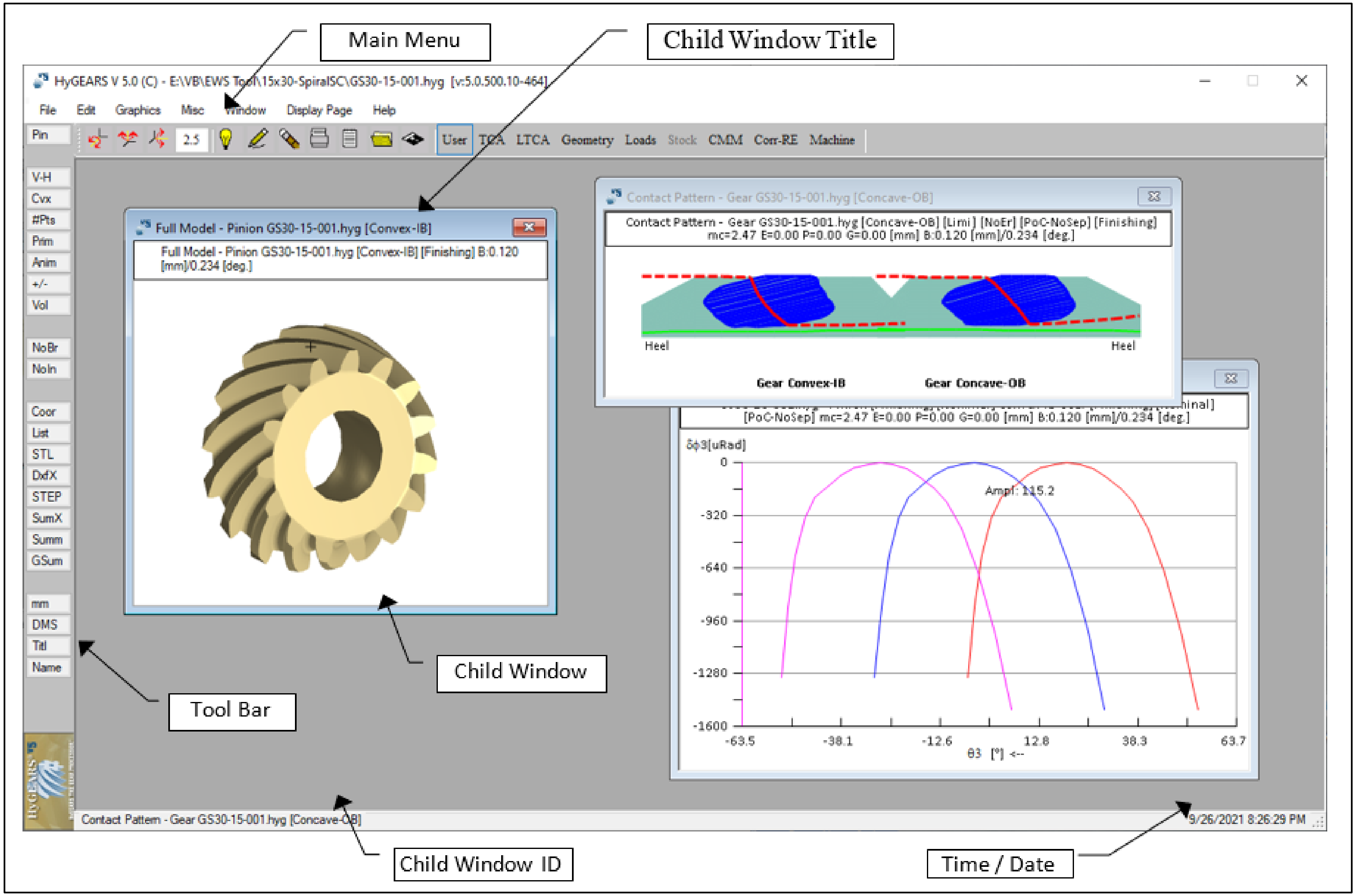


# Software Calibration

12x41 Face Hobbed Hypoid gear set



# HyGEARS Windows: the Parent Window



# Parent Window Menu

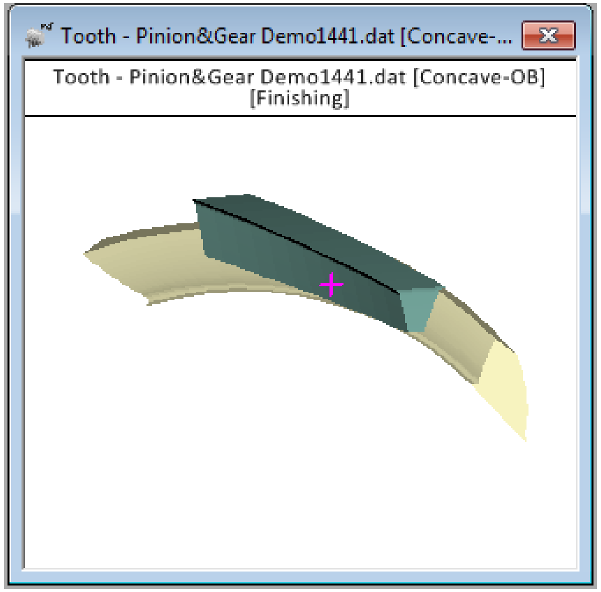
| File | Edit | Graphics | | Misc. | Window | | Display Page | Help |
|---|---|---|---|---|---|---|---|---|
| Open | Pinion | Pinion | | Pinion | Cascade | | User Defined | About HyGEARS |
| Save | Gear | Gear | | Gear | Tile | | BP TCA | HyGEARS Help |
| Save As | Number Points | Pinion and Gear | | Pinion and Gear | Template ▶ | Open | BP LTCA | |
| New Geometry | Alignment | Reference Frames | | | | Save | Tooth Geometry | |
| Input Existing Summ. | Configuration | | | | Close | | Stock Distribution | |
| Exit | Reset Corr Hist | | | Num. Results | Close All | | CMM Nominal | |
| | Reset BPat Hist | Tooth – M/C ▶ | Tooth | Action Trace | Child Windows ▶ | #1 | Correction – R.E. | |
| 1 File x | Registration | | Blank | | | #2 | Cutting Machine | |
| 2 File y | | | Cutter Blade | | | #3 | | |
| 3 File z | | | Dia. Over Ball | | | #4 | | |
| 4 | | | Caliper Meas. | | | … | | |
| 5 | | | Full Model | | | | | |
| 6 | | | Cutting Machine | | | | | |
| 7 | | | | | | | | |
| 8 | | Kinematics ▶ | Path of Contact | | | | | |
| | | | Bearing Pattern | | | | | |
| | | | B. Pattern (LTCA) | | | | | |
| | | | BP Development | | | | | |
| | | | Sliding Speeds | | | | | |
| | | | Ease Off | | | | | |
| | | Measurement ▶ | Measured Surfaces | | | | | |
| | | | Tooth Errors | | | | | |
| | | | Comp. Mes-Sim Surf | | | | | |
| | | | Stock Distribution | | | | | |
| | | | Corrective MC Sett | | | | | |
| | | | Reverse Engineering. | | | | | |
| | | | CMM Nominal Data | | | | | |
| | | 2D Graph | | | | | | |
| | | TE-Peak to Valley | | | | | | |
| | | Complete Summary | | | | | | |
| | | Meshing ▶ | FEA Model | | | | | |
| | | | Finite Strips | | | | | |

# HyGEARS Display Modes

**HyGEARS can display results in 1 of 2 modes:**

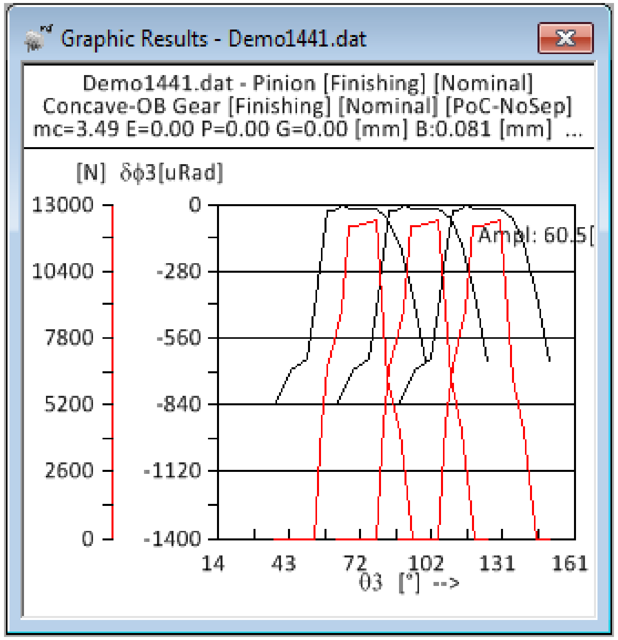
- **User Defined:** user decides what Child window is to be displayed, and where;
- **Pre-defined: 9** displays allow the user to access the most current functions
    - TCA
    - LTCA
    - Geometry
    - Loads (Radial, Axial, Transverse)
    - Stock (Spiral bevel gears; Distribution)
    - Modifications (Spur/Helical gears; Profile, Crowning)
    - CMM (Target file)
    - Corr-RE (Closed Loop; Reverse Engineering)
    - Machine (5Axis CnC)

# Display Modes: 3D Child Windows



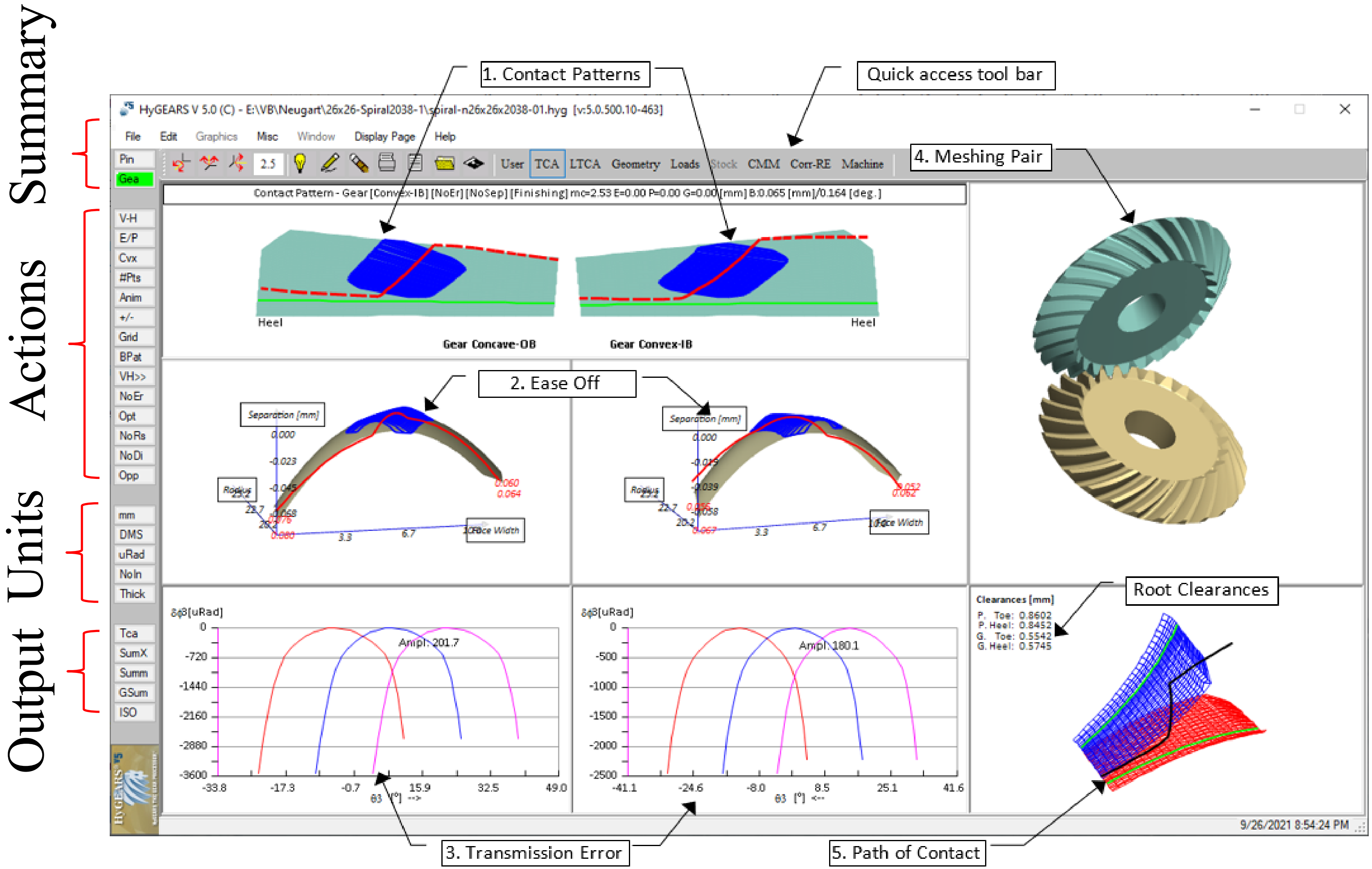

- Tooth,
- Blank Contour,
- Diameter over Balls,
- Caliper Measurement,
- Full Model,
- Cutting Machine,
- Path of Contact,
- Contact Pattern,
- Ease Off,
- FEA Model,
- Finite Strips,
- Measured Surfaces,
- CMM Nominal Data

# Display Modes: 2D Child Windows

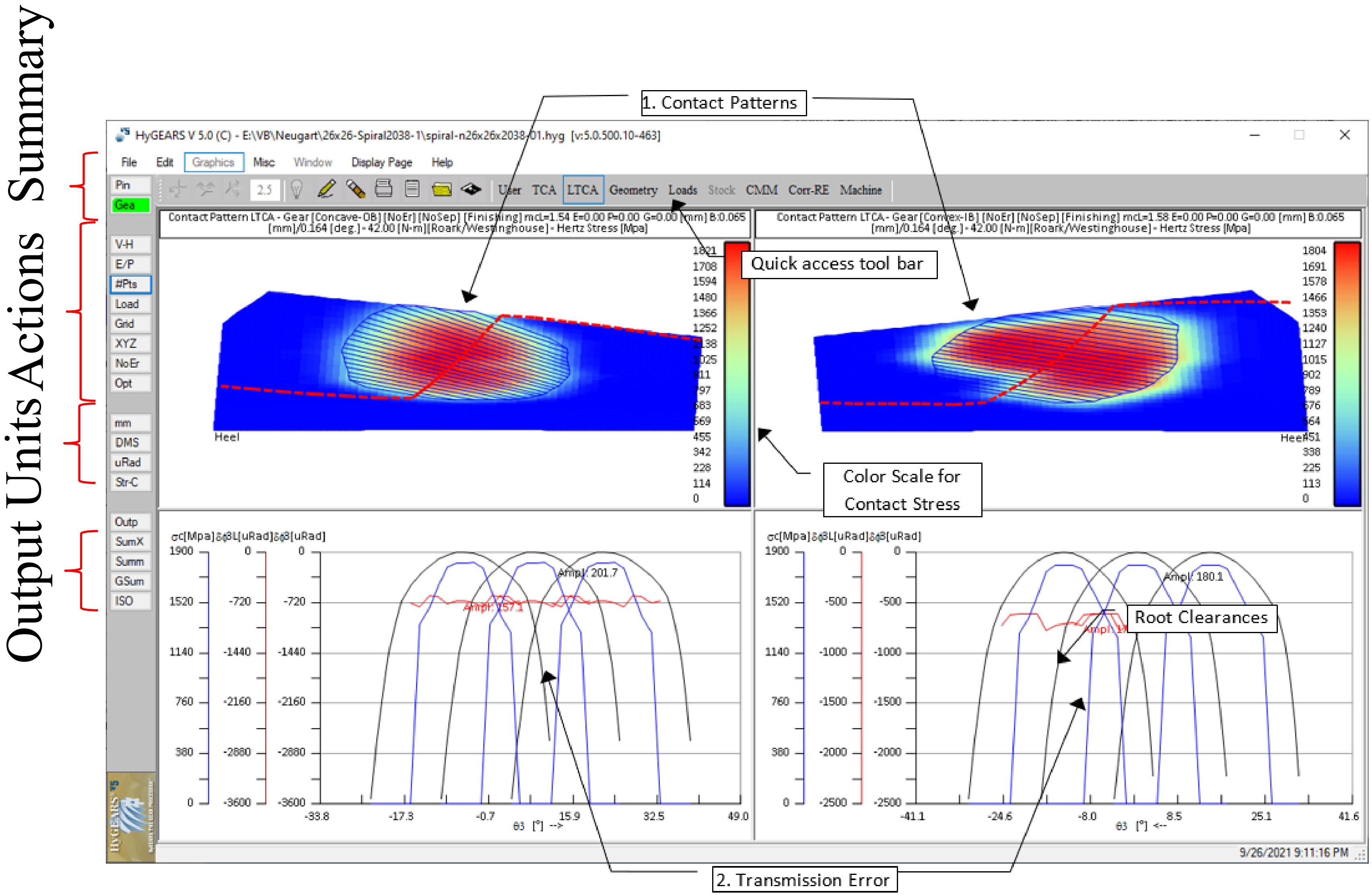



- Tooth Errors (thickness and pitch),
- Comparison of Measured and Simulated Surfaces,
- Corrective Machine Settings,
- Reverse Engineering,
- Cutter Blade,
- 2D Graphs

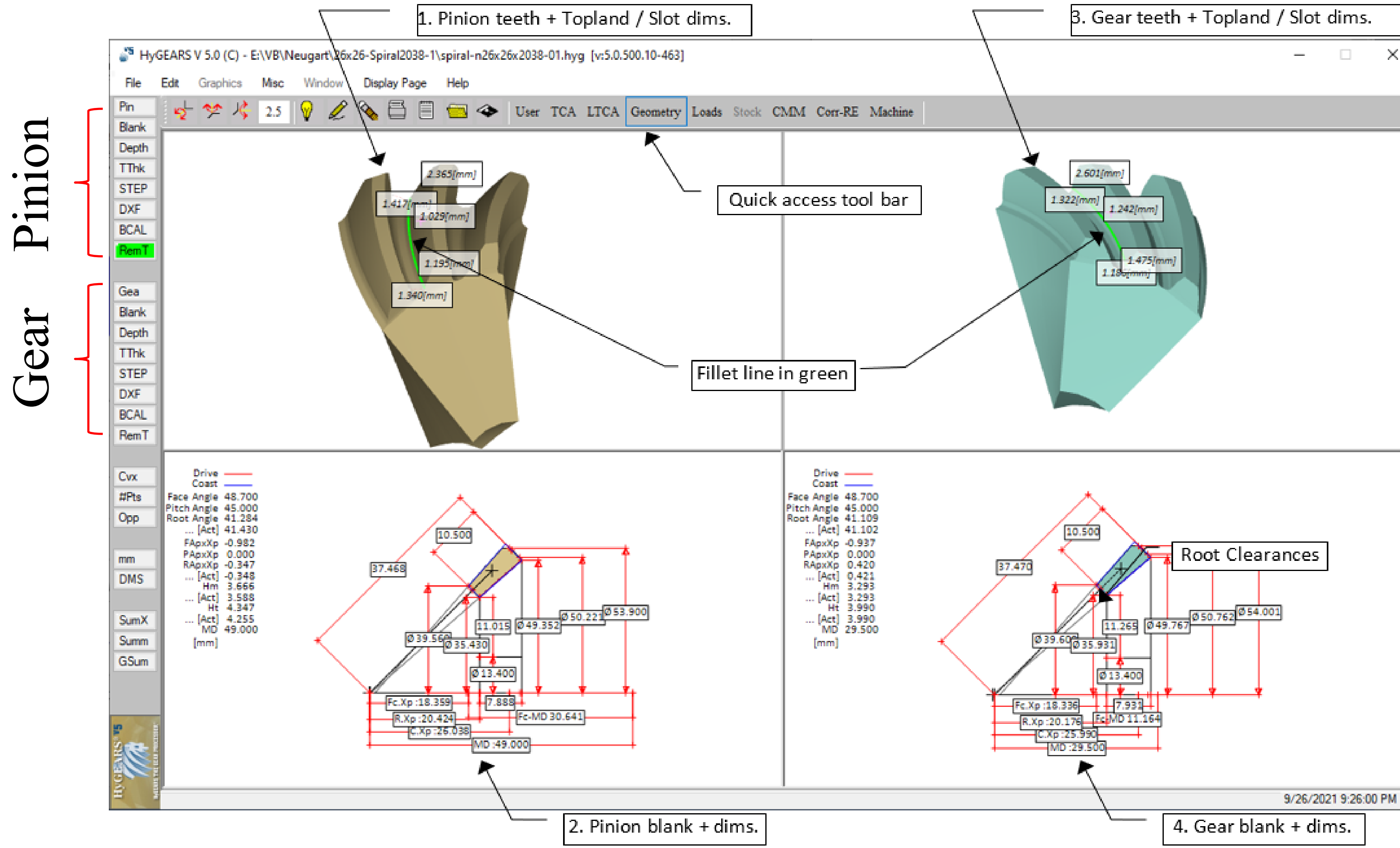
# Display Modes: TCA



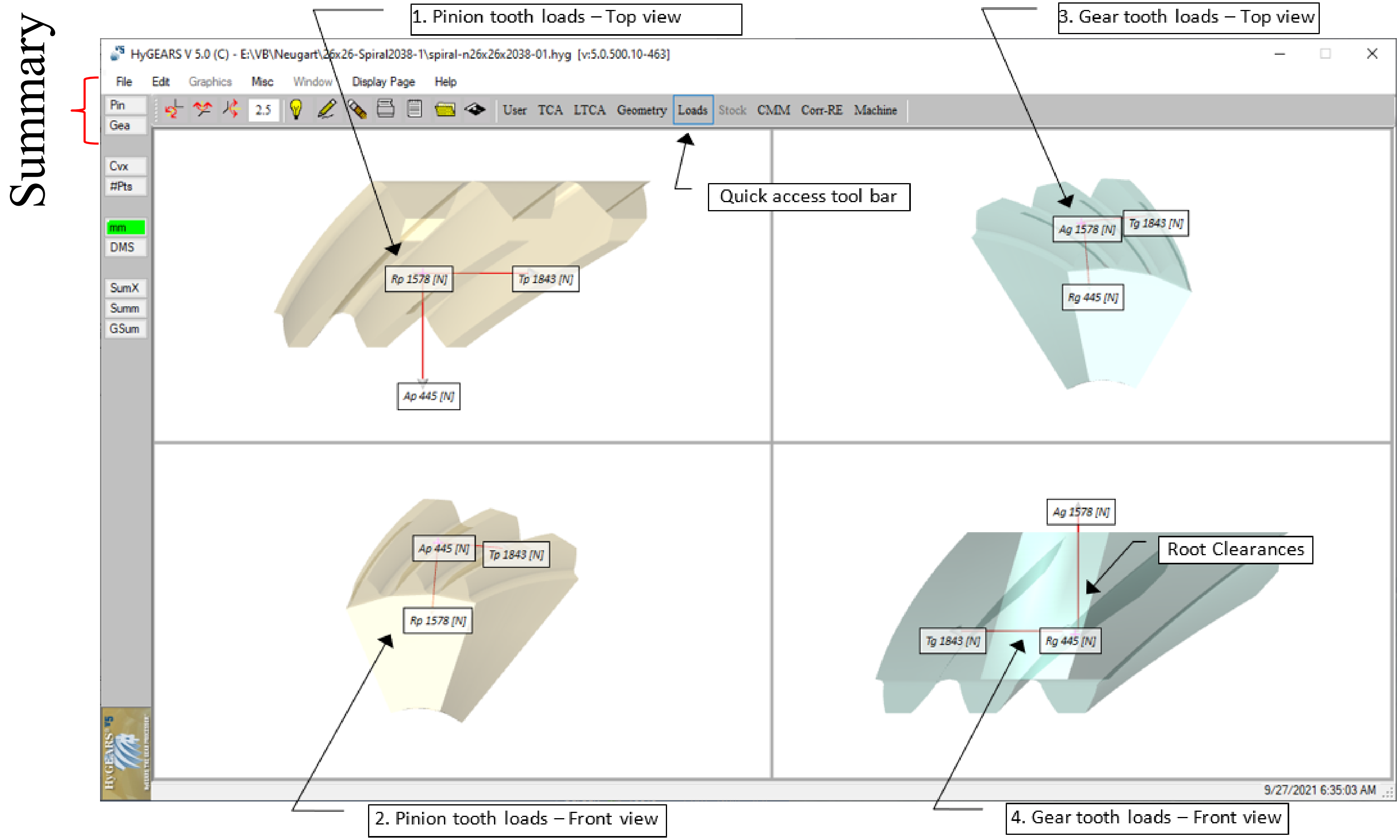
# Display Modes: LTCA



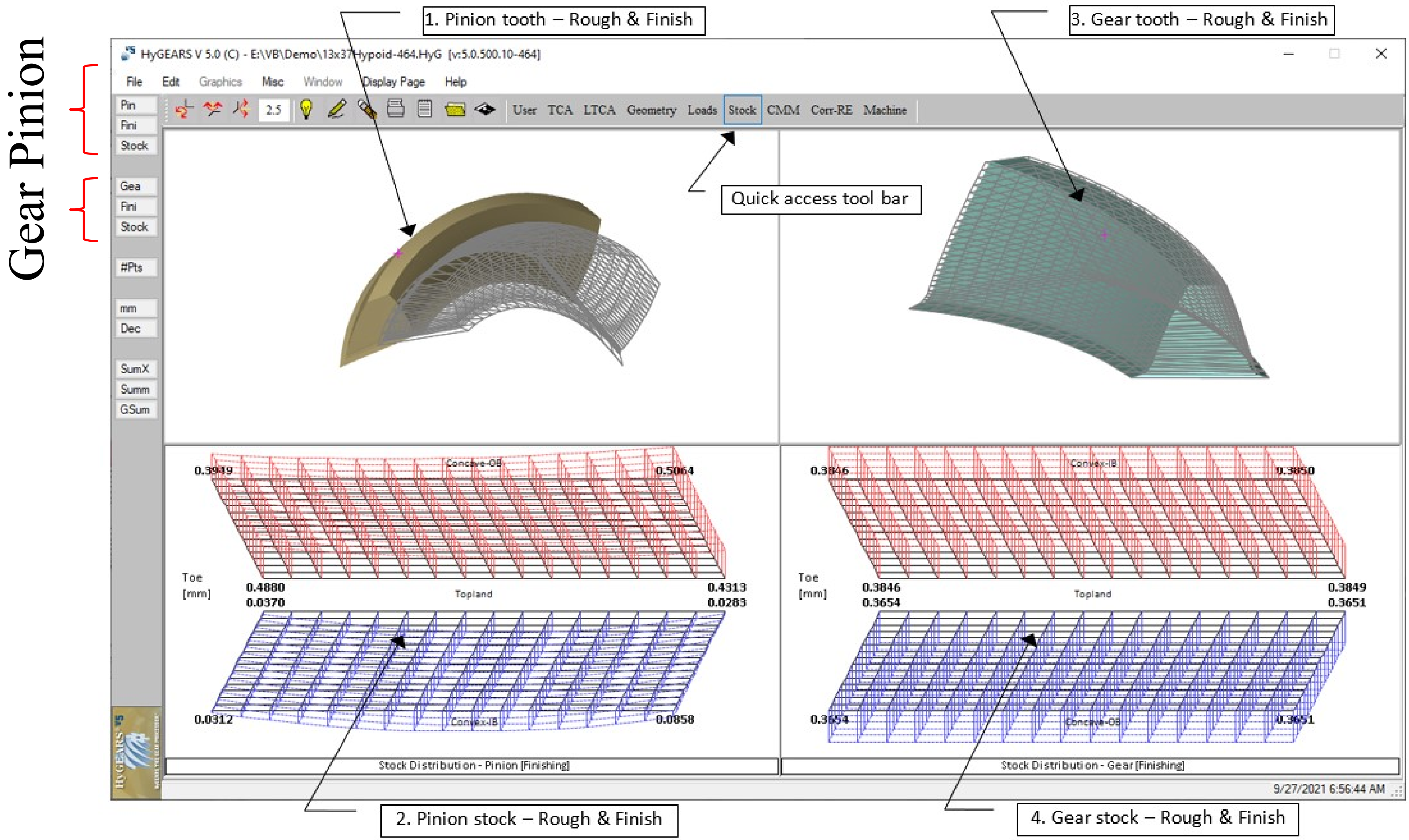
# Display Modes: Geometry



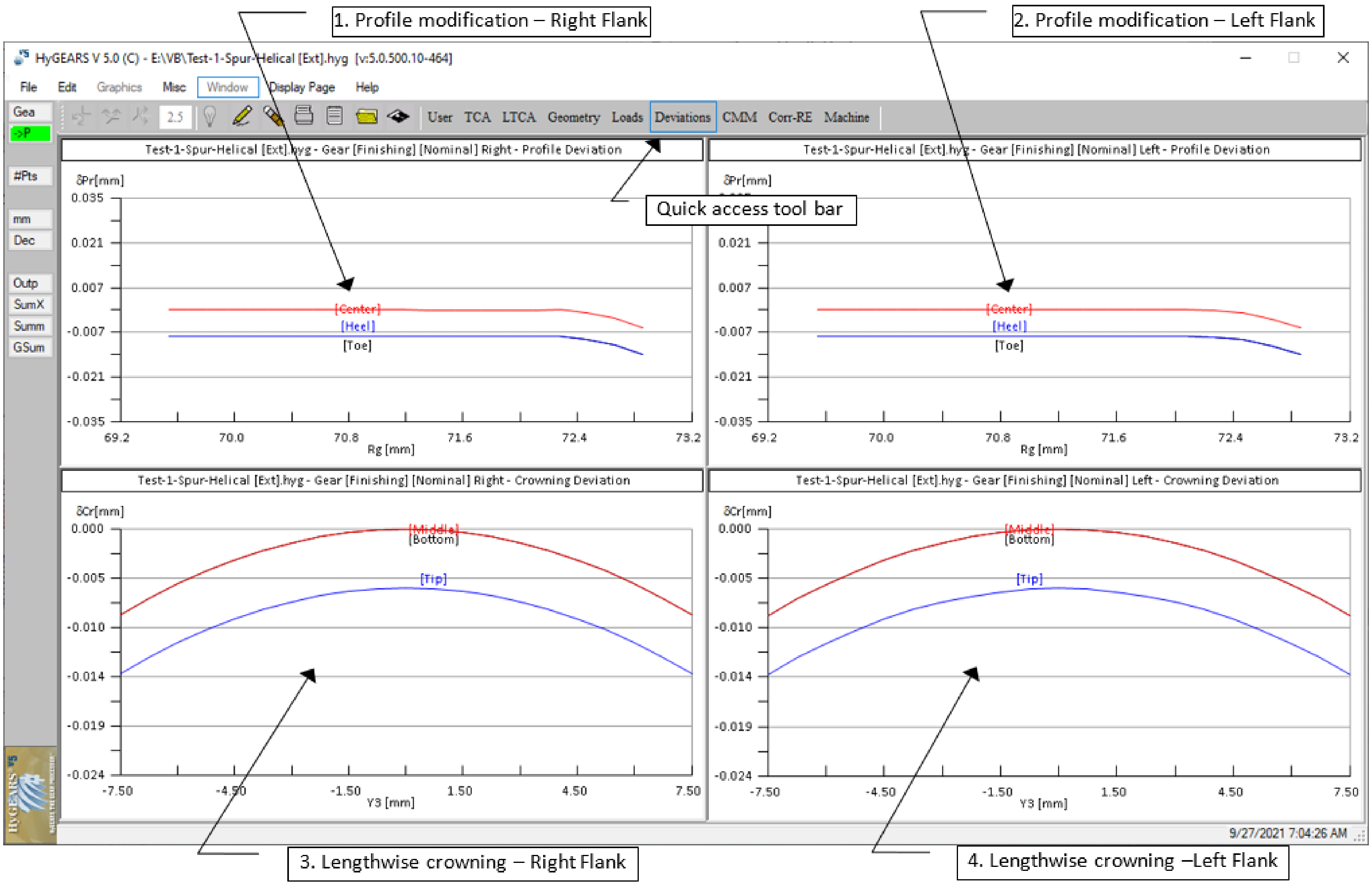
# Display Modes: Tooth Loads



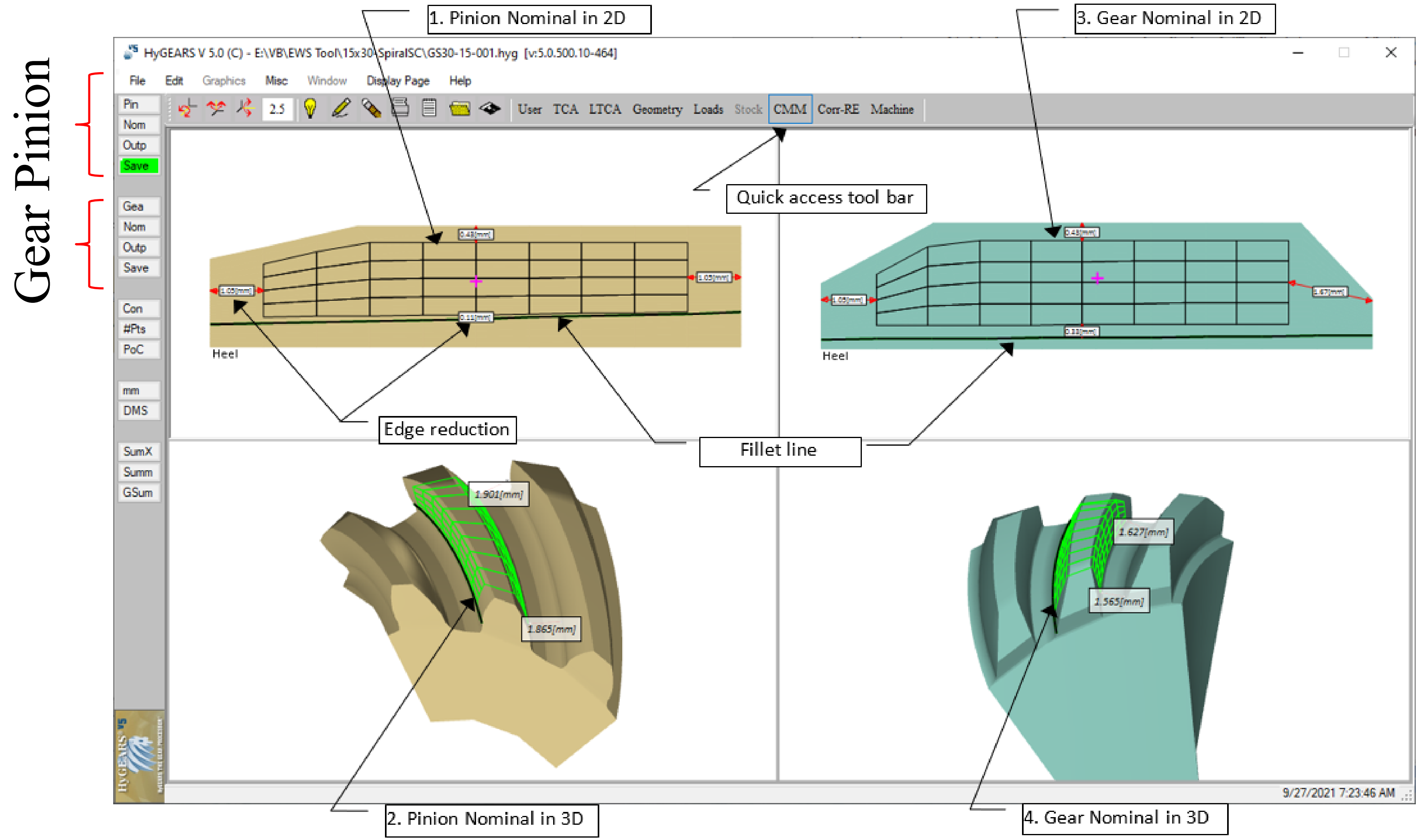
# Display Modes: Stock (Distribution – Fixed Setting)



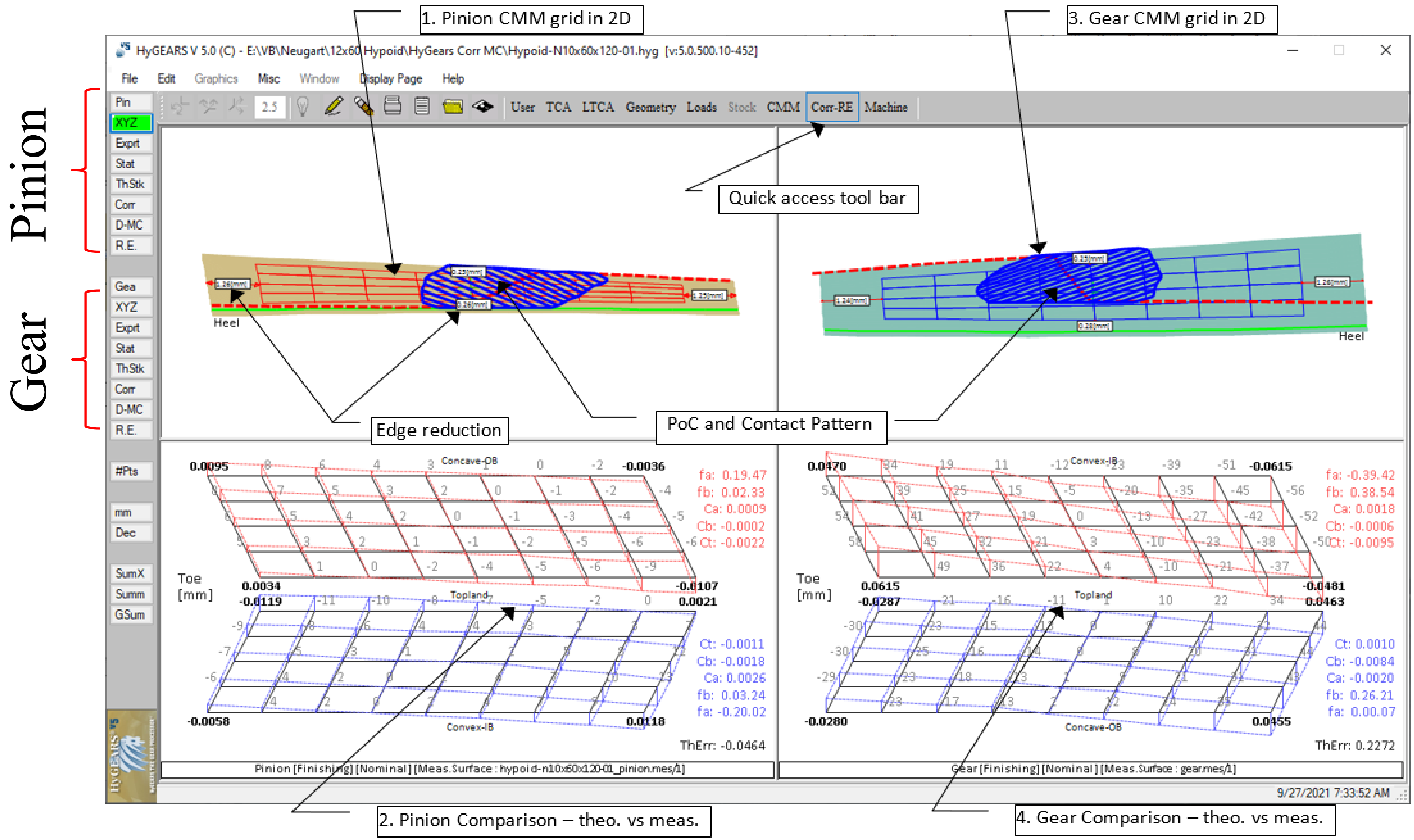
# Display Modes: Modifications (Profile, Crowning)



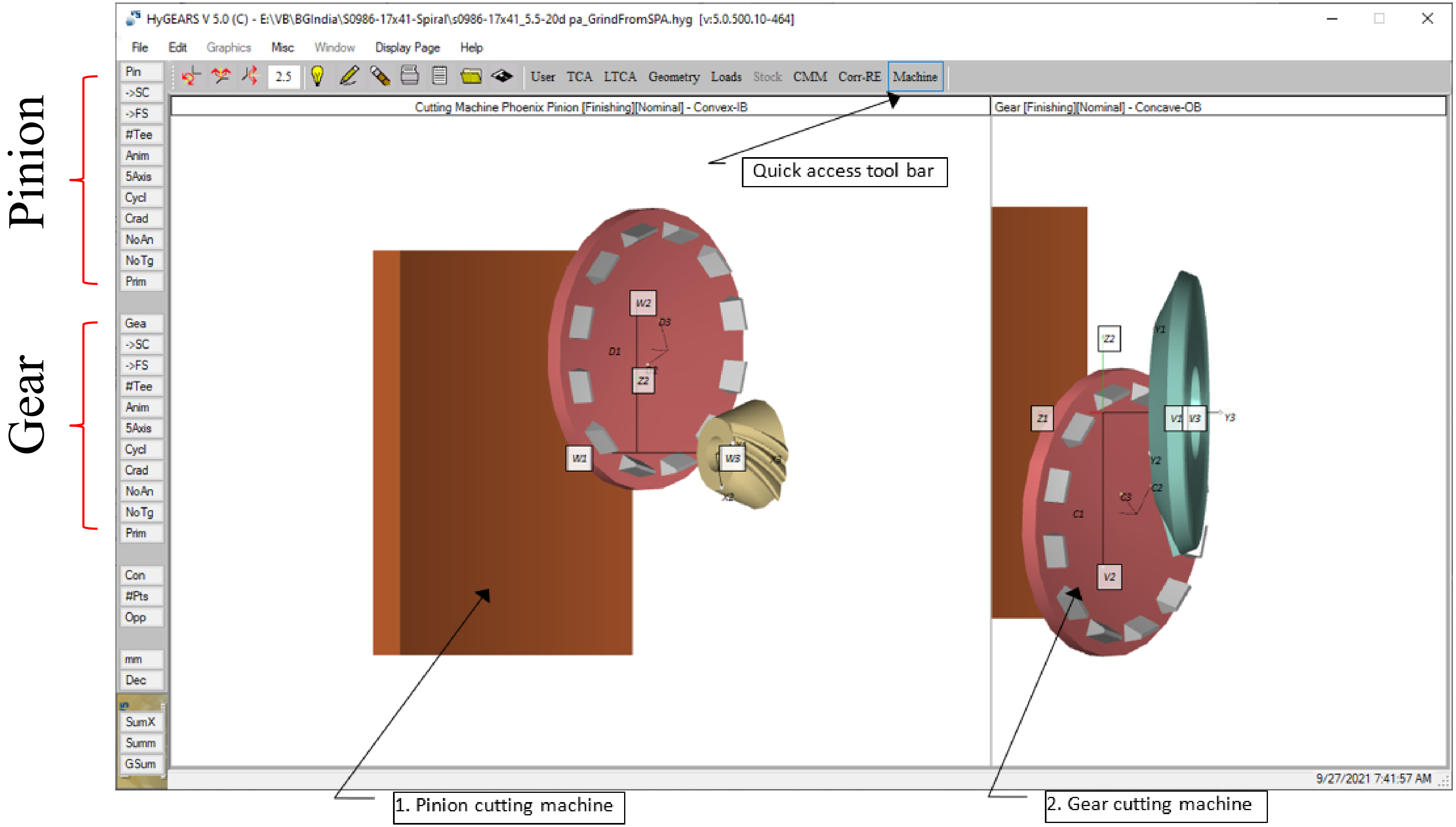
# Display Modes: CMM (Target nominal)



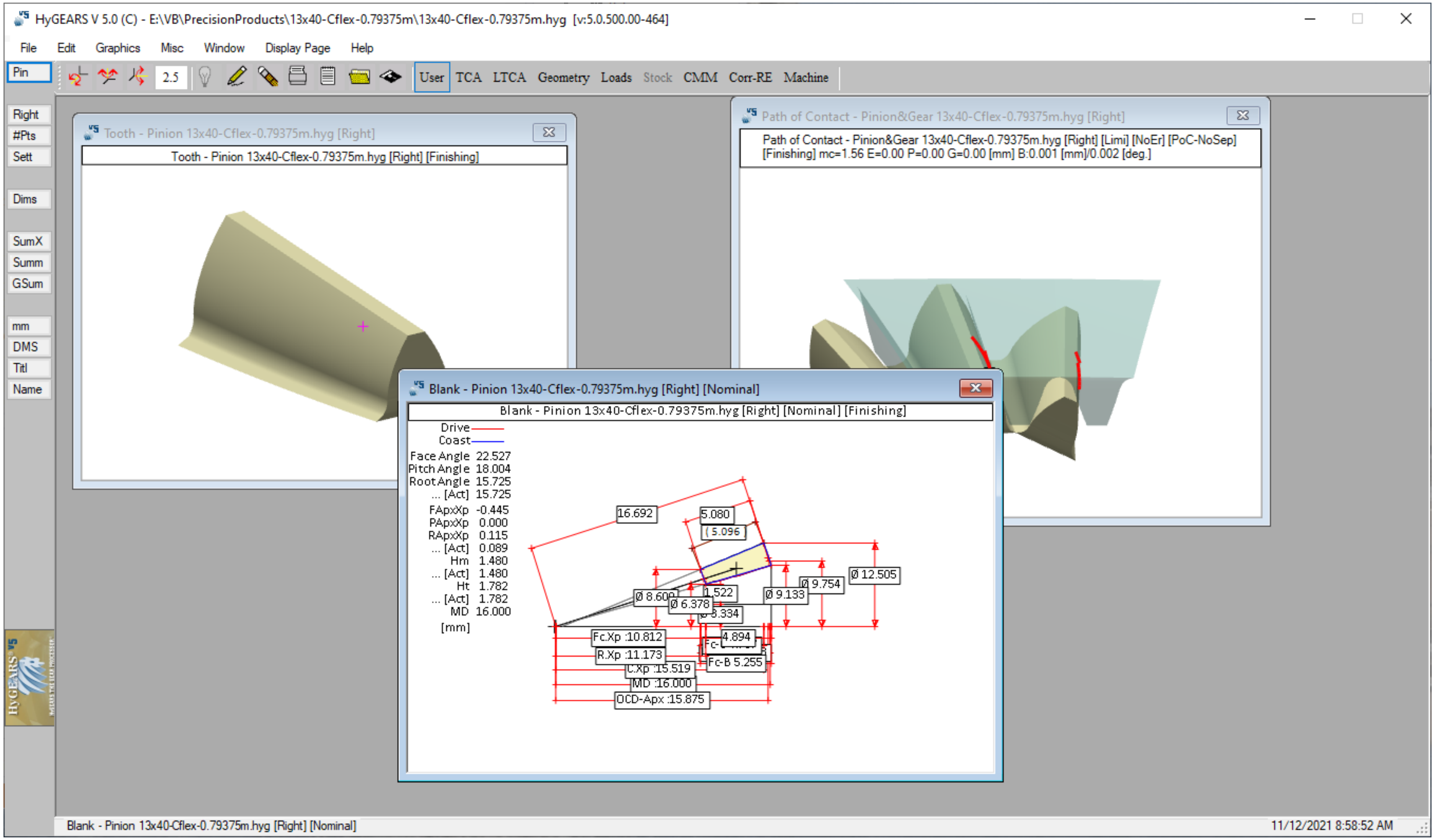
# Display Modes: Corr-RE (Closed Loop)



# Display Modes: Machine (5Axis CnC)



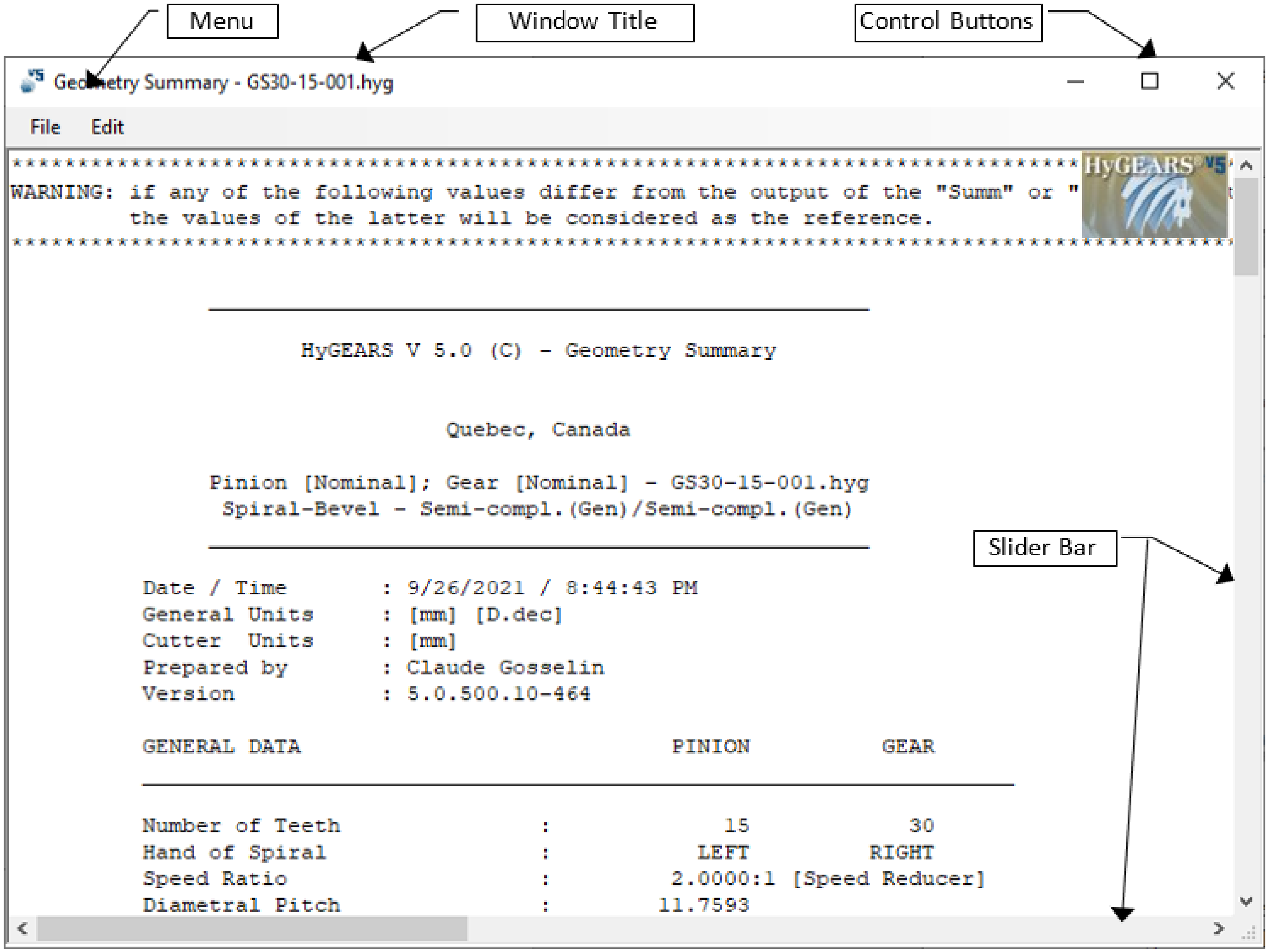
# Display Modes: User



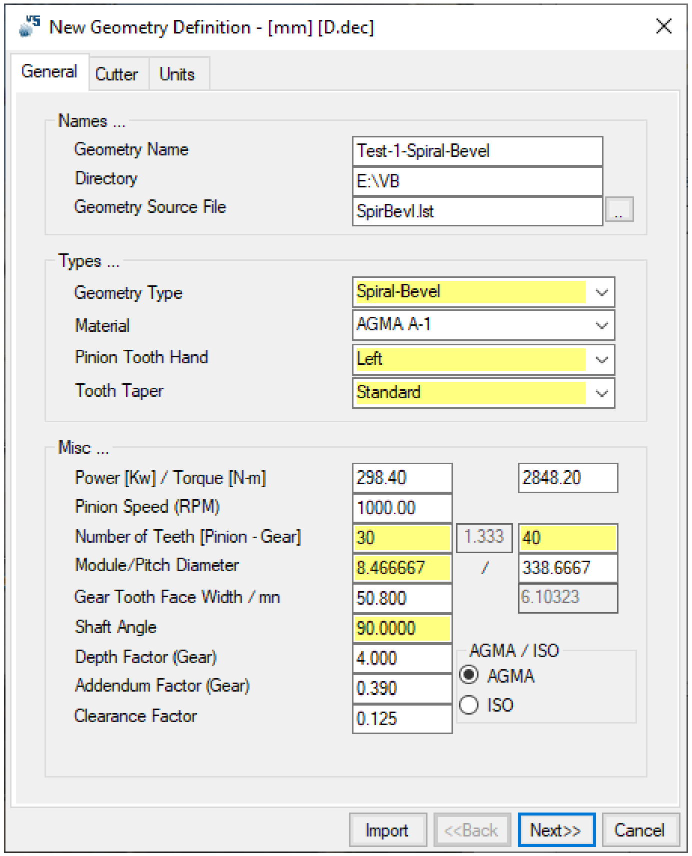
# Keyboard Shortcuts

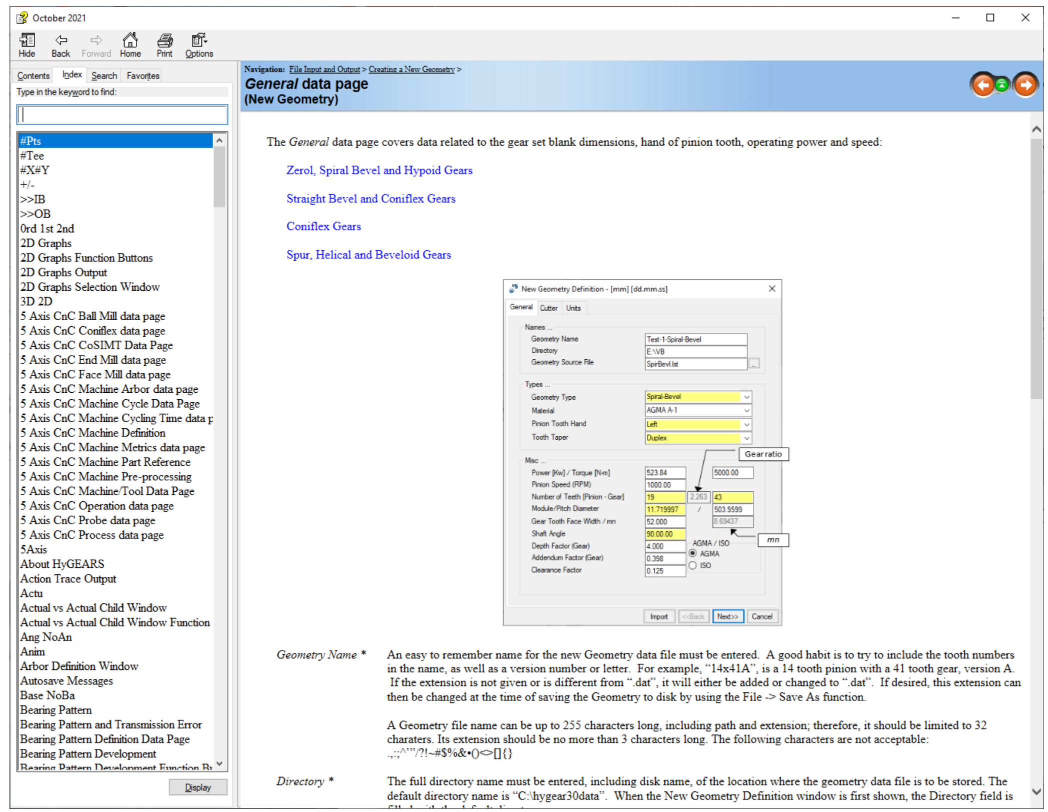
| | |
|---|---|
| Dbl-Click | maximizes / normalizes the current Child Window |
| ^C | copies the content of the current Child Window to the Windows Clipboard, |
| Shift^C | copies the content of the current Child Window + Borders to the Windows Clipboard, |
| ^E | toggles the current Child Window in 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, |
| ^H | cycles through the various possible Hide levels (no, partial, total and rendering) for the current Child Window, |
| ^I | Zooms in one level (max = 10 levels) |
| ^J | cycles through the various possible display projections for the current Child Window, |
| ^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, Bearing Pattern and 2D Graphs, |
| ^O | to open a 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 (Ease Off Child window) |
| ^U | Zooms out one level |
| ^Z | toggles the current Child Window in and out of the AutoZoom mode. |

# Text Results Window



# Context Sensitive Help: F1 Key



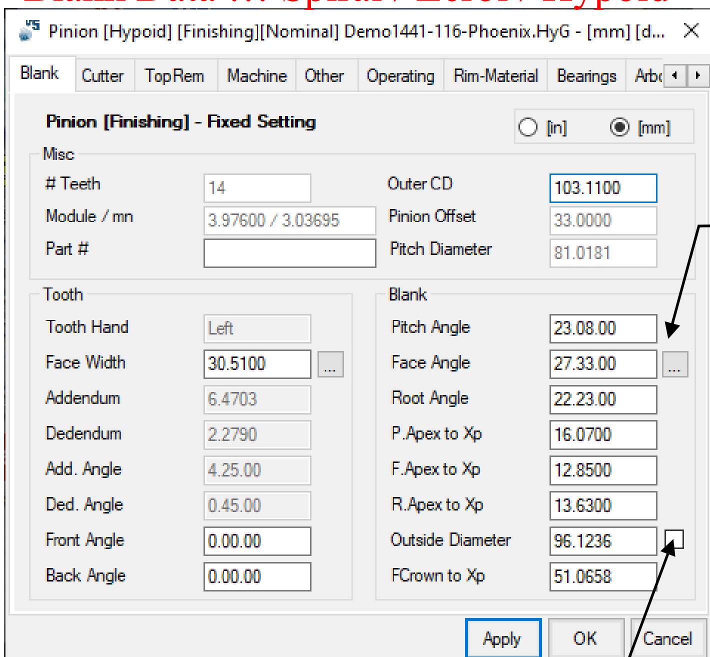
# Geometry Summary Editor

HyGEARS offers a *Geometry Summary Editor*, in which all aspects of the geometry, including Machine Settings, can be *consulted and modified* at any time.

“**Pin**” -> Pinion Summary Editor

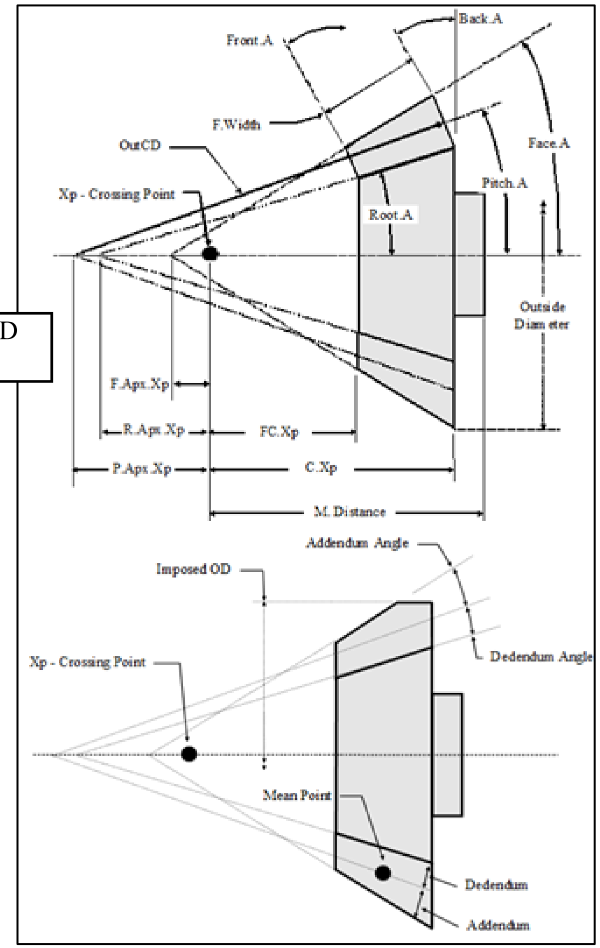
“**Gea**” -> Gear Summary Editor

Blank Data … Spiral / Zerol / Hypoid

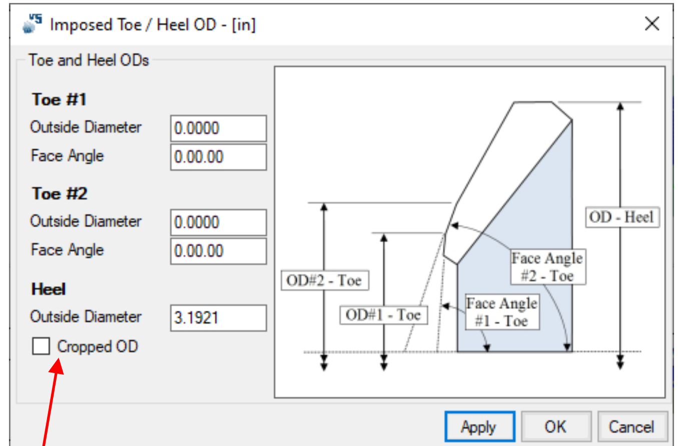



- Tapered Toe OD definition

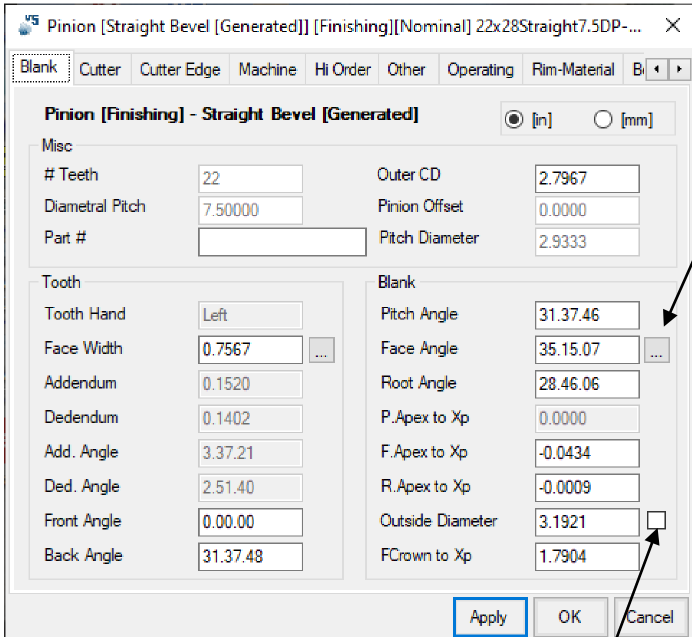
- Checked: the entered OD is *imposed*
- Unchecked: FApxXp is modified to *suit OD*



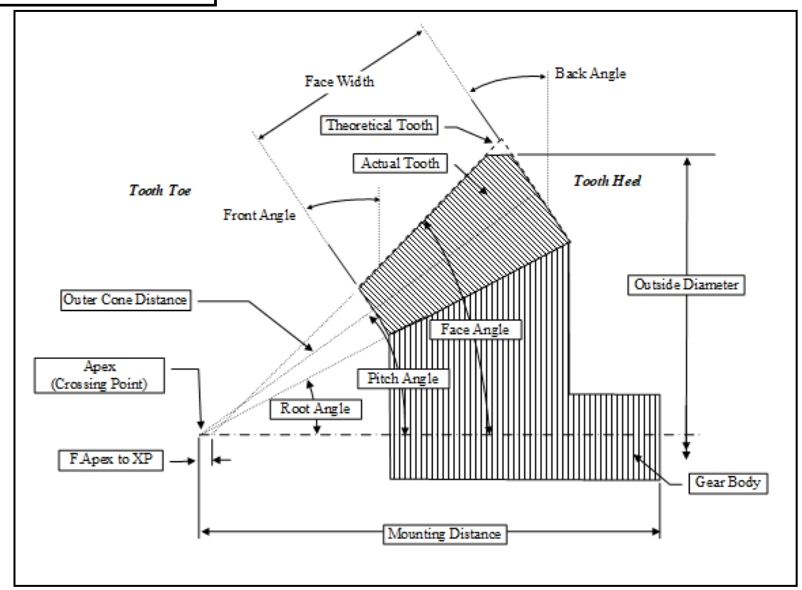
# Geometry Summary Editor




## Blank Data … Straight Bevel



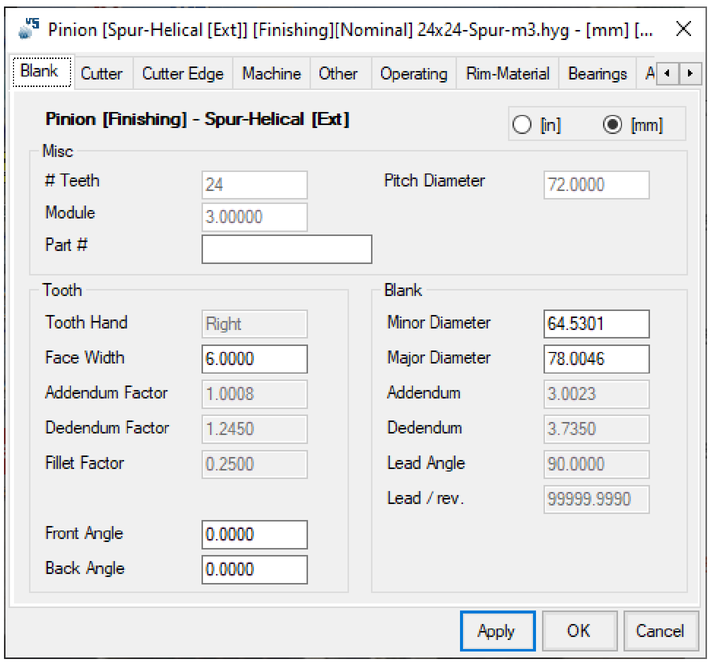

Tapered Toe OD definition

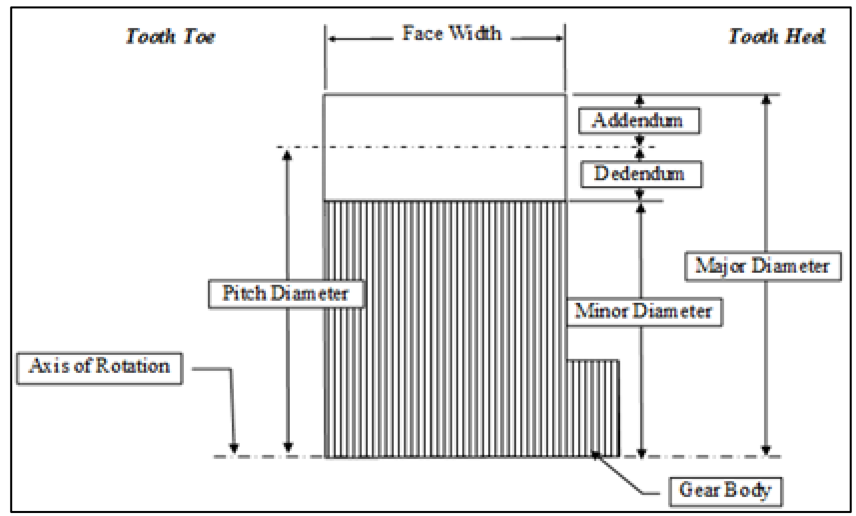



- Checked: the entered OD is *imposed*
- Unchecked: FApxXp is modified to *suit OD*

# Geometry Summary Editor

Blank Data … Spur / Helical / Beveloid

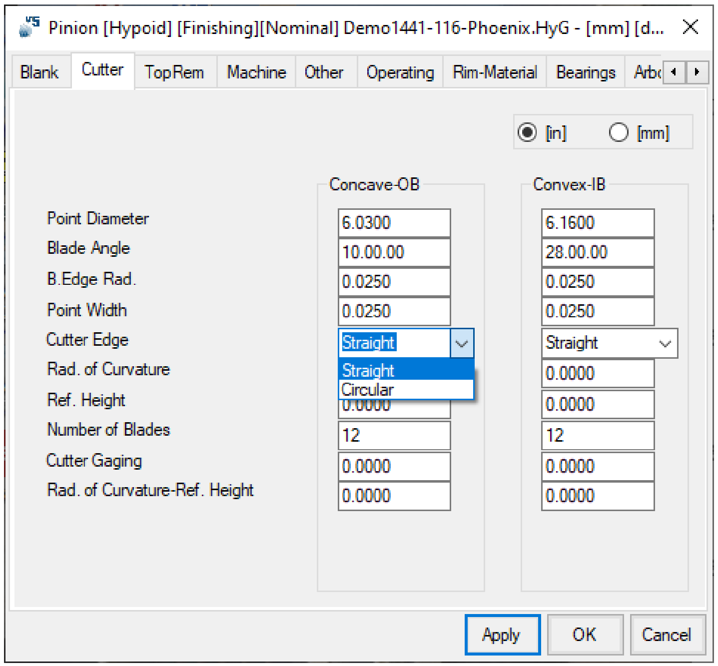


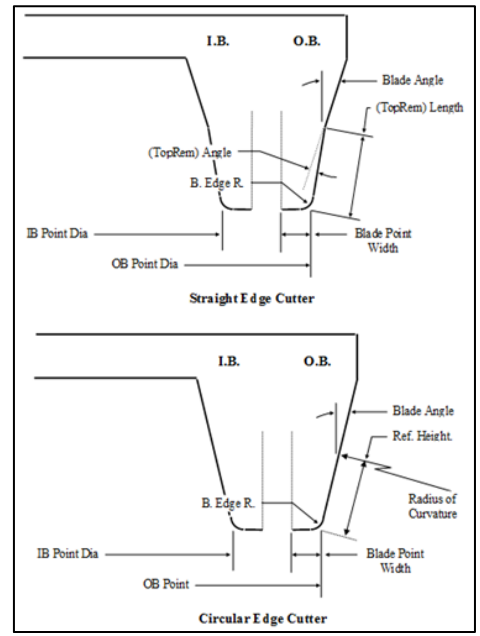



# Geometry Summary Editor

Spiral Bevel Cutter Data …

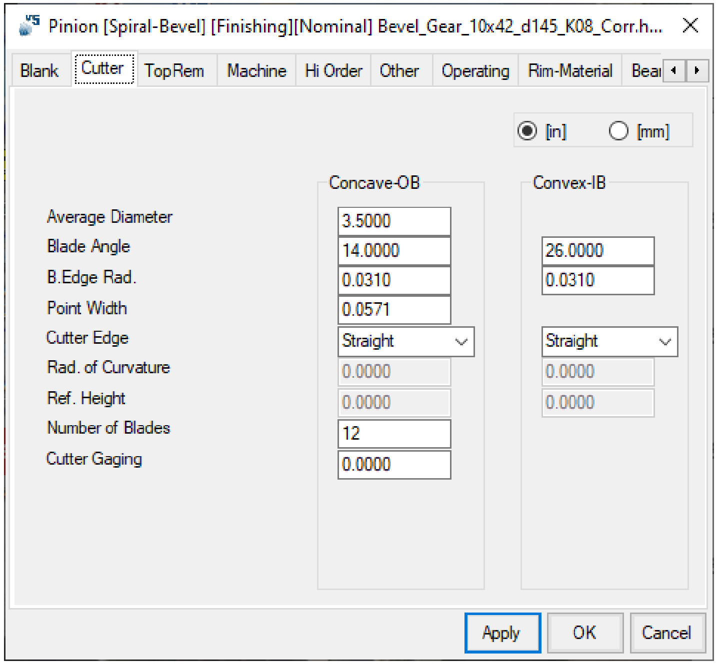
Fixed Setting



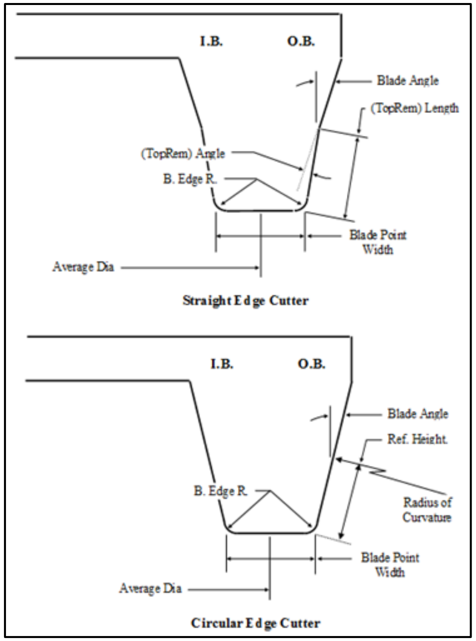



# Geometry Summary Editor

Spiral Bevel Cutter Data …

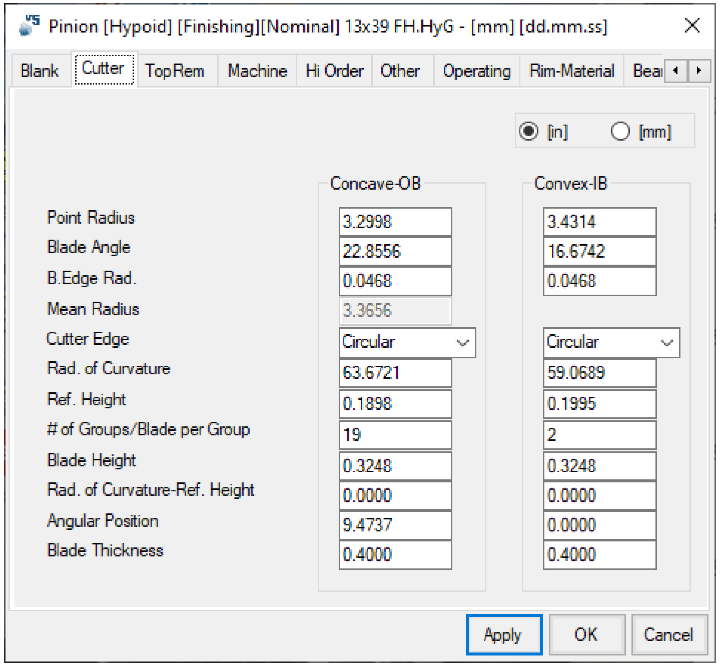



Spread Blade / DH

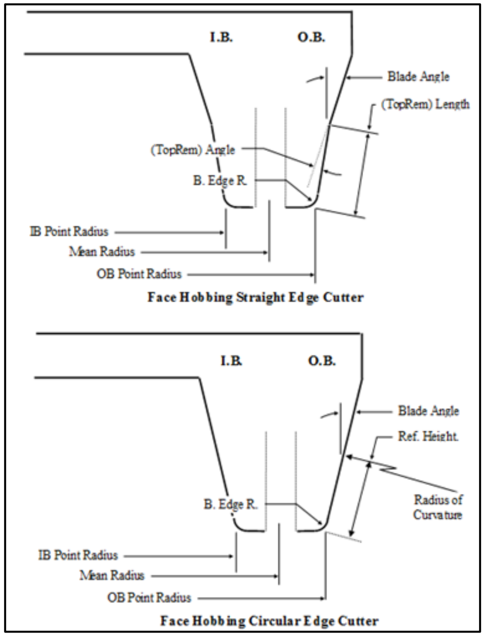


# Geometry Summary Editor

Spiral Bevel Cutter Data …

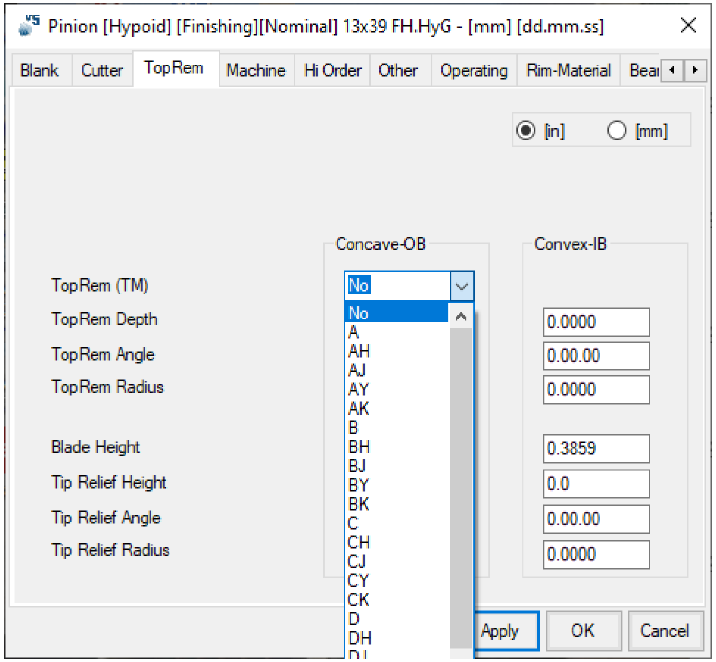


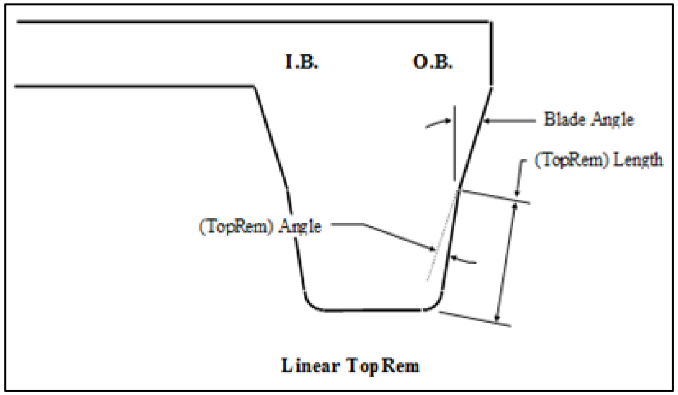

Face Hobbing

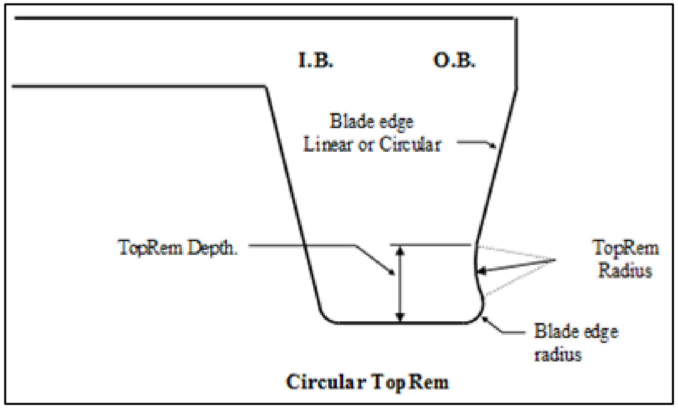


# Geometry Summary Editor

Spiral Bevel TopRem Data …



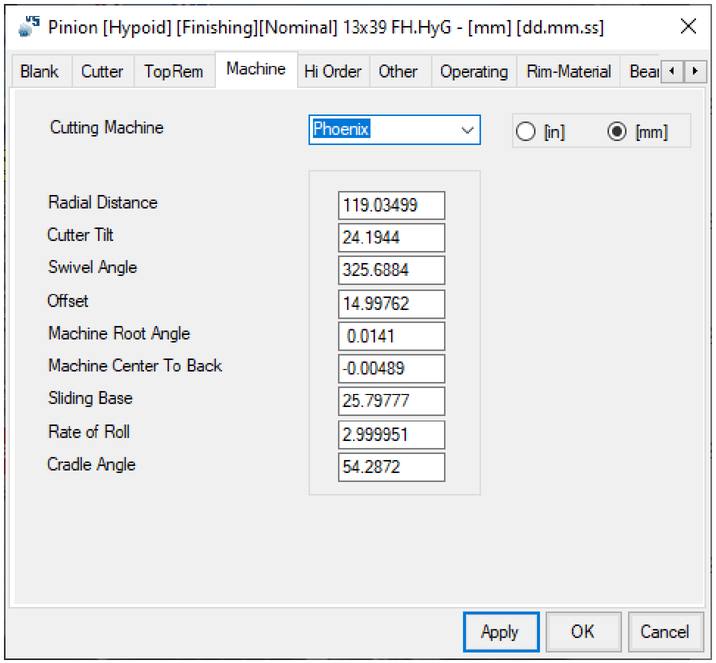




- Linear Blade: Linear *and* Circular TopRem
- Circular Blade: Circular TopRem *only*

# Geometry Summary Editor

Spiral Bevel Machine Data …

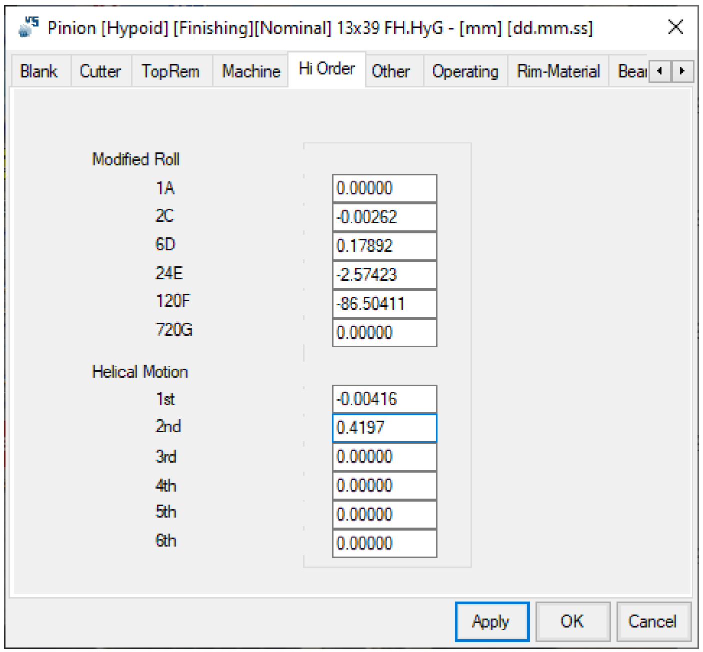



Changes with the process and machine:

- Fixed Setting
- Modified Roll
- Duplex Helical
- SimplexT
- Non Generated (Formate)
- Face Hobbing
- Cyclo-Palloid
- Etc.

# Geometry Summary Editor

Higher Order Data … Controls Modified Roll and Helical Motion up to 6th order



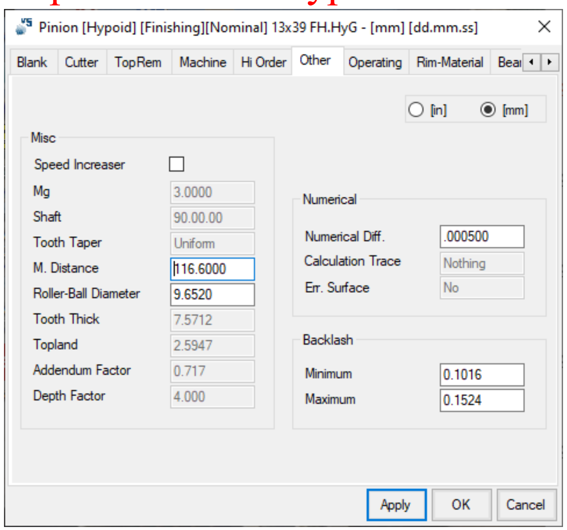

$$L_{1m} = \alpha_3 R_r + \frac{2C}{2}(C_r - \alpha_3 R_r)^2 - \frac{6D}{6}(C_r - \alpha_3 R_r)^3 + \frac{24E}{24}(C_r - \alpha_3 R_r)^4 - \frac{120F}{120}(C_r - \alpha_3 R_r)^5 + \frac{720G}{720}(C_r - \alpha_3 R_r)^6$$

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

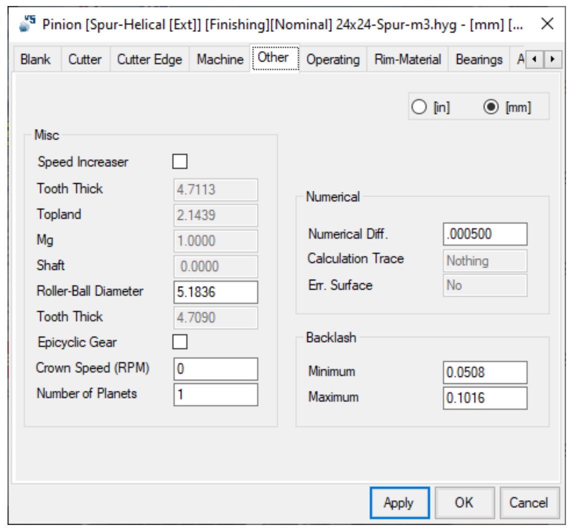
# Geometry Summary Editor

Other Data …

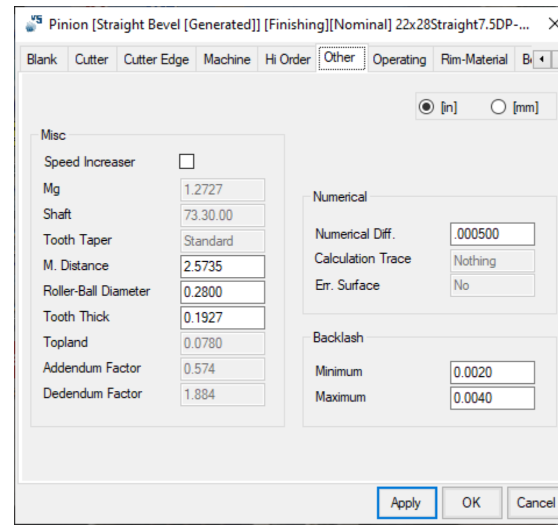
Spiral-Bevel / Hypoid




Spur / Helical / Beveloid

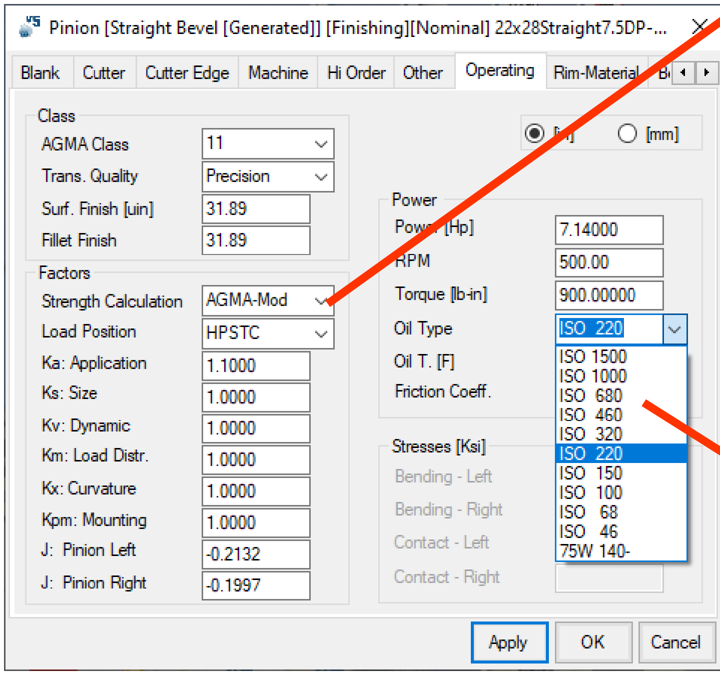



Straight-Bevel



# Geometry Summary Editor

Operating Data …




*AGMA*: traditional way,

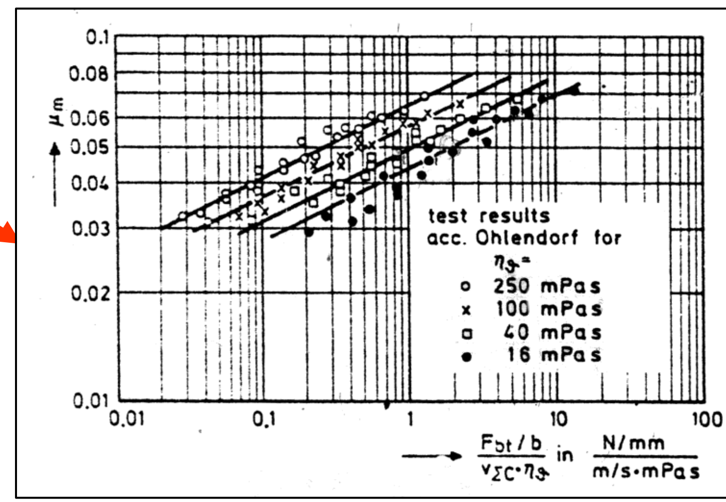
$$\sigma_b = \frac{2T_p P_d K_a K_s K_m}{D F J K_v K_x}$$

*AGMA-Mod*: variant of AGMA

$$\sigma_b = \frac{2T_p P_d K_a K_s K_m}{D \boxed{F/2} J K_v K_x}$$

*Aida+Terauchi*: Spur gears

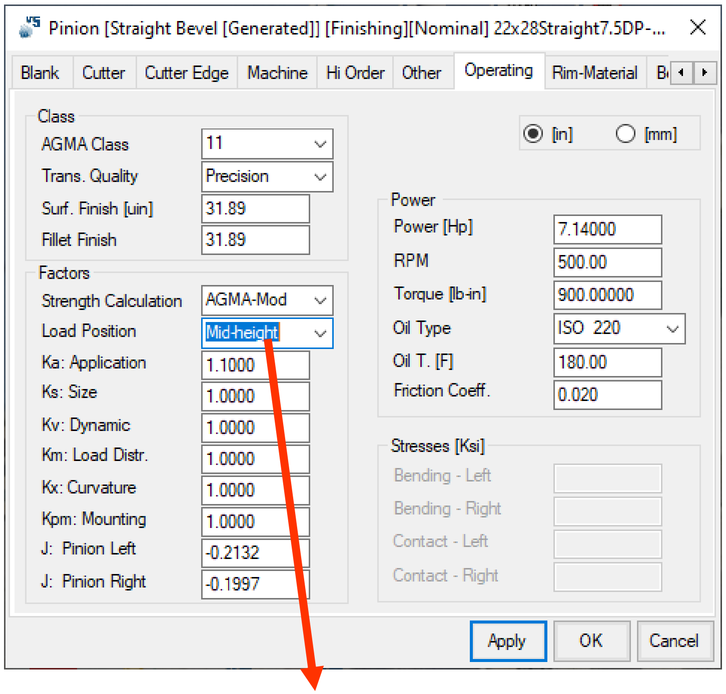
$$\sigma_{A+Tb} = \frac{2T_p}{DF}\left\{1+\frac{0.08T}{r_f}\right\}\frac{0.66S_b+0.4\sqrt{S_b^2+36\tau^2}+1.15S_c}{}\frac{K_a K_s K_m}{K_v K_x}$$

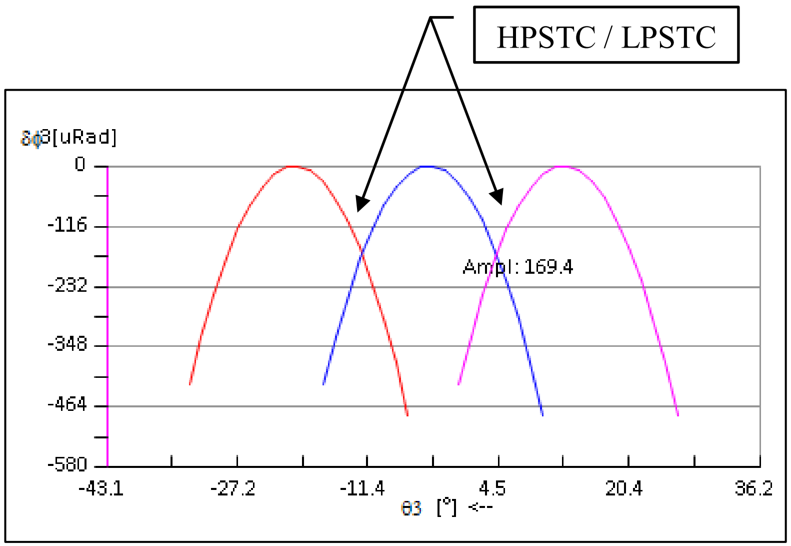



[ISO 46 ~ 320] – Prof. H. Winter

# Geometry Summary Editor

Operating Data …



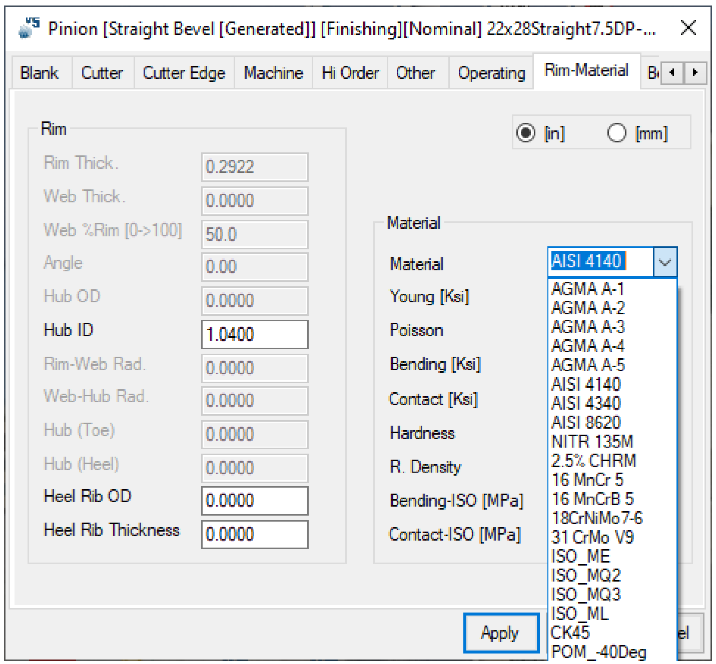

| | |
|---|---|
| HPSTC: | Highest point of single tooth contact (or Transfer Point); thus the PoC is first calculated; |
| Mid-height: | mid tooth-height, at mid-face width; |
| Free: | at tooth tip if AGMA Class < 9; at HPSTC if AGMA Class > 8 |

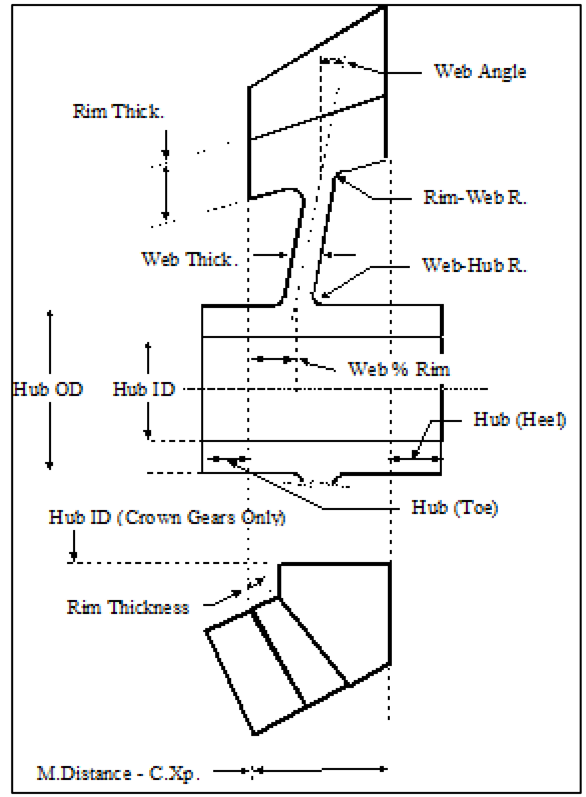
# Geometry Summary Editor

```
*** HYGEARS OIL DEFINITION FILE ***
;
;  Source:
;  Errichello R.,  The Lubrication of Gears, Part I,  Gear Technology, March/April 1991
;  Errichello R.,  The Lubrication of Gears, Part II, Gear Technology, May/June 1991
;
;  Equivalences:
;  ISO        AGMA       SAE Crankase       SAE Gear
;  --------------------------------------------------
;  1500                                     250
;  1000       8A                            250 (lower)
;   680       8                             140 (upper)
;   460       7                             140
;   320       6                             140 (lower)
;   220       5            50                90-85W
;   150       4            40                   85W
;   100       3            30                   80W
;    68       2         20W-30                  80W
;    46       1         20W-20                  75W
;
;  This is a comment line that is ignored
;  by HyGEARS. Comment lines should appear at the
;  beginning of the file, and start with a ";" semi-colon character.
;
;  Each oil definition is made of 2 consecutive lines:
;              one for Absolute Viscosity                   (uReyns, Reyns or lb/in2)
;       one for Pressure-Viscosity Coefficient              (in2/lb, m2/N)
;
;  1st  Oil data line is given in the following sequence:
;              Oil Name
;              Absolute Viscosity Units (UREYN, REYN, CP)
;              Temperature Units        (F,    C)
;              Data Sets                      (Viscosity-Temperature)
;
;  2nd  Oil data line is given in the following sequence:
;              Oil Name
;              Pressure-Viscosity Coefficient Units  (IN2/LB, M2/N)
;              Temperature Units                   (F,      C)
;              Data Sets                     (Pressure-Viscosity Coefficient-Temperature)
;
; Warning : the character "-" is a separator between        Viscosity and Temperature
;                                                           Pressure-viscosity coefficient and Temperature
;
ISO 1500, UREYN,  F,  200-100,   90-120,   47-140,   25-160,   15-180,  9.5-200,  6.1-220,  4.3-240,    3-260
ISO 1500, IN2/LB, F,  2.2-100,  1.9-125, 1.75-150, 1.61-175, 1.48-200, 1.35-225, 1.25-250, 1.15-275, 1.07-300
```

# Geometry Summary Editor

Rim - Material Data …



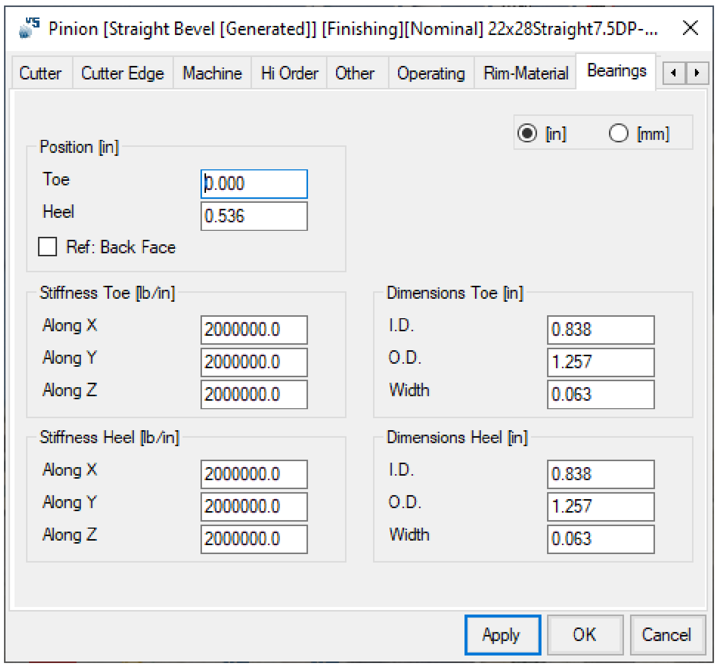



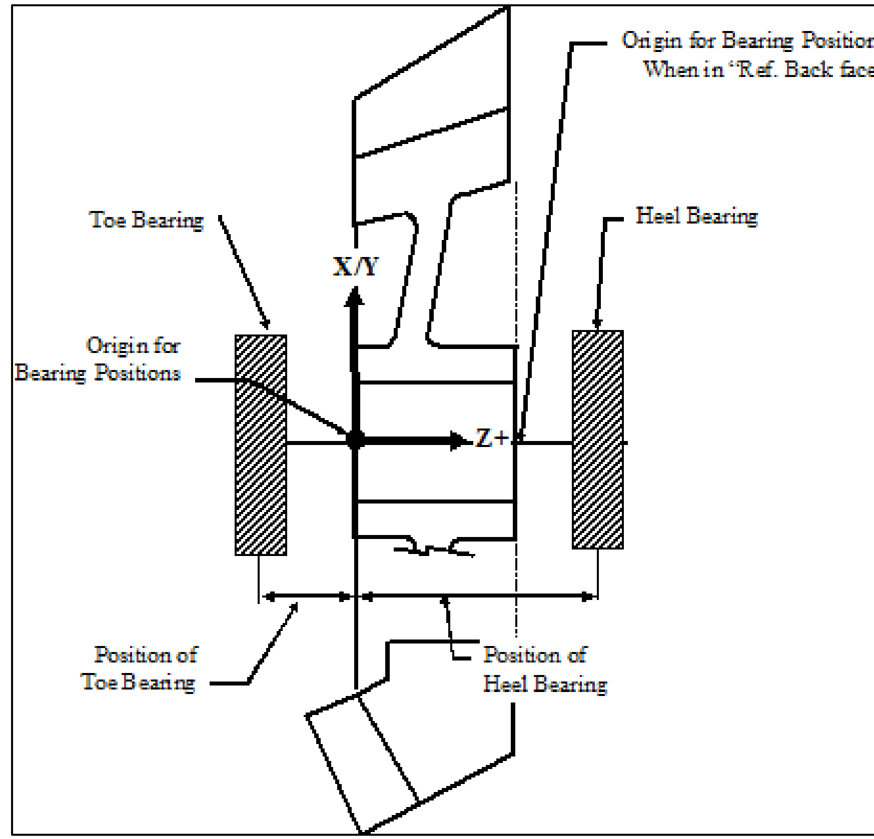
# Geometry Summary Editor

```
*** HYGEARS MATERIAL FILE ***
;  This is comment line which is ignored
;  by HyGEARS. Comment lines should appear at the
;  beginning of the file, and start with a ";" semi-colon character.
;
;  Material data is given in the following sequence:
;              Material Name
;              Bending Strength
;              Compressive Strength
;              Strength units (PA, KPA, MPA, GPA, PSI, KSI)
;              Young Modulus
;              Poisson ratio
;              Young Modulus units (PA, KPA, MPA, GPA, PSI, KSI)
;              Hardness value
;              Hardness units (BHN, HRC, HRB)
;              Relative density (relative to water)
AGMA A-1          ,  200,  630, MPA, 200, 0.3, GPA, 180, BHN, 7.8
AGMA A-2          ,  250,  750, MPA, 200, 0.3, GPA, 240, BHN, 7.8
AGMA A-3          ,  280,  870, MPA, 200, 0.3, GPA, 300, BHN, 7.8
AGMA A-4          ,  320, 1050, MPA, 200, 0.3, GPA, 360, BHN, 7.8
AGMA A-5          ,  340, 1150, MPA, 200, 0.3, GPA, 400, BHN, 7.8
AISI 4140         ,  270, 1175, MPA, 200, 0.3, GPA,  48, HRC, 7.8
AISI 4340         ,  290, 1125, MPA, 200, 0.3, GPA,  46, HRC, 7.8
NITR 135M         ,  295, 1250, MPA, 200, 0.3, GPA,  60, HRC, 7.8
2.5% CHRM         ,  415, 1300, MPA, 200, 0.3, GPA,  57, HRC, 7.8
```

# Geometry Summary Editor

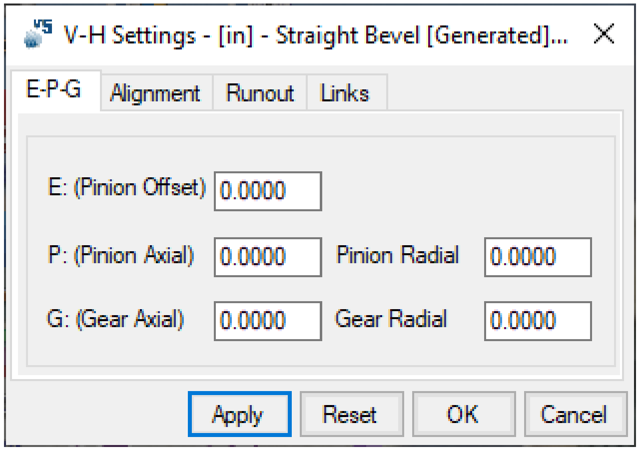
## Bearing Data …

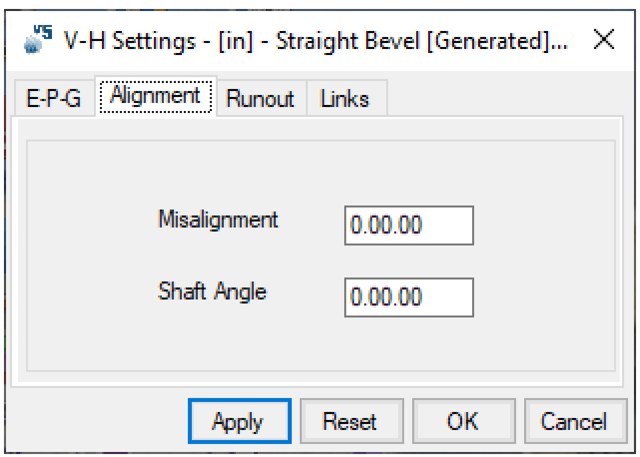


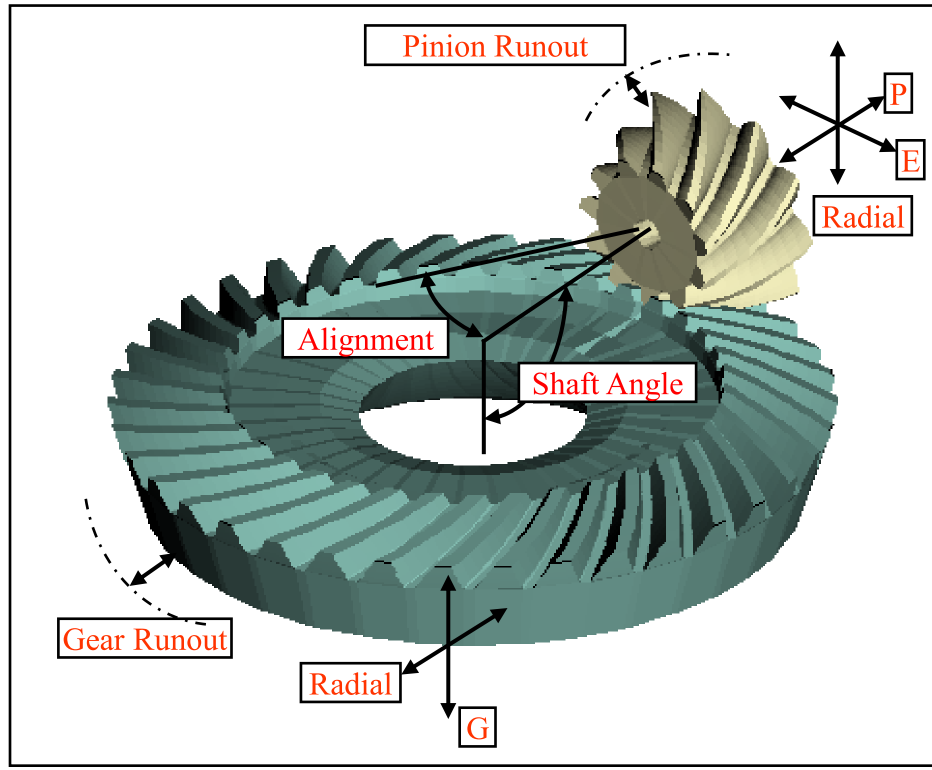



# VH Settings Editor

Bevel Gears …

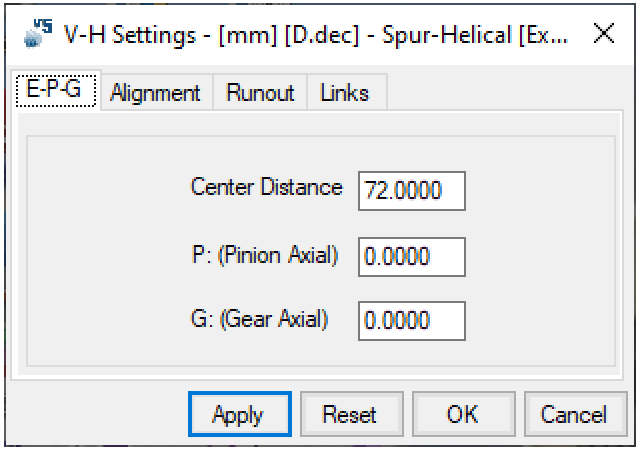


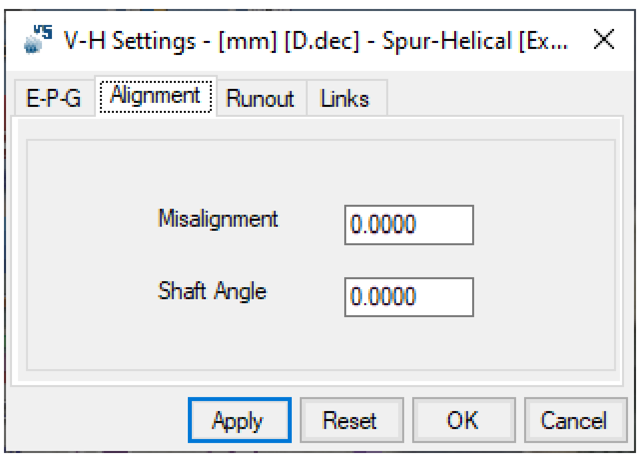



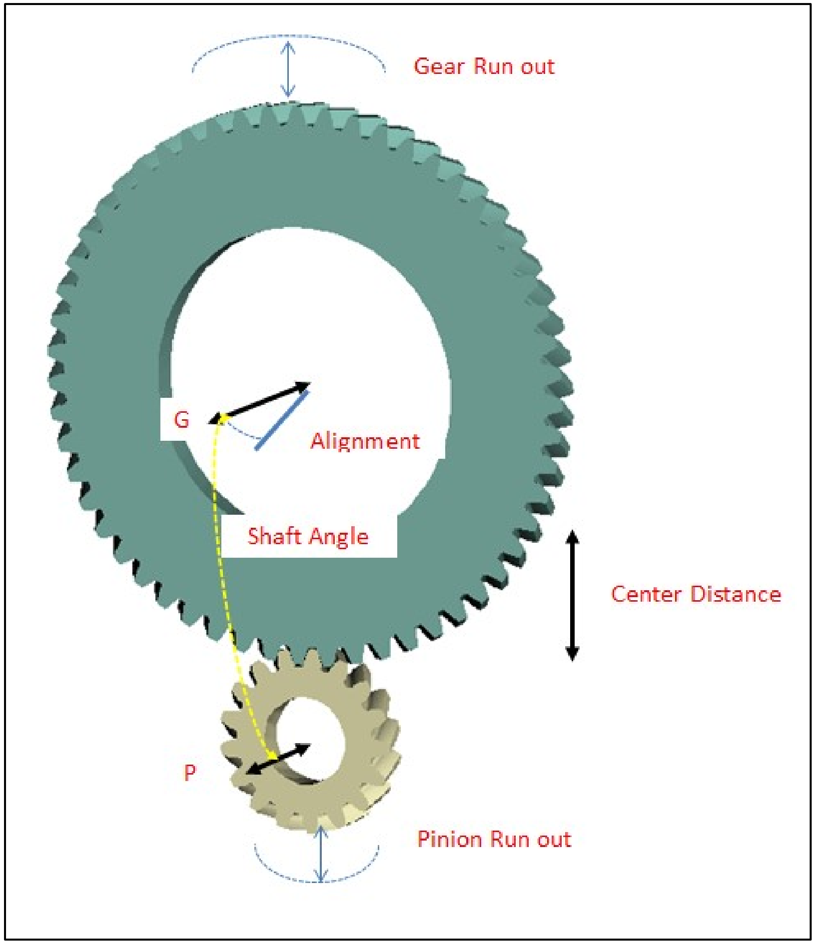



# VH Settings Editor

Spur / Helical Gears …

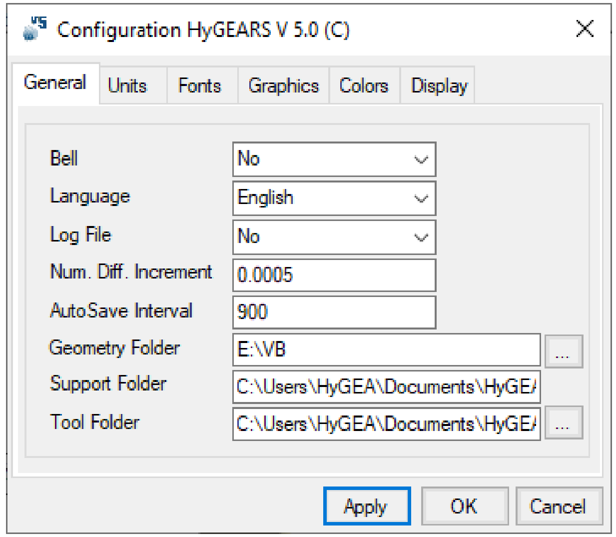


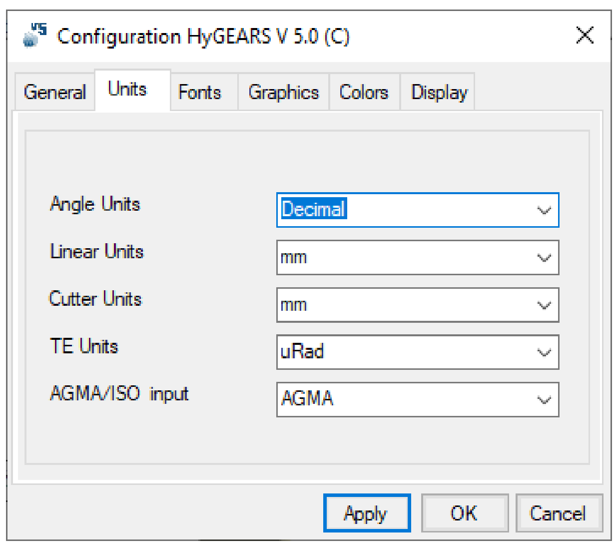



# HyGEARS Configuration

General Data Page



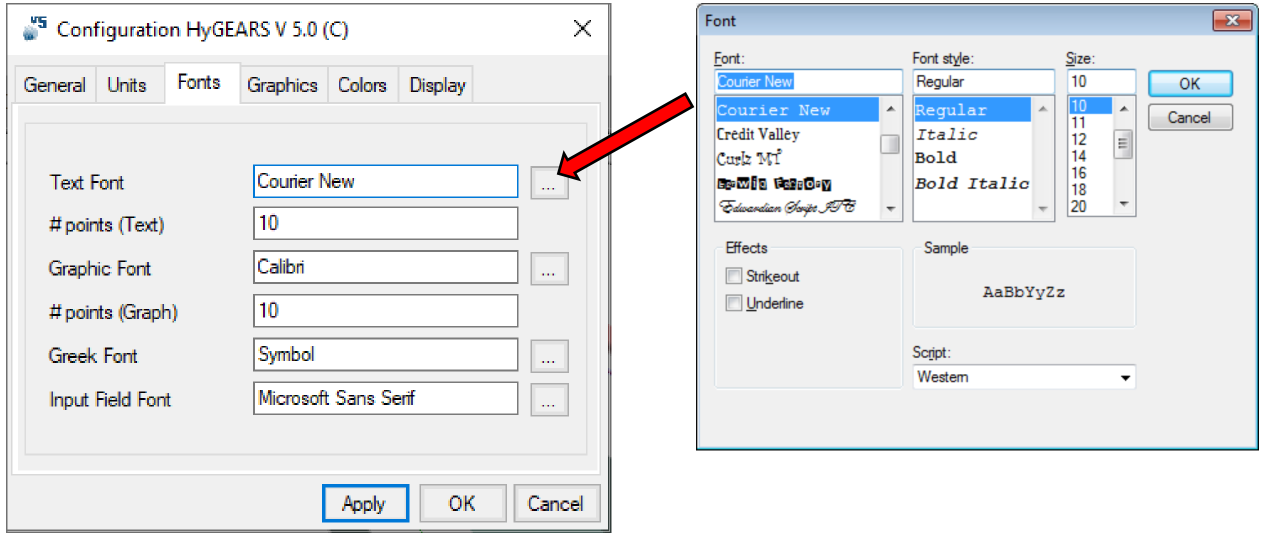

Units Data Page



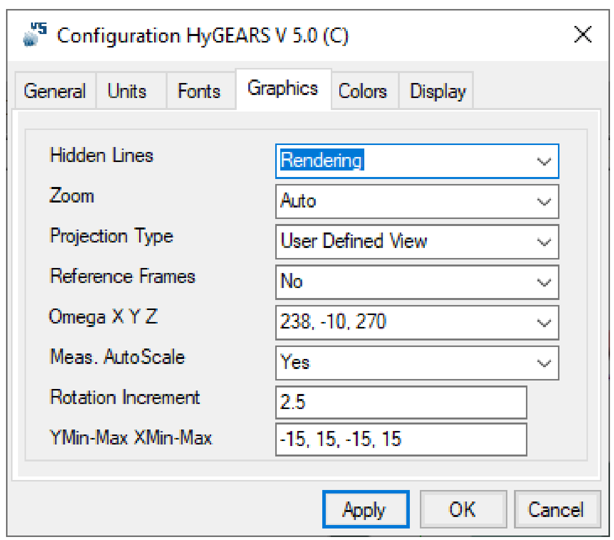

| | [in] | [mm] |
|---|---|---|
| Torque | [lb-in] | [N-m] |
| Force | [lb] | [N] |
| Stress | [Ksi] | [Mpa] |
| Power | [HP] | [Kw] |
| Stiffness | [lb/in] | [N/mm] |
| Volume | [in$^3$] | [mm$^3$] |
| Mass | [lbm] | [kgm] |
| Inertia | [lbm- in$^2$] | [kgm- mm$^2$] |
| Speed | [ft/min] | [m/min] |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

# HyGEARS Configuration / 2

Fonts Data Page

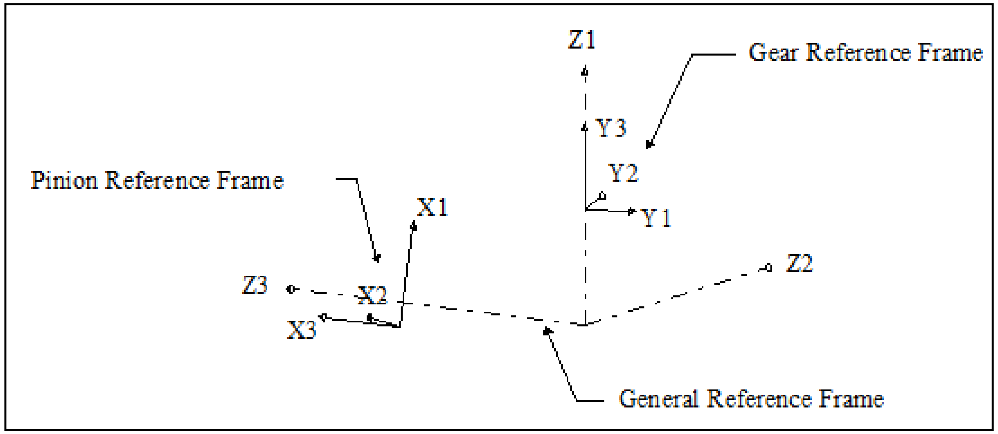



Graphics Data Page

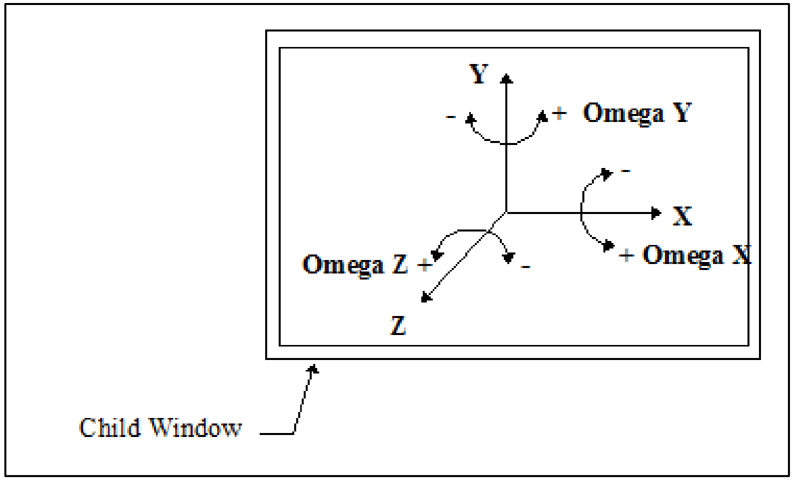


# HyGEARS Configuration / 3

Reference Frames

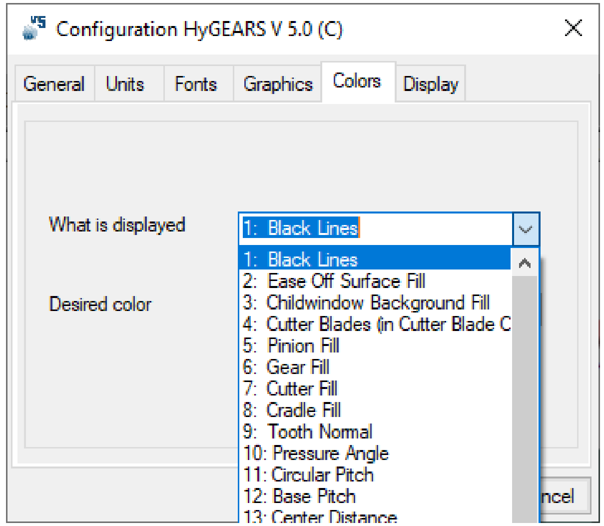


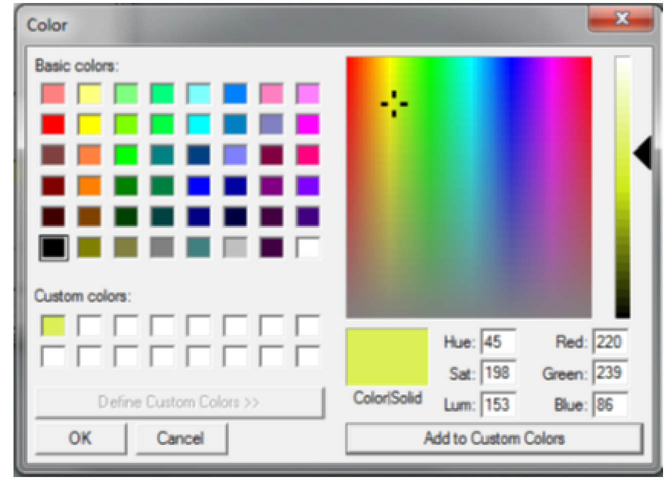

Rotation Axes



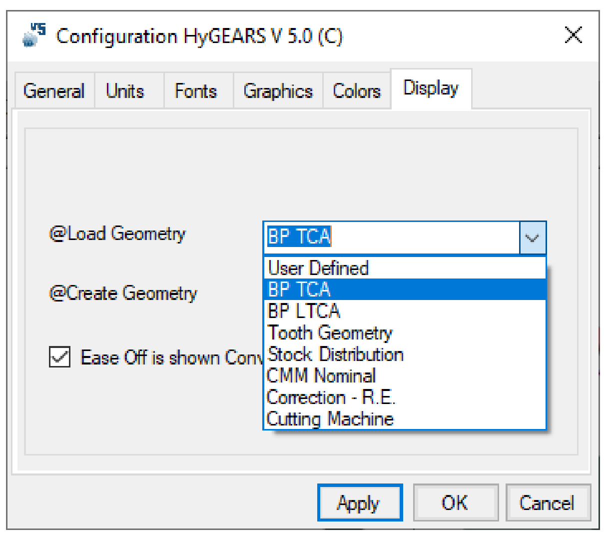
# HyGEARS Configuration / 4

Colors Data Page




Display Data Page



# Creating a *New* Geometry

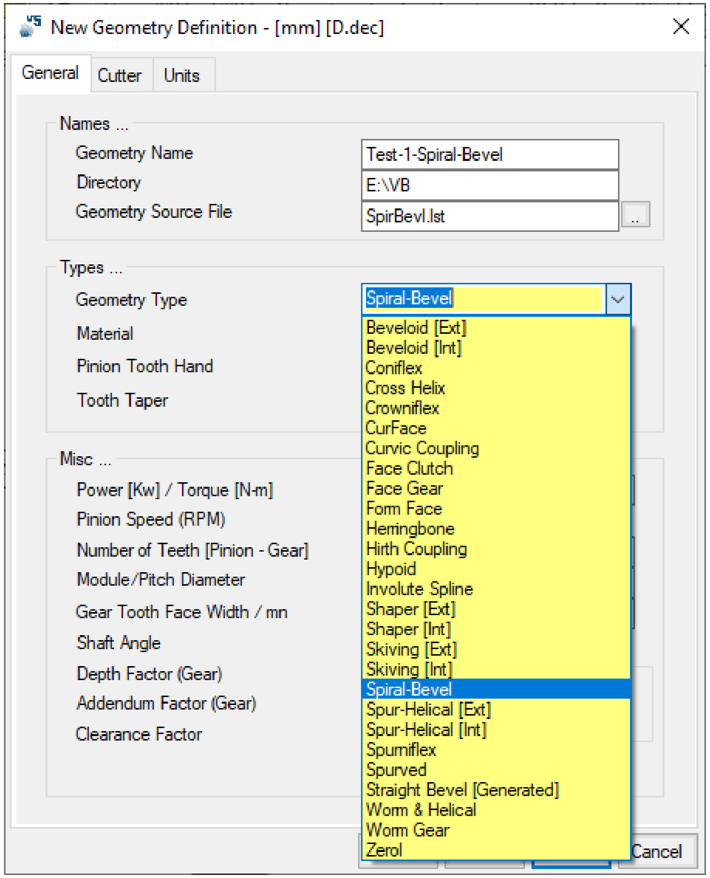
In HyGEARS, creating a new geometry is simple.

The New Geometry Definition Window offers basic input fields in which the required data is provided.

The New Geometry can be processed at once, and saved in a file for later retrieval.

At every step, HyGEARS offers *default values* to ease creation.

Entries in yellow must be provided by the user.



# Creating a *New* Geometry

## Bevel Gear Macro and Micro Geometry:

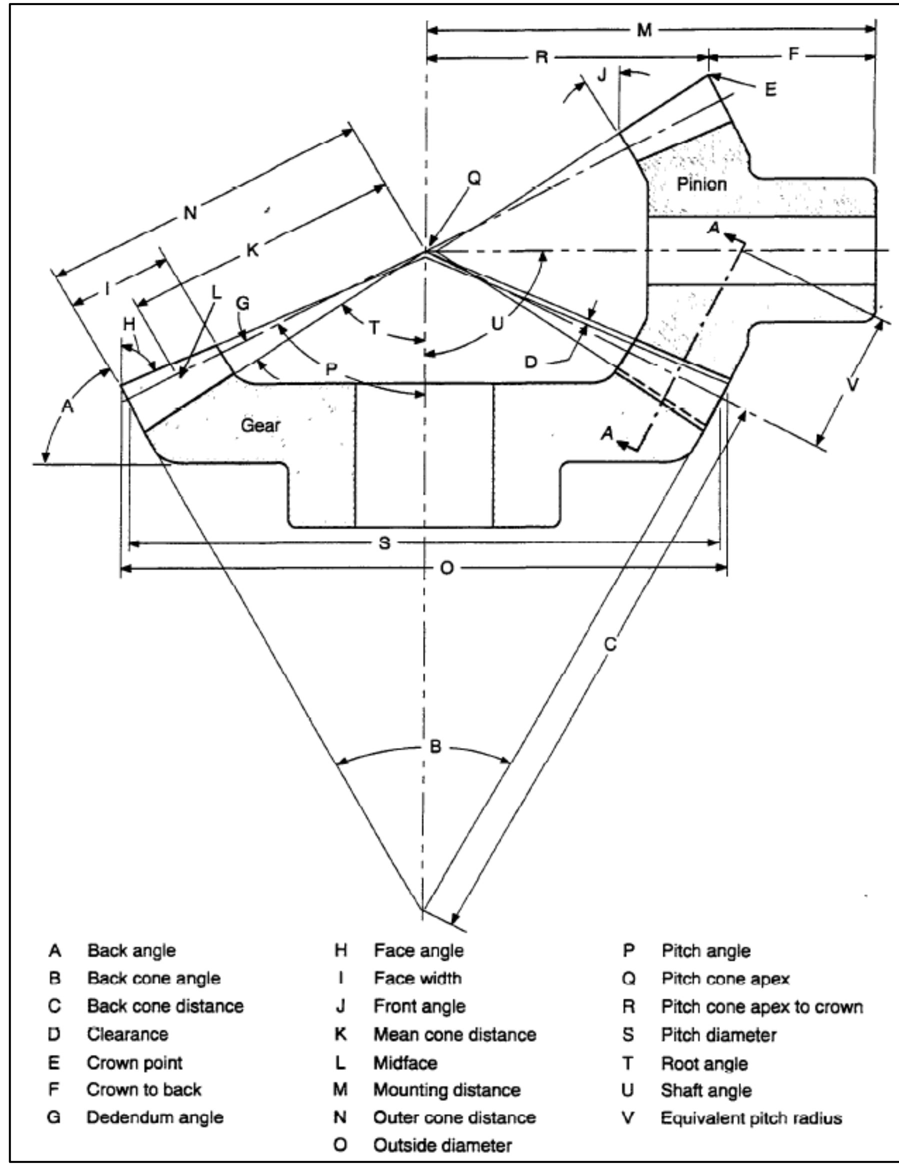
- Basic dimensions are established as per AGMA 2005.
- Initial machine settings are established from Basic dimensions and given cutter specs.
- Tooth dimensions are applied as per Depth and Addendum factors; thus, generated members are not checked for undercutting; profile shift is *not modified* if undercutting is present.
- Clearance is calculated on pinion and gear;
- Contact Pattern is *pre-developed*:
  - CP is *Centered Length wise* on Gear Tooth
  - CP is *Centered Depth wise* on Gear Tooth
  - Any Bias *is ignored* at this time
- Design is displayed for user evaluation.

# Creating a *New* Geometry

Bevel Gear Macro Geometry

Basic dimensions are based on AGMA 2005:

- Depth and Addendum Factors
- Clearance
- Outer Cone Distance
- Face Width
- Cutter Diameter
- Pitch Angle
- Addendum and Dedendum Angles



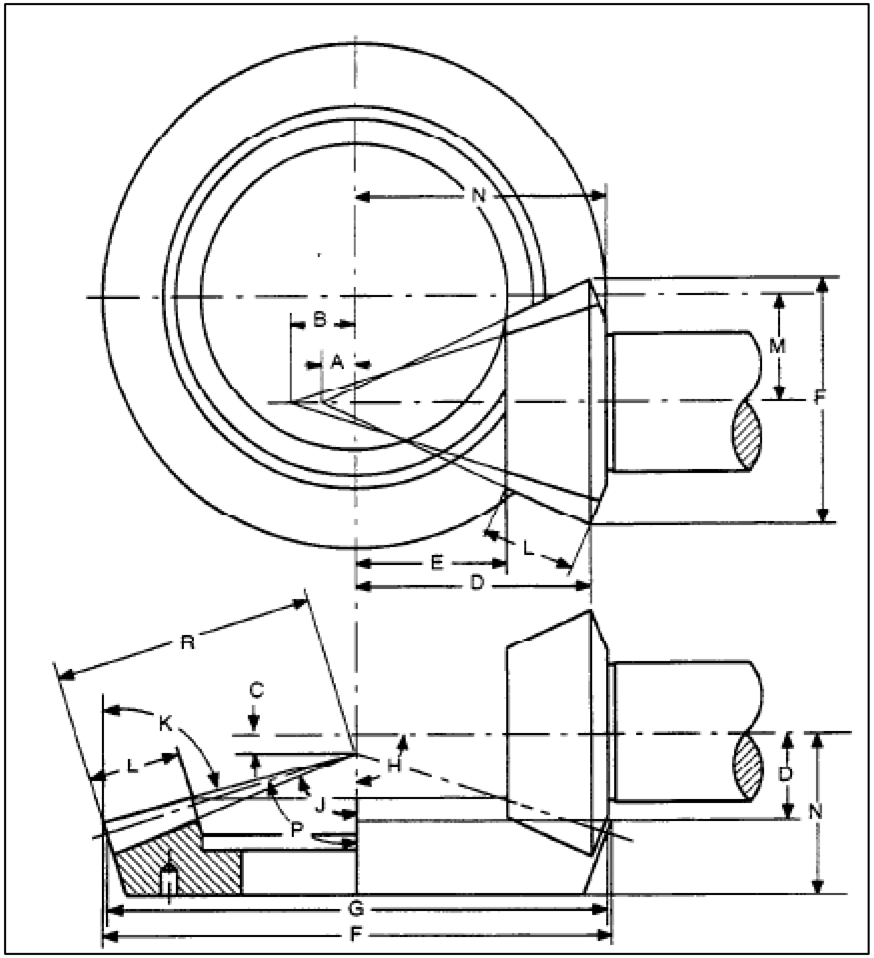
# Creating a *New* Geometry

## Bevel Gear Macro Geometry

For Hypoid gears:

Spiral Angle (based on Offset)

$$\psi_P = 25 + 5\sqrt{\frac{N}{n}} + 90\frac{E}{D}$$

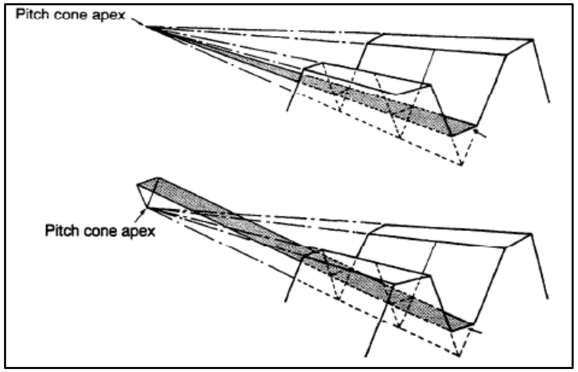



| | |
|---|---|
| FApx-Xp | (A) |
| RApx-Xp | (B) |
| PApx-Xp | (C) |
| C-Xp | (D) |
| FC-Xp | (E) |

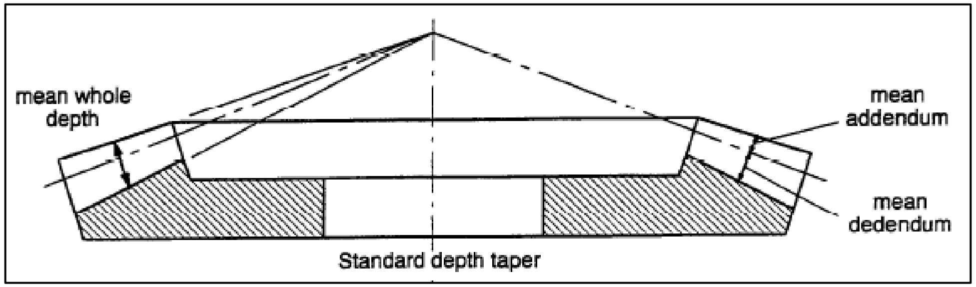
# Creating a *New* Geometry

## Bevel Gear Macro Geometry

Tooth Taper (Zerol, Spiral Bevel, Hypoid):

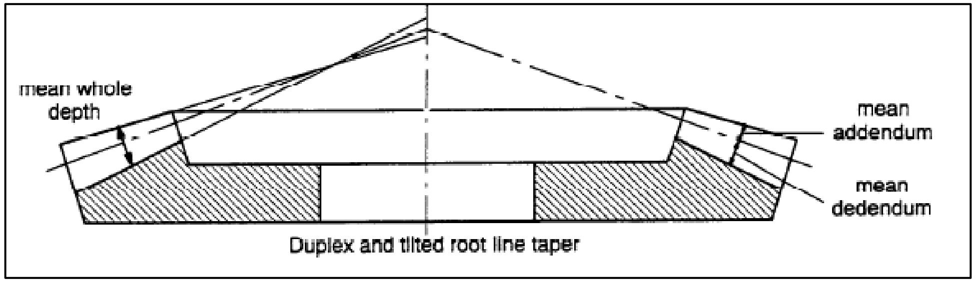



*Standard*




*Duplex = f (cutter radius)*

$$\Sigma\delta_D = \frac{90}{P_d A_o \tan\phi \cos\psi}\left(1 - A_{mG}\frac{\sin\psi}{r_c}\right)\ldots$$



# Creating a *New* Geometry

## Bevel Gear Macro Geometry:

### Dedendum Angle

| Depthwise taper | Sum of dedendum angles (degrees) |
|---|---|
| Standard | $\Sigma\delta_S = \arctan\left(\frac{b_P}{A_{mG}}\right) + \arctan\left(\frac{b_G}{A_{mG}}\right)$ |
| Uniform depth | $\Sigma\delta_U = 0$ |
| Duplex | $\Sigma\delta_D = \left(\frac{90.0}{P_d A_{oG} \tan\phi \cos\psi}\right)\left(1 - \frac{A_{mG}\sin\psi}{r_c}\right)$ <br> $\Sigma\delta_D = \left(\frac{m_{et}\,90.0}{A_{oG} \tan\phi \cos\psi}\right)\left(1 - \frac{A_{mG}\sin\psi}{r_c}\right)$ (M) |
| TRL | $\Sigma\delta_T = \Sigma\delta_D$ or $1.3\,\Sigma\delta_S$, whichever is smaller |

| Depthwise taper | Dedendum angles (degrees) |
|---|---|
| Standard | $\delta_P = \arctan\left(\frac{b_P}{A_{mG}}\right)$ <br> $\delta_G = \Sigma\delta_S - \delta_P$ |
| Uniform depth | $\delta_P = \delta_G = 0$ |
| Duplex | $\delta_P = \Sigma\delta_D \frac{a_G}{h}$ <br> $\delta_G = \Sigma\delta_D - \delta_P$ |
| TRL | $\delta_P = \Sigma\delta_T \frac{a_G}{h}$ <br> $\delta_G = \Sigma\delta_T - \delta_P$ |

# Creating a *New* Geometry

## Straight, Zerol and Spiral Bevel Gears

| Item | Pinion | Both pinion and gear | Gear |
|---|---|---|---|
| Pitch diameter | $d = \frac{n}{P_d}$ | | $D = \frac{N}{P_d}$ |
| (metric) | $(d = n\, m_{et})$ | | $(D = N\, m_{et})$ |
| Pitch angle | $\gamma = \arctan\left[\frac{\sin\Sigma}{\frac{N}{n} + \cos\Sigma}\right]$ | | $\Gamma = \Sigma - \gamma$ |
| Outer cone distance | | $A_o = \frac{0.5D}{\sin\Gamma}$ | |
| Mean cone distance | | $A_m = A_o - 0.5F$ | |
| Depth factor | | $k_1$ (See table 4) | |
| Mean working depth | | $h = \frac{k_1}{P_d}\left(\frac{A_m}{A_o}\right)\cos\psi$ | |
| (metric) | | $\left(h = k_1\, m_{et}\left(\frac{A_m}{A_o}\right)\cos\psi\right)$ | |
| Clearance factor | | $k_2$ (See 7.5) | |
| Clearance | | $c = k_2 h$ | |
| Mean whole depth | | $h_m = h + c$ | |
| Equivalent 90° ratio | | $m_{90} = \sqrt{\frac{N}{n}\frac{\cos\gamma}{\cos\Gamma}}$ | |
| Mean addendum factor | | $c_1$ (See table 5) | |
| Mean circular pitch | | $p_m = \frac{\pi}{P_d}\left(\frac{A_m}{A_o}\right)$ | |

| Item | Pinion | Both pinion and gear | Gear |
|---|---|---|---|
| Mean circular pitch (metric) | | $\left(p_m = \pi\, m_{et}\frac{A_m}{A_o}\right)$ | |
| Mean addendum | $a_P = h - a_G$ | | $a_G = c_1 h$ |
| Mean dedendum | $b_P = h_m - a_P$ | | $b_G = h_m - a_G$ |
| Sum of dedendum angles | | $\Sigma\delta$ (See table 6) | |
| Dedendum angle | $\delta_P$ (See table 7) | | $\delta_G$ (See table 7) |
| Face angle | $\gamma_o = \gamma + \delta_G$ | | $\Gamma_o = \Gamma + \delta_P$ |
| Root angle | $\gamma_R = \gamma - \delta_P$ | | $\Gamma_R = \Gamma - \delta_G$ |
| Outer addendum | $a_{oP} = a_P + 0.5F\tan\delta_G$ | | $a_{oG} = a_G + 0.5F\tan\delta_P$ |
| Outer dedendum | $b_{oP} = b_P + 0.5F\tan\delta_P$ | | $b_{oG} = b_G + 0.5F\tan\delta_G$ |
| Outer working depth | | $h_k = a_{oP} + a_{oG}$ | |
| Outer whole depth | | $h_t = a_{oP} + b_{oP}$ | |
| Outside diameter | $d_o = d + 2a_{oP}\cos\gamma$ | | $D_o = D + 2a_{oG}\cos\Gamma$ |
| Pitch cone apex to crown | $x_o = A_o\cos\gamma - a_{oP}\sin\gamma$ | | $X_o = A_o\cos\Gamma - a_{oG}\sin\Gamma$ |
| Mean diametral pitch | | $P_{dm} = P_d\left(\frac{A_o}{A_m}\right)$ | |
| Mean pitch diameter | $d_m = \frac{n}{P_{dm}}$ | | $D_m = \frac{N}{P_{dm}}$ |
| Thickness factor | | $k_3$ (See figure 21) | |
| Mean normal circular thickness theoretical without backlash | $t_n = p_m\cos\psi - T_n$ | | $T_n = (0.5p_m\cos\psi) - (a_P - a_G)\tan\phi - \frac{k_3\cos\psi}{P_{dm}}$ |
| Outer normal backlash allowance | | $B$ (See table 8) | |
| Outer spiral angle (face milling) | | $\sin\psi_o = \frac{2A_m r_c\sin\psi - A_m^2 + A_o^2}{2A_o r_c}$ | |
| Outer spiral angle (face hobbing) | | $N_c = \frac{N}{\sin\Gamma}$ | |
| | | $\sin\nu = \frac{A_m N_s}{r_c N_c}\cos\psi$ | |
| | | $\lambda = 90° - \psi + \nu$ | |
| | | $S_1 = \sqrt{A_m^2 + r_c^2 - 2A_m r_c\cos\lambda}$ | |
| | | $Q = \frac{S_1}{1 + \frac{N_s}{N_c}}$ | |
| | | $\cos\eta_o = \frac{A_o^2 + S_1^2 - r_c^2}{2A_o S_1}$ | |
| | | $\tan\psi_o = \frac{A_o - Q\cos\eta_o}{Q\sin\eta_o}$ | |
| Mean normal chordal thickness | $t_{nc} = t_n - \left(\frac{t_n^3}{6d_m^2}\right) - 0.5B\left[\frac{\frac{A_m}{A_o}}{\cos\phi\frac{\cos\psi}{\cos\psi_o}}\right]$ | | $T_{nc} = T_n - \left(\frac{T_n^3}{6D_m^2}\right) - 0.5B\left[\frac{\frac{A_m}{A_o}}{\cos\phi\frac{\cos\psi}{\cos\psi_o}}\right]$ |
| Mean chordal addendum | $a_{cP} = a_P + 0.25\frac{t_n^2\cos\gamma}{d_m}$ | | $a_{cG} = a_G + 0.25\frac{T_n^2\cos\Gamma}{D_m}$ |

# Creating a *New* Geometry

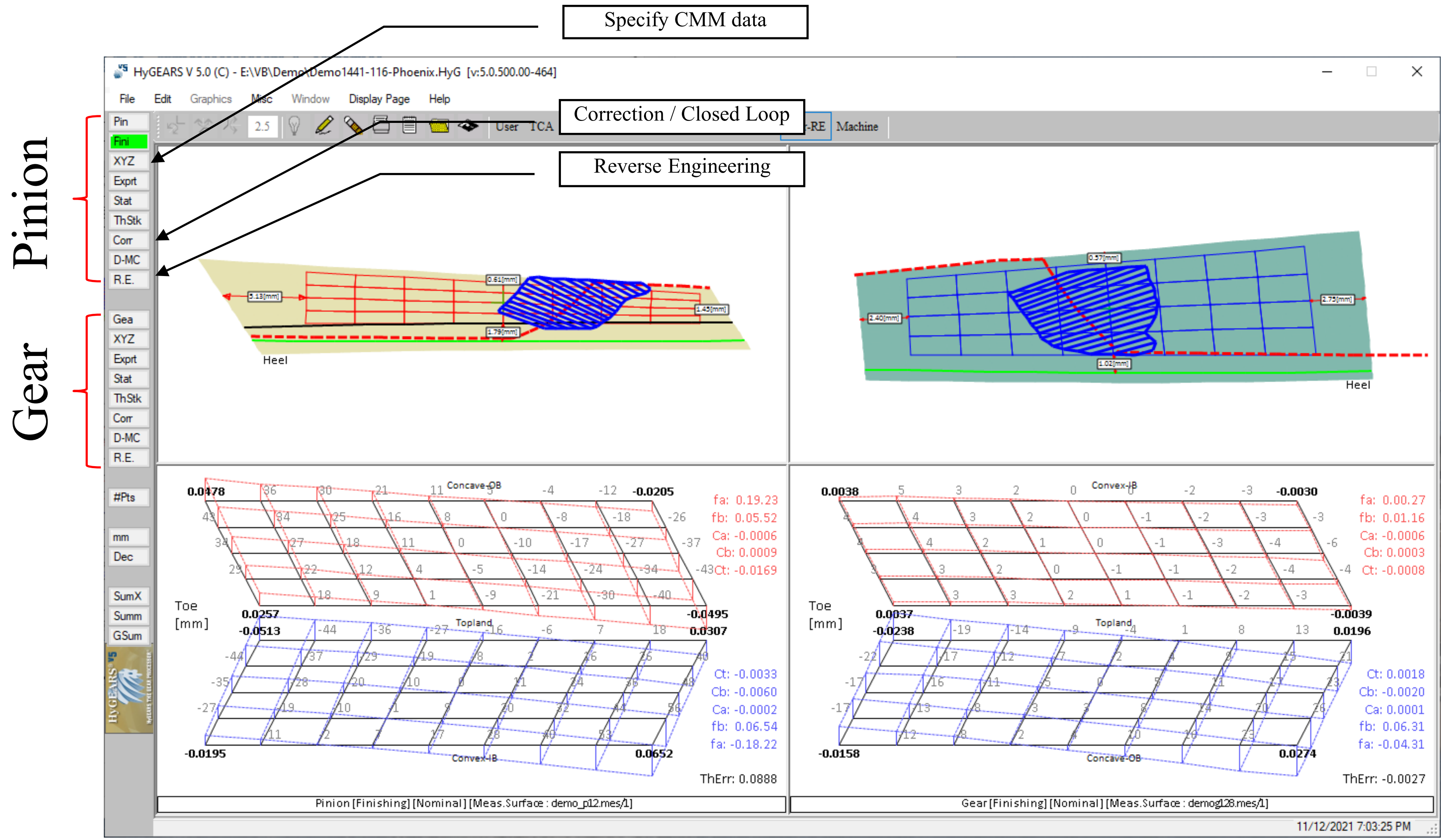
## Hypoid Gears …

| Item | Pinion | Both pinion and gear | Gear |
|---|---|---|---|
| Pitch diameter | | | $D = \frac{N}{P_d}$ |
| (metric) | | | $(D = Nm_{et})$ |
| Gear ratio | | $m_G = \frac{N}{n}$ | |
| Desired pinion spiral angle | $\psi_{oP} = \psi_P$ | | |
| Shaft angle departure from 90° | | $\Delta\Sigma = \Sigma - 90$ | |
| Approximate gear pitch angle | | | $\tan\Gamma_i = \frac{m_G(\cos\Delta\Sigma)}{1.2(1 - m_G\sin\Delta\Sigma)}$ |
| Gear mean pitch radius | | | $R = \frac{D - F\sin\Gamma}{2}$ |
| Approximate pinion offset angle in pitch plane | $\sin\varepsilon'_i = \frac{E\sin\Gamma_i}{R}$ | | |
| Approximate hypoid dimension factor | | $K_1 = \tan\psi_{oP}\sin\varepsilon'_i + \cos\varepsilon'_i$ | |
| Approximate pinion mean radius | $R_{2P} = \frac{RK_1}{m_G}$ | | |
| | | **Start of iteration** First trial | |
| Gear offset angle in axial plane | | | $\tan\eta = \frac{E}{R(\tan\Gamma_i\cos\Delta\Sigma - \sin\Delta\Sigma) + R_{2P}}$ |
| | | Second trial | |
| Intermediate pinion offset angle in axial plane | $\sin\varepsilon_2 = \frac{E - R_{2P}\sin\eta}{R}$ | | |
| Intermediate pinion pitch angle | $\tan\gamma_2 = \frac{\sin\eta}{\tan\varepsilon_2\cos\Delta\Sigma} + \tan\Delta\Sigma\cos\eta$ | | |
| Intermediate pinion offset angle in pitch plane | $\sin\varepsilon'_2 = \frac{\sin\varepsilon_2\cos\Delta\Sigma}{\cos\gamma_2}$ | | |
| Intermediate pinion mean spiral angle | $\tan\psi_{2P} = \frac{K_1 - \cos\varepsilon'_2}{\sin\varepsilon'_2}$ | | |
| Increment in hypoid dimension factor | | $\Delta K = \sin\varepsilon'_2(\tan\psi_{oP} - \tan\psi_{2P})$ | |
| Ratio of pinion mean radius increment to gear mean pitch radius | | $\frac{\Delta R_P}{R} = \frac{\Delta K}{m_G}$ | |
| Pinion offset angle in axial plane | $\sin\varepsilon_1 = \sin\varepsilon_2 - \frac{\Delta R_P}{R}\sin\eta$ | | |
| Pinion pitch angle | $\tan\gamma = \frac{\sin\eta}{\tan\varepsilon_1\cos\Delta\Sigma} + \tan\Delta\Sigma\cos\eta$ | | |
| Pinion offset angle in pitch plane | $\sin\varepsilon'_1 = \frac{\sin\varepsilon_1\cos\Delta\Sigma}{\cos\gamma}$ | | |

| Item | Pinion | Both pinion and gear | Gear |
|---|---|---|---|
| Spiral angle | $\tan\psi_P = \frac{K_1 + \Delta K - \cos\varepsilon'_1}{\sin\varepsilon'_1}$ | | $\psi_G = \psi_P - \varepsilon'_1$ |
| Gear pitch angle | | | $\tan\Gamma = \frac{\sin\varepsilon_1}{\tan\eta\cos\Delta\Sigma} + \cos\varepsilon_1\tan\Delta\Sigma$ |
| Mean cone distance | | | $A_{mG} = \frac{R}{\sin\Gamma}$ |
| Pinion mean radius increment | $\Delta R_P = \left(\frac{\Delta R_P}{R}\right)R$ | | |
| Mean cone distance | $A_{mP} = \frac{R_{2P} + \Delta R_P}{\sin\gamma}$ | | |
| Mean pinion radius | $R_P = A_{mP}\sin\gamma$ | | |
| Limit pressure angle | | $(-\tan\phi_o) = \frac{\tan\gamma\tan\Gamma}{\cos\varepsilon'_1}\left(\frac{A_{mP}\sin\psi_P - A_{mG}\sin\psi_G}{A_{mP}\tan\gamma + A_{mG}\tan\Gamma}\right)$ | |
| For face hobbed gears make the following calculations | | $N_c = \frac{N}{\sin\Gamma}$<br>$\sin\nu = \frac{A_{mG}N_s}{r_cN_c}\cos\psi$<br>$\lambda = 90° - \psi_G + \nu$<br>$S_1 = \sqrt{A_{mG}^2 + r_c^2 - 2A_{mG}r_c\cos\lambda}$<br>$\cos\eta_1 = \frac{A_{mG}\cos\psi_G}{S_1N_c}(N_c + N_s)$ | |
| Mean tooth curvature face hobbed gears | | $\rho = A_{mG}\cos\psi_G\left[\tan\psi_G + \frac{\tan\eta_1}{1 + \tan\nu(\tan\psi_G + \tan\eta_1)}\right]$ | |
| Mean tooth curvature face milled gears | $\rho = r_c$ | | |
| | Calculate the following | | |
| For Method 1 | | $r_{c1} = \frac{\sec\phi_o\tan\psi_P - \tan\psi_G}{(-\tan\phi_o)\left(\frac{\tan\psi_P}{A_{mP}\tan\gamma} + \frac{\tan\psi_G}{A_{mG}\tan\Gamma}\right) + \frac{1}{A_{mP}\cos\psi_P} + \frac{1}{A_{mG}\cos\psi_G}}$ | |
| Limit curvature radius | | Change $\eta$ until $\frac{\rho}{r_{c1}} - 1 \le 0.01$ | |
| For Method 2 | Calculate the following<br>$\Delta = \frac{r_c\cos(\psi_G - \nu)}{A_{mG}\sin\Gamma - r_c\sin\Gamma\sin(\psi_G - \nu)} - \frac{n\cos\psi_G\sin\varepsilon'_1}{N\cos\psi_P\sin\gamma - n\cos\psi_G\cos\varepsilon'_1}$<br>Change $\eta$ until $\Delta \le 0.001$ | | |
| | | **End of iteration** | |
| Pressure angle concave | $\phi_1 = \phi + \phi_o$ | | $\phi_2 = \phi - \phi_o$ |
| Pressure angle convex | $\phi_2 = \phi - \phi_o$ | | $\phi_1 = \phi + \phi_o$ |
| Crossing point to mean point along pinion axis | $Z_P = A_{mP}\tan\gamma\sin\Gamma - \frac{E\tan\Delta\Sigma}{\tan\varepsilon_1}$ | | |
| Gear pitch apex beyond crossing point | | | $Z = \frac{R}{\tan\Gamma} - Z_P$ |
| Outer cone distance | | | $A_{oG} = \frac{0.5D}{\sin\Gamma}$ |

# HyGEARS Production Control

*Correction and RE*



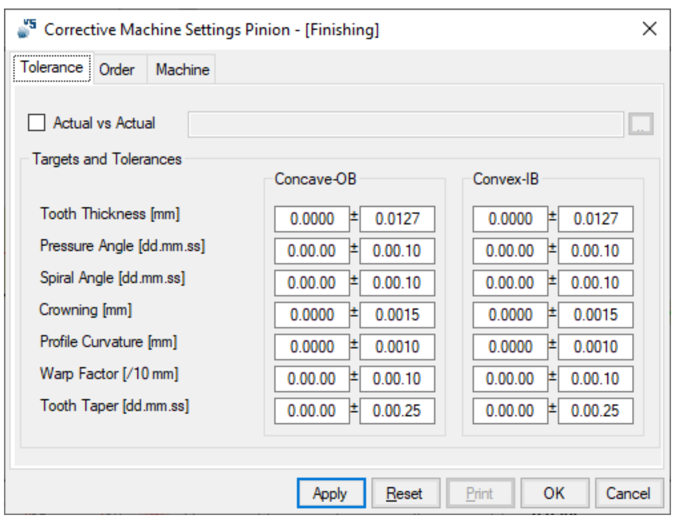
# HyGEARS Production Control

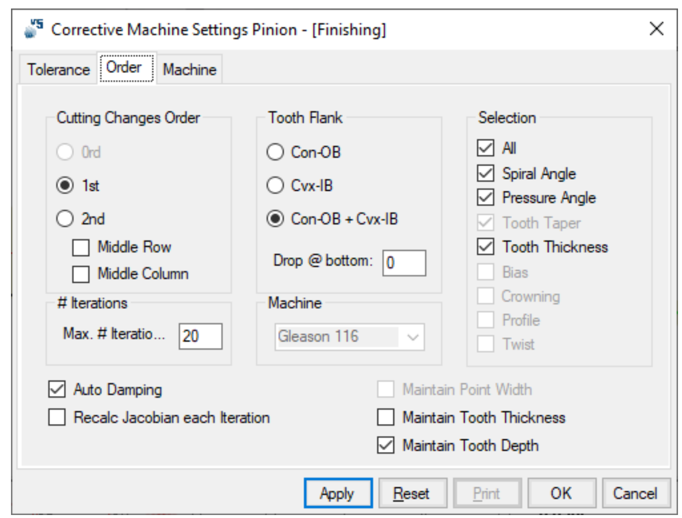
Corrective Machine Settings – i.e. Closed Loop - (like Gleason's GAGE) and Reverse Engineering

CMM data is used to calculate changes in machine settings needed for the actual tooth surface to match the theoretical tooth surface.

Corrective Machine Settings/RE support:

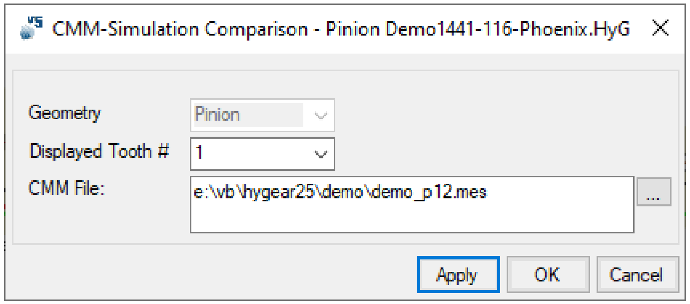
- 1st order errors: spiral angle, pressure angle, tooth taper;
- 2nd order errors: crowning and tooth warp (bias);
- Roughing and Finishing;
- All FM and FH cutting processes, Straight bevel, Coniflex, Spur, Helical and Face gears.

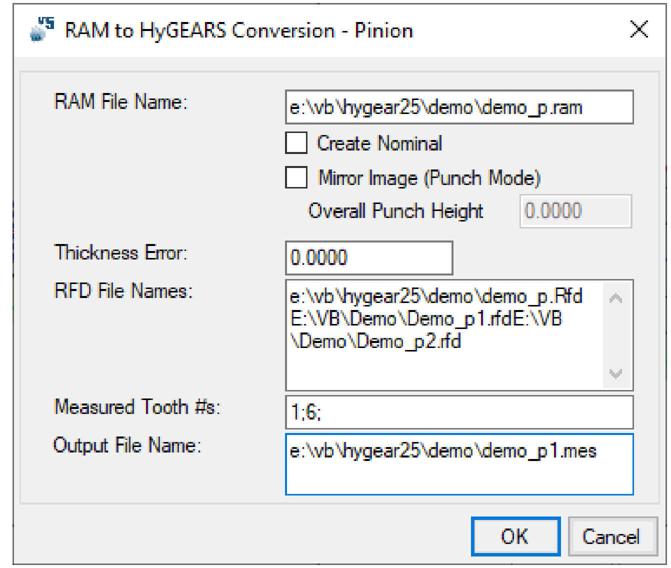


# HyGEARS Production Control

*CMM Output converted to HyGEARS common format*




HyGEARS tests if the data file is of type:

- "Ram" / "Rfd";
- "Gleason-Zeiss";
- "Hoeffler";
- "MdM";
- "Klingelnberg-P";
- "GAGE";
- "Zeiss Gear Pro";
- "Mitutoyo";
- "HyGEARS".

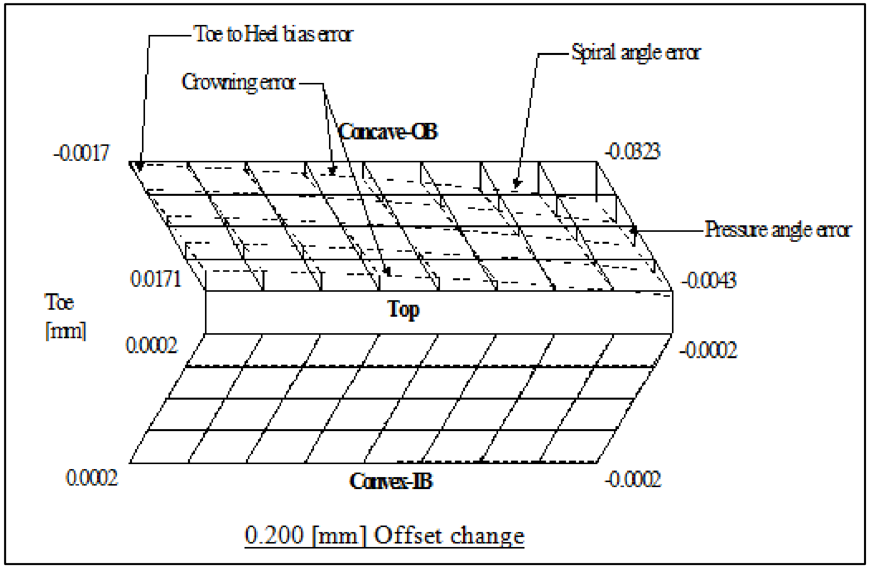
If not HyGEARS type, then the file must be converted to the HyGEARS format

# HyGEARS Production Control

## *Surface Match Algorithm for Correction / R.E.*

The *Surface Match* algorithm (introduced in 1994) :

- Changes the machine settings of the selected member until the *measurement surface statistics* are within given tolerances;
- Uses the *sensitivity of the error surface* (difference between measurement and simulation) to chosen control parameters to iterate until the desired tolerances are met;

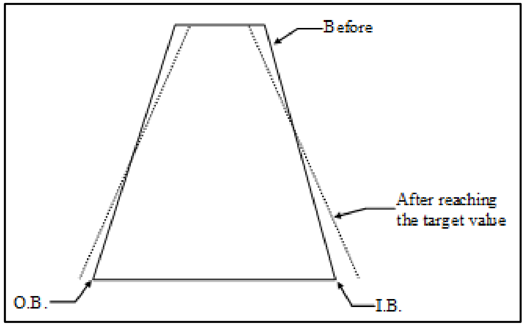



- Applies a Newton-Raphson based iterative process to solve objective functions.

# HyGEARS Production Control

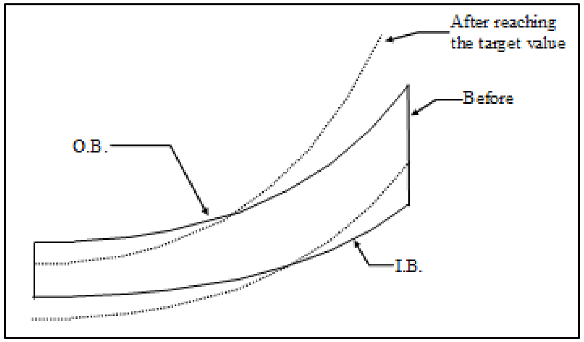
### *Surface Errors*

Pressure Angle Error:



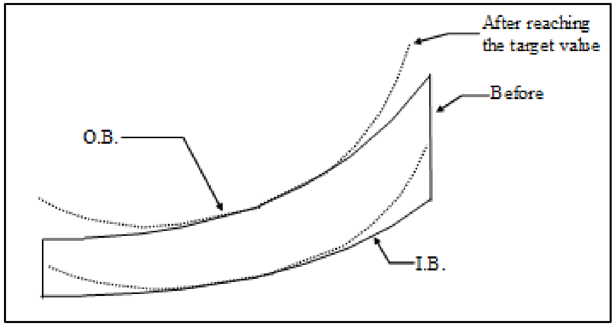

$$\Phi = \frac{\sum_{col=1}^{j} \frac{\left[ \sum_{row=1}^{i} \frac{\varepsilon_{i,j} - \varepsilon_{1,j}}{y_{i,j} - y_{1,j}} \right]}{i}}{j}$$

Spiral Angle Error:




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

Crowning Error:

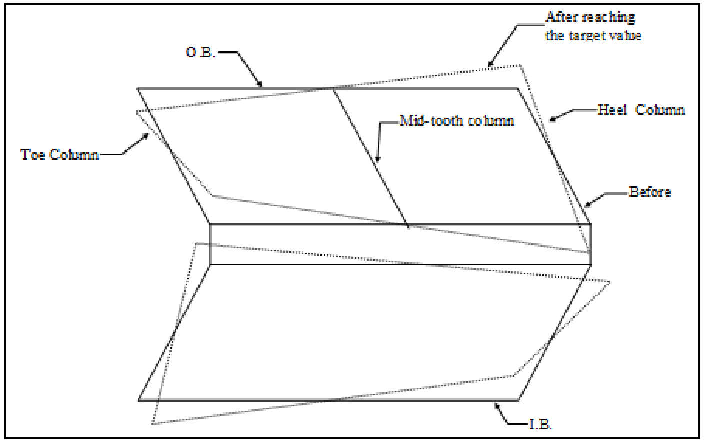



$$\Xi = \frac{\sum_{row=1}^{i} \frac{(2\varepsilon_{i,mid} - (\varepsilon_{i,1} + \varepsilon_{i,j}))}{2}}{i}$$

# HyGEARS Production Control

## *Surface Errors*

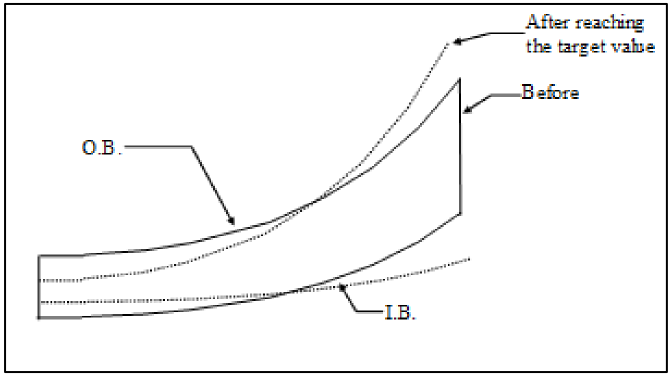
Warp (Bias) Error:




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

$$\zeta = \Phi_1 - \Phi_j$$

Taper Error:



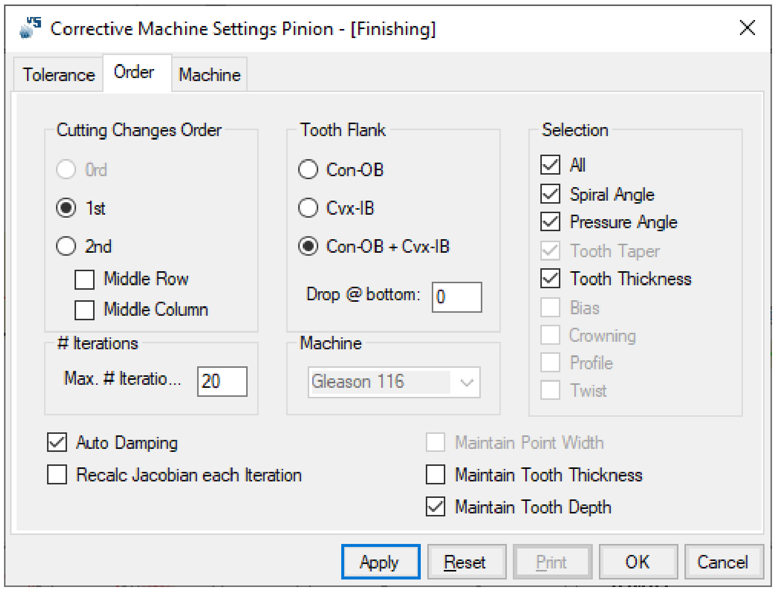

$$\Psi = \frac{\sum_{row=1}^{i} \frac{\left[ \sum_{col=1}^{j} \frac{\varepsilon_{i,j} - \varepsilon_{i,1}}{x_{i,j} - x_{i,1}} \right]}{j}}{i}$$

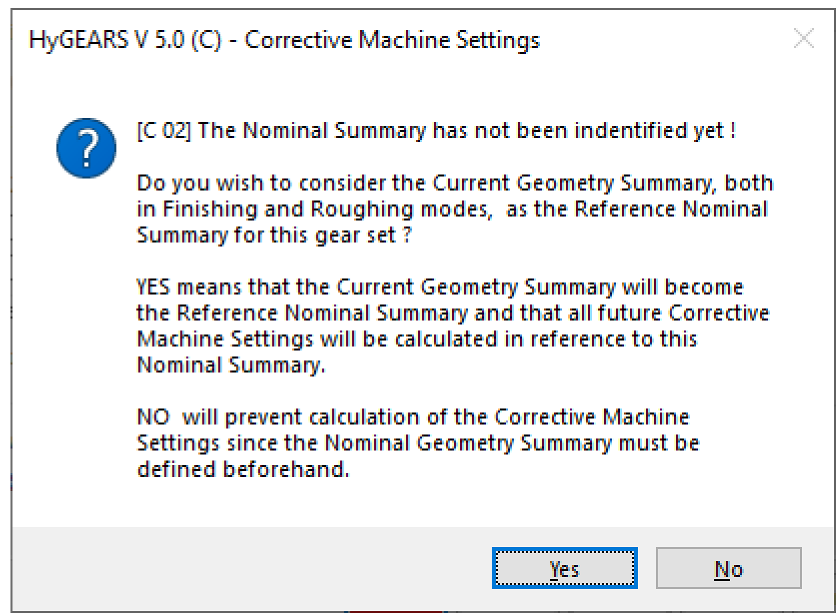
$$\Delta\Psi = \Psi_{IB} - \Psi_{OB}$$

# HyGEARS Production Control

## *Correction and RE*

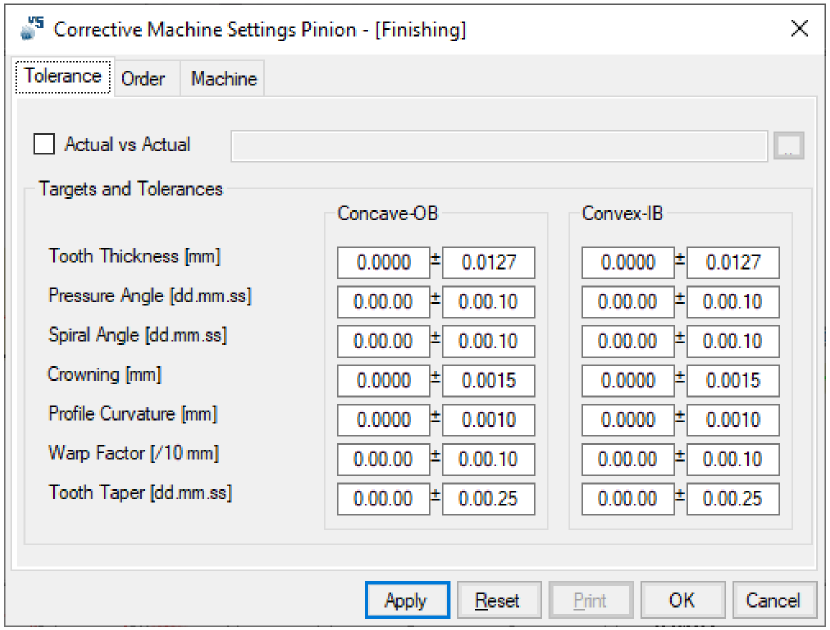
Corrective Machine Settings (Closed Loop): 1$^{st}$ time -> identify the reference Nominal Summary

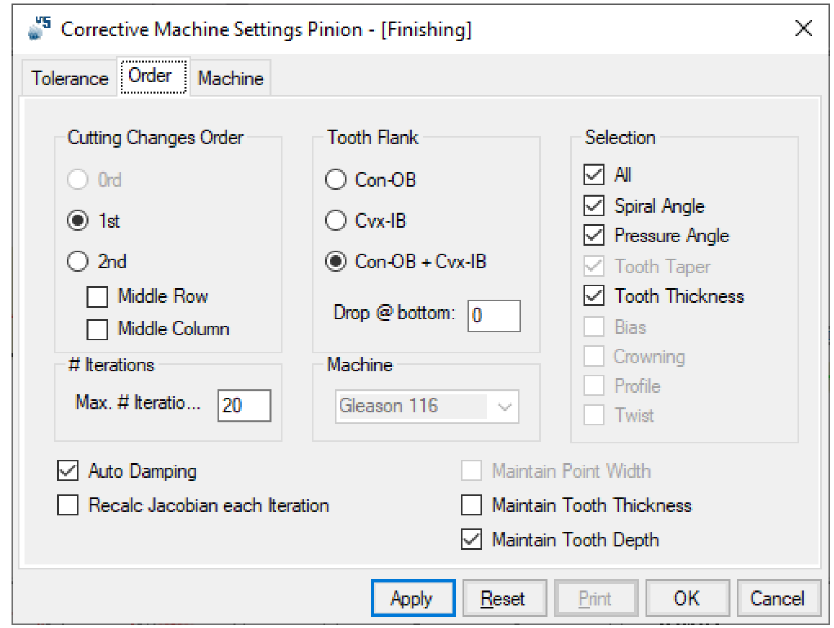


# HyGEARS Production Control

## *Correction and RE*

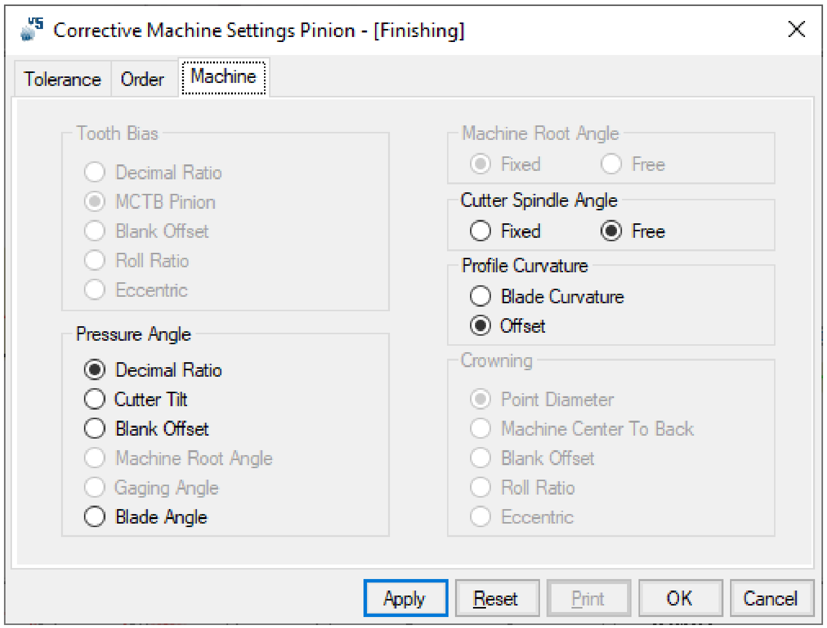


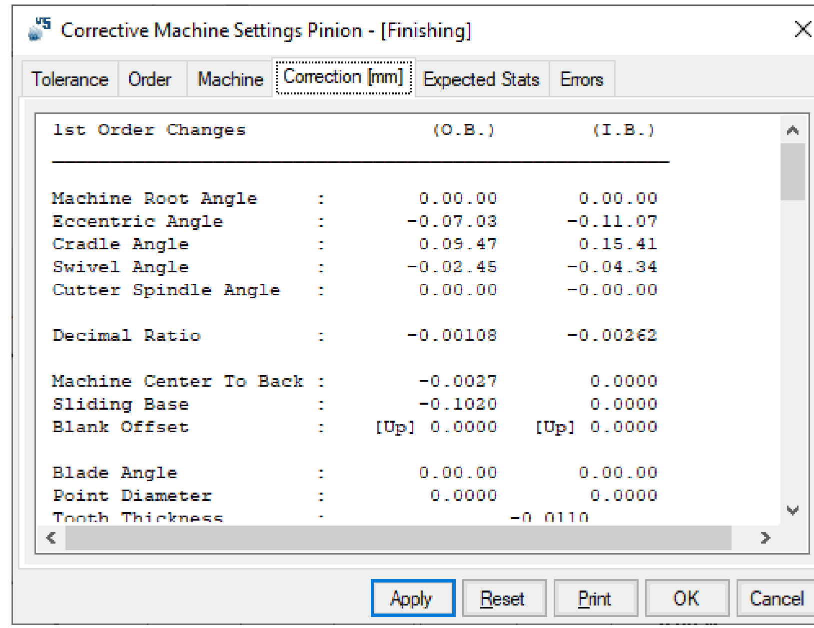




| | |
|---|---|
| Tolerance | options on target values and tolerances; |
| Order | options on what is to be corrected; |
| Machine | options on control parameters constraints; |
| Correction | calculated changes in machine settings; |
| Expected Stats | what HyGEARS expects after correction; |
| Errors | point by point differences |

# HyGEARS Production Control

## *Correction and RE*




| | |
|---|---|
| Tolerance | options on target values and tolerances; |
| Order | options on what is to be corrected; |
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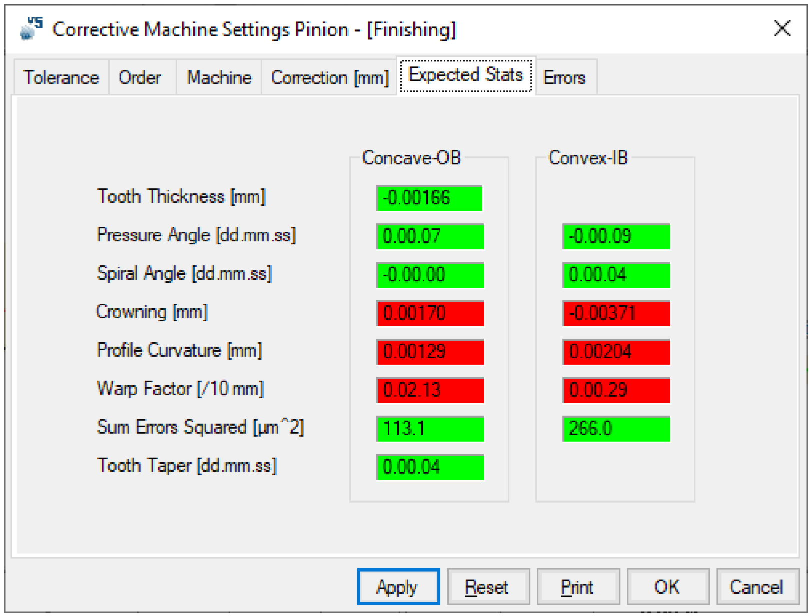
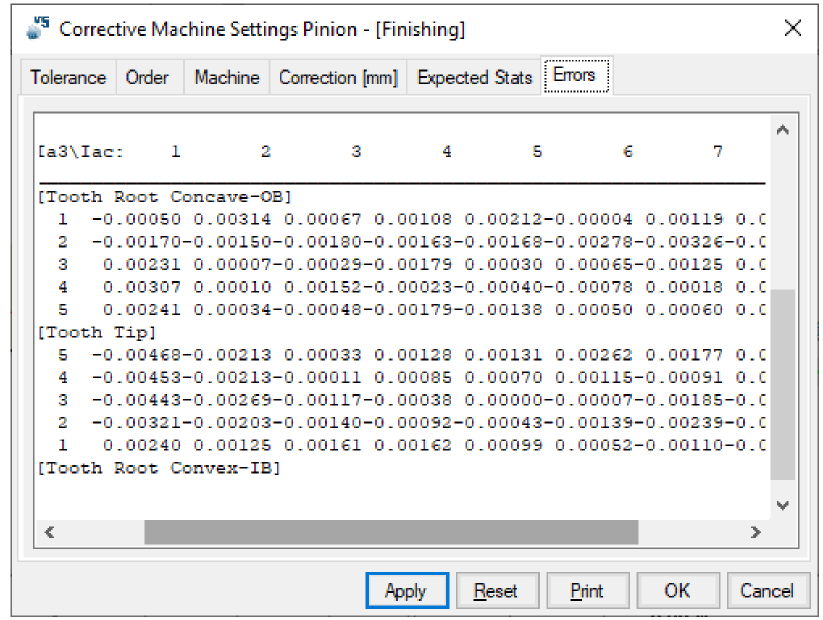
# HyGEARS Production Control

## *Correction and RE*




| | |
|---|---|
| Tolerance | options on target values and tolerances; |
| Order | options on what is to be corrected; |
| Machine | options on control parameters constraints; |
| Correction | calculated changes in machine settings; |
| Expected Stats | what HyGEARS expects after correction; |
| Errors | point by point differences |

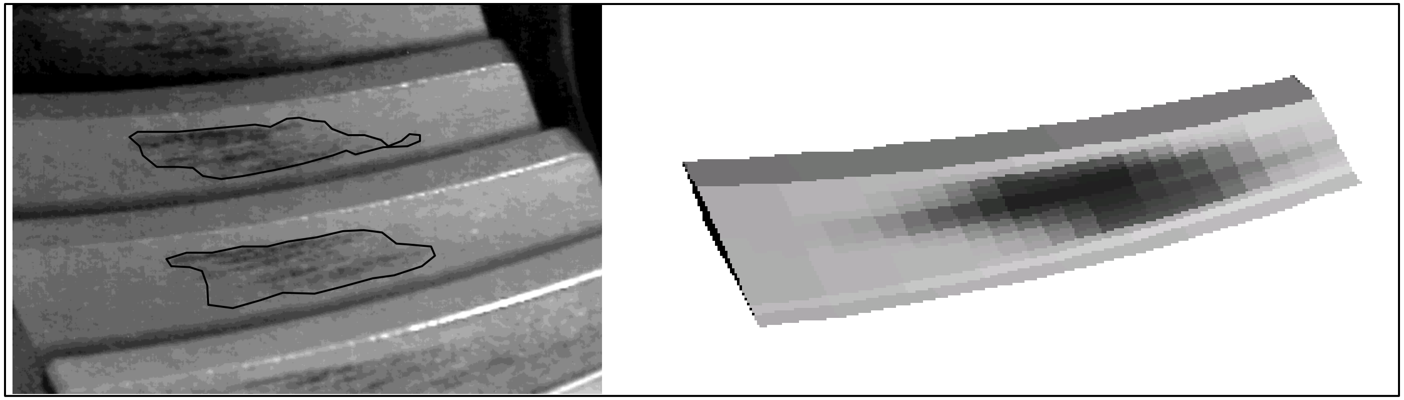
# HyGEARS Production Control

## *Reverse Engineering (RE)*

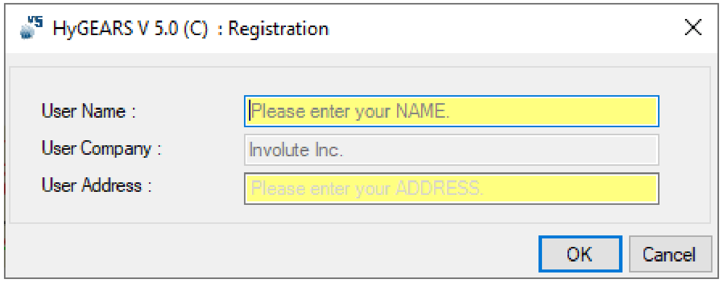
HyGEARS uses the Surface Match algorithm to *Reverse Engineer* existing tooth surfaces.

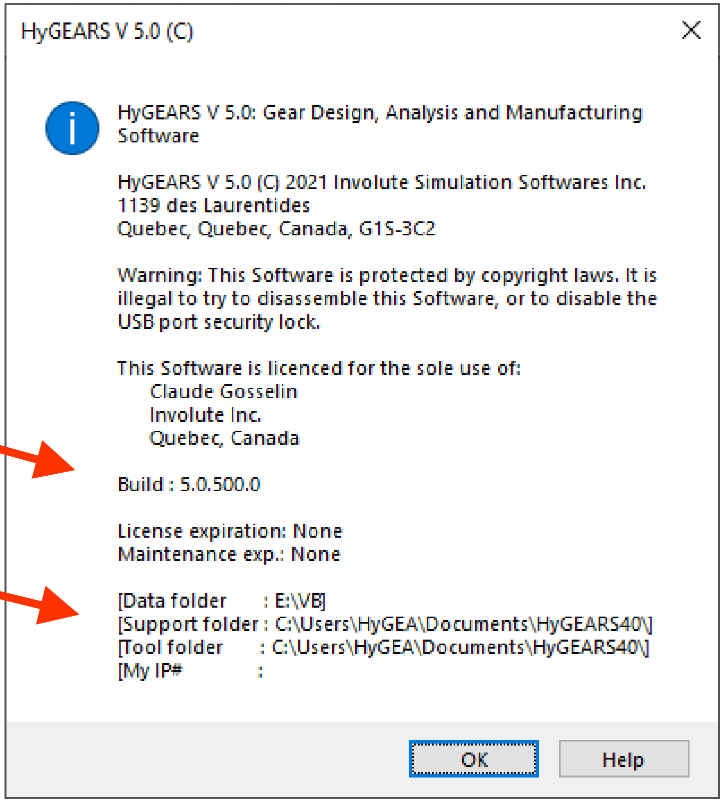
Reverse Engineering is useful to:

- identify the machine settings of existing gear sets for which the *summaries are lost*;
- *analyze existing gear sets* and identify the machine settings or provide a reference surface leading to quietness;
- *diagnose the reason for a failure* by simulating meshing and load sharing;
- optimize the Stock Distribution;
- *use different cutters* on a given geometry (Fixed Setting only);
- *calibrate mechanical machines* to pre-compensate for their inaccuracies;
- etc.



# Starting HyGEARS: Registration




Build number

Data Folders

# Example: Start HyGEARS for the 1st time

Start HyGEARS

Fill in the Registration form: your name

your address

Watch the HyGEARS Copyright screen

Watch the HyGEARS Parent Window appear in the screen

# Example: Import a Gleason Spa file

Import the Spa file

File->Open

Navigate to the proper folder

Select “Gleason SPA (*.Spa)”

Select “Summary for CNC.spa”

Look at the different display modes

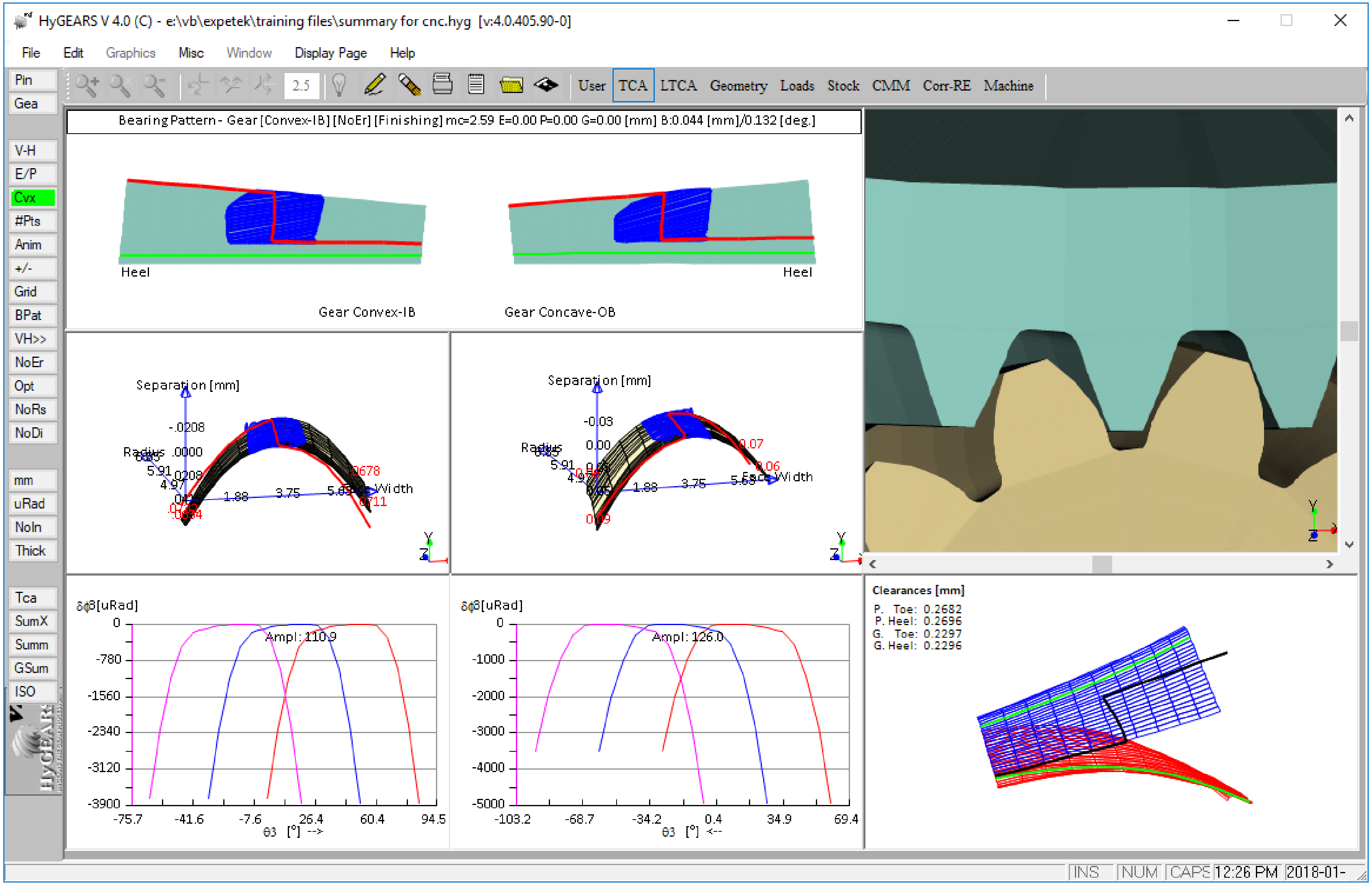
TCA, LTCA, Geometry, etc.

Save the imported geometry

File->Save As

Name: “Summary for CNC.HyG”

# Example: Import a Gleason Spa file



# Example: Keyboard Shortcuts

Start MS-Word; Experiment ^C (select a Child window: Copy the Child Window contents to the clipboard) and then Paste it into Word (^V)

Experiment ^+ (Zoom In)

Experiment ^Z (Center and Fit Display)

Experiment ^R (Reference frames On/Off) and then Rotate/Zoom the Tooth Child Window display

Experiment ^F (toggle tooth flank)

# Example: Open an existing geometry file

Open the Summary for CNC.HyG file

**File**->Open

Watch the CP-TCA Pre-Defined display

Create a Tooth Child Window

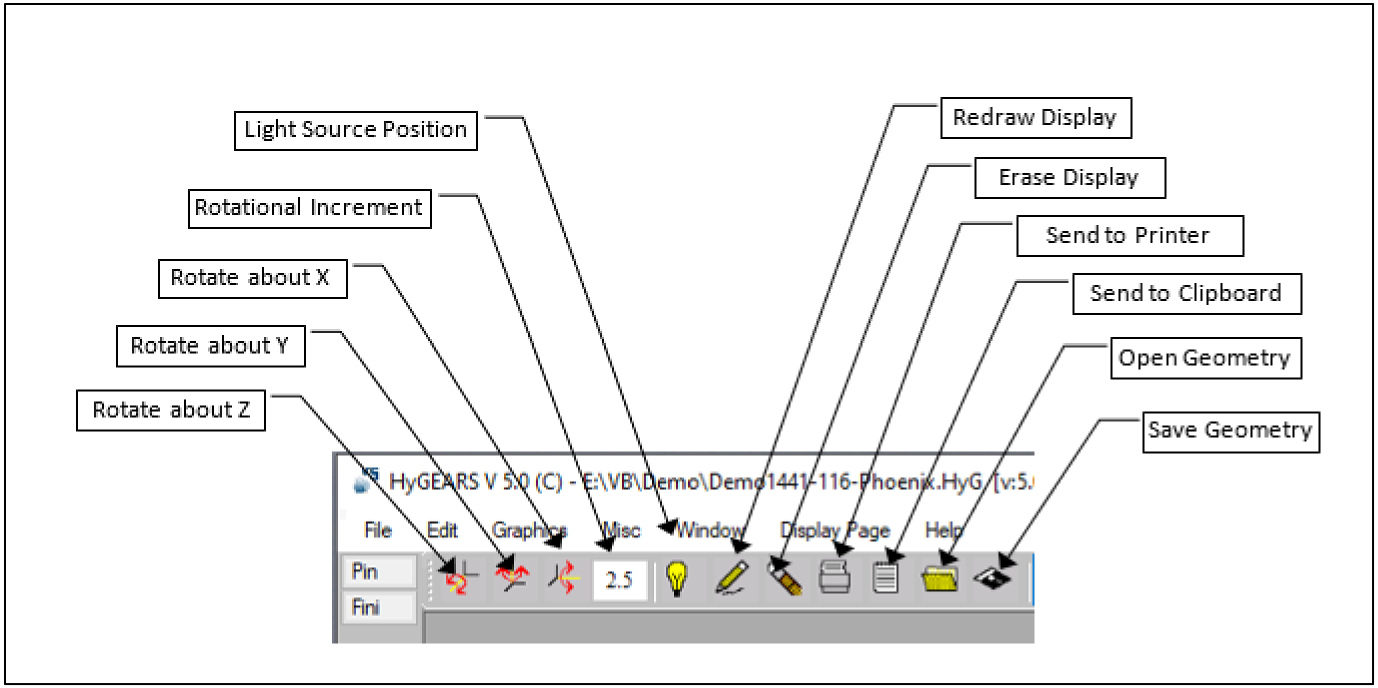
**Display** -> User

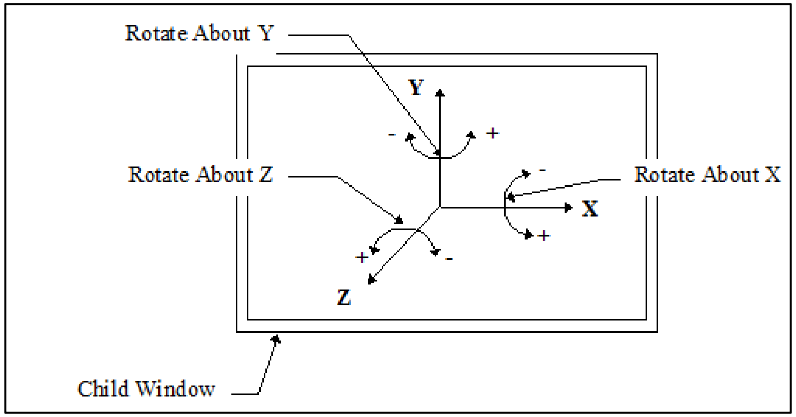
**Graphics**->Tooth->Tooth

Create a 2D Graph

**Graphics**->2D Graphs (Click on Ok)

# HyGEARS Toolbar: Graphics Controls

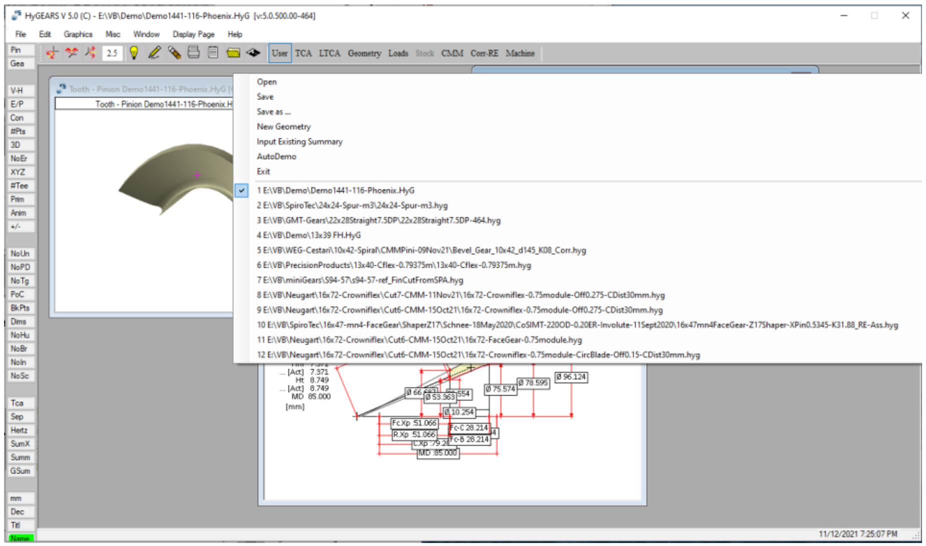


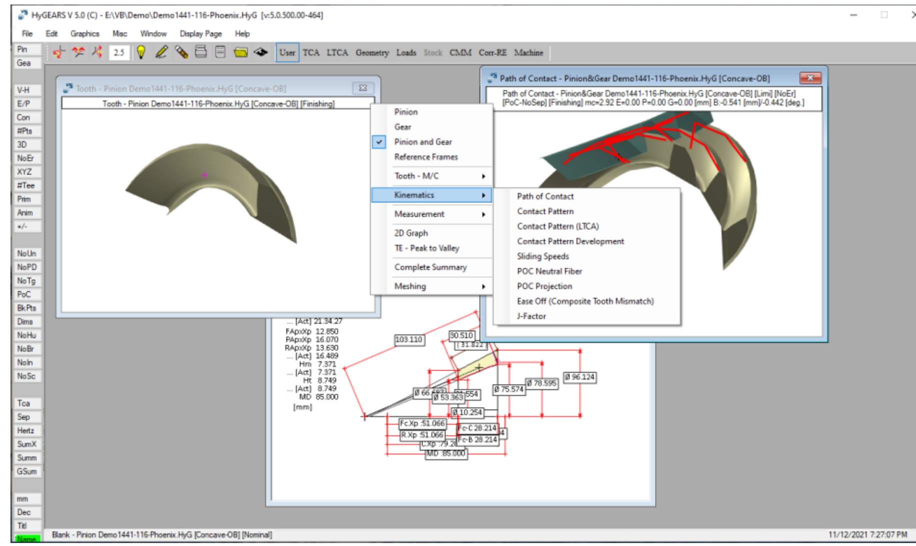



# Example: Rotation With the Mouse

Experiment the Rotation With the Mouse (left mouse button depressed) on the **Tooth** Child Window

# Parent Window: Mouse Behavior




Left mouse button over grey area:

File menu

Right mouse button over grey area:

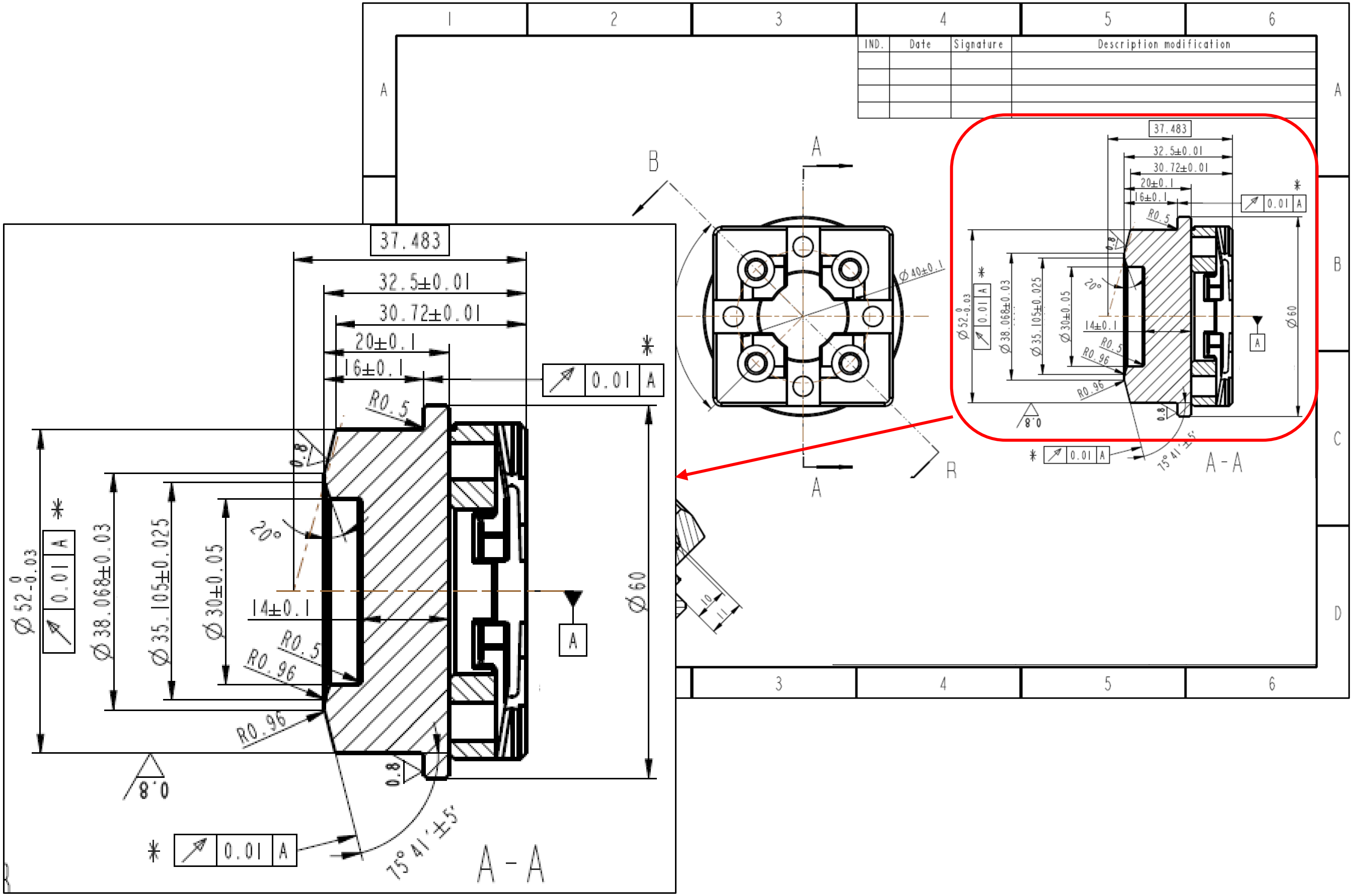
Graphics menu

# Example: Left and Right mouse buttons

Experiment the Left Mouse Button - call the **File** menu

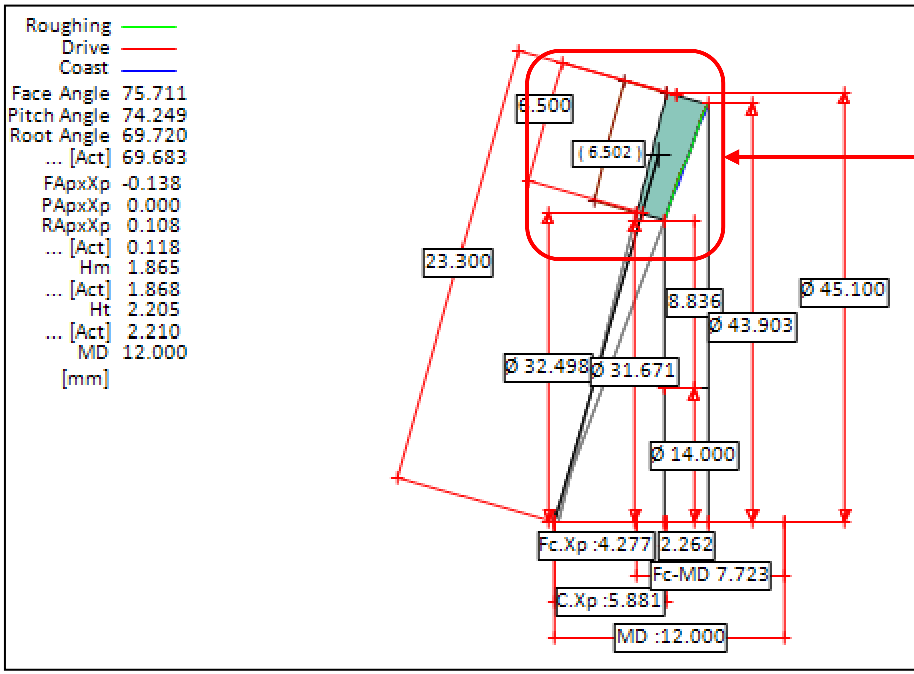
Experiment the Right Mouse Button - call the **Graphics** menu

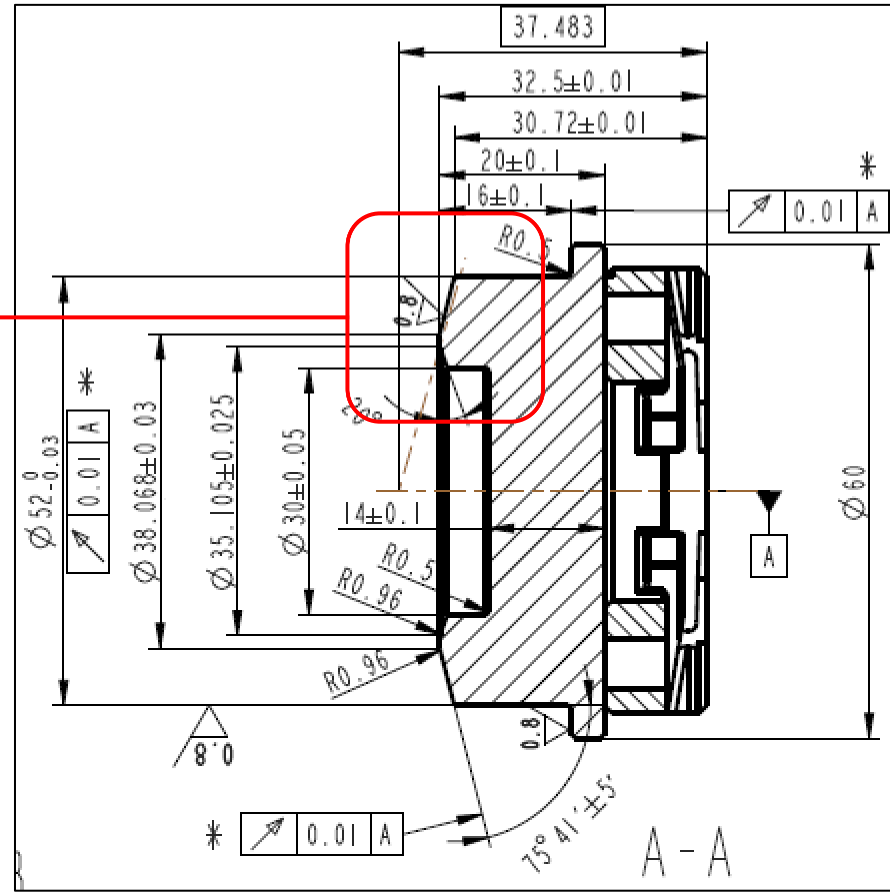
# Example: Establishing a Complex Blank



# Example: Establishing a Complex Blank

Differences appear between the drawing and HyGEARS default tooth outlines.



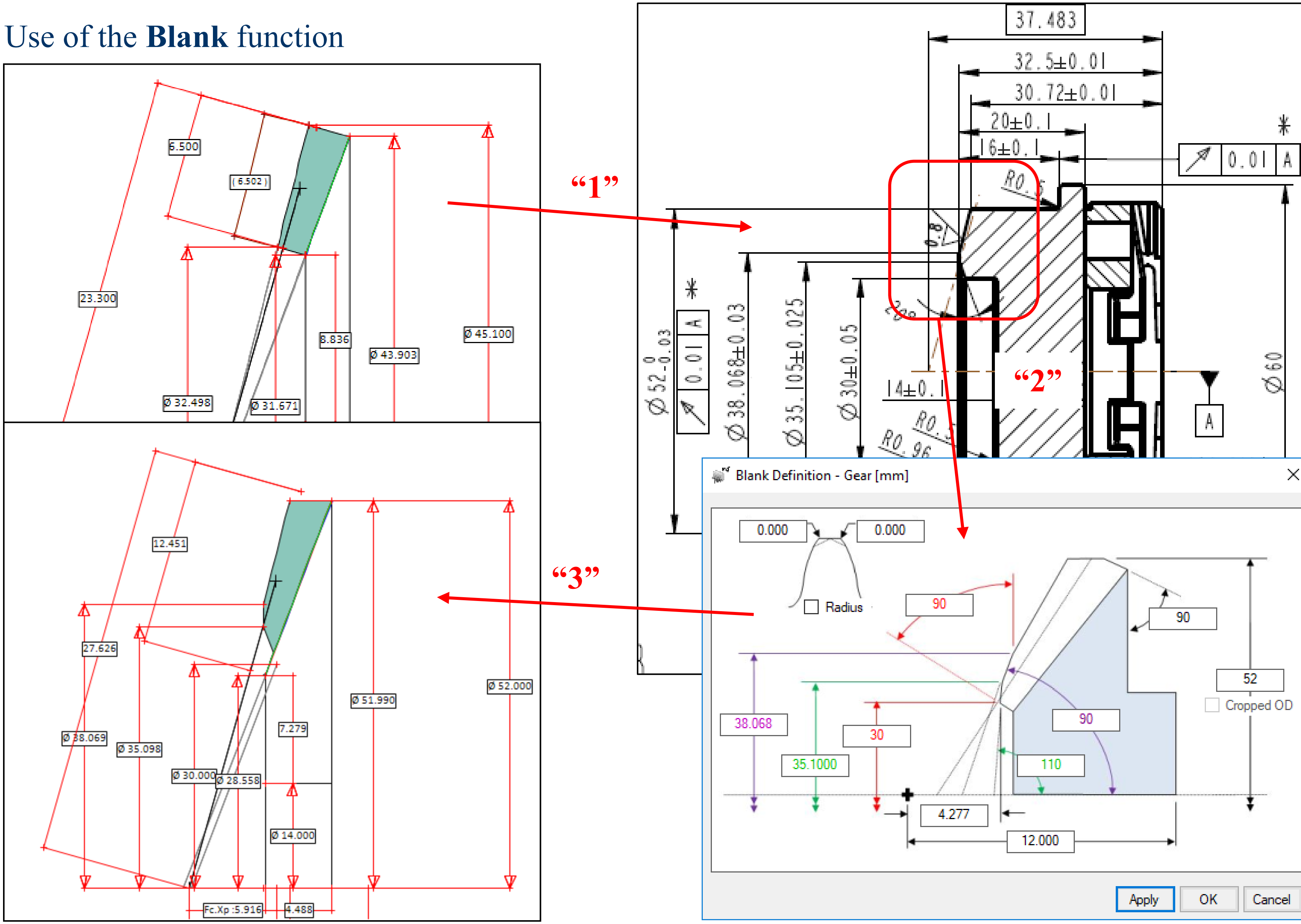




**Default tooth – as created / imported**

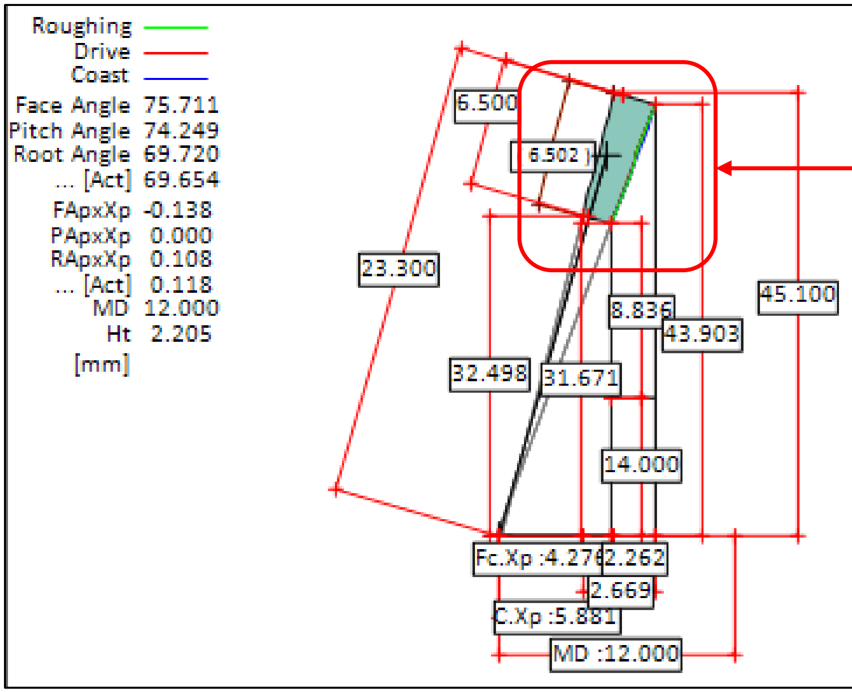
**Requested tooth**

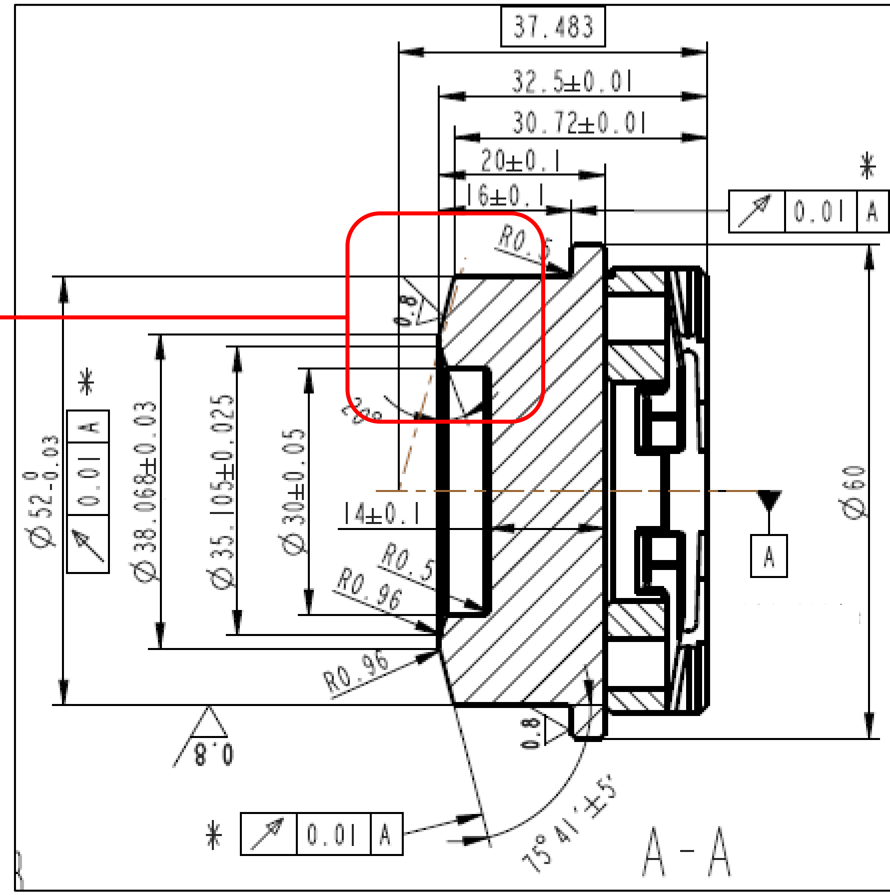
# Example: Establishing a Complex Blank

Use of the **Blank** function



# Example: Establishing a Turned OD



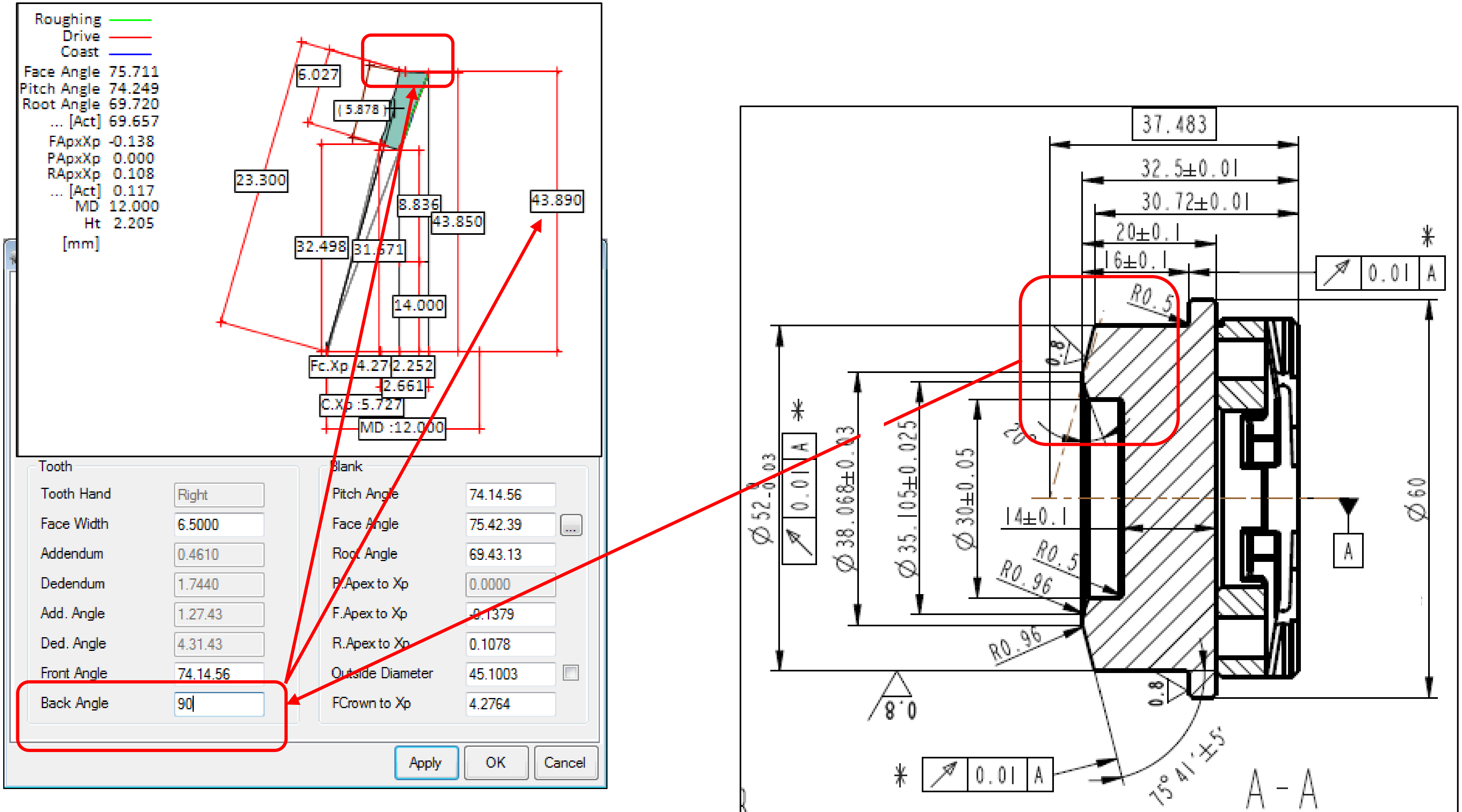



# Example: Establishing a Turned OD – Method 1

Select the Gear Summary Editor: “Gea” function button

1- Set the Back Angle to 90 deg.

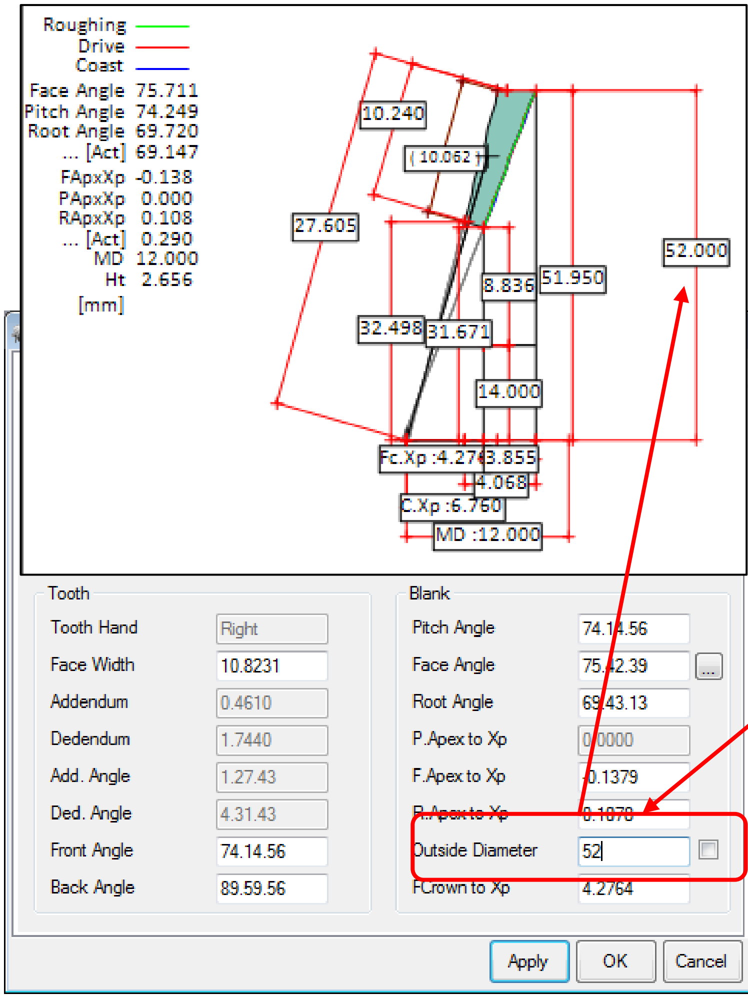
2- Click on “Apply”

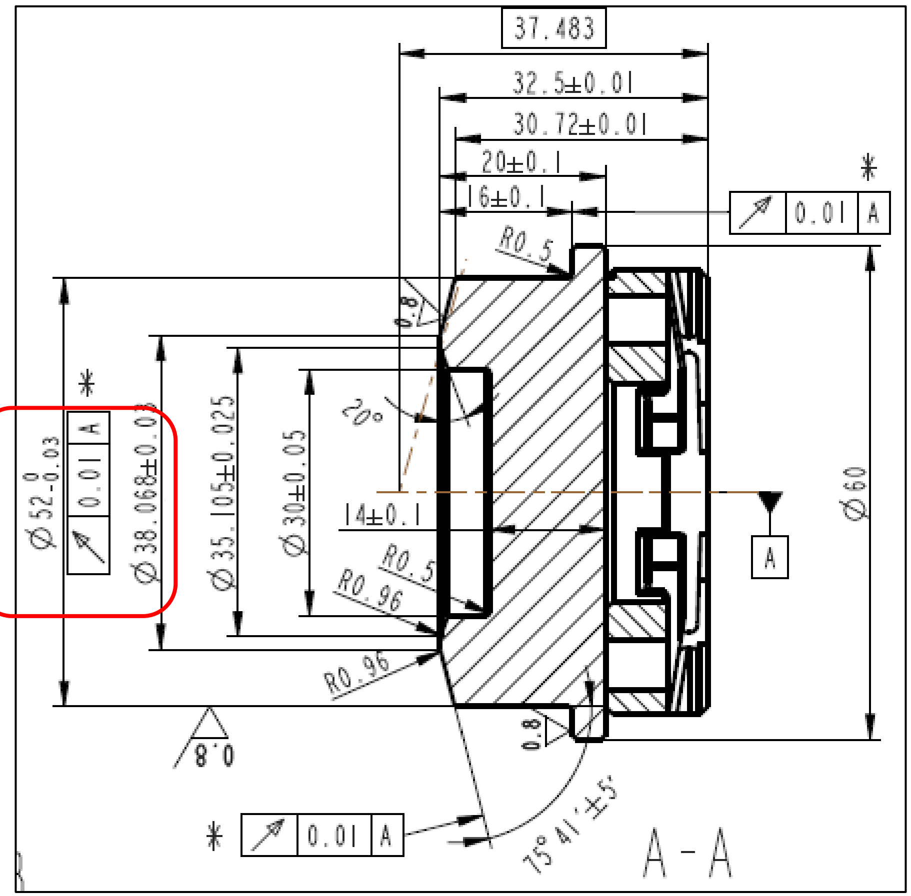


# Example: Establishing a Turned OD – Method 1

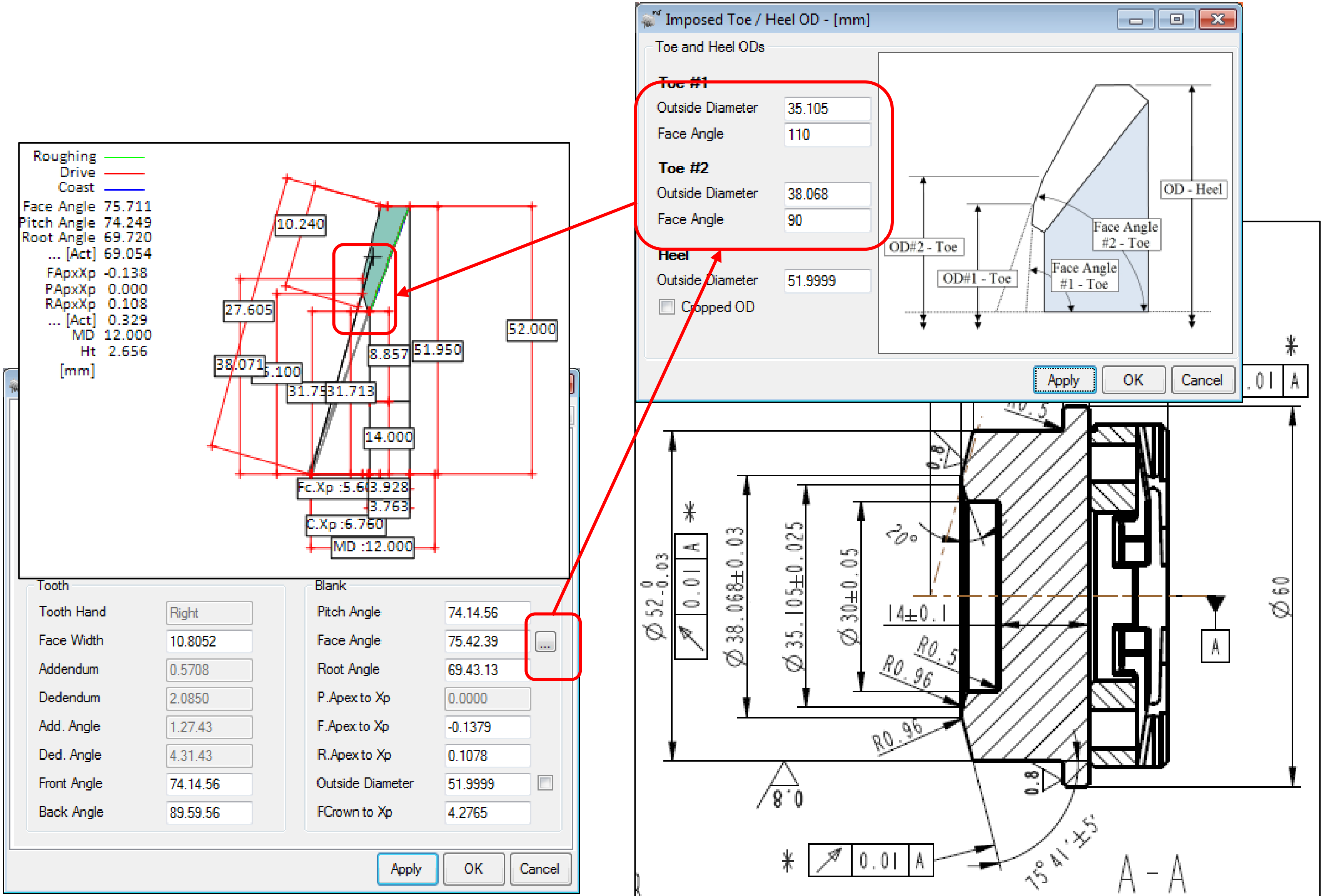
3- Enter the requested OD: 52 [mm]

4- Click on "Apply"



# Example: Establishing a Tapered Toe OD – Method 1

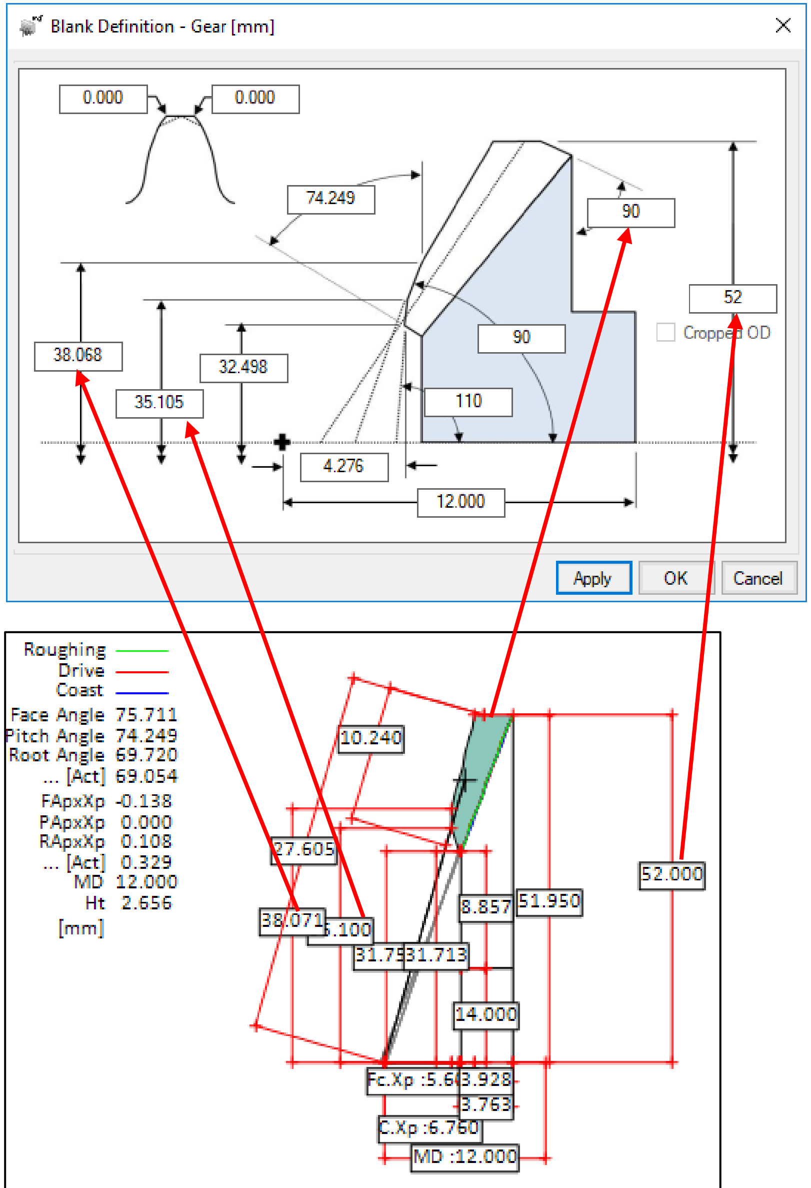


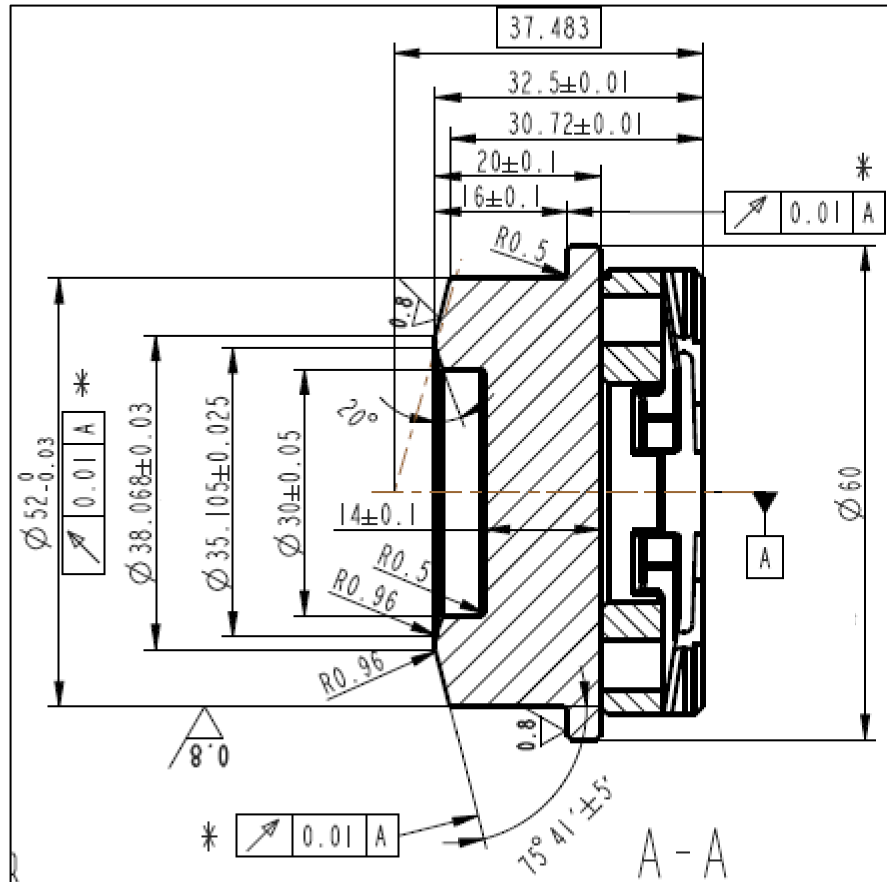
# Example: Establishing a Tapered Toe OD- Method 2

Blank Editor: “Blank” function button (Gear Group)

1- Enter the desired values

2- Click on “Apply”



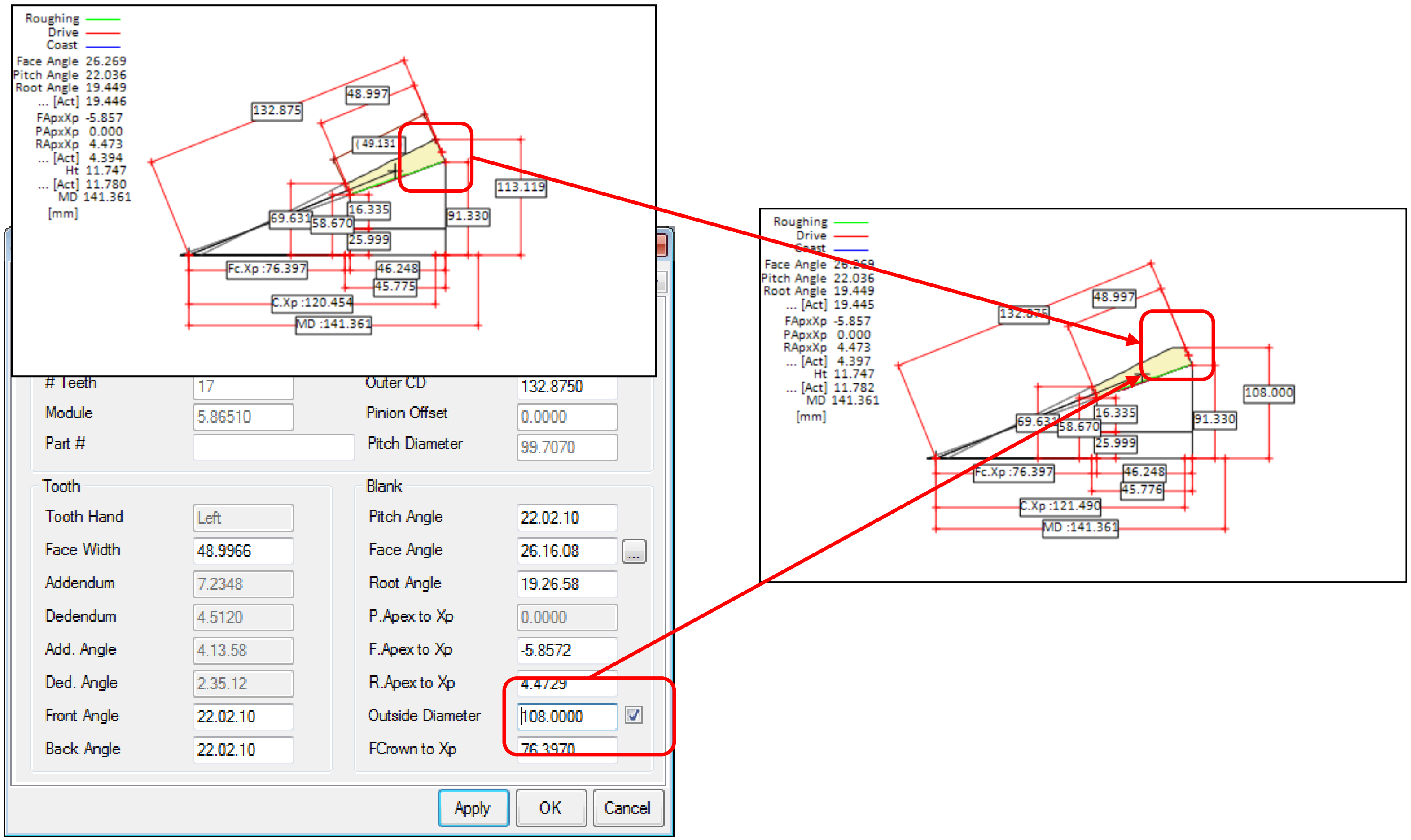
# Example: Establishing a Cropped Heel OD – Method 1

Pinion Summary Editor: “Pin” function button

1- Click on the check box to the right of the Outside Diameter input field;

2- Enter the desired Cropped OD;

3- Click on “Apply”



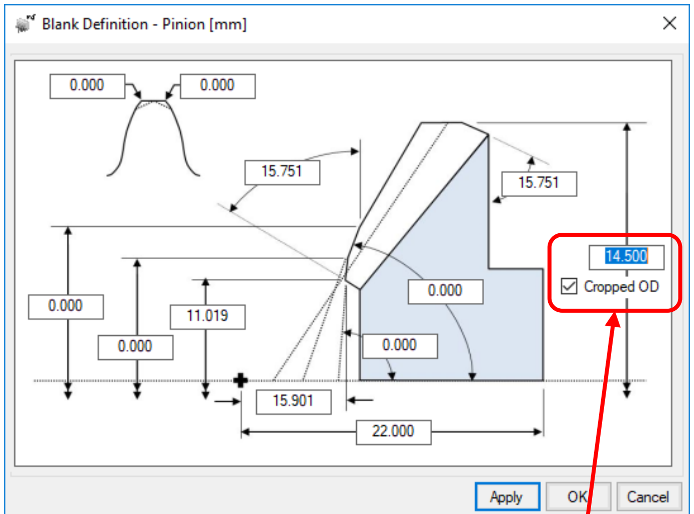
# Example: Establishing a Cropped Heel OD – Method 2

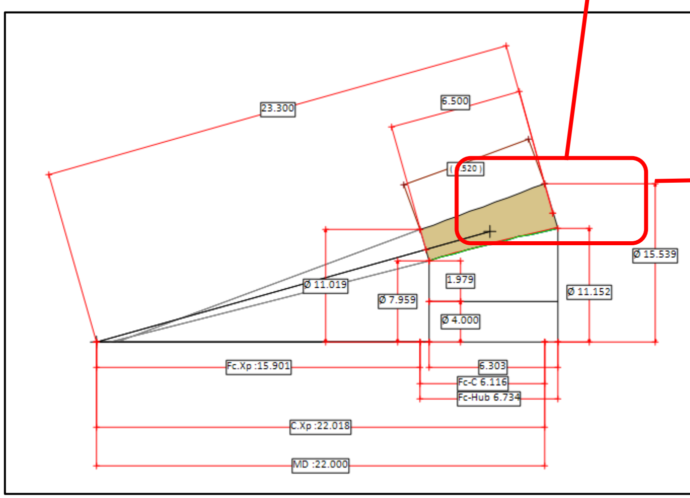
Blank Editor: “Blank” function button (Pinion Group)

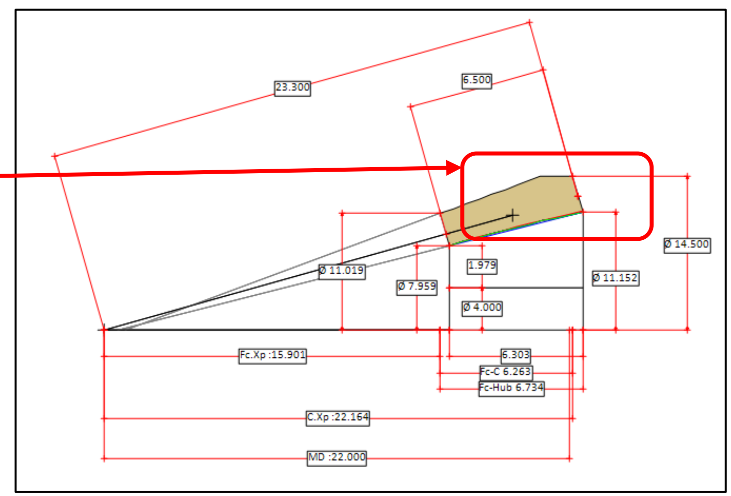
1- Click on the Cropped OD check box;

2- Enter the desired Cropped OD;

3- Click on “Apply”

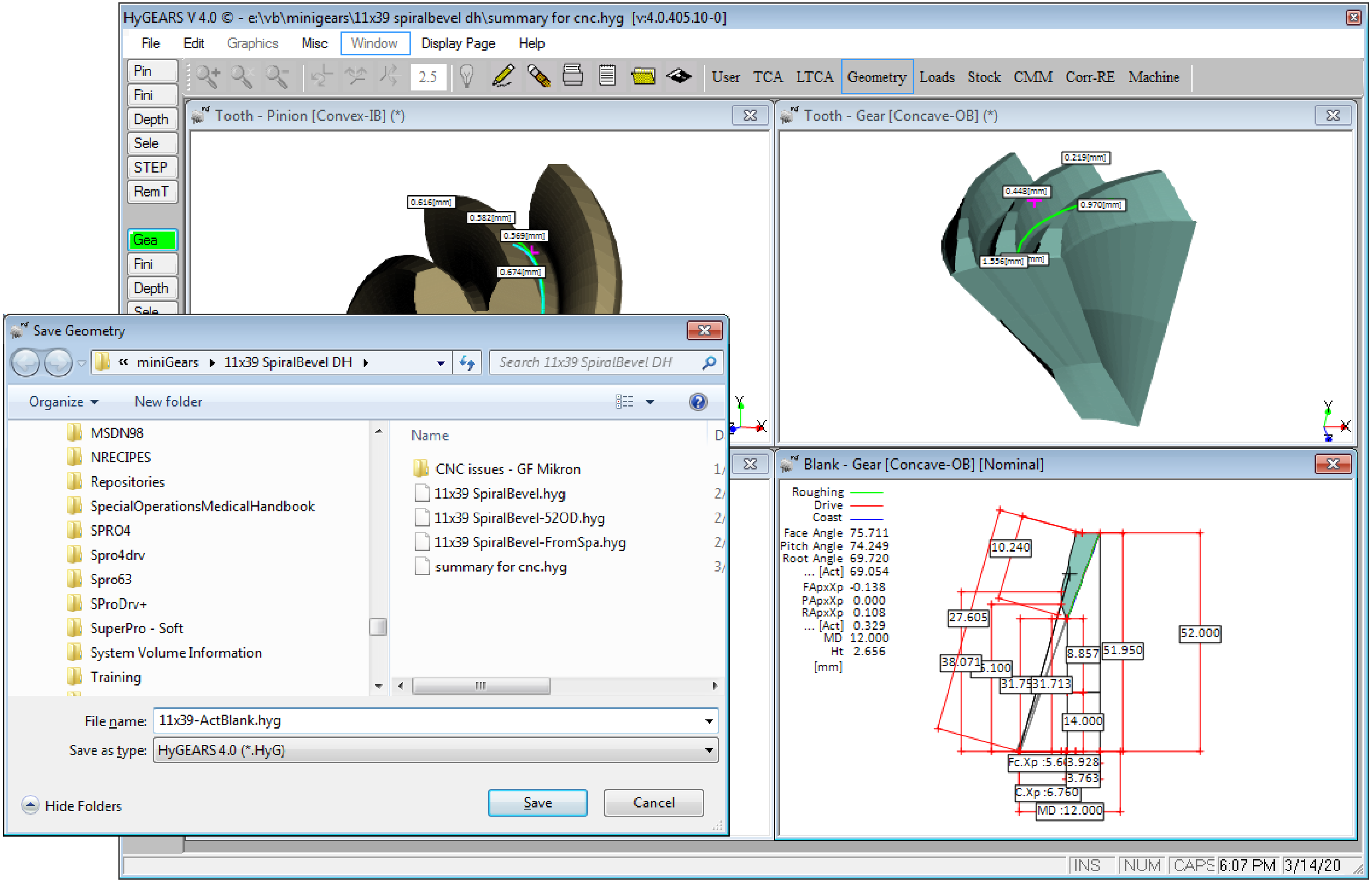


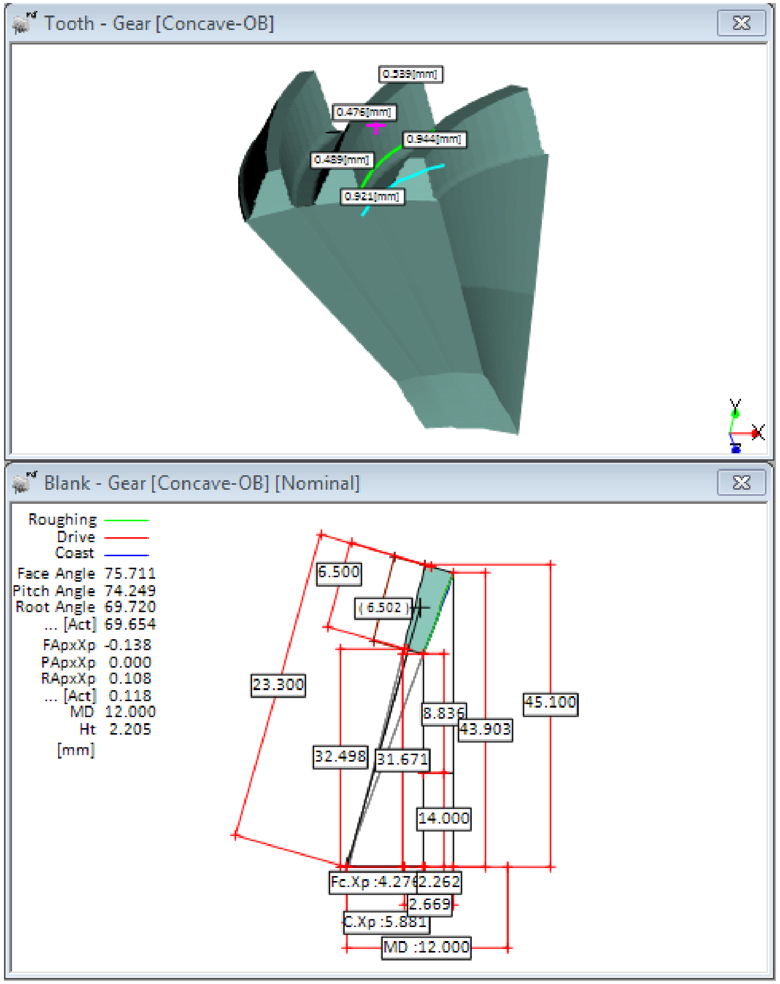



# Example: Establishing the Correct Blank

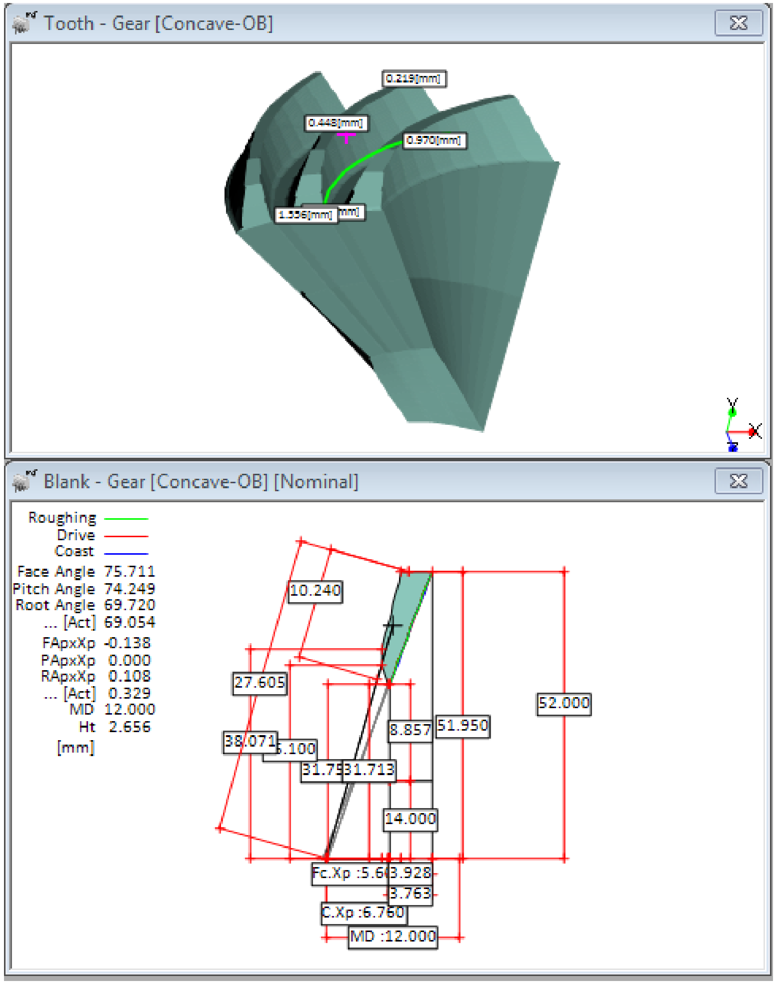
Save your geometry under a different name to be able to compare



# Example: Establishing the Correct Blank

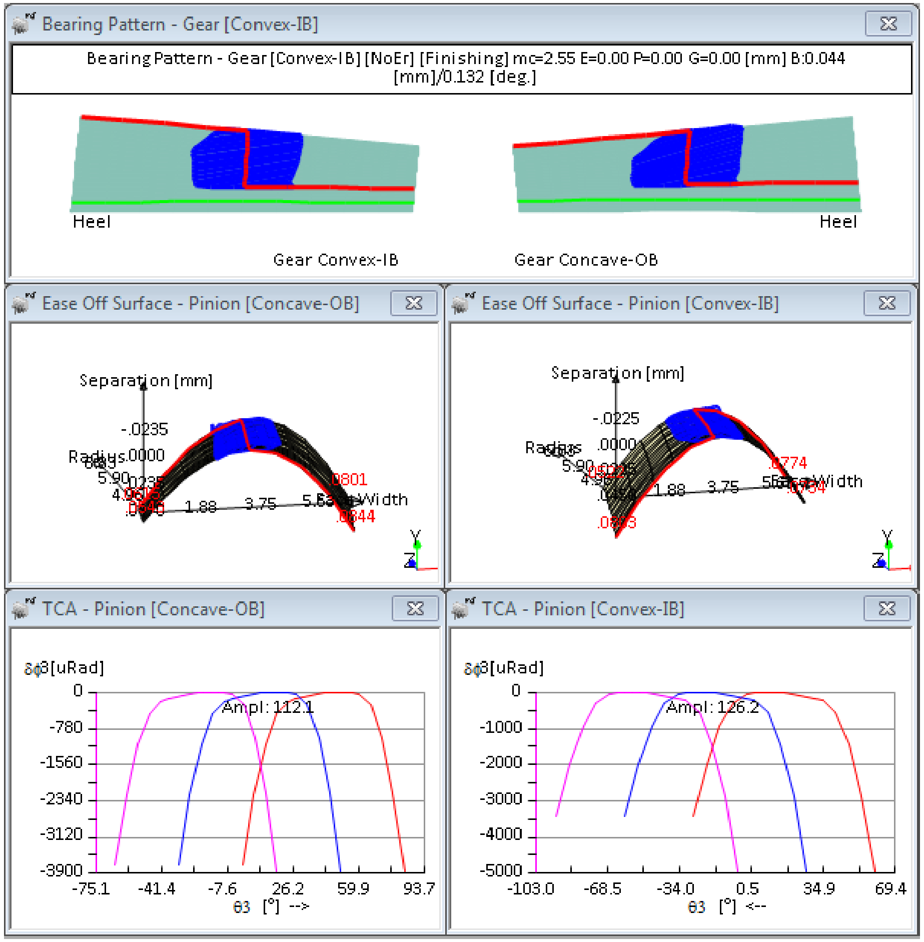



**Geometry as Created/Imported**

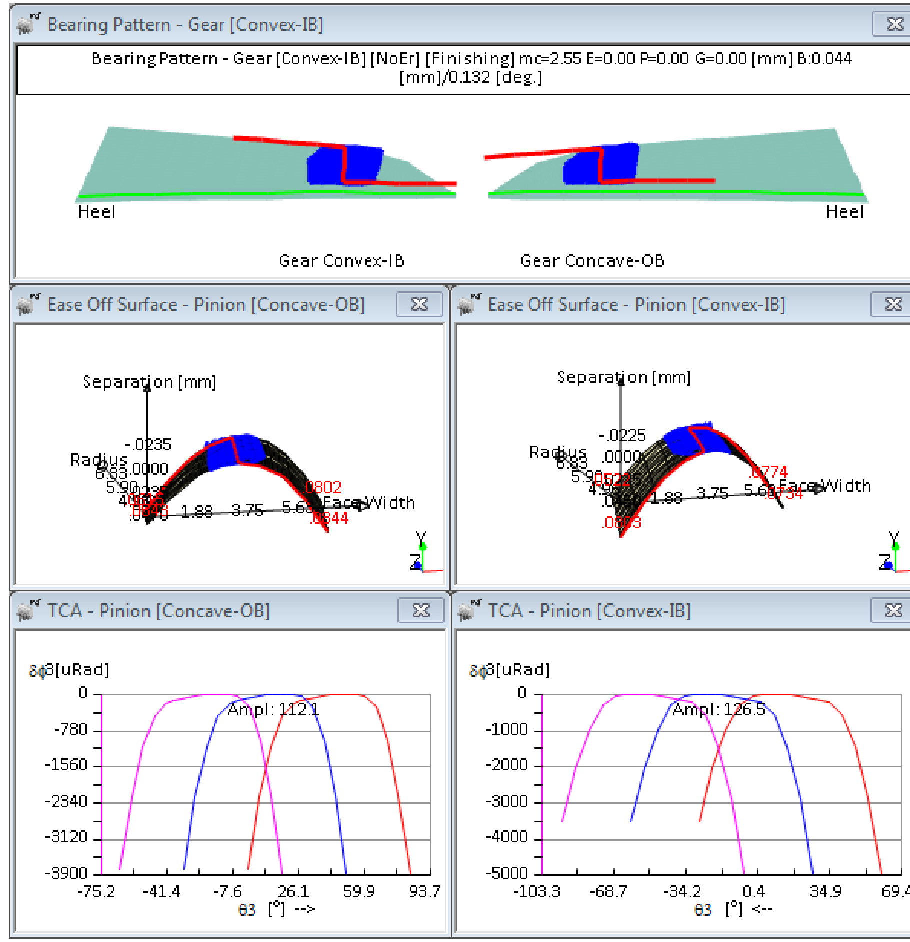



**Geometry as Modified**

# Example: Establishing the Correct Blank

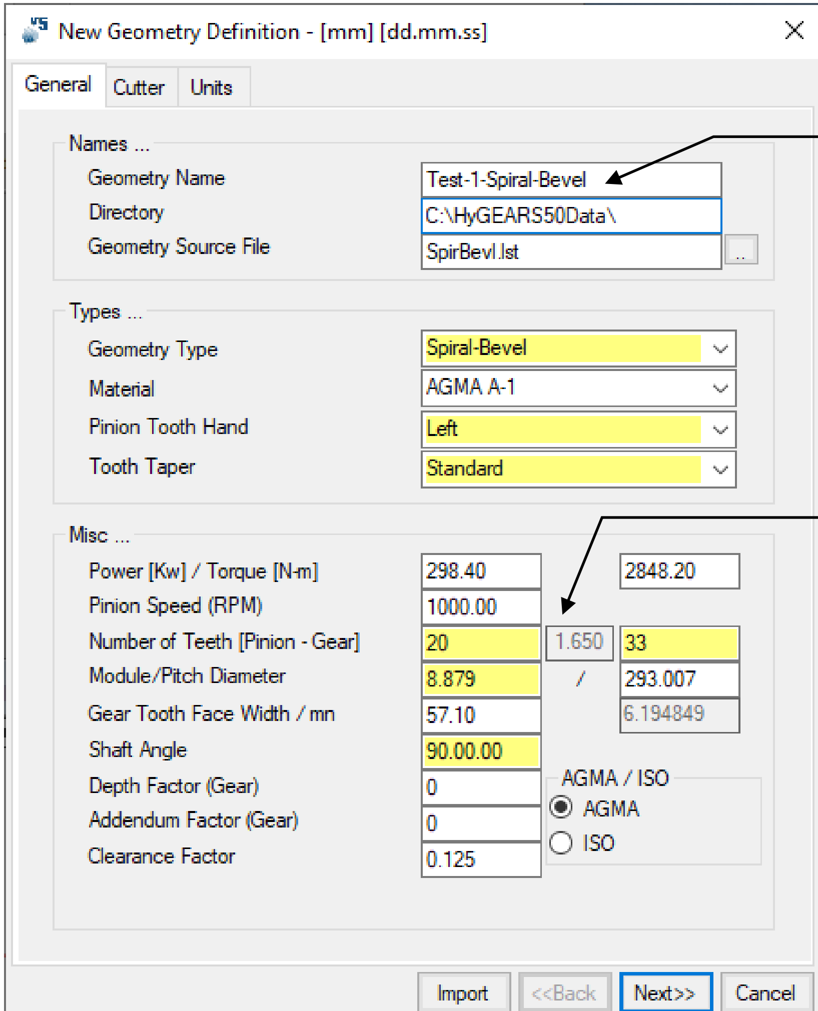



TCA as Created/Imported




TCA as Modified

# Creating a Spiral Bevel/Hypoid gear set (FM)




Default name

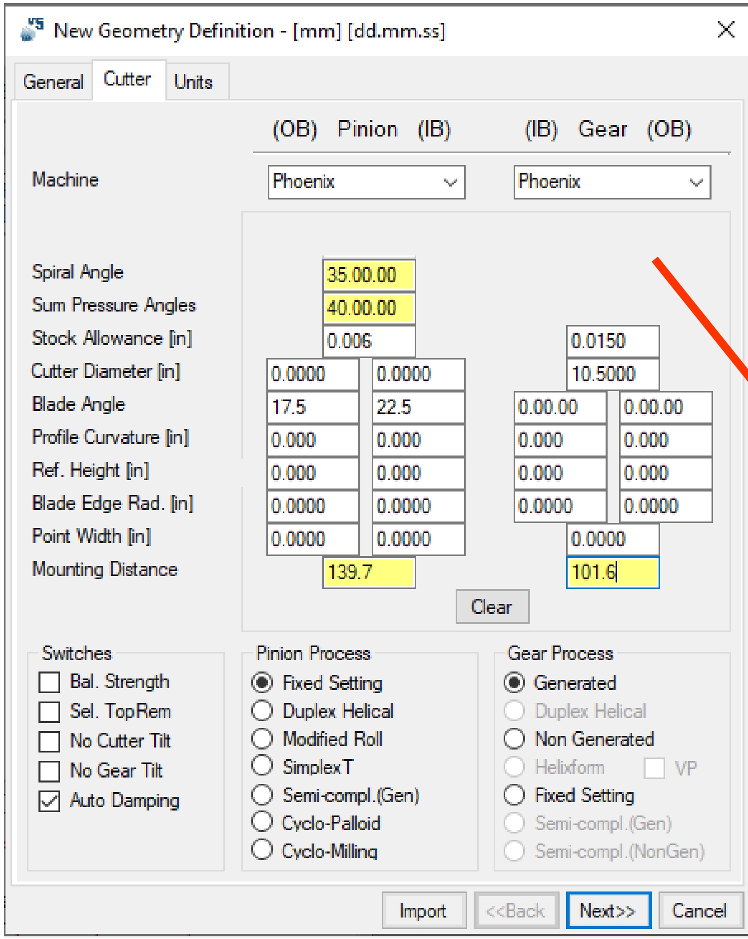
Gear ratio

Enabled if geometry present in memory

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

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

# Creating a Spiral Bevel/Hypoid gear set (FM) / 2



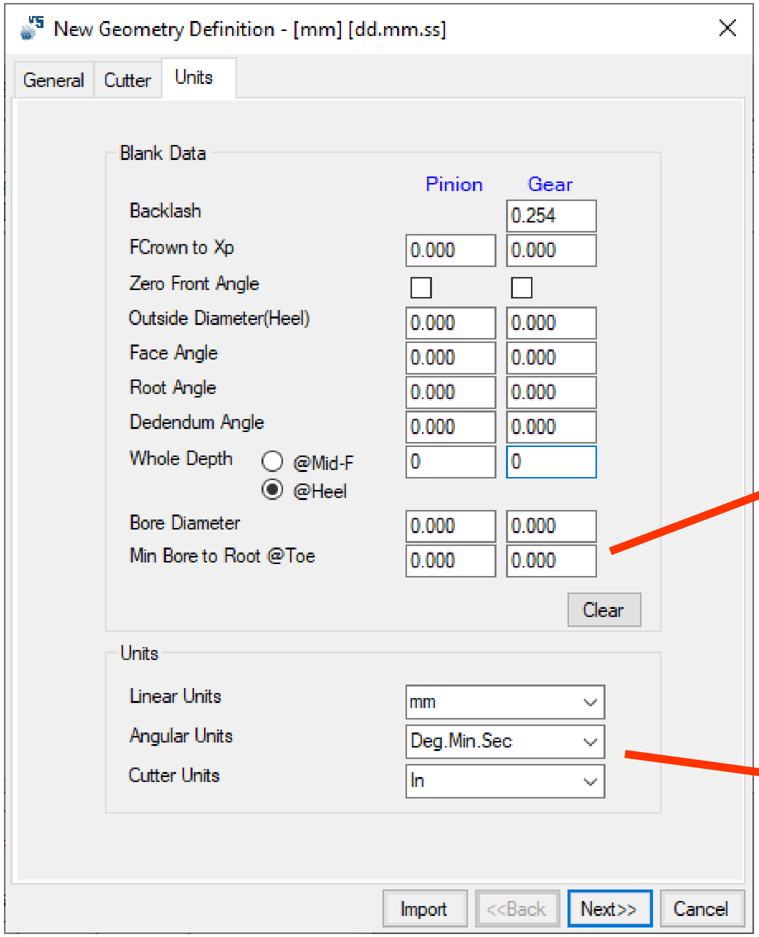

| Finishing Process | Roughing Process |
|---|---|
| Fixed Setting | Spread Blade |
| Duplex Helical | Spread Blade |
| Modified Roll | Spread Blade |
| Face Hobbing | Face Hobbing |
| Spread Blade | Spread Blade |
| Formate | Plunge cut |
| Helixform | Plunge cut |
| Simplex-T | Spread Blade |

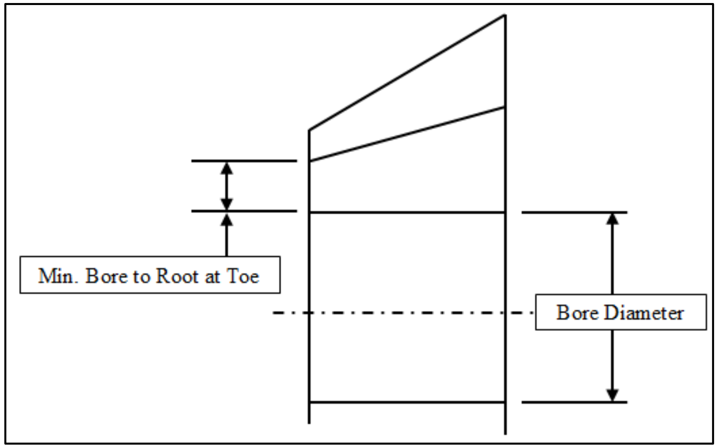
| Gleason Machine Number |
|---|
| 16 |
| 22 |
| 26 |
| 102 |
| 106 |
| 108 |
| 116 |
| Phoenix |
| 607 |
| 613 |
| 631 |
| 641 |
| Basic |

| 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 |

| Klingelnberg Machine Number |
|---|
| K-ND (neutral data) |
| **Other Machine Number** |
| 603 (no cutter tilt) |

# Creating a Spiral Bevel/Hypoid gear set (FM) / 3




Angular input formats:

22.30.00 ⇔ 22.50

# Creating a Spiral Bevel/Hypoid gear set (FM) / 4

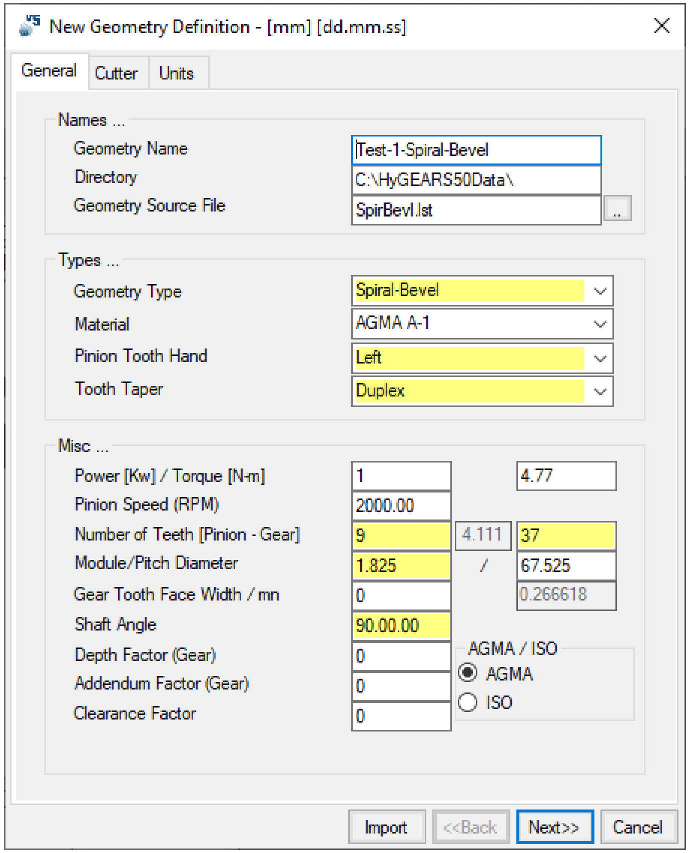
Example: 9x37 Generated Spiral Bevel gear set

| | |
|---|---|
| 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 4:1 |
| Pinion Speed: | 2000 RPM |
| Available diameter space: | About 70 mm (2.75 in) |
| Power: | 1 kW (1.3 HP) |
| Application: | Power tool |

# Creating a Spiral Bevel/Hypoid gear set (FM) / 5

Example: 9x37 Generated Spiral Bevel gear set

Call the **File-> New Geometry** menu entry – Spiral Bevel

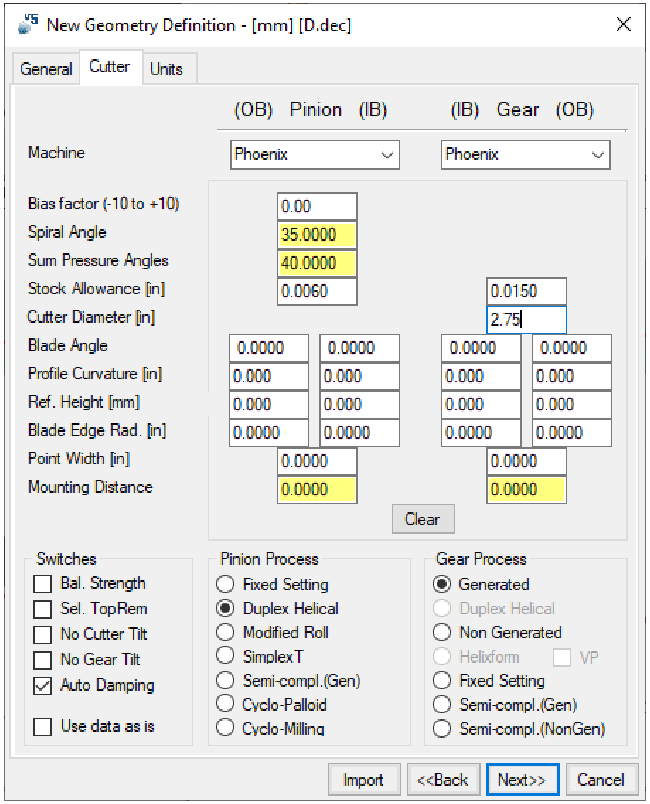



Click on Next >>

# Creating a Spiral Bevel/Hypoid gear set (FM) / 6

Example: 9x37 Generated Spiral Bevel gear set

Cutter Data Section:

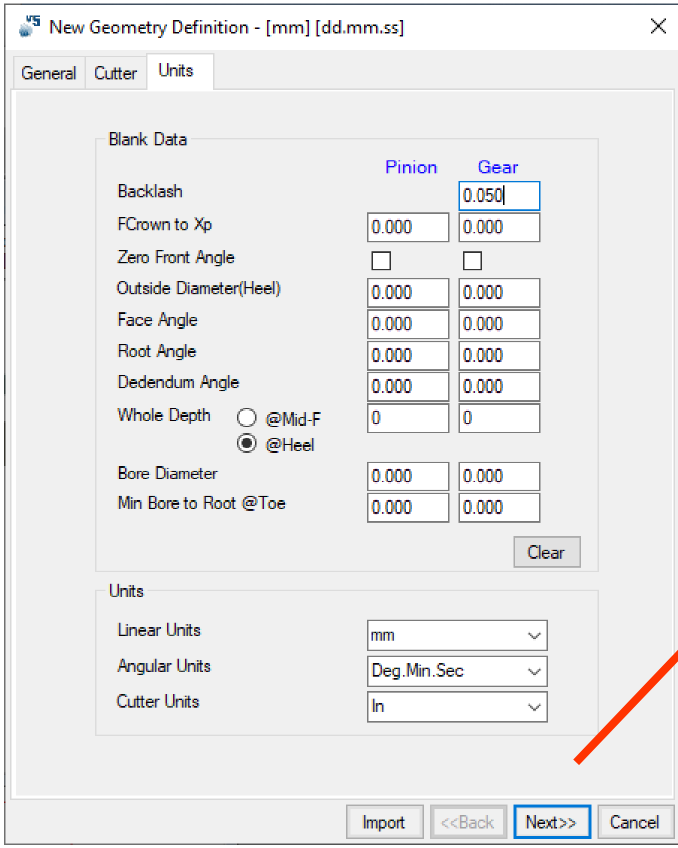


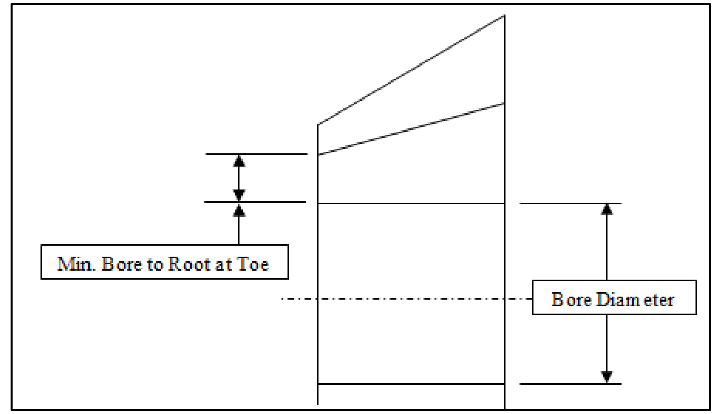

Click on Next >>

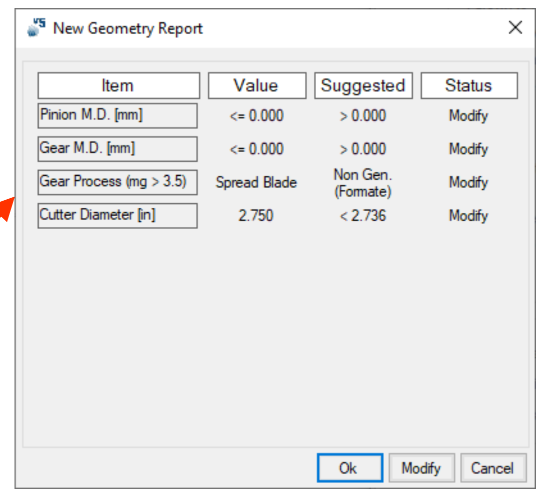
# Creating a Spiral Bevel/Hypoid gear set (FM) / 6

Example: 9x37 Generated Spiral Bevel gear set

## Units Data Section:



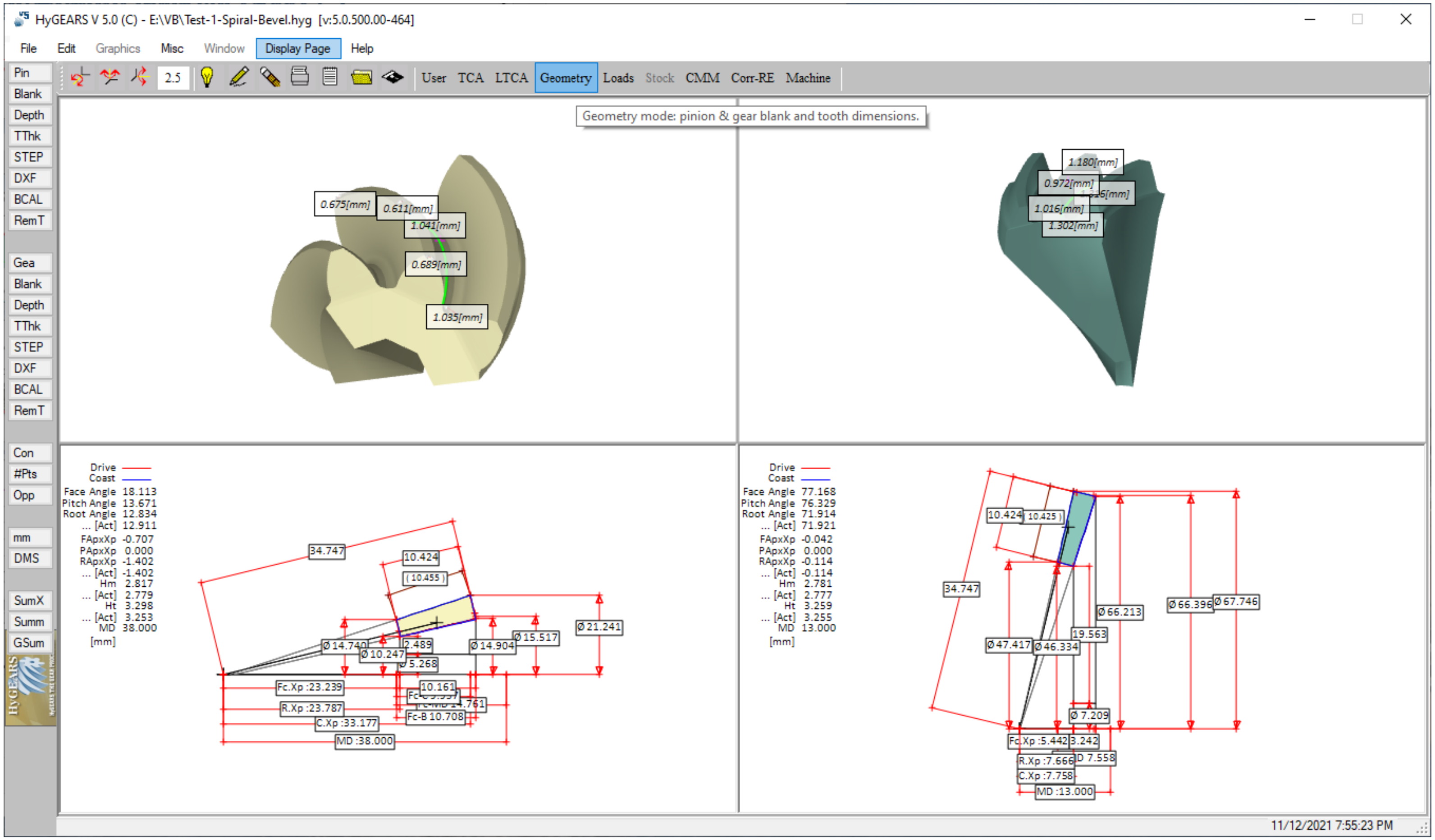




Click on Next >>

Click on Ok

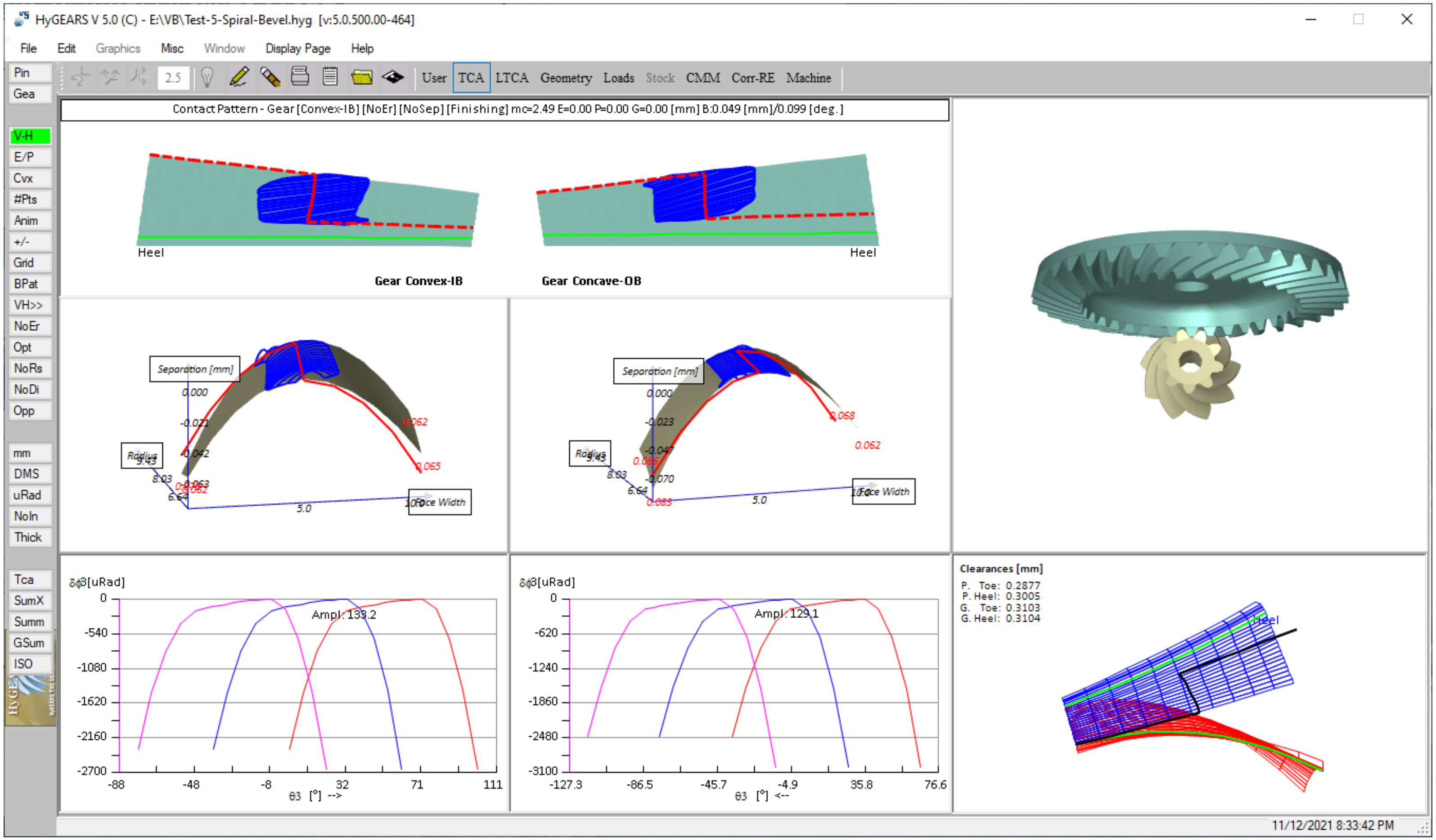
# Creating a Spiral Bevel/Hypoid gear set (FM) / 7

Example: 9x37 Generated Spiral Bevel gear set



# Creating a Spiral Bevel/Hypoid gear set (FM) / 8

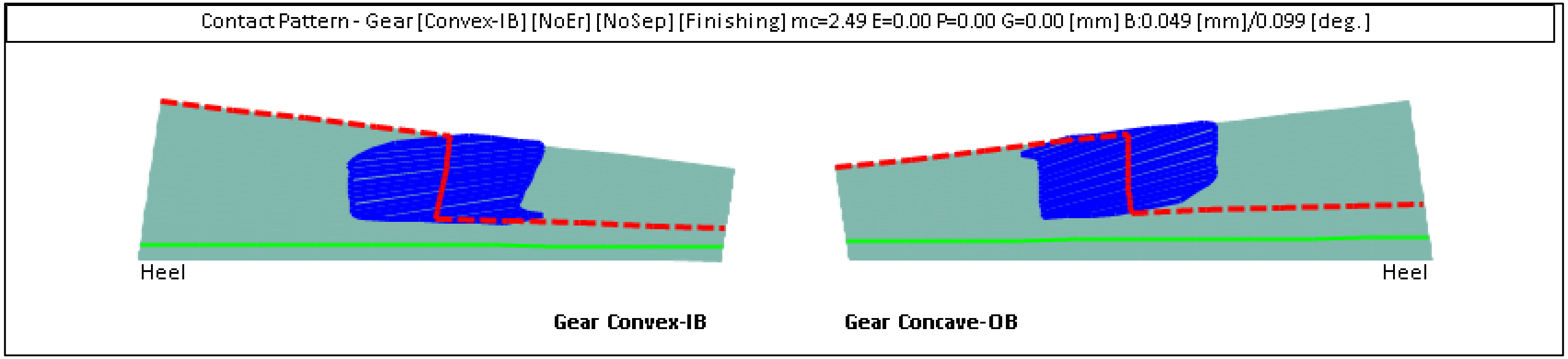
Example: 9x37 Generated Spiral Bevel gear set



# Creating a Spiral Bevel/Hypoid gear set (FM) / 9

Example: 9x37 Generated Spiral Bevel gear set

Press the ^S (Save) keyboard combination and agree to the questions asked.

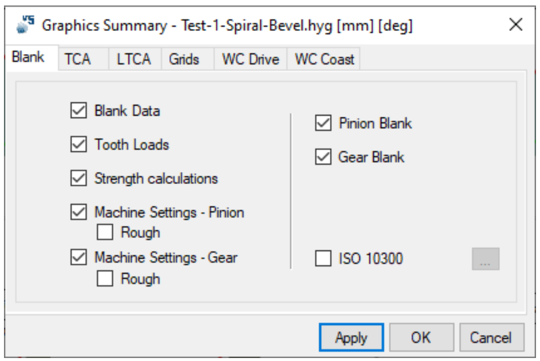


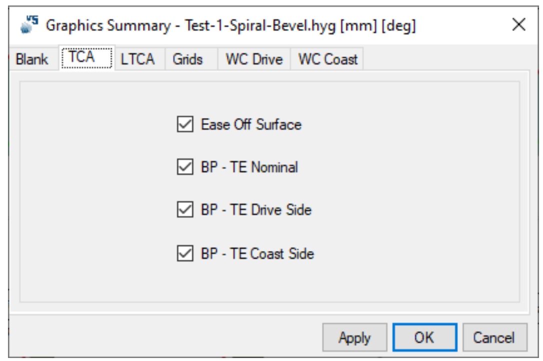

Contact Pattern Display of the 9x37a.dat Geometry

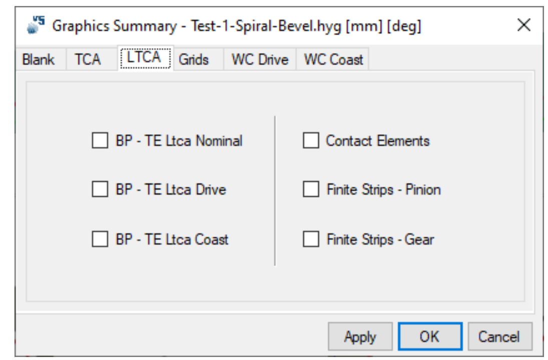
# Creating a Spiral Bevel/Hypoid gear set (FM) / 10

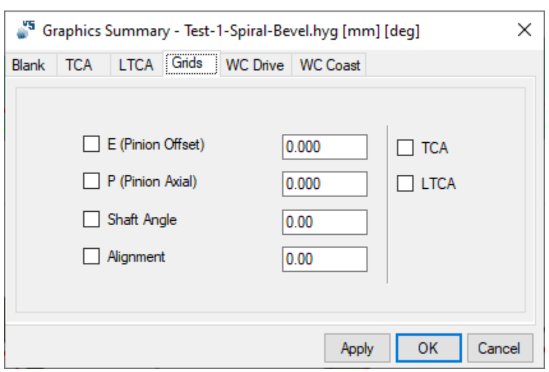
Example: 9x37 Generated Spiral Bevel gear set

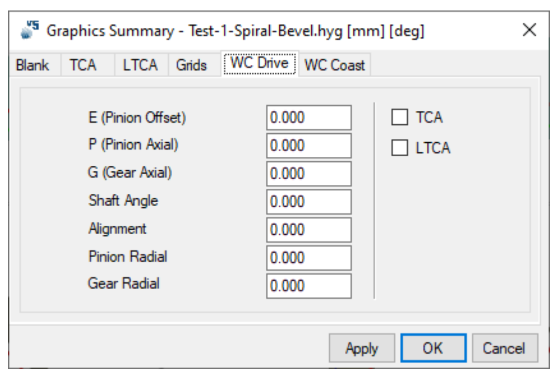
Click on the **GSum** function button:



# Creating a Spiral Bevel/Hypoid gear set (FM) / 11

Example: 9x37 *Generated* Spiral Bevel gear set

Test-1-Spiral-Bevel.hyg

**HyGEARS V 5.0 (C) - Spiral-Bevel Geometry Summary**
**Duplex Helical Pinion [Nominal]**
**Spread Blade Gear [Nominal]**

| | | |
|---|---|---|
| Date / Time | : | 11/12/2021 / 8:01:18 PM |
| General Units | : | [mm] [D.dec] |
| Cutter Units | : | [mm] |
| Prepared by | : | Claude Gosselin / |
| Version | : | 5.0.500.00-464 |

| GENERAL DATA | | PINION | GEAR |
|---|---|---|---|
| Number of Teeth | : | 9 | 37 |
| Hand of Spiral | : | LEFT | RIGHT |
| Speed Ratio | : | 4.1111:1 [Speed Reducer] | |
| Diametral Pitch | : | 13.9178 | |
| Module | : | 1.8250 | |
| Mean Normal Module | : | 1.2707 | 1.2707 |
| Circular Pitch | : | 5.7334 | |
| Face Width | : | 10.4241 | 10.4241 |
| Angular Face | : | | 31.0691 |
| Outer Cone Distance | : | 34.7470 | 34.7470 |
| Mean Cone Distance | : | 29.5349 | 29.5349 |
| Ratio Involute/Cone Dist | : | 1.04 | |
| Shaft Angle | : | 90.0000 | |
| Pitch Diameter | : | 16.4250 | 67.5250 |
| Outside Diameter | : | 21.2411 | 67.7463 |
| Tooth Taper | : | Duplex | |
| AGMA Depth Factor | : | 3.8839 | 3.8839 |
| Addendum Factor | : | 0.8411 | 0.1589 |
| Clearance Factor | : | 0.2088 | 0.2088 |
| ISO Addendum Factor | : | 0.9710 | 0.9710 |
| Dedendum Factor | : | 1.3764 | 1.3764 |
| Profile Shift Factor | : | 0.6624 | -0.6624 |
| Face Width % Cone Distance | : | 30.0000 | 30.0000 |
| Mounting Distance | : | 38.0000 | 13.0000 |
| Profile C.Ratio [Drive/Coast] | : | 0.9297 | 1.0093 |
| Actual C.Ratio | : | 1.3767 | 1.4438 |
| Face C.Ratio | : | 2.3617 | 2.3536 |
| Total C.Ratio | : | 2.5381 | 2.5609 |

| BLANK DATA | | PINION | GEAR |
|---|---|---|---|
| Face Apex Beyond XP | : | -0.7074 | -0.0419 |
| Root Apex Beyond XP | : | -1.4024 | -0.1140 |
| Root Apex Beyond XP [Act] | : | -1.4024 | -0.1140 |
| Crown to XP | : | 33.1768 | 7.7577 |
| Front Crown to XP | : | 23.2394 | 5.4423 |
| Addendum | : | 2.4783 | 0.4681 |
| Dedendum | : | 0.8192 | 2.7913 |
| Ht | : | 3.2975 | 3.2594 |
| Ht ...[Act] | : | 3.2525 | 3.2550 |
| Addendum Angle | : | 4.4413 | 0.8391 |
| Dedendum Angle | : | 0.8371 | 4.4148 |
| Face Angle of Blank | : | 18.1126 | 77.1678 |
| Pitch Angle | : | 13.6713 | 76.3287 |
| Root Angle | : | 12.8342 | 71.9139 |
| Root Angle (Actual) | : | 12.9115 | 71.9210 |
| Front Angle | : | 13.6713 | 76.3287 |
| Back Angle | : | 13.6713 | 76.3287 |
| Reference Values | | | |
| Spiral Angle-Center | : | 35.0000 | 35.0000 |
| Press. Angle (IB) | : | 20.0000 | 20.0000 |
| Press. Angle (OB) | : | 20.0000 | 20.0000 |
| Outer Cone Distance | : | 34.7470 | 34.7470 |
| Face Width | : | 10.4241 | 10.4241 |
| Spiral & Pressure Angles - Pitch Cone [Actual] | | | |
| Spiral Angle-Toe | : | 28.0697 | 28.0820 |
| Spiral Angle-Center | : | 35.0553 | 35.0823 |
| Spiral Angle-Heel | : | 42.6835 | 42.7699 |
| Press Angle (IB) | : | 20.0458 | 19.7764 |
| Press Angle (OB) | : | 19.7267 | 20.0176 |
| Spiral & Pressure Angles - Root Cone [Actual] | | | |
| Spiral Angle-Center | : | 35.0486 | 34.9941 |
| Press Angle (IB) | : | 20.5218 | 22.2873 |
| Press Angle (OB) | : | 19.2412 | 17.4574 |

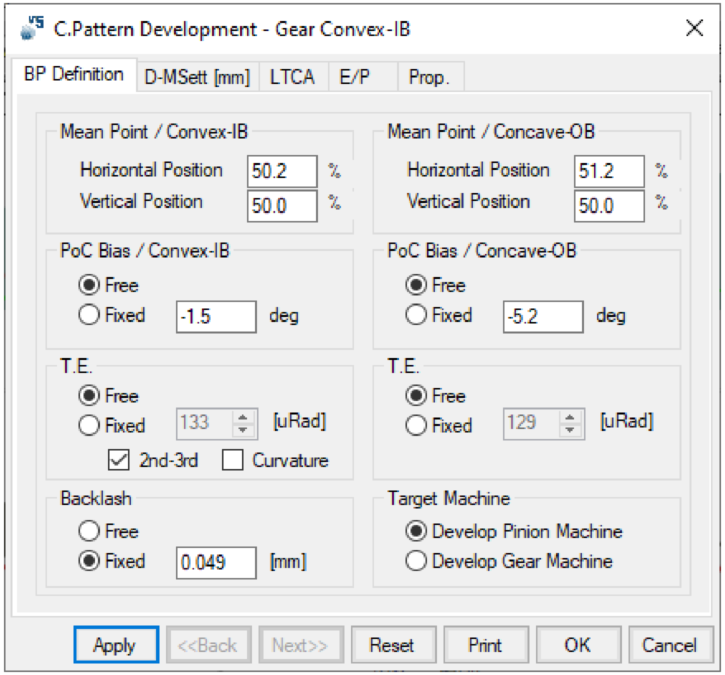
| TOOTH DATA | | PINION | GEAR |
|---|---|---|---|
| Calculated Tooth Depths (Chordal) | | | |
| Pinion + Gear [Finishing] | | | |
| Form Depth (Toe) | : | 2.1201 | 1.9448 |
| Whole Depth (Toe) | : | 2.6056 | 2.3225 |
| Form Depth (Mid-F) | : | 2.5469 | 2.4539 |
| Whole Depth (Mid-F) | : | 2.9998 | 2.8385 |
| Form Depth (Heel) | : | 3.0380 | 2.8993 |
| Whole Depth (Heel) | : | 3.4685 | 3.2709 |
| Calculated Tooth Depths (Circular) | | | |
| Pinion + Gear [Finishing] | | | |
| Form Depth (Toe) | : | 1.9603 | 1.8837 |
| Whole Depth (Toe) | : | 2.3125 | 2.2889 |
| Form Depth (Mid-F) | : | 2.4371 | 2.3885 |
| Whole Depth (Mid-F) | : | 2.7640 | 2.7970 |
| Form Depth (Heel) | : | 2.9454 | 2.8563 |
| Whole Depth (Heel) | : | 3.2611 | 3.2421 |
| Fillet Radius @ Mid-Face | | | |
| Drive - Root Diameter | : | 0.4036 | 0.5253 |
| Coast | : | 0.4021 | 0.5382 |
| Drive - Form Diameter | : | 0.3636 | 0.3846 |
| Coast | : | 0.3740 | 0.4121 |
| Theo. Finish Thickness @ M.Po | : | 2.2920 | 1.6894 |
| Meas. Addendum (Chordal) | : | 2.2105 | 0.4046 |
| Theo. Finish Thickness @ M.Po | : | 2.2920 | 1.6894 |
| Normal Thick. @ M.Point | : | 2.6689 | 1.2558 |
| Trans. Thick. | : | 3.2604 | 1.5346 |
| Axial Position | : | 28.6981 | 6.9806 |
| Radial Position | : | 6.9797 | 28.6982 |
| Angular Thick. [deg] | : | 27.0075 | 3.0633 |
| Normal Thick. @Heel | : | 2.8238 | 1.2054 |
| Trans. Thick. | : | 3.8413 | 1.6420 |
| Axial Position | : | 33.7625 | 8.2125 |
| Radial Position | : | 8.2113 | 33.7625 |
| Angular Thick. [deg] | : | 27.0434 | 2.7863 |
| Topland (Mid-Face - Normal Pl | : | 0.6115 | 0.9718 |
| Topland (Toe - Normal Plane) | : | 0.5637 | 0.8316 |
| Topland (Heel - Normal Plane) | : | 0.5527 | 0.9656 |
| Topland (Toe - Transv. Plane) | : | 0.6887 | 1.0162 |
| Topland (Heel - Transv. Plane | : | 0.6752 | 1.1799 |

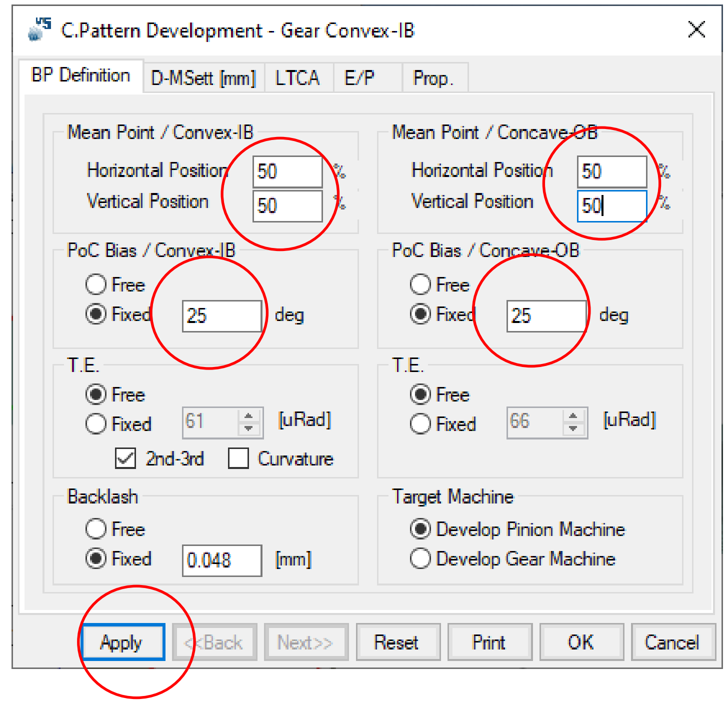
| OPERATING DATA | | PINION | GEAR |
|---|---|---|---|
| Backlash (Min) | : | | 0.0254 |
| Backlash (Max) | : | | 0.0762 |
| Backlash (@ M.Point) | : | | 0.0484 |
| Backlash (@ M.Point) [deg.] | : | | 0.0967 |
| Backlash (@Heel) | : | | 0.0570 |
| Bottom Clearance (Toe) | : | 0.3114 | 0.3206 |
| Bottom Clearance (Heel) | : | 0.3024 | 0.3186 |

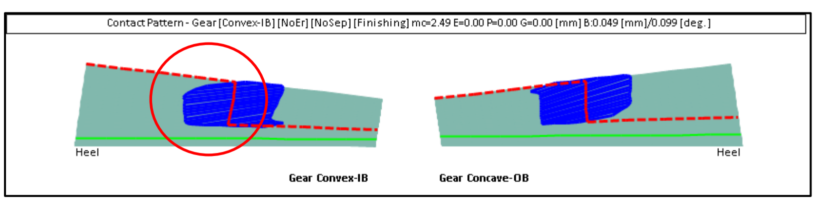
(Gear Concave-OB E=0.00 P=0.00 G=0.00 [mm])
(Gear Convex-IB E=0.00 P=0.00 G=0.00 [mm])

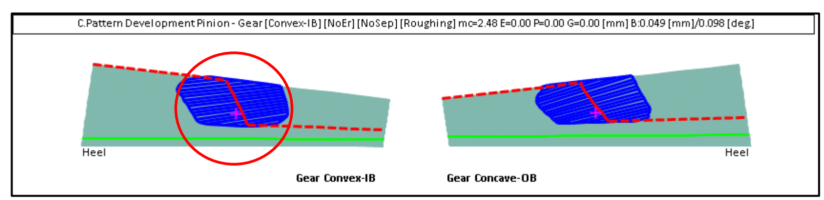
# Creating a Spiral Bevel/Hypoid gear set (FM) / 12

Example: Modifying the CP and TE 9x37 Generated Spiral Bevel gear set



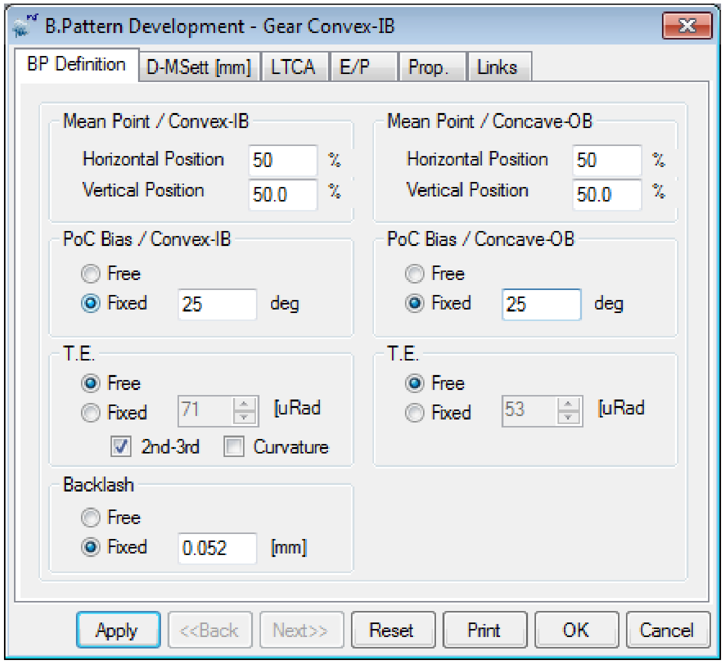



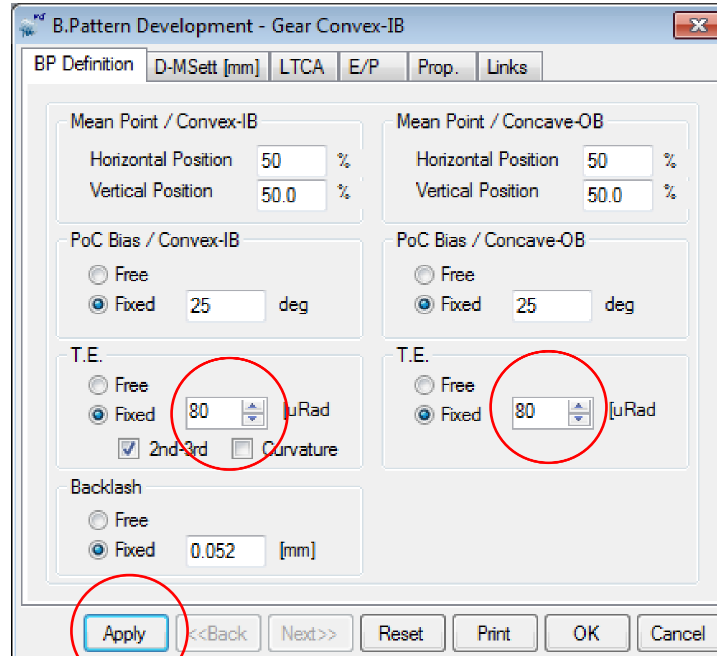



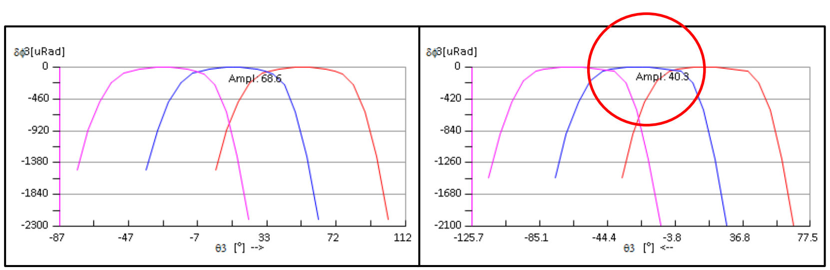



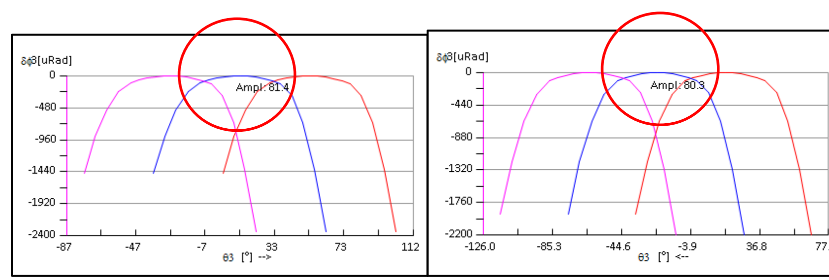
# Creating a Spiral Bevel/Hypoid gear set (FM) / 13

Example: Modifying the CP and TE 9x37 Generated Spiral Bevel gear set



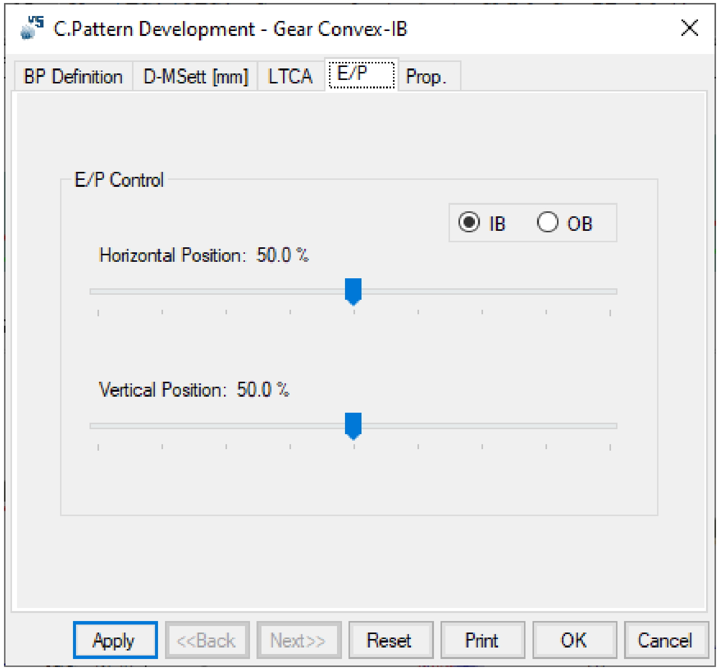



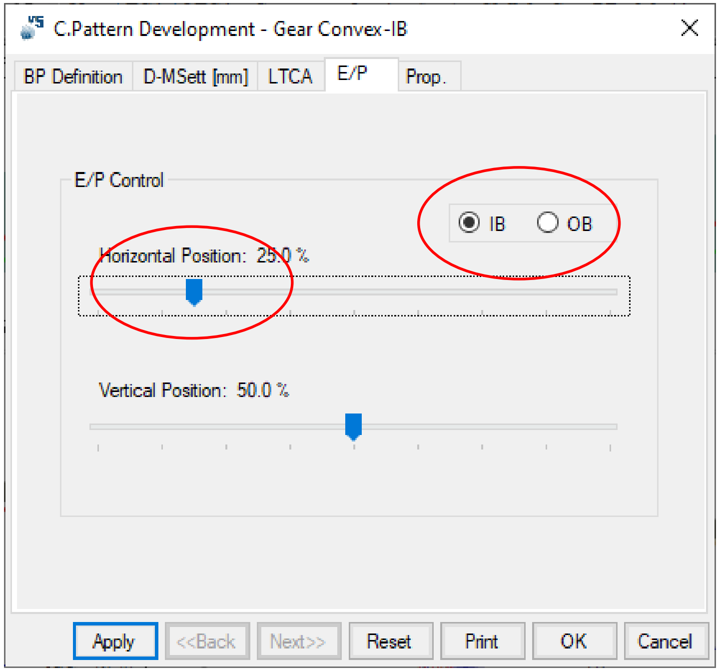



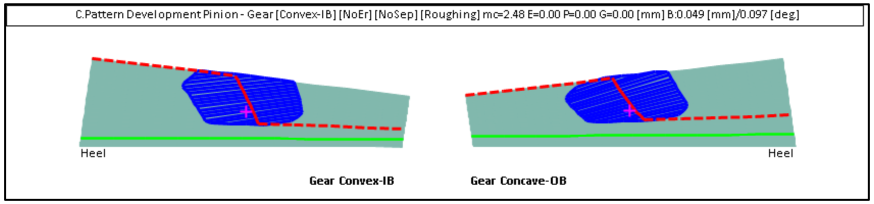



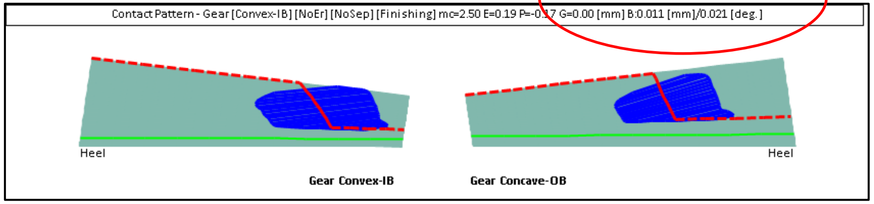
# Creating a Spiral Bevel/Hypoid gear set (FM) / 14

Example: Modifying the CP and TE 9x37 Generated Spiral Bevel gear set



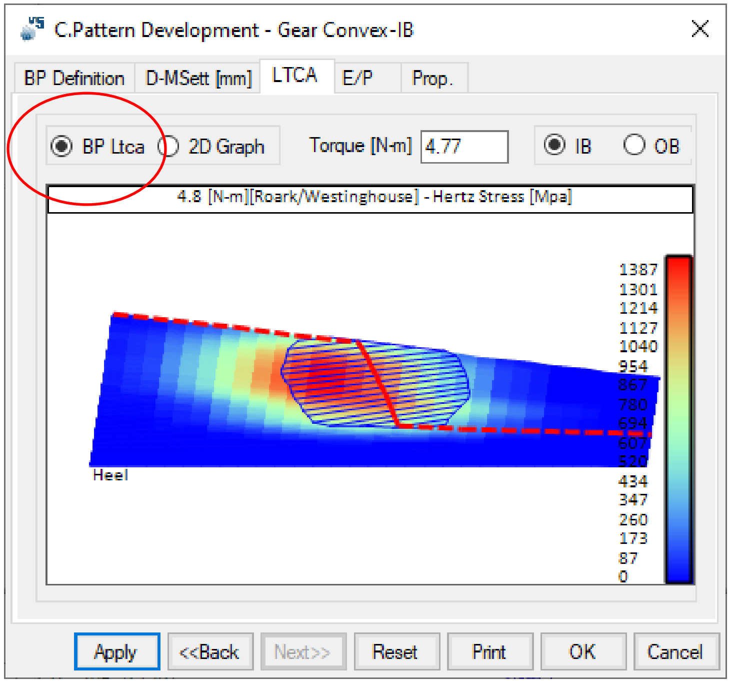



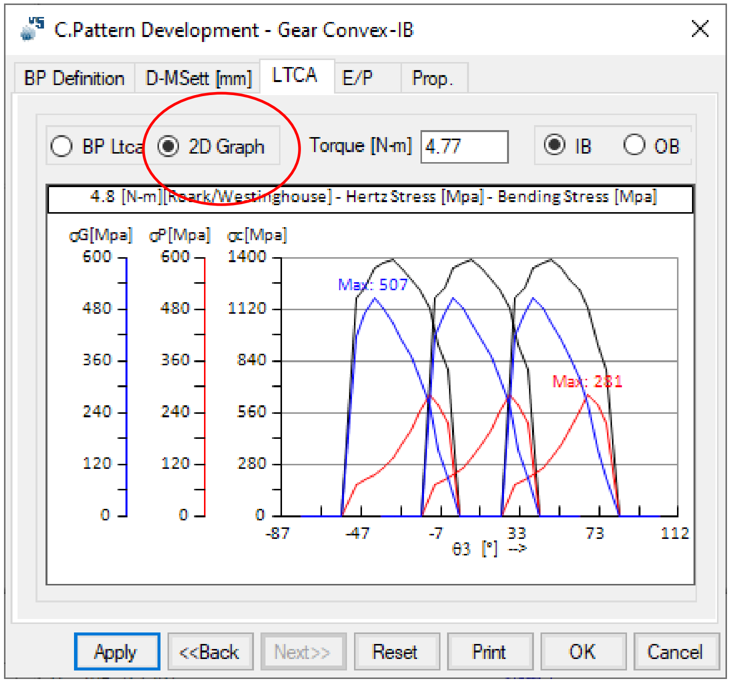



# Creating a Spiral Bevel/Hypoid gear set (FM) / 15

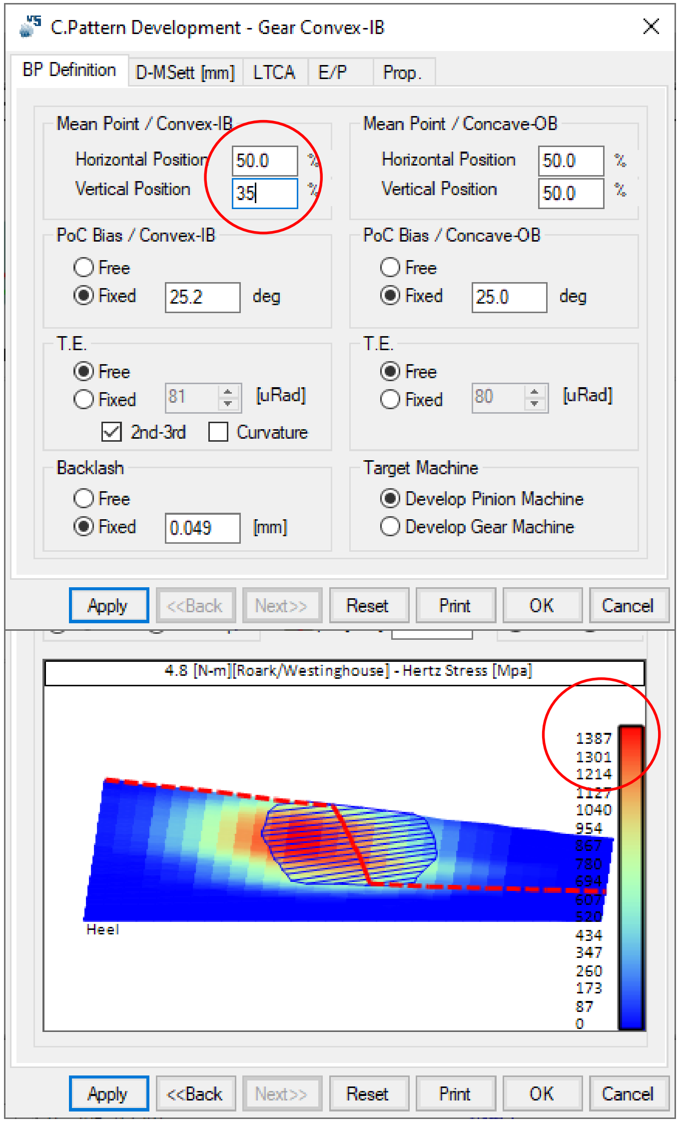
Example: Modifying the CP and TE 9x37 Generated Spiral Bevel gear set

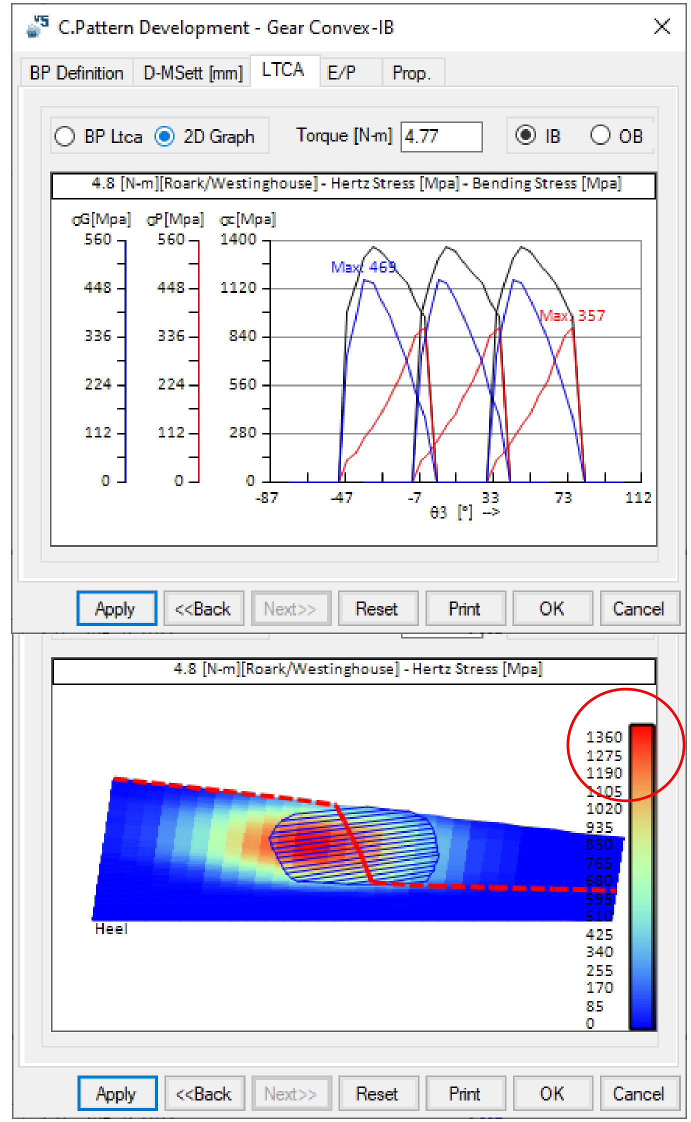


# Creating a Spiral Bevel/Hypoid gear set (FM) / 16

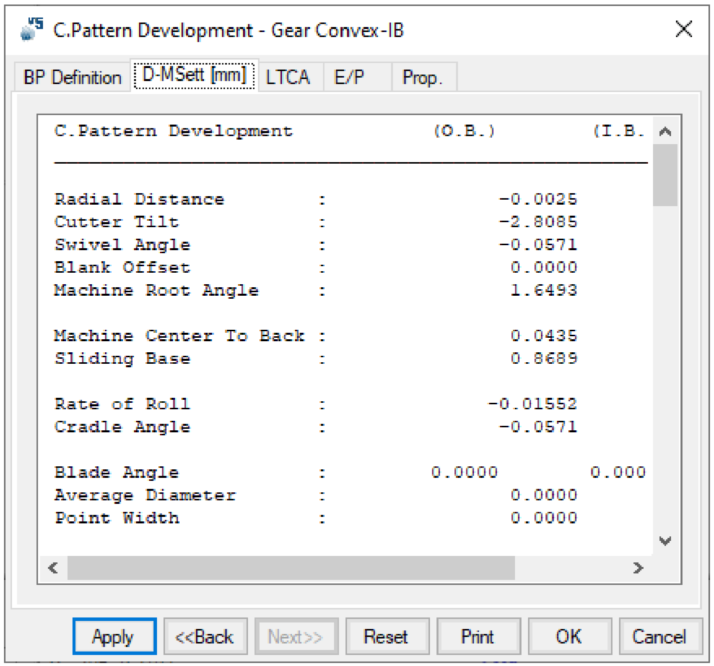
Example: Modifying the CP and TE 9x37 Generated Spiral Bevel gear set

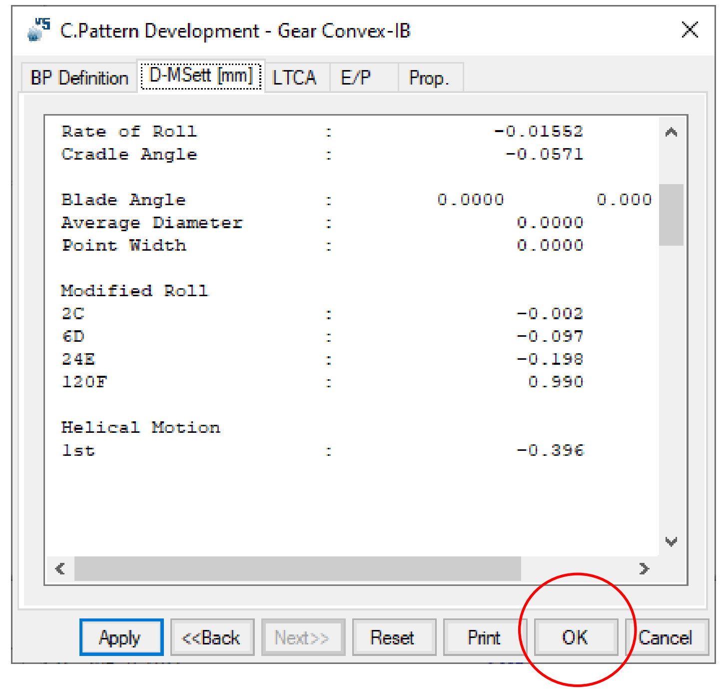


# Creating a Spiral Bevel/Hypoid gear set (FM) / 17

Example: Modifying the CP and TE 9x37 Generated Spiral Bevel gear set




Click on Ok to keep the changes

# Creating a Spiral Bevel/Hypoid gear set (FM) / 18

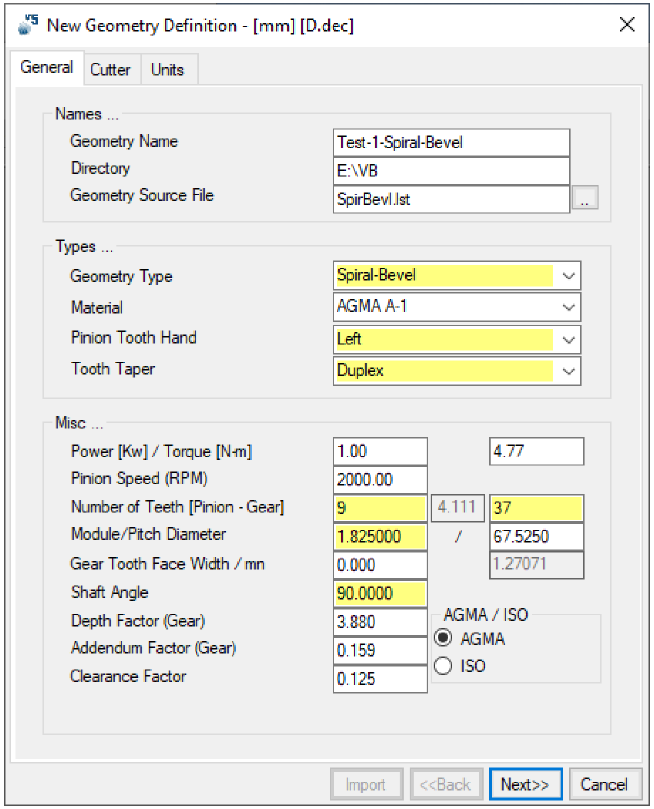
Example: 9x37 *Non-Generated* Spiral Bevel gear set

| | |
|---|---|
| Gear tooth type: | Non-Generated |
| Pinion tooth type: | Generated, Duplex Helical |
| Pinion Tooth Hand: | Left |
| Gear Face Width: | 30% of outer cone distance |
| Speed ratio: | Approximately 4:1 |
| Pinion Speed: | 2000 RPM |
| Available diameter space: | About 70mm (2.75 in) |
| Power: | 1 kW (1.3 HP) |
| Application: | Power tool |

# Creating a Spiral Bevel/Hypoid gear set (FM) / 19

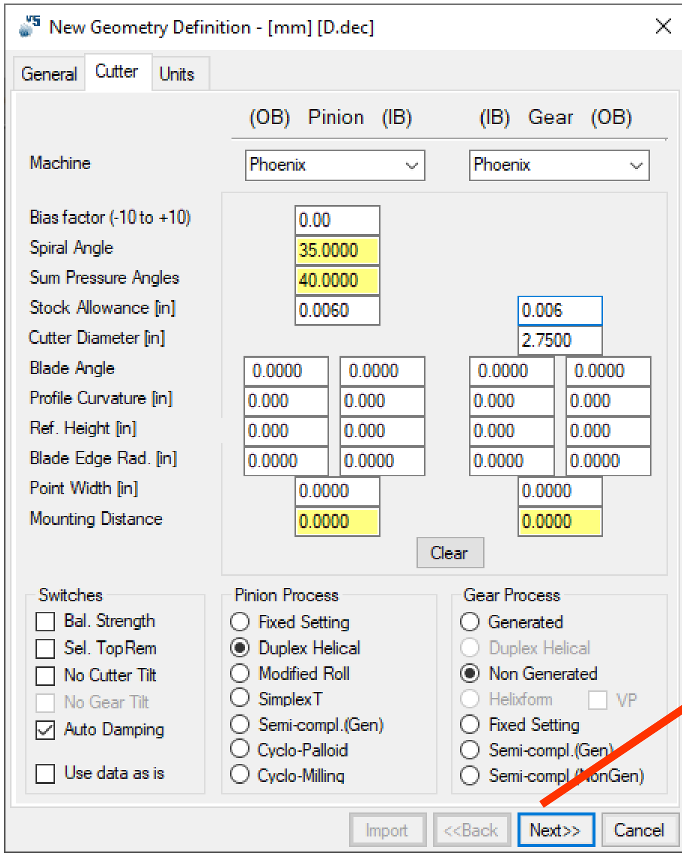
Example: 9x37 Non-Generated Spiral Bevel gear set

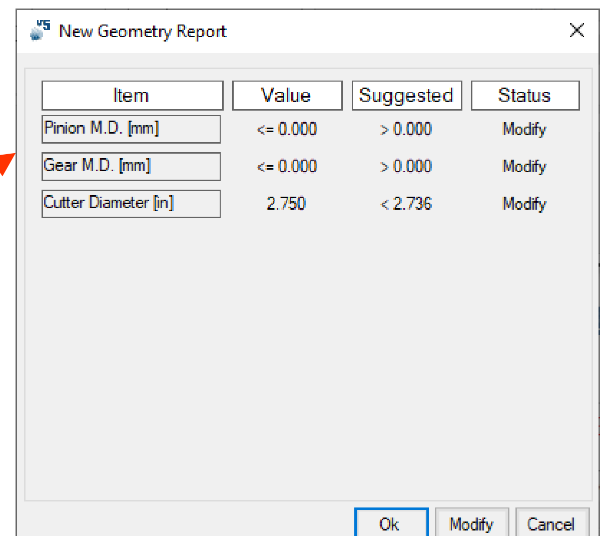
Call the **File-> New Geometry** menu entry – Spiral Bevel



# Creating a Spiral Bevel/Hypoid gear set (FM) / 20

Example: 9x37 Non-Generated Spiral Bevel gear set

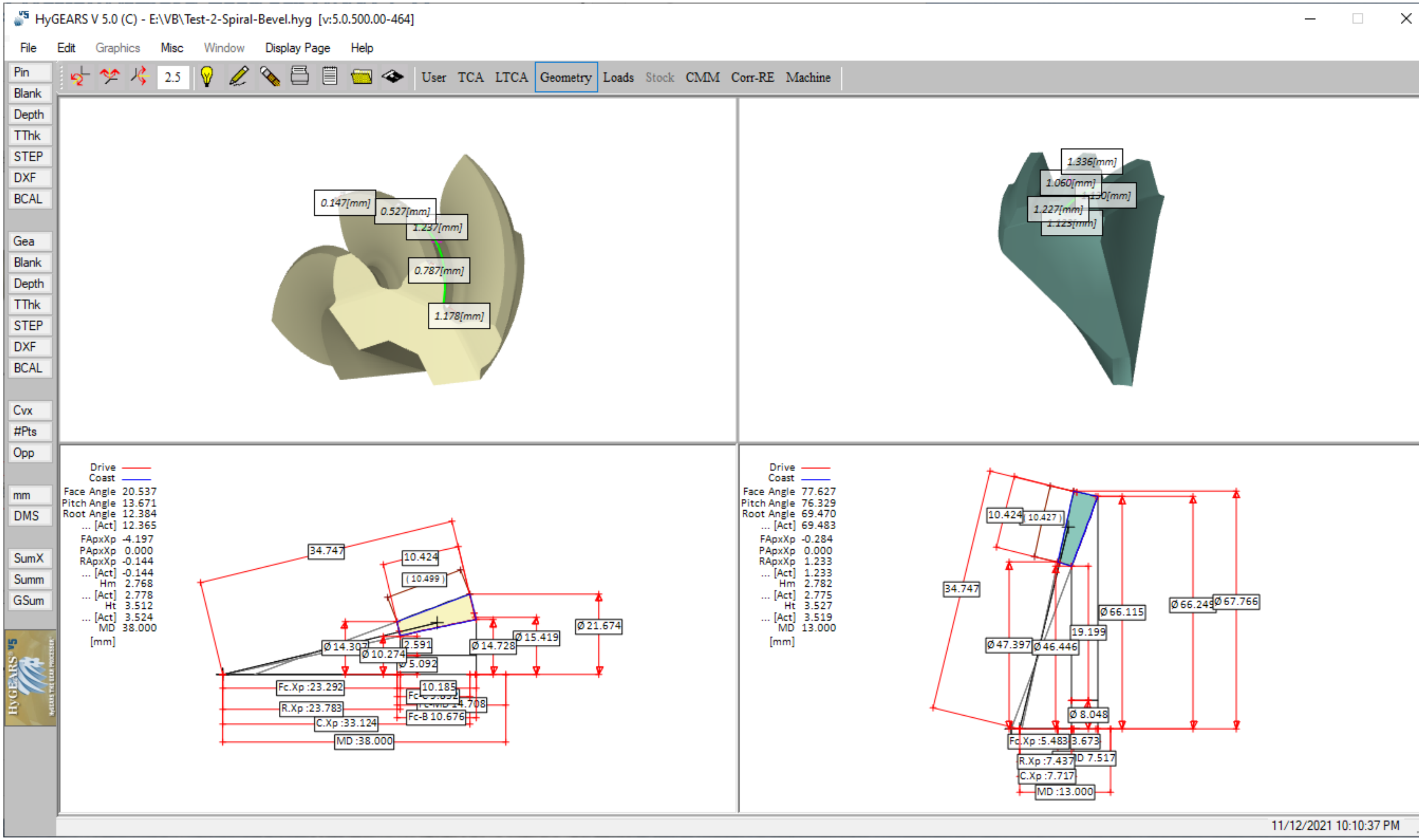



Click on Next >> twice and Ok

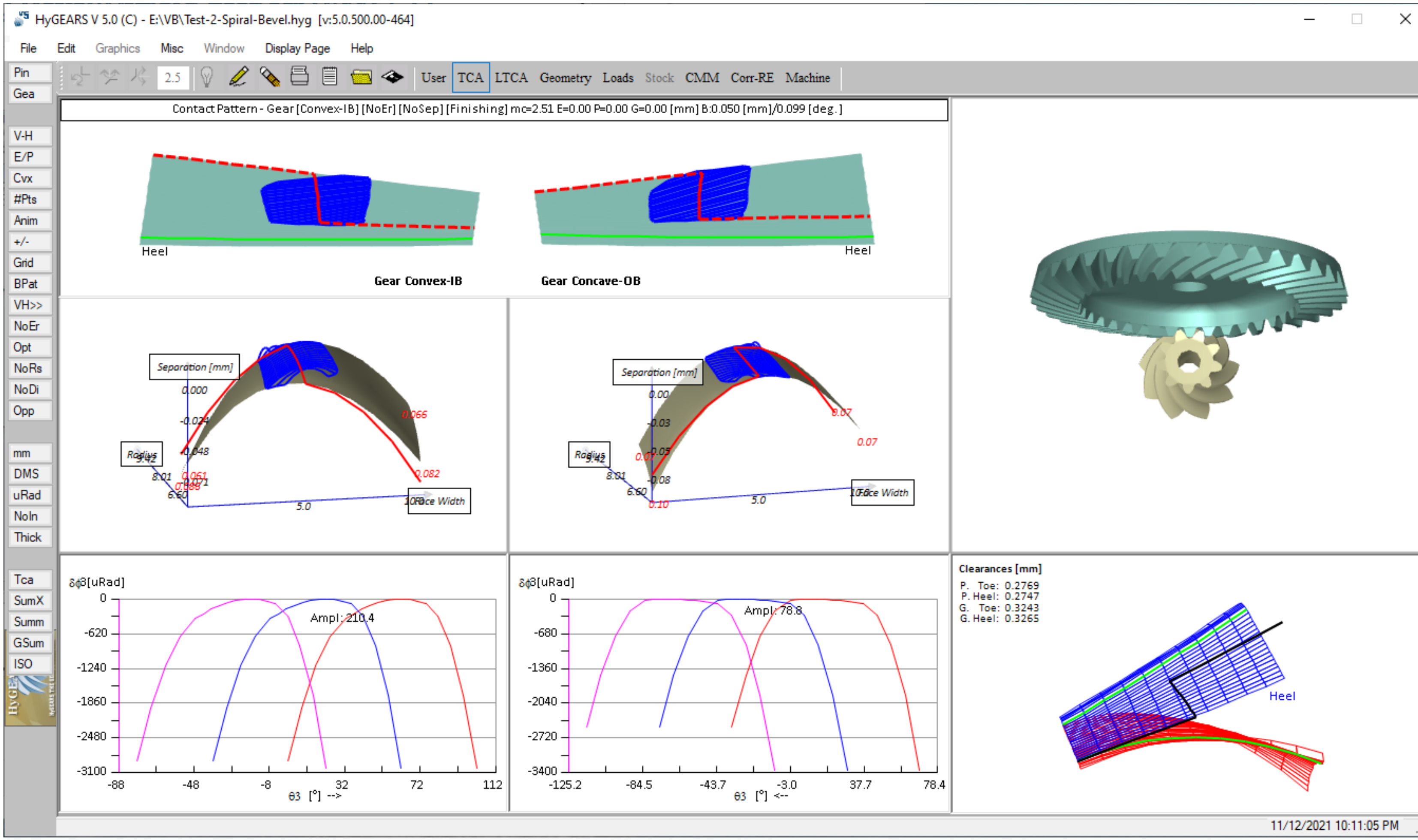
# Creating a Spiral Bevel/Hypoid gear set (FM) / 21

Example: 9x37 Non-Generated Spiral Bevel gear set

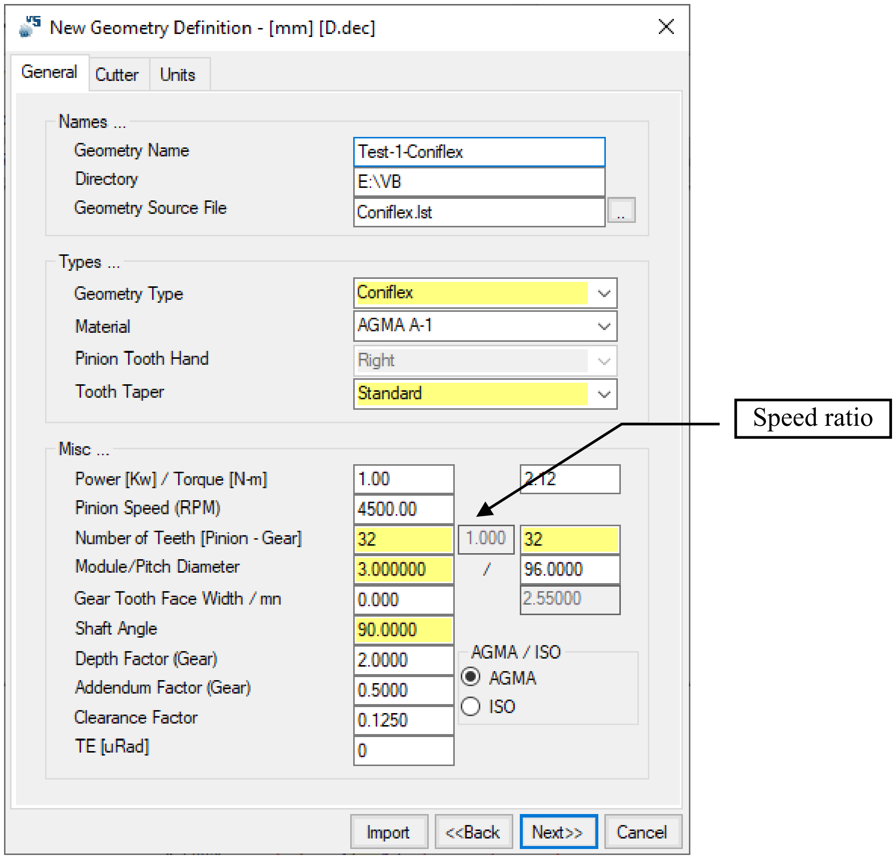


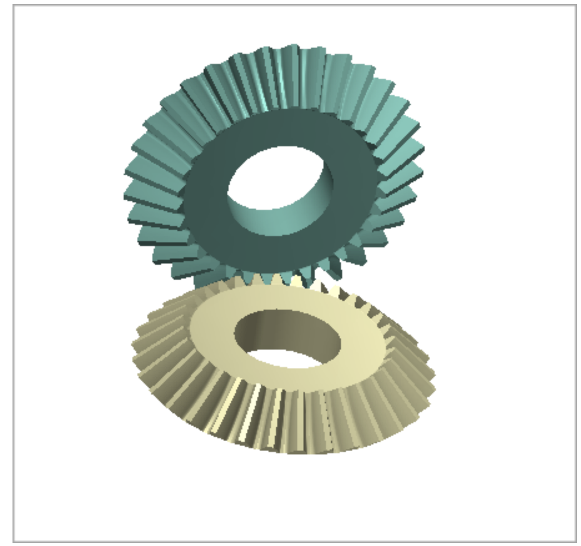
# Creating a Spiral Bevel/Hypoid gear set (FM) / 22

Example: 9x37 Non-Generated Spiral Bevel gear set



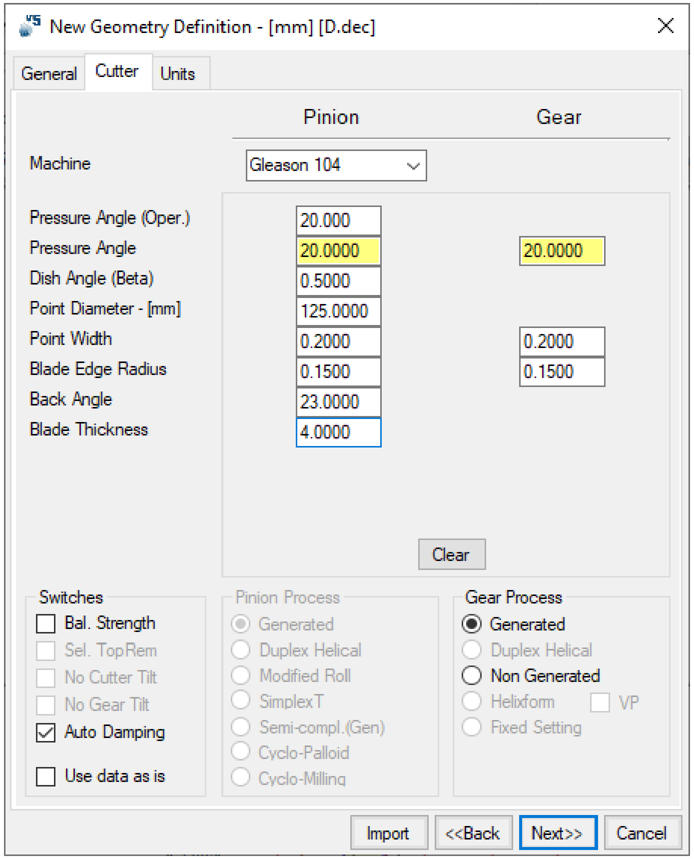
# Creating a Coniflex Bevel gear set

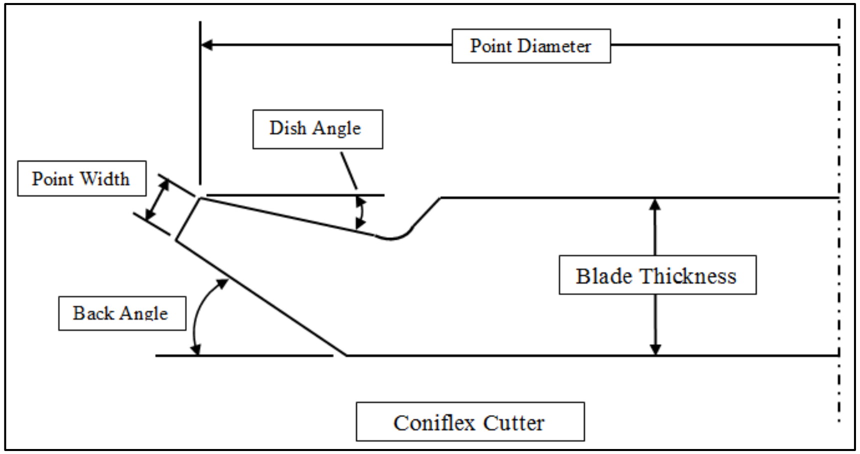


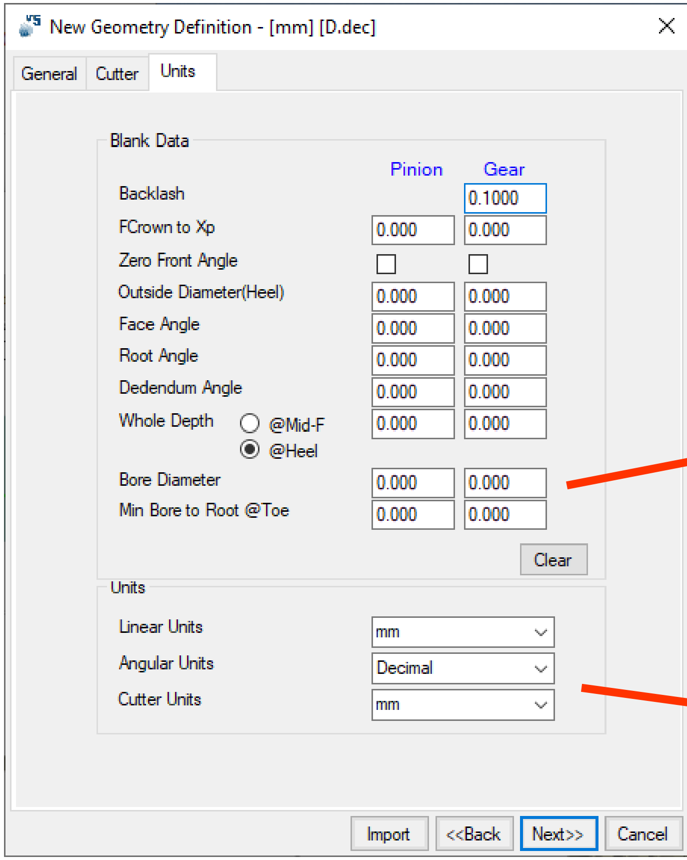
| Pinion Tooth Number | Depth Factor |
|---|---|
| 12 and + | 2.000 |
| 11 | 1.995 |
| 10 | 1.975 |
| 9 | 1.940 |
| 8 | 1.900 |
| 7 | 1.835 |
| 6 | 1.752 |

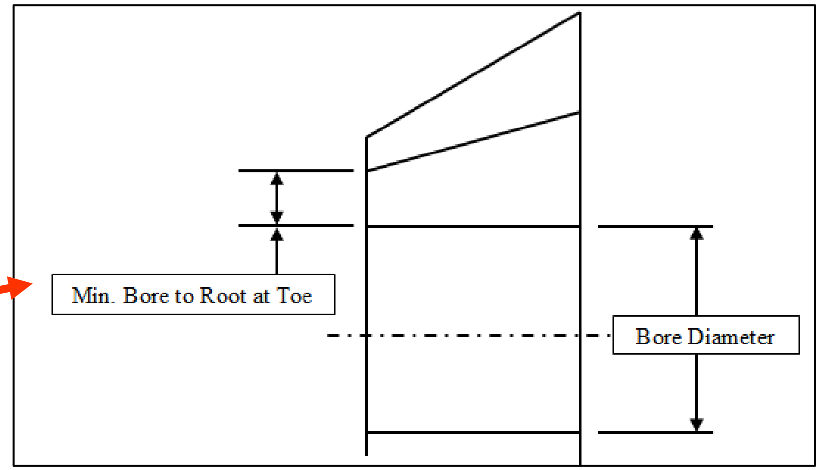
# Creating a Coniflex Bevel gear set / 2



# Creating a Coniflex Bevel gear set / 3

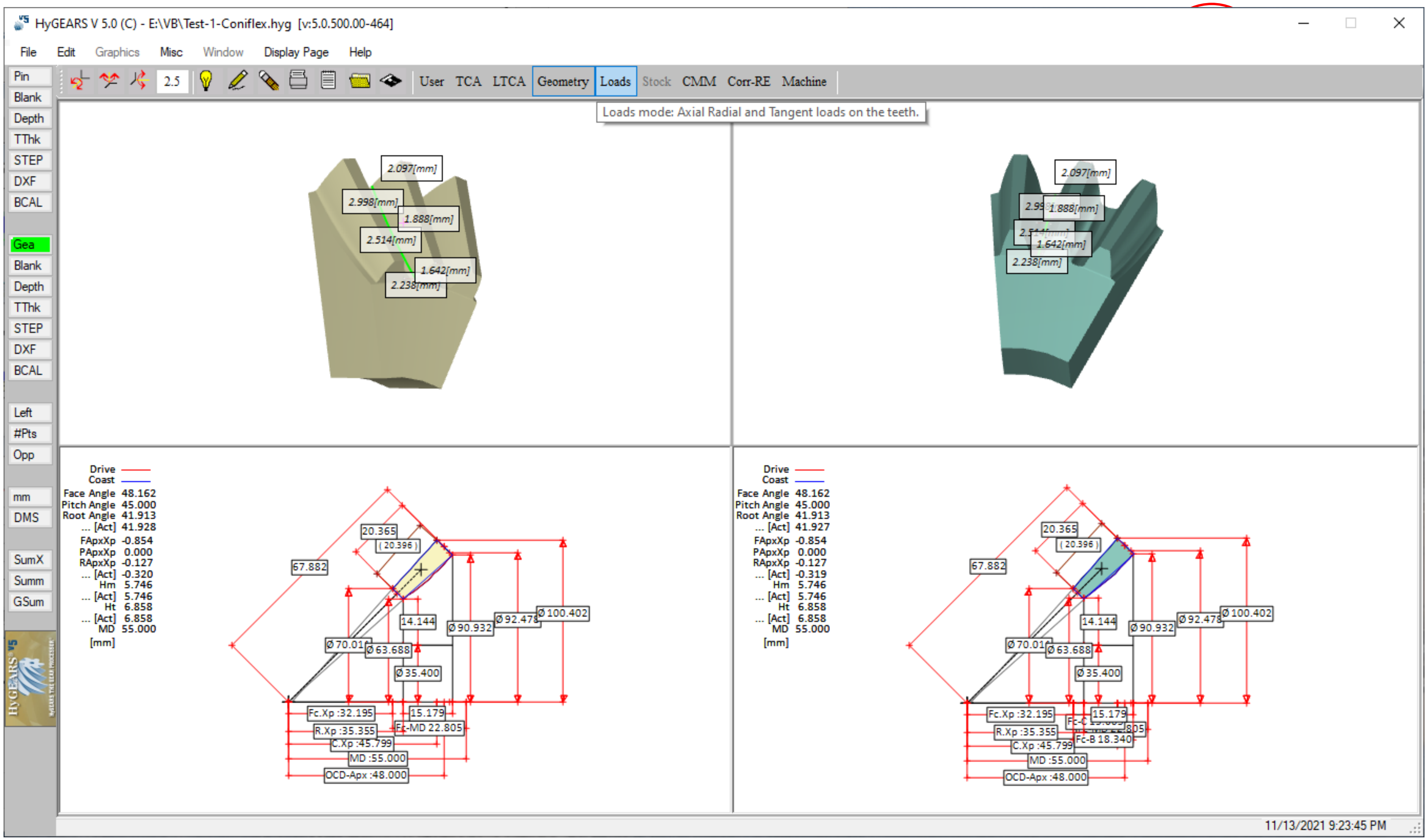


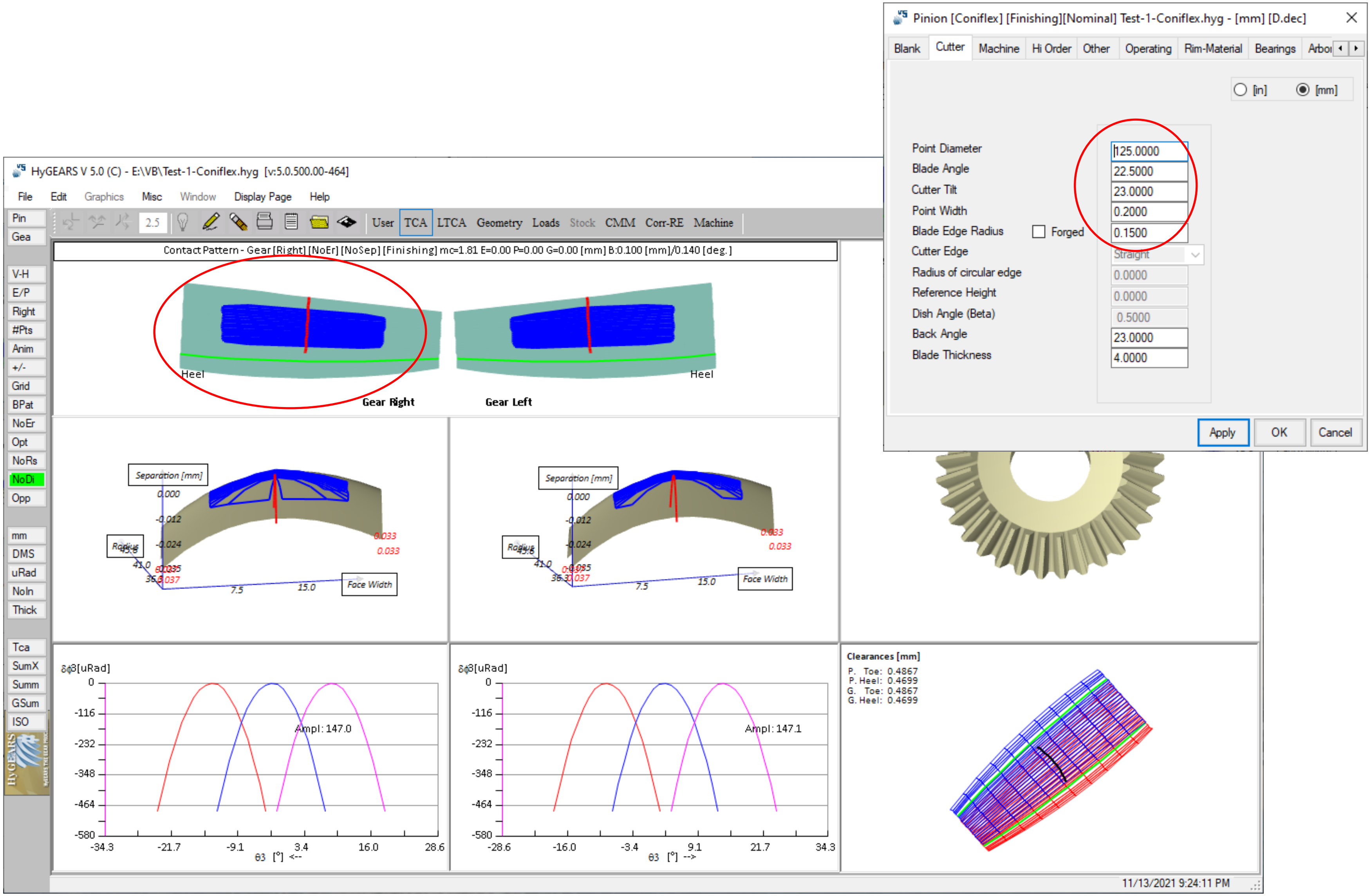

Angular input formats:

22.30.00 ⇔ 22.50

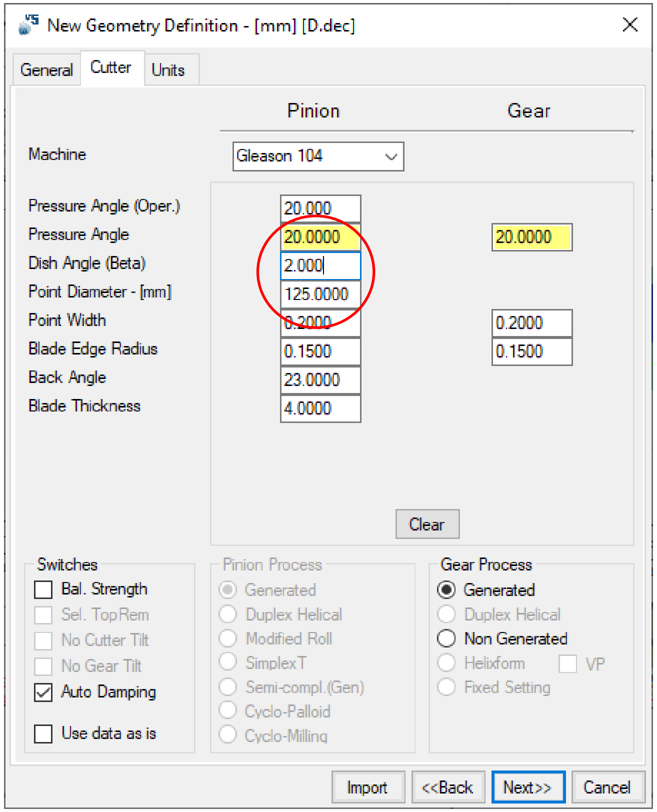
# Creating a Coniflex Bevel gear set / 4

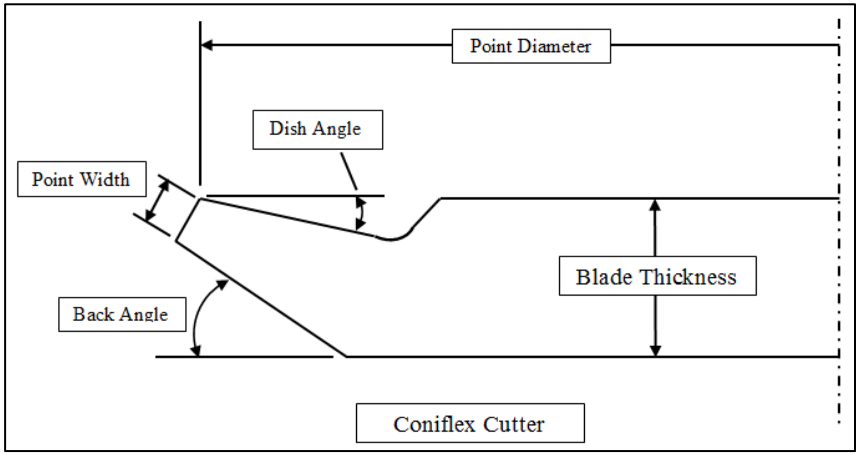


# Creating a Coniflex Bevel gear set / 5

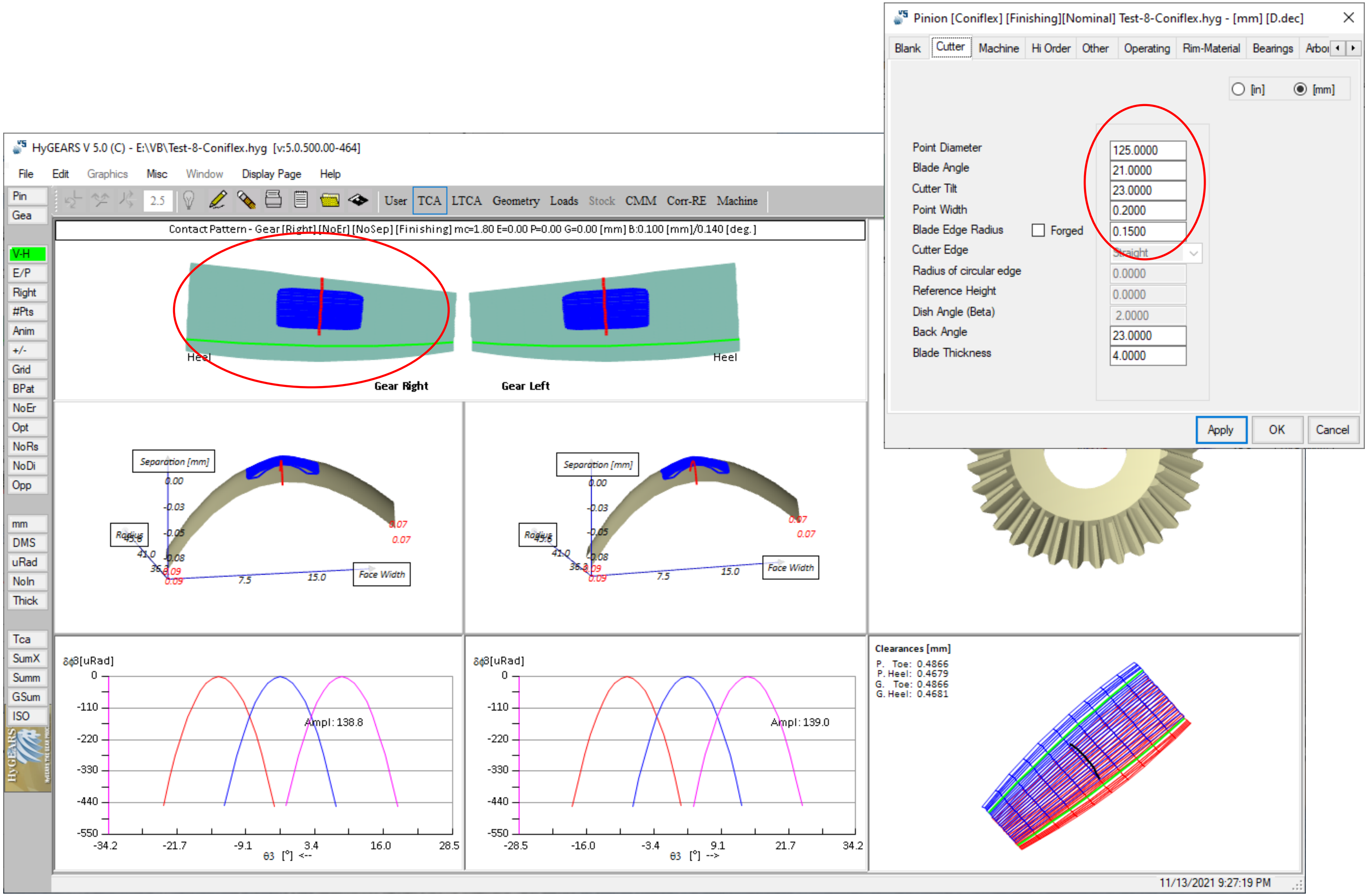


# Creating a Coniflex Bevel gear set / 6

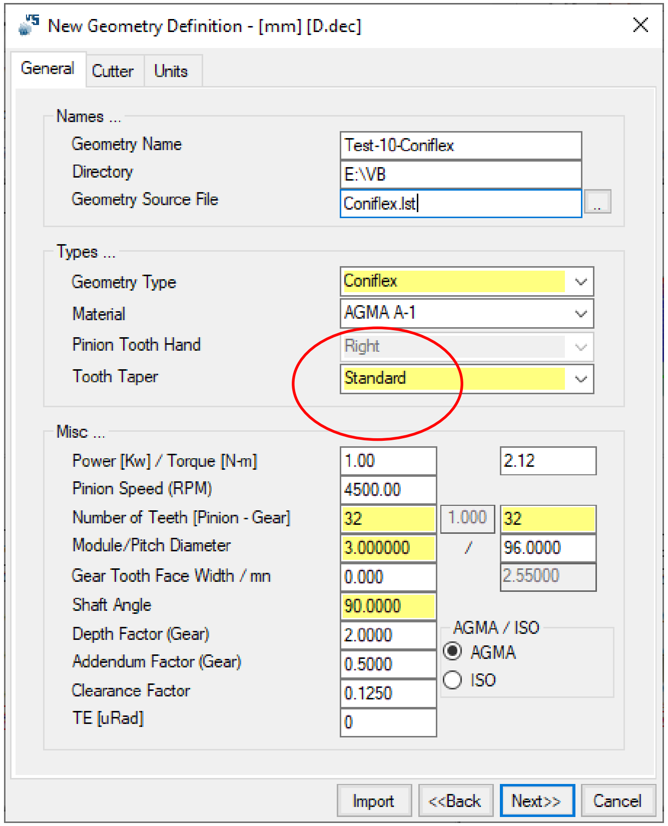


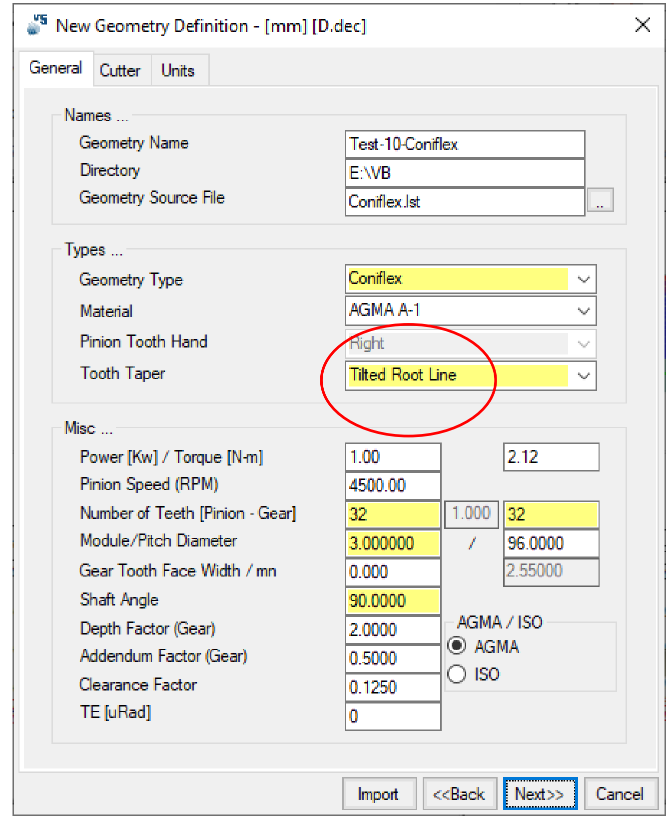



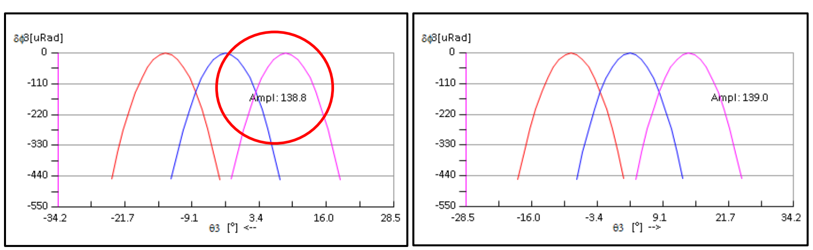
# Creating a Coniflex Bevel gear set / 7

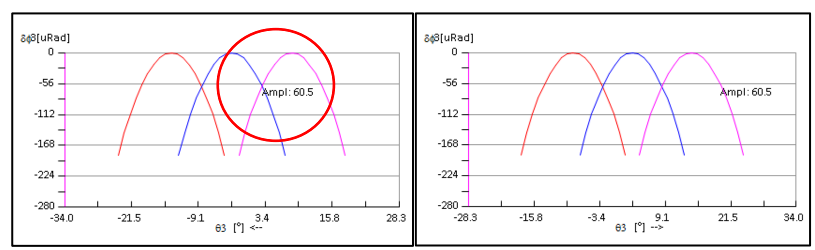


# Creating a Coniflex Bevel gear set / 8

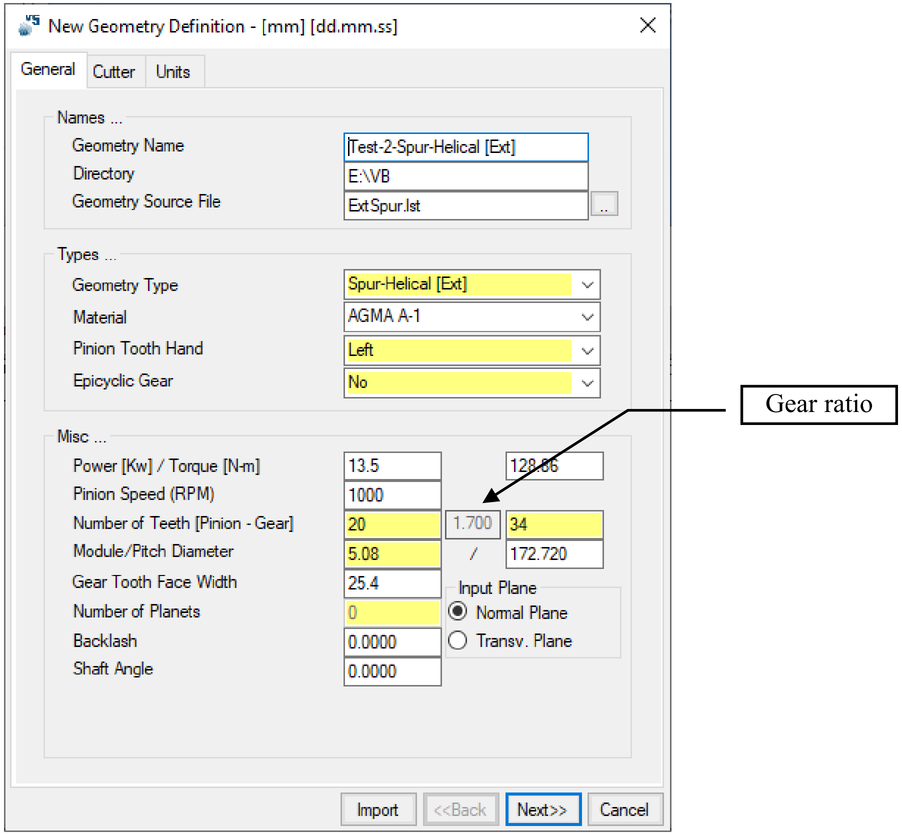


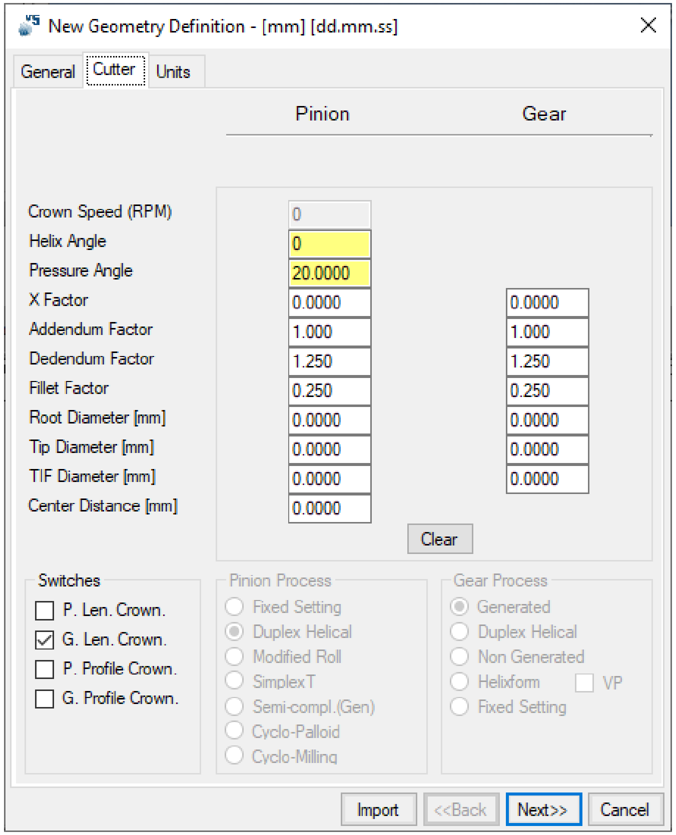



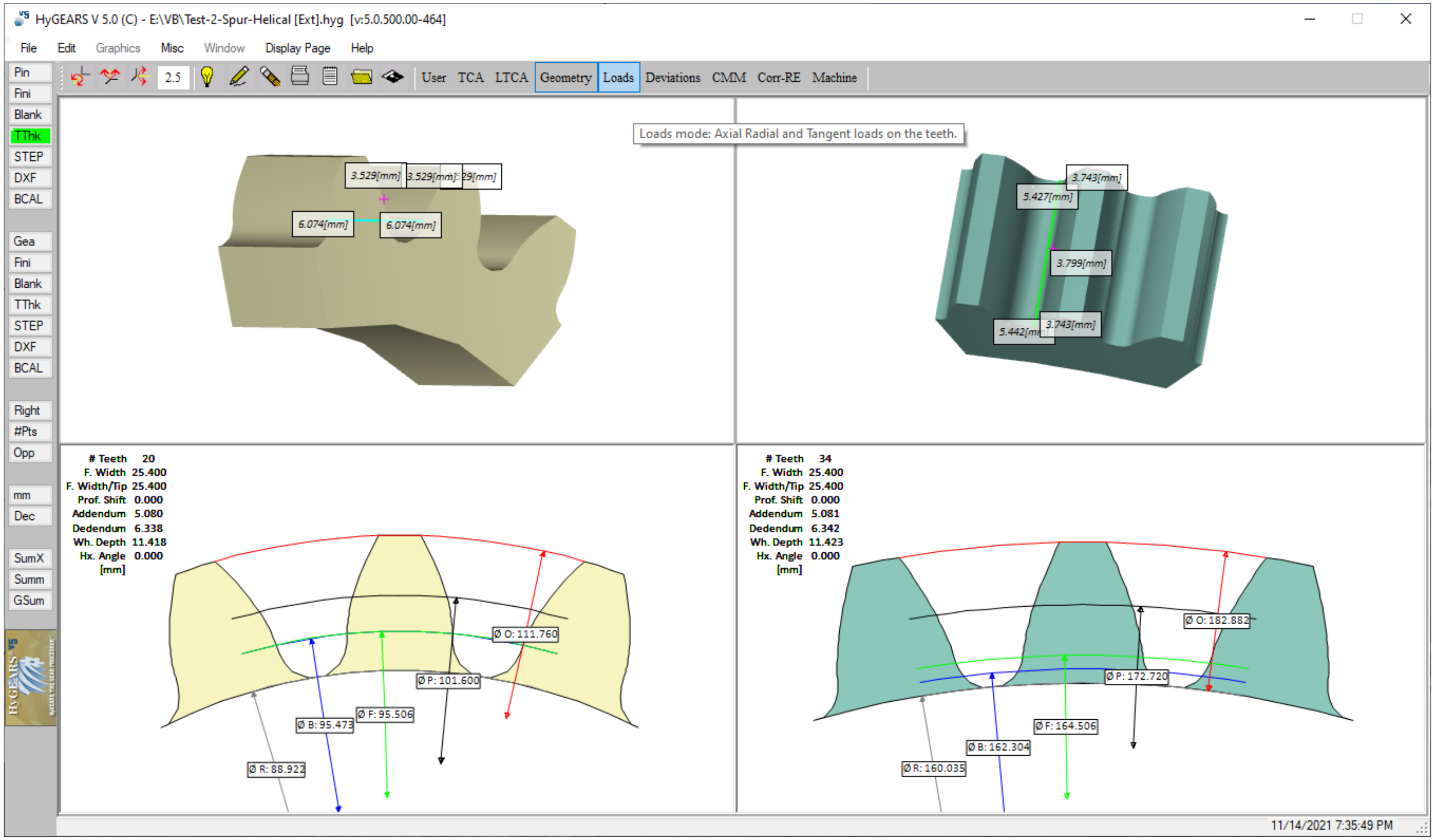



# Creating a Spur gear set

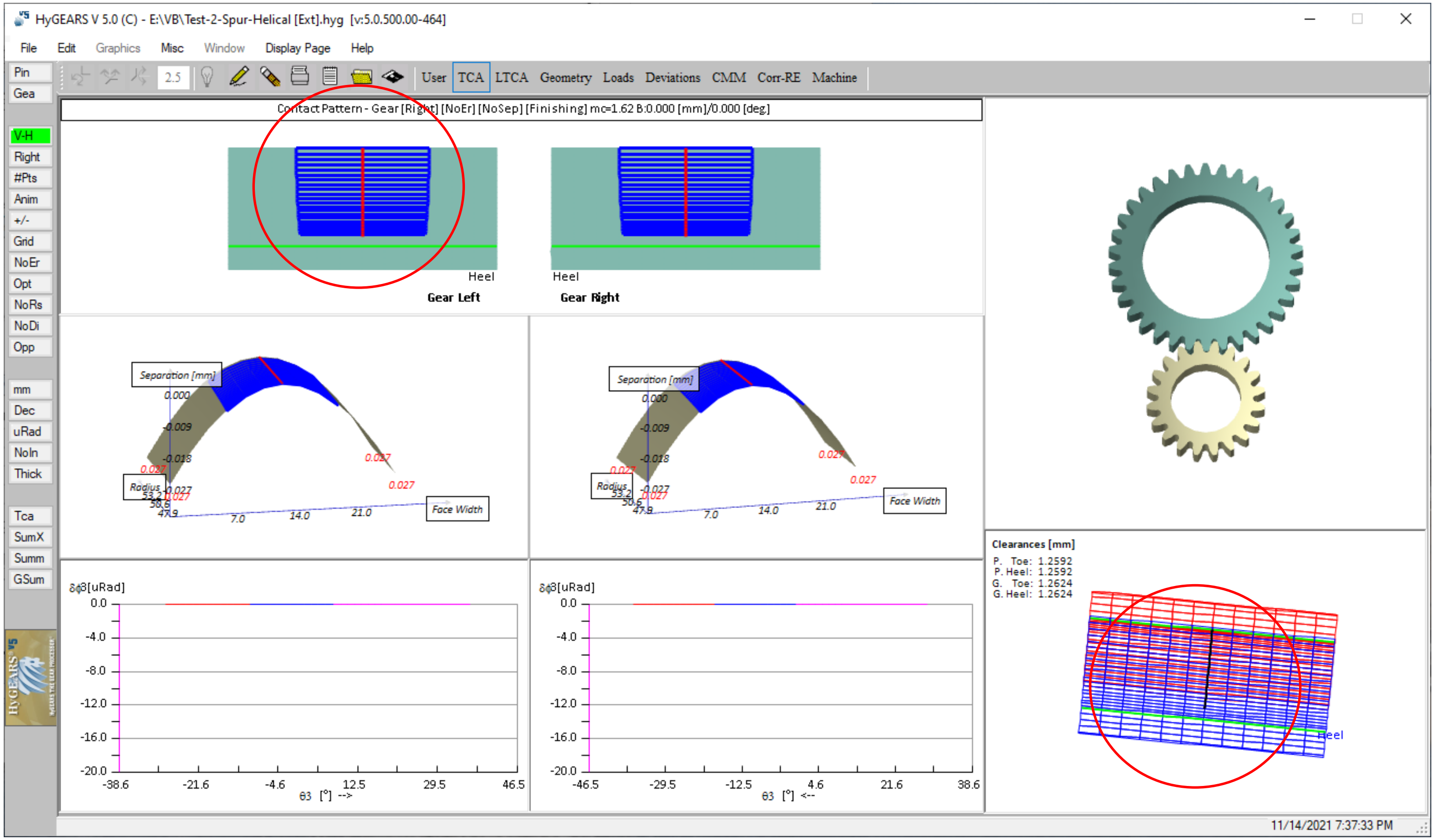


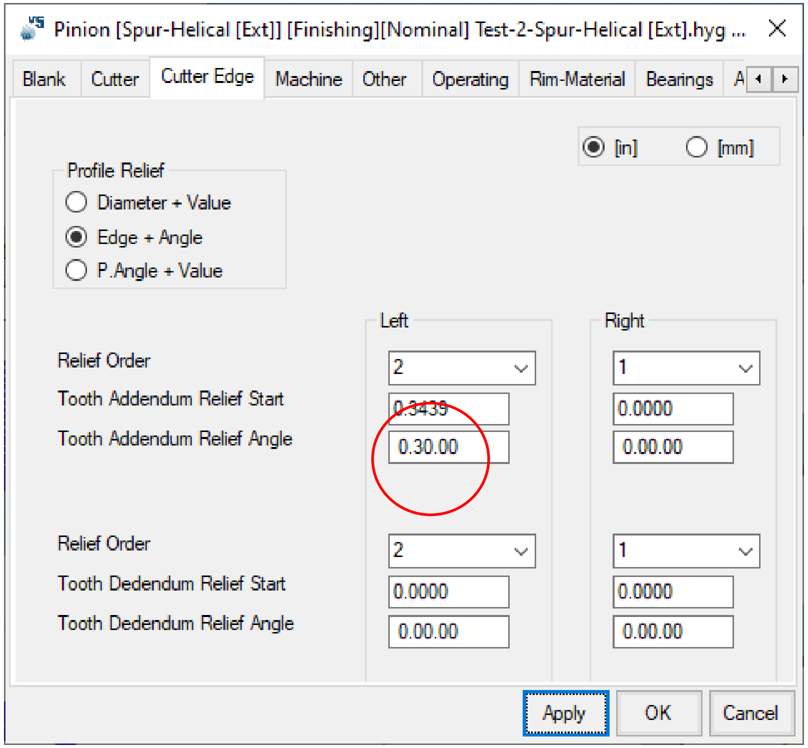
# Creating a Spur gear set / 2

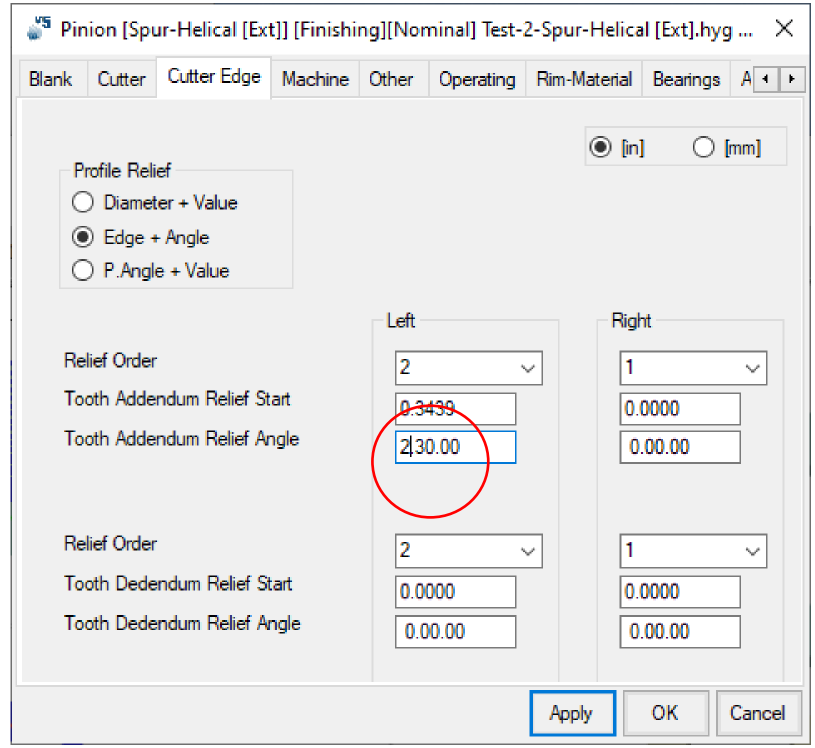


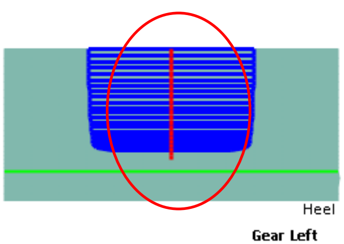
# Creating a Spur gear set / 3

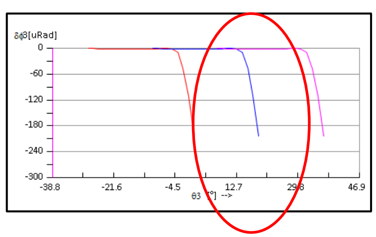


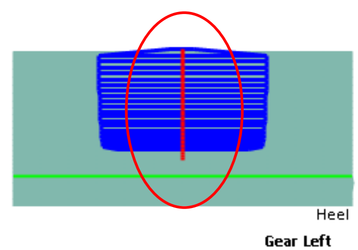
# Creating a Spur gear set / 4

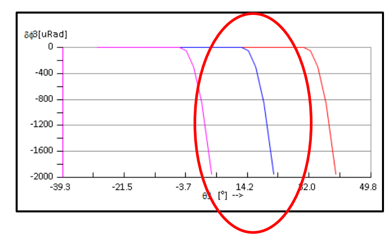


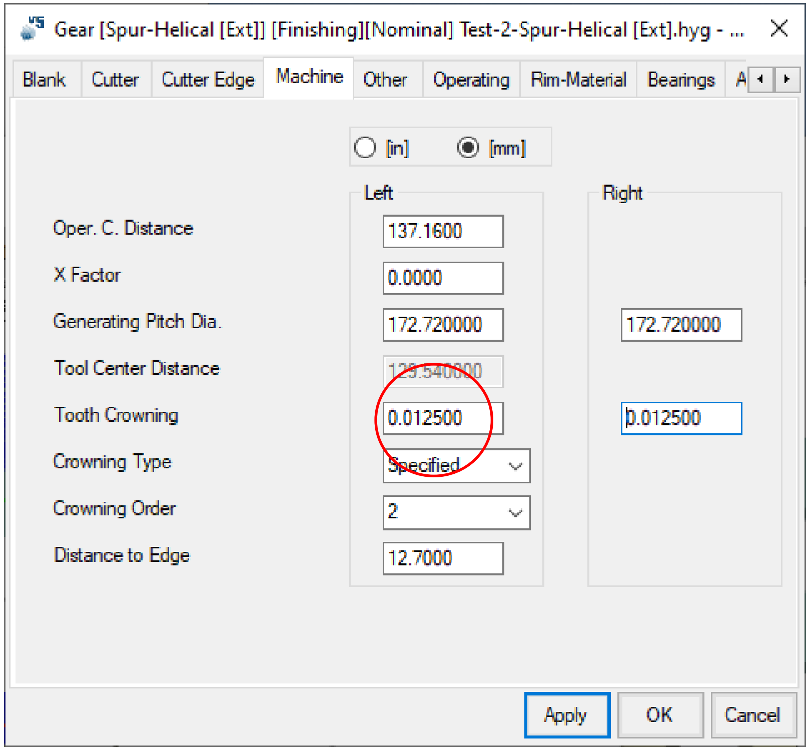



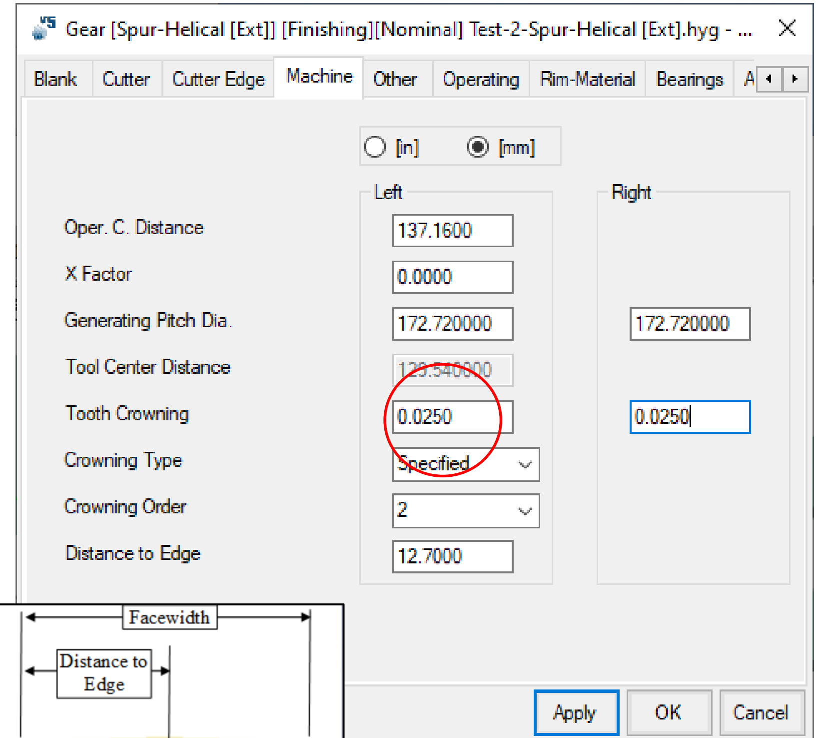



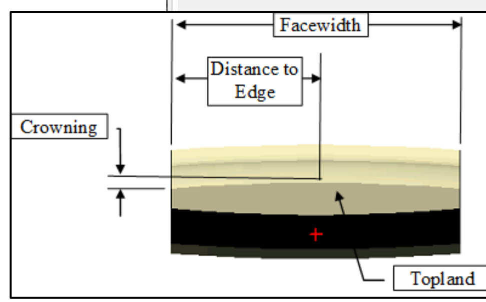


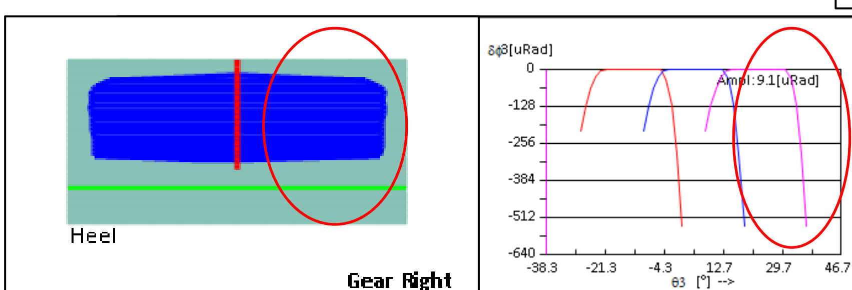



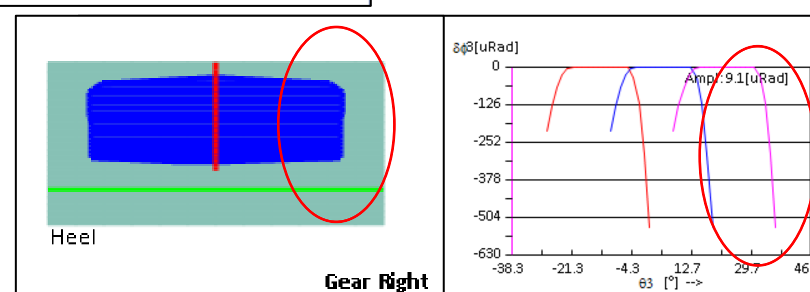
# Creating a Spur gear set / 5



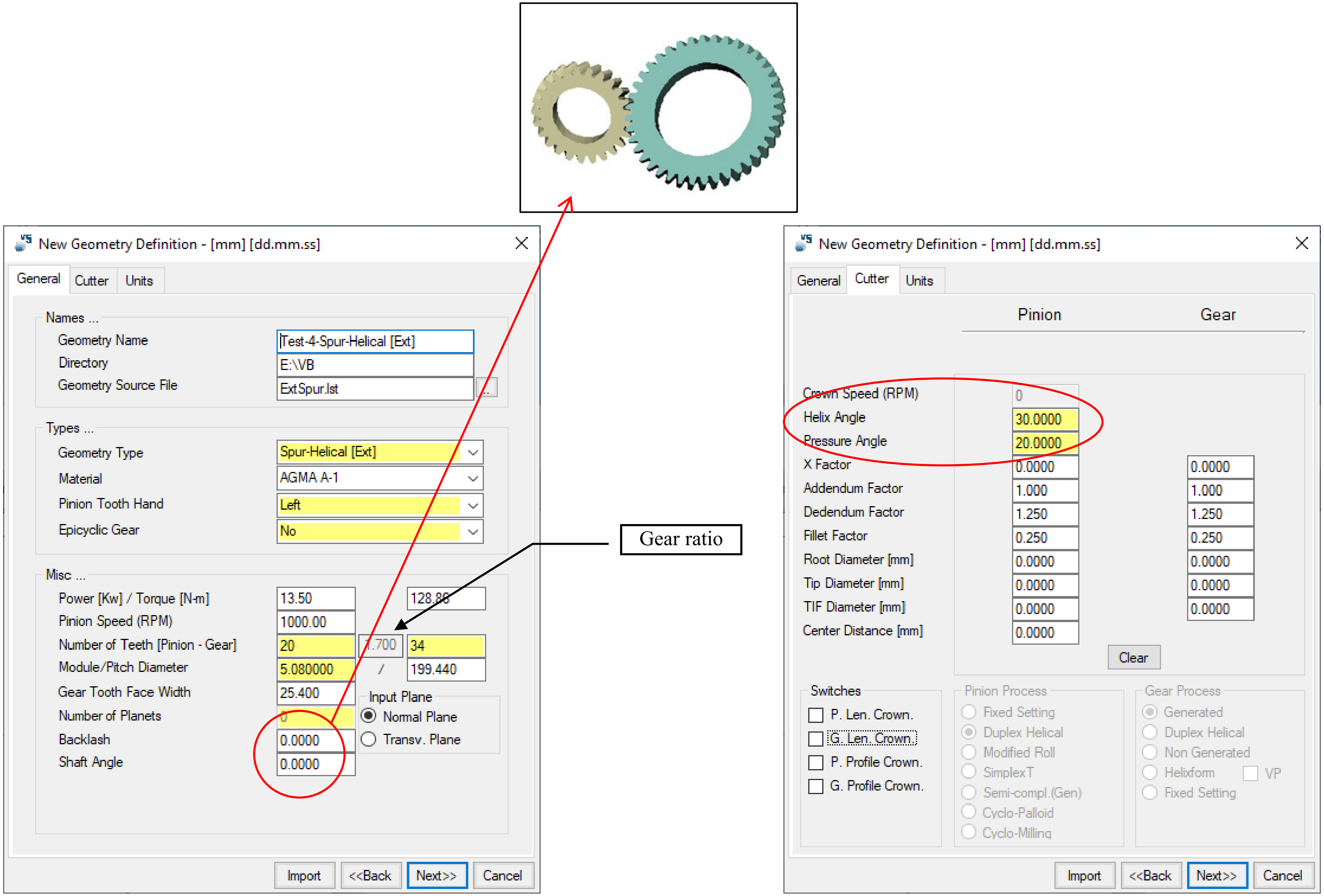



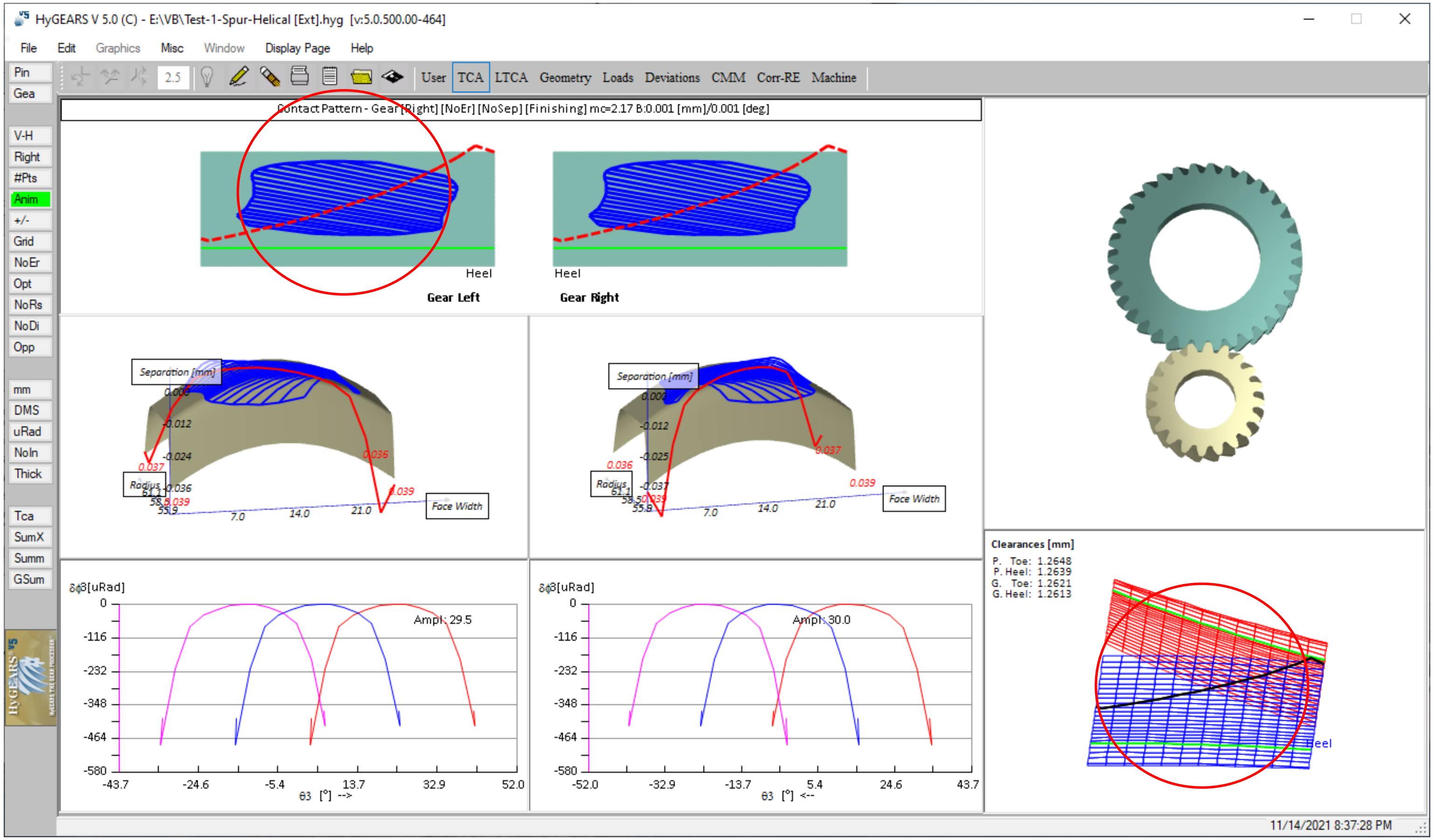



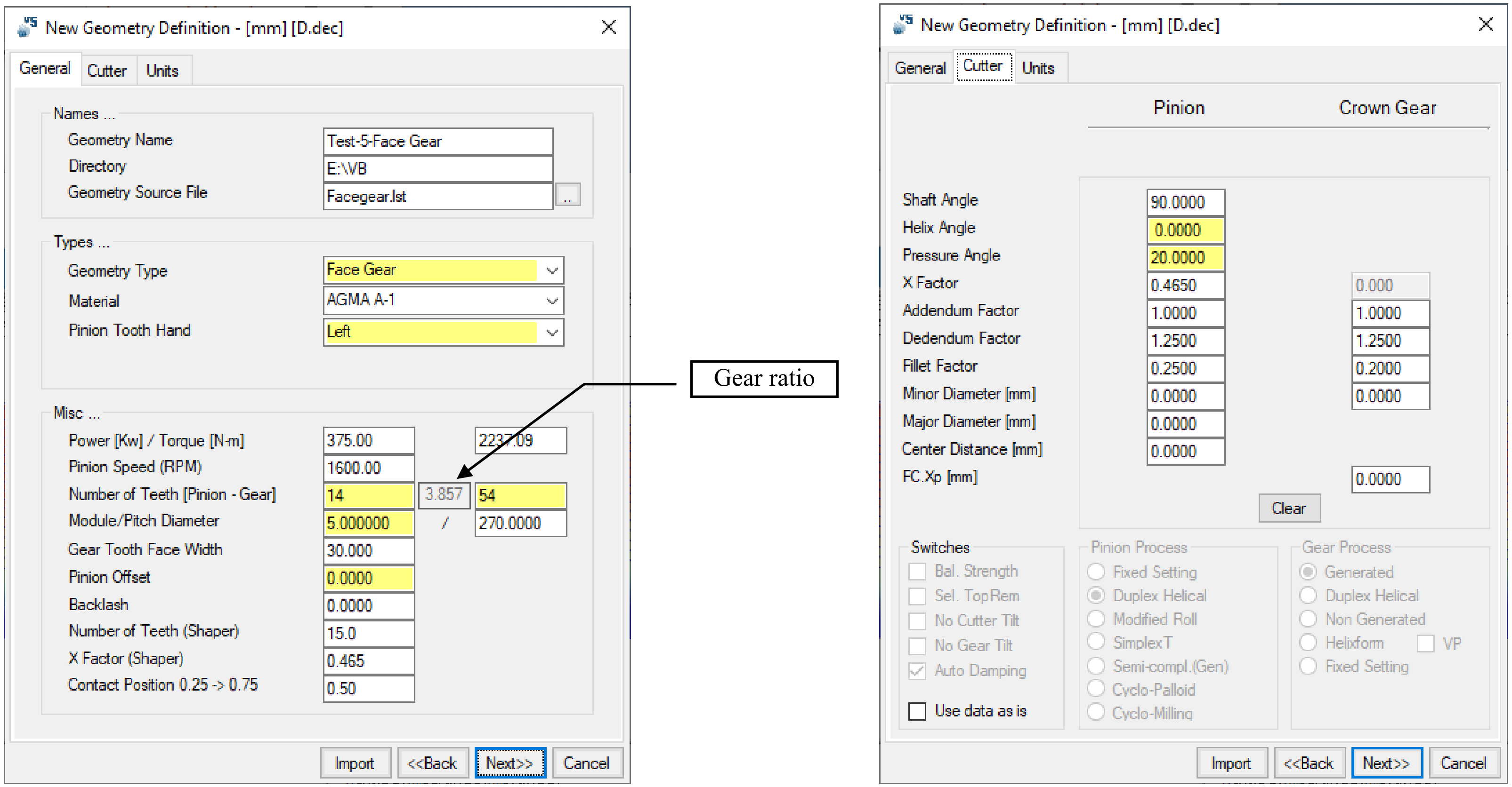
# Creating a Helical gear set



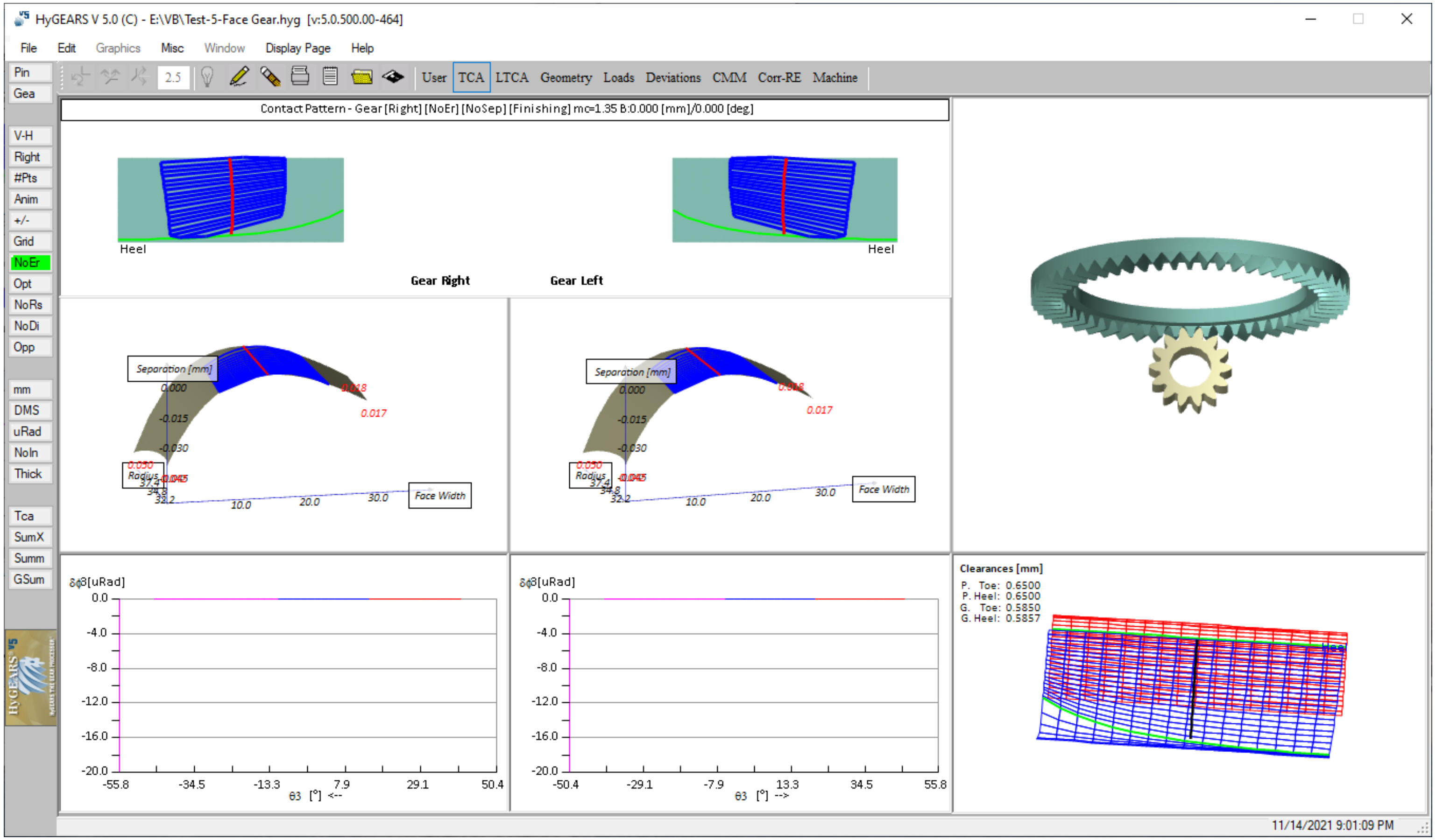
# Creating a Helical gear set / 2



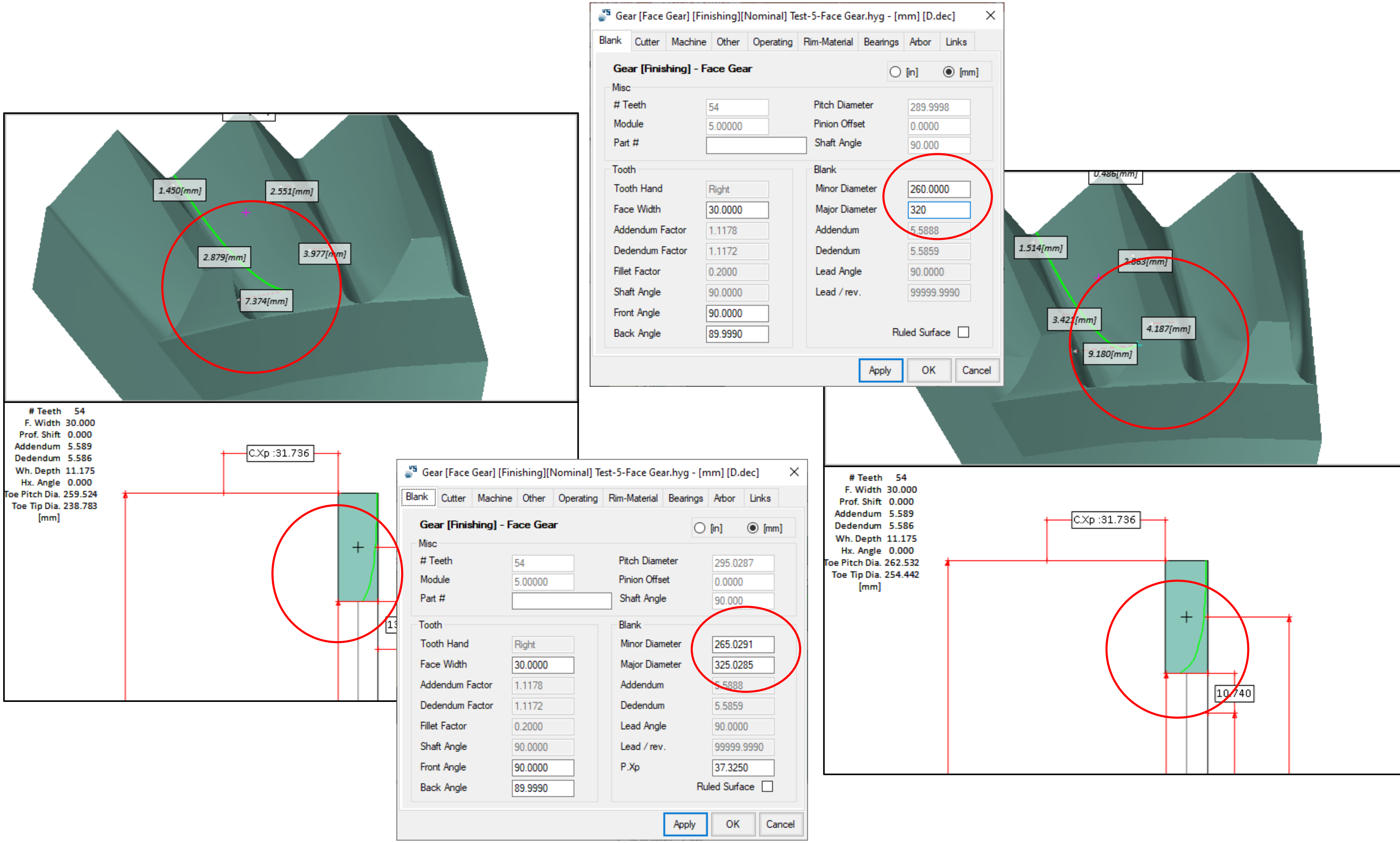
# Creating a Face gear set



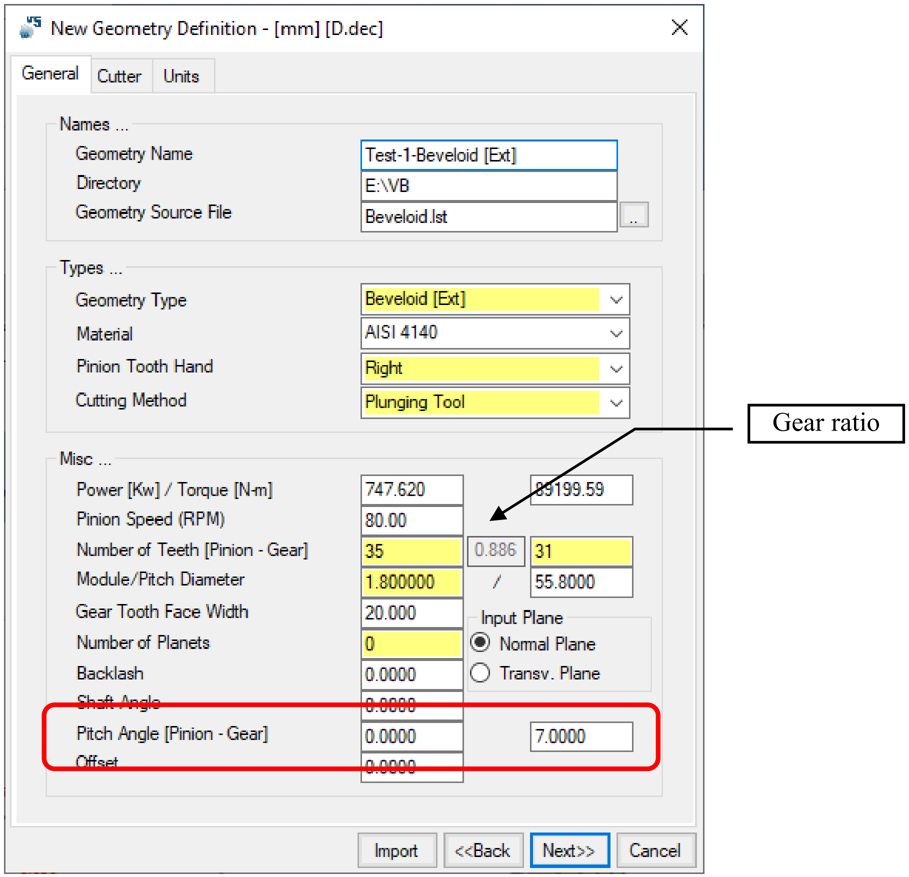
# Creating a Face gear set / 2

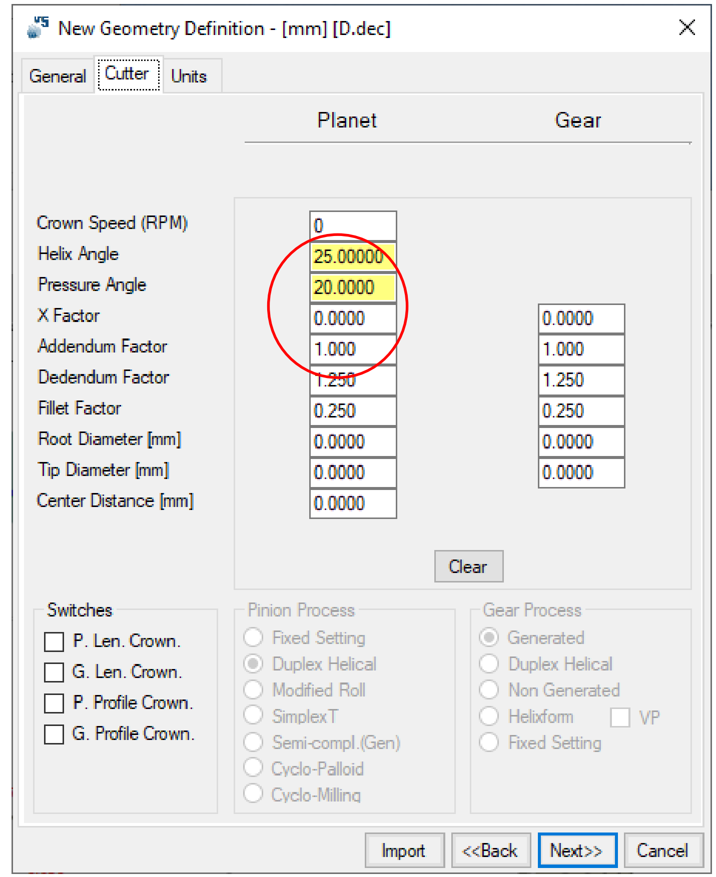


# Creating a Face gear set / 3

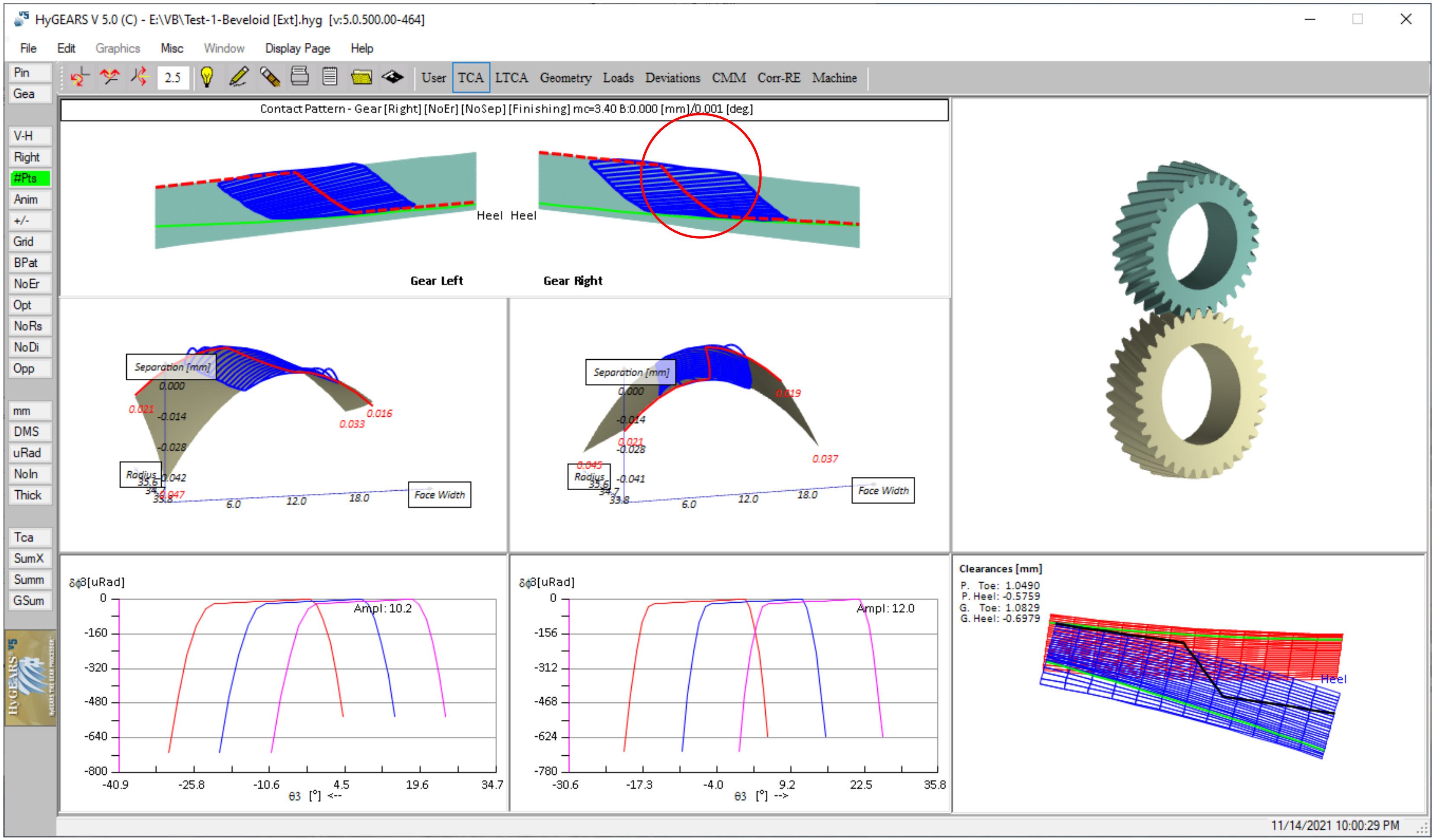


# Creating a Beveloid gear set

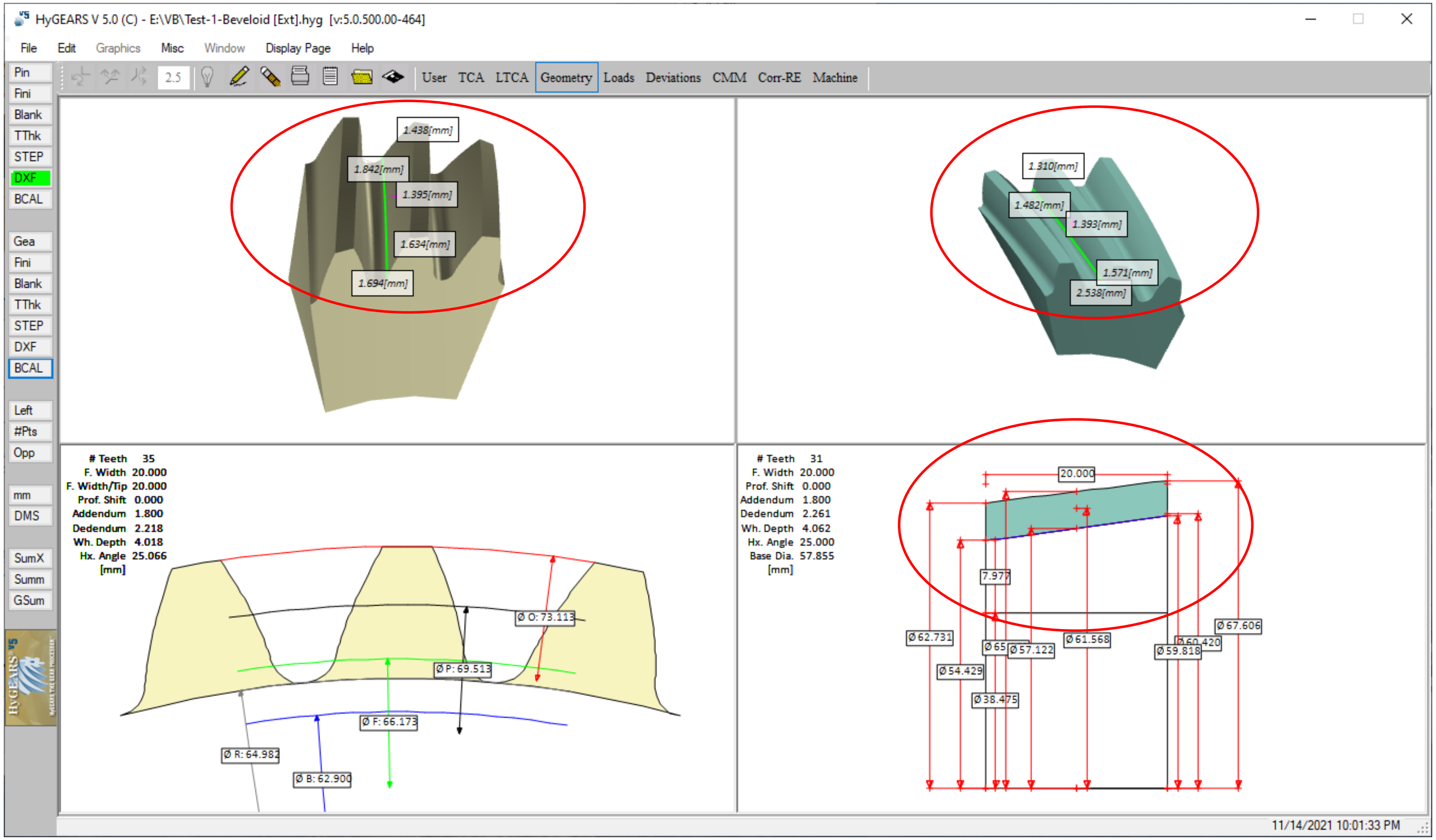


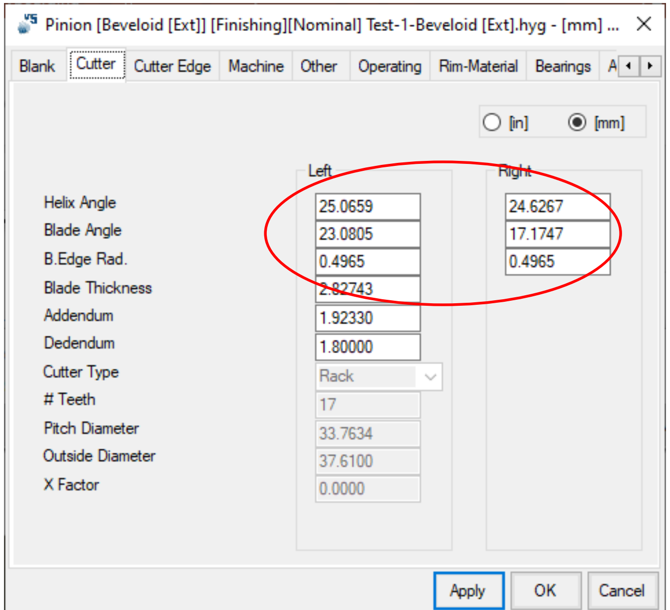
# Creating a Beveloid gear set / 2

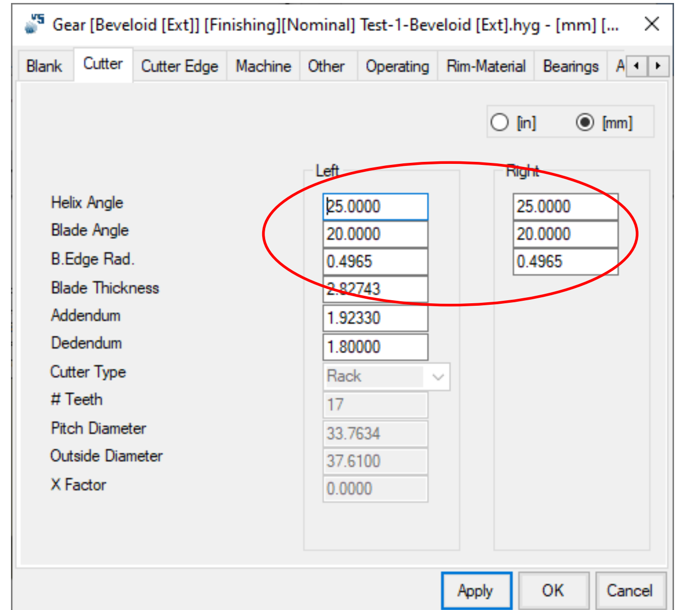


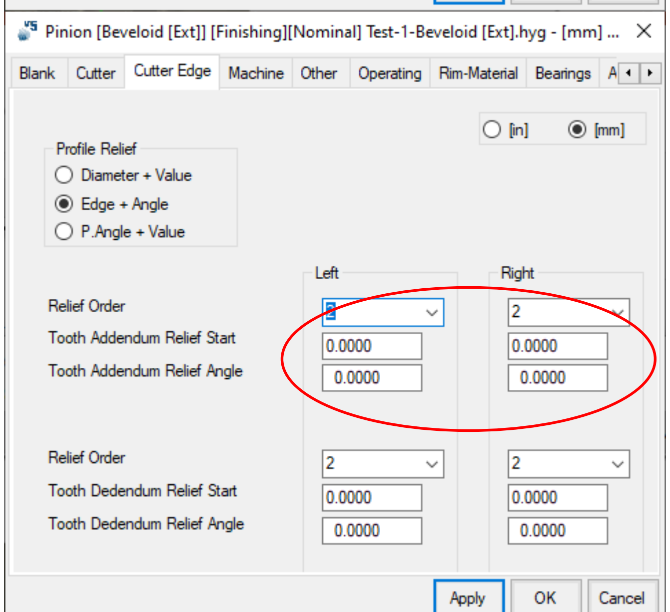
# Creating a Beveloid gear set / 3

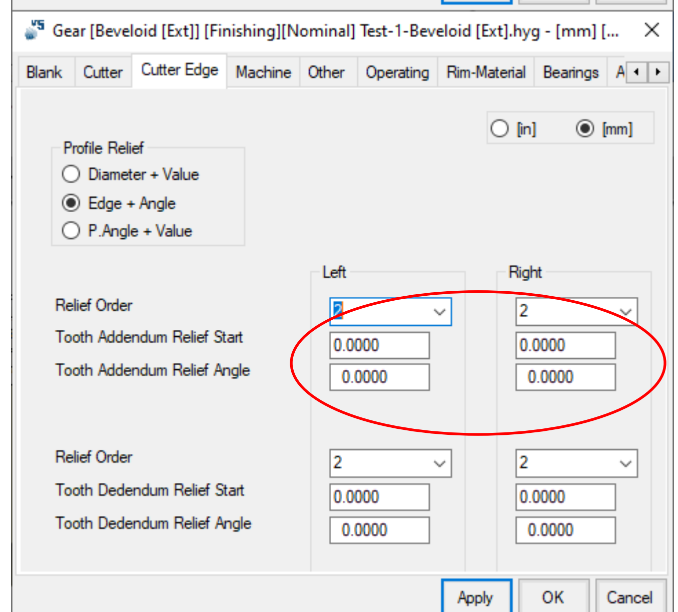


# Creating a Beveloid gear set / 4



# Creating a Straight Bevel gear set

In HyGEARS, Straight-Bevel gear Blank shapes come in 2 flavors:

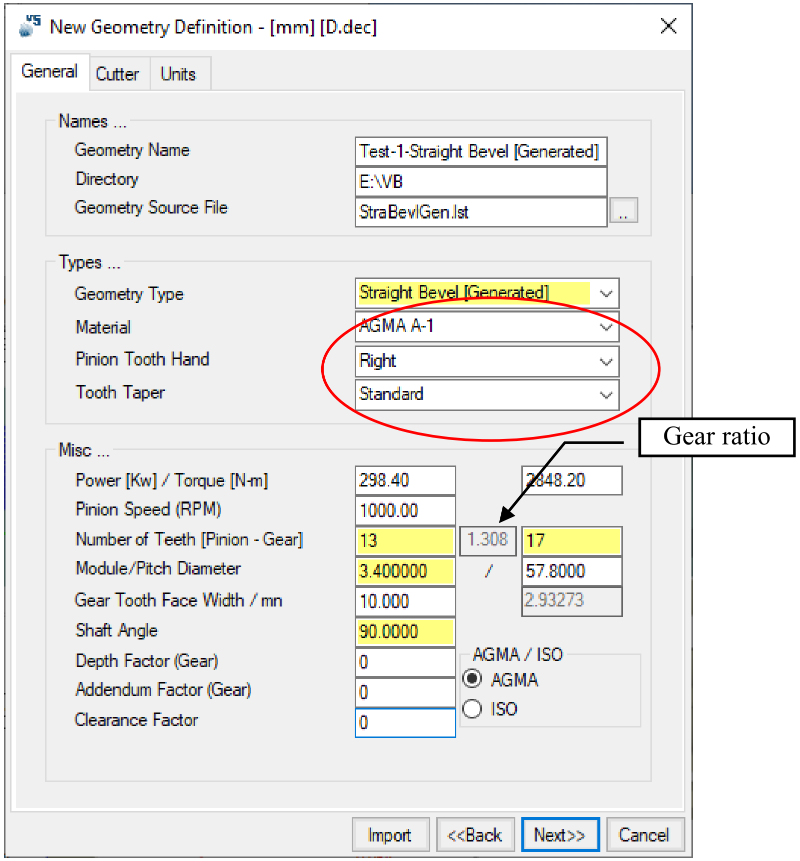
- "Differential" they usually forged or injection molded; the Front angle is zero degree; TE can be larger such as to be more tolerant.

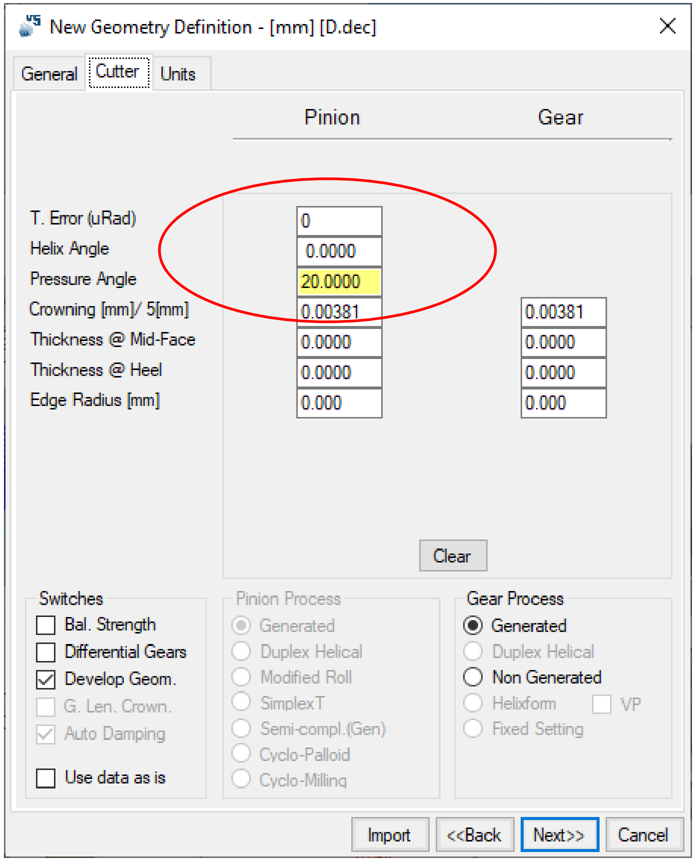
- "Standard" where the Front angle equals the pitch angle; TE can be lesser, such as to be quieter.

Both variants can be cut on a 5 Axis CNC machine using:

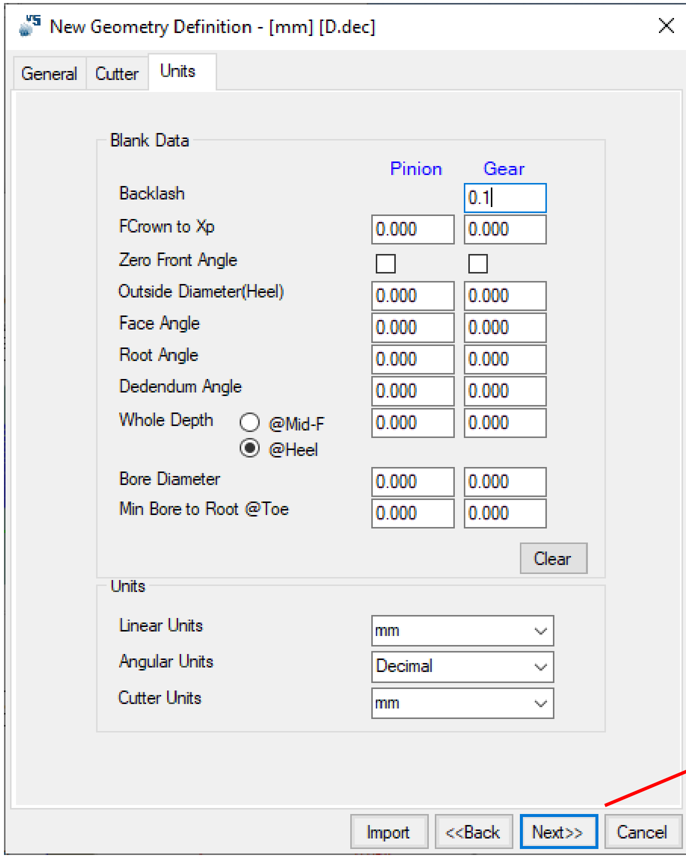
- a Conical Side Milling Tool (or CoSIMT),
- an End Mill or
- a Ball Mill.

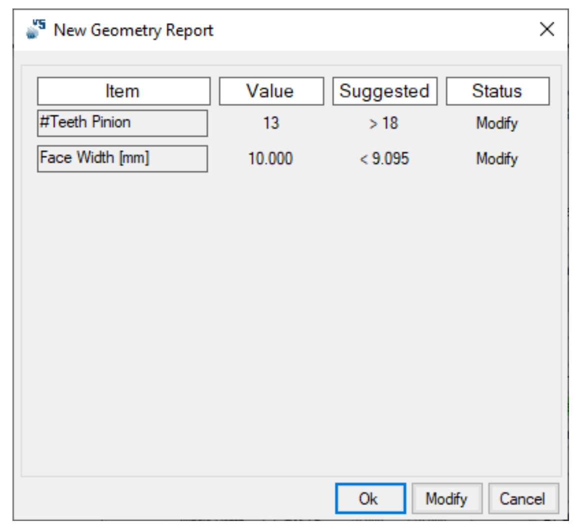
# Creating a Straight Bevel gear set



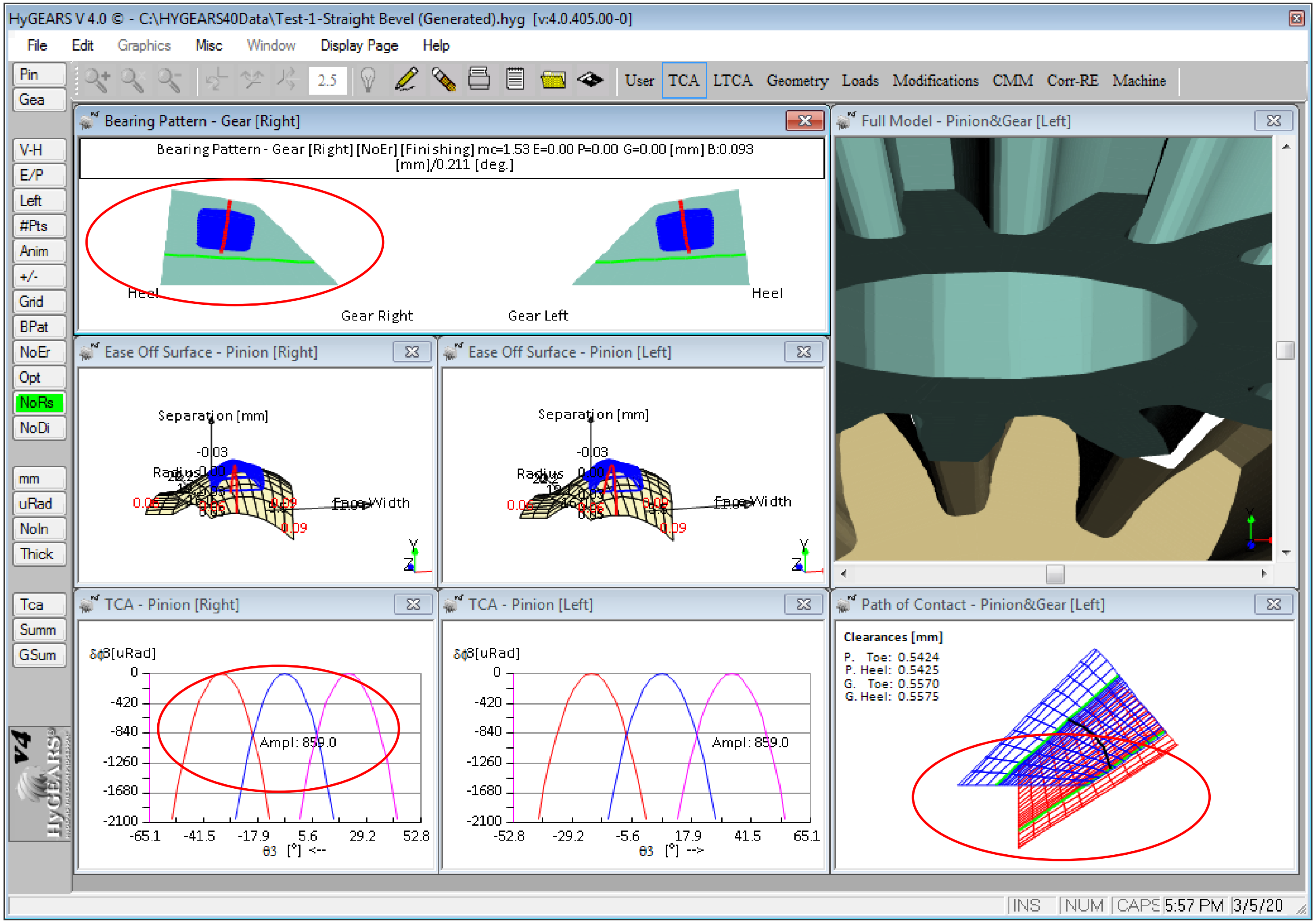



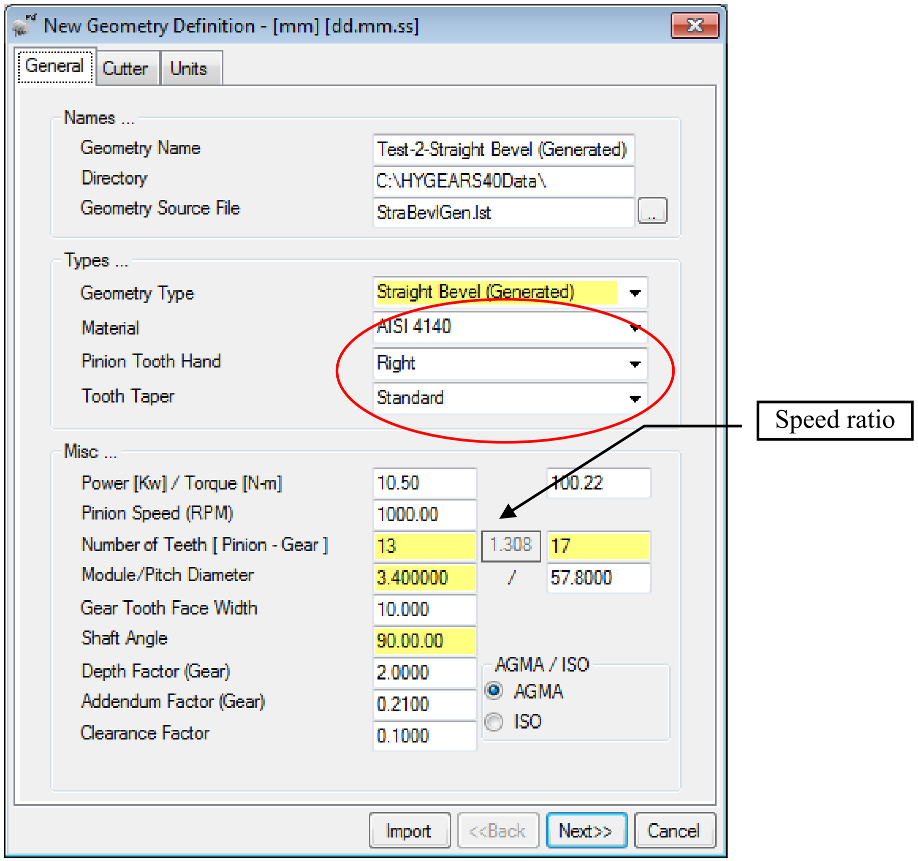
# Creating a "Differential" Straight Bevel gear set

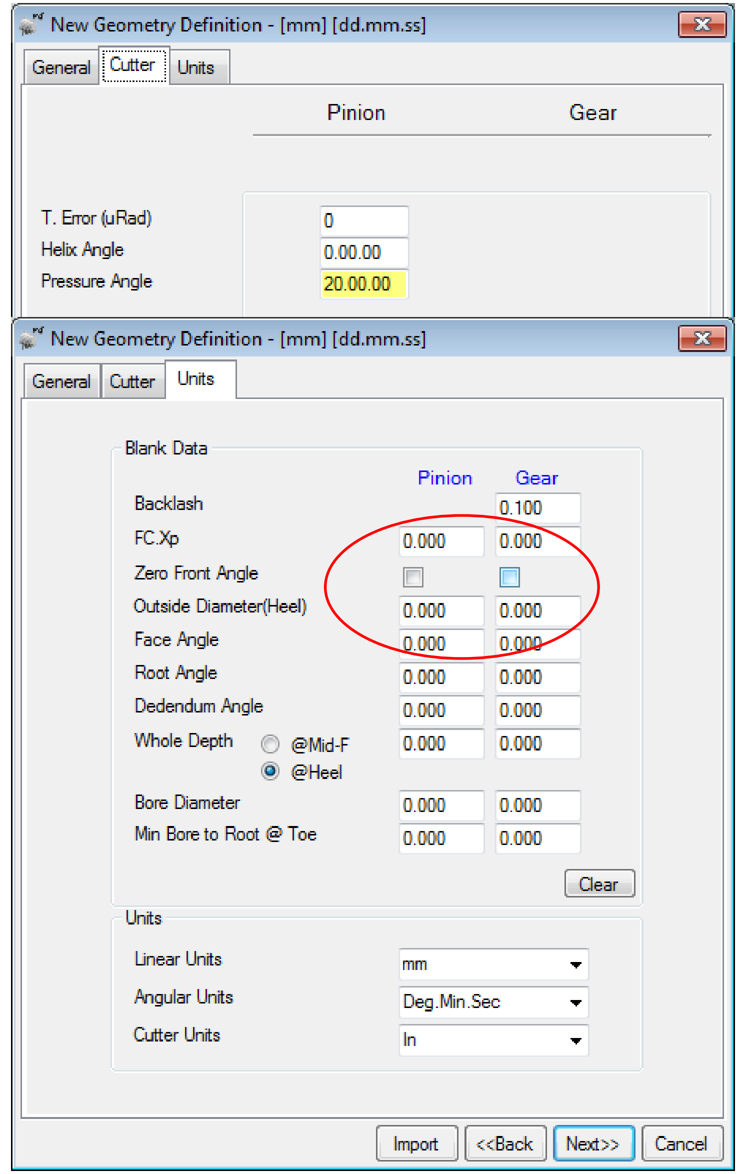


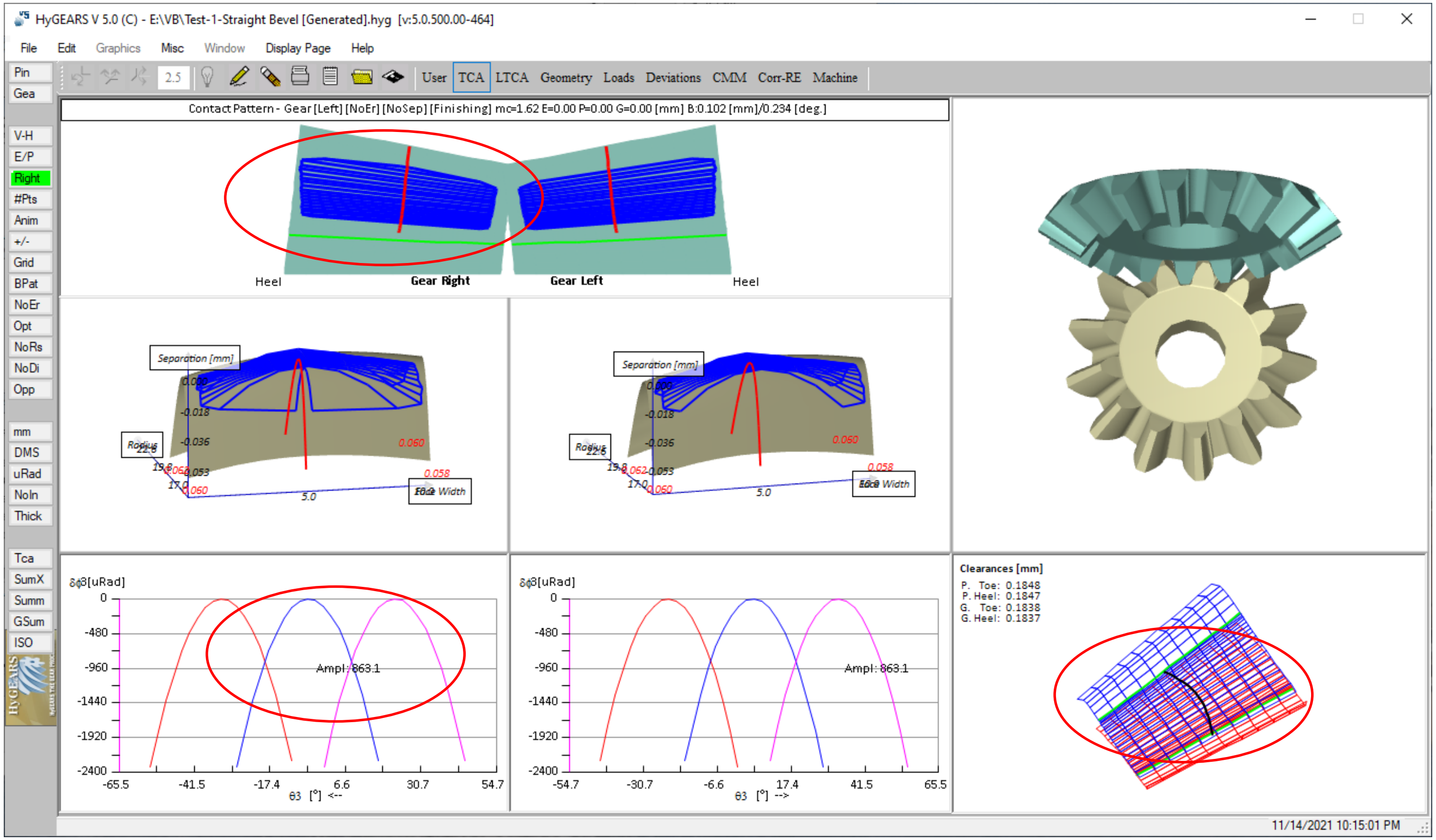

Click on Next >> and Ok


HyGEARS V 4.0 © - C:\HYGEARS40Data\Test-1-Straight Bevel (Generated).hyg [v:4.0.405.00-0]
File Edit Graphics Misc Window Display Page Help
User TCA LTCA Geometry Loads Modifications CMM Corr-RE Machine
Bearing Pattern - Gear [Right]
Bearing Pattern - Gear [Right] [NoEr] [Finishing] mc=1.53 E=0.00 P=0.00 G=0.00 [mm] B:0.093 [mm]/0.211 [deg.]
Heel
Gear Right
Gear Left
Full Model - Pinion&Gear [Left]
Ease Off Surface - Pinion [Right]
Ease Off Surface - Pinion [Left]
Separation [mm]
Face Width
TCA - Pinion [Right]
TCA - Pinion [Left]
Ampl: 859.0
Path of Contact - Pinion&Gear [Left]
Clearances [mm]
P. Toe: 0.5424
P. Heel: 0.5425
G. Toe: 0.5570
G. Heel: 0.5575




Click on Next >> and Ok


HyGEARS V 5.0 (C) - E:\VB\Test-1-Straight Bevel [Generated].hyg [v:5.0.500.00-464]
File Edit Graphics Misc Window Display Page Help
User TCA LTCA Geometry Loads Deviations CMM Corr-RE Machine
Pin Gea V-H E/P Right #Pts Anim +/- Grid BPat NoEr Opt NoRs NoDi Opp mm DMS uRad NoIn Thick Tca SumX Summ GSum ISO
Contact Pattern - Gear [Left] [NoEr] [NoSep] [Finishing] mc=1.62 E=0.00 P=0.00 G=0.00 [mm] B:0.102 [mm]/0.234 [deg.]
Heel
Gear Right
Gear Left
Heel
Separation [mm]
Radius
Face Width
δφ3[uRad]
Ampl: 863.1
θ3 [°] <--
θ3 [°] -->
Clearances [mm]
P. Toe: 0.1848
P. Heel: 0.1847
G. Toe: 0.1838
G. Heel: 0.1837
11/14/2021 10:15:01 PM

# Universal 5 Axis CnC Post-Processing

*Tooth – M/C -> Cutting Machine Child Window -> 5 Axis CNC manufacturing*

***Overview:***

*HyGEARS integrates a **5Axis Post-Processor** that can generate CnC part programs to cut **any HyGEARS supported gear type on any 5 Axis CnC machine**.*

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

***Tool and machine movements are displayed in 3D**, can be rotated in any direction for better 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 machine architectures of "BA", "BC", "AB" and "AC" types, where :*

- *the A axis rotates about the X axis*
- *the B axis rotates about the Y axis*
- *the C axis rotates about the Z axis*

*Specific machines with special kinematics 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.*

# Universal 5 Axis CnC Post-Processing

***Main features of the Post-Processor***:

- *supports "AB", "AC", "BA" and "BC" architecture machines;*
- *supports GCodes, Heidenhain, Siemens, Okuma, Mazak and Fanuc controllers;*
- *supports Traori (Siemens), TCPM (Heidenhain) , TCP (Fanuc) and TCPC (Okuma);*
- *allows creation of specific 3, 4, 5 Axis machines from the 4 basic architectures; specific machines can be fully customized by the user to reproduce exactly the machine implementation;*
- *offers 10 pre-defined cutting cycles for CoSIMT, End Mill and Ball Mill tools; and 4 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 roughing / multi-pass semi-finishing and finishing for CoSIMT, End Mill and Ball Mill tools;*
- *allows the generation of a 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 gears;*
- *allows the creation of "Processes" which are a series of "Operations" in a given order; Processes can thus generate a complete single file part program including roughing and semi-finishing of the tooth flank and fillet using different tools.*

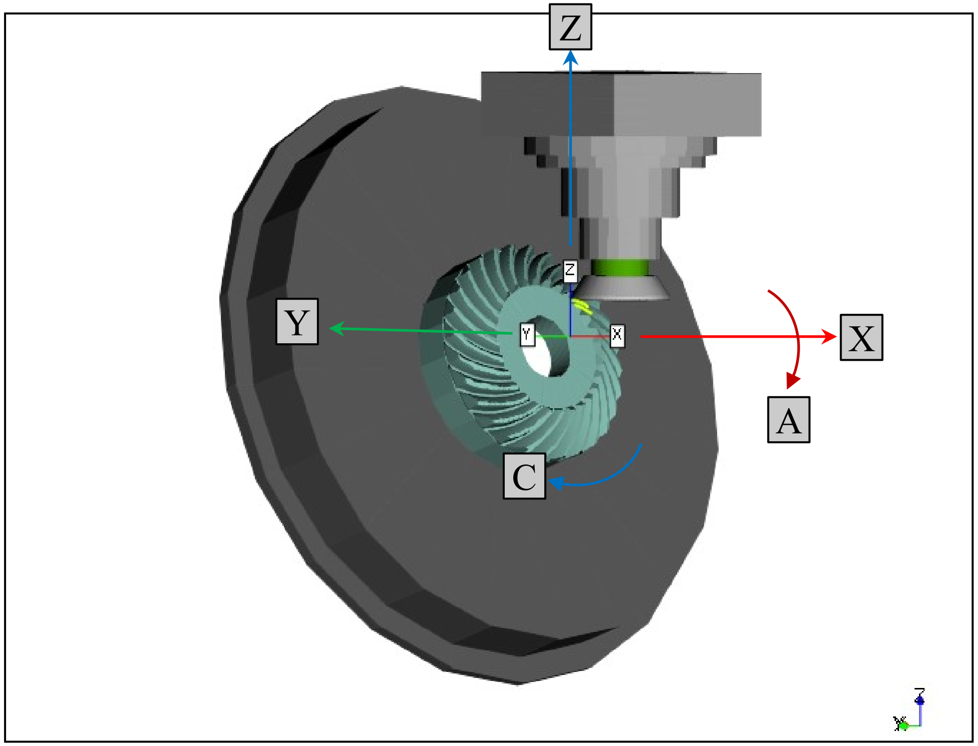
***Part Programs***:

- *can be in CSV (comma separated values) format for import in Excel;*
- *can include or exclude comments describing the 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, PTR-TEC), End Mill, Ball Mill cutters.*

# Universal 5 Axis CnC Post-Processing

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

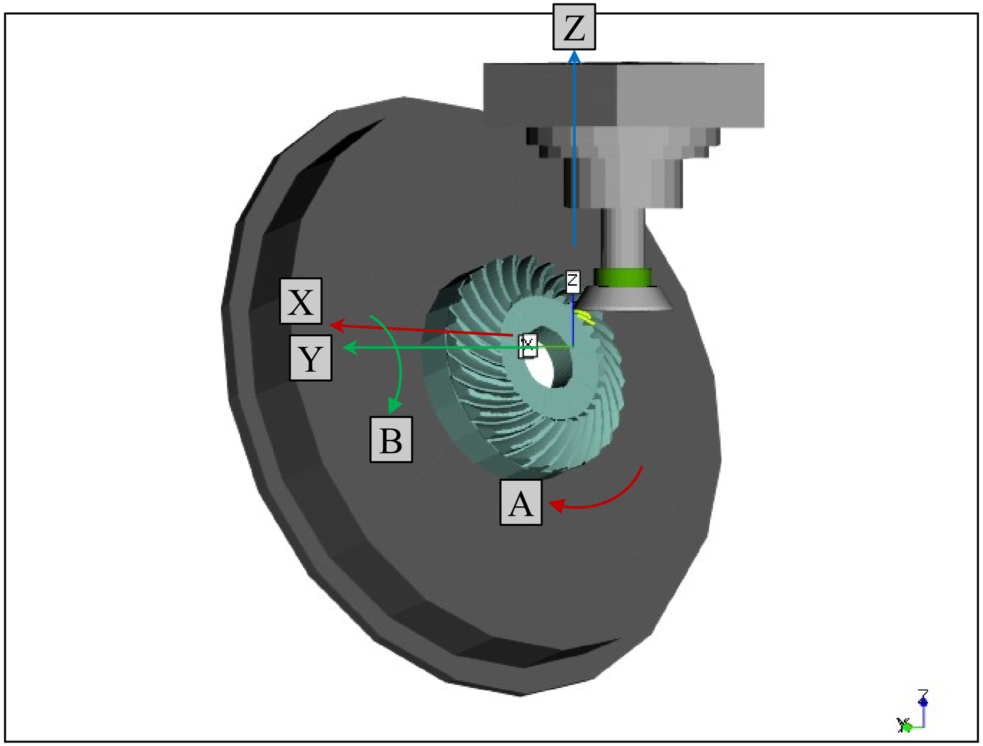
- X, Y, Z translations (on the tool and/or work piece)
- Tilting Turntable about X axis: angle A
- Rotation about work axis: angle C



# Universal 5 Axis CnC Post-Processing

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

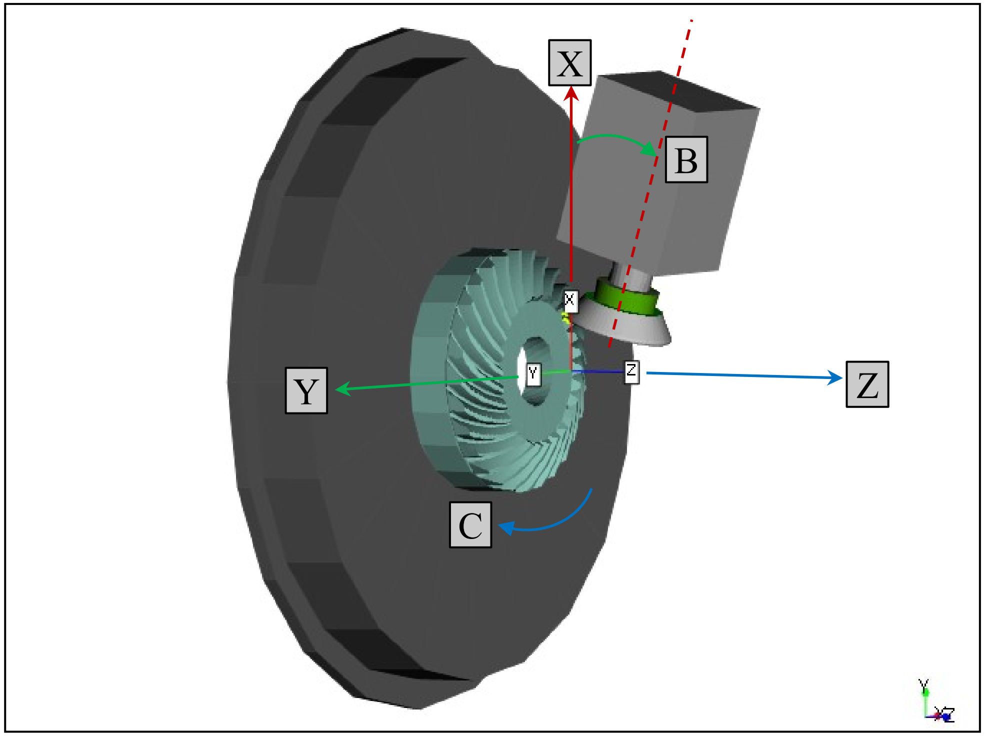
- X, Y, Z translations (on the tool and/or work piece)
- Tilting Turntable about Y axis: angle B
- Rotation about work axis: angle A



# Universal 5 Axis CnC Post-Processing

***B-C* machine architecture**:

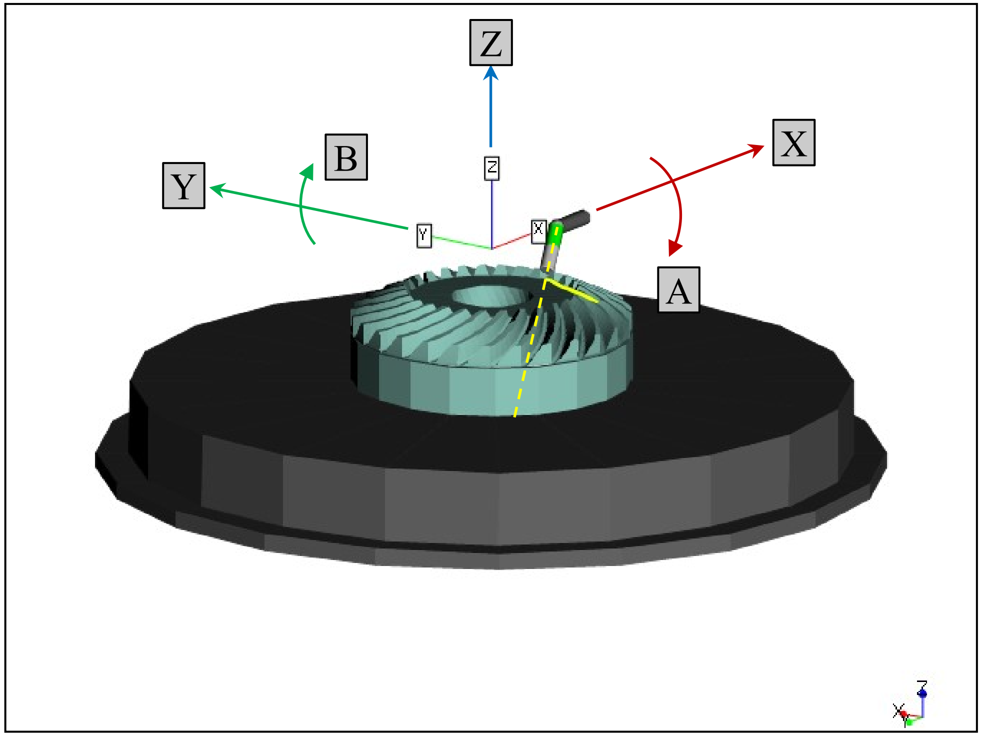
- X, Y, Z translations (on the tool and/or work piece)
- Tilting Tool about Y axis: angle B
- Rotation about work axis: angle C



# Universal 5 Axis CnC Post-Processing

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

- X, Y, Z translations (on the tool and/or work piece)
- Swiveling Tool about X axis: angle A
- Tilting Tool about Y axis: angle B



# Universal 5 Axis CnC Post-Processing

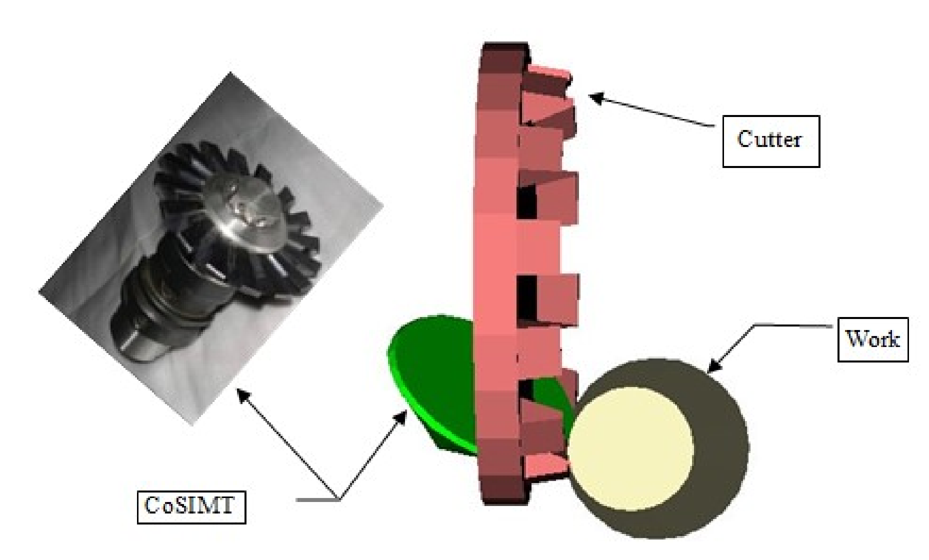
***Conversion:*** *To generate a part program, HyGEARS converts the movements of the conventional cutter in a conventional machine into movements of a Face Mill, Coniflex™ dish, CoSIMT, End Mill or a Ball Mill tool in a 3, 4, 5 Axis CnC machine where:*

- 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.*

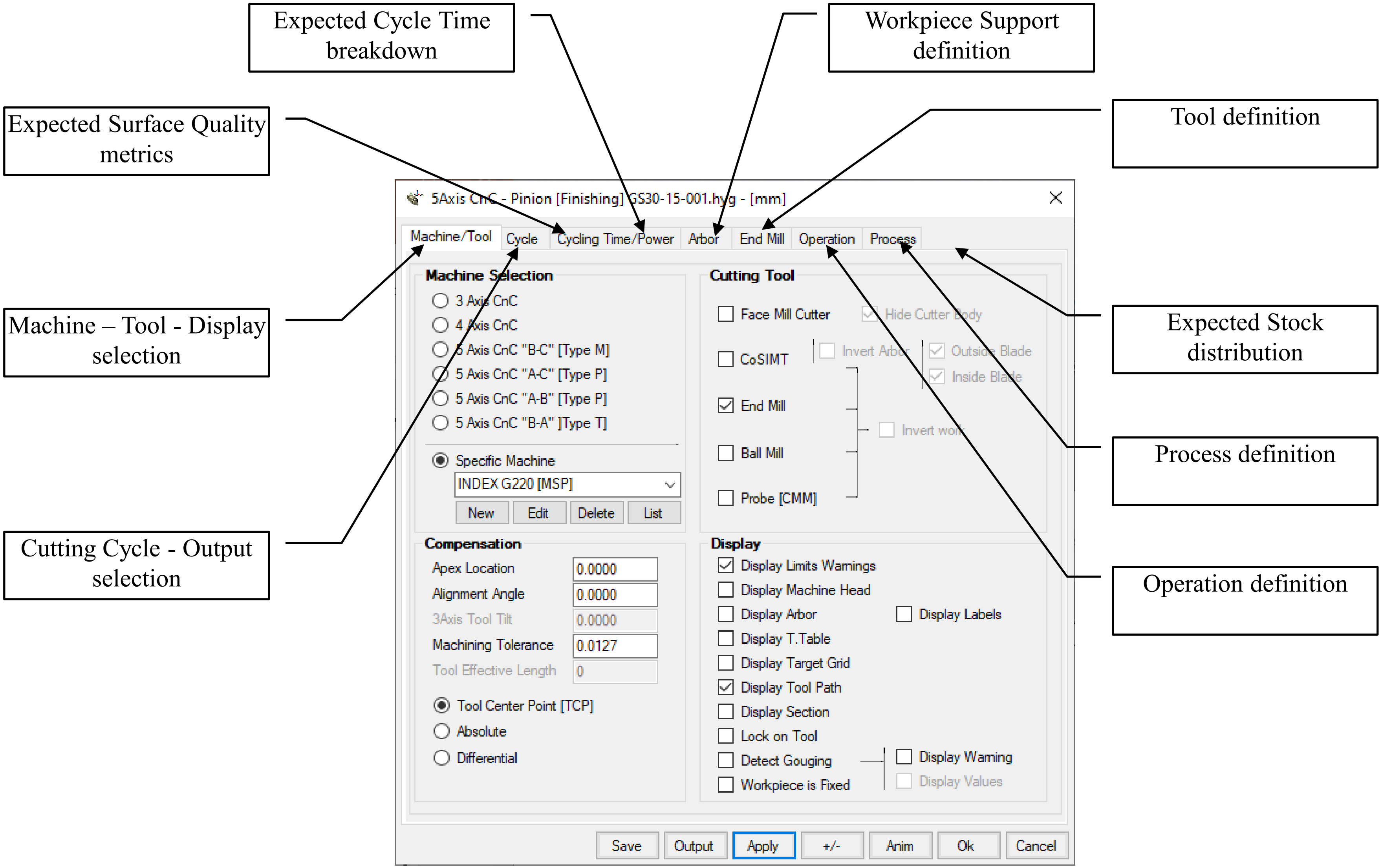
*The HyGEARS Post Processor tracks the movements of the Face Mill cutter in the conventional machine and converts them to CoSIMT movements in a 5Axis CnC machine.*

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



# Universal 5 Axis CnC Post-Processing

***Interface**: Several Tabs display different options and information*

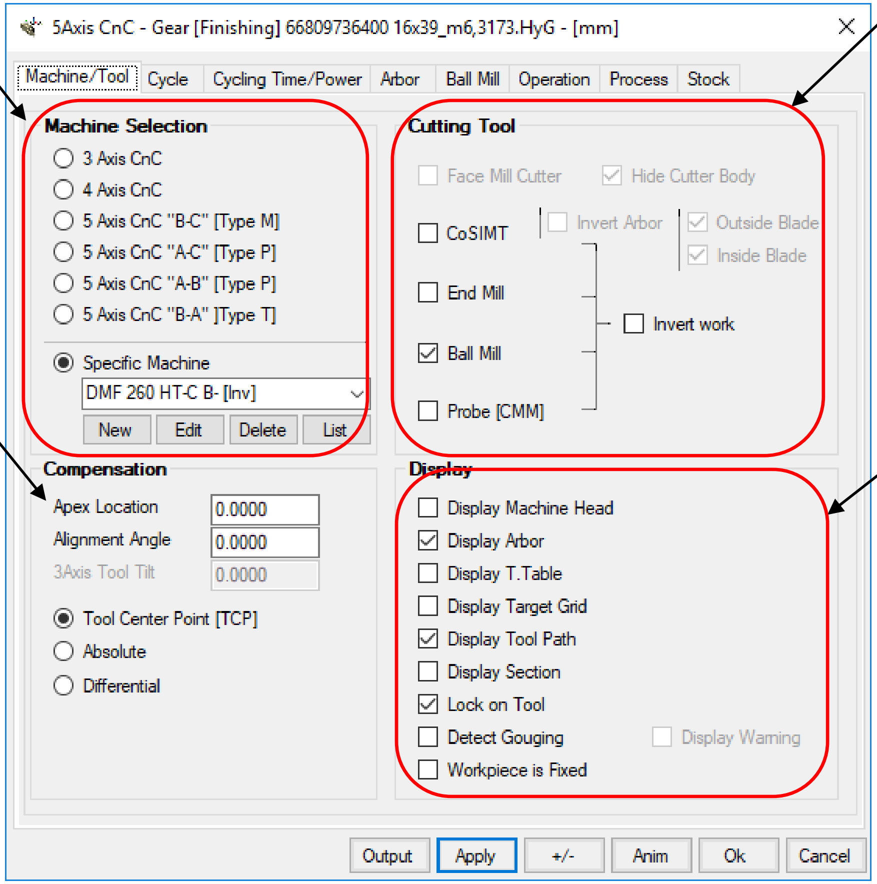


# Universal 5 Axis CnC Post-Processing

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

Machines are optional;
- Generic type
- Specific type

Apex Location: used in "Machine" coordinates

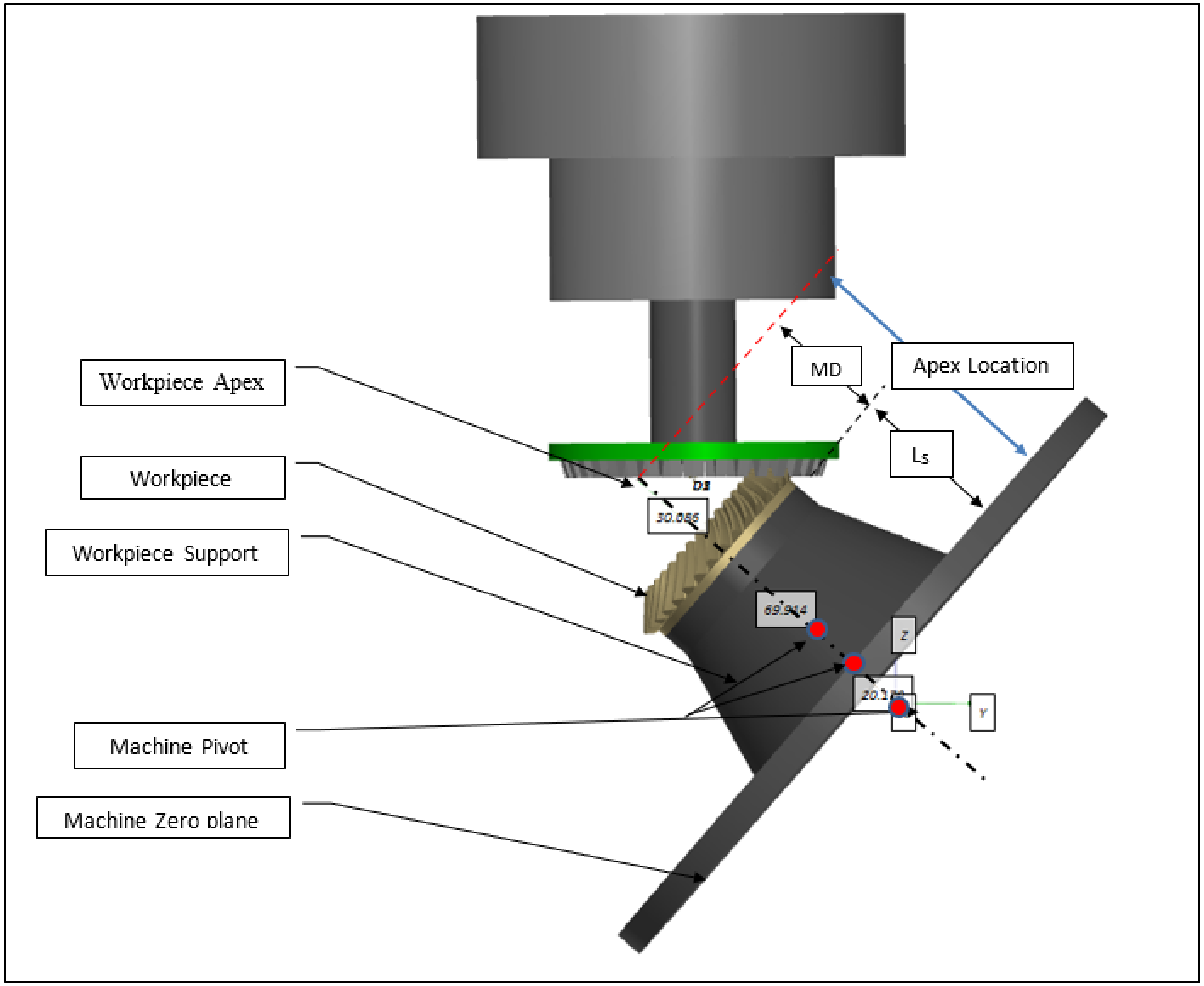



Cutting Tools are optional; they are user defined.

Display switches control what is shown on screen..

# Universal 5 Axis CnC Post-Processing

***Machine/Tool**: The Apex Location is used in Machine coordinates to compensate for turntable tilt*



# Universal 5 Axis CnC Post-Processing

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

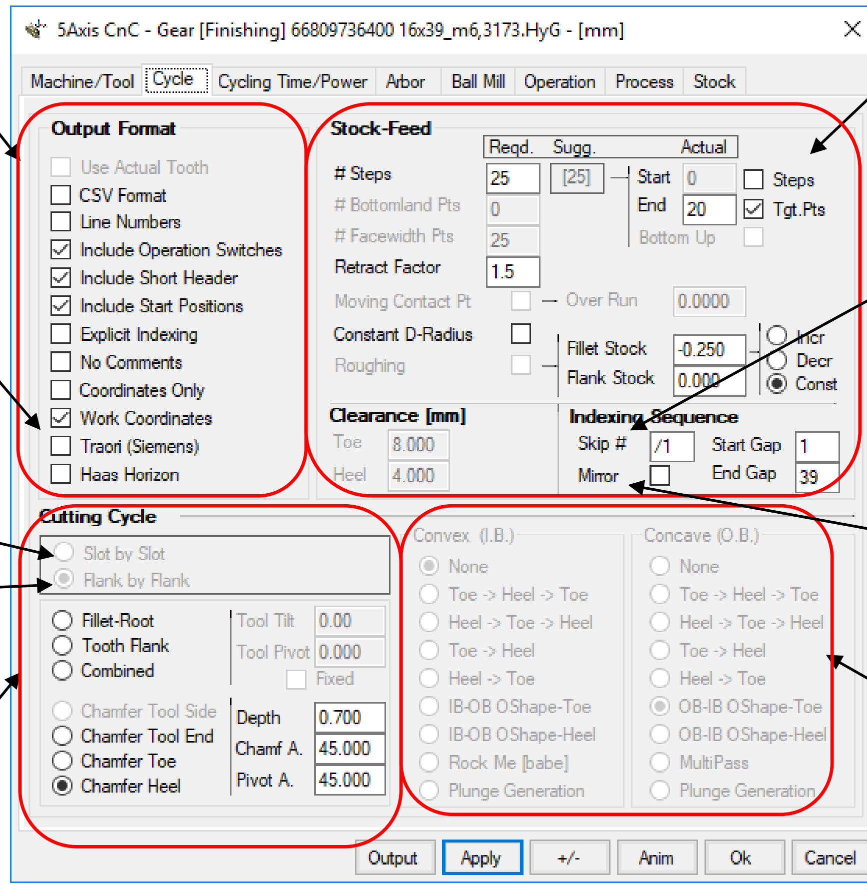
Output Format: allows selecting wanted or unwanted features

•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

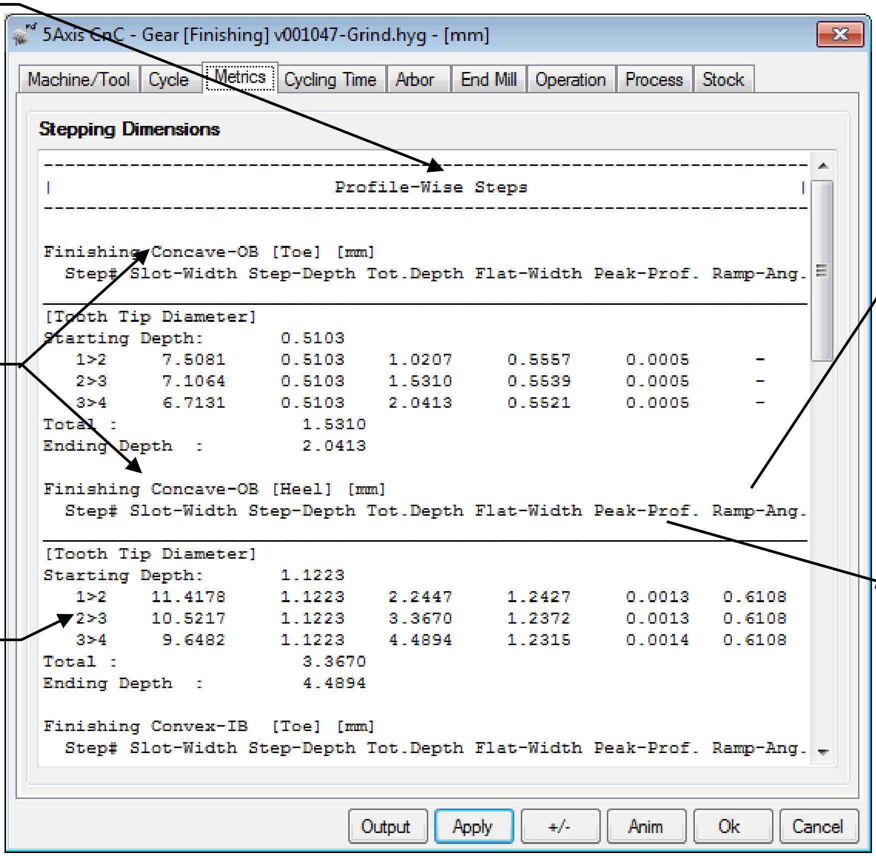
# Universal 5 Axis CnC Post-Processing

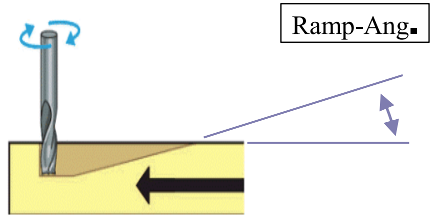
***Metrics**: Profile-wise step depth, slot width, expected surface quality*

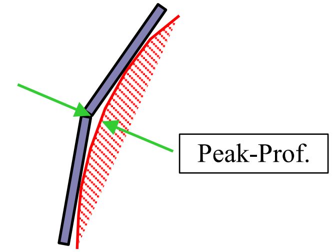
Profile-wise Steps

Considered Tooth flank

Step by step breakdown

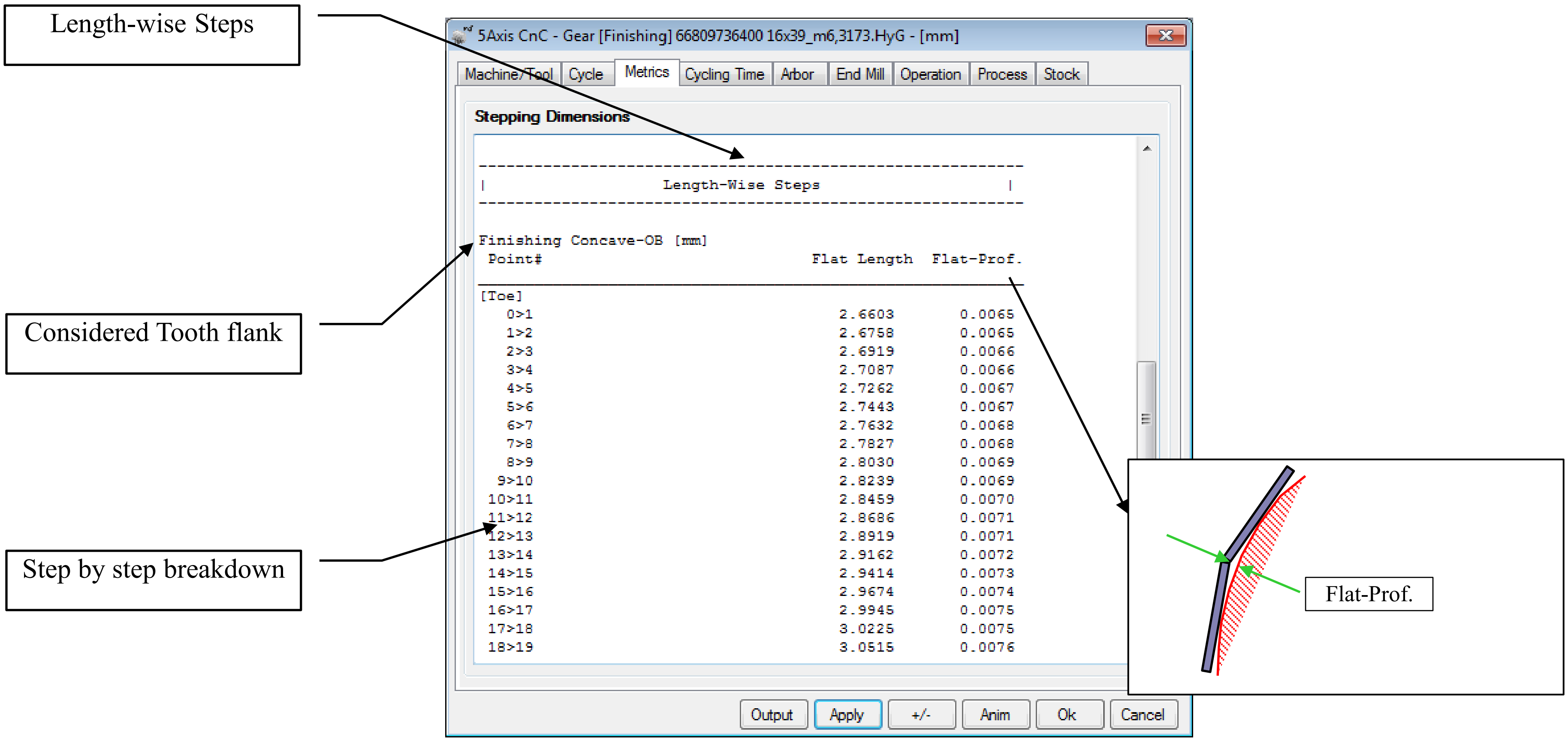


# Universal 5 Axis CnC Post-Processing

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




| Point# | Flat Length | Flat-Prof. |
|---|---|---|
| [Toe] | | |
| 0>1 | 2.6603 | 0.0065 |
| 1>2 | 2.6758 | 0.0065 |
| 2>3 | 2.6919 | 0.0066 |
| 3>4 | 2.7087 | 0.0066 |
| 4>5 | 2.7262 | 0.0067 |
| 5>6 | 2.7443 | 0.0067 |
| 6>7 | 2.7632 | 0.0068 |
| 7>8 | 2.7827 | 0.0068 |
| 8>9 | 2.8030 | 0.0069 |
| 9>10 | 2.8239 | 0.0069 |
| 10>11 | 2.8459 | 0.0070 |
| 11>12 | 2.8686 | 0.0071 |
| 12>13 | 2.8919 | 0.0071 |
| 13>14 | 2.9162 | 0.0072 |
| 14>15 | 2.9414 | 0.0073 |
| 15>16 | 2.9674 | 0.0074 |
| 16>17 | 2.9945 | 0.0075 |
| 17>18 | 3.0225 | 0.0075 |
| 18>19 | 3.0515 | 0.0076 |

# Universal 5 Axis CnC Post-Processing

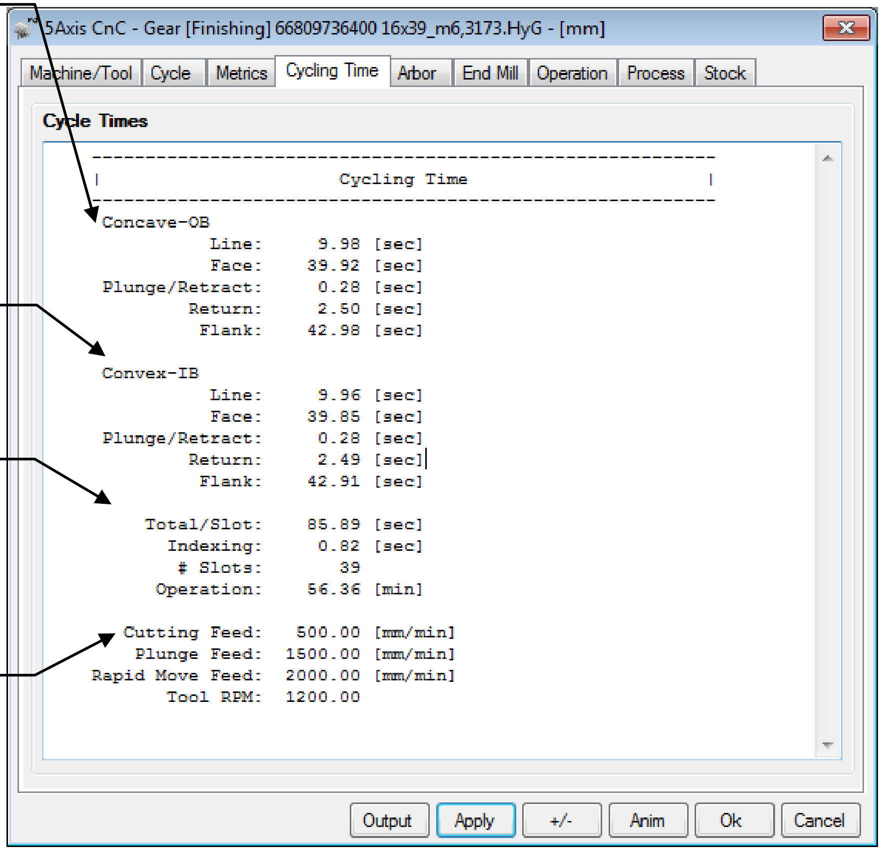
***Cycling Time**: Flank by flank operation Cycling time breakdown*

Concave Tooth Flank

Convex Tooth flank

Complete Cycle

Tool Feeds & Speeds




***For Each Tooth Flank***

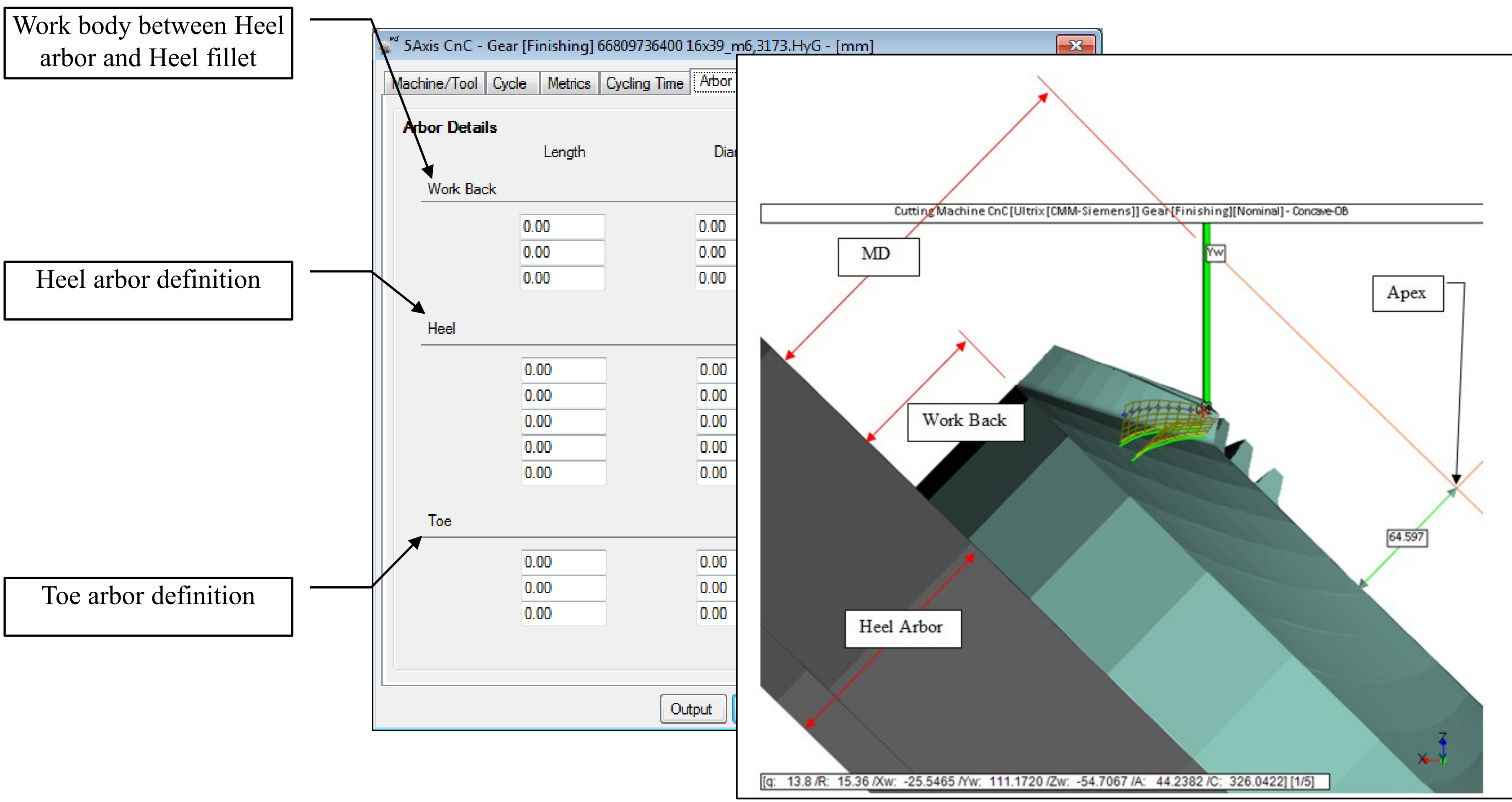
- *Line: each line in the face width direction*
- *Face: the complete tooth flank*
- *Plunge/Retract: time needed to go in and out of the slot;*
- *Return: return trip time (when applicable)*

***For the current cycle***

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

# Universal 5 Axis CnC Post-Processing

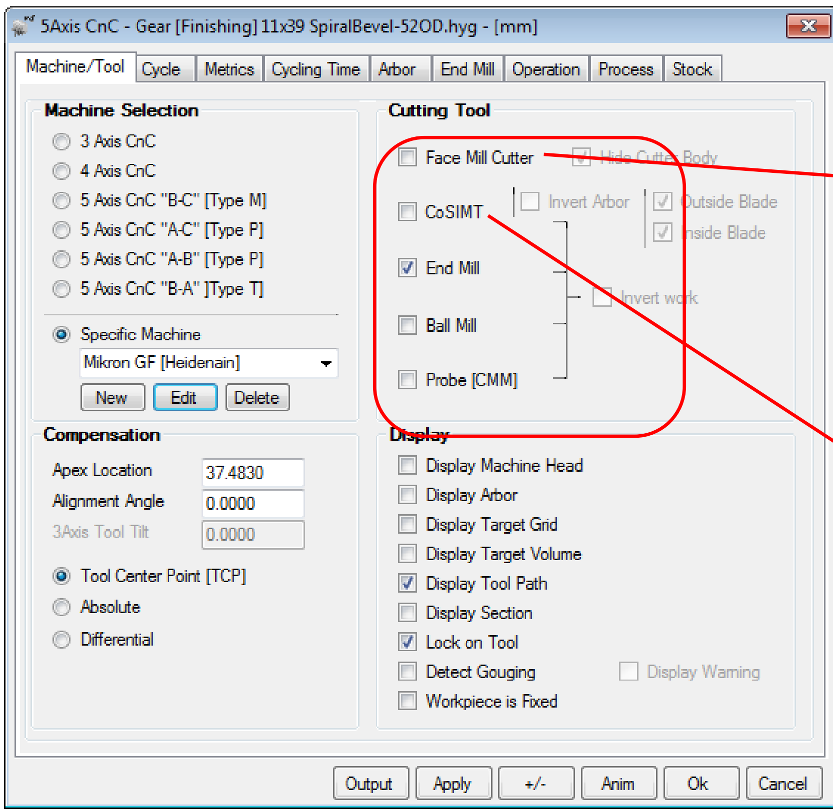
***Arbor**: Blank supports on the machine.*

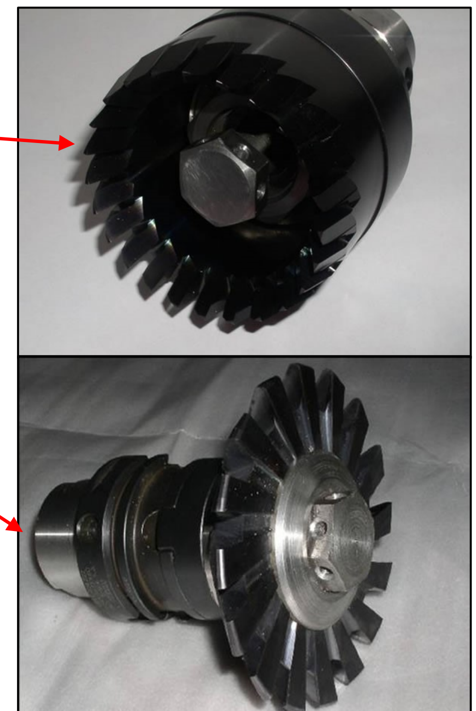


# Universal 5 Axis CnC Post-Processing

***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)* |



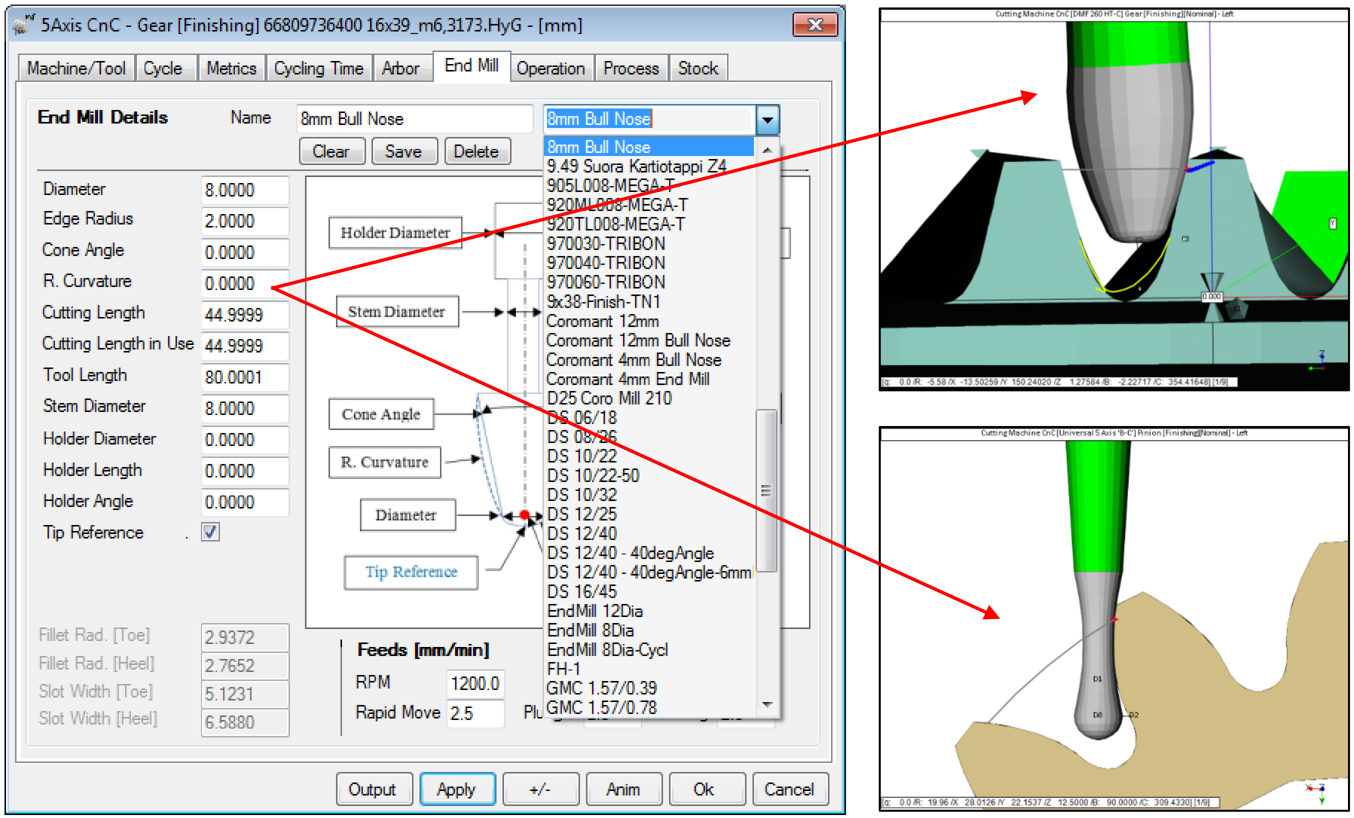



*Photos courtesy of PTR-TEC.de*

# Universal 5 Axis CnC Post-Processing

***Tools:*** *Each tool type 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.*

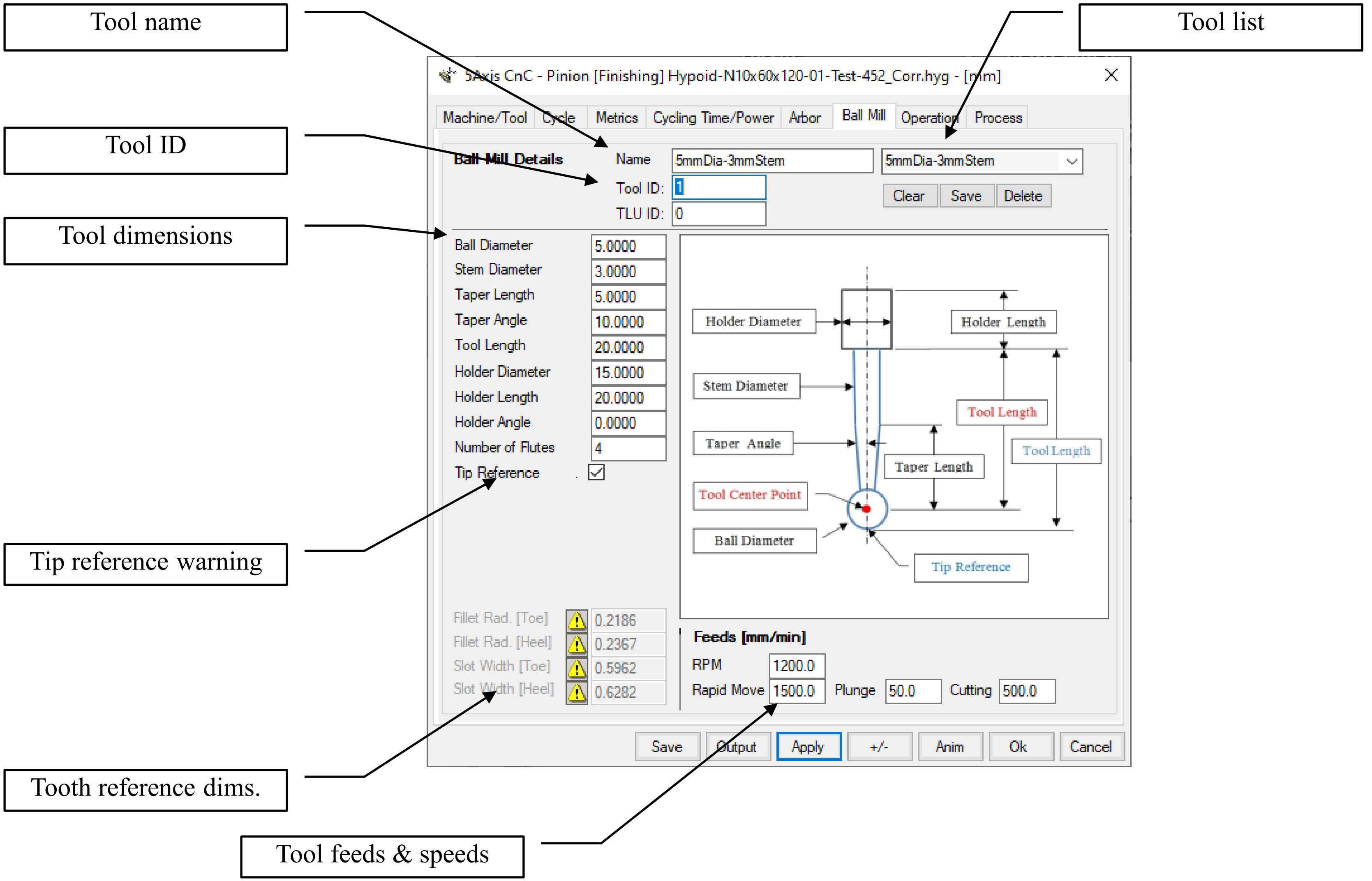
*The tools can be saved for re-use and are specific to users, i.e. they are not distributed with HyGEARS. Hence, proprietary information remains proprietary.*




*Definition of an 8mm Bull Nose*

# Universal 5 Axis CnC Post-Processing

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



# Universal 5 Axis CnC Post-Processing

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

Tool name

Tool ID

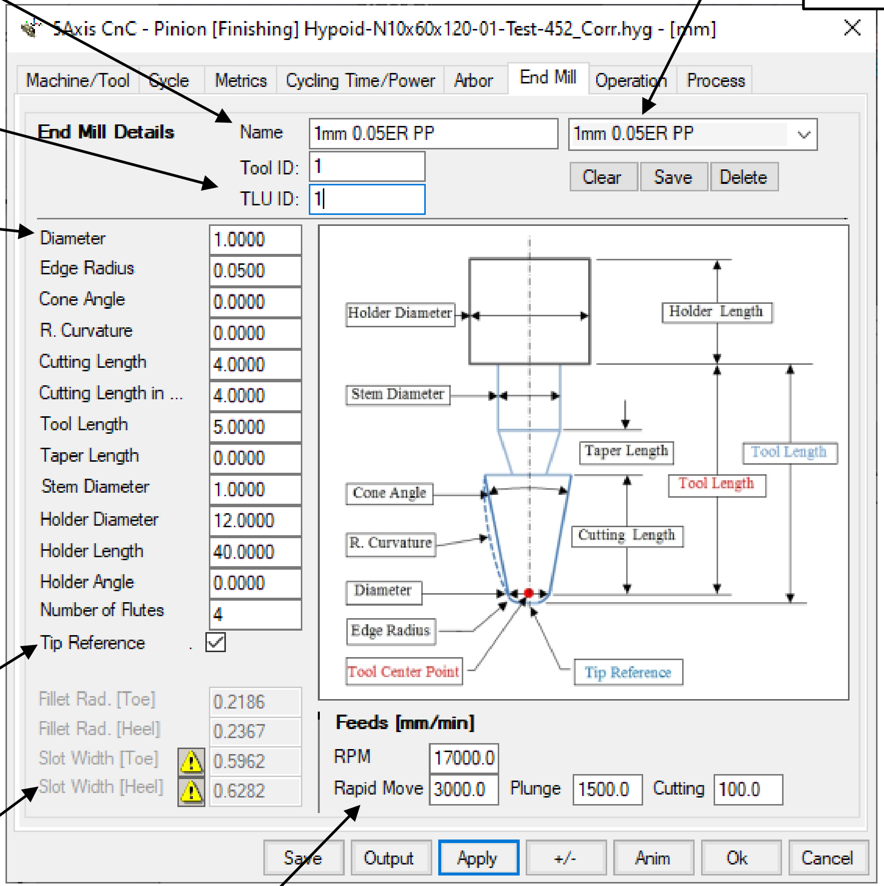
Tool dimensions

Tip reference warning

Tooth reference dims.

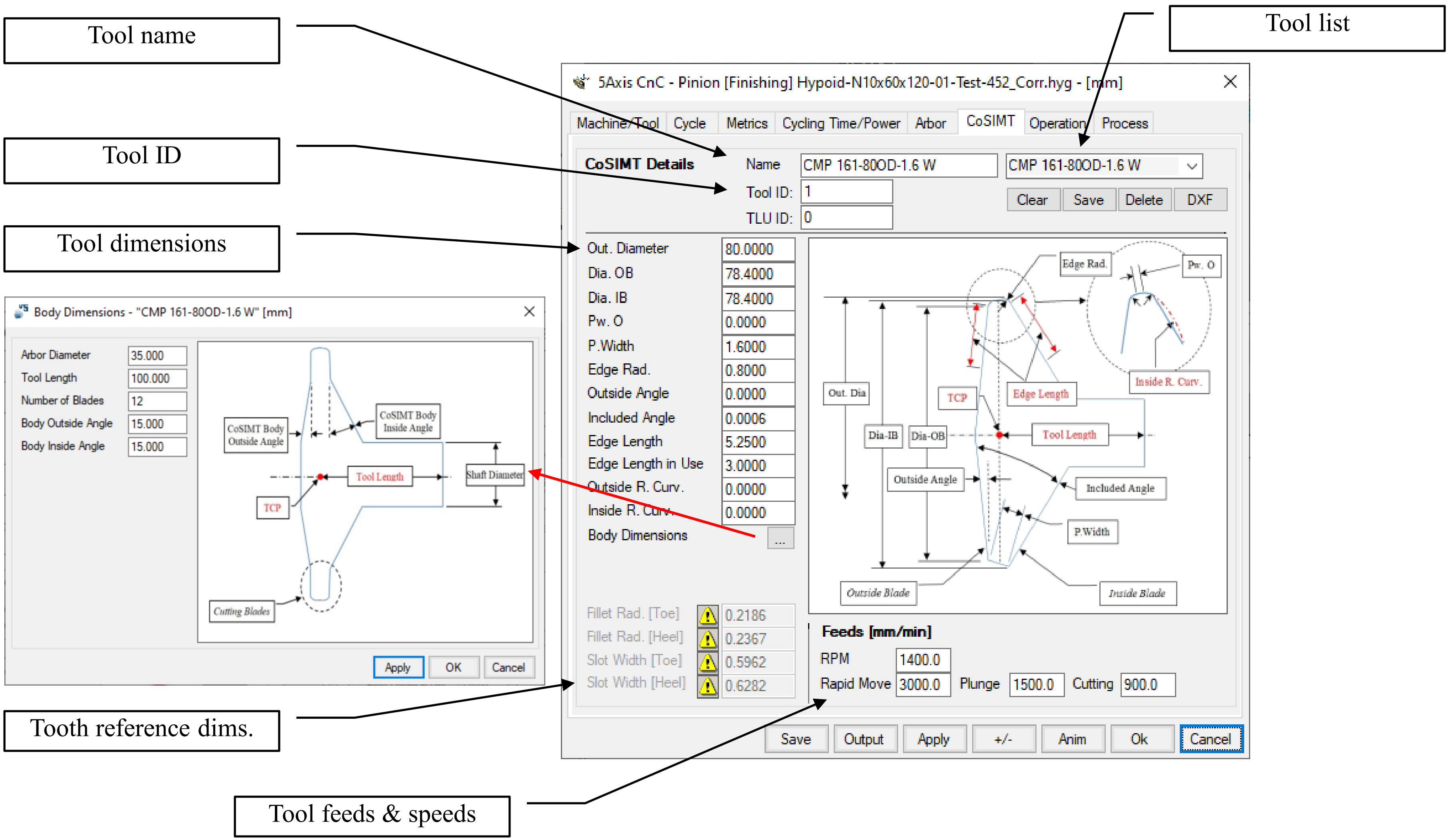
Tool list

Tool feeds & speeds



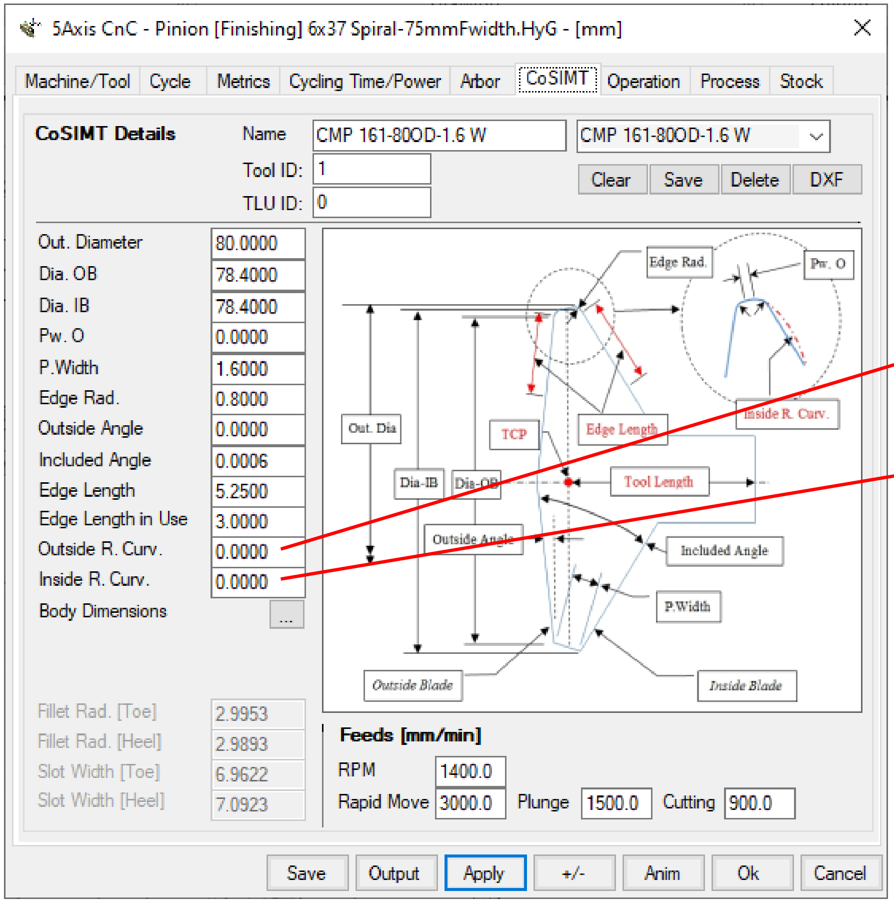
# Universal 5 Axis CnC Post-Processing

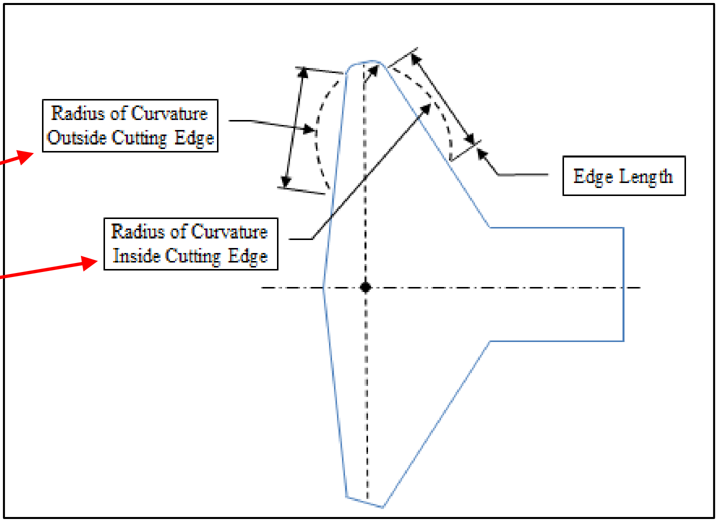
***CoSIMT Definition**: Tool dimensions, reference (tools are user defined).*



# Universal 5 Axis CnC Post-Processing

***CoSIMT Definition :*** *CoSIMT tools can have circular cutting edges which allow the generation of tooth profiles with concave curvature, such as Face Gears.*



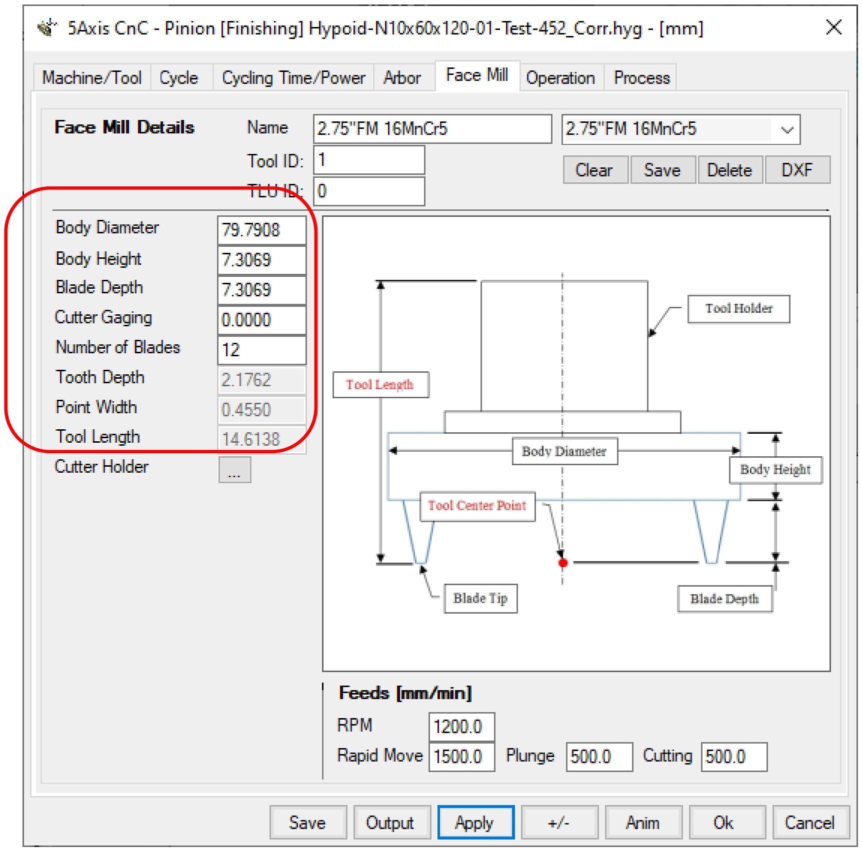



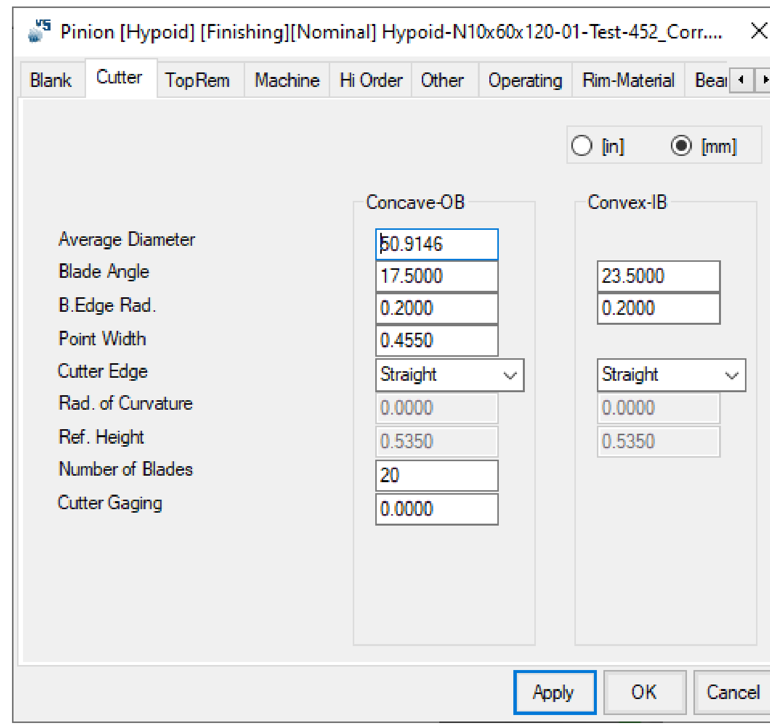

*Definition of a CoSIMT*

# Universal 5 Axis CnC Post-Processing

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

- *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).*

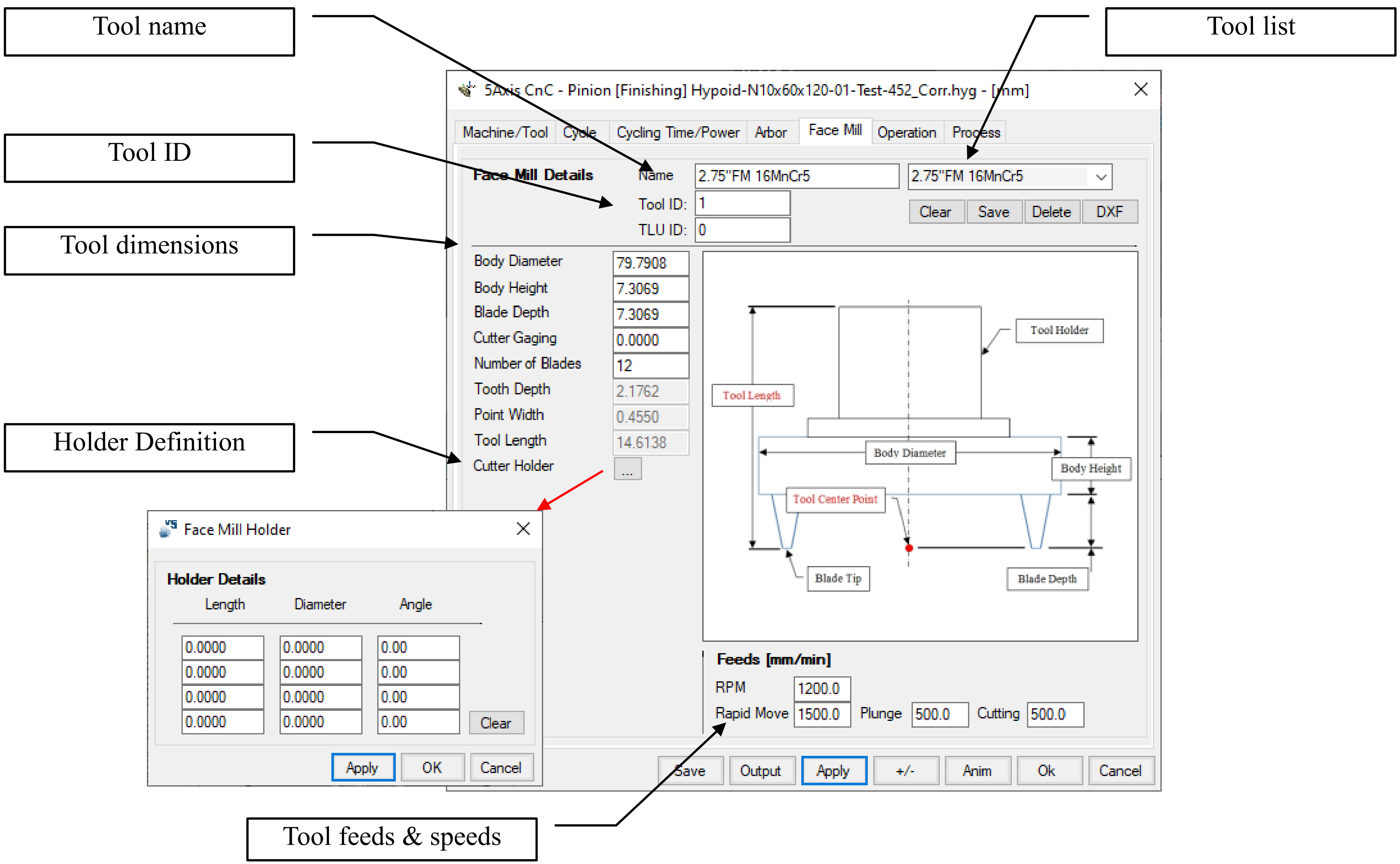



*Face Mill cutter definition*

# Universal 5 Axis CnC Post-Processing

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



# Universal 5 Axis CnC Post-Processing

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

Tool name

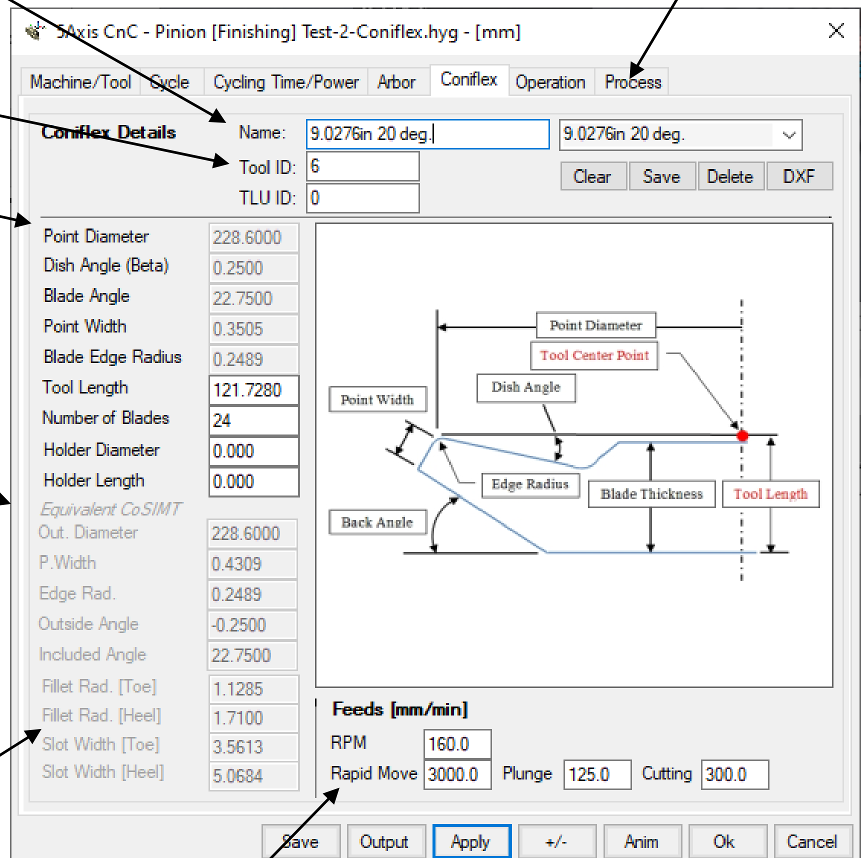
Tool ID

Tool dimensions

Equivalent CoSIMT

Tooth reference dims.

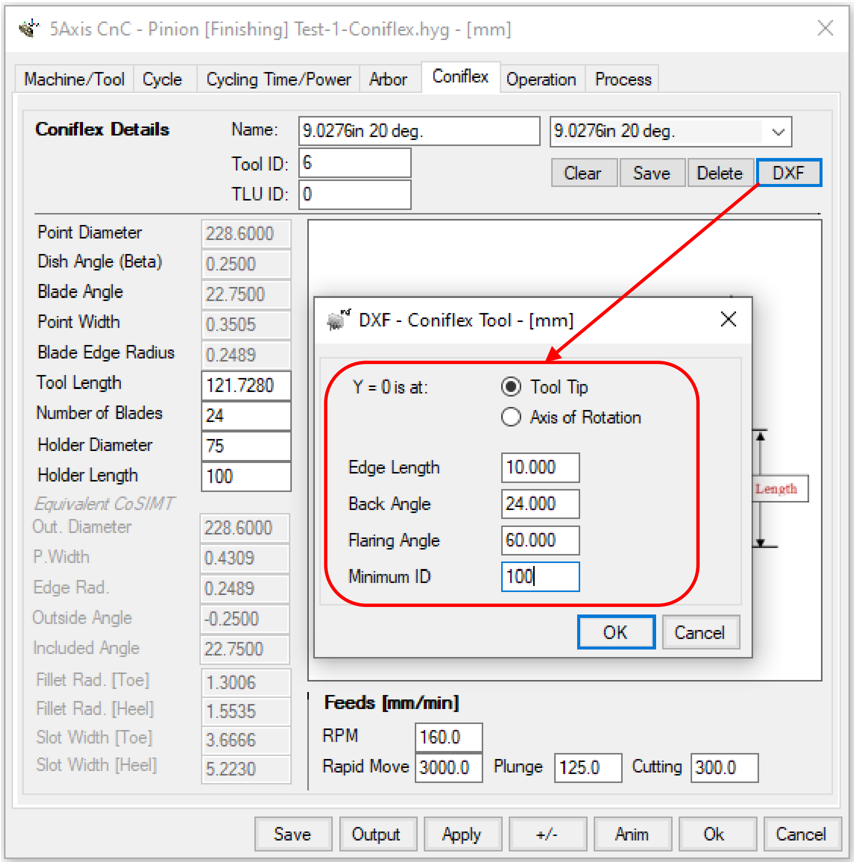
Tool list

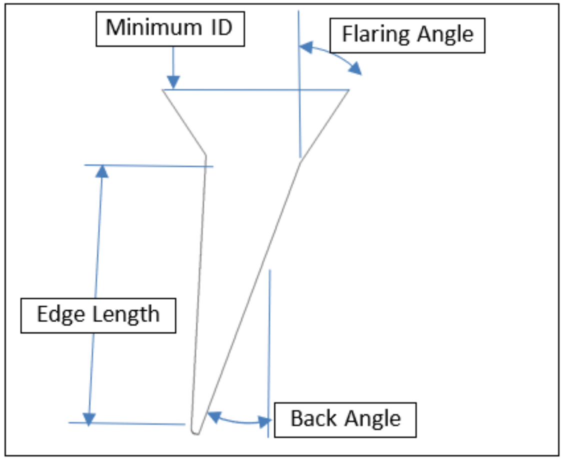



Tool feeds & speeds

# Universal 5 Axis CnC Post-Processing

***Coniflex Definition**: DXF export.*



# Universal 5 Axis CnC Post-Processing

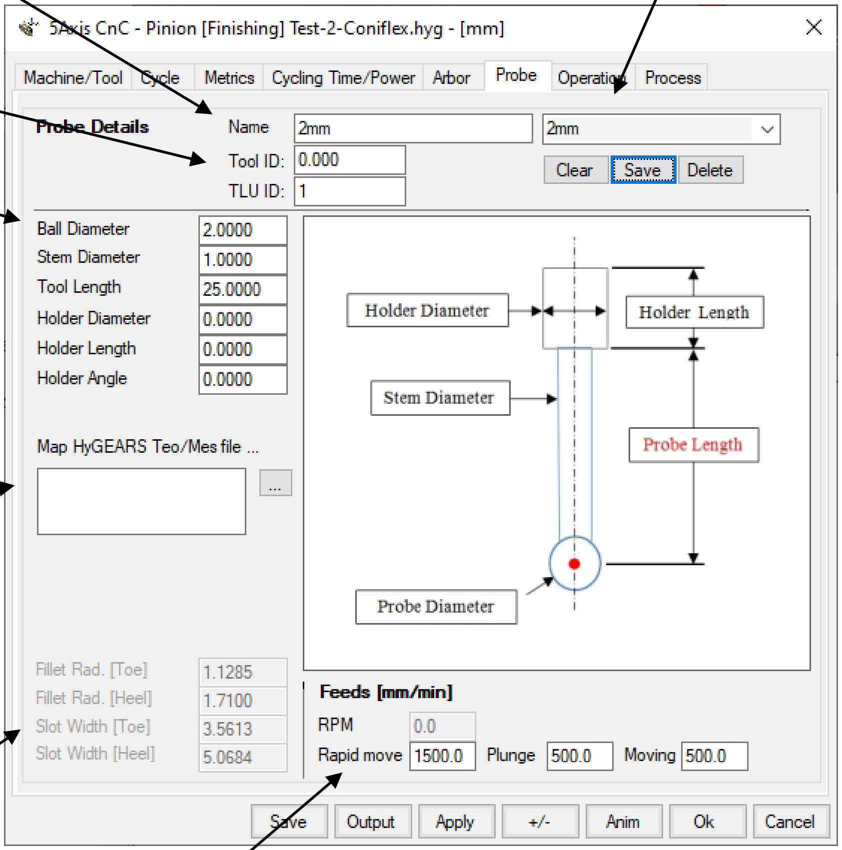
***Probe Definition**: Tool dimensions, reference (tools are user defined).*

Tool name

Tool list

Tool ID

Tool dimensions




To use an existing Measurement (*.Mes) or Theoretical (*.Teo) CMM data file

Tooth reference dims.

Tool feeds & speeds

# Universal 5 Axis CnC Post-Processing

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

Operation name

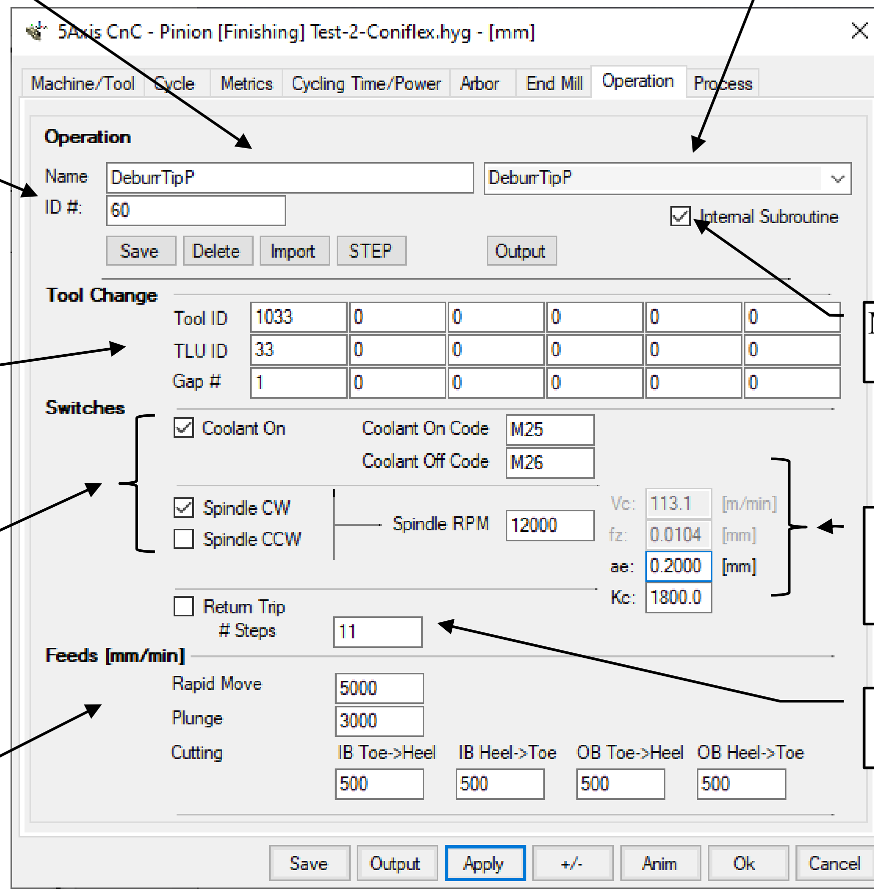
Operation list

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

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

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

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



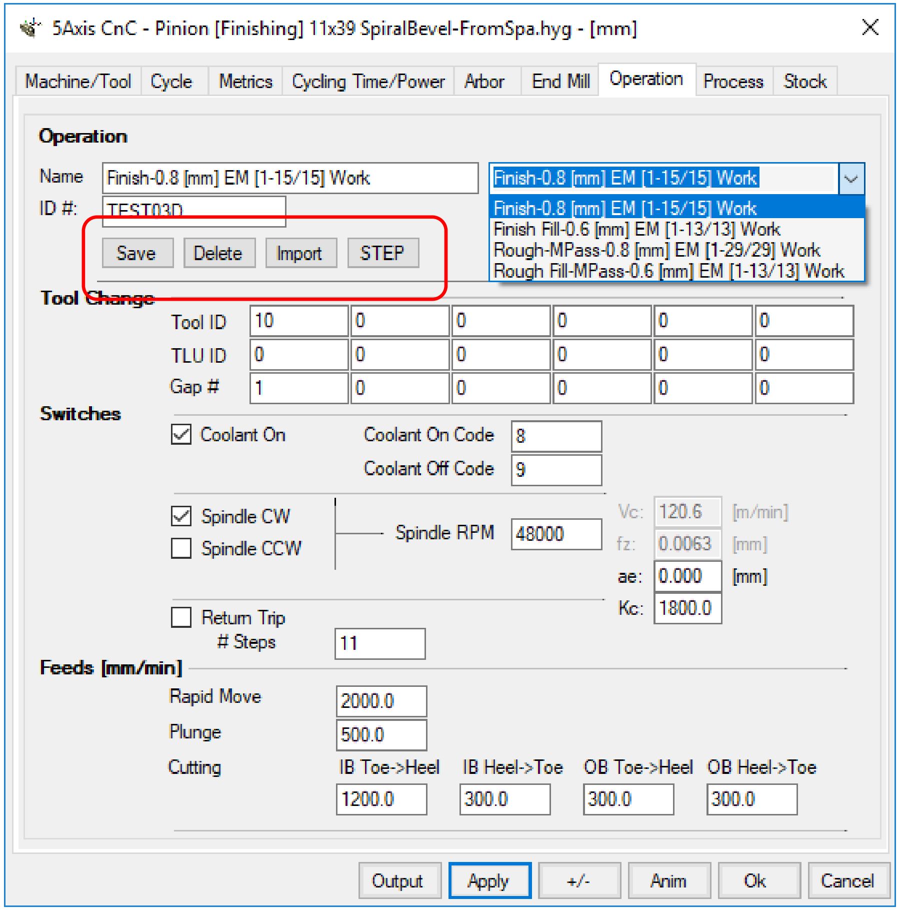

Main and sub programs in same file

Vc and fz; used to estimate required torque & power.

Imposes the tool return path

# Universal 5 Axis CnC Post-Processing

***Operation:*** *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.*

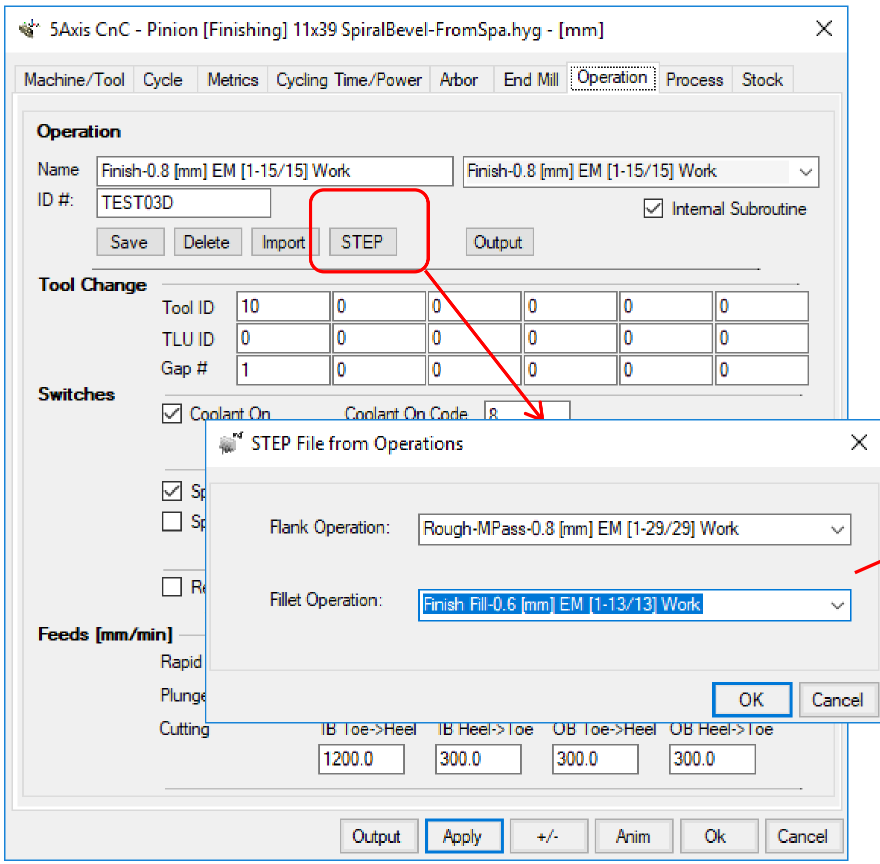



*Operations Tab*

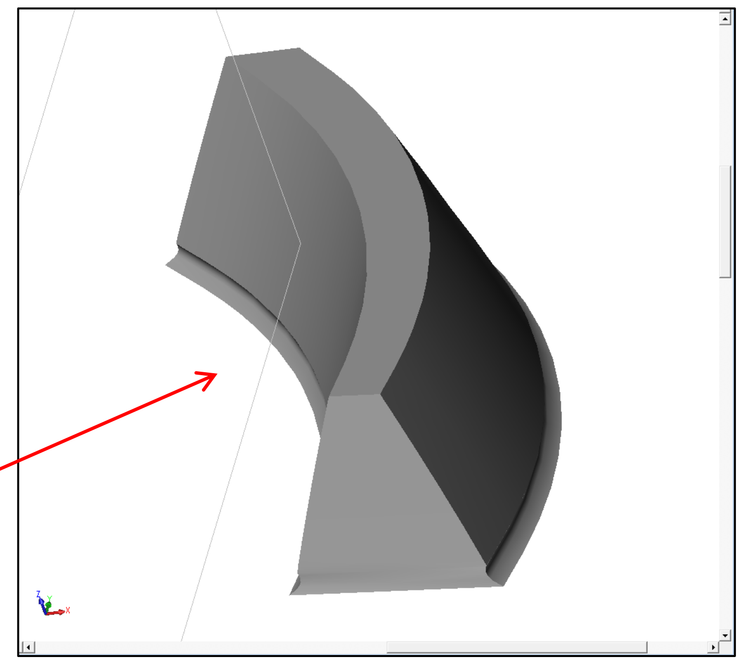
- *an Operation is specific to a geometry, i.e. it is saved in the "Operations.fil" file stored in the current geometry's folder;*
- *the **Save / Delete** buttons conserve and erase the selected operation;*
- *the **Import** button allows importing Operations from other geometries; thus, Operations 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.*

# Universal 5 Axis CnC Post-Processing

***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*

# Universal 5 Axis CnC Post-Processing

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

Process name

Process list

Process ID
Used for the name of the part program and sub programs

All Main and sub programs in same file

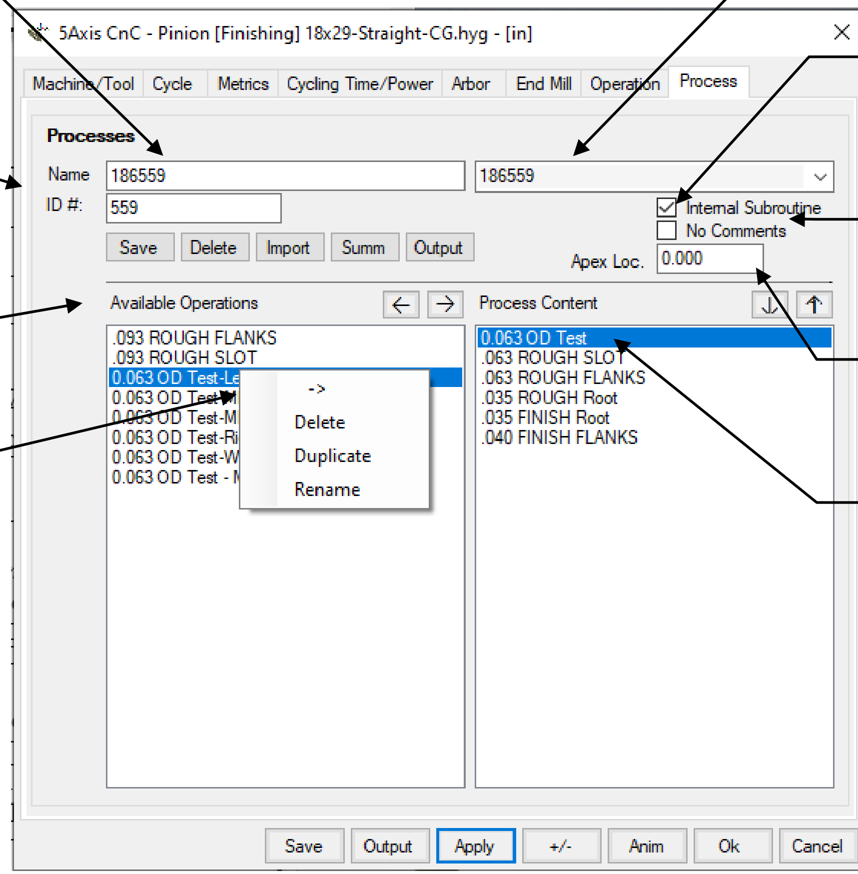
Available Operations

Overrides the *No Comments* switch for all Operations of a Process

Overrides the *Apex Location* for all Operations of a Process

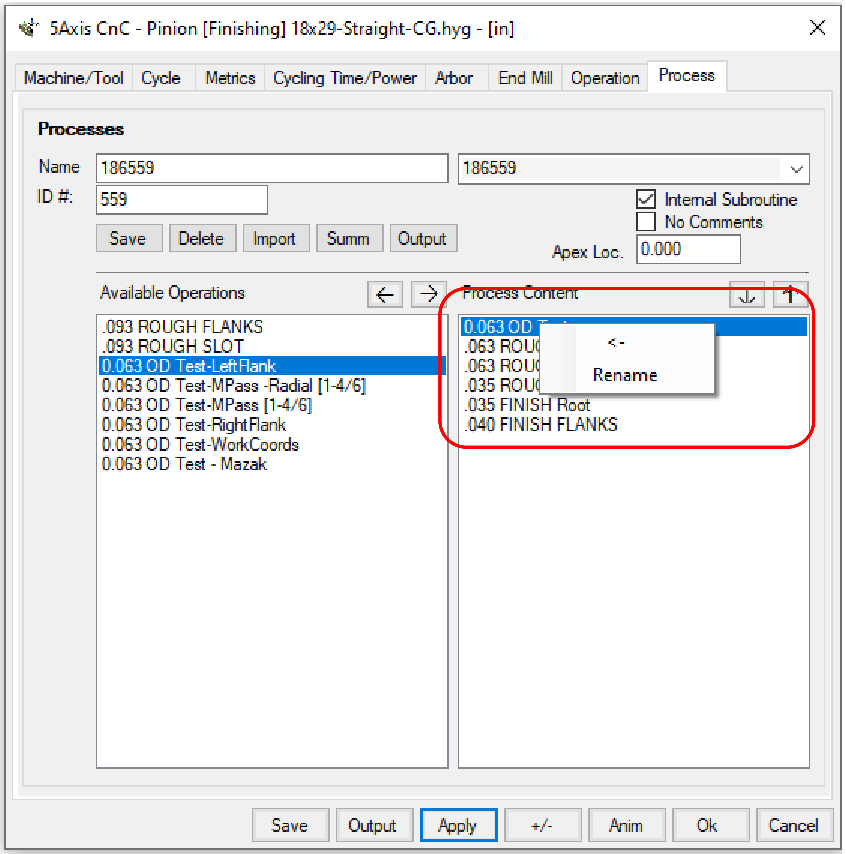
Right Click opens menu

Selected Operations for the current Process



# Universal 5 Axis CnC Post-Processing

***Processes:*** *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-0.8 [mm] …" first, and then Operation "Rough-Fil-Mpass …"*



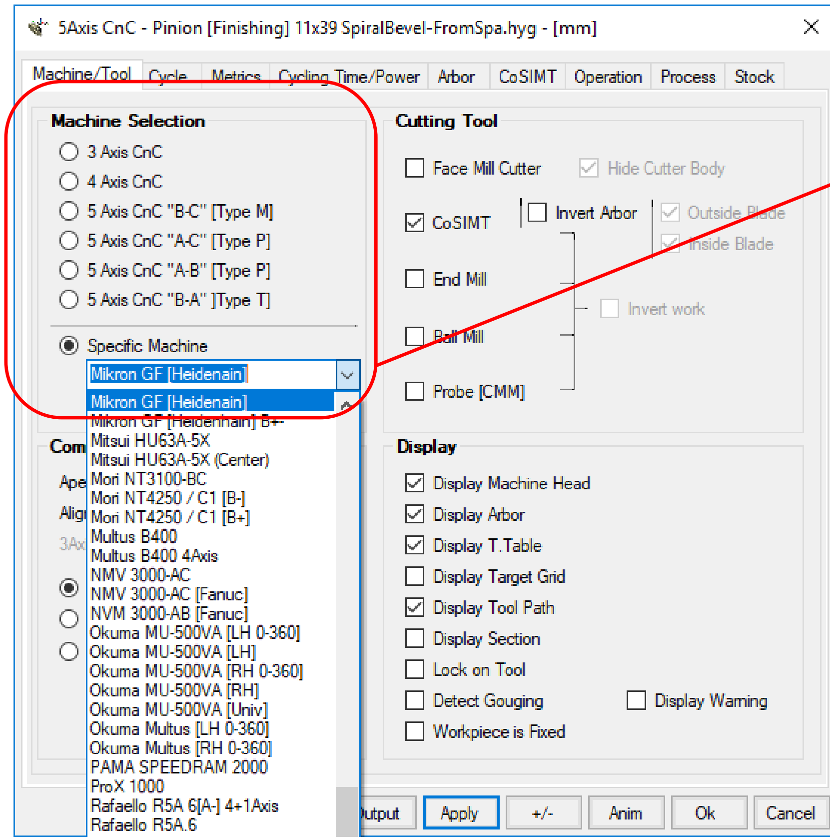

*Processes Tab*

- *A Process is specific to a geometry, i.e. it is saved in the "Processes.fil" file stored in the current 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.*

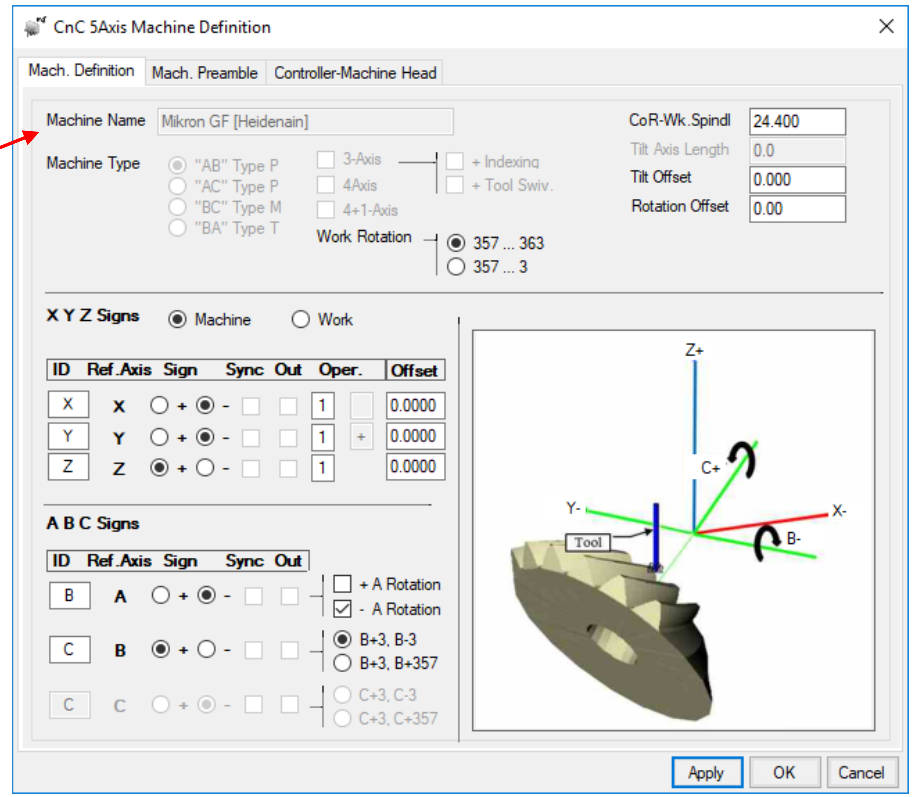
# Universal 5 Axis CnC Post-Processing

***Machines**: 4 basic CnC machine architectures are available: BC, AC, AB and BA (bottom left figure); plus 3 and 4 Axis machines.*

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




Machine Selection

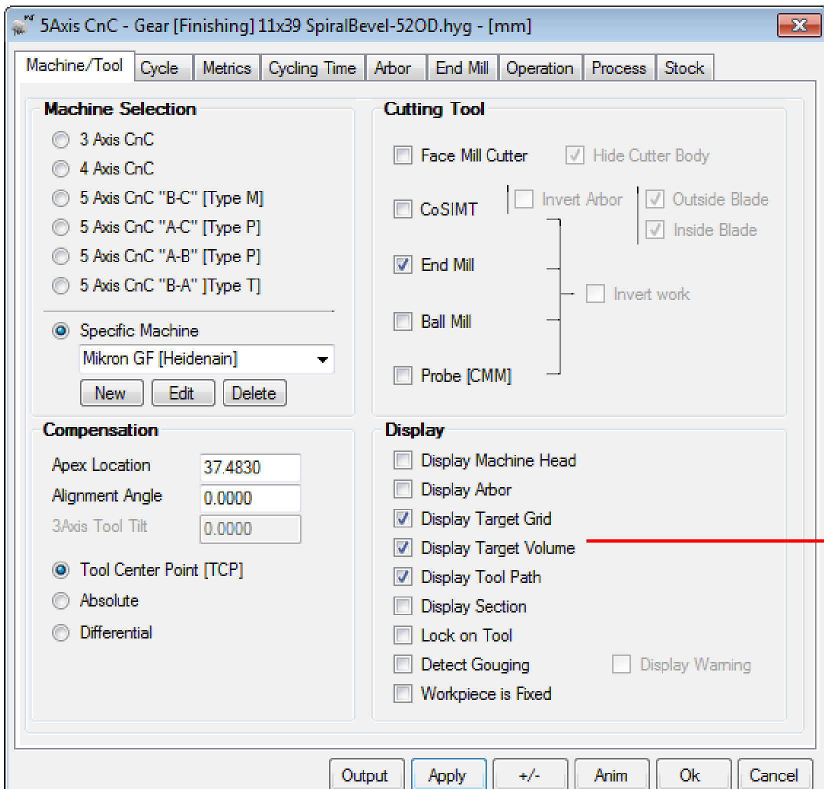


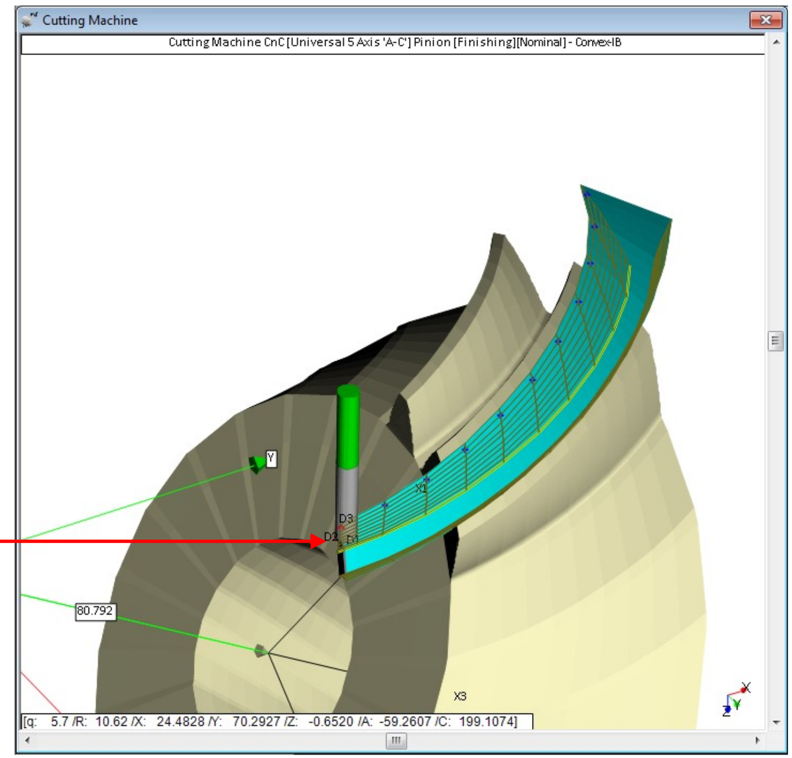

Machine Editor

# Universal 5 Axis CnC Post-Processing

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

- *the Machine Head,*
- *the Work Arbor and support,*
- *the Target Grid, where the target coordinates are displayed in wire frame mesh,*
- *the Target Volume which will be removed by the selected operation,*
- *the Tool Path.*

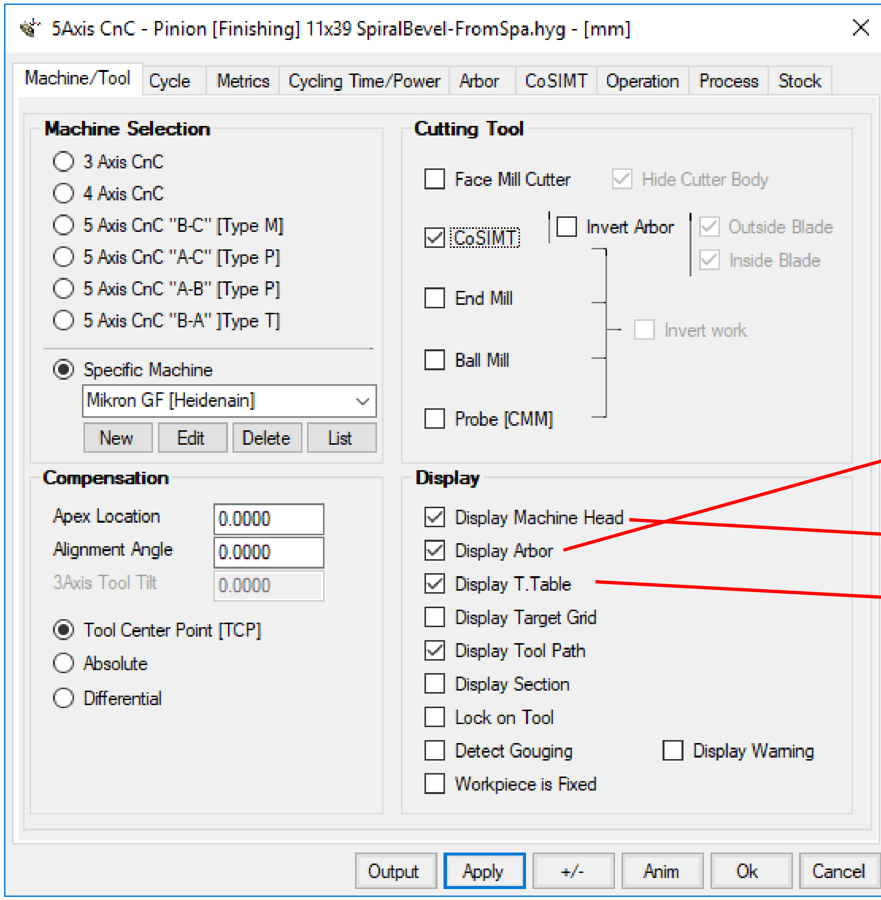


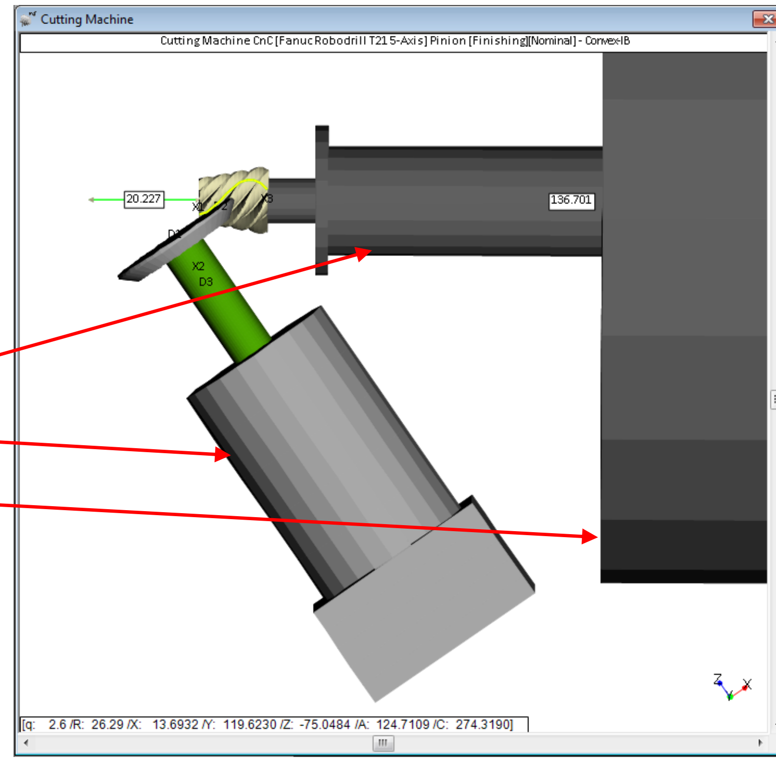




*Display of the Target Grid (beige) and Volume (light blue)*

# Universal 5 Axis CnC Post-Processing

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

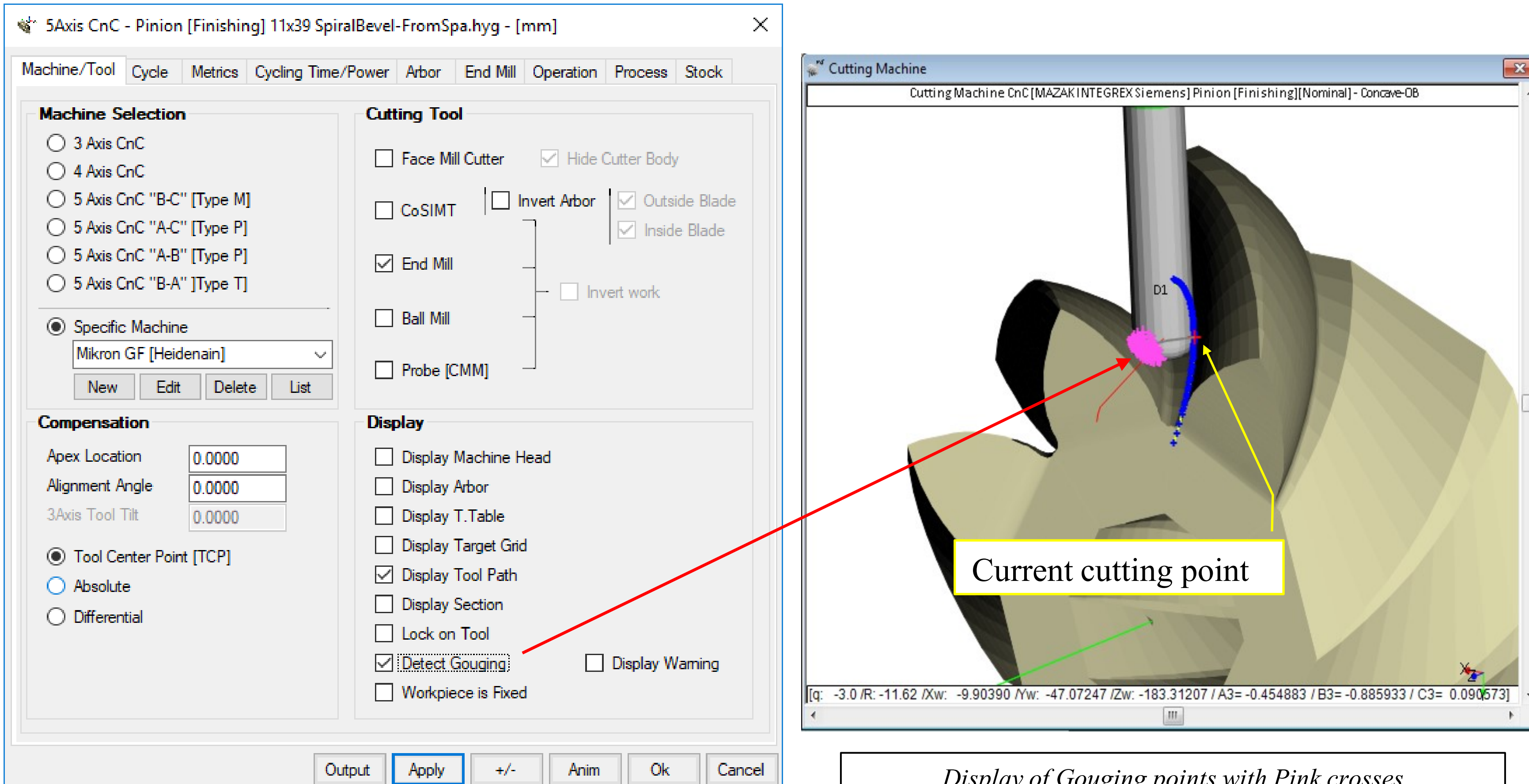



*Display of the Arbor and Tool Holder*

# Universal 5 Axis CnC Post-Processing

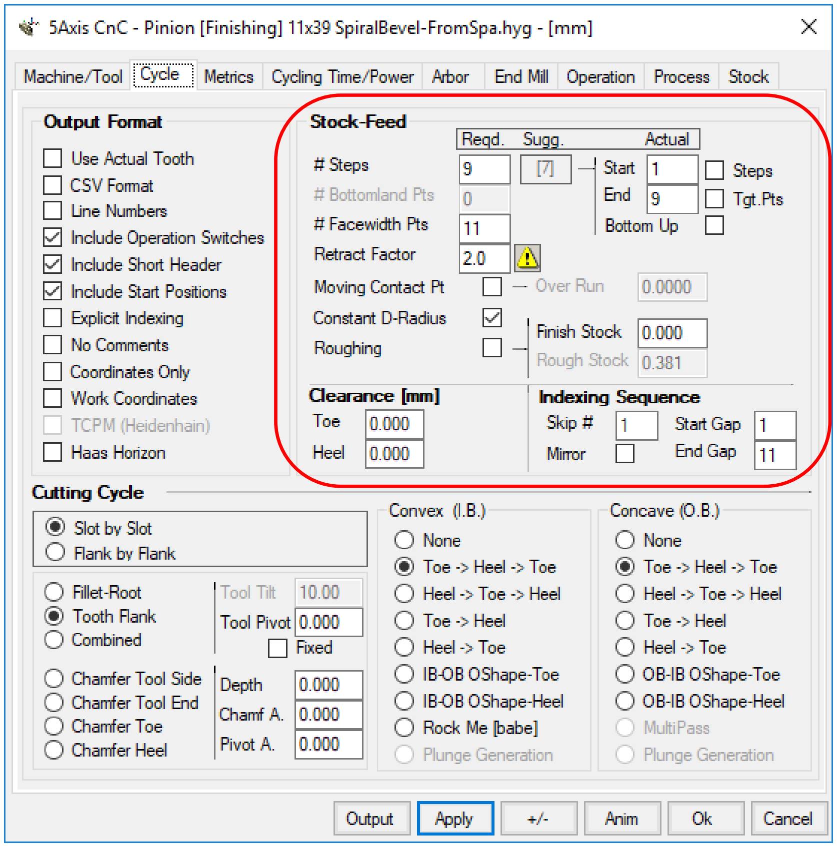
**Display:** *Detection of Gouging interference (tool back side contact with opposite tooth flank): HyGEARS can determine, and display where, if any Gouging occurs such as to alert the user of potential profile mutilation; valid for CoSIMT, End Mill, Ball Mill tools.*




*Display of Gouging points with Pink crosses*

# Universal 5 Axis CnC Post-Processing

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



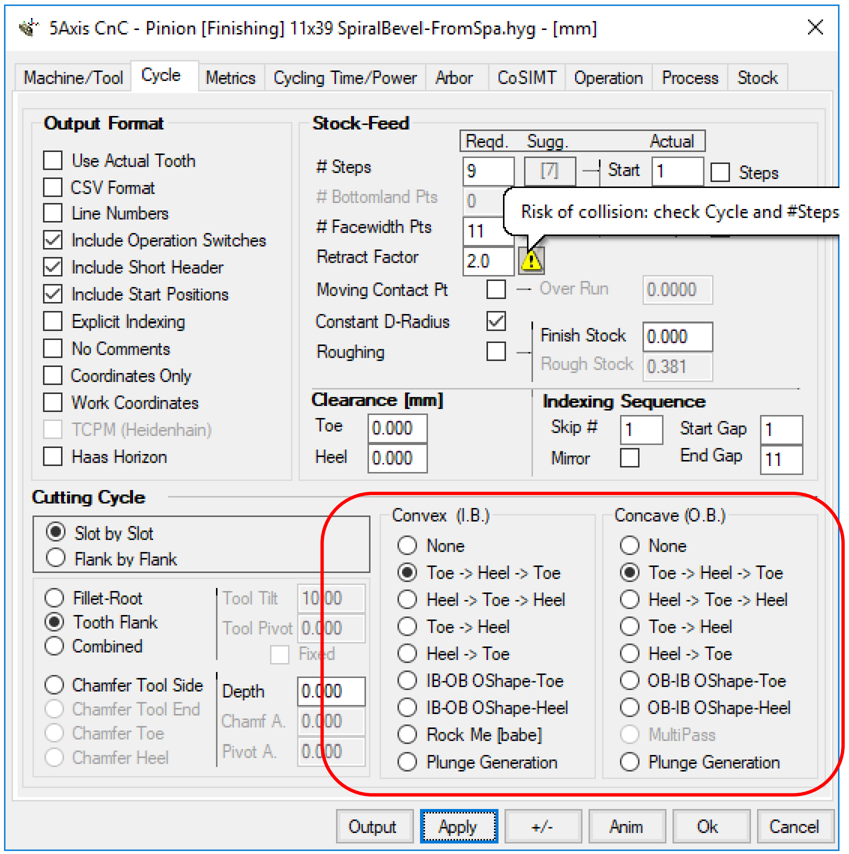

*Cycle Options for CoSIMT, End Mill and Ball Mill tools*

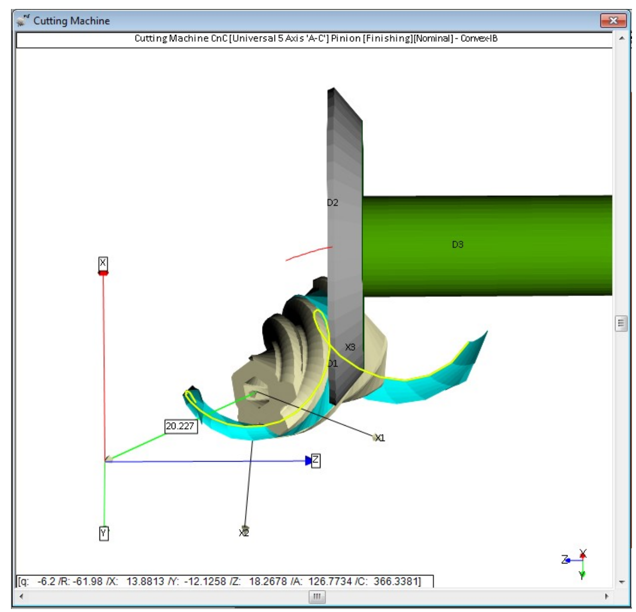
- *Stock feed along the face width (#Facewidth Pts) and tooth depth (#Steps)*
- *Step# where cutting starts and ends (Start / End)*
- *Tool retraction at end of cycle (Retract Factor, based on Heel tooth depth)*
- *Whether the tooth is digitized with constant roll angle or constant radius increments (Constant D-Radius)*
- *Whether the contact point moves along the tool cutting edge (Moving Contact Pt)*
- *Roughing and Finishing cycles*
- *Toe and Heel clearances, to plunge the tool full speed*
- *Tip, Toe and Heel chamfering*
- *Indexing sequence in order to spread tool wear and thermal load over non sequential tooth Gaps (Skip#).*

# Universal 5 Axis CnC Post-Processing

***Cycles:*** *CoSIMT, End Mill, Ball Mill*

- *CoSIMT tools can **rough** tooth flanks and fillet;*
- *CoSIMT, End Mill and Ball Mill tools can **finish** tooth flanks;*
- *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 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.*

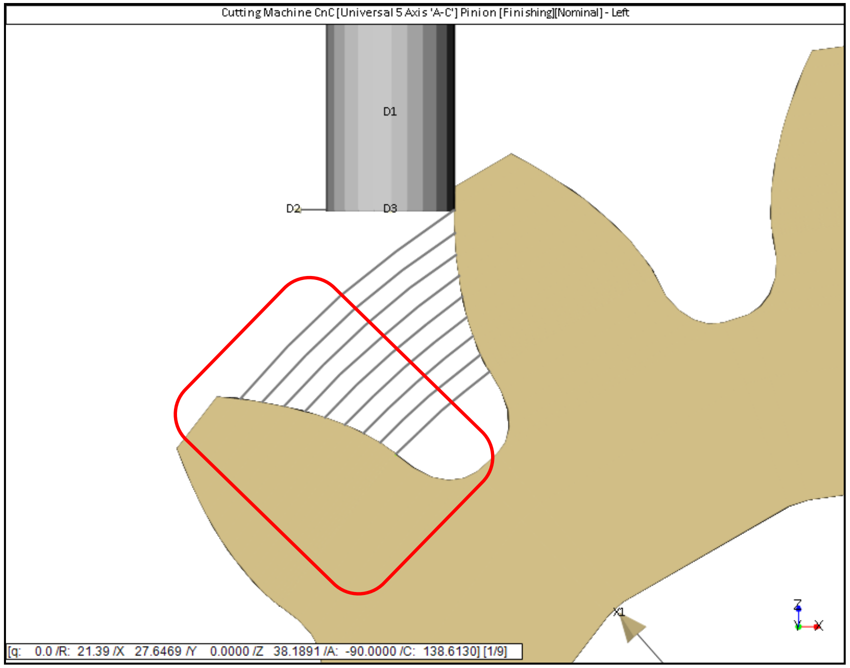


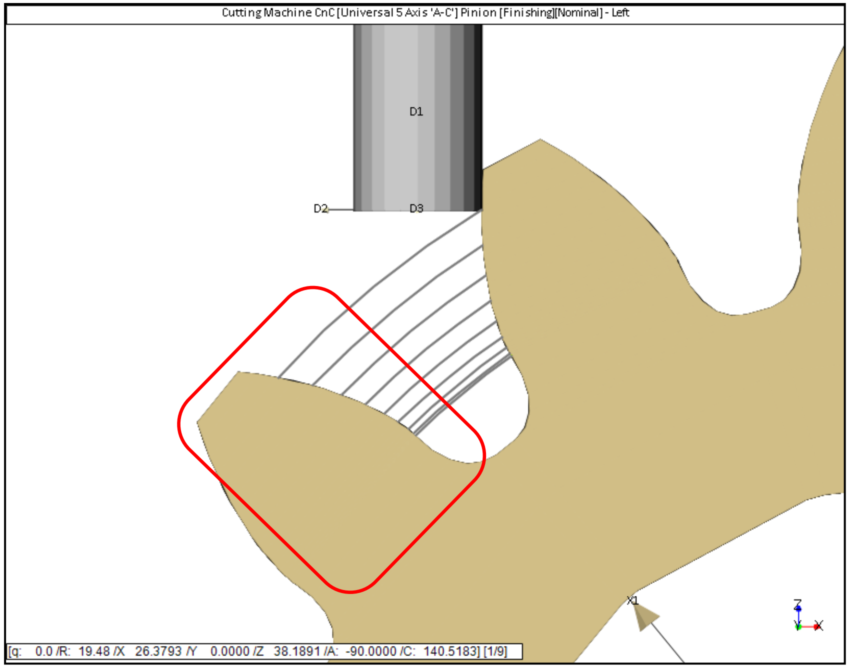




*Cycles for CoSIMT, End Mill and Ball Mill tools*

# Universal 5 Axis CnC Post-Processing

| | | | |
|---|---|---|---|
| ***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* |



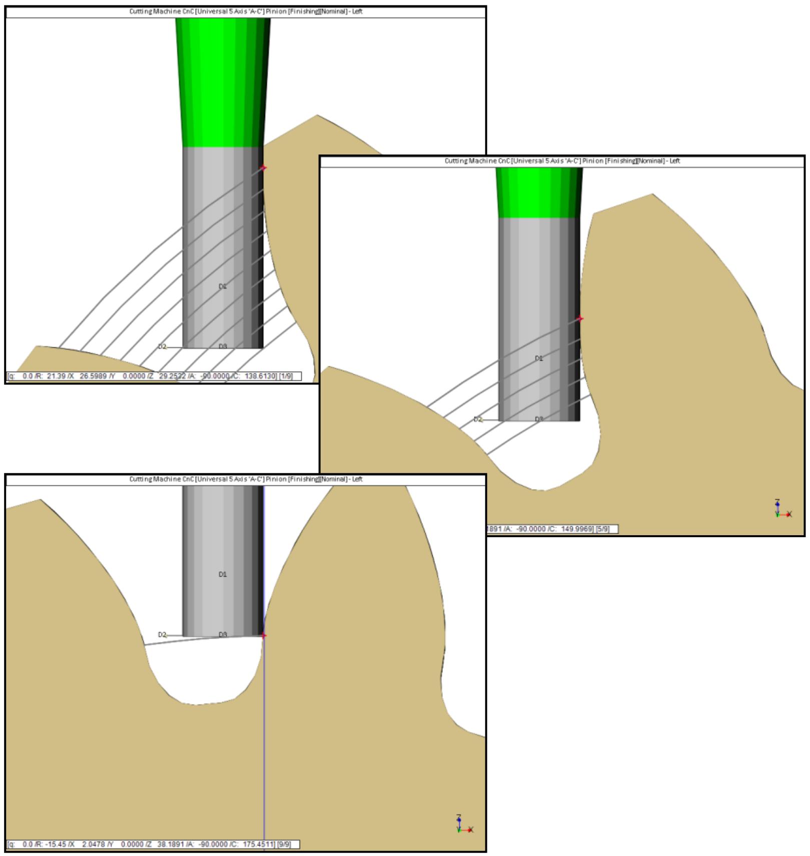




*Constant D-Radius*

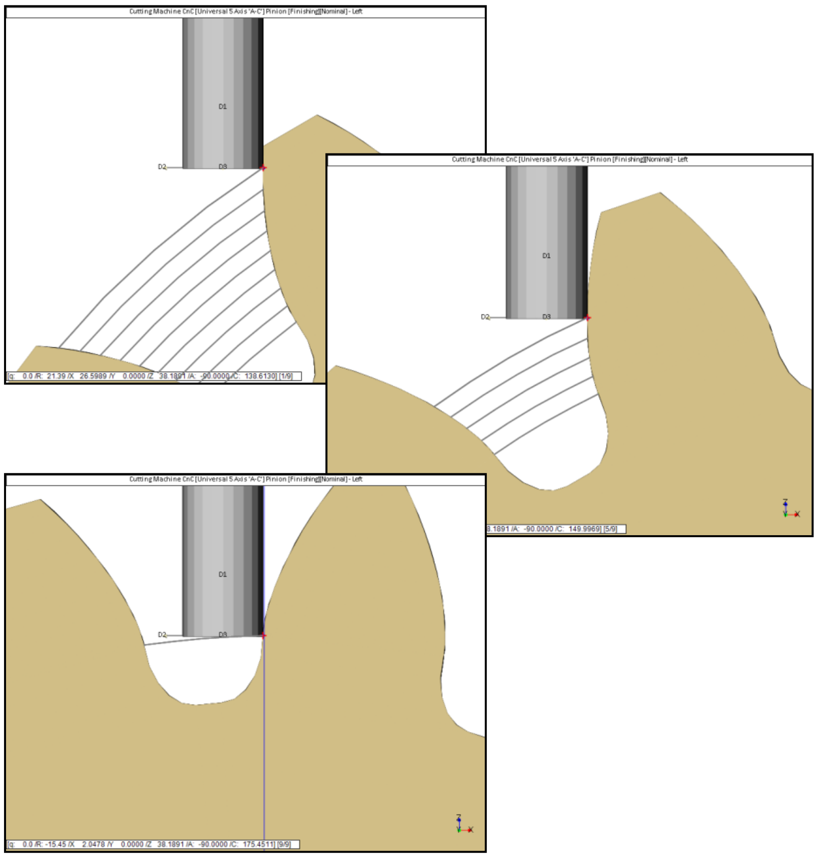
*Constant D-Roll*

# Universal 5 Axis CnC Post-Processing

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



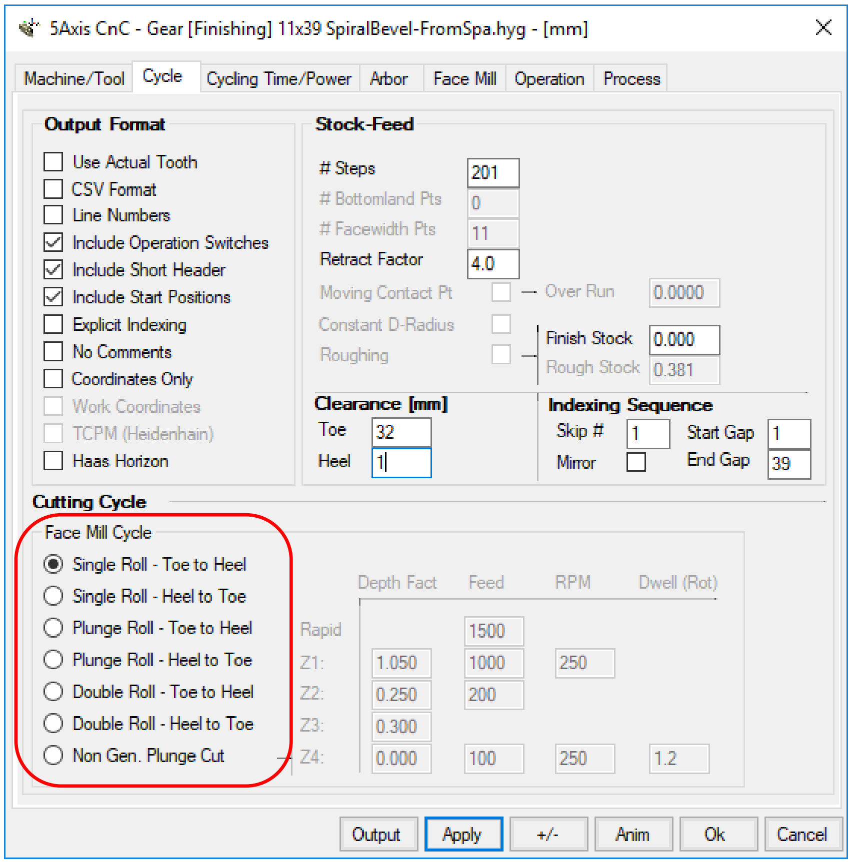
*Moving Contact Pt: Finishing*

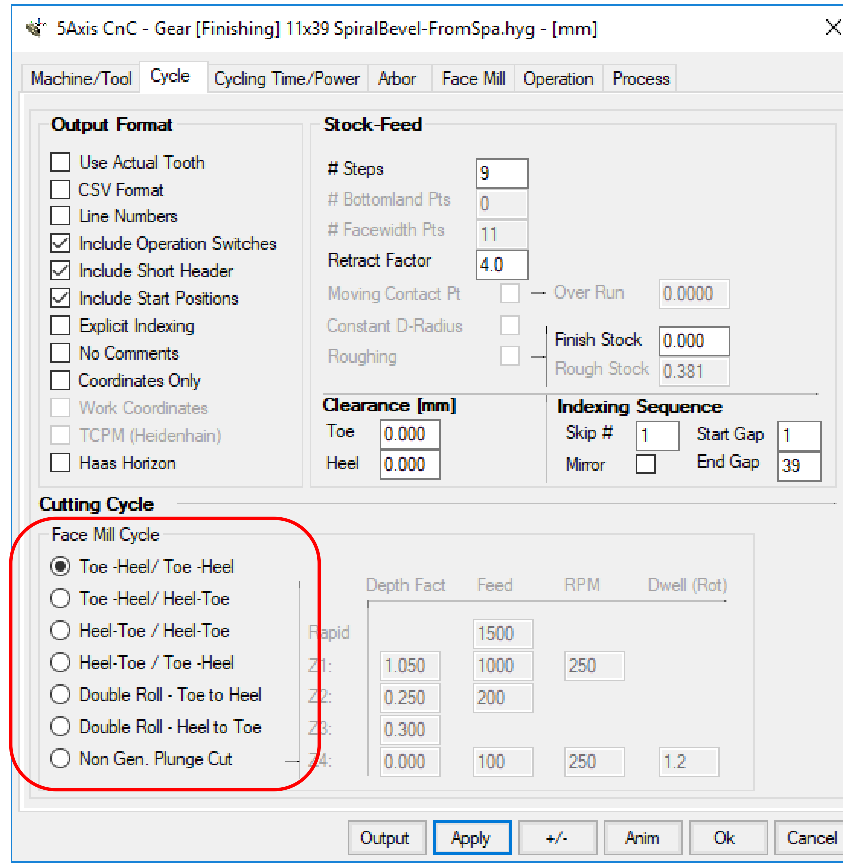


*Fixed Contact Pt: Roughing*

# Universal 5 Axis CnC Post-Processing

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



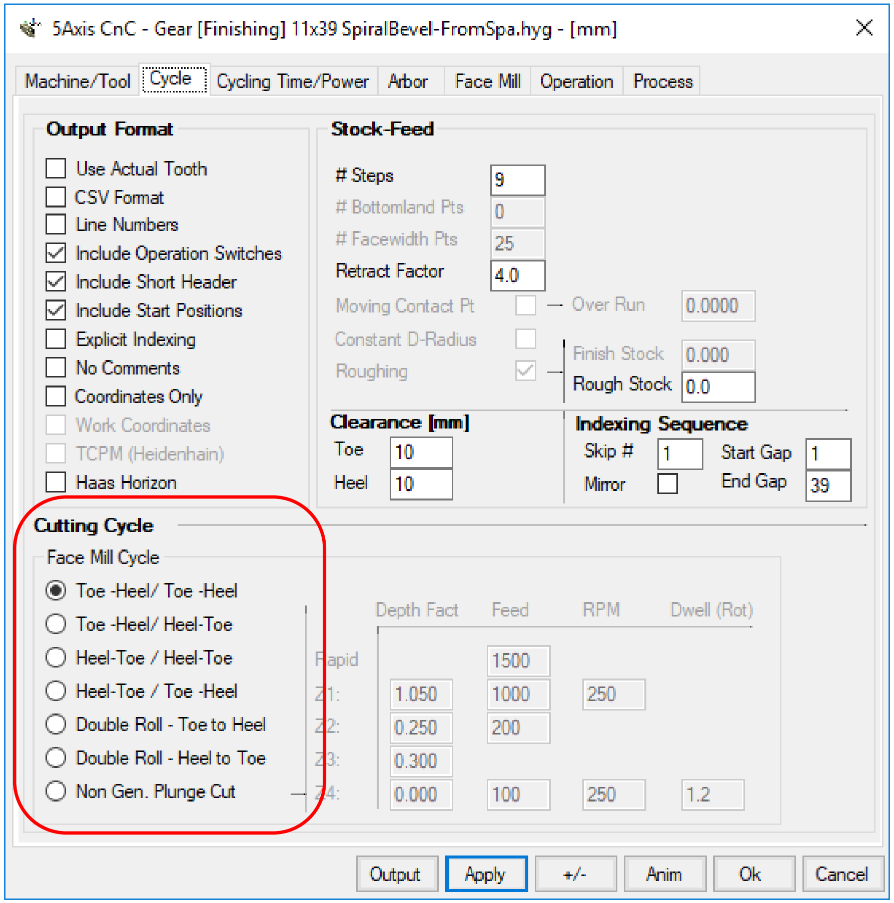




*Cycles for Face Mill cutters / Completing*

*Cycles for Face Mill cutters / Semi-Completing*

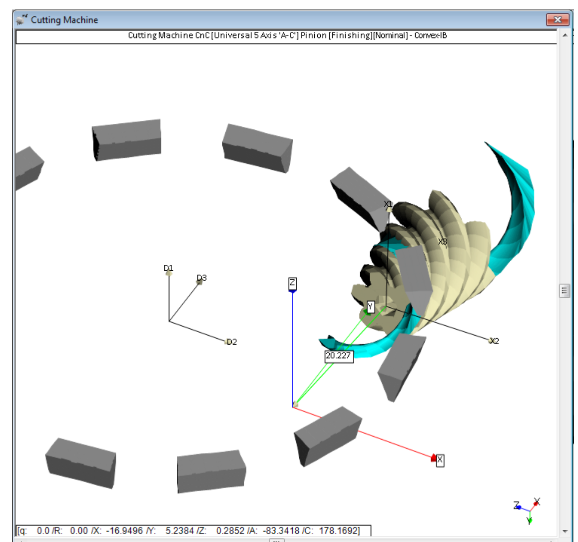
# Universal 5 Axis CnC Post-Processing

***Cycles:*** *Face Mill Cutter – Completing cutting processes*



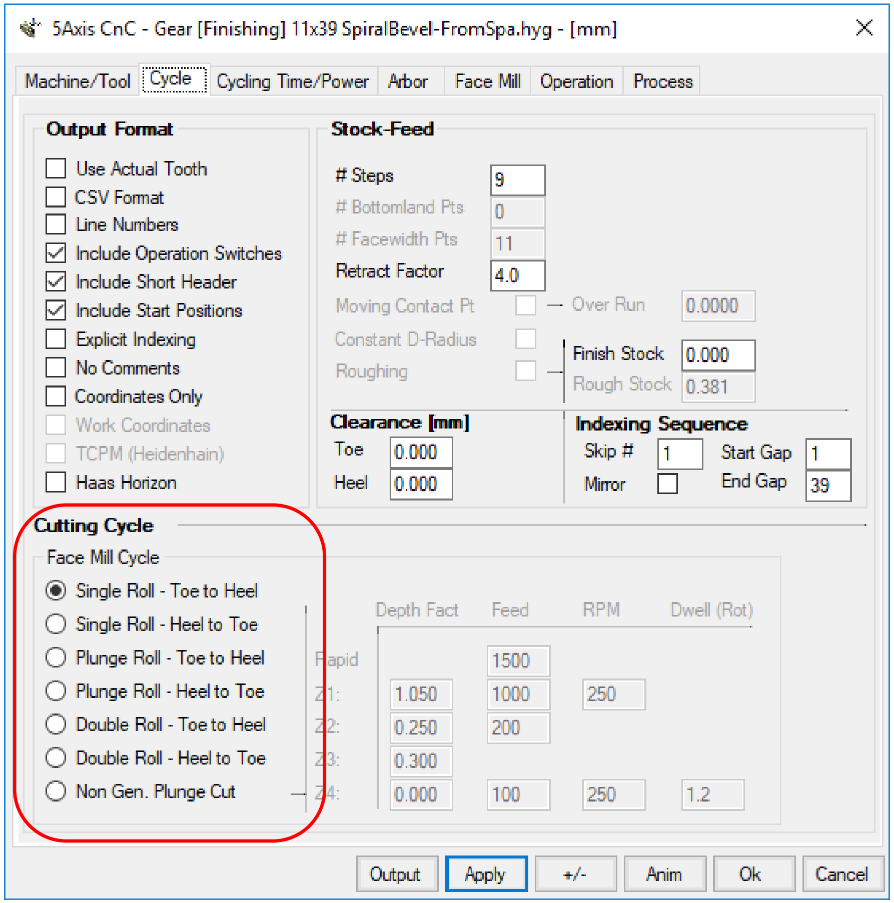

Cycles for Face Mill cutters

- *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.*

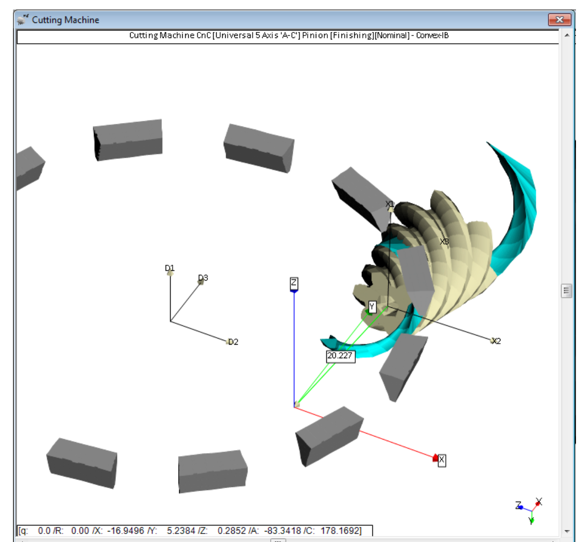


# Universal 5 Axis CnC Post-Processing

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



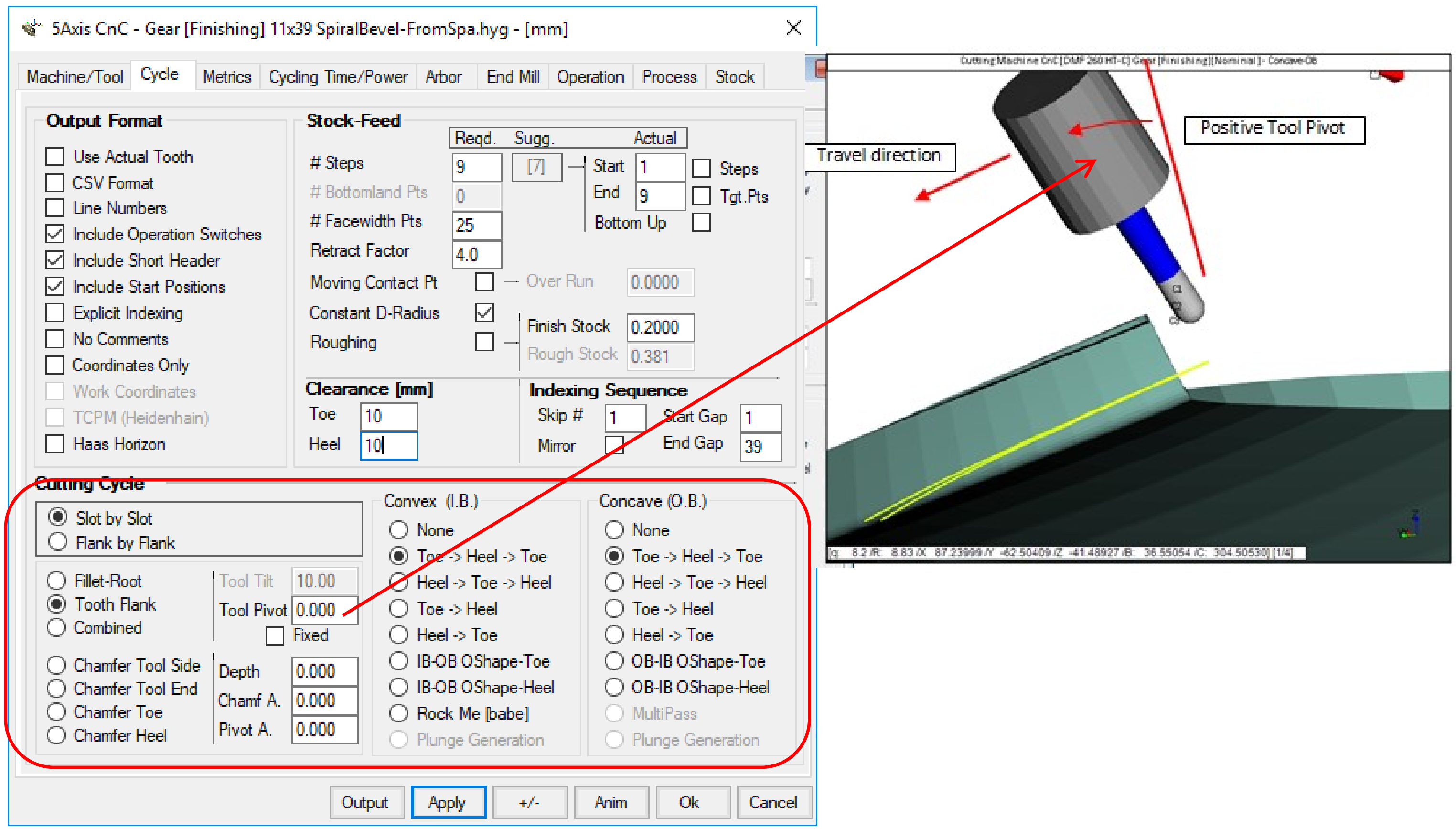

- *xx / yy: 1st part is Convex flank; 2nd part is Concave flank*
- *the use of Toe/Heel clearances allows progressive cutter entry/retract for better tool life (see the Target Volume in light blue below);*
- *Negative Finish stock pushes the cutter In such as to compensate for tool wear;*
- *the Indexing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




*Cycles for Face Mill cutters*

# Universal 5 Axis CnC Post-Processing

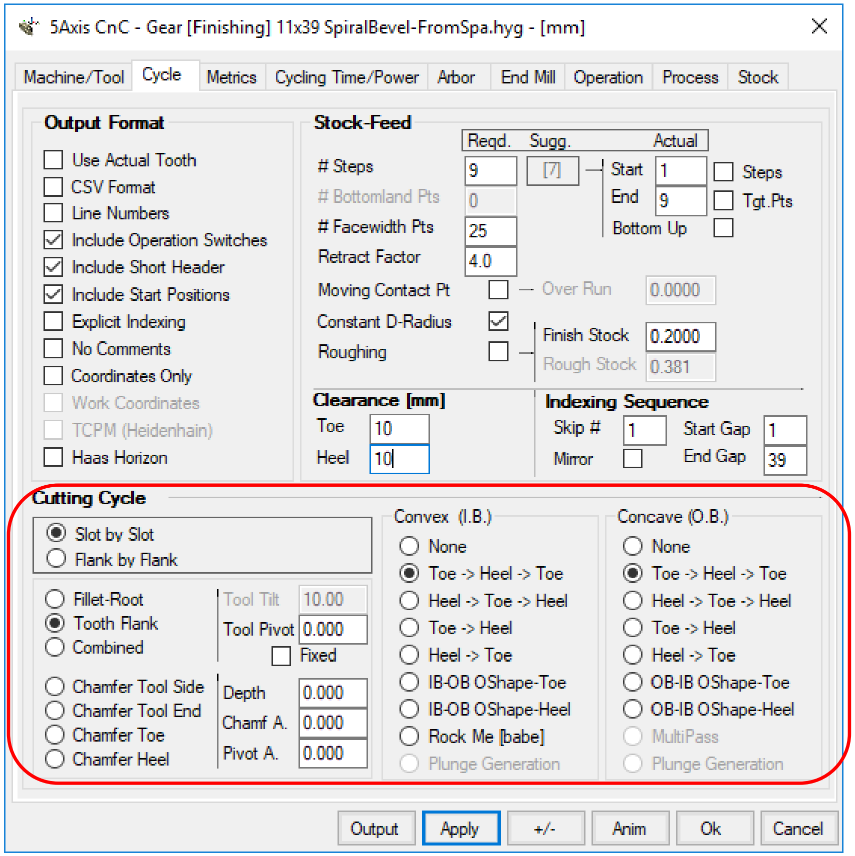
***Cycles:*** *HyGEARS offers 14+ different cutting cycles for CoSIMT, End Mill and Ball Mill tools.*




Cycles for CoSIMT, End Mill and Ball Mill tools

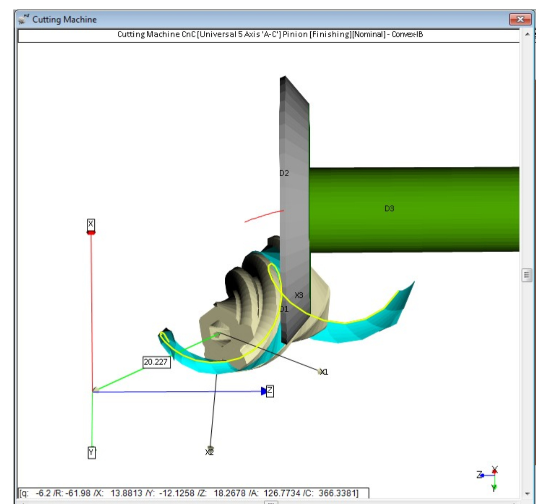
# Universal 5 Axis CnC Post-Processing

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



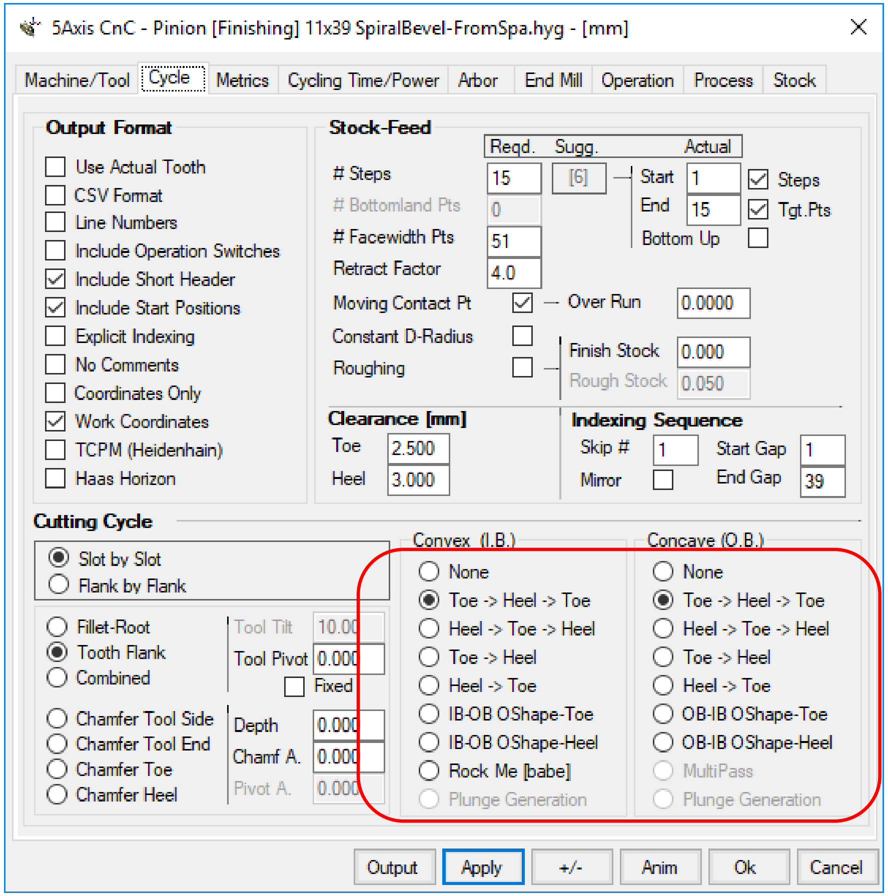

*Finishing Cycles for CoSIMT, End Mill and Ball Mill tools*

- *Fillet/Root, Tooth Flank, Combined, 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 need not be the same on both tooth flanks;*



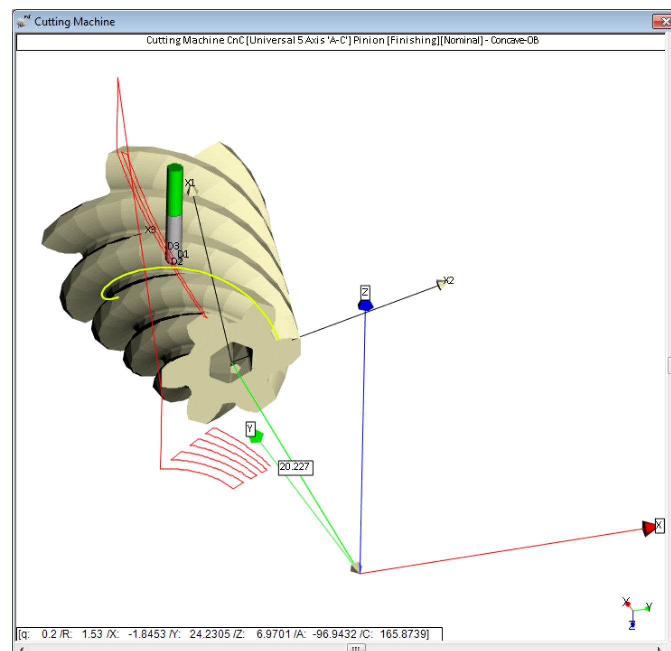
# Universal 5 Axis CnC Post-Processing

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



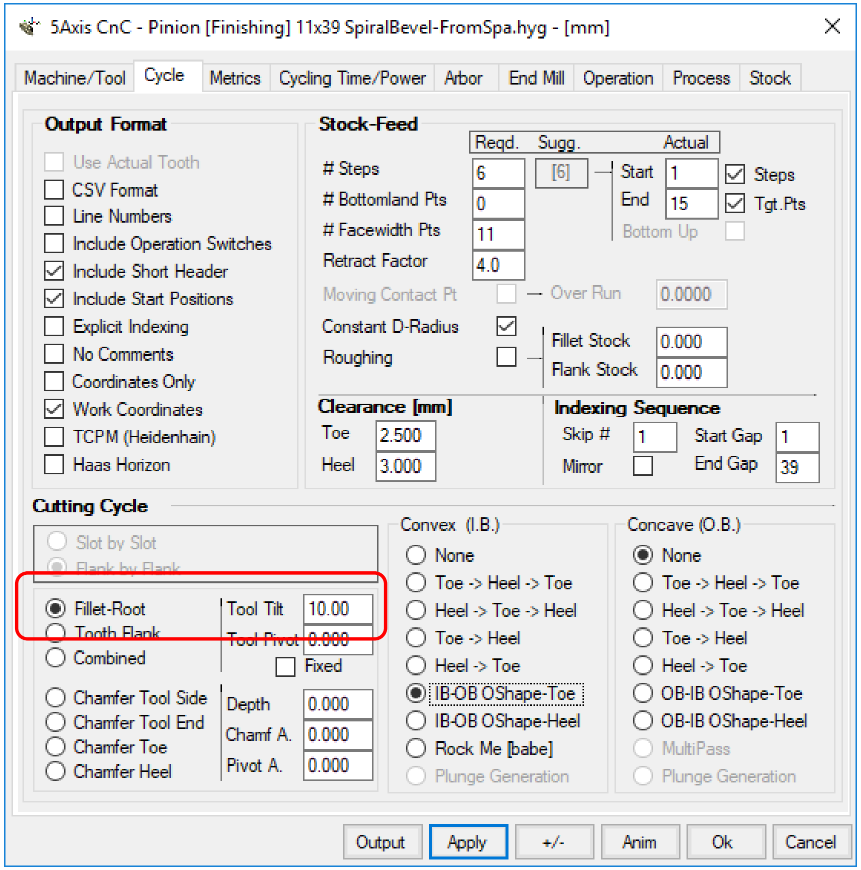

*End Mill cycles*

- *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).*



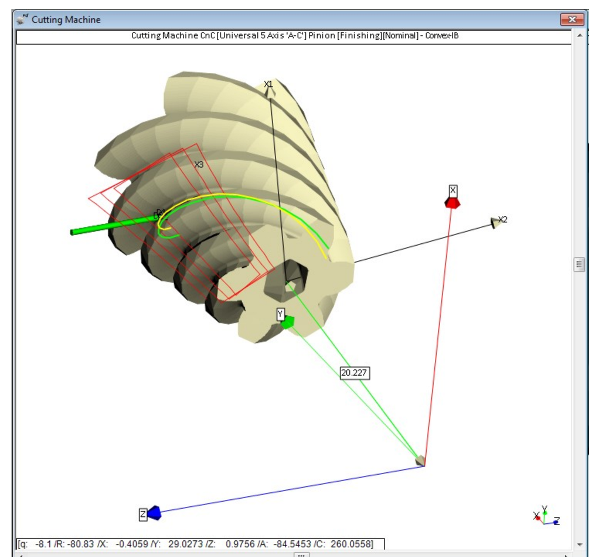
# Universal 5 Axis CnC Post-Processing

***Cycles:*** *Example: End Mill tool, Fillet*



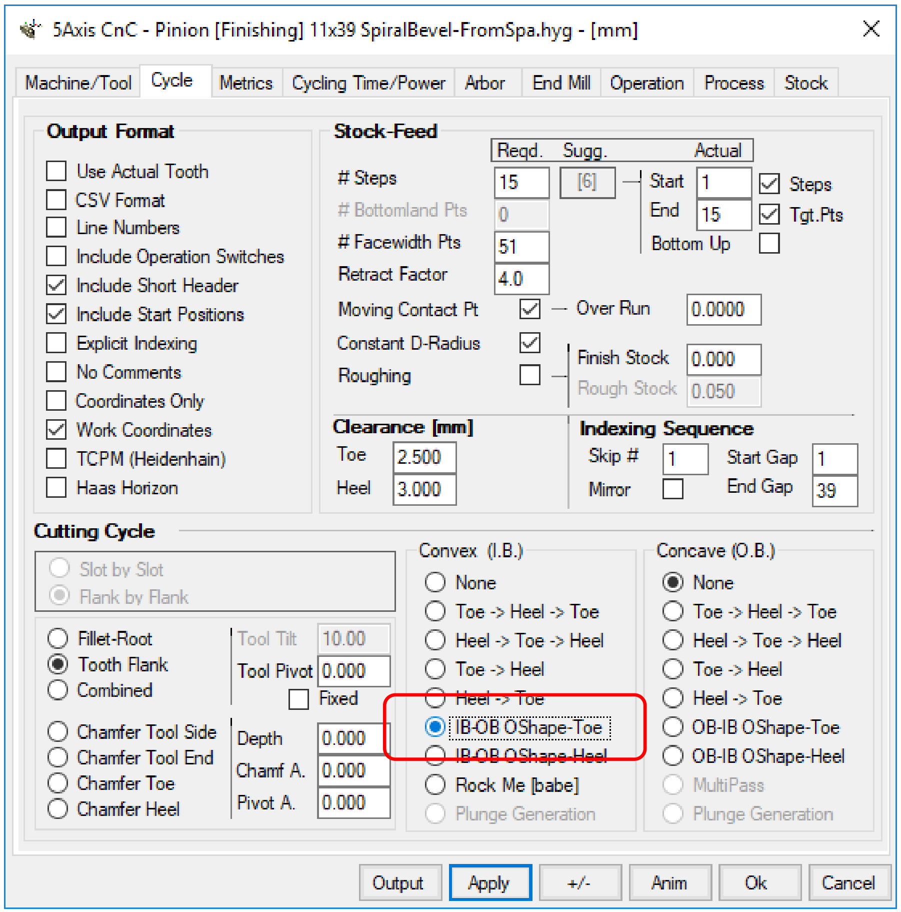

Fillet cycles

- *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 an End Mill or Ball Mill tool;*
- *negative Stock can be imposed to produce a protuberance;*
- *the tool can be tilted away from the tooth to avoid interference;*
- *Fillet finishing uses the same cycles as for Flank finishing.*



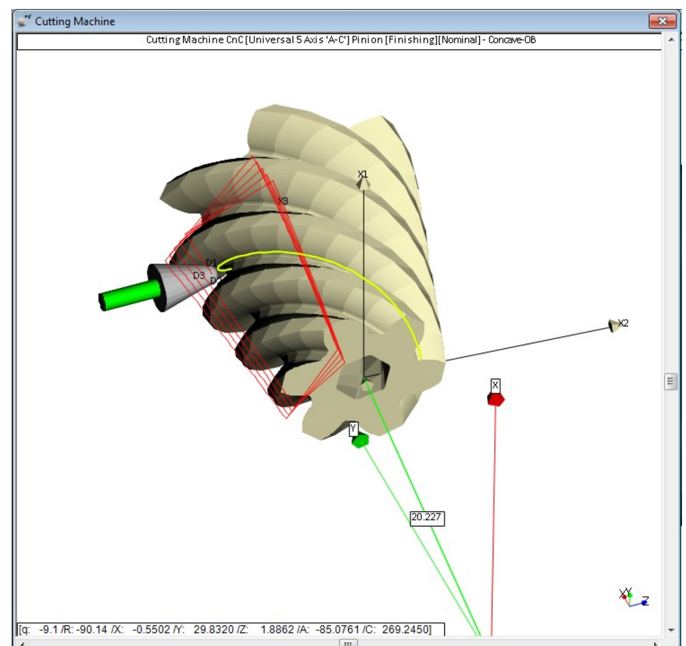
# Universal 5 Axis CnC Post-Processing

***Cycles:*** *Example: tapered End Mill tool, IB-OB O-Shaped / OB-IB O-Shaped*



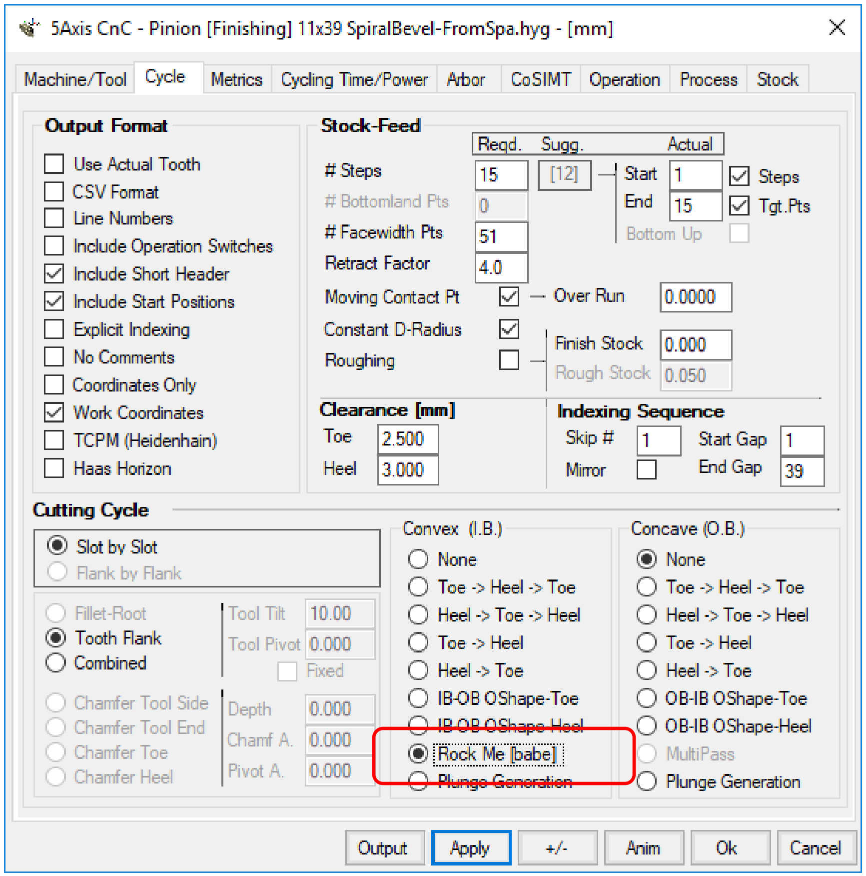

*IB-OB O-Shaped cycle*

- *only one starting flank can be selected, the other being slave;*
- *for IB-OB, the cutting cycle takes a pass along the face width on the IB and switches to the OB for return; the cycle then switches back to the IB 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.*

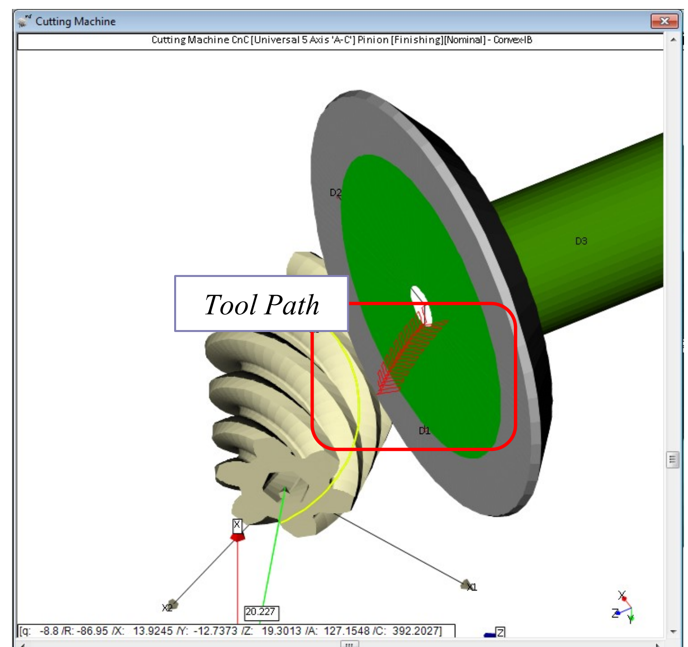


# Universal 5 Axis CnC Post-Processing

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



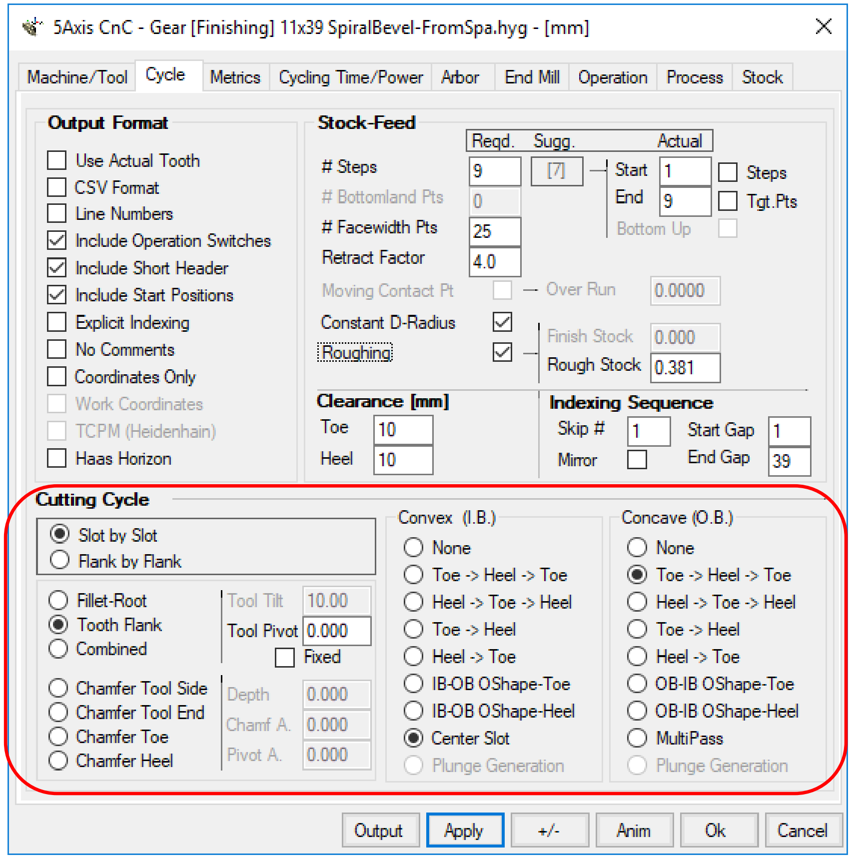

- *the cycle starts at IB Toe-Tip, generates depth wise to the Fillet, switches to the OB and generates from Fillet to Tip, advances along the OB face width, generates depth wise along the OB side to the Fillet, switches to the IB and generates till Tip, advances along the IB face width, and starts over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




*Rock Me (babe) cycle*

# Universal 5 Axis CnC Post-Processing

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

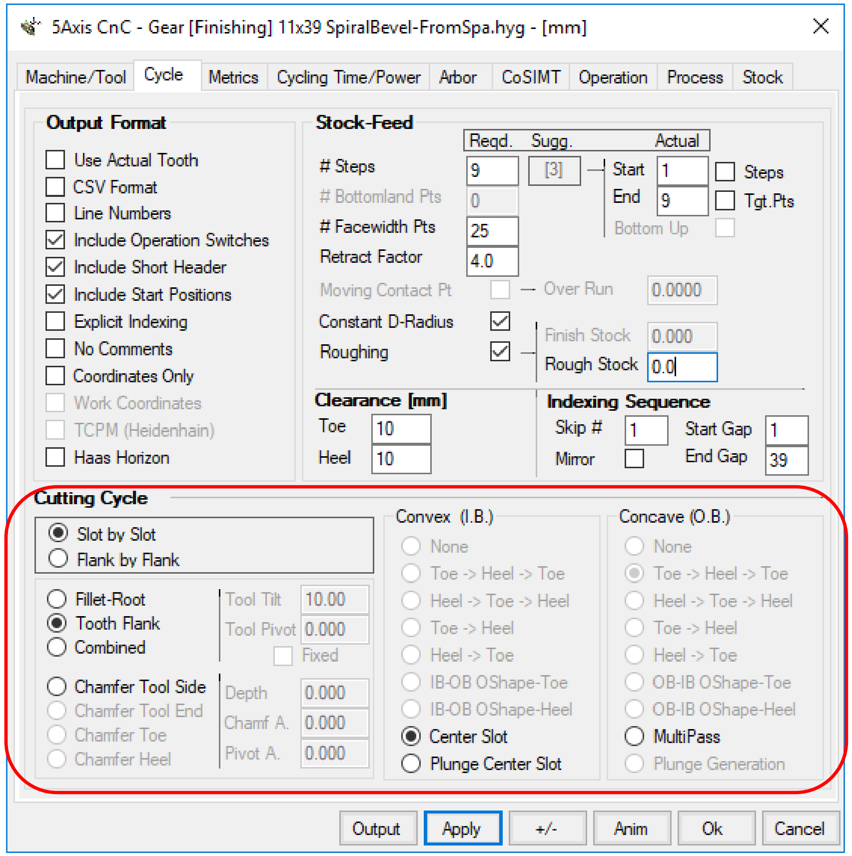



*Roughing Cycles for End Mill and Ball Mill tools*

- *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;*
- *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.*

# Universal 5 Axis CnC Post-Processing

***Cycles:*** *Roughing cycles for CoSIMT tools.*

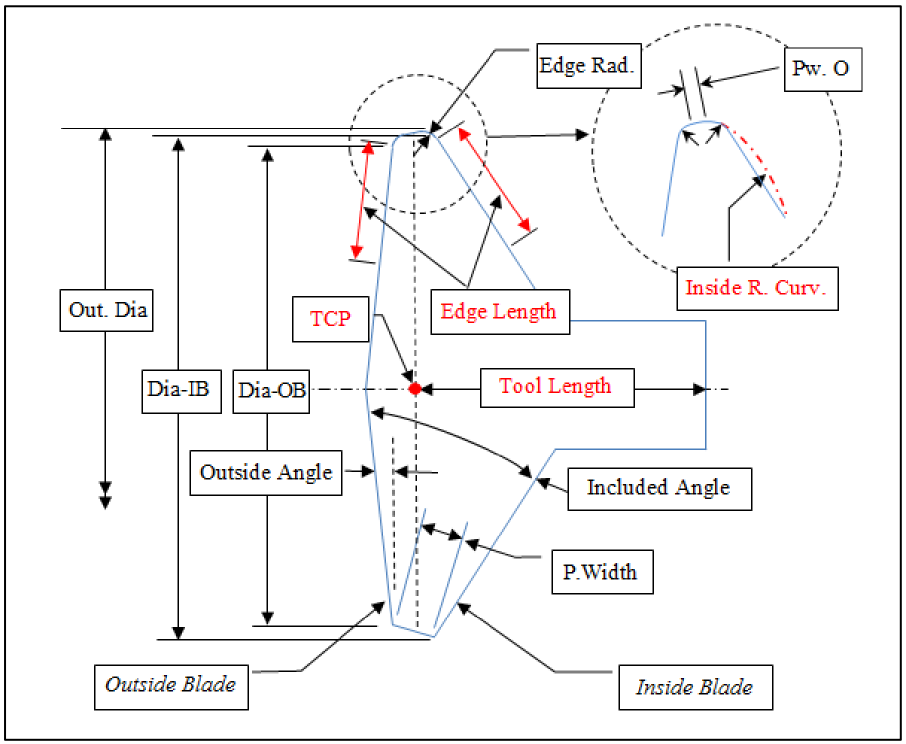


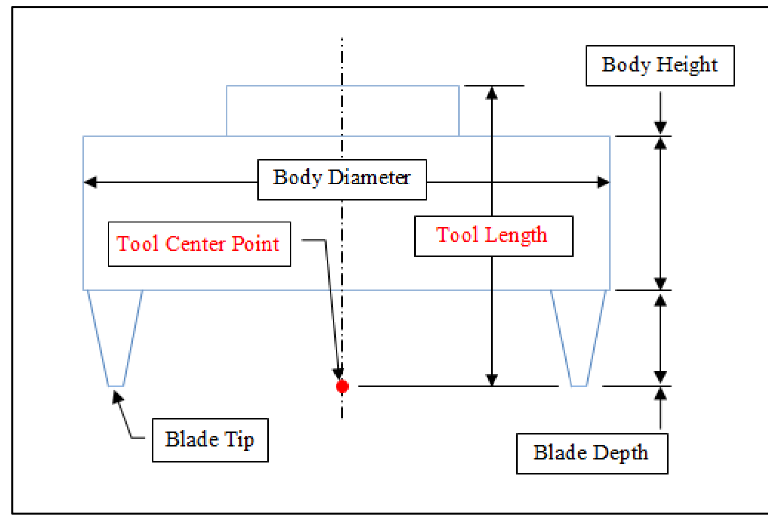

*Roughing Cycles for CoSIMT tools*

- *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;*
- *Roughing cycles need not be the same on both tooth flanks;*
- *Center Slot cuts a through in the center of the gap;*
- *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;*
- *For Fillet roughing, only Center Slot is available;*

# Universal 5 Axis CnC Post-Processing

| | |
|---|---|
| ***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.* |



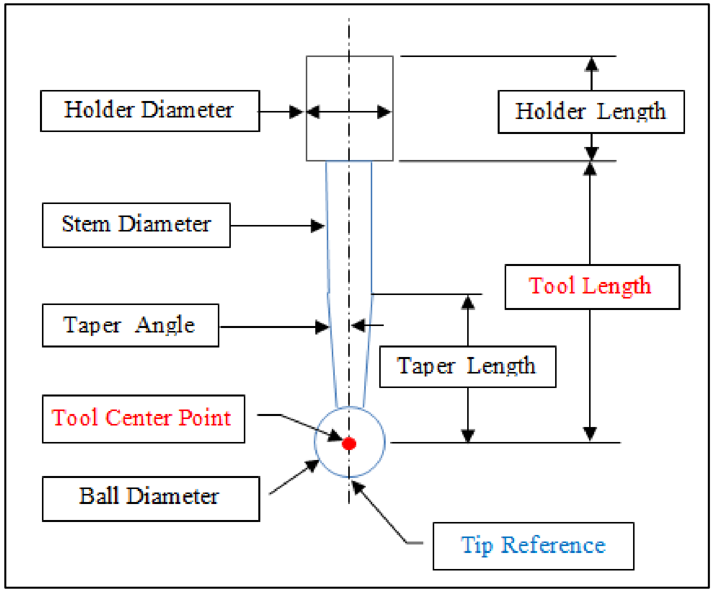




*CoSIMT : TCP (located @ mid P.Width)*

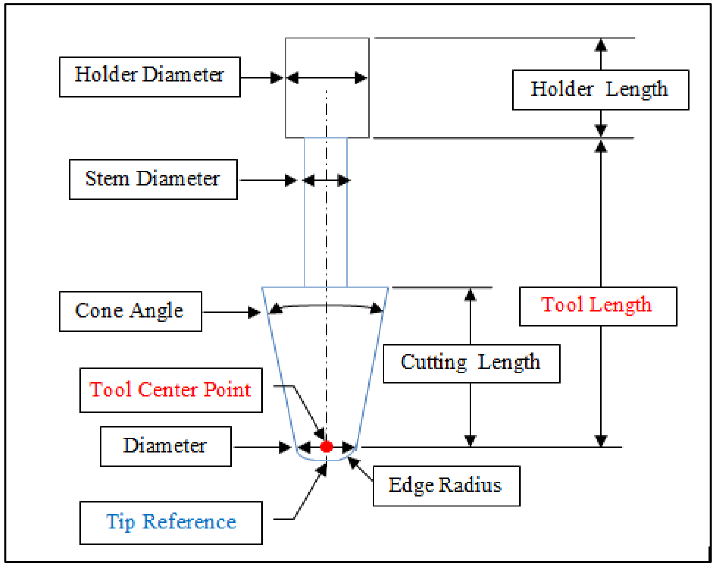
*Face Mill Cutter: TCP (in the plane of blade tips)*

# Universal 5 Axis CnC Post-Processing

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



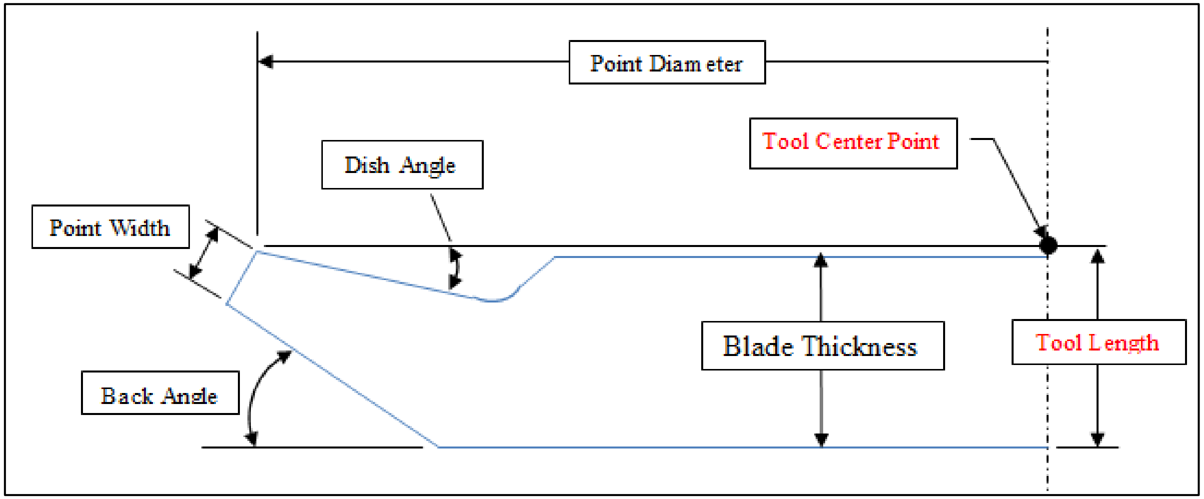

*Ball Mill : TCP and Tip*




*End Mill: TCP and Tip*

# Universal 5 Axis CnC Post-Processing

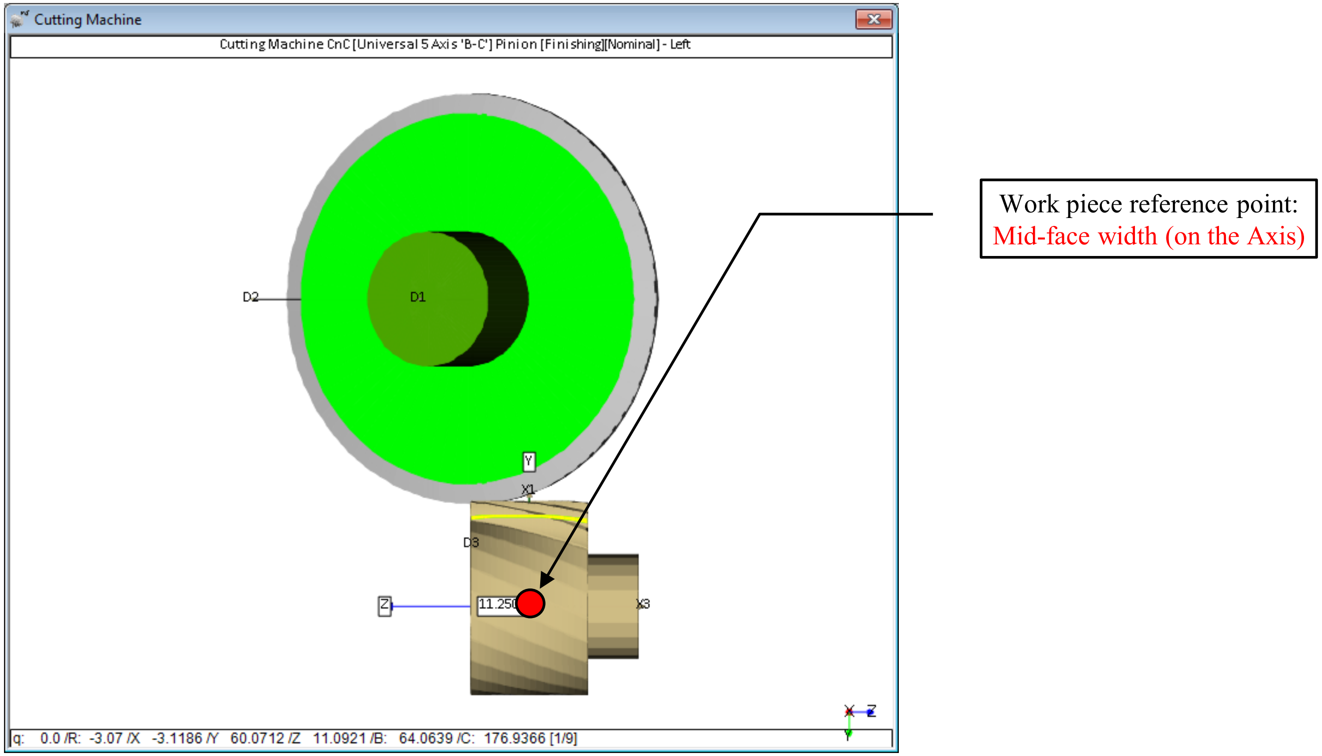
***Tool Reference Point:*** *Coniflex™ dish type cutter: TCP.*




*Coniflex Dish Reference Point*

# Universal 5 Axis CnC Post-Processing

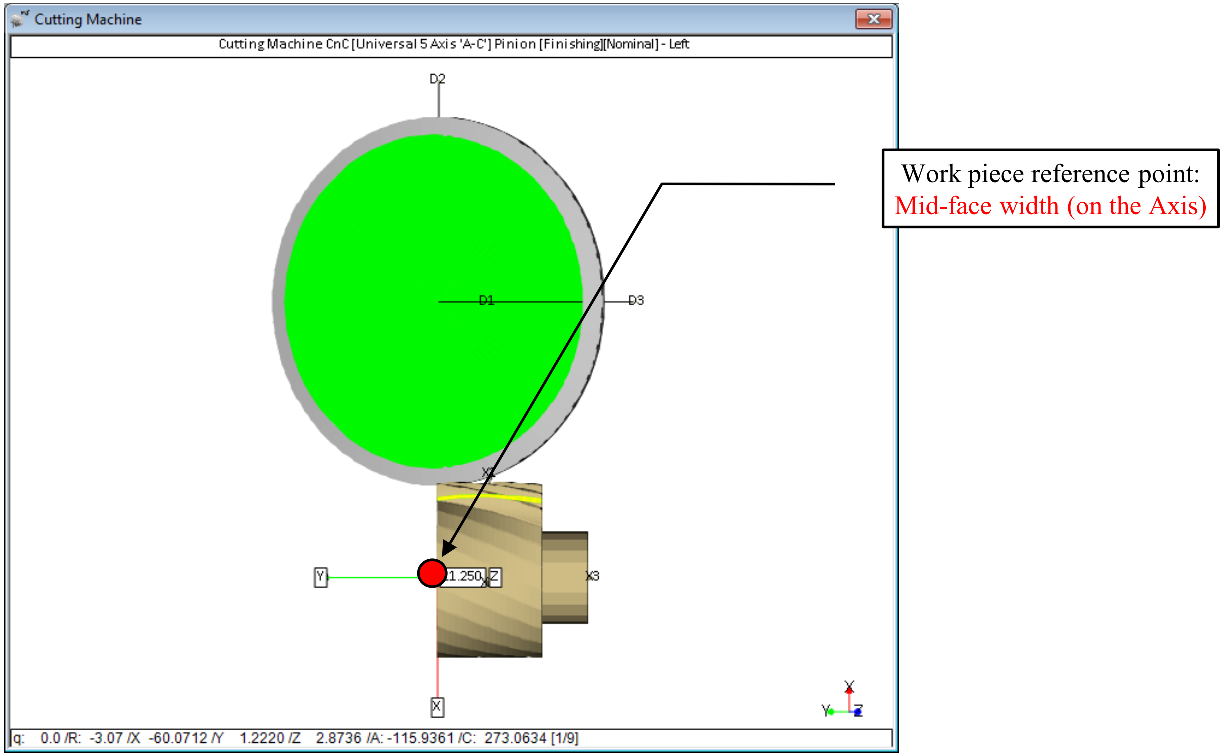
| | |
|---|---|
| ***Part Reference Point:*** | *The reference point on the work piece changes with geometry type; it is tool independent.* |




*Spur/Helical/Beveloid/Herringbone gears: BC type machines*

# Universal 5 Axis CnC Post-Processing

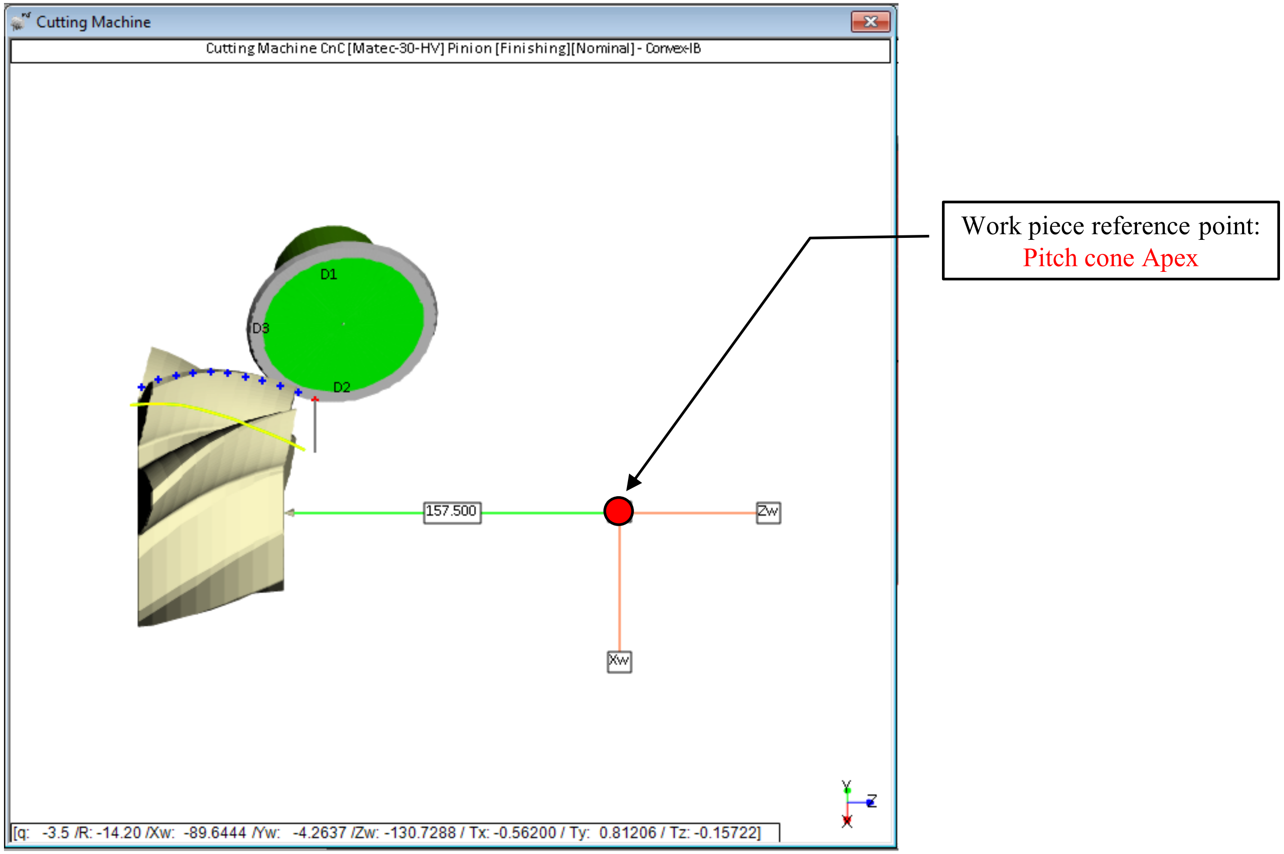
***Part Reference Point:*** *The reference point on the work piece changes with geometry type; it is tool independent.*




*Spur/Helical/Beveloid/Herringbone gears: AC-AB type machines*

# Universal 5 Axis CnC Post-Processing

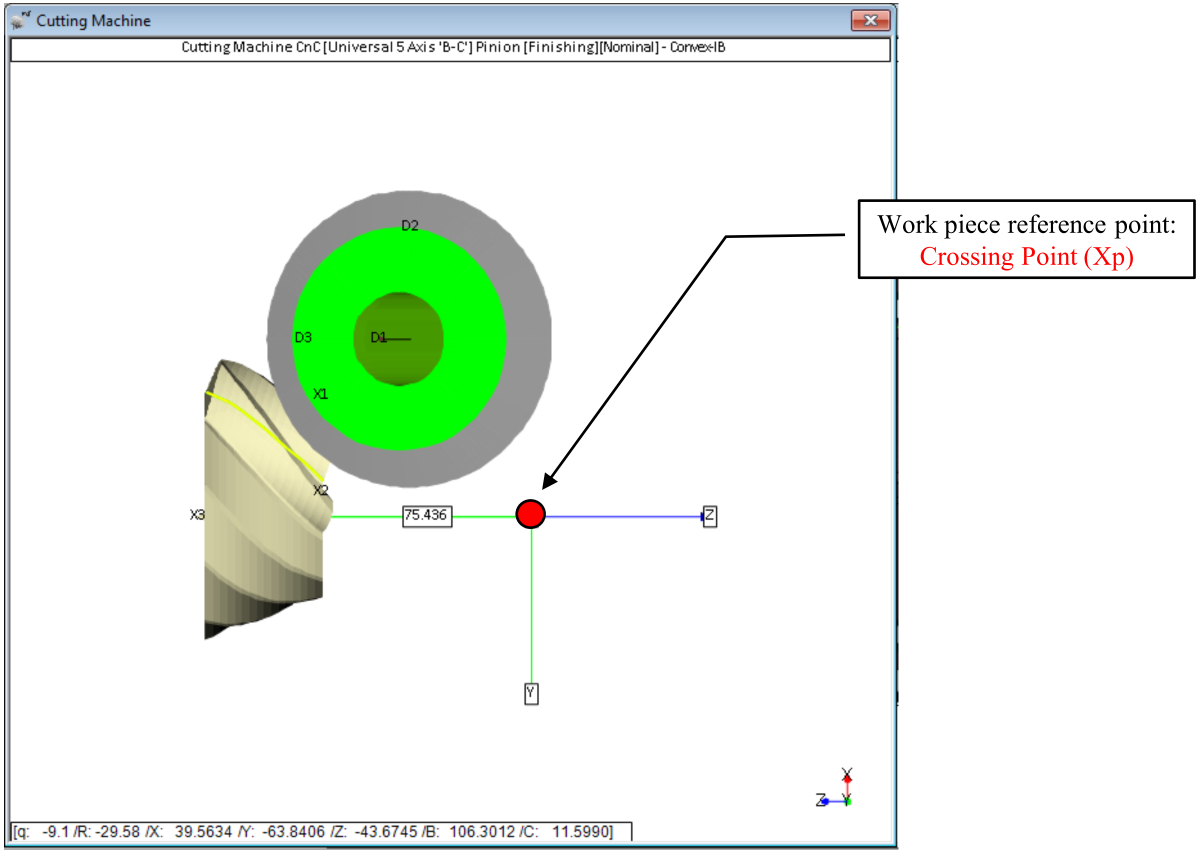
***Part Reference Point:*** *Straight Bevel / Spiral Bevel / Zerol / Coniflex gears.*




*Straight Bevel/Spiral Bevel/Zerol/Coniflex gears*

# Universal 5 Axis CnC Post-Processing

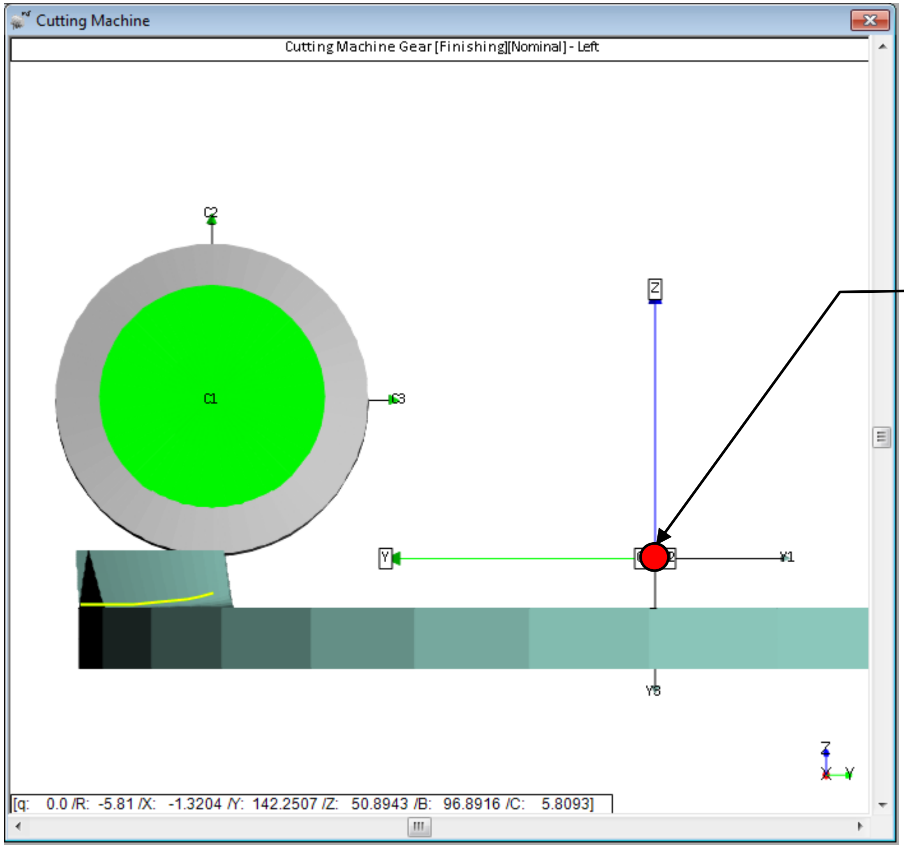
***Part Reference Point:*** *Hypoid gears.*




*Hypoid gears*

# Universal 5 Axis CnC Post-Processing

***Part Reference Point:*** *Face gears.*

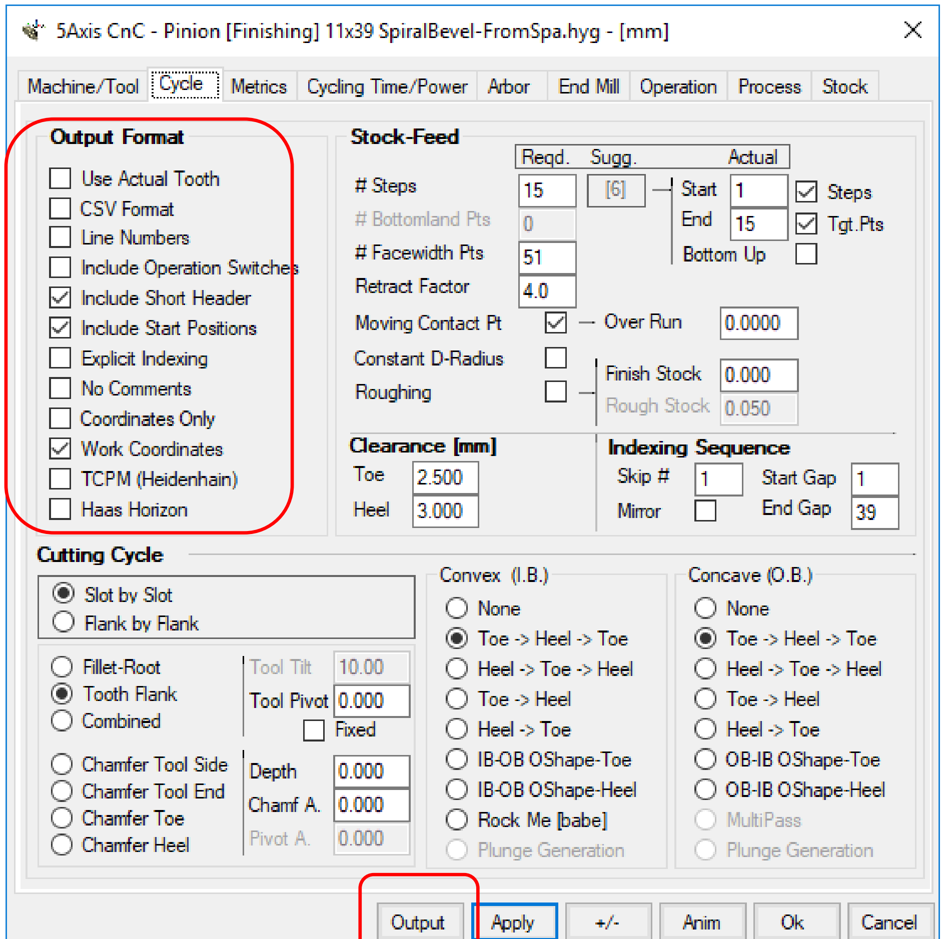



Work piece reference point:
Pitch Plane (on the Axis)

*Face gears*

# Universal 5 Axis CnC Post-Processing

***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.*

# Universal 5 Axis CnC Post-Processing

***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*

# Universal 5 Axis CnC Post-Processing

***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*

# Universal 5 Axis CnC Post-Processing

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

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

File Edit

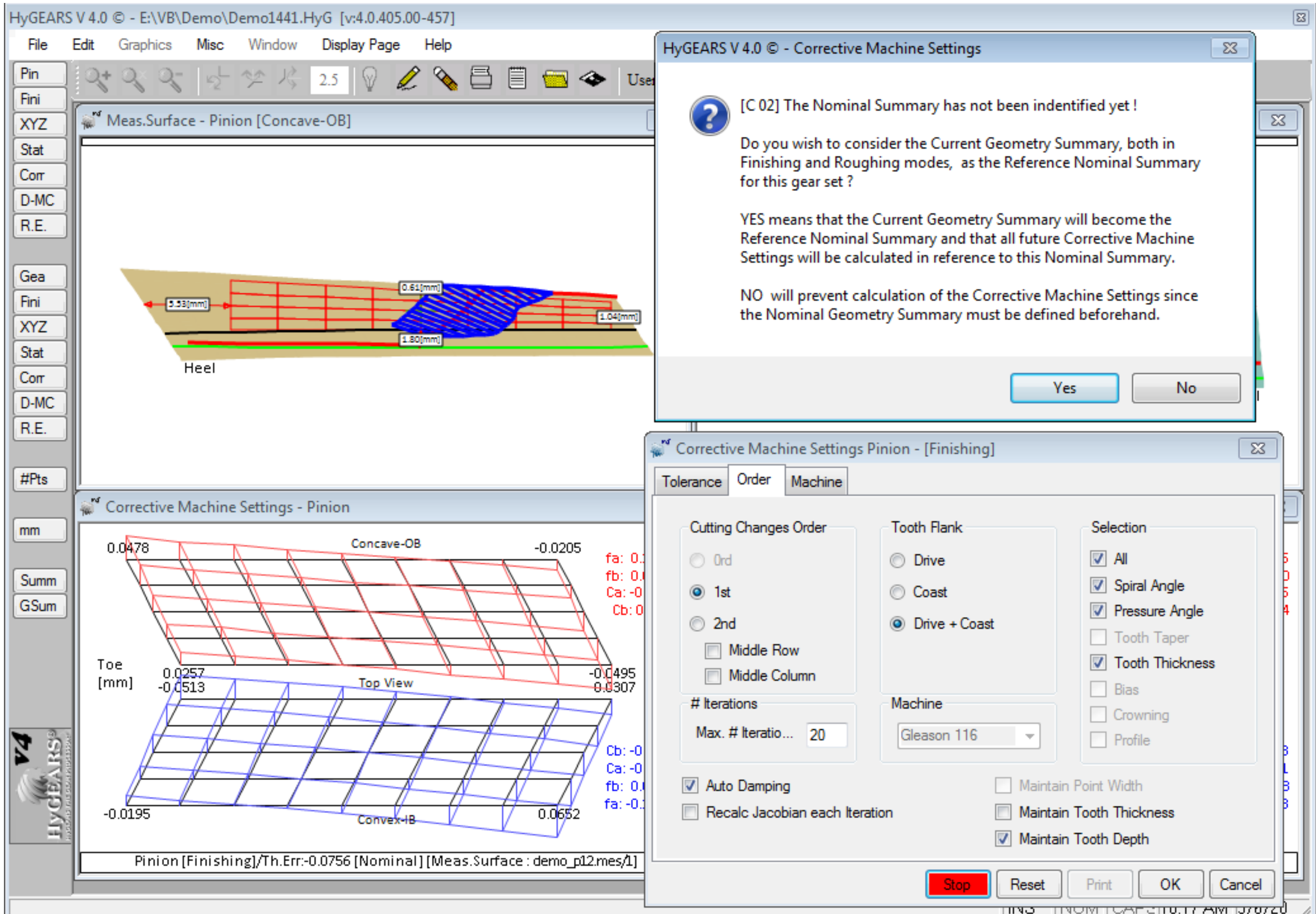
```
          ;  ----------    Cutting Cycle    ------------
START1:
TRANS C=(TEETH_ANGLE*SEQINDEX[(RESTART_TEETH)])
STOPRE

          ;  ------------------- 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)*

# Universal 5 Axis CnC Post-Processing

***Closed Loop:*** *Integral to HyGEARS*

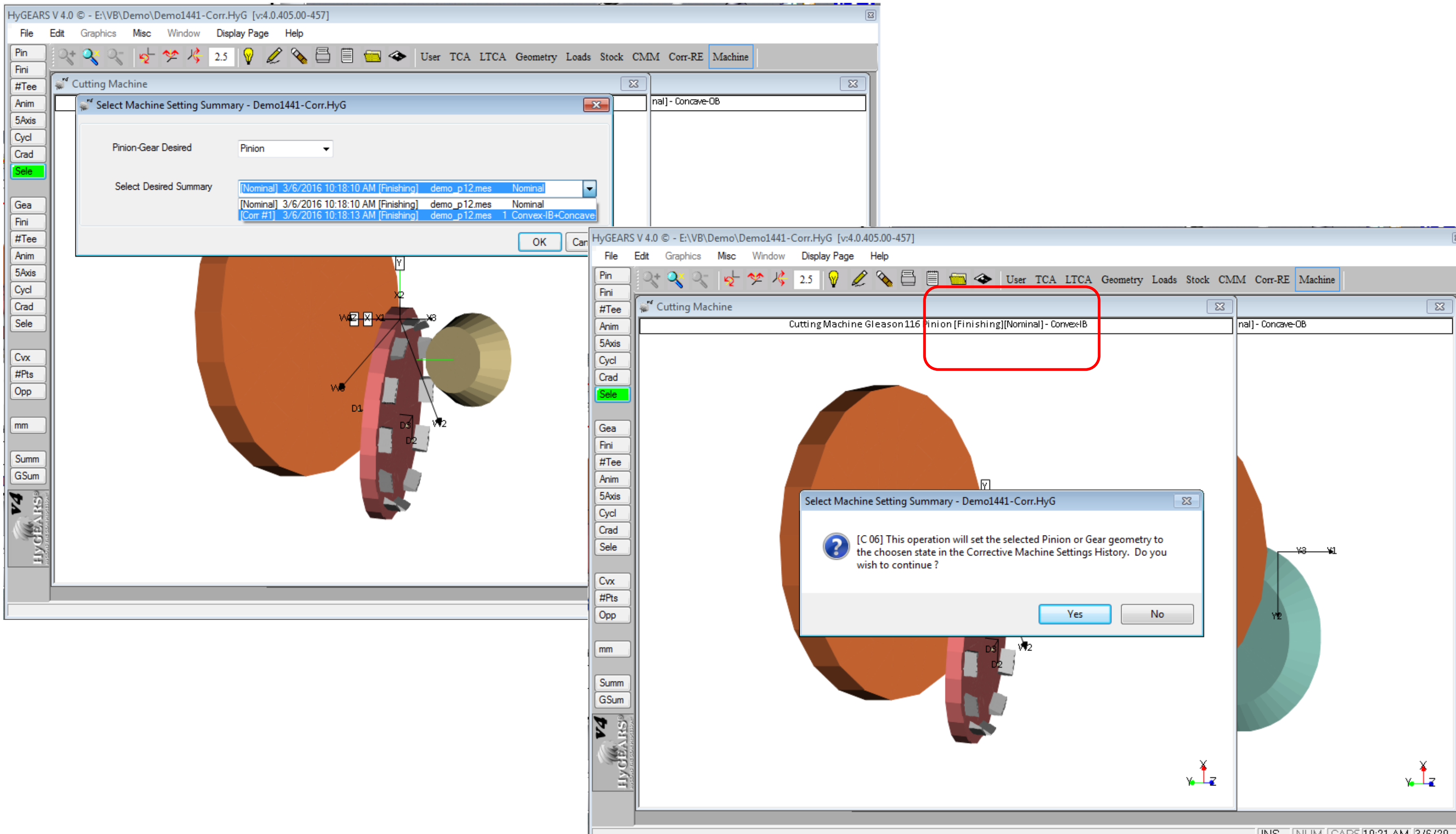
*A) Corrective Machine Settings must have been applied to the desired part;*




*A: Calculating Corrective Machine Settings*

# Universal 5 Axis CnC Post-Processing

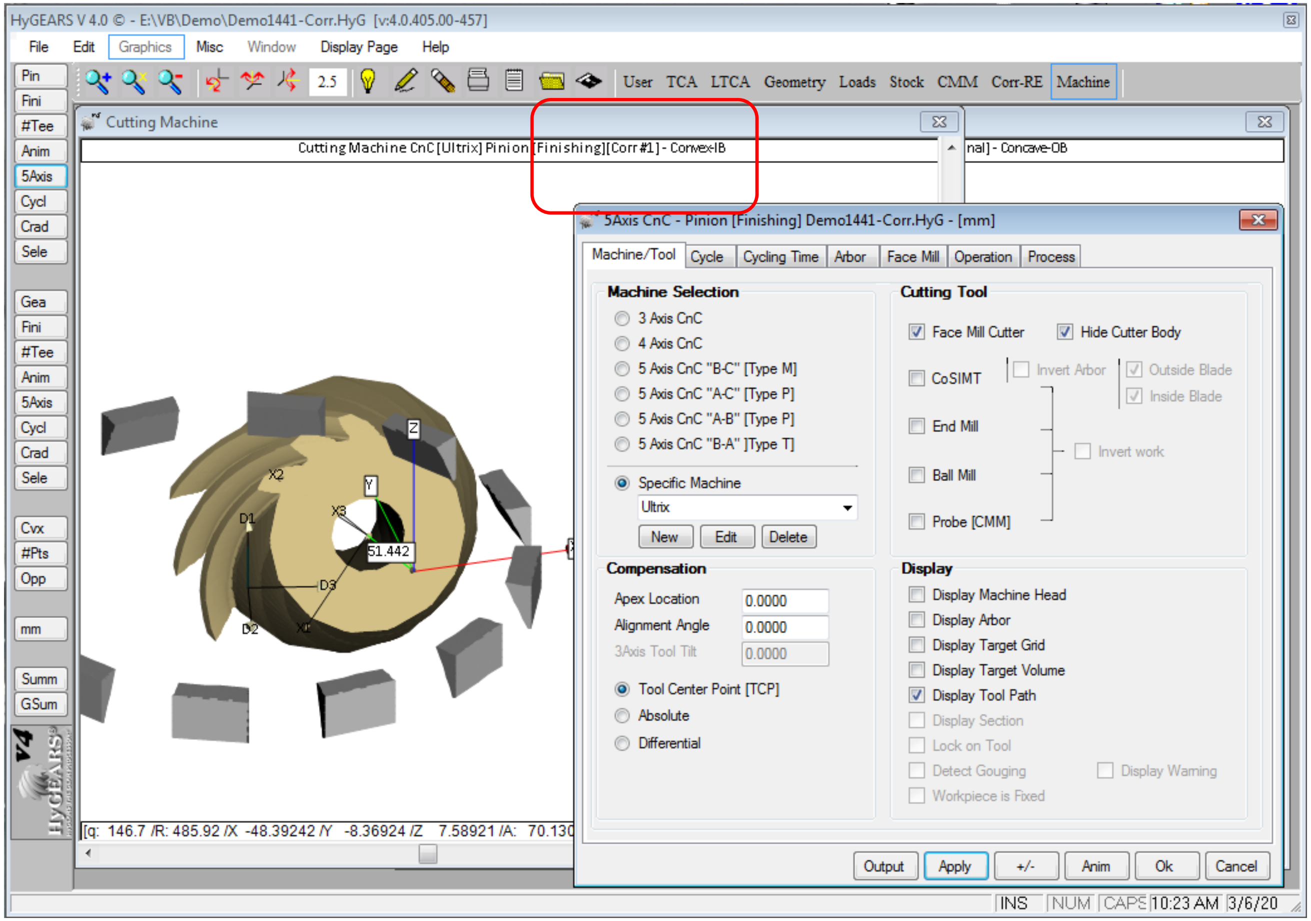
***Closed Loop:*** *B) Select the desired Correction iteration*




*B: Selecting the desired Correction*

# Universal 5 Axis CnC Post-Processing

***Closed Loop:*** *C) Work in 5Axis as usual*



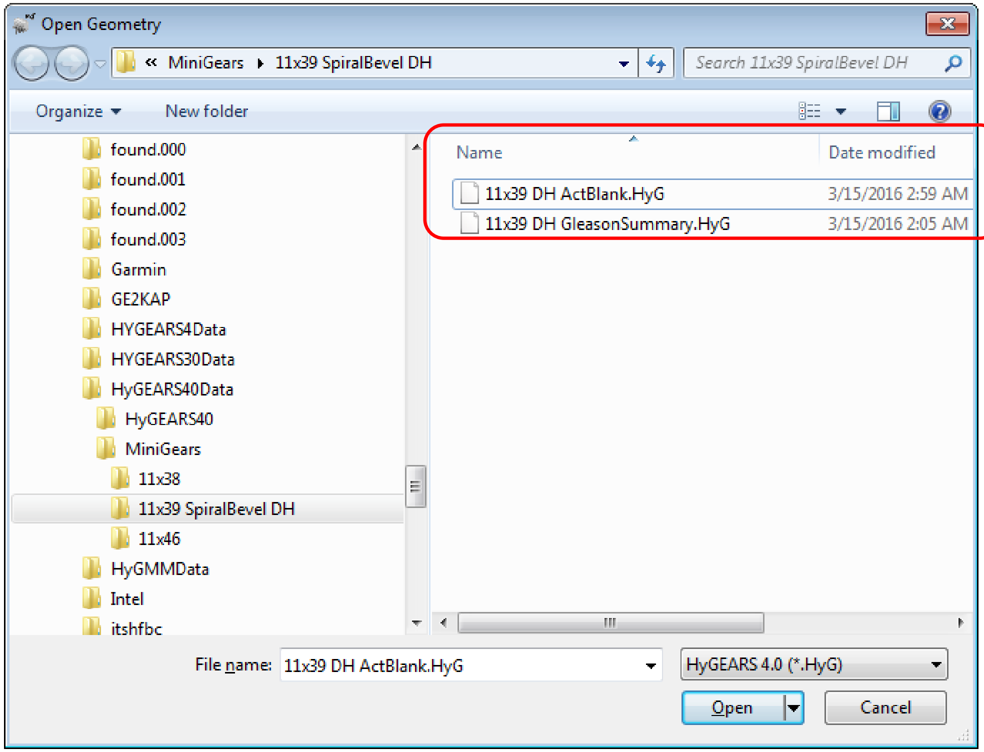
*C: Working in 5Axis with 1st Correction "[Corr #1]"*

# Universal 5 Axis CnC Post-Processing

***Example:*** *Create a sequence of Operations to:*

- *Rough the Flanks – 0.040 mm Stock*
- *Rough the Fillet – 0.020 mm Stock*
- *Finish the Fillet – 0 Stock*
- *Finish the Flanks – 0 Stock*

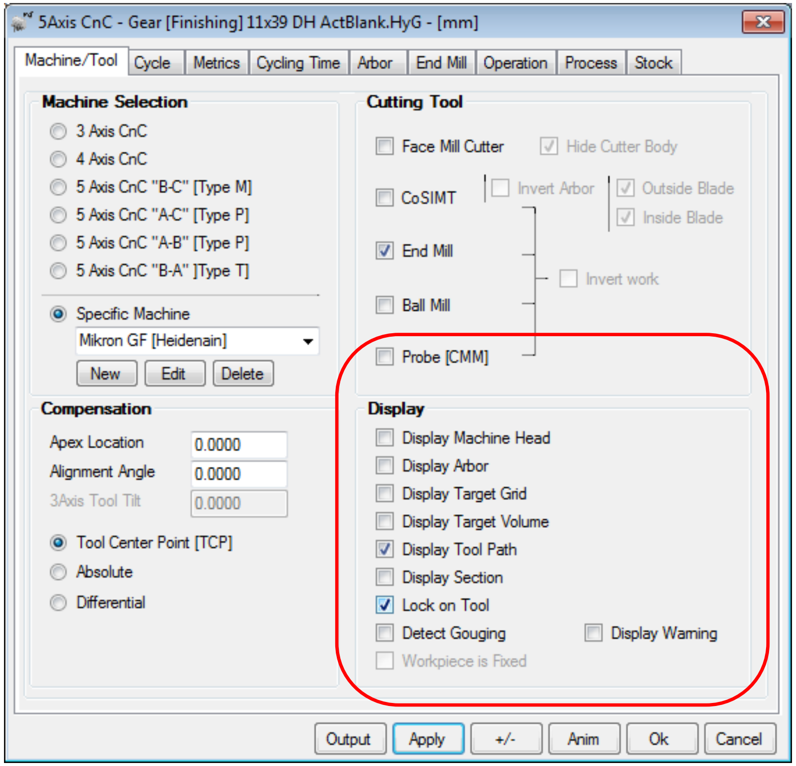
*Use the imported 11x39 spiral-bevel gear set*



# Universal 5 Axis CnC Post-Processing

***Example:*** *Go into Machine mode:*

- *Click on "5Axis", Gear group*
- *"Machine/Tool" tab*
- *In "Specific Machine", select "Mikron GF [Heidenhain]"*
- *Select "End Mill" tool*
- *Select the "Display" options*
- *Click on "Apply"*



# Universal 5 Axis CnC Post-Processing

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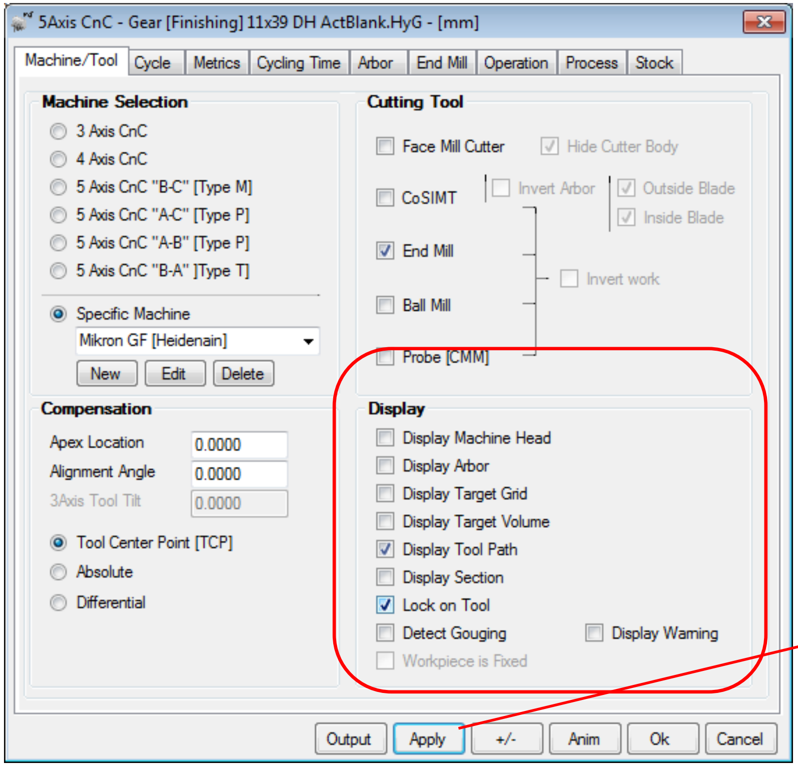
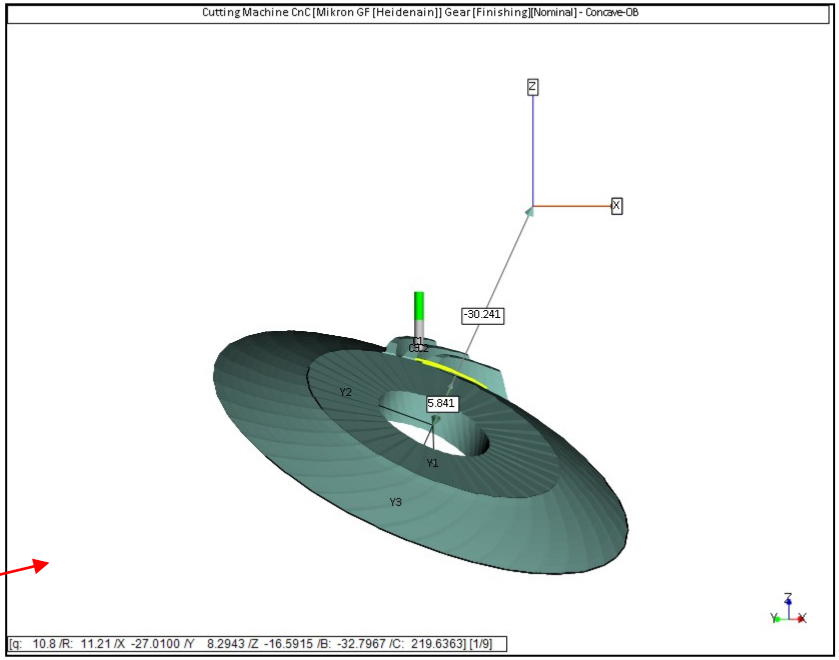
- *Click on "Apply"*

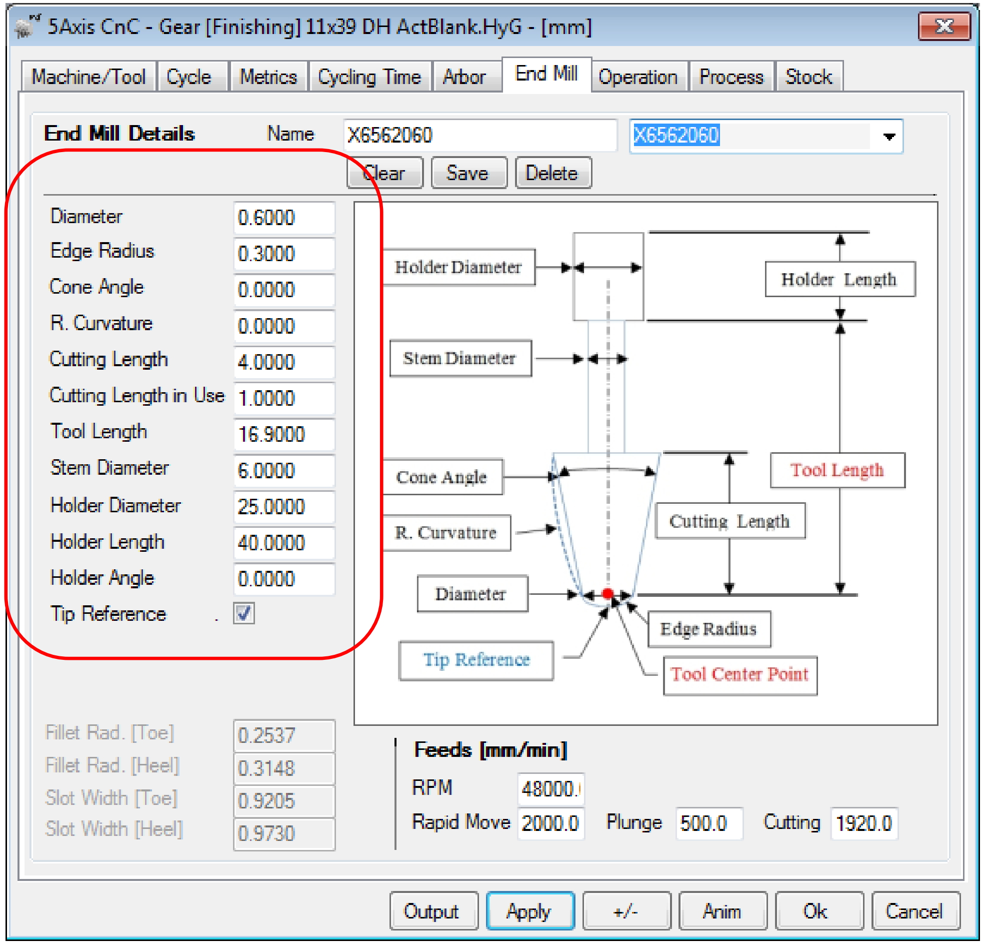


# Universal 5 Axis CnC Post-Processing

***Example:***

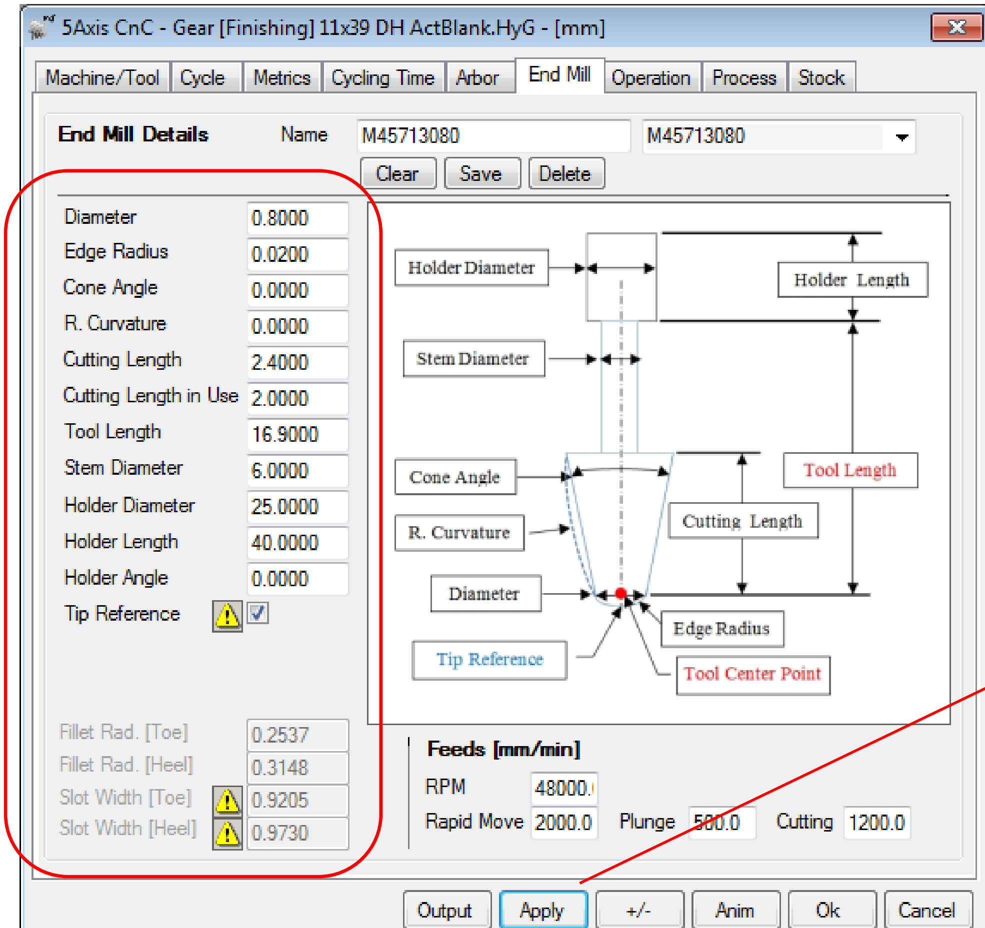
- *Select "End Mill" Tab*
- *Enter the data for the X6562060 tool (below)*
- *Click on "Apply", click on "Save"*

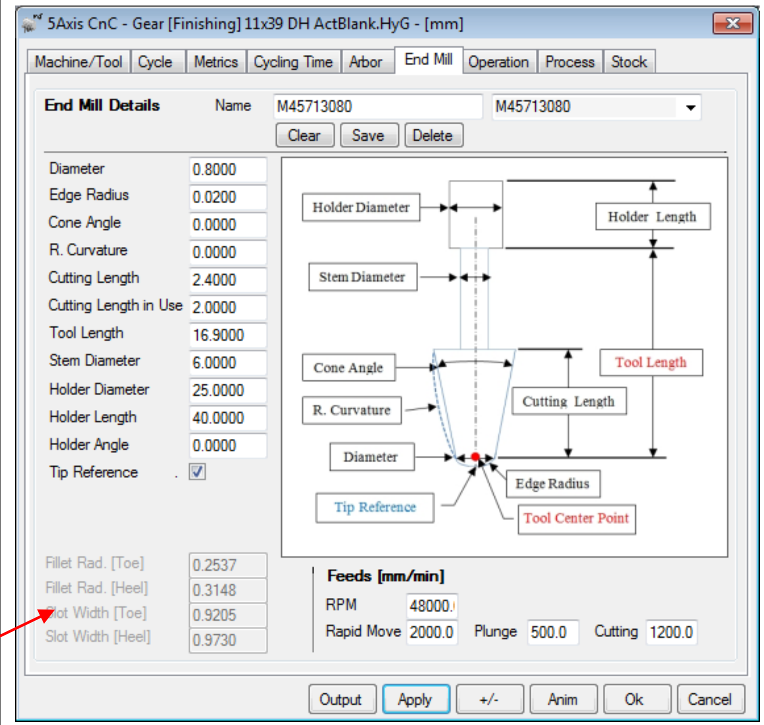


# Universal 5 Axis CnC Post-Processing

***Example:***

- *Enter the data for the M45713080 tool (below)*
- *Click on "Apply", click on "Save"*

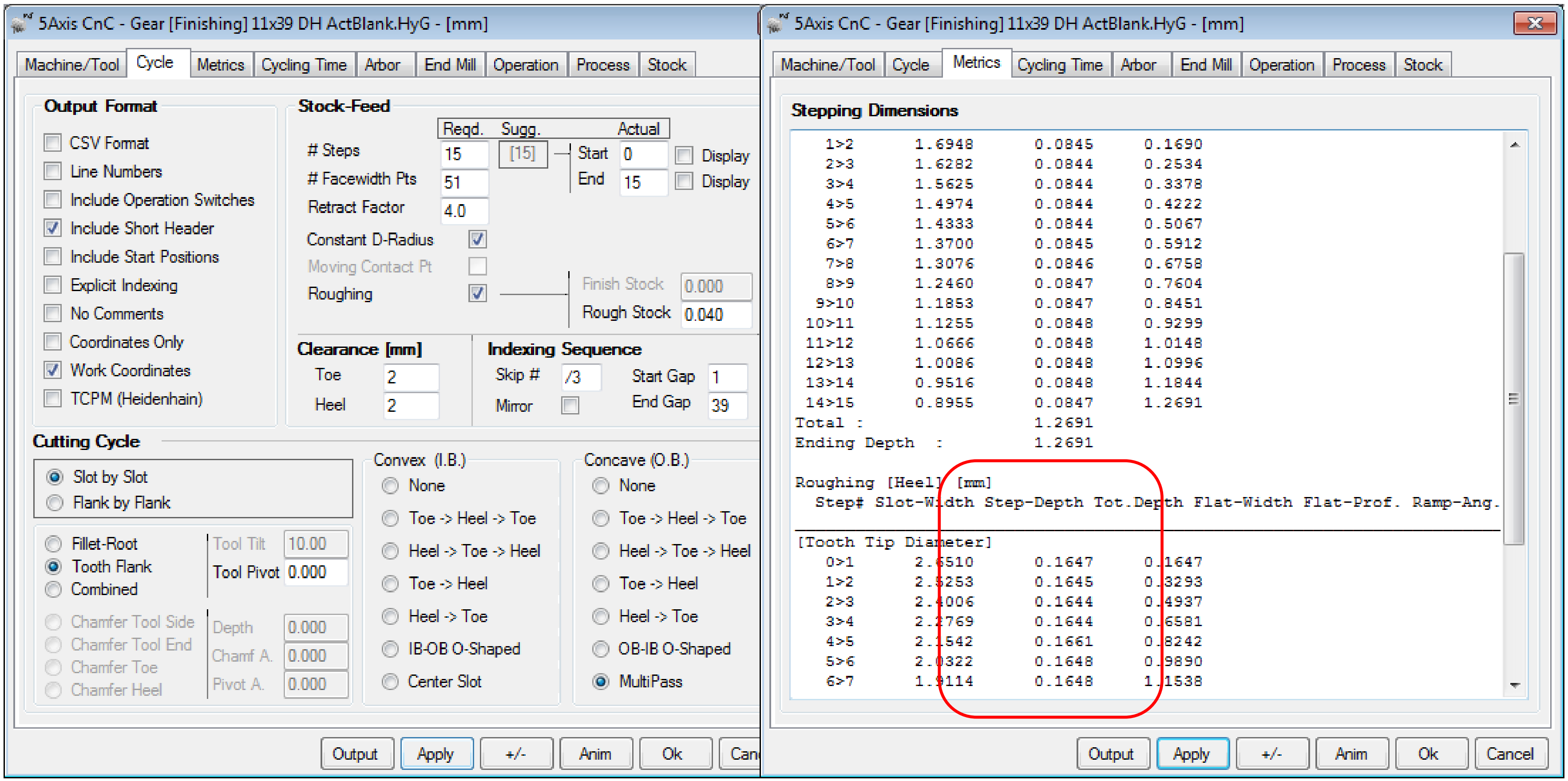


# Universal 5 Axis CnC Post-Processing

***Example:*** *1st Operation: Rough the Flanks – 0.040 [mm] Stock with M45713080 tool*

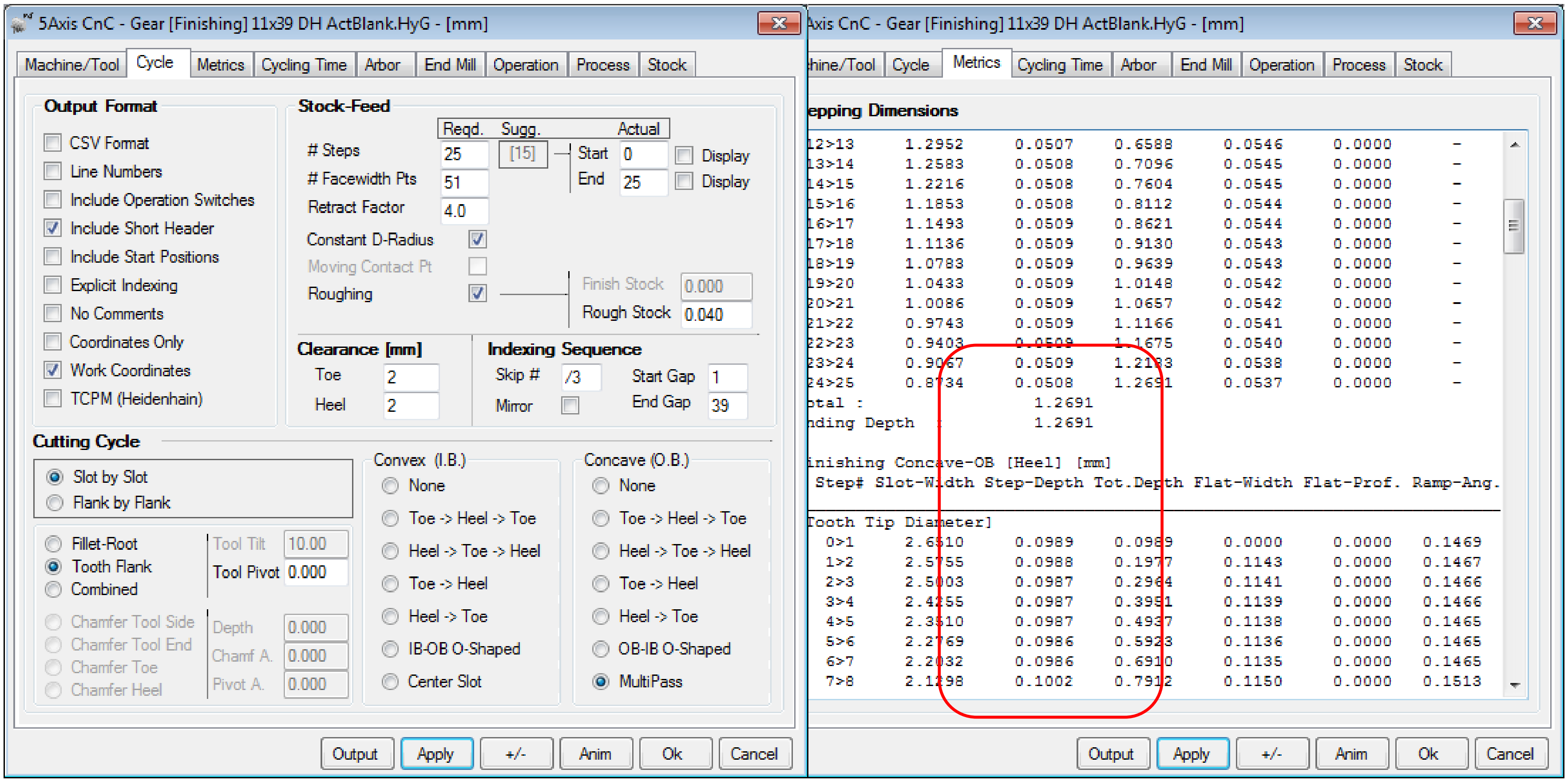
- *Select the "Cycle" Tab*
- *Maximum Step depth is 0.1 [mm] (from tool manufacturer)*
- *Make the selections as below, Click on "Apply"*
- *Check the Metrics for Step Depth: too large => Increase #Steps*



# Universal 5 Axis CnC Post-Processing

***Example:*** *1st Operation: Rough the Flanks – 0.040 [mm] Stock*

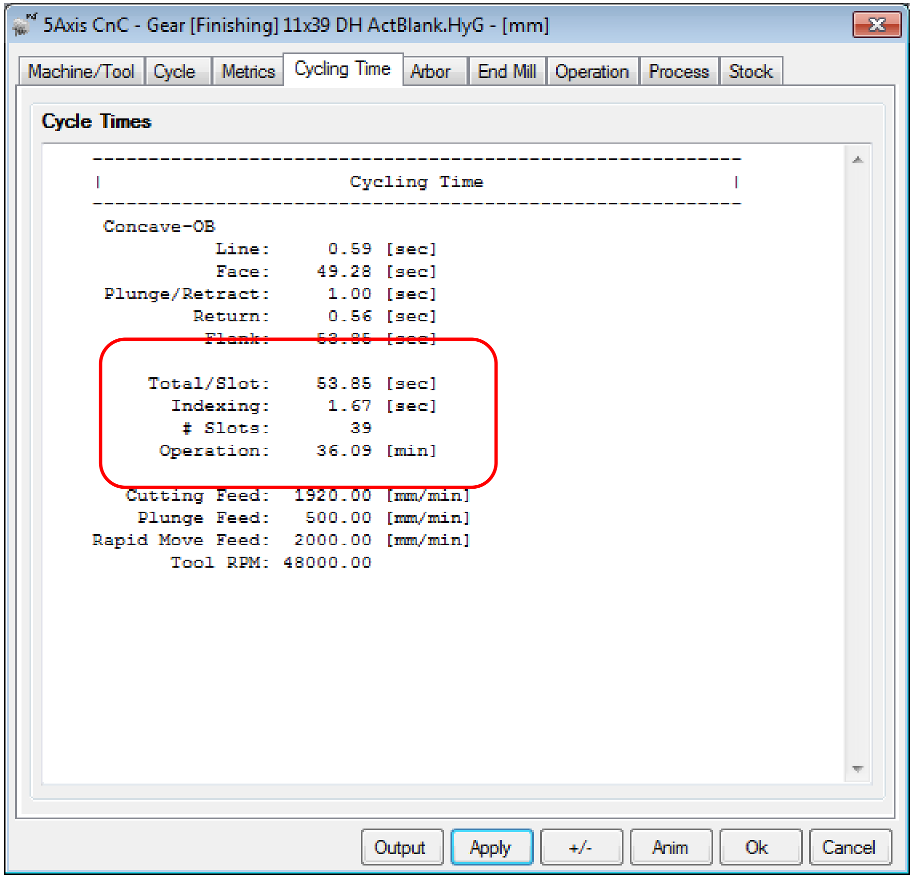
- *Select the "Cycle" Tab*
- *Increase #Steps to 25; Click on "Apply"*
- *Check the Metrics for Step Depth: Ok this time*



# Universal 5 Axis CnC Post-Processing

***Example:*** *1st Operation: Rough the Flanks – 0.040 [mm] Stock*

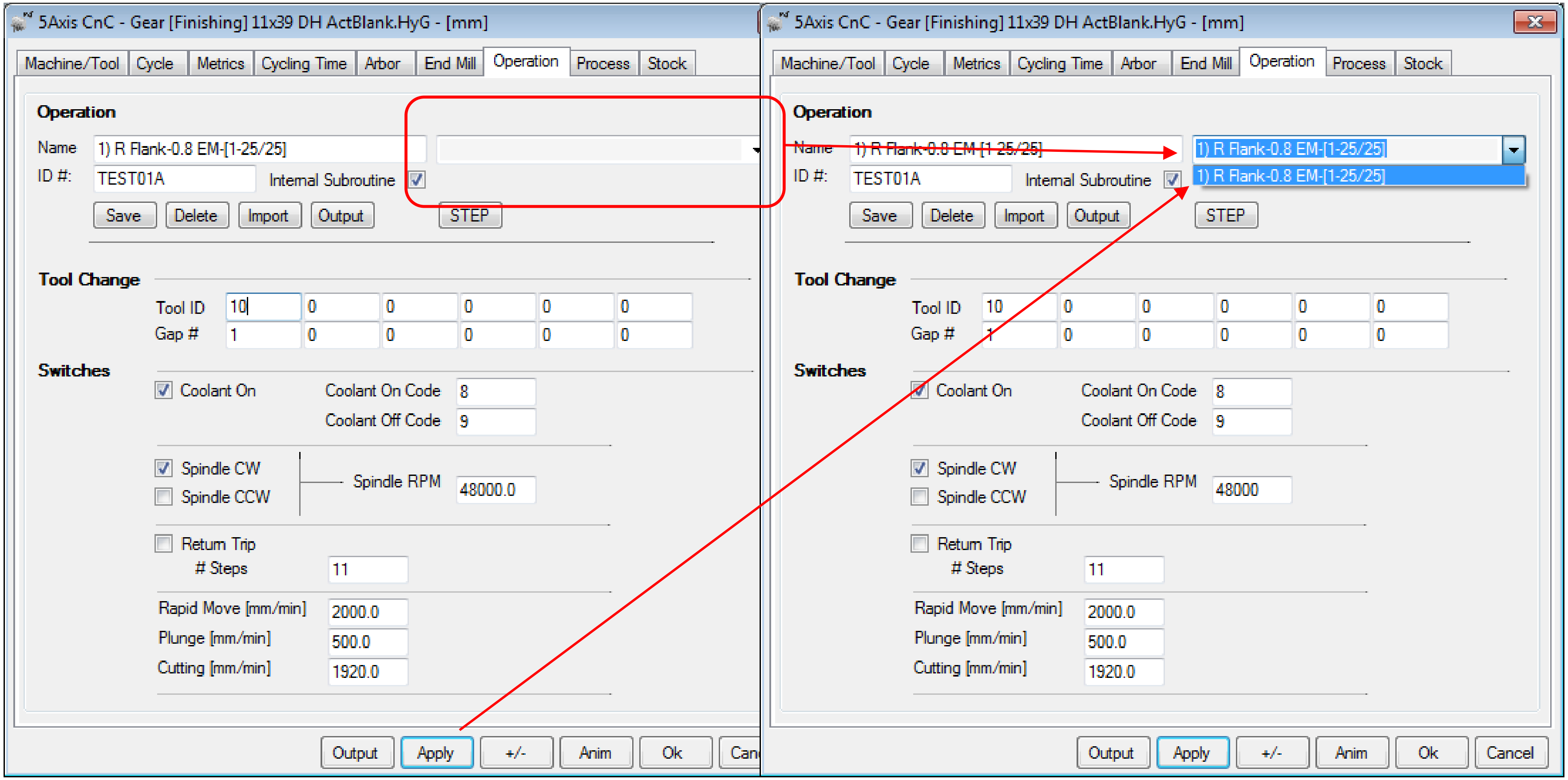
- *Select the "Cycling Time" Tab*
- *Operation time ~ 36 min.*



# Universal 5 Axis CnC Post-Processing

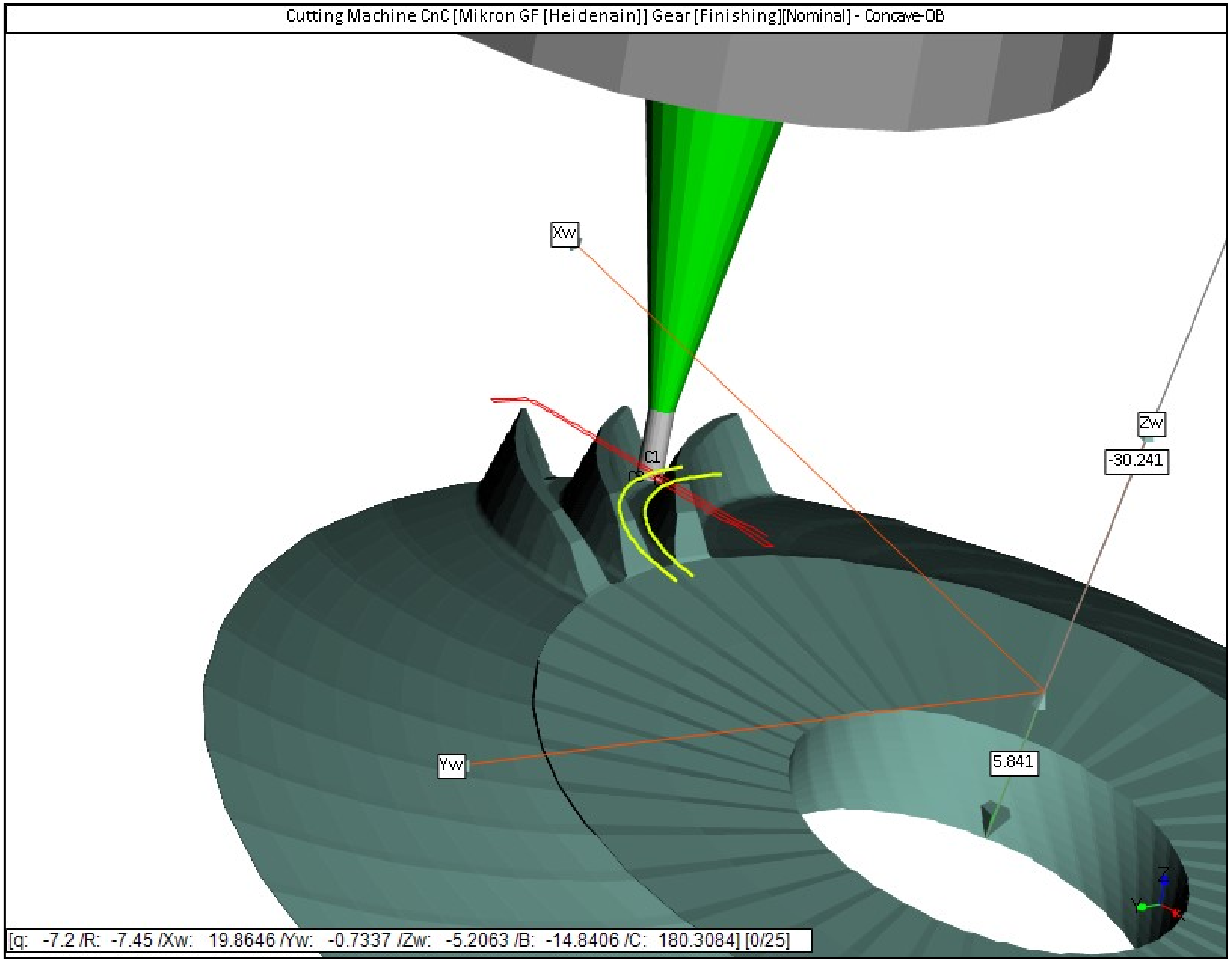
***Example:*** *1st Operation: Rough the Flanks – 0.040 [mm] Stock*

- *Select the "Operation" Tab*
- *Enter the data as shown below*
- *Click on "Apply"; click on "Save"*



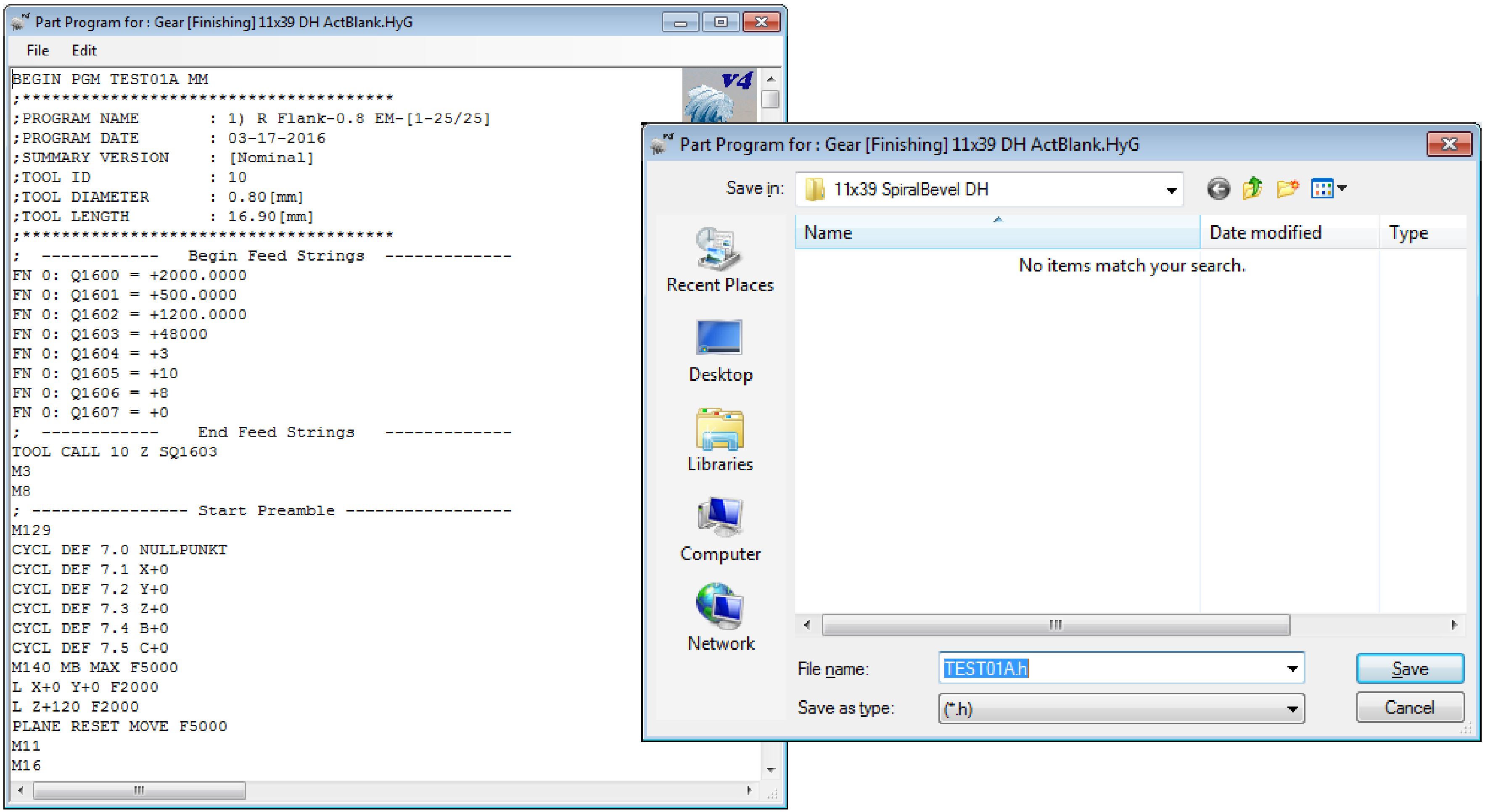
# Universal 5 Axis CnC Post-Processing

| | |
|---|---|
| ***Example:*** | *1st Operation: Rough the Flanks – 0.040 [mm] Stock* |
| | • *Visualize your Operation;* |
| | • *"Anim" and / or "+/-"; Zoom in / out for better view* |



# Universal 5 Axis CnC Post-Processing

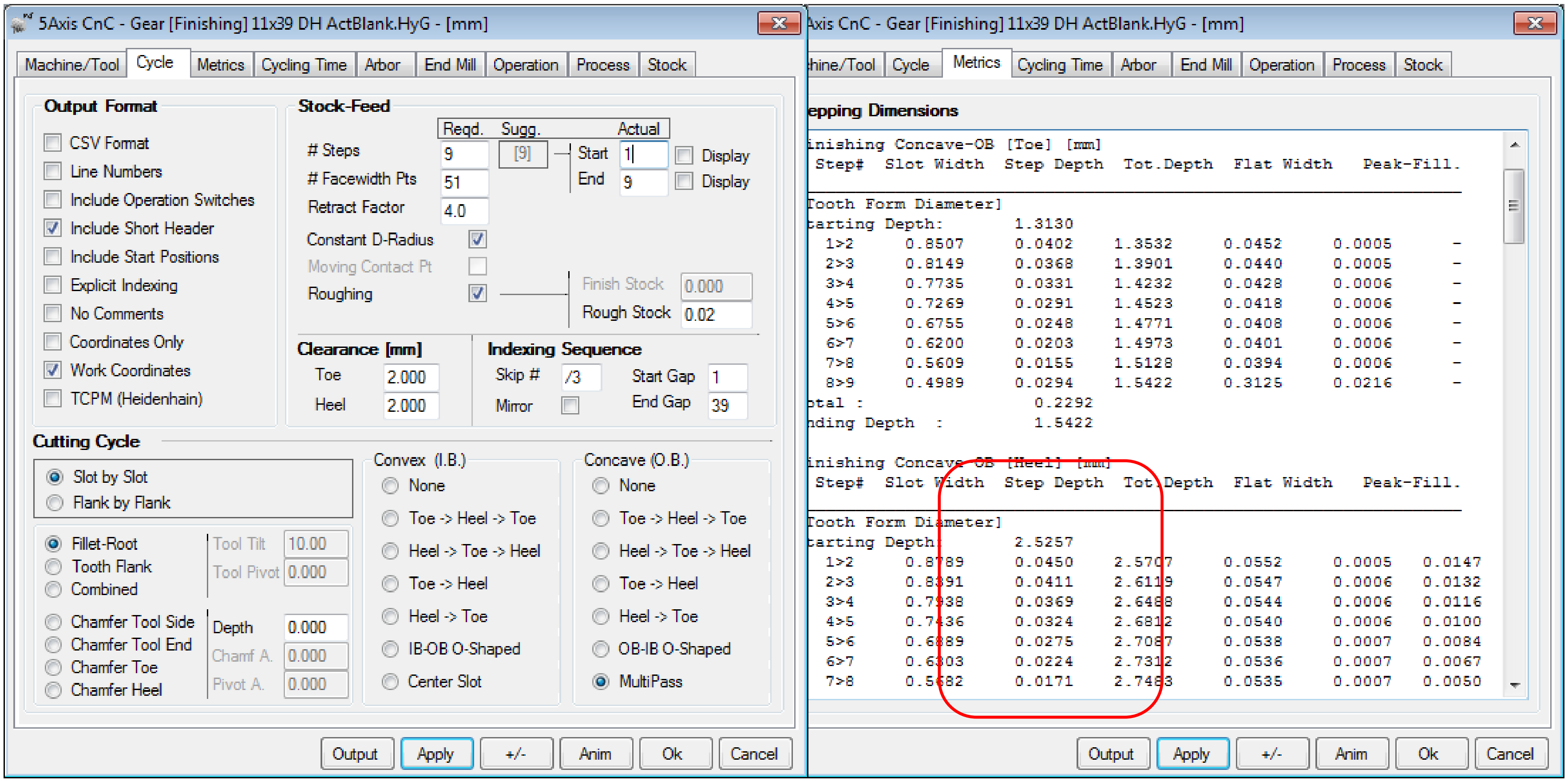
| | |
|---|---|
| ***Example:*** | *1st Operation: Rough the Flanks – 0.040 [mm] Stock* |
| | • *Click on "Output" to generate the part program* |
| | • *Click on File->Save to save your program* |



# Universal 5 Axis CnC Post-Processing

***Example:*** *2nd Operation: Rough the Fillet – 0.030 [mm] Stock with X6562060 tool*

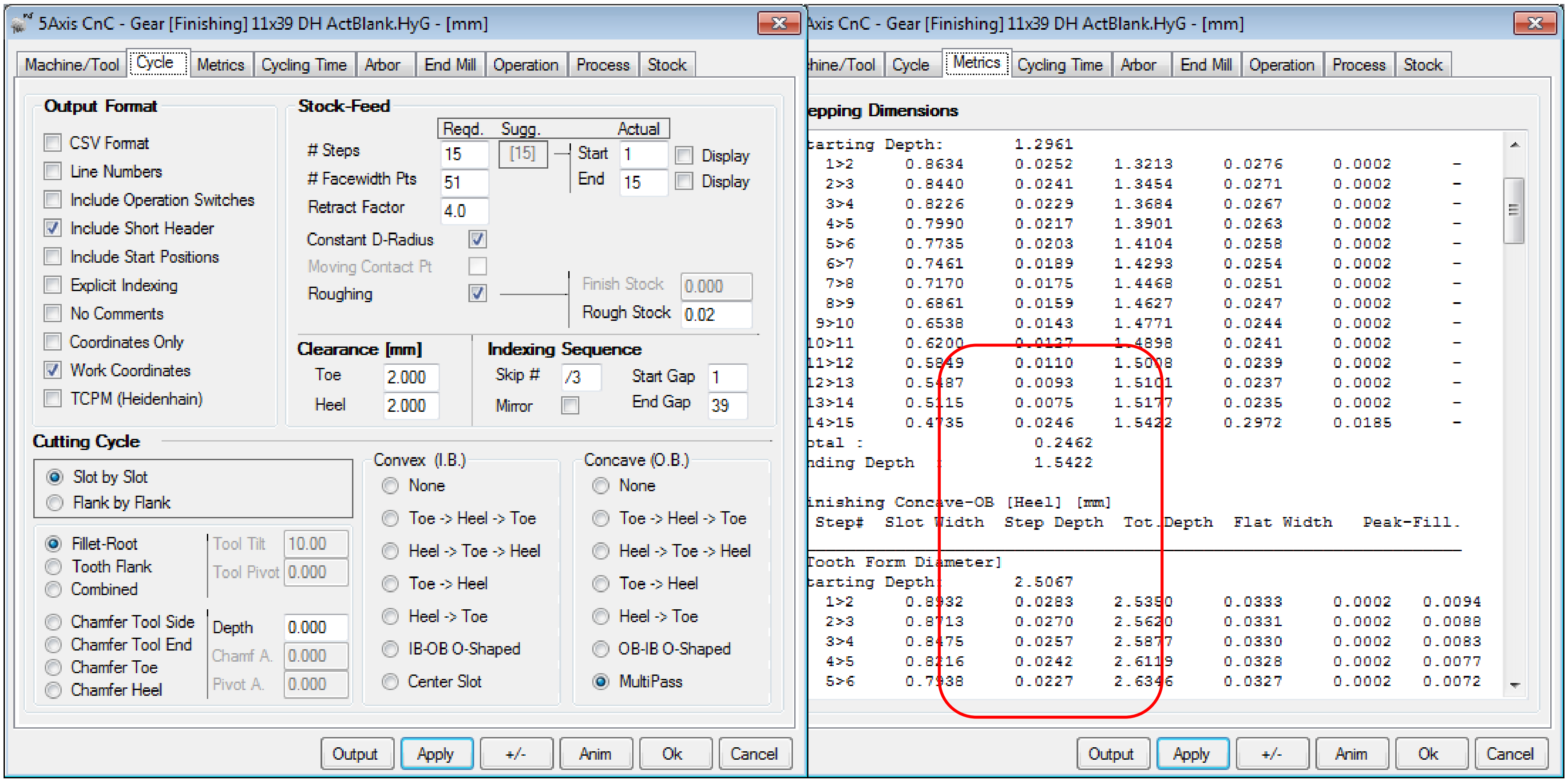
- *Select the "End Mill" Tab; select the X6562060 tool*
- *Maximum Step depth is 0.03 [mm] (from tool manufacturer)*
- *Make the selections as below, Click on "Apply"*
- *Check the Metrics for Step Depth: too large => Increase #Steps*



# Universal 5 Axis CnC Post-Processing

***Example:*** *2nd Operation: Rough the Fillet – 0.020 [mm] Stock*

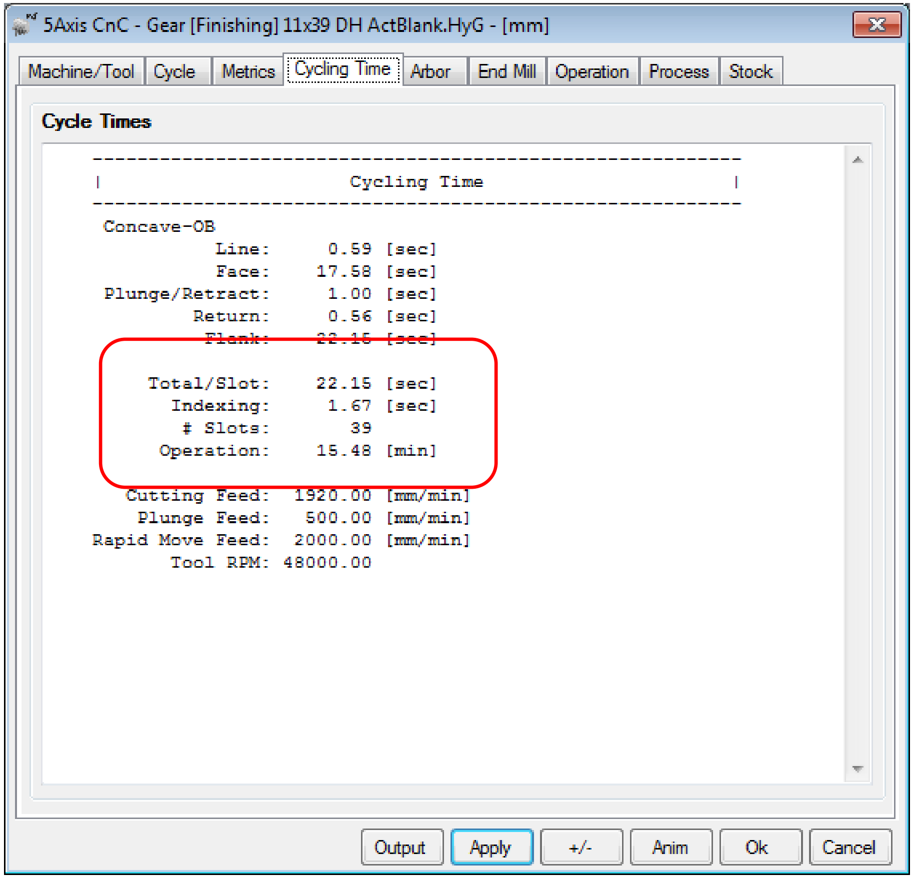
- *Select the "Cycle" Tab*
- *Increase #Steps to 15; Click on "Apply"*
- *Check the Metrics for Step Depth: Ok this time*



# Universal 5 Axis CnC Post-Processing

***Example:*** *2nd Operation: Rough the Fillet – 0.020 [mm] Stock*

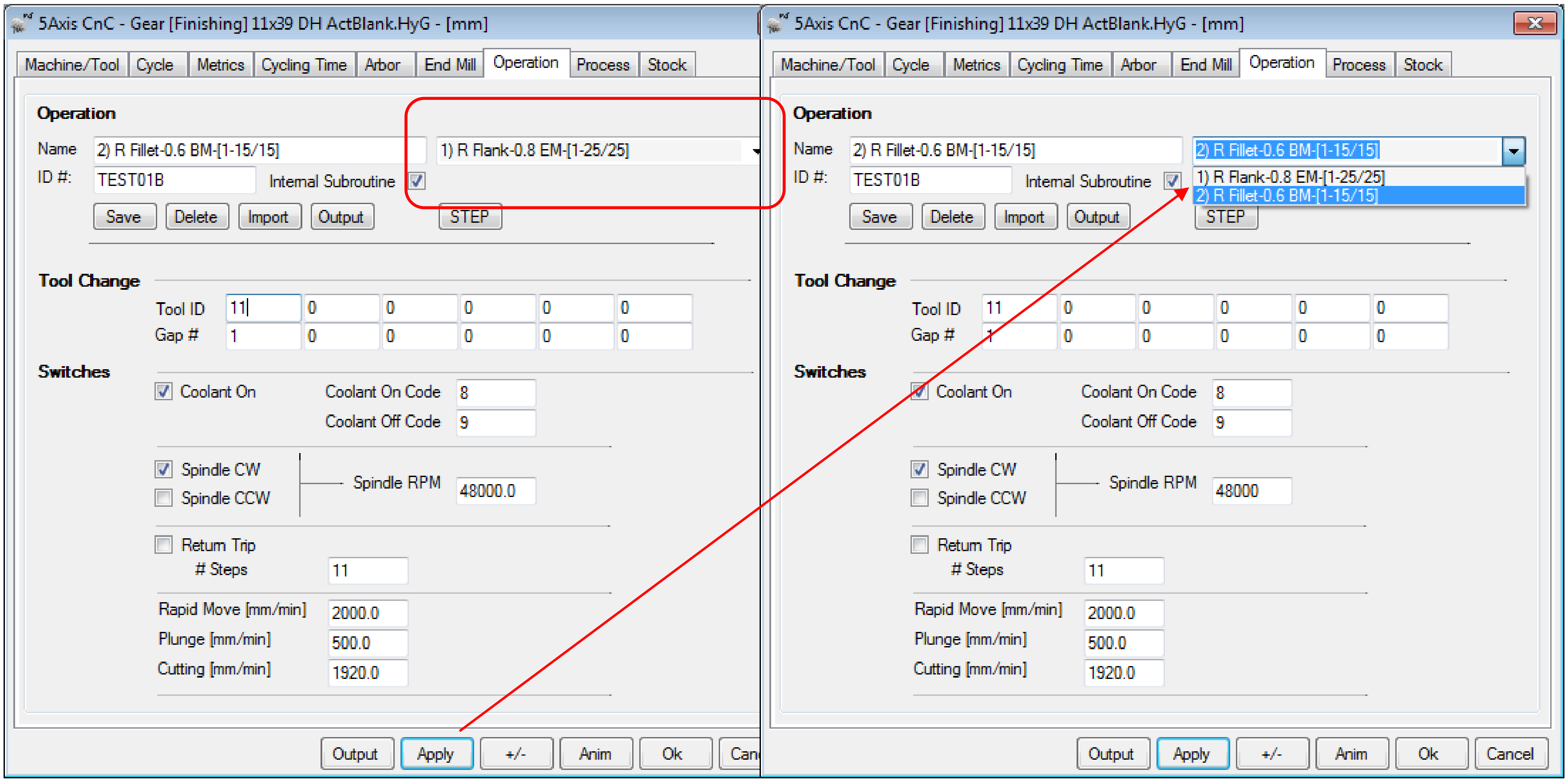
- *Select the "Cycling Time" Tab*
- *Operation time ~ 16 min.*



# Universal 5 Axis CnC Post-Processing

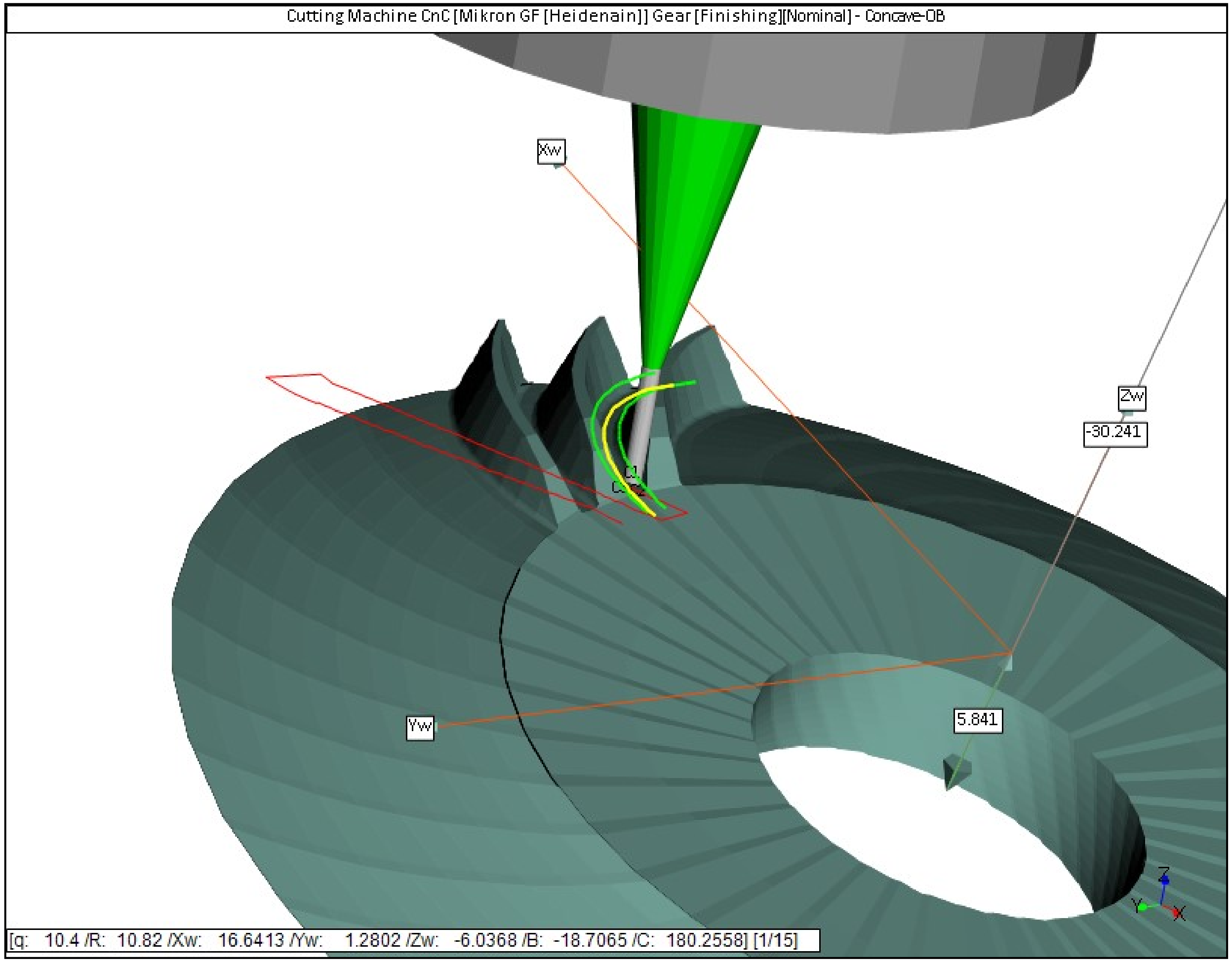
***Example:*** *2nd Operation: Rough the Fillet – 0.020 [mm] Stock*

- *Select the "Operation" Tab*
- *Enter the data as shown below*
- *Click on "Apply"; click on "Save"*



# Universal 5 Axis CnC Post-Processing

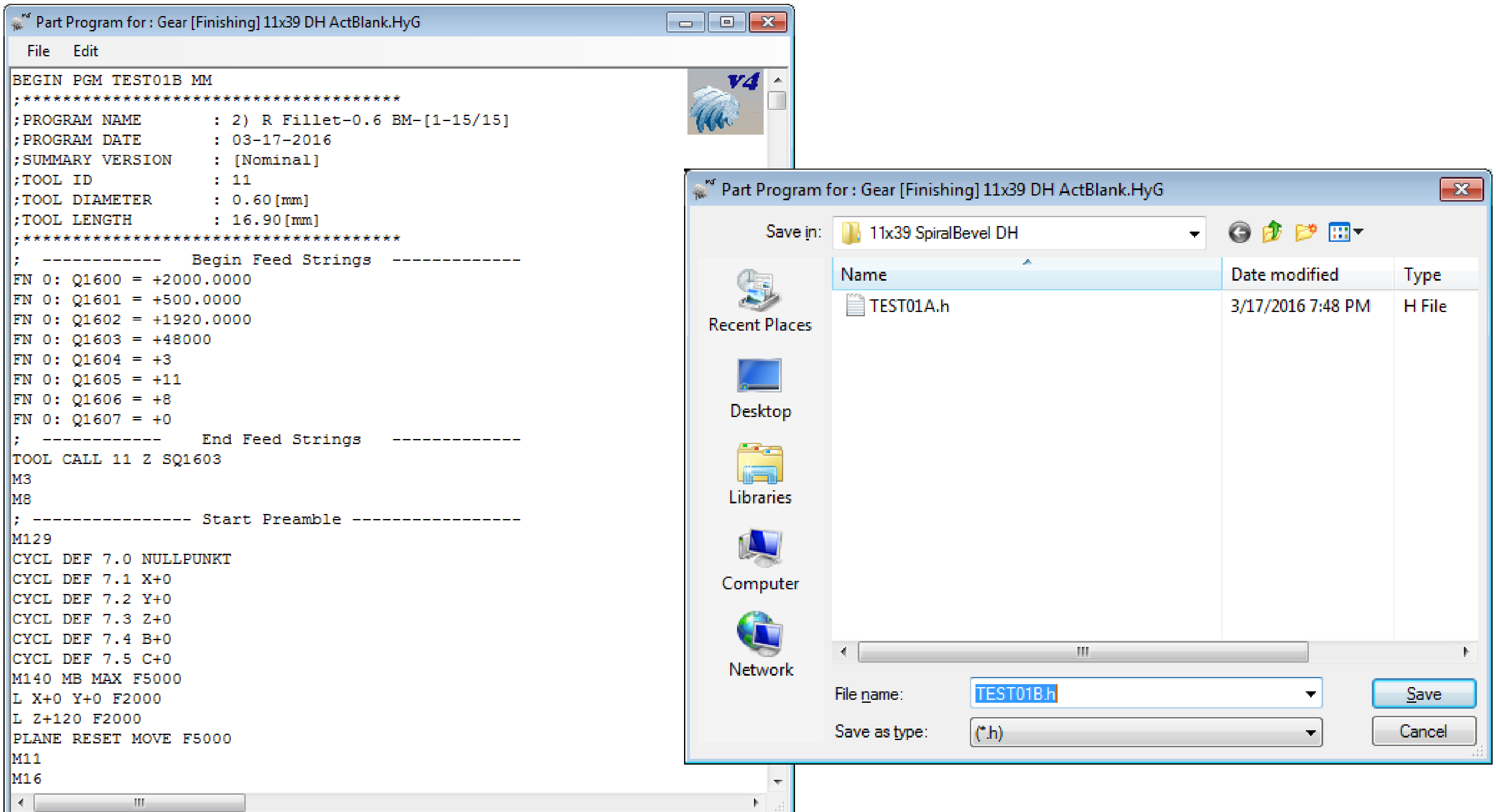
| | |
|---|---|
| ***Example:*** | *2nd Operation: Rough the Fillet – 0.020 [mm] Stock* |
| | • *Visualize your Operation;* |
| | • *“Anim” and / or “+/-”; Zoom in / out for better view* |



# Universal 5 Axis CnC Post-Processing

***Example:*** *2nd Operation: Rough the Fillet – 0.020 [mm] Stock*

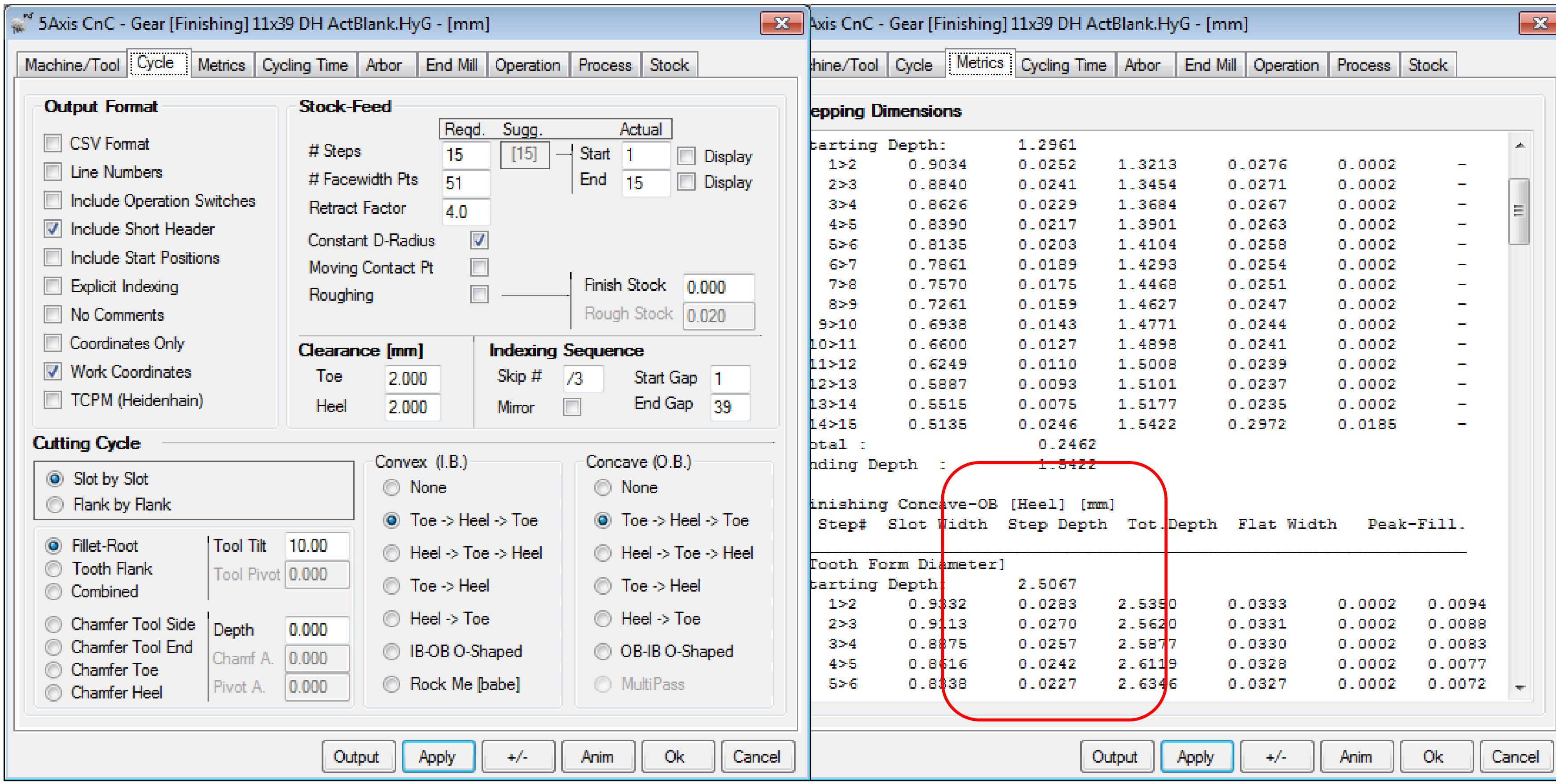
- *Click on “Output” to generate the part program*
- *Click on File->Save to save your program*



# Universal 5 Axis CnC Post-Processing

***Example:*** *3rd Operation: Finish the Fillet – 0.0 [mm] Stock with X6562060 tool*

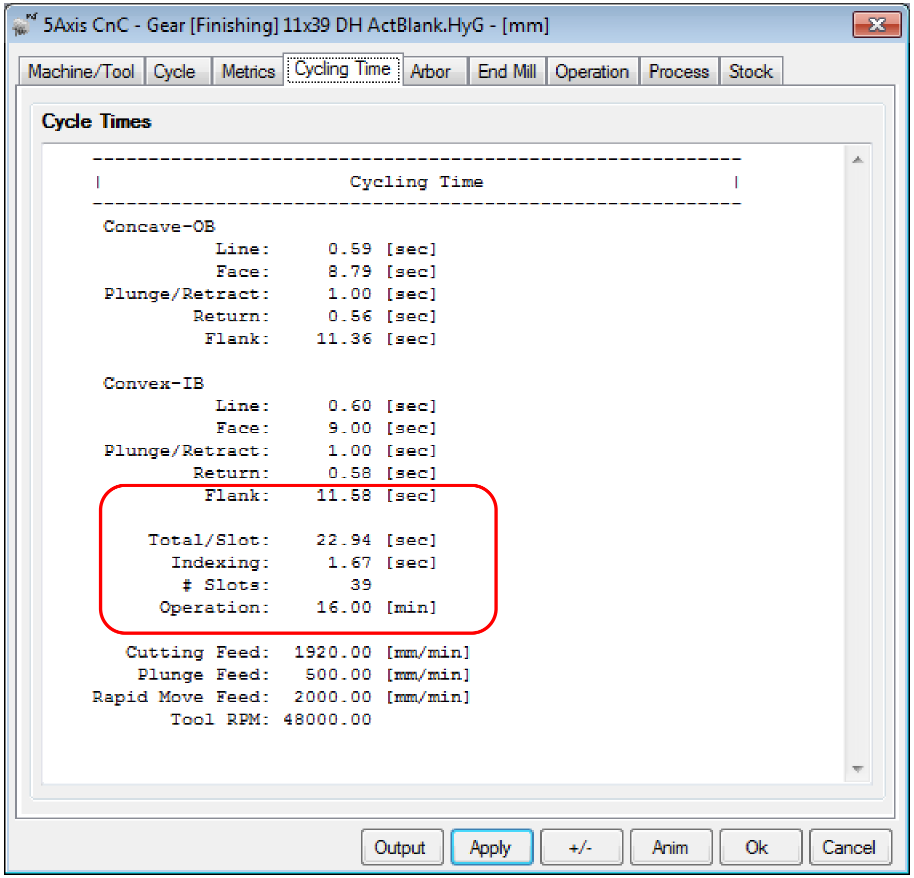
- *Select the “End Mill” Tab; select the X6562060 tool*
- *Maximum Step depth is 0.03 [mm] (from tool manufacturer)*
- *Make the selections as below, Click on “Apply”*
- *Check the step depth in the “Metrics”tab; Ok*



# Universal 5 Axis CnC Post-Processing

***Example:*** *3rd Operation: Finish the Fillet – 0.0 [mm] Stock*

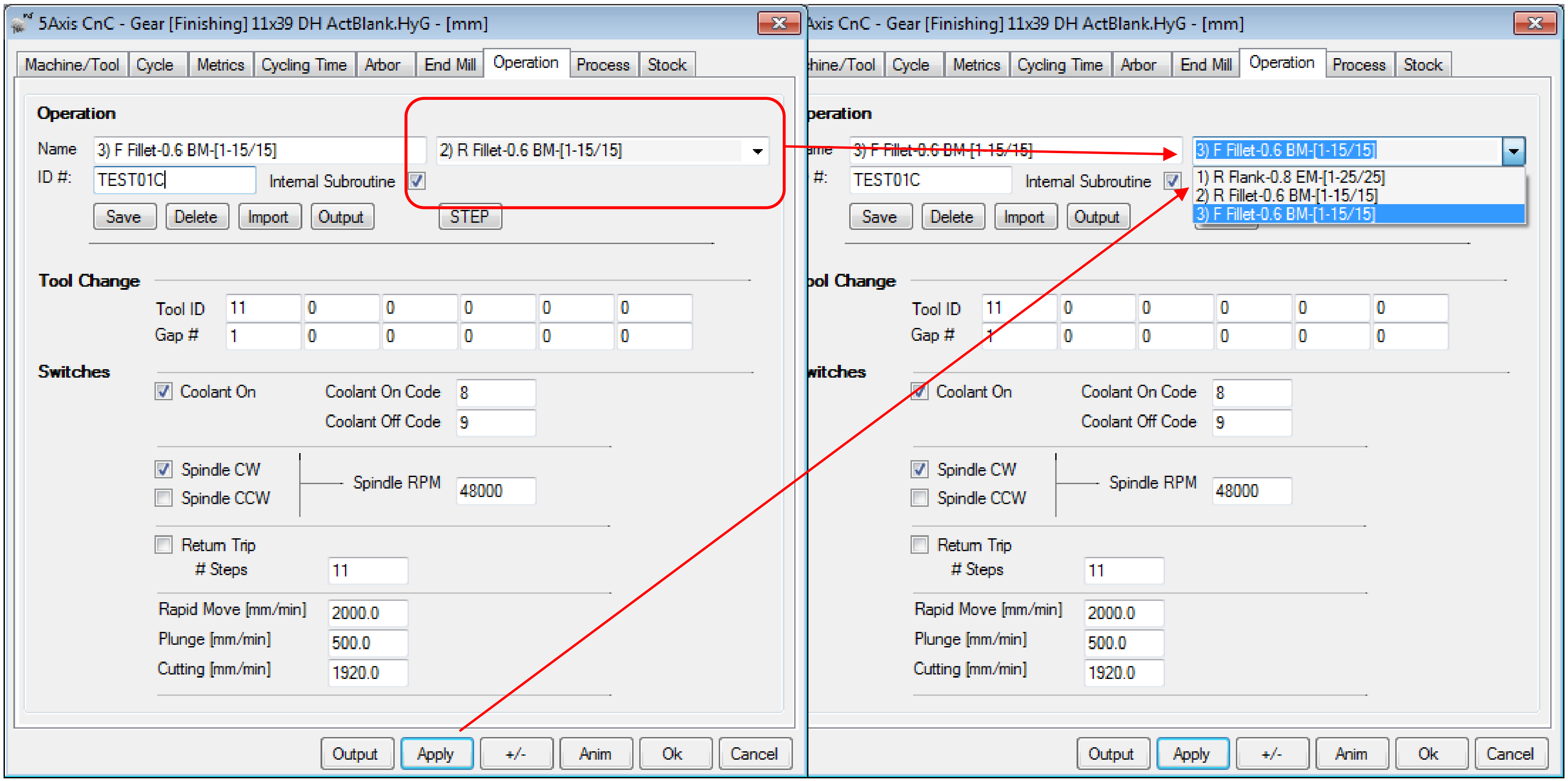
- *Select the "Cycling Time" Tab*
- *Operation time ~ 16 min.*



# Universal 5 Axis CnC Post-Processing

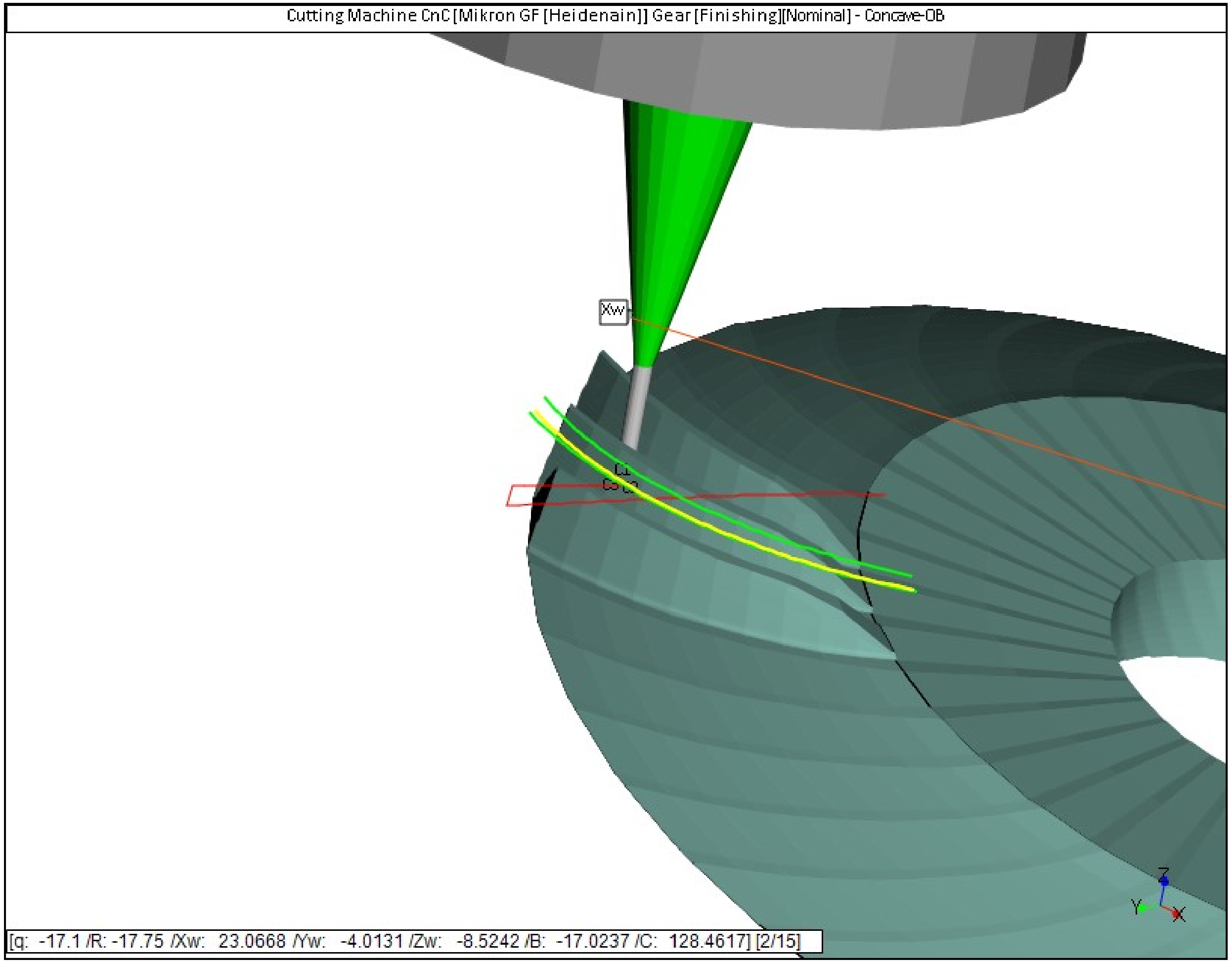
***Example:*** *3rd Operation: Finish the Fillet – 0.0 [mm] Stock*

- *Select the "Operation" Tab*
- *Enter the data as shown below*
- *Click on "Apply"; click on "Save"*



# Universal 5 Axis CnC Post-Processing

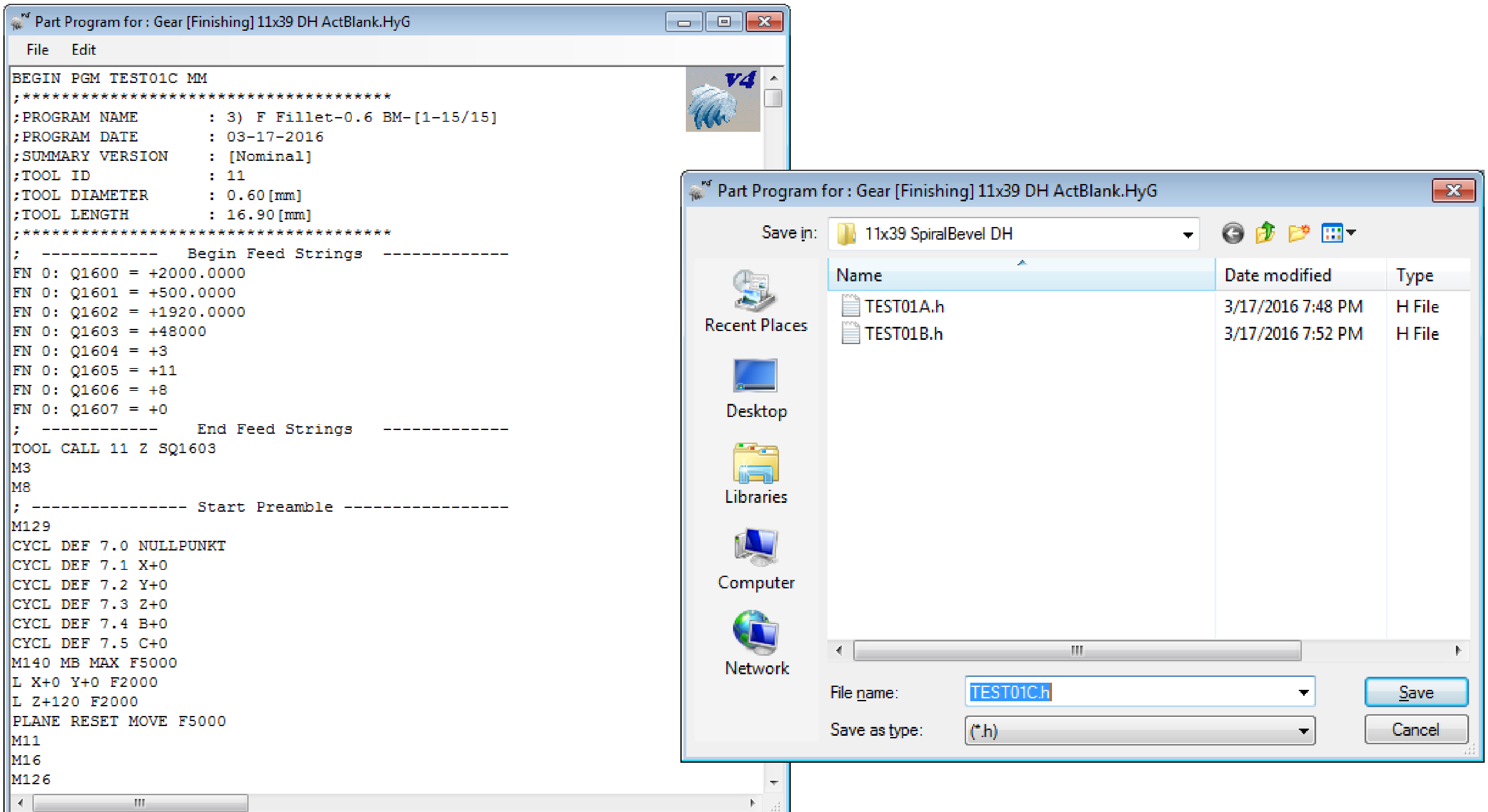
| | |
|---|---|
| ***Example:*** | *3rd Operation: Finish the Fillet – 0.0 [mm] Stock* |
| | • *Visualize your Operation;* |
| | • *"Anim" and / or "+/-"; Zoom in / out for better view* |



# Universal 5 Axis CnC Post-Processing

***Example:*** *3rd Operation: Finish the Fillet – 0.0 [mm] Stock*

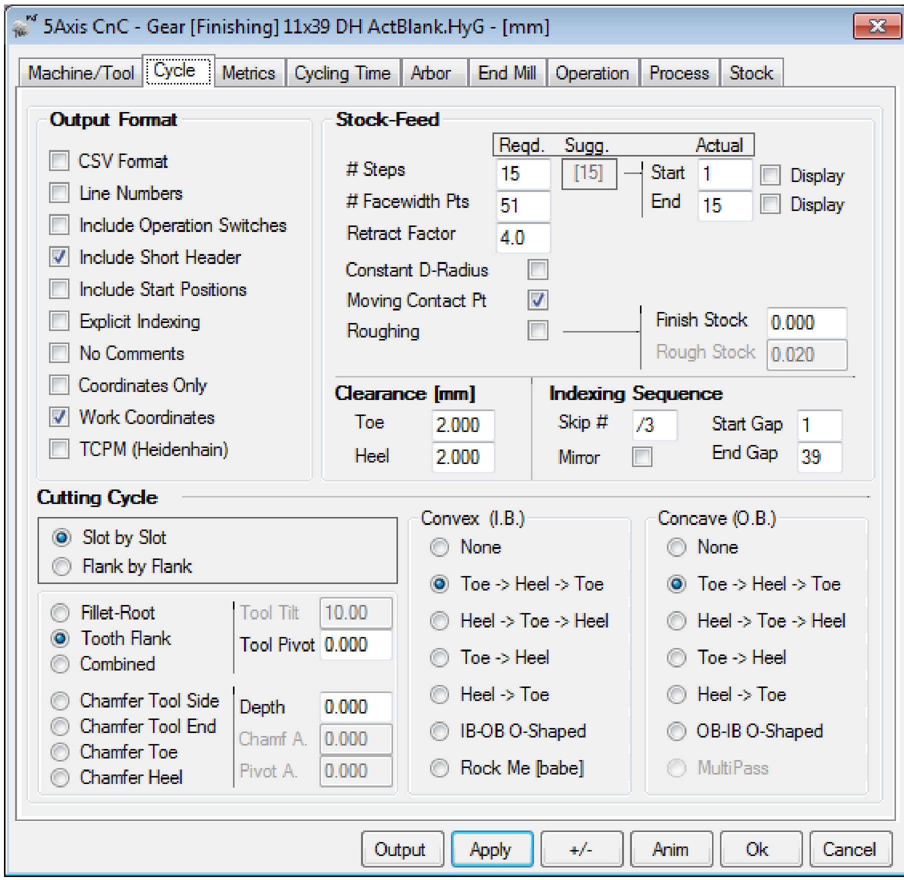
- *Click on "Output" to generate the part program*
- *Click on File->Save to save your program*

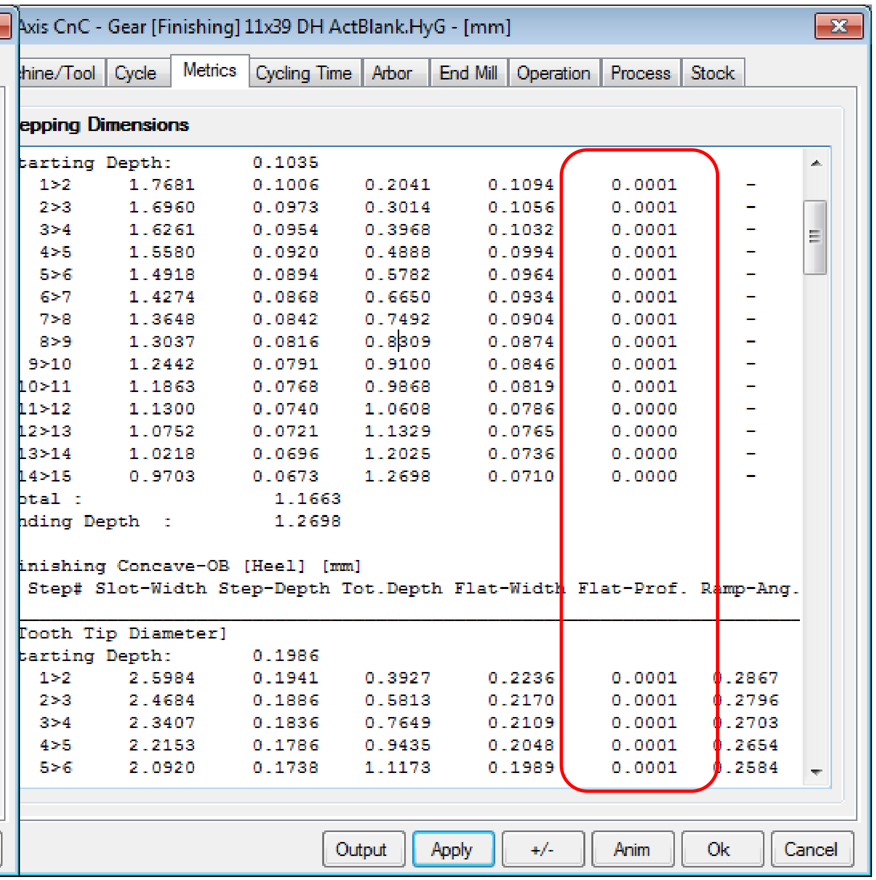


# Universal 5 Axis CnC Post-Processing

***Example:*** *4th Operation: Finish the Flank – 0.0 [mm] Stock with M45713080 tool*

- *Select the "End Mill" Tab; select the M45713080 tool*
- *Flat-Prof deviation < 2 um*
- *Make the selections as below, Click on "Apply"*
- *Check the "Flat-Prof" in the "Metrics" tab; ~ 0.1 um -> Ok*

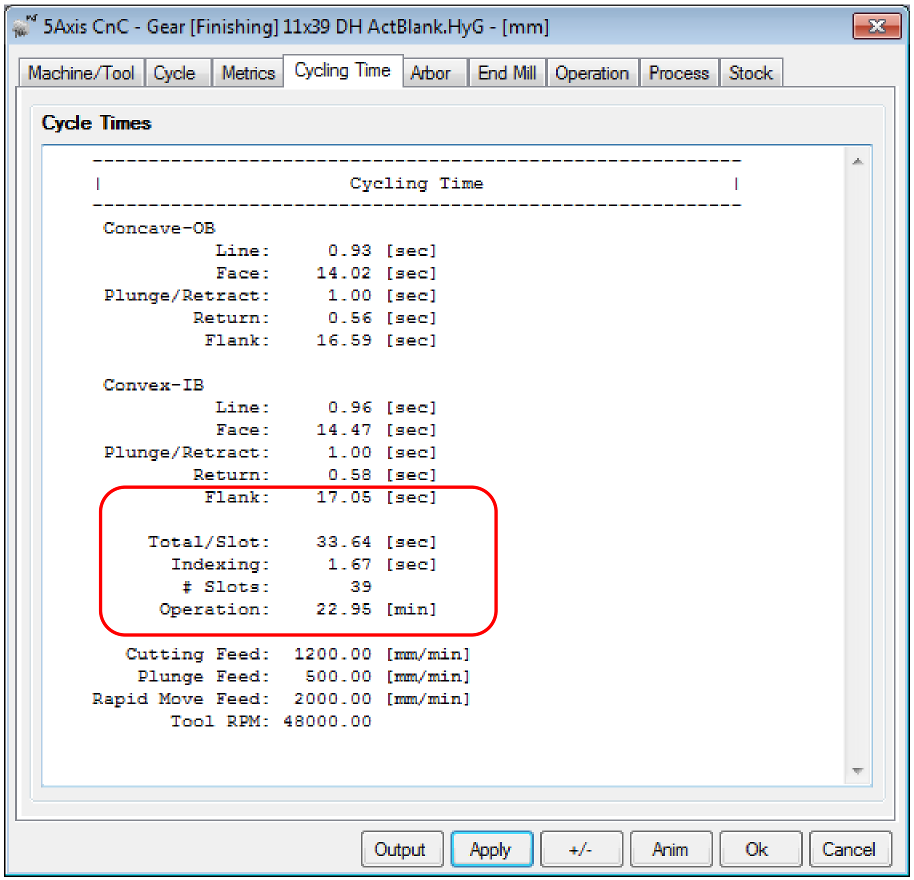


# Universal 5 Axis CnC Post-Processing

***Example:*** *4th Operation: Finish the Flank – 0.0 [mm] Stock*

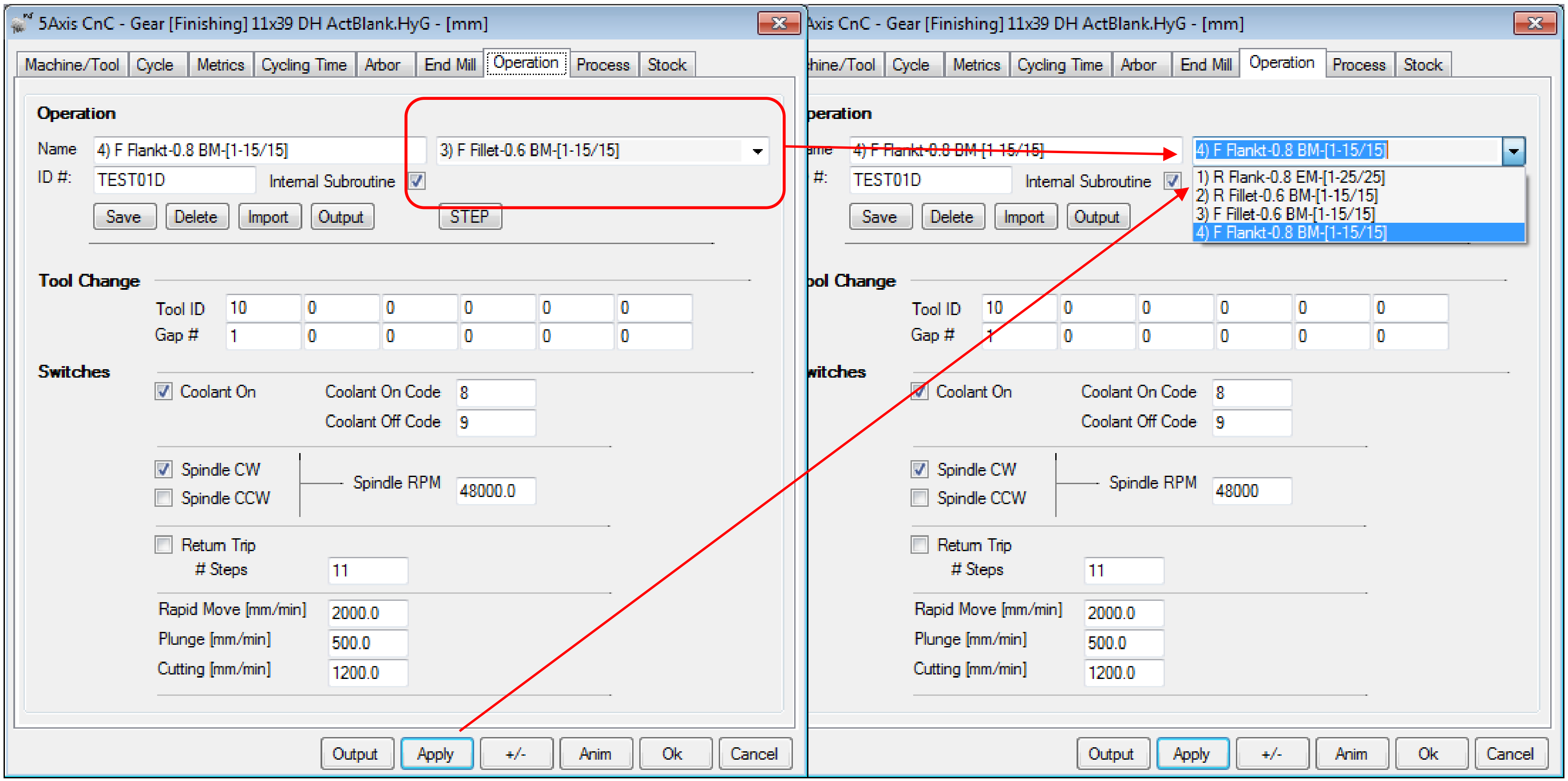
- *Select the "Cycling Time" Tab*
- *Operation time ~ 23 min.*



# Universal 5 Axis CnC Post-Processing

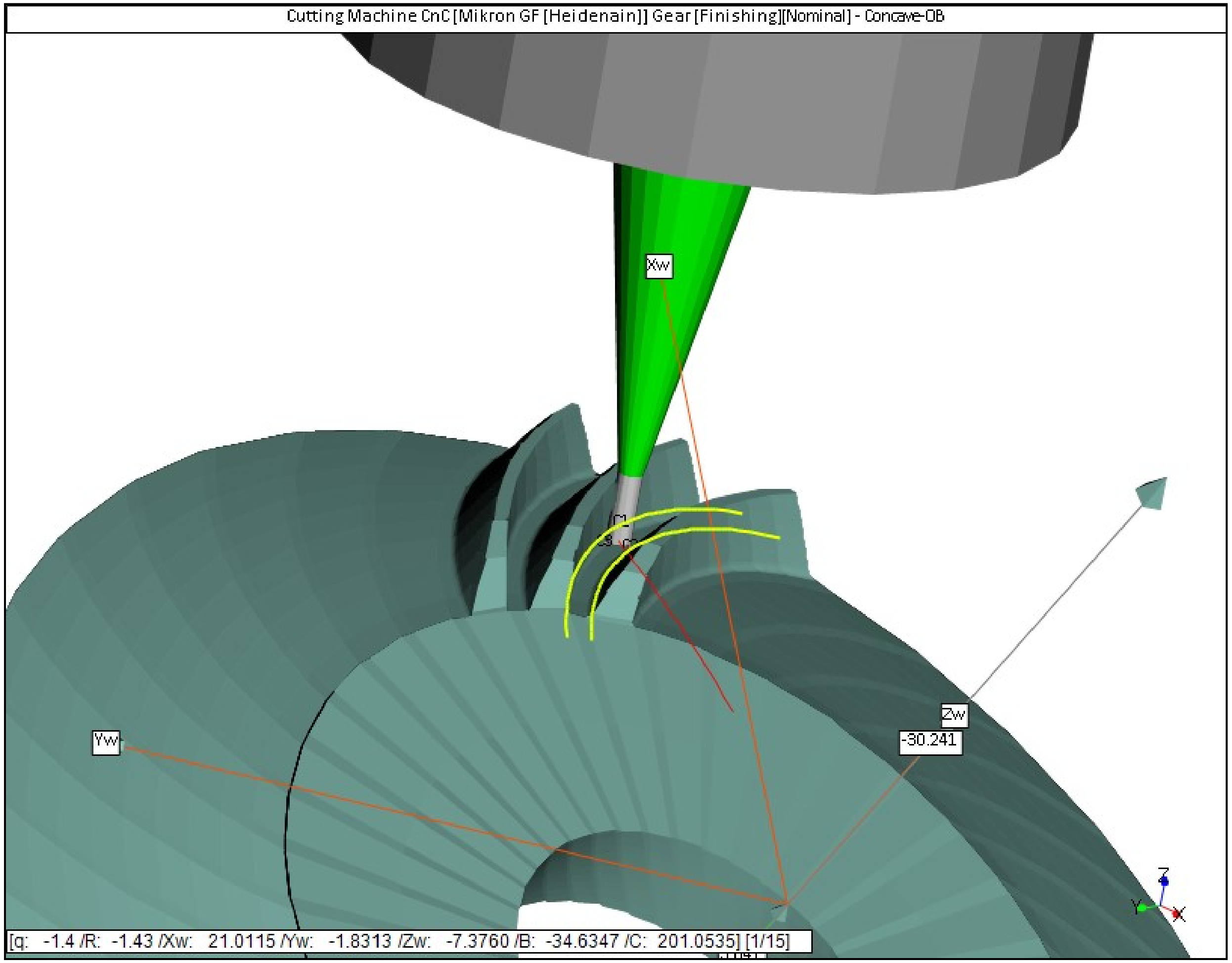
***Example:*** *4th Operation: Finish the Flank – 0.0 [mm] Stock*

- *Select the "Operation" Tab*
- *Enter the data as shown below*
- *Click on "Apply"; click on "Save"*



# Universal 5 Axis CnC Post-Processing

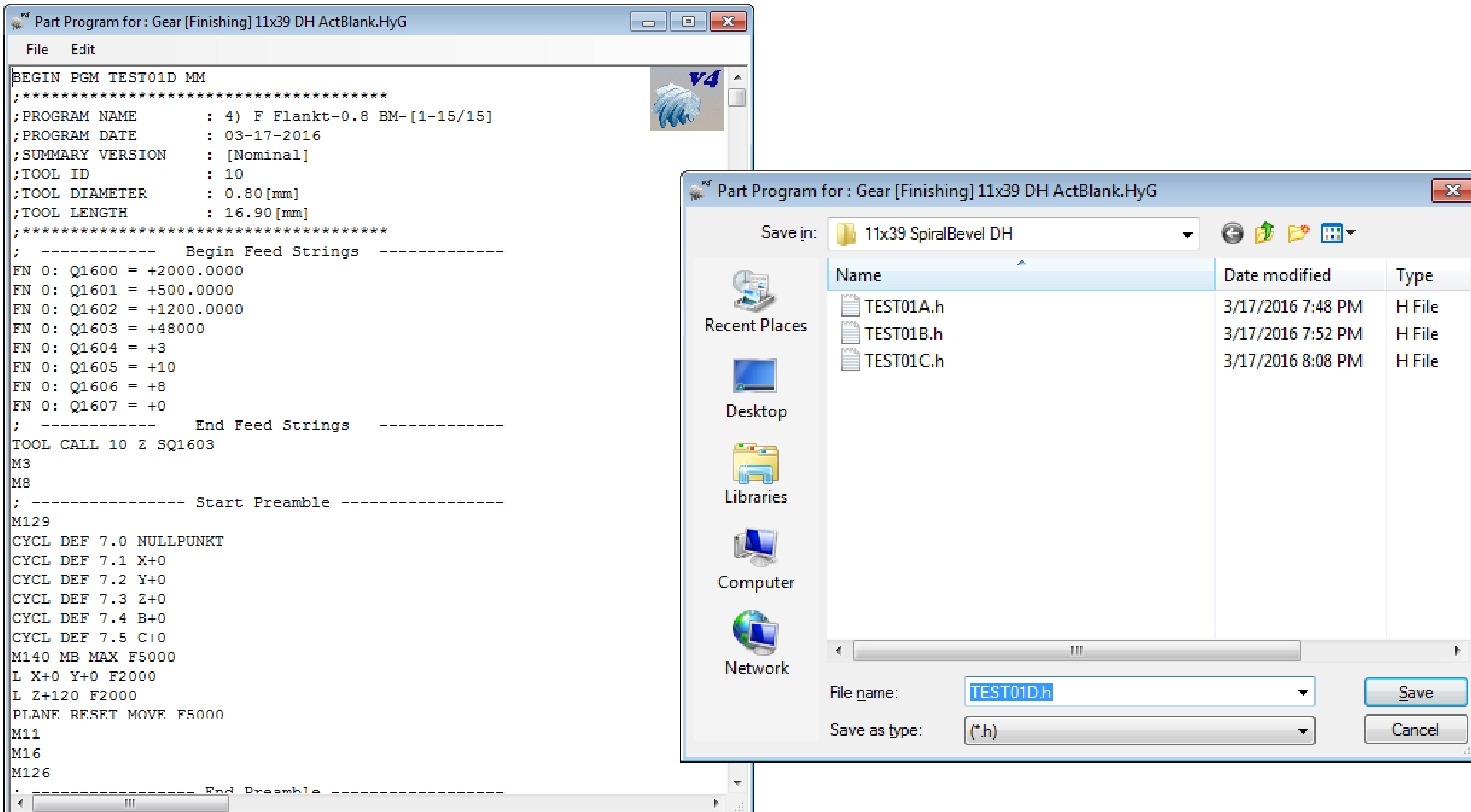
| | |
|---|---|
| ***Example:*** | *$4^{th}$ Operation: Finish the Flank – 0.0 [mm] Stock*<br>• *Visualize your Operation;*<br>• *“Anim” and / or “+/-”; Zoom in / out for better view* |



# Universal 5 Axis CnC Post-Processing

***Example:*** *4th Operation: Finish the Flank – 0.0 [mm] Stock*

- *Click on "Output" to generate the part program*
- *Click on File->Save to save your program*



# Universal 5 Axis CnC Post-Processing

***Example:*** *Save the Geometry to include the name of the current Operation*

*Total Process time:*

- *1) Rough Flank:* *~ 26 min*
- *2) Rough Fillet:* *~ 16 min*
- *3) Finish Fillet:* *~ 16 min*
- *4) Finish Flank:* *~ 23 min*

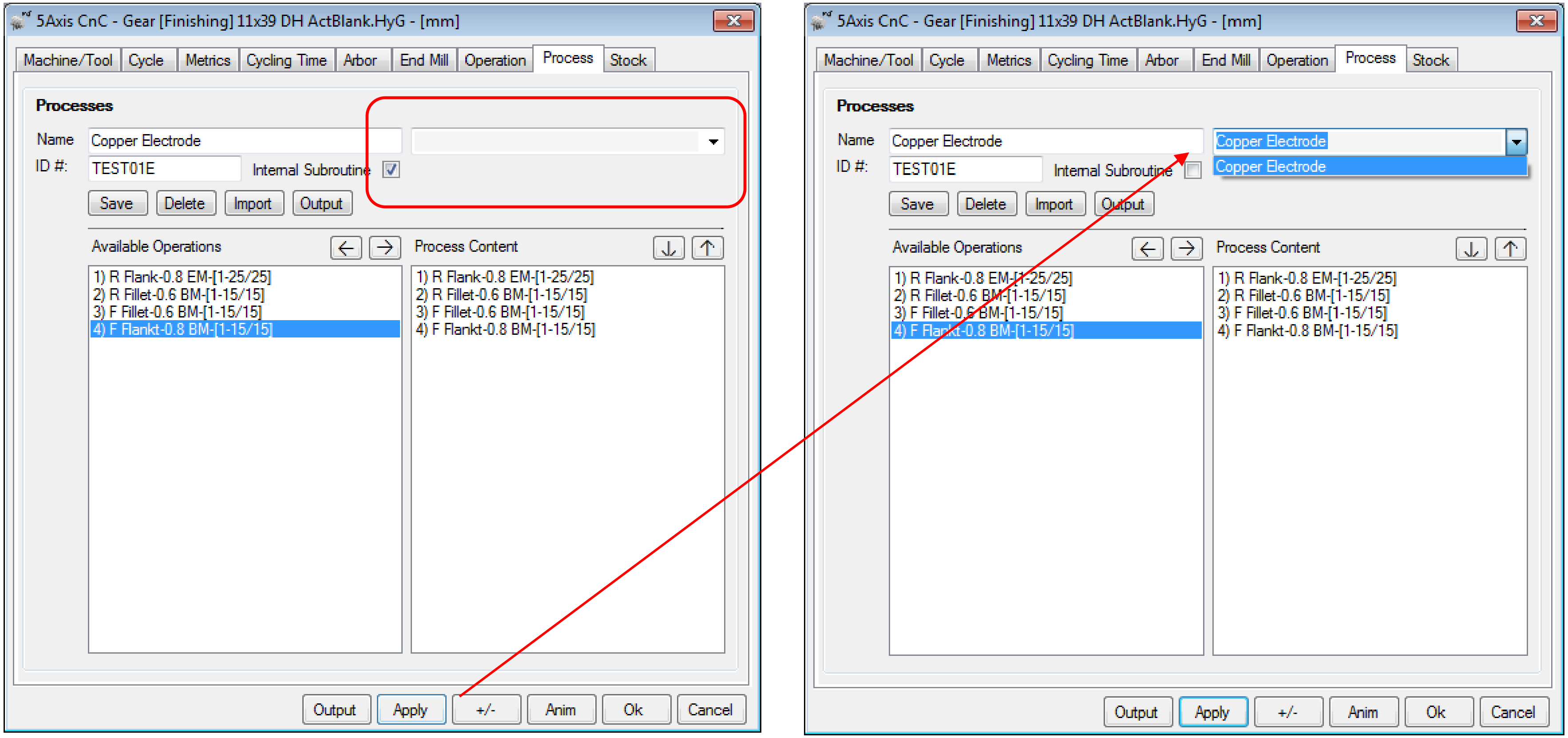
*Total:* *~ 1.35 Hour*

*Effect:* *~ 2.03 Hour (Total x ~1.5)*

# Universal 5 Axis CnC Post-Processing

***Example:*** *Create a Process*

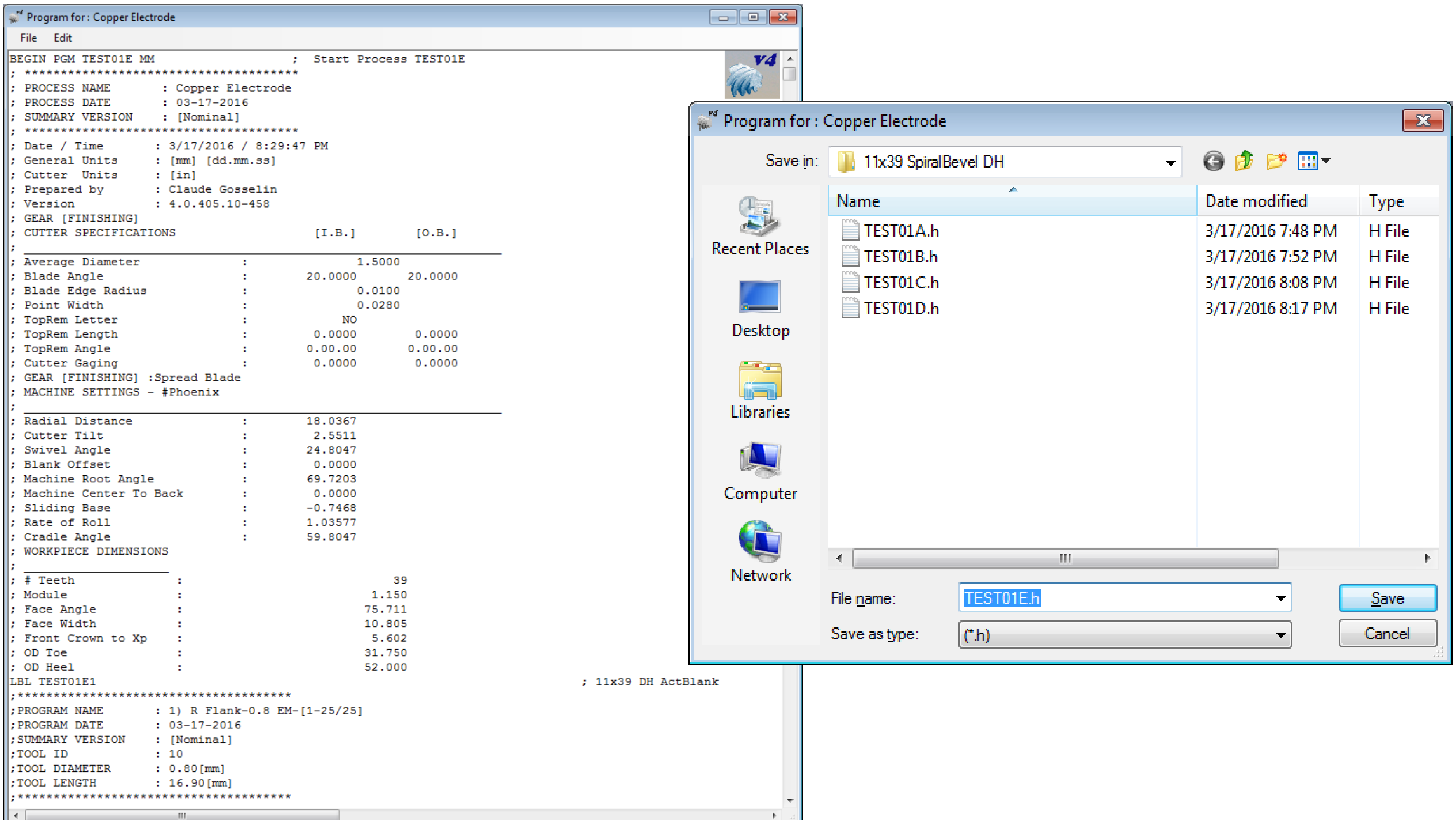
- *Select the "Process" tab*
- *Select each Operation in the desired sequence and move to Process Content*
- *Ensure "Internal Subroutine"*
- *Give a Name and ID to the Process*
- *Click on "Apply" and "Save"*



# Universal 5 Axis CnC Post-Processing

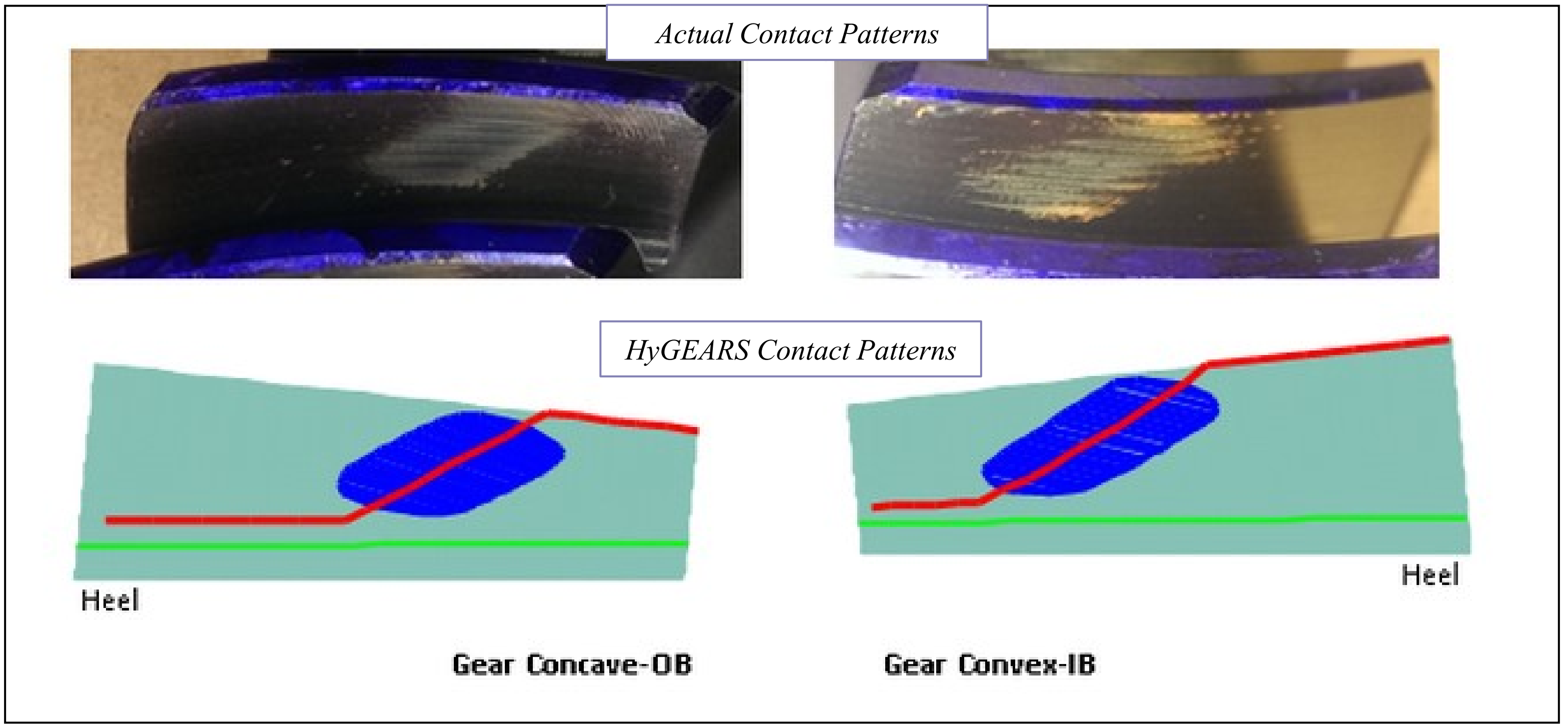
***Example:*** *Create a Process*

- *Click on "Output" to get a complete Process in 1 file*
- *Click on "File->Save" to save the Process file*



# Universal 5 Axis CnC Post-Processing

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



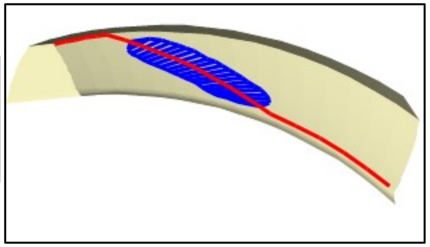
# Universal 5 Axis CnC Post-Processing

***Sample Result 1:*** *13x37 6.5 mm module, 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*

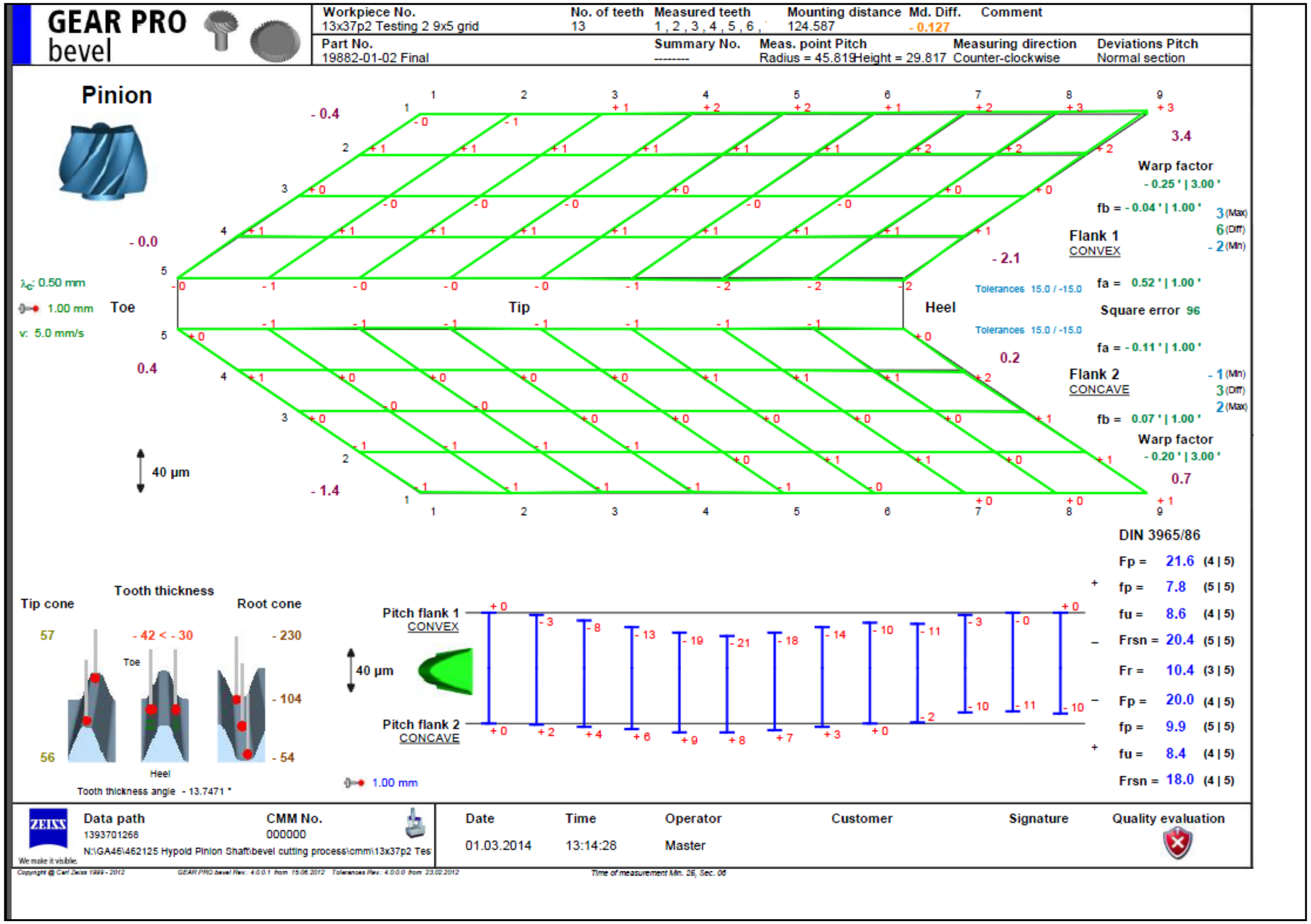
*Actual Contact Pattern*
*Pinion OB*



*HyGEARS'*
*Predicted Contact Pattern*
*Pinion OB*

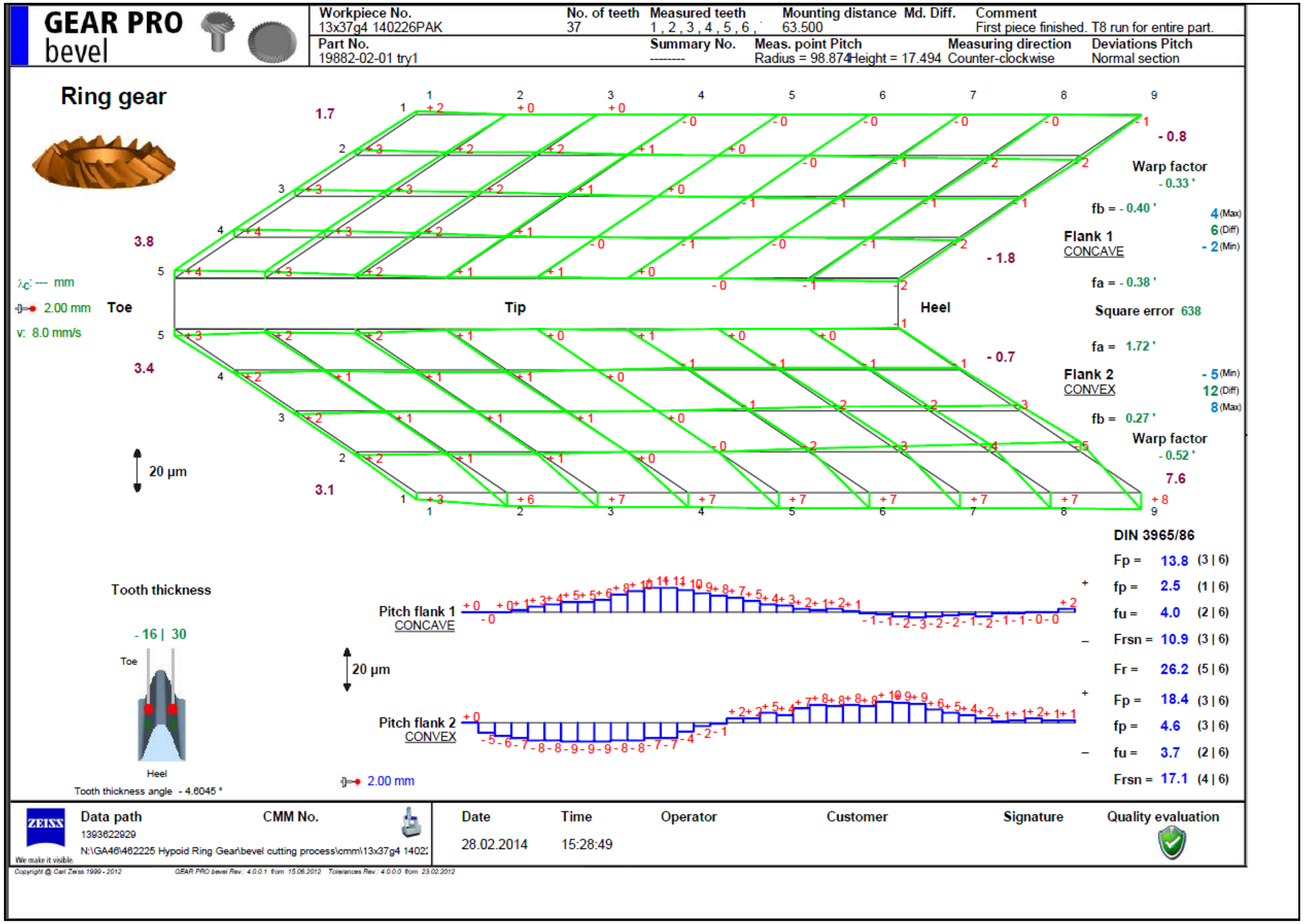
# Universal 5 Axis CnC Post-Processing

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



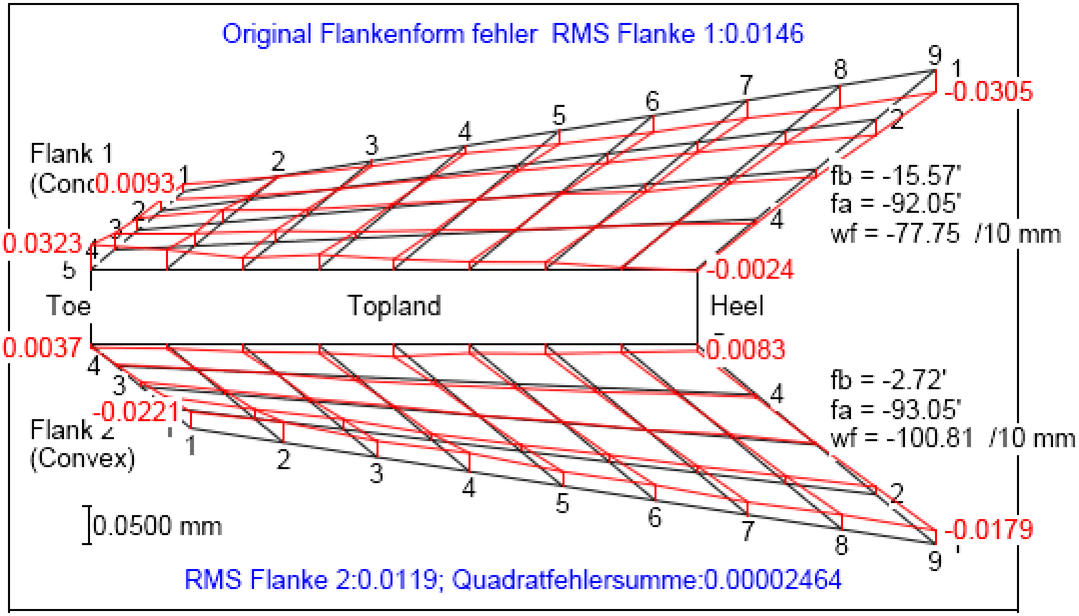
# Universal 5 Axis CnC Post-Processing

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



# Universal 5 Axis CnC Post-Processing

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



# Universal 5 Axis CnC Post-Processing

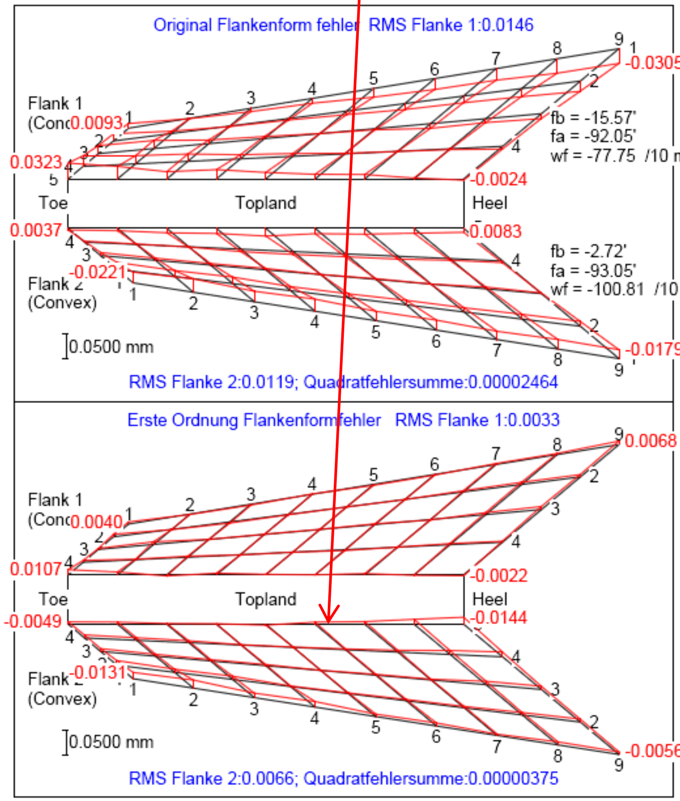
***Sample Result 2:*** *GAGE's calculated Correction data and expected residual errors after re-cut show negligible pressure and spiral angle errors, but crowning will remain on the Concave tooth flank.*

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 |



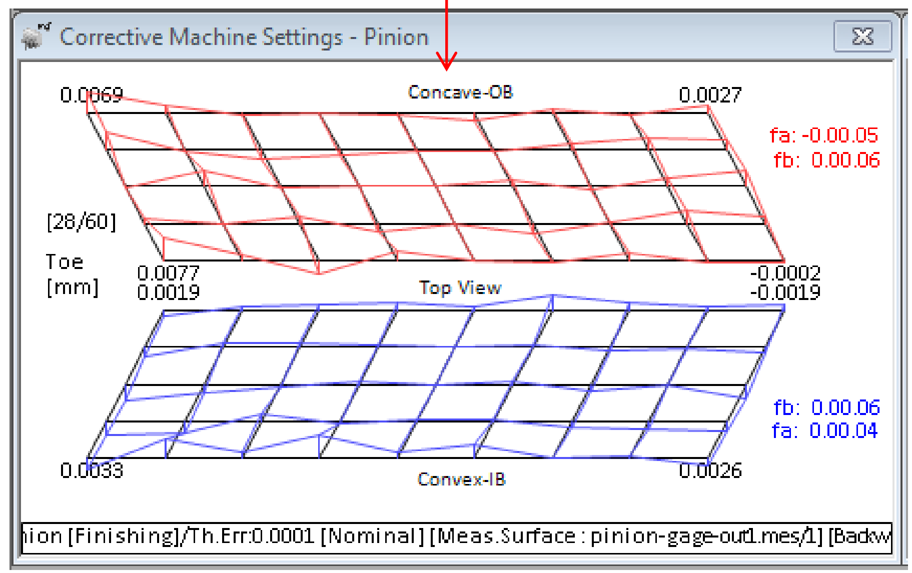
# Universal 5 Axis CnC Post-Processing

***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

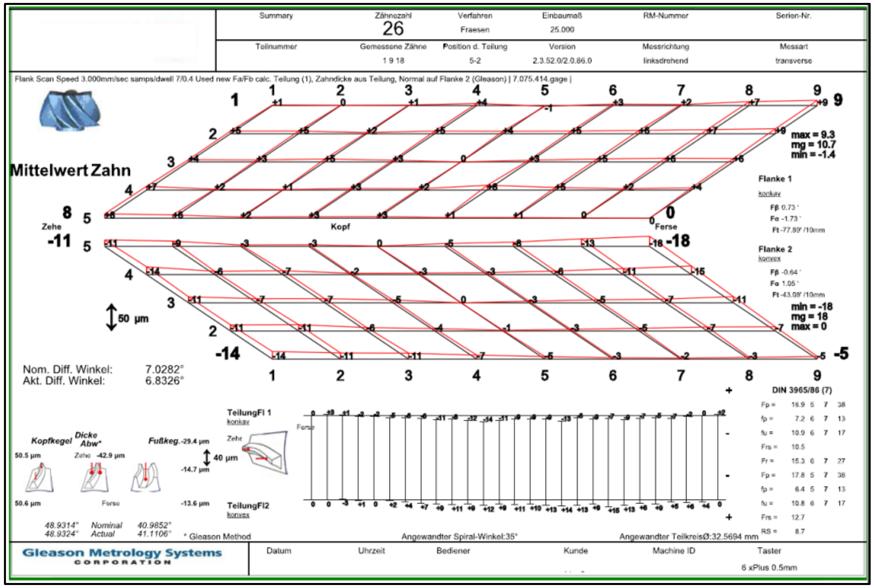
Machine Setting Changes
175U - Meas.Surface : pinion-gage-out1.mes/1
Pinion [Finishing] [2/2] [Backward]

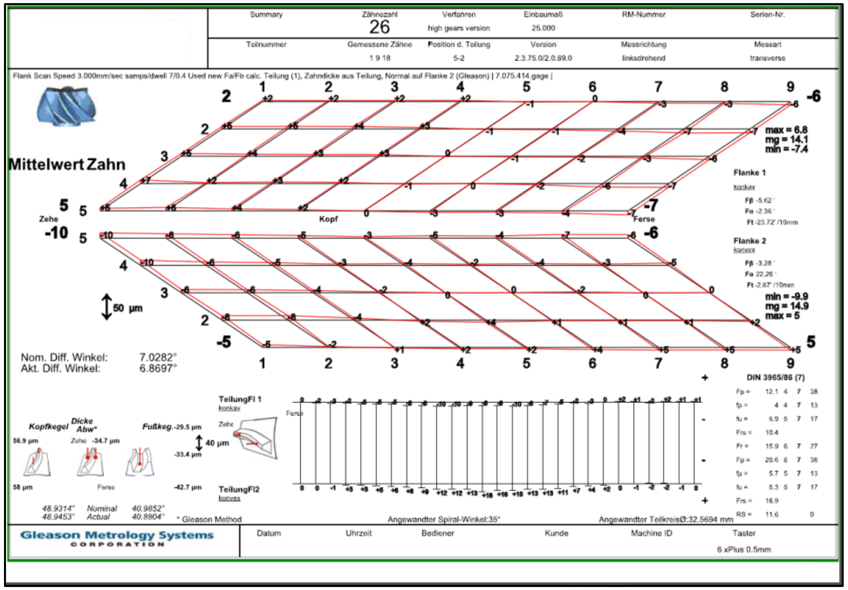
| 2nd Order Changes | | (O.B.) | (I.B.) |
|---|---|---|---|
| Radial Distance | : | 0.1969 | |
| Cutter Tilt | : | 0.2661 | |
| Swivel Angle | : | -0.8929 | |
| Blank Offset | : | 0.2178 | |
| Machine Root Angle | : | -360.0001 | |
| Machine Center To Back | : | -0.3698 | |
| Sliding Base | : | -0.0545 | |
| 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 | | | |



# Universal 5 Axis CnC Post-Processing

***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*

# Universal 5 Axis CnC Post-Processing

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 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. *Geometries 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 the many 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 and Fanuc;*
10. *Part programs can be in* ***Machine coordinates, Work piece coordinates*** *with axis angles, or Work piece coordinates with tool axis vector (****Traori, TCPM*** *and* ***TCP****);*

# Universal 5 Axis CnC Post-Processing

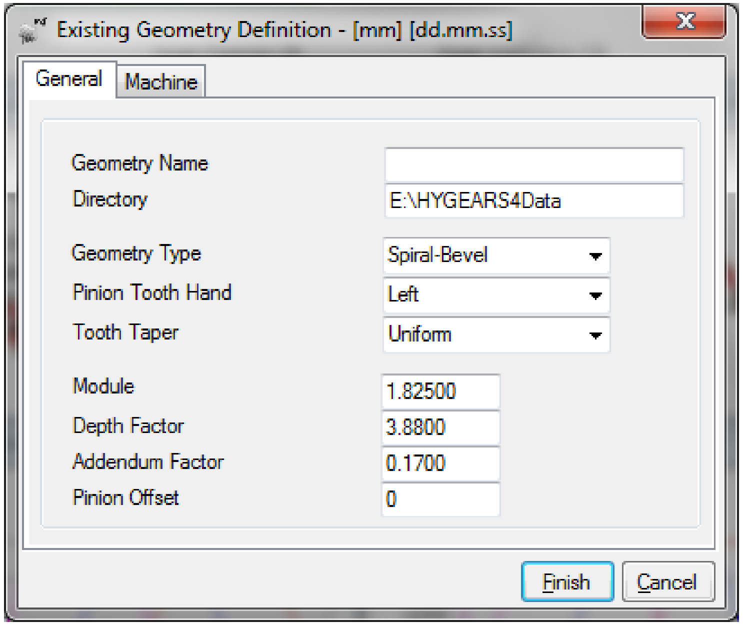
11. *Users can **define their own tool box** for Face Mill, CoSIMT, End Mill and Ball Mill tools;*
12. *Cutting Cycles include **Slot by Slot** and **Flank by Flank**, both for tooth flank and fillet; tip chamfering is available;*
13. ***Animations and single stepping** allow the visualization of tool 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 optimized to minimize "flats", "peaks"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. *A **"Roughing mode"** moves the selected tool in the center of the gap to quickly remove as much material as possible;*
18. ***"Operations"**, including all user selections for a given task, may be saved for later re-use;*
19. ***Closed Loop**, also called Corrective Machine Settings, is **integral to HyGEARS** and allows the seamless manufacture of gears to the required tolerances.*
20. *The **HyGEARS** Closed Loop corrections match (and in some respect are better than) those of Gleason's GAGE.*

# Inputting an *Existing* Geometry

HyGEARS allows the *direct input of existing **Face Hobbing** summaries* through the Existing Geometry Definition Window coupled to the Geometry Summary Editor.

The Existing Geometry Definition Window offers input fields and *navigation tools to input the needed parameters*.

The Existing Geometry can be *processed at once, and saved in a file* for later retrieval.



# Graphic Display Functions (User Mode)

The displayed **geometry**;

**Teeth and machines**;

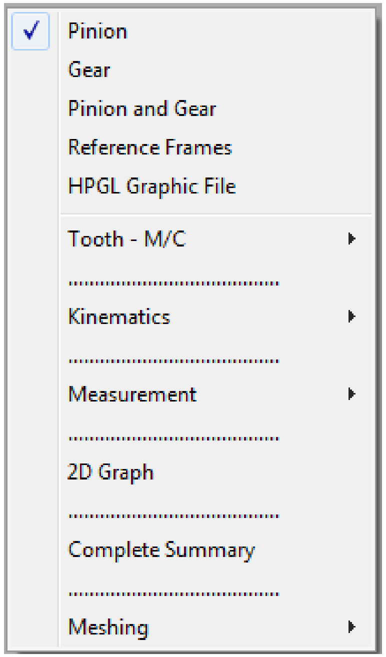
**Kinematics** and Contact Pattern;

Surface **measurement**

Kinematic results in **2D Graphs**

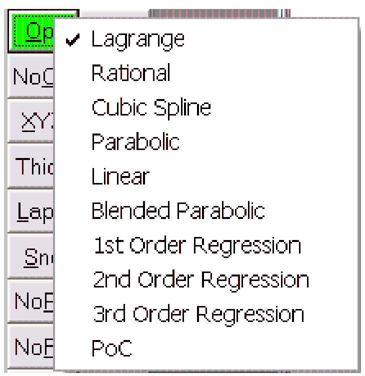
**Complete Summary** macro function

**Finite Element** Meshing / **Finite Strips**.



# Graphic Display Functions

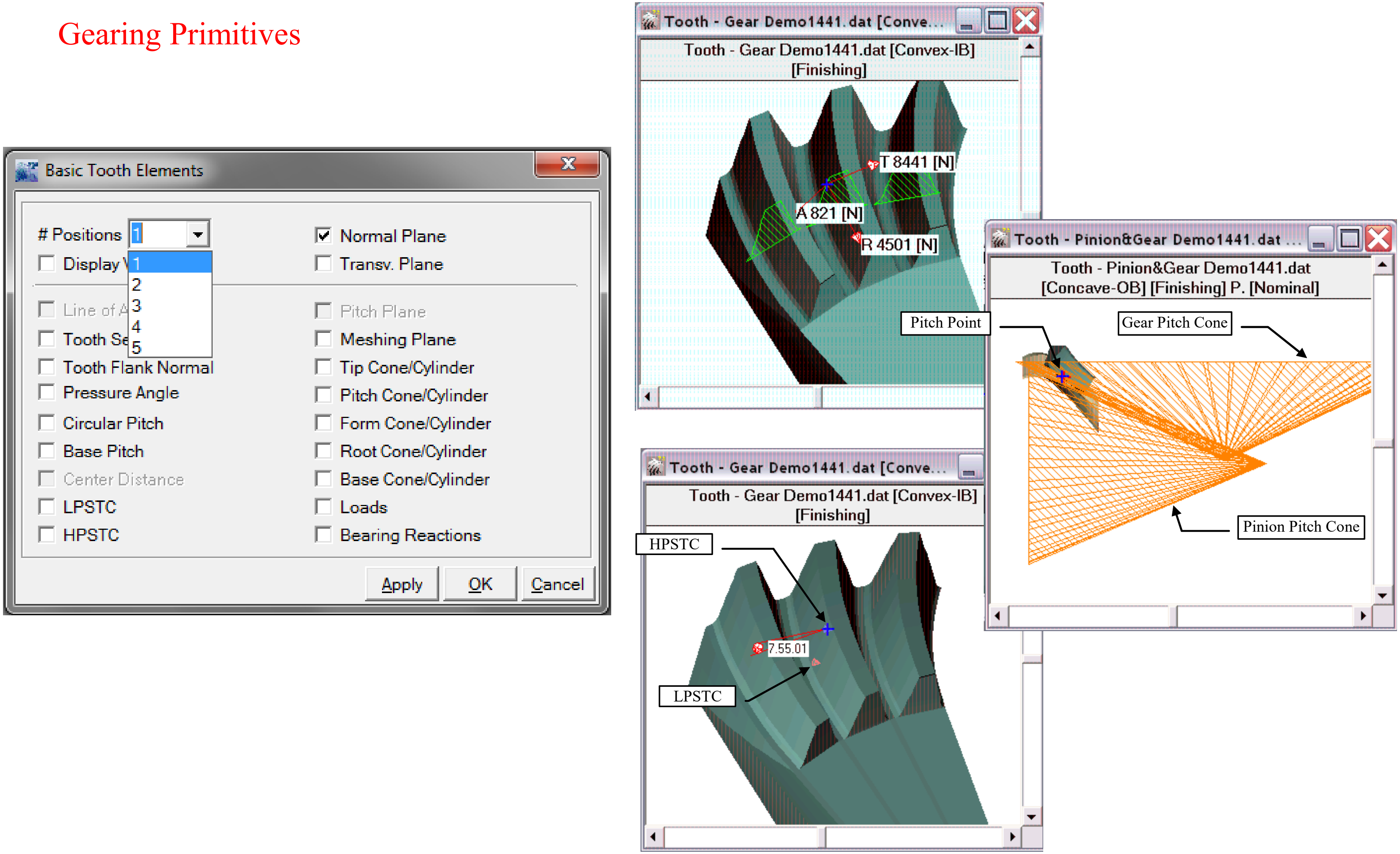
Interpolation Options (with Error Surface)




| Interpolator Name | Order of Preference |
|---|---|
| Lagrange | N/R |
| Rational | N/R |
| Cubic Spline | # 4 |
| Parabolic | # 2 |
| Linear | # 1 |
| Blended Parabolic * | N/R |
| 1st Order Regression | # 3 |
| 2nd Order Regression | N/R |
| 3rd Order Regression | N/R |

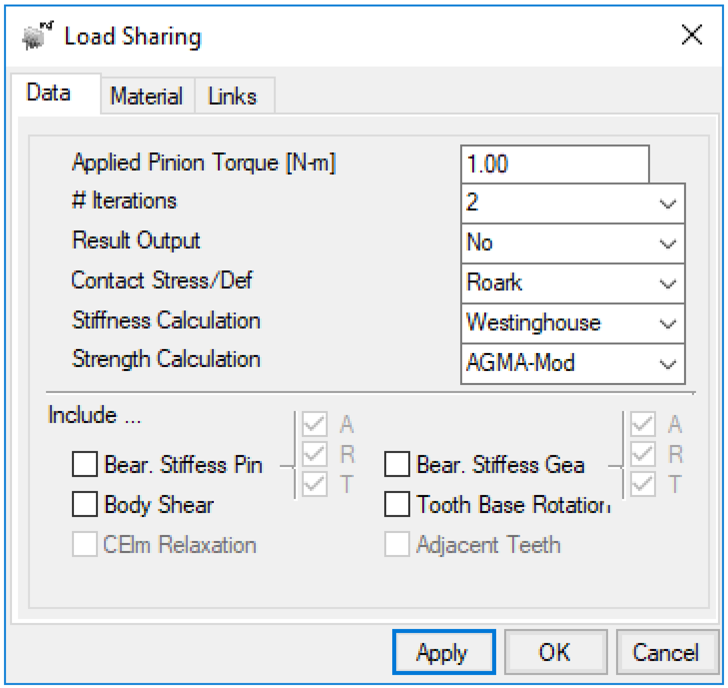
# Graphic Display Functions

Gearing Primitives



# Graphic Display Functions

LTCA Editor




Stiffness Calculation:

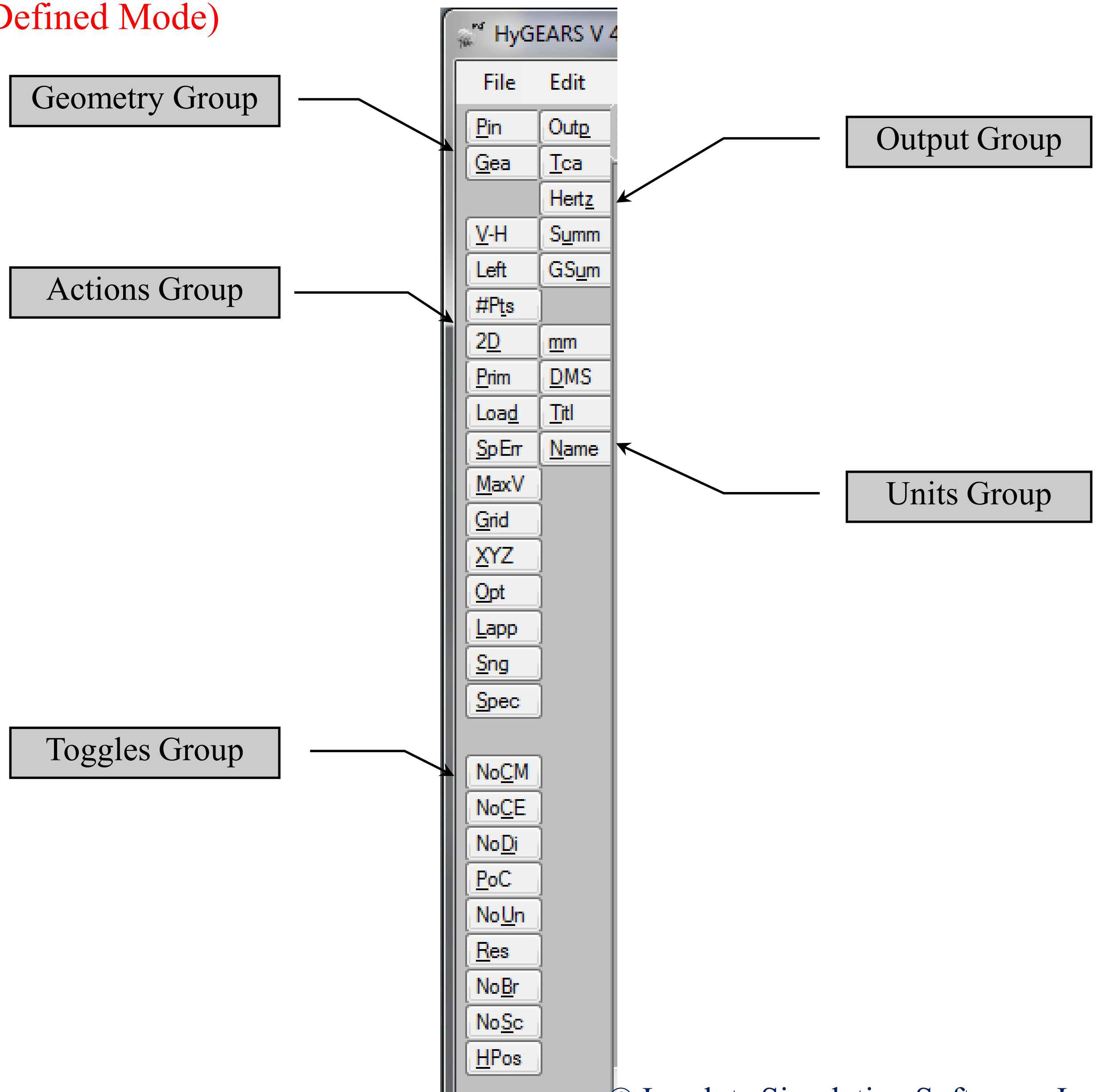
- Westinghouse formula,
- Nakada formula,
- Finite Strips (option).

Strength Calculation:

- AGMA-Mod (J factor at each contact point),
- AGMA ("),
- Aida and Terauchi,
- Finite Strips (option).

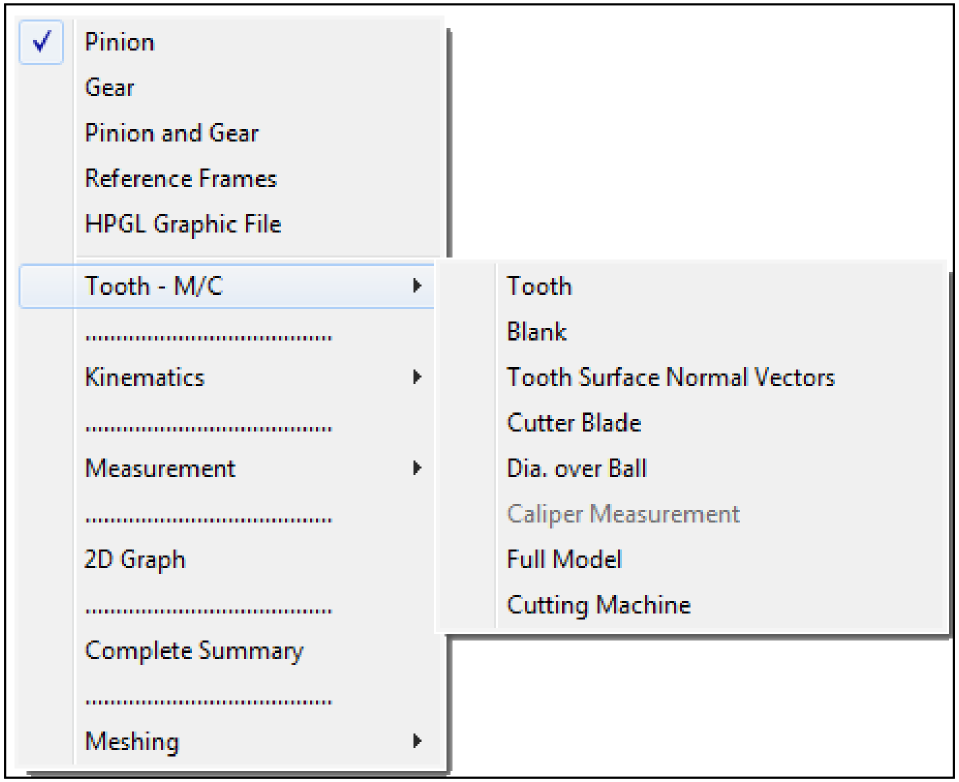
# Graphic Display Functions

Function Buttons (User Defined Mode)



# Graphic Display Functions

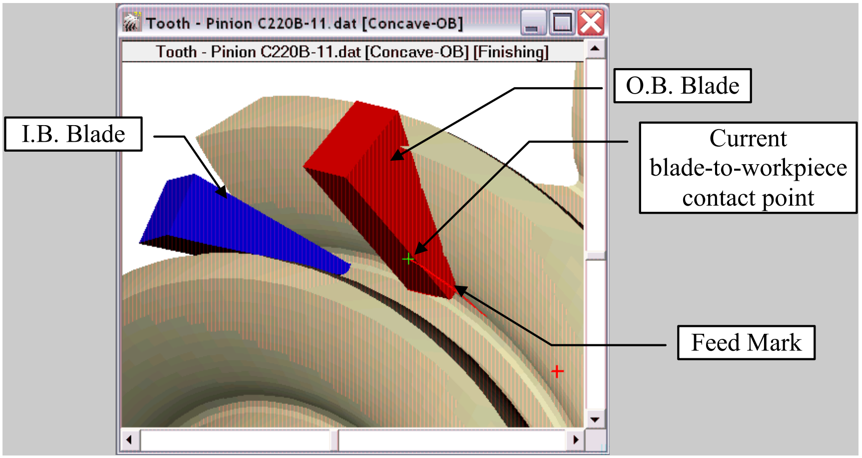
*Teeth and Machine*



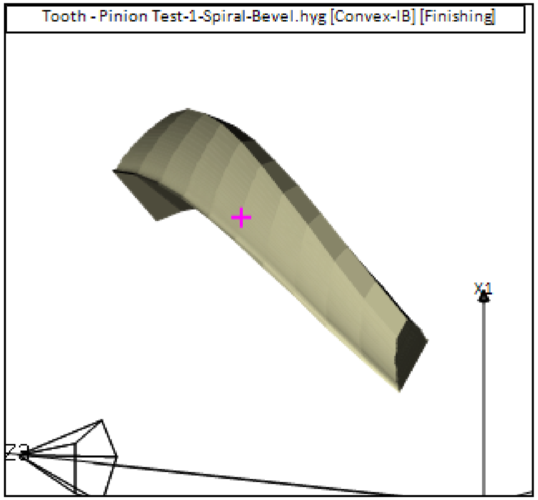
# Graphic Display Functions

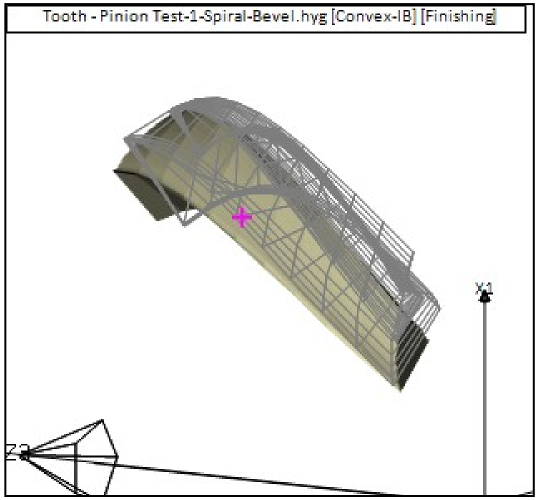
*Tooth – M/C -> Tooth Child Window*

Blade animation (FH only)



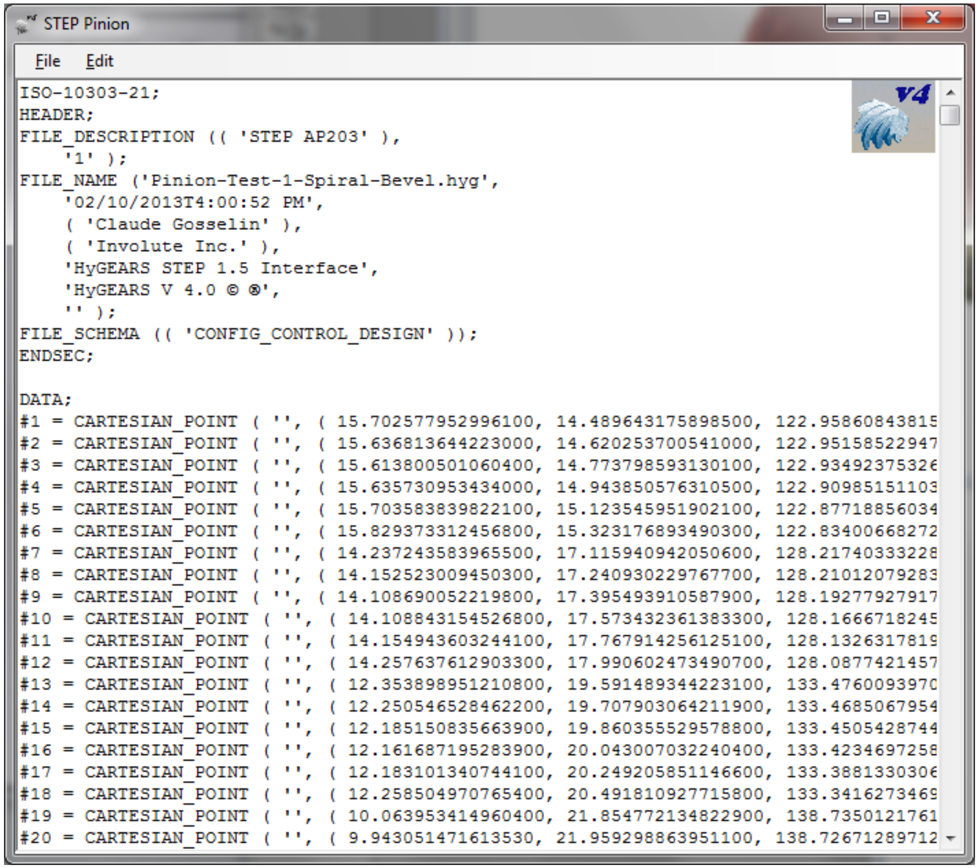

Finish + rough (fixed setting)



# Graphic Display Functions

*Tooth – M/C -> Tooth Child Window*



STEP Pinion

File Edit

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    '1' );
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    '02/10/2013T4:00:52 PM',
    ( 'Claude Gosselin' ),
    ( 'Involute Inc.' ),
    'HyGEARS STEP 1.5 Interface',
    'HyGEARS V 4.0 © ®',
    '' );
FILE_SCHEMA (( 'CONFIG_CONTROL_DESIGN' ));
ENDSEC;

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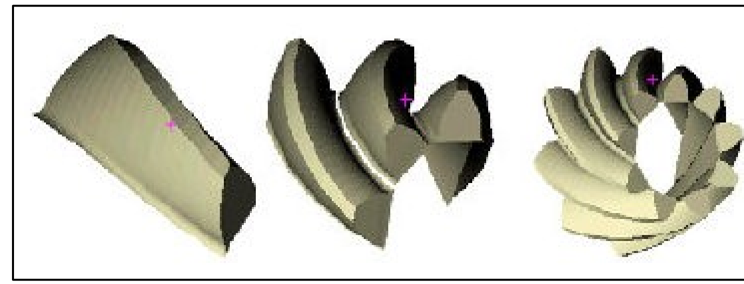
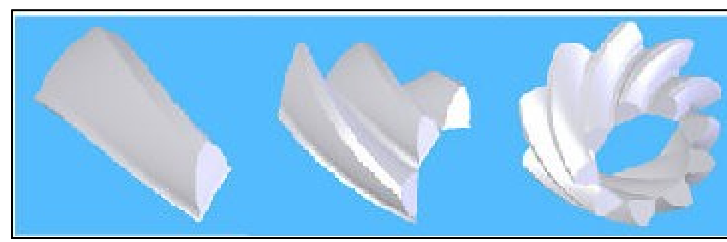
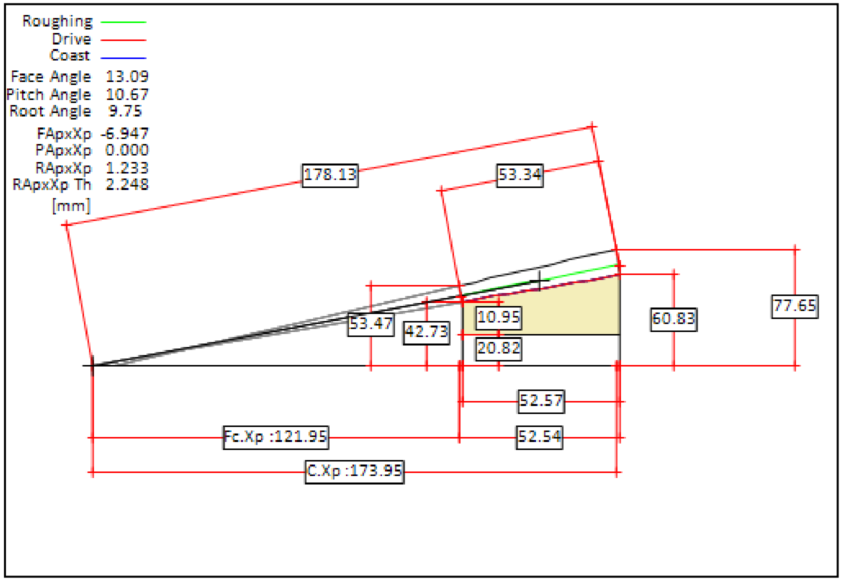


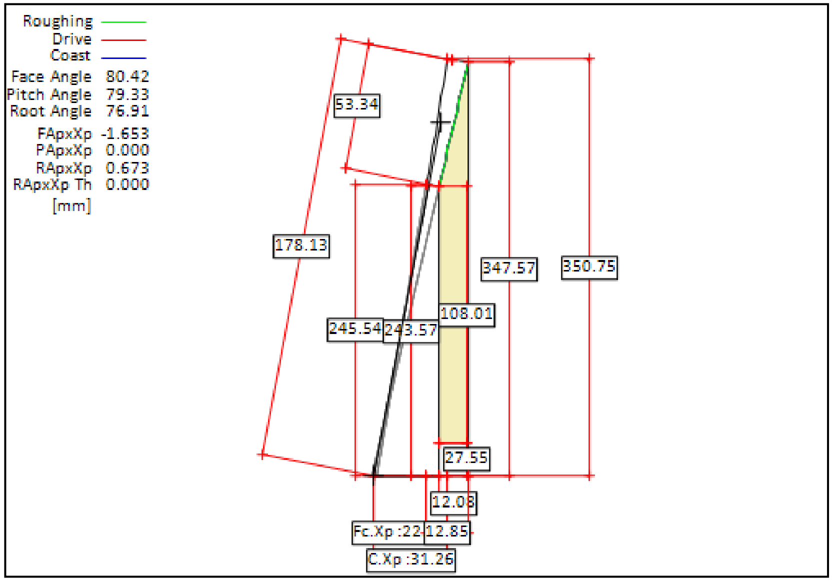


STEP Output -> Export to CadCam

# Graphic Display Functions

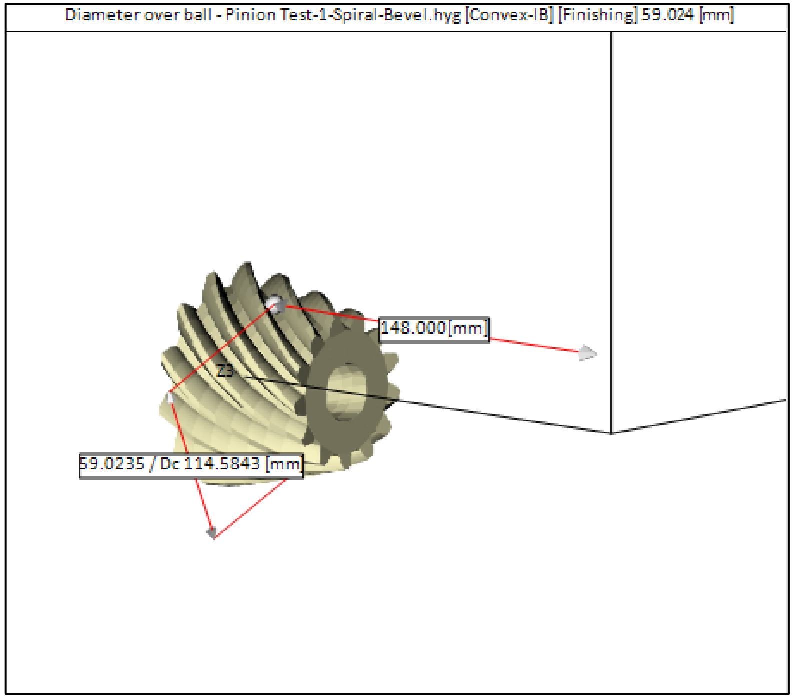
*Tooth – M/C -> Blank Child Window*

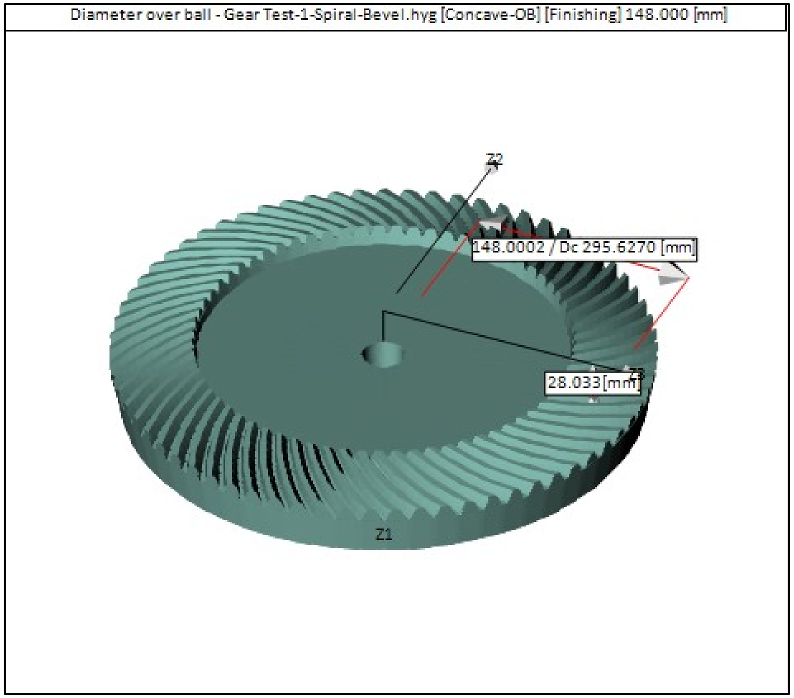


# Graphic Display Functions

*Tooth – M/C -> Dia. over Balls Child Window – Bevel gears*



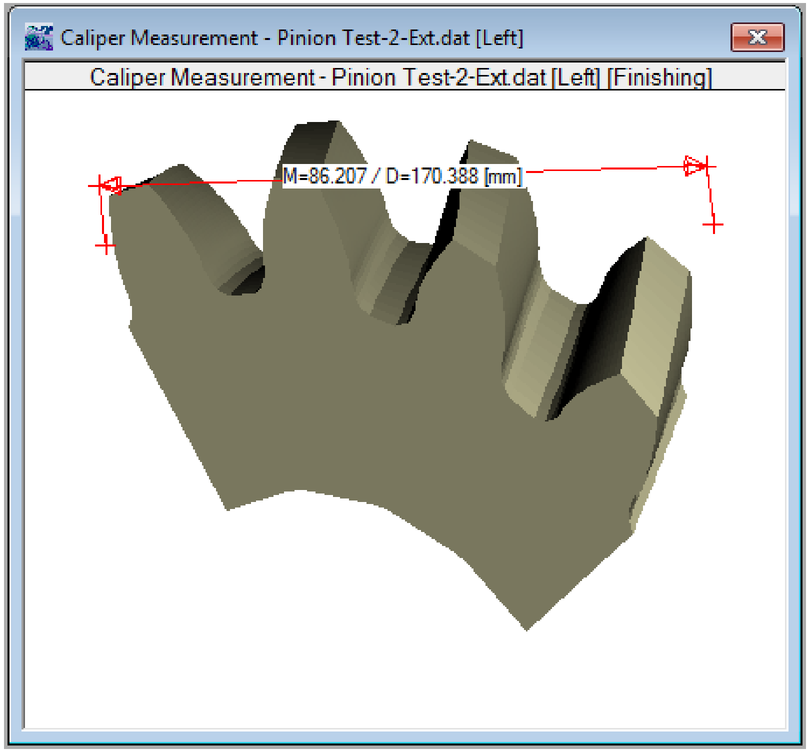




Give Ball dia. + distance -> Get Dia over Balls

Give Ball dia. + Diameter -> Get distance

# Graphic Display Functions

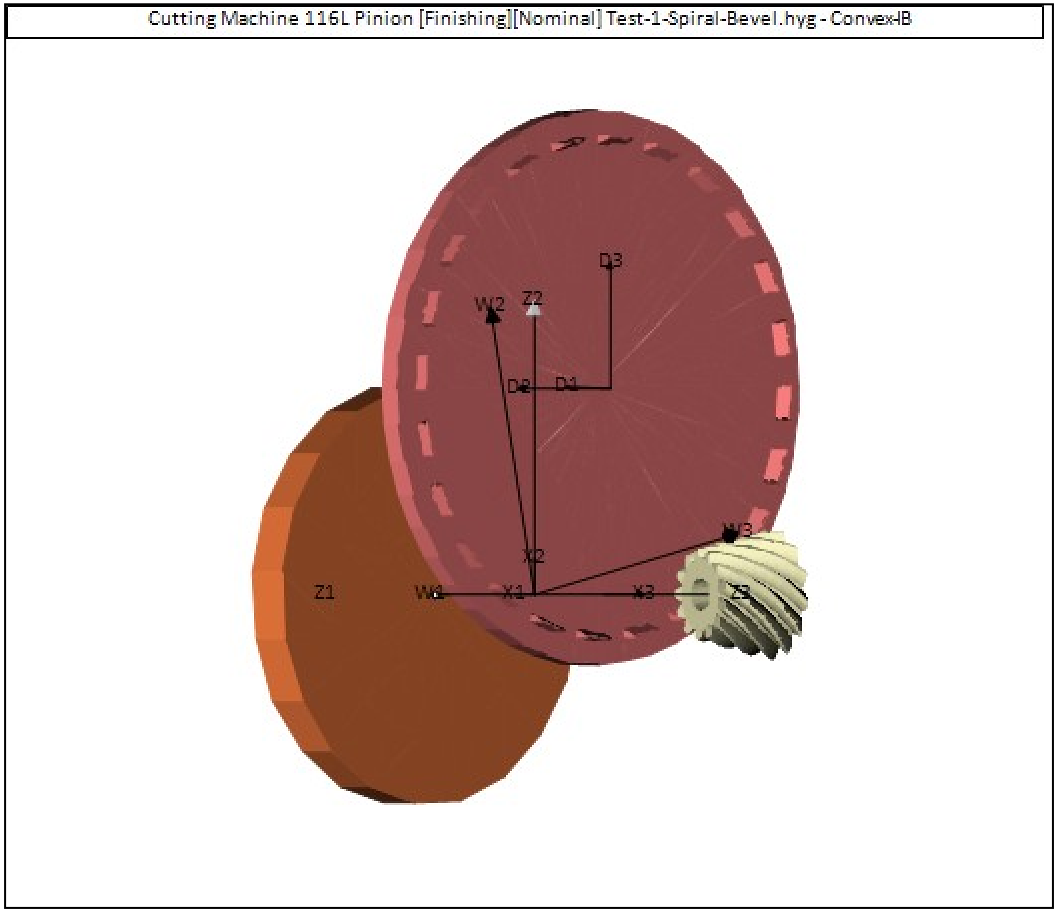
*Tooth – M/C -> Caliper Measurement Child Window – Cylindrical gears*




Give # Teeth -> Get measurement

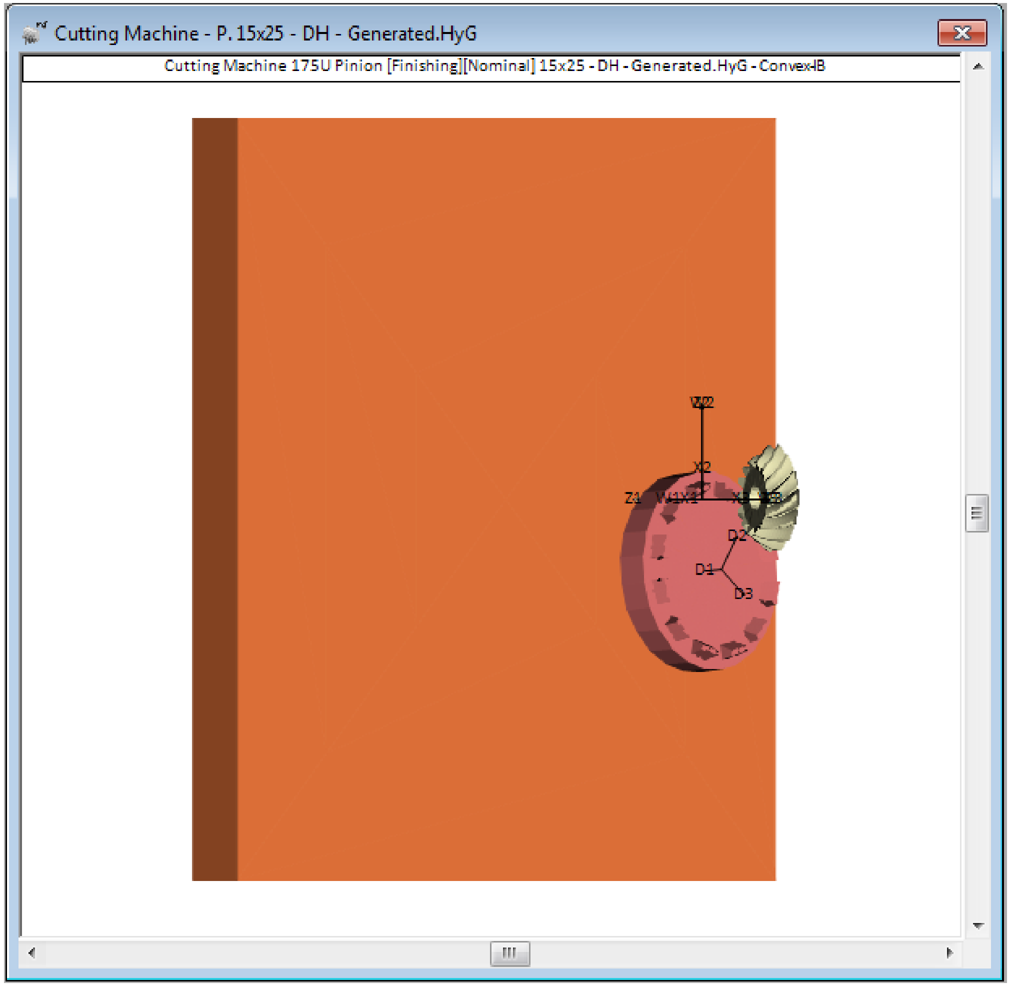
# Graphic Display Functions

*Tooth – M/C -> Cutting Machine Child Window -> Conventional Generator*



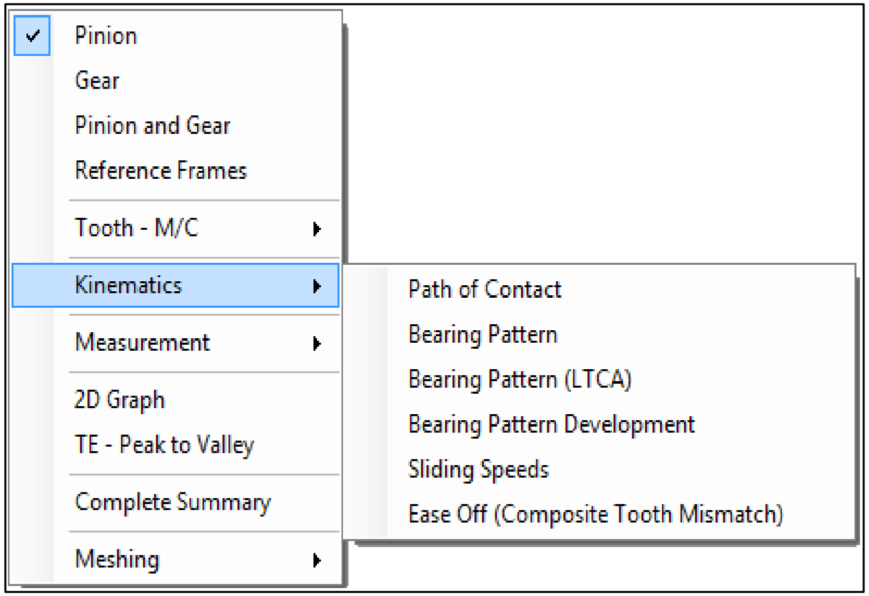
# Graphic Display Functions

*Tooth – M/C -> Cutting Machine Child Window -> Phoenix Generator*



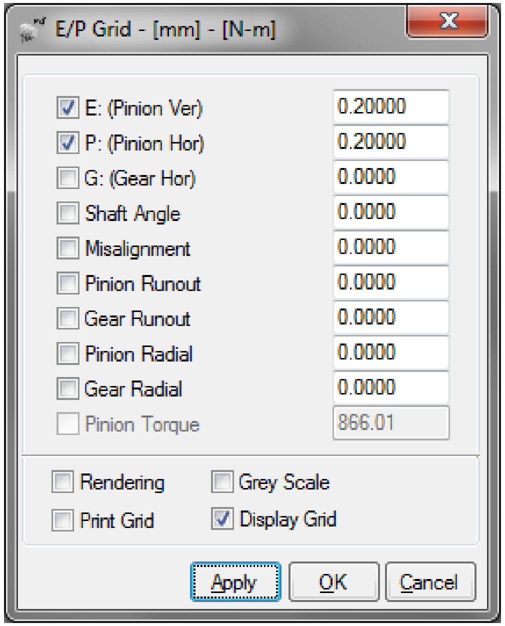
# Graphic Display Functions

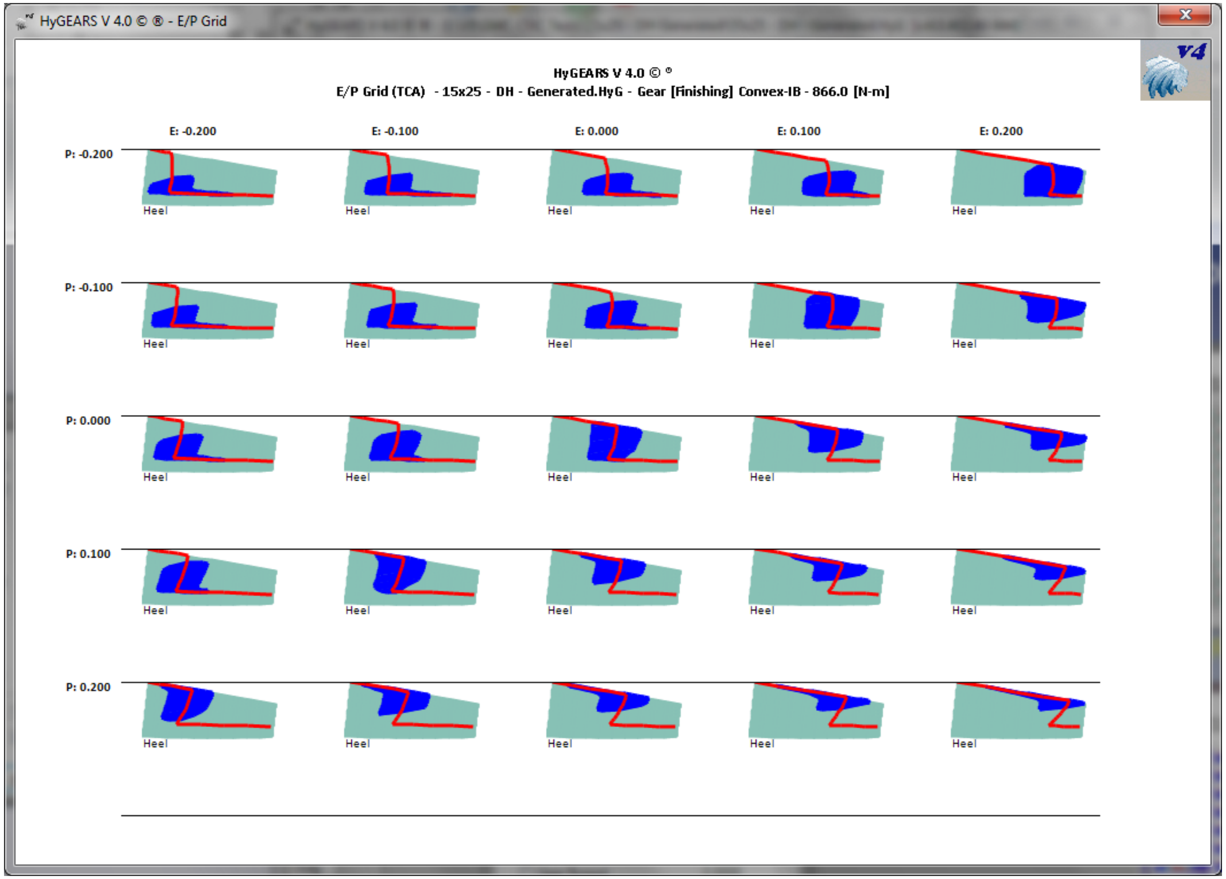
*Kinematics and Contact Pattern*



# Graphic Display Functions

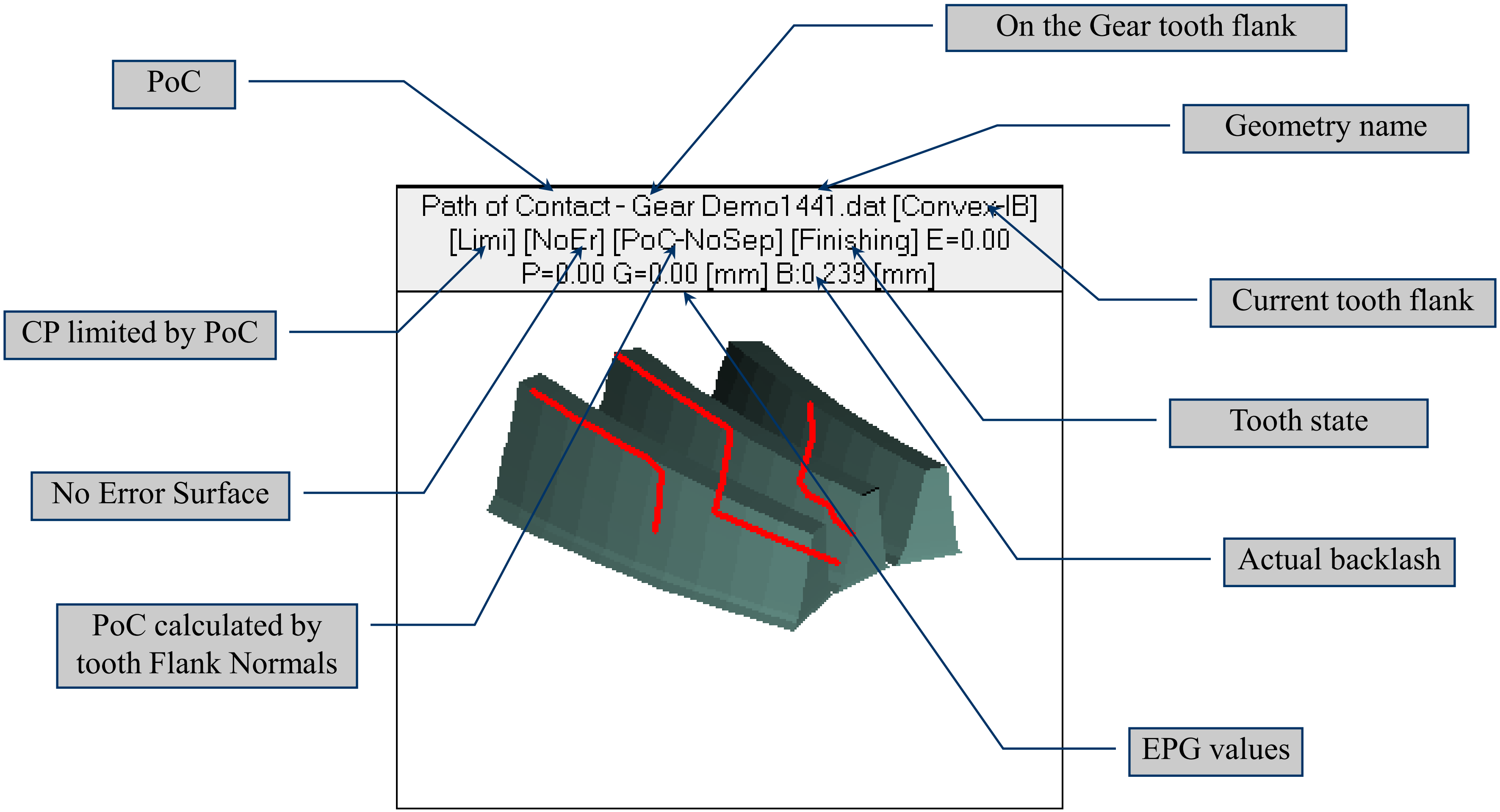
*Kinematics -> E/P Grids*



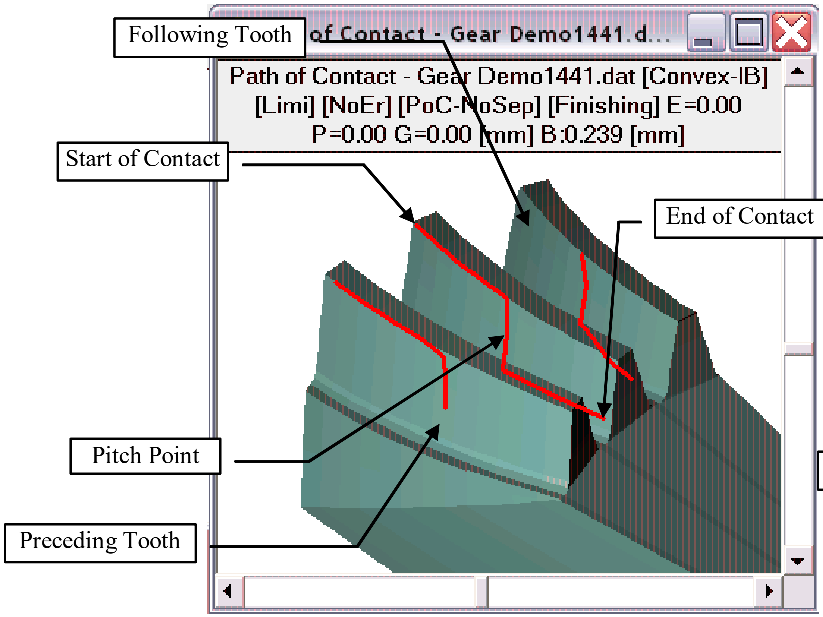
# Graphic Display Functions

*Kinematics -> Path of Contact Child Window*

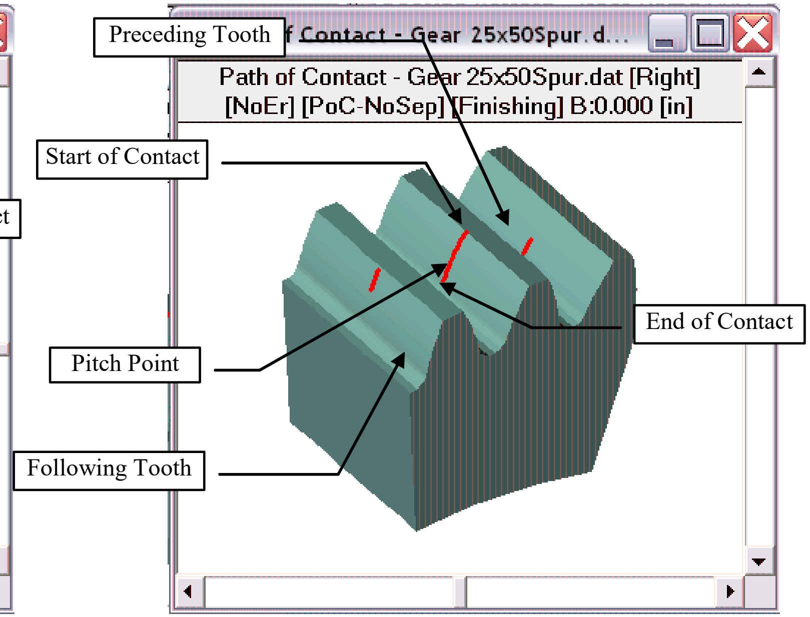


# Graphic Display Functions

*Kinematics -> Path of Contact Child Window*



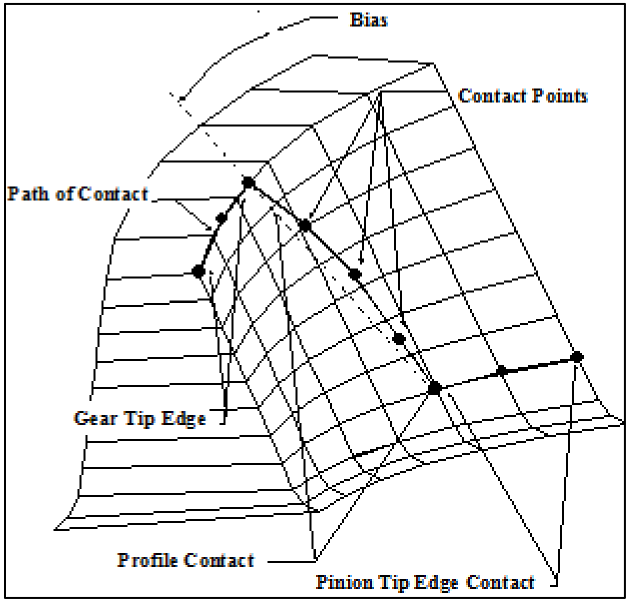

PoC on Hypoid gear



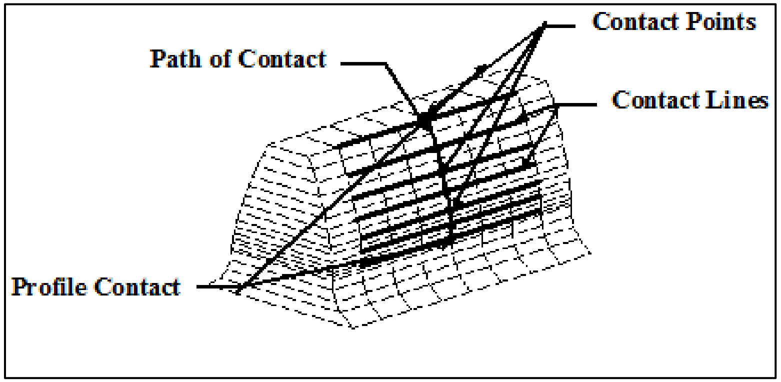

PoC on Spur gear

# Graphic Display Functions

*Kinematics -> Path of Contact Child Window*



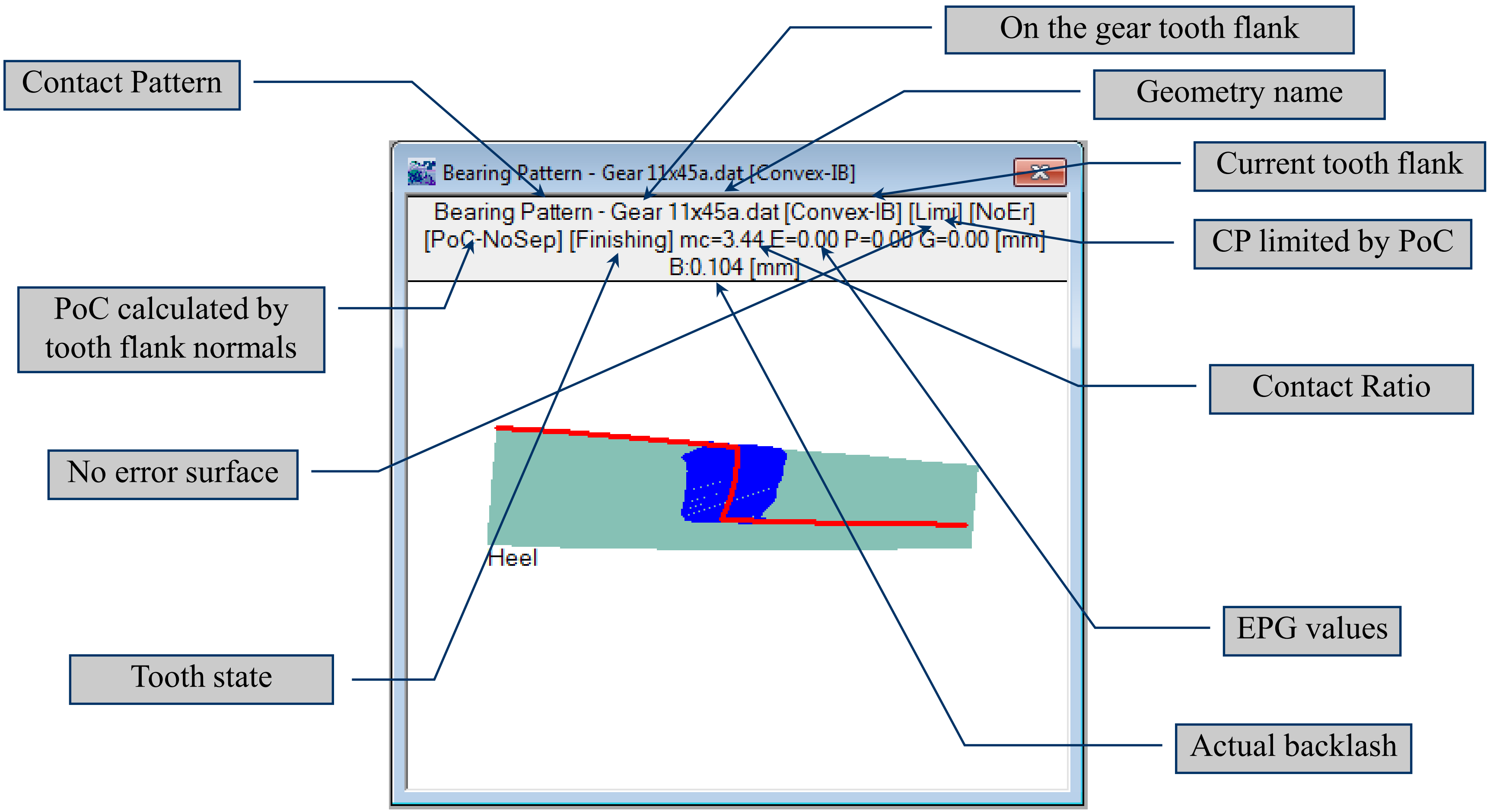

PoC on Hypoid gear




PoC on Spur gear

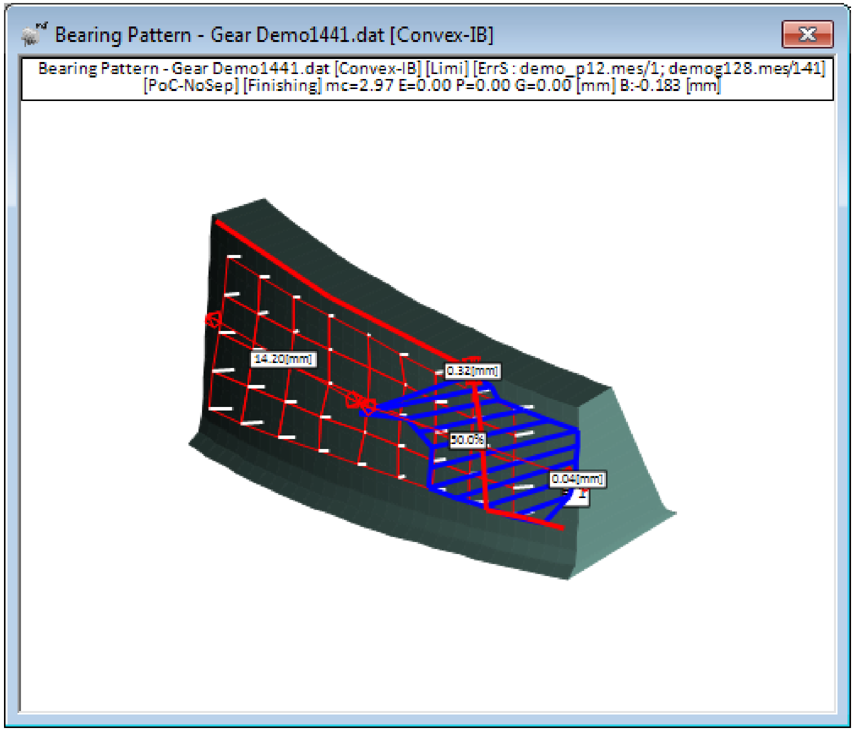
# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*



# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*




Relationship between Error Surface and CP

# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*

Example: Use the Demo1441.dat geometry, for the Gear.

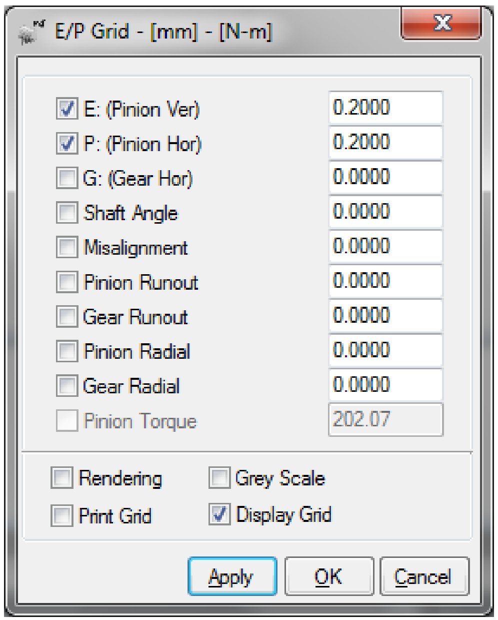
Test the following Contact Pattern child window function buttons, one by one :

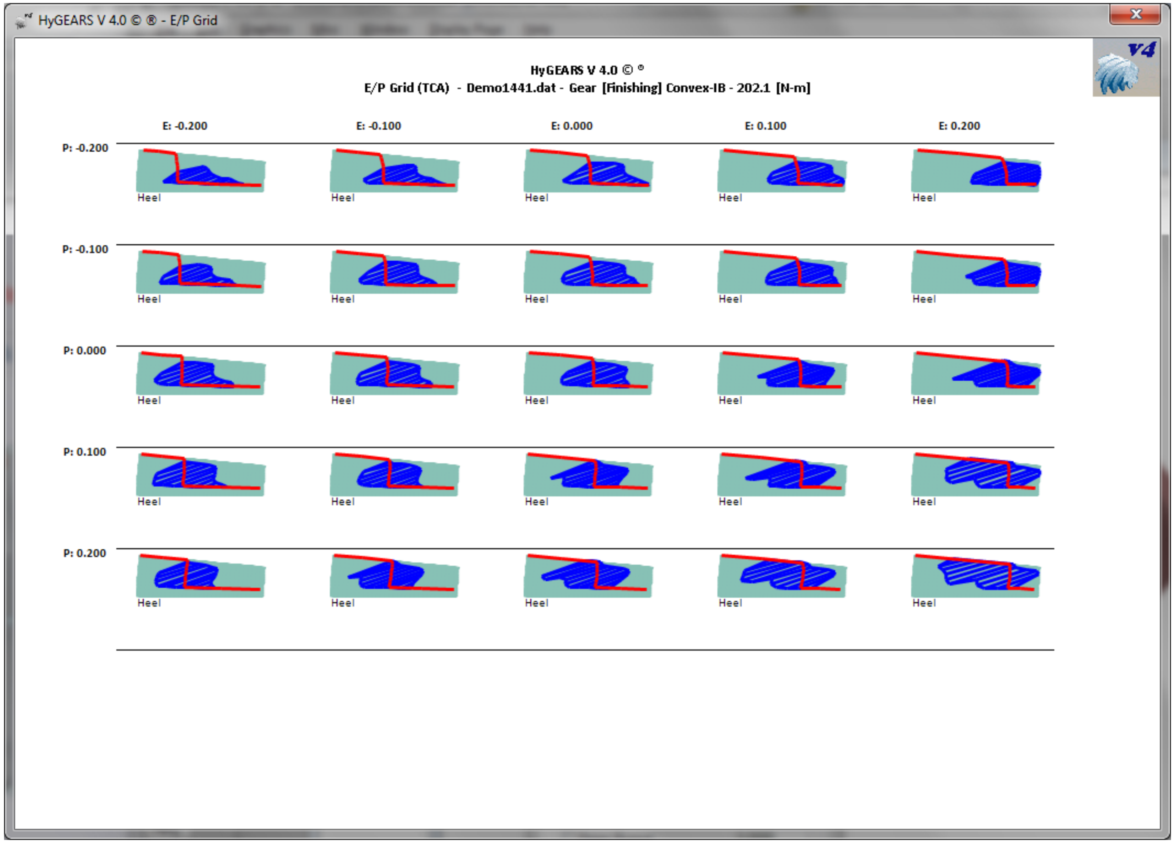
- ^N toggle in and out of the calculation of the PoC by the normals
- E/P change Horizontal to 25%, 75% - then Cancel – check the EP values
- Limi toggle in and out of limited PoC
- NoRs toggle into rendered display
- Thick change CP compound thickness
- PoC toggle in and out the display of the PoC

# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*

Grid – display a grid with E and P = 0.200 mm (Apply button)

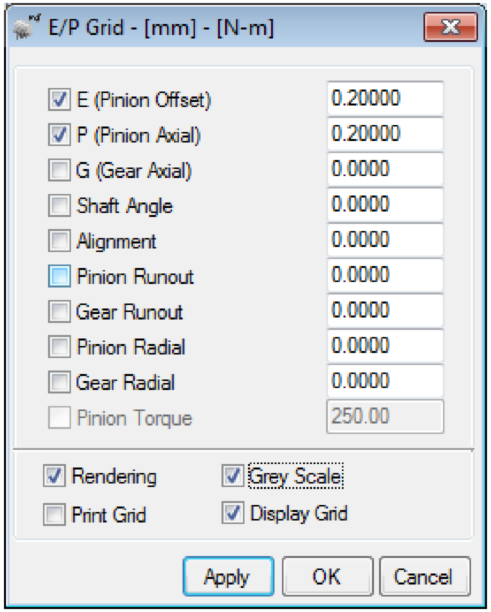


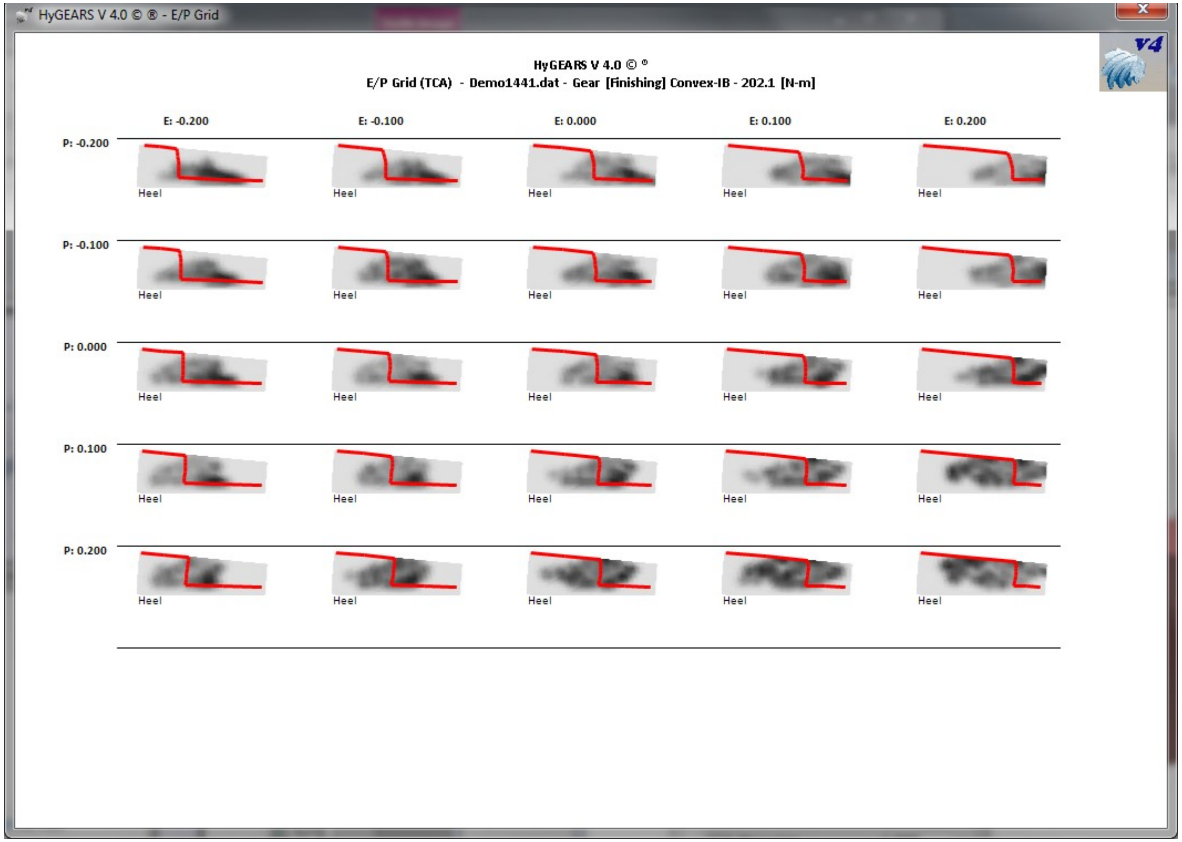



# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*

Grid – display a grid with E and P = 0.200 mm + rendering (Apply button)



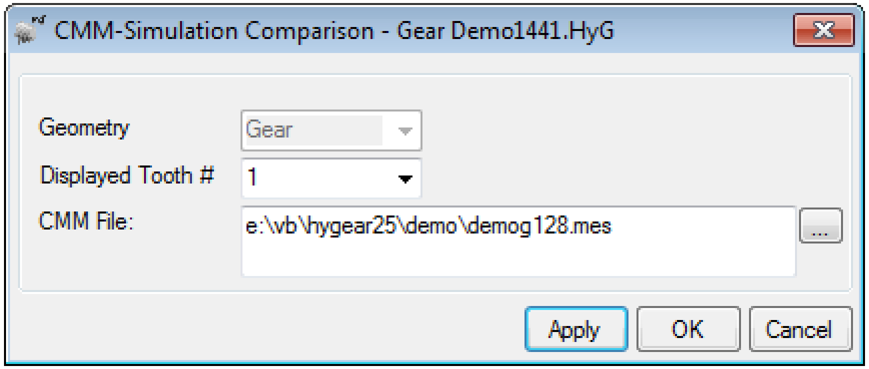



# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*

With CMM Data

- Delete the Contact Pattern child window
- Create a new Contact Pattern child window
- XYZ – make sure “Gear” is displayed in the Geometry field
- Use the […] button to browse
- Select the **demog128.mes** file
- Click on “Apply”

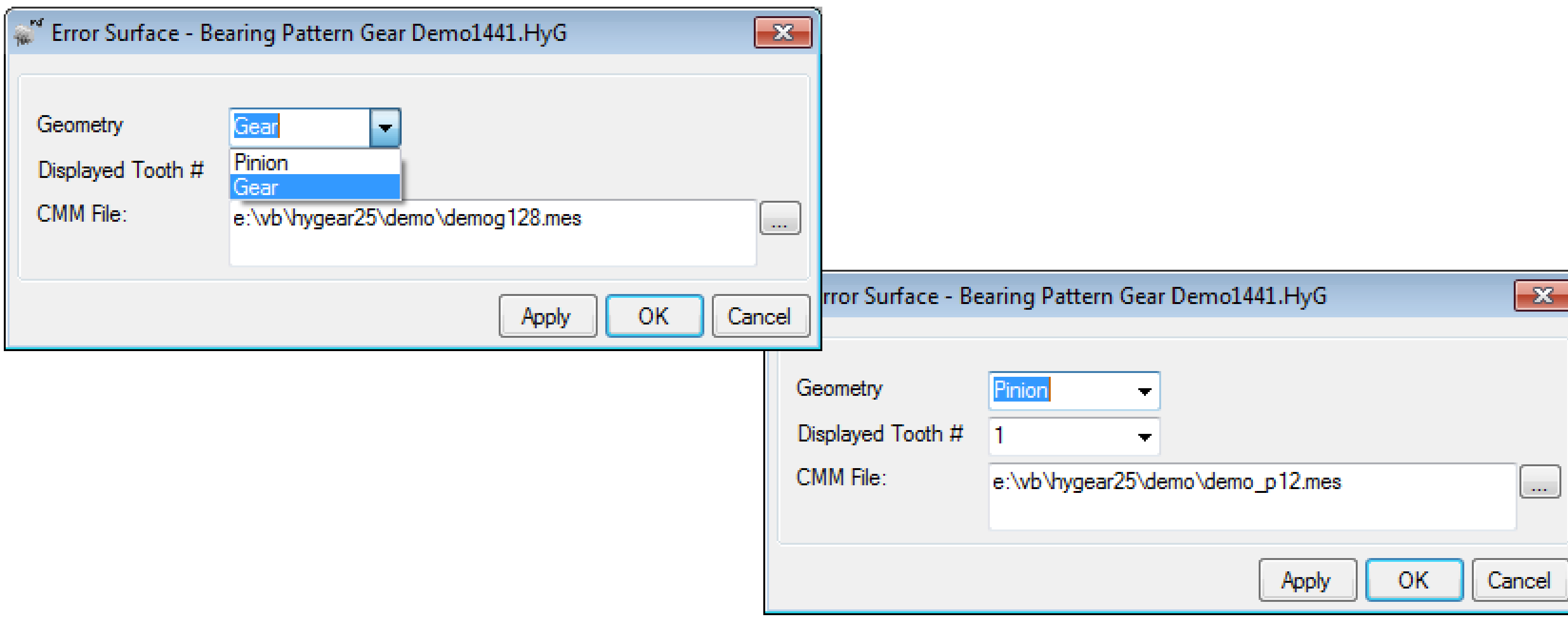


# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*

With CMM Data

- Click to select “Pinion” in the Geometry field
- Use the […] button to browse
- Select the **demo_p12.mes** file
- Click on “Apply”
- Click on “Ok”

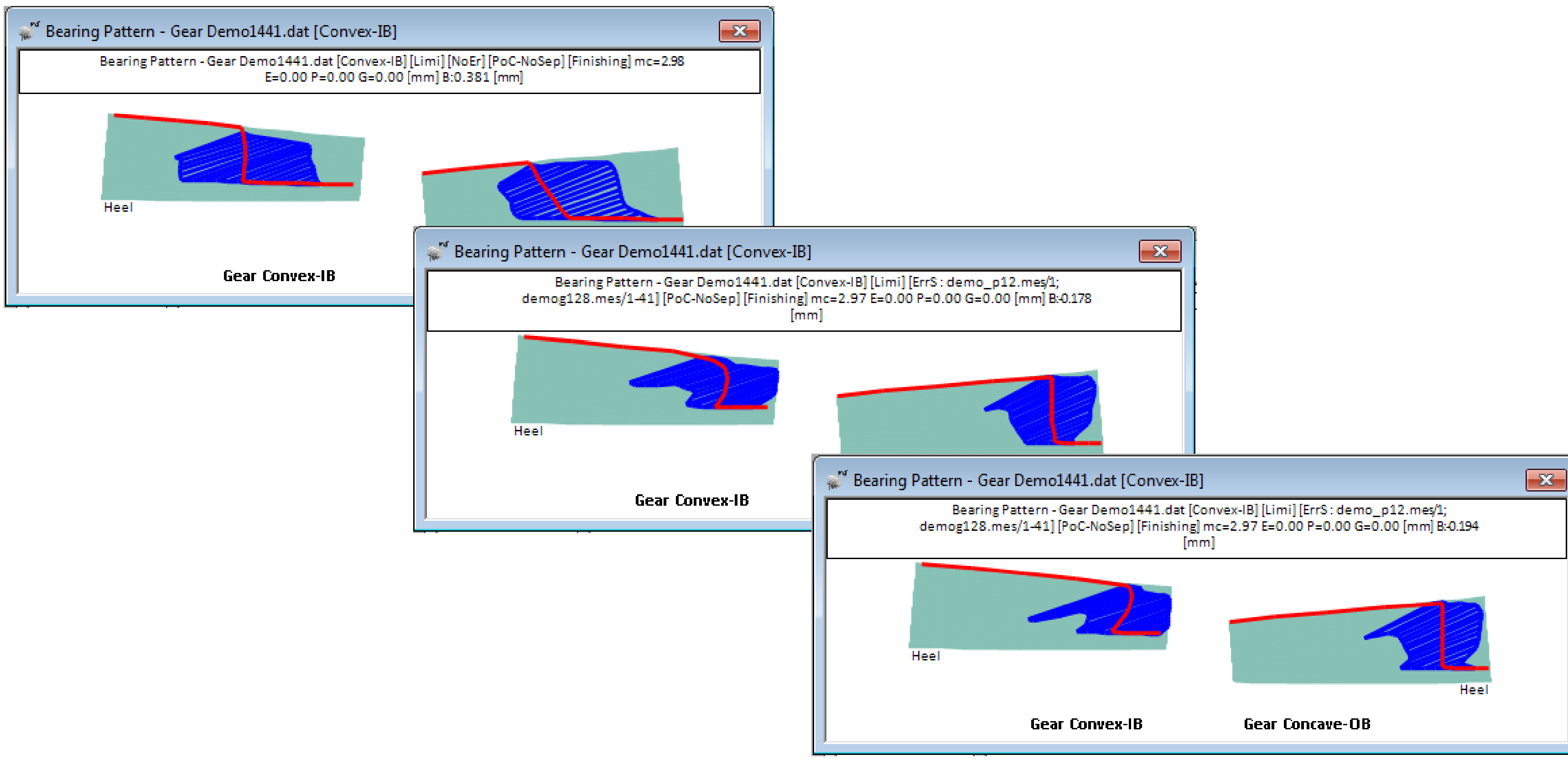


# Graphic Display Functions

*Kinematics -> Contact Pattern Child Window*

With CMM Data

- Click on the “NoEr” function button – watch the CP change
- Click on the “Opt” function button – Select 2$^{nd}$ Order Regression - watch the CP change
- Press “^S” to save the measurement datafile names in the geometry file



# Graphic Display Functions

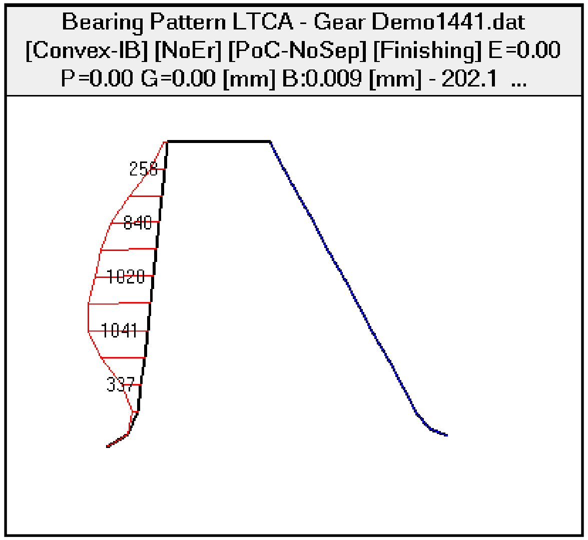
*Kinematics -> Contact Pattern LTCA Child Window*

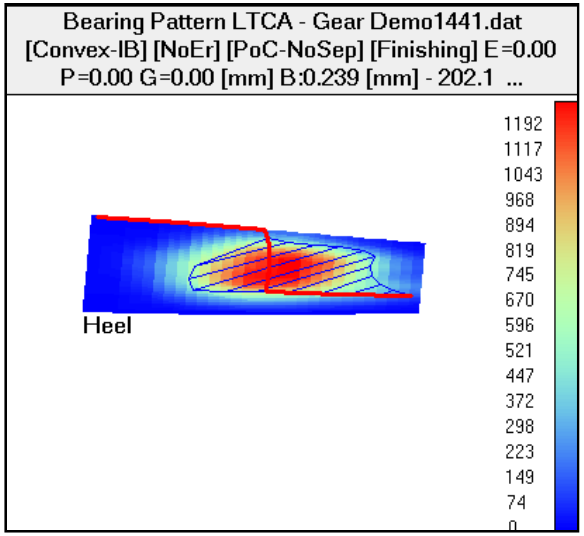
HyGEARS can calculate how *load is shared between adjacent tooth pairs*, accounting for tooth bending and shearing stiffness, and contact deformation.

Pitch errors can also be introduced in the analysis.

Results include

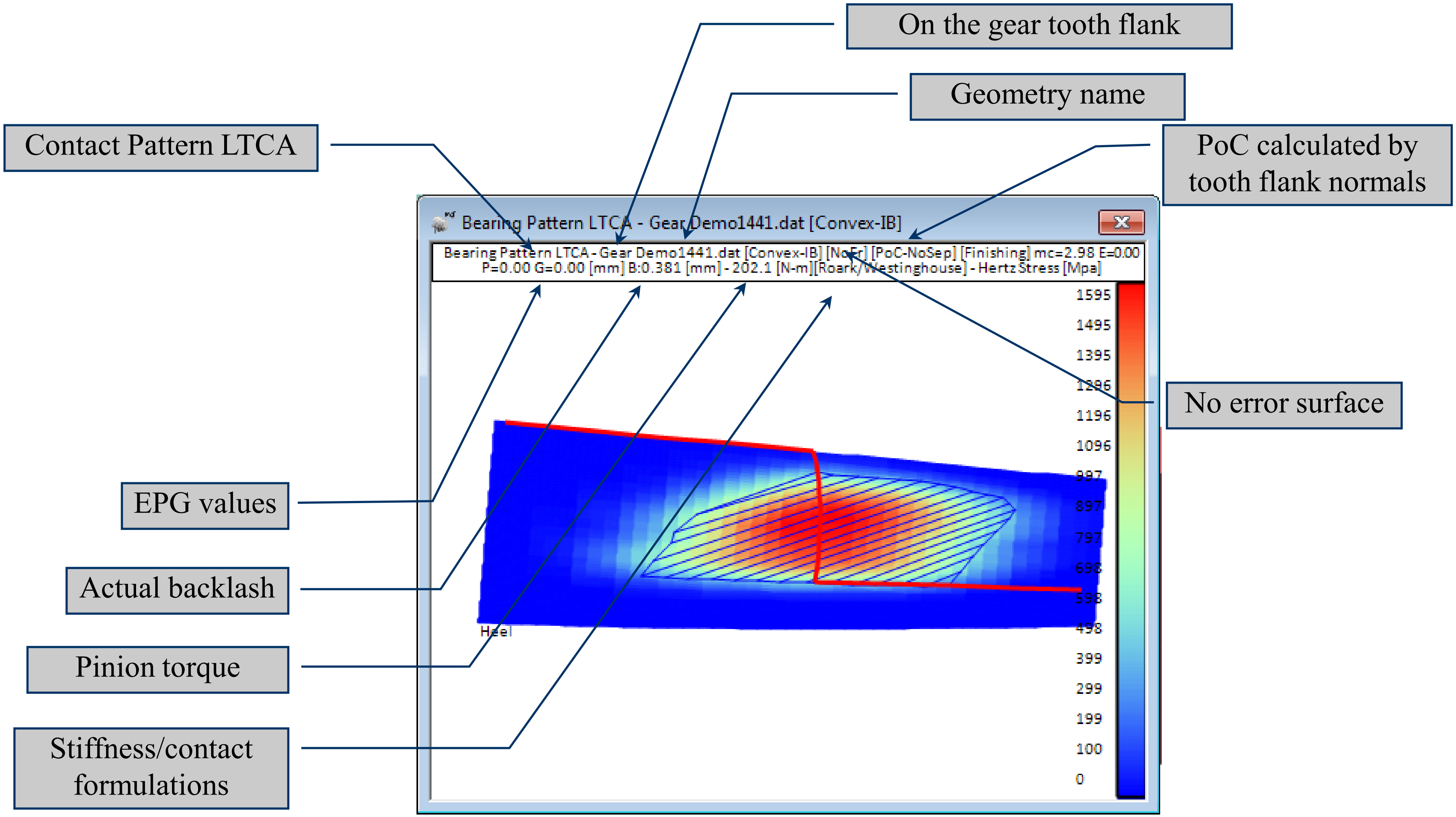
- *Contact stress* (by Hertz) (Roark, Formulas for Stress and Strain, 1975),
- Maximum *Shear stress*,
- *Depth* of maximum shear,
- Minimum *Oil film thickness* (Hamrock, 1994),
- *Flash temperature* (ΔT over mesh; Blok' s Flash Temperature, Erichello, 1991).



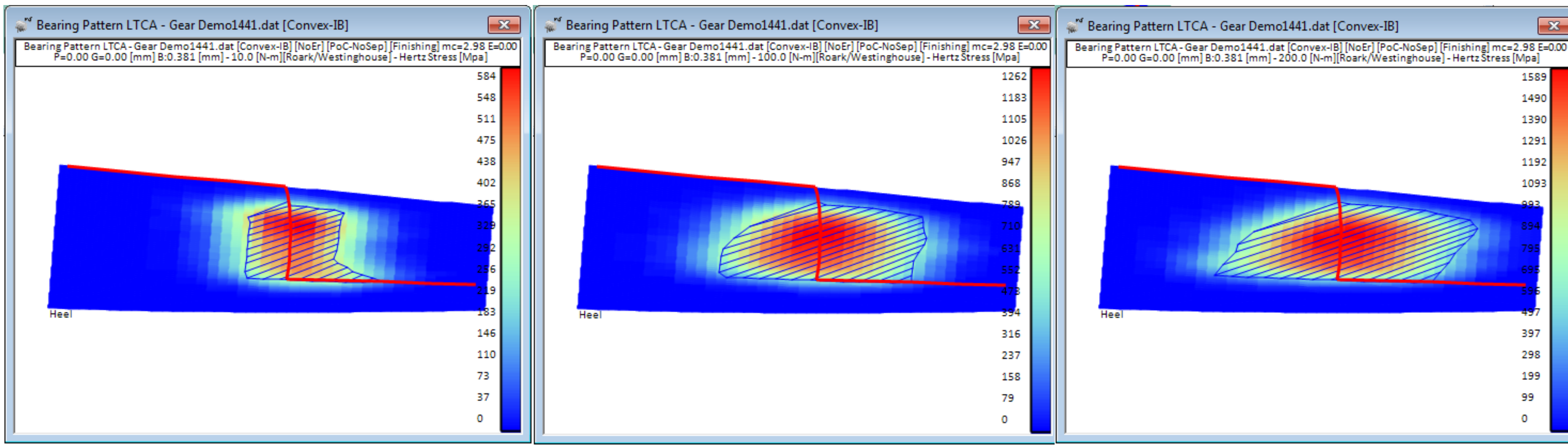
# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*



# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*




Evolution of the CP with applied torque

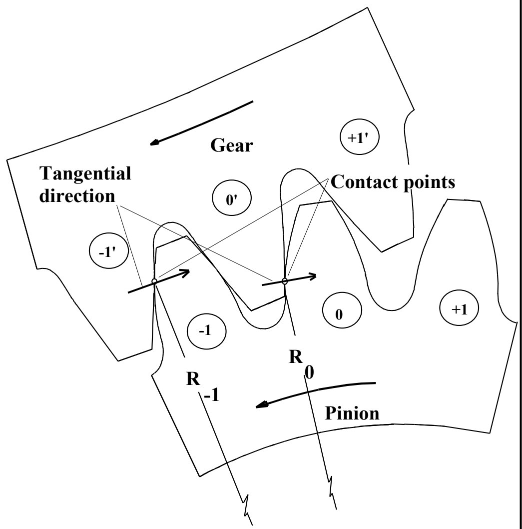
# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*

LTCA Solution:

$$\left[\frac{F_j/K_j + \delta H_j + \delta W_j + \delta R_j + \delta I_j}{R_j}\right]_{j=-2,-1,+1,+2} = \left[\frac{F_i/K_i + \delta H_i + \delta W_i + \delta R_i + \delta I_i}{R_i}\right]$$

$$T_{tot} = \sum_{j=-2}^{j=+2} T_j$$



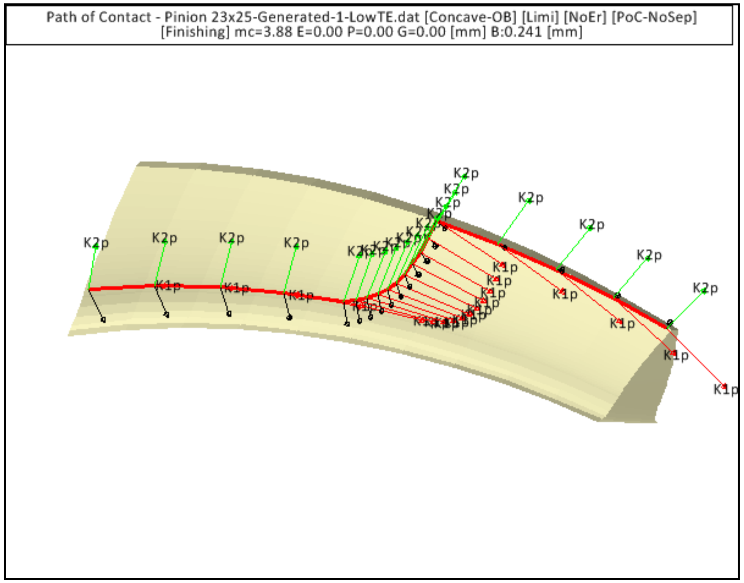

| | |
|---|---|
| $i$ | is the main tooth pair; |
| $j$ | is a tooth pair on either side of the main tooth pair (up to two on each side); |
| $F_{i/j}$ | is the load applied on each meshing tooth pair; |
| $K_{i/j}$ | is the tooth stiffness obtained from the Westinghouse beam formula or the FSM; |
| $\delta H_{i/j}$ | is the Hertz contact deformation; |
| $\delta W_{i/j}$ | is the displacement of a contact point caused by web shearing; |
| $\delta R_{i/j}$ | is the displacement of a contact point caused by tooth base rotation; |
| $\delta I_{i/j}$ | is the initial tooth separation; |
| $R_{i/j}$ | is the radius of the point of contact; |
| $T_{i/j}$ | is the torque share of each meshing tooth pair. |

# Graphic Display Functions

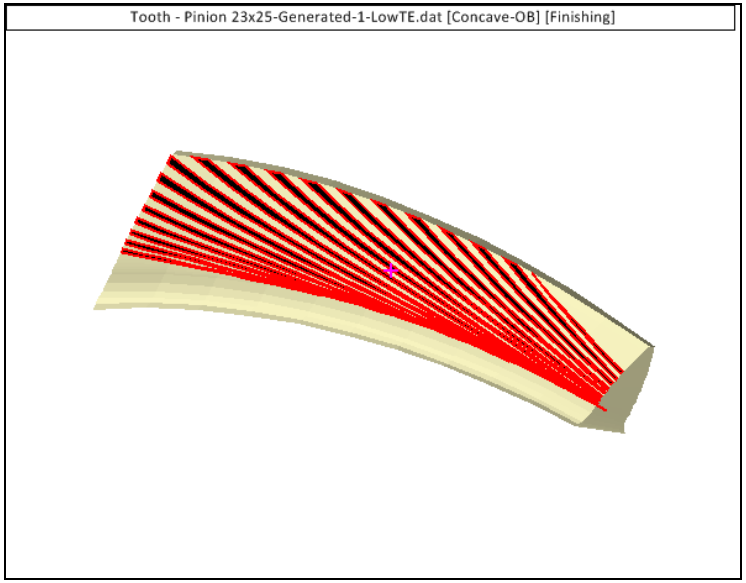
*Kinematics -> Contact Pattern LTCA Child Window*

- Surface principle curvatures are calculated (numerically) at each contact point.
- Relative directions of the principle curvatures affect contact stress and deformation.

Principle curvatures




Feed Marks

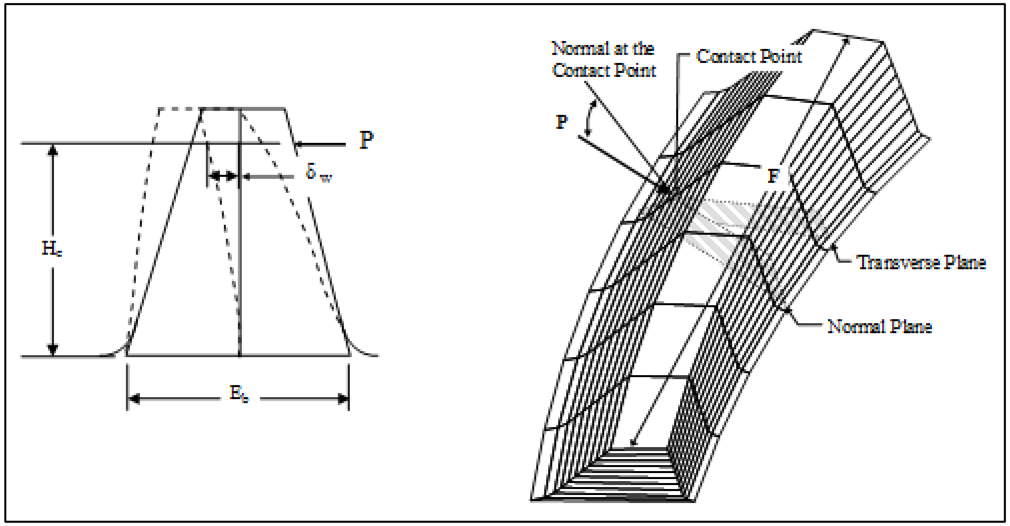


# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*

Bending Displacement : Westinghouse beam formula
(Ted Krenzer, The Gleason Works, “Tooth Contact Analysis of Spiral Bevel and Hypoid Gears Under Load”)

$$\delta_w = \frac{P}{3\,E\left(\frac{F\ t_l^3}{12}\right)}\left\{1 + 1.3\,t_l + \left(0.25 + 0.75\,(1-\ \nu)\,t_l^2\right) + 0.35\,t_l^3\right\}$$



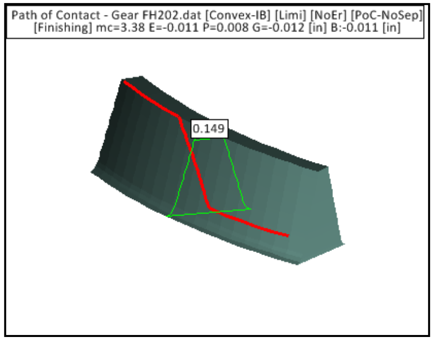

| | |
|---|---|
| $\delta_w$: | displacement at point of applied load P |
| $H_c$: | tooth height, between the applied load P and tooth root |
| $E_b$: | tooth thickness at base |
| P: | applied load (perpendicular to $H_c$) |
| F: | tooth face width (projected in the direction perpendicular to P) |
| E: | Young’s modulus |
| ν: | Poisson’s ratio |
| $t_l$: | $\frac{E_b}{H_c}$ |

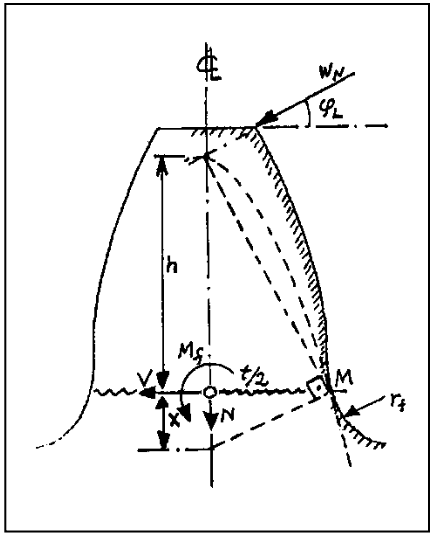
# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*

LTCA – Lewis beam formula:

- J Factor extracted from the actual tooth section at the considered point along the PoC




$$\sigma = \frac{W_N \cos\phi_L h}{\frac{(Ft^2)}{6}} - \frac{W_N \sin\phi_L}{tF}$$

$$W_t = W_N \cos\phi_c$$

$$\left(\frac{t}{2}\right)^2 = h\,X$$

$$\sigma = \frac{W_t P}{F}\left[\frac{\cos\phi_L}{\cos\phi_c}\left(\frac{1.5}{X\,P} - \frac{\tan\phi_L}{t\,P}\right)\right]$$

$$\frac{1}{Y} = \left[\frac{\cos\phi_L}{\cos\phi_c}\left(\frac{1.5}{X\,P} - \frac{\tan\phi_L}{t\,P}\right)\right]$$

$$K_f = 0.18 + \left(\frac{t}{r_f}\right)^{0.15}\left(\frac{t}{h}\right)^{0.45}$$

$$J = \frac{Y}{K_f}$$

$$\sigma = \frac{W_t\,P}{F\,J}$$

# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*

Minimum oil film thickness:

$$\Lambda = \frac{H_{min}}{\sigma_m}$$

$\Lambda$: Oil film thickness ratio
$H_{min}$: Minimum oil film thickness
$\sigma_m$: Composite surface roughness

For elliptical contacts:

$$H_{min} = 3.63\, U^{0.68}\, G^{0.49}\, W^{-0.073}\, \left(1 - e^{-0.68k}\right)$$

For rectangular contacts:

$$H_{min} = 1.714\, U^{0.694}\, G^{0.508}\, W^{-0.128}$$

U: Dimensionless speed parameter
G: Dimensionless materials parameter
W: Dimensionless load parameter
k: Ellipticity parameter

Blok's flash temperature:

$$\Delta T_f = \frac{0.8\, \mu\, X_r W_{nr} \left|\sqrt{V_{rp}} - \sqrt{V_{rg}}\,\right|}{b_m \sqrt{b_H}}$$

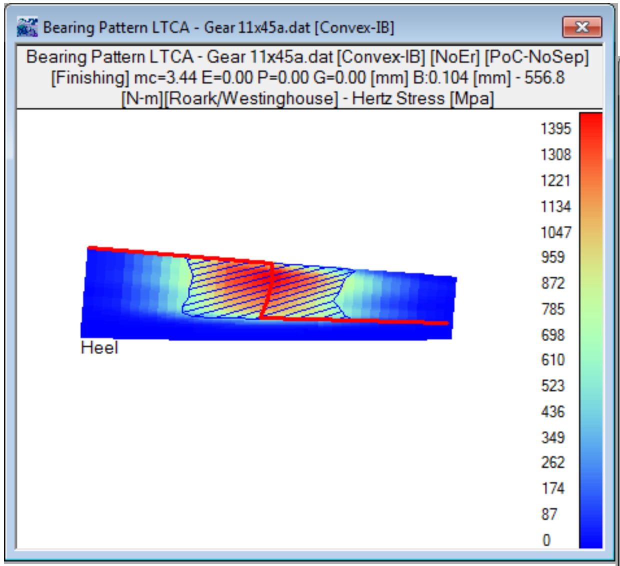
$\mu$: Coefficient of friction (in oil)
$X_r$: Load sharing factor (= 1 in HyGEARS)
$W_{nr}$: Normal unit load
$V_{rp}$: Rolling velocity of the pinion
$V_{rg}$: Rolling velocity of the gear
$b_m$: Thermal contact coefficient
$b_H$: Semi-width of the Hertzian contact

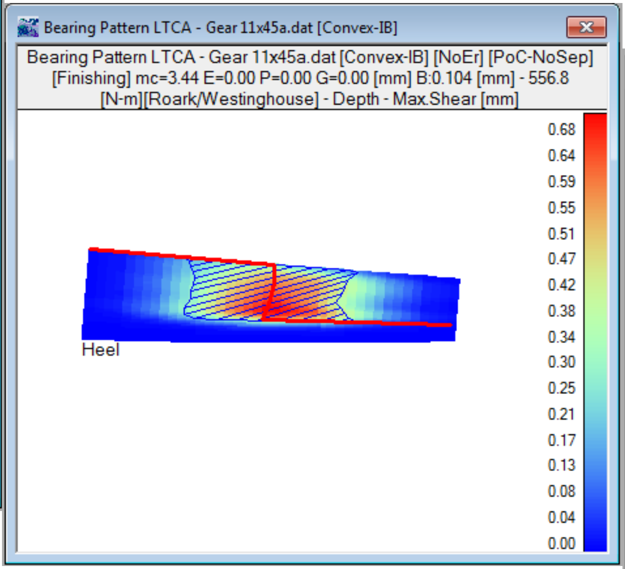
# Graphic Display Functions

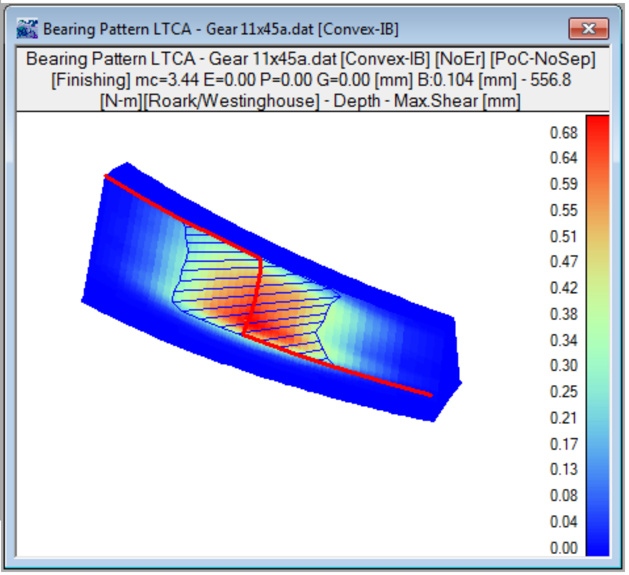
*Kinematics -> Contact Pattern LTCA Child Window*

Use the 11x45a.dat geometry, for the Gear. Test the following Contact Pattern LTCA child window function buttons, one by one :

- Opt –> Results - select "Depth – Max Shear"
- 2D – get into 3D mode
- ^J – change to user defined projection mode (3 rotation arrows enabled)
- Get a proper view angle with the rotation buttons



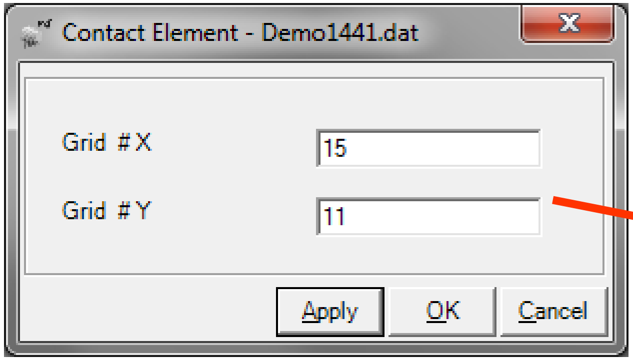
# Graphic Display Functions

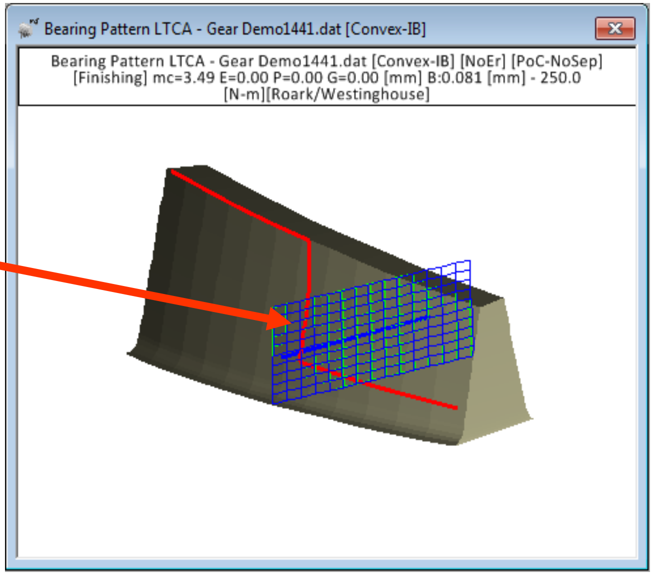
*Kinematics -> Contact Pattern LTCA Child Window / Contact Element*

HyGEARS offers a Contact Element which is integrated to the LTCA.

The Contact Element:

- Subdivides the contact area into small rectangular areas, or *contact cells*;
- On each *contact cell*, the pressure is varied until the *sum of the initial separation and deformation* is equal on all contacting cells (Love, 1929)
- Provides results identical to Hertz for full contact ellipses; (results are different when ellipse is truncated);
- Contact Grid can be modified for increased precision / decreased computing times;
- Can account for surface deviations as obtained from the CMM



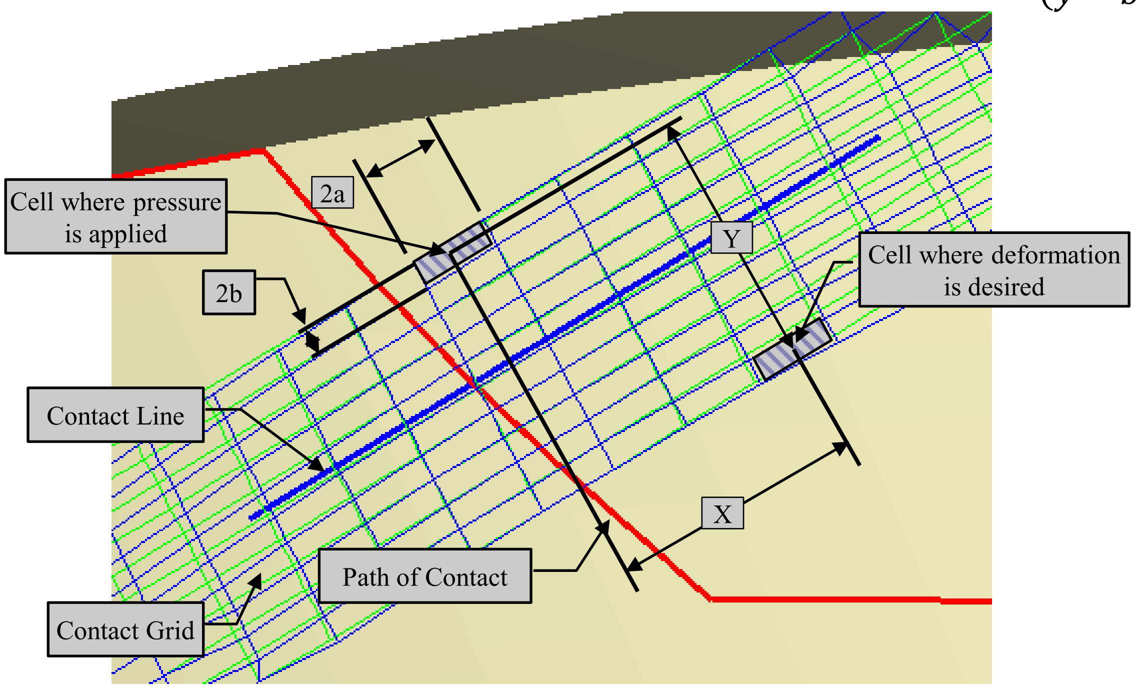



# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window / Contact Element*

Contact deformation (Love, 1929).

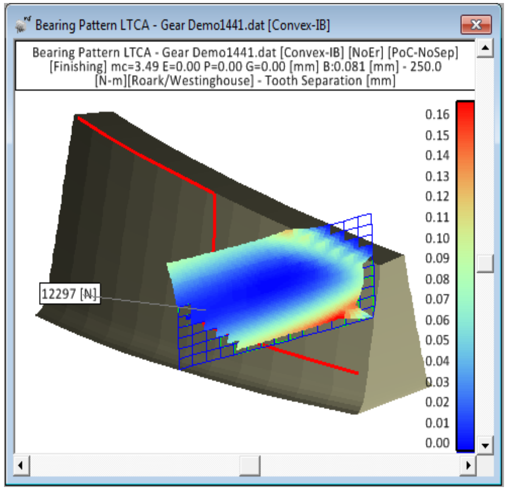
$$\frac{\pi E}{1-\nu^2}\frac{u_z}{p} = (x+a)\,ln\left[\frac{(y+b)+\sqrt{(y+b)^2+(x+a)^2}}{(y-b)+\sqrt{(y-b)^2+(x+a)^2}}\right] + (y+b)\,ln\left[\frac{(x+a)+\sqrt{(y+b)^2+(x+a)^2}}{(x-a)+\sqrt{(y+b)^2+(x-a)^2}}\right] + (x-a)\,ln\left[\frac{(y-b)+\sqrt{(y-b)^2+(x-a)^2}}{(y+b)+\sqrt{(y+b)^2+(x-a)^2}}\right] + (y-b)\,ln\left[\frac{(x-a)+\sqrt{(y-b)^2+(x-a)^2}}{(x+a)+\sqrt{(y-b)^2+(x+a)^2}}\right]$$



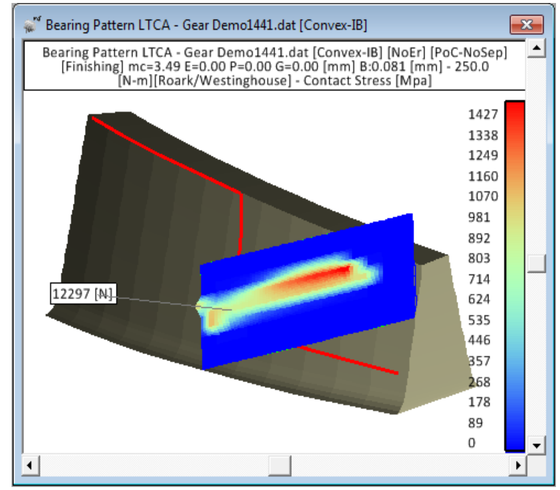

| | |
|---|---|
| E: | Young's modulus |
| ν: | Poisson's ratio |
| $u_z$: | surface deformation on a given cell |
| p: | surface pressure on a given cell |
| x, y: | coordinates of a point in relation to the center of a given cell |
| 2a, 2b: | sides of a given cell |

# Graphic Display Functions

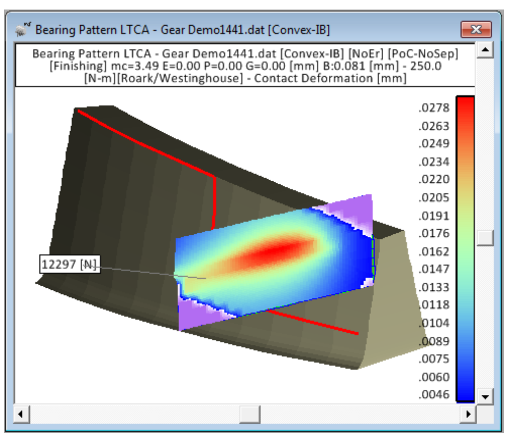
*Kinematics -> Contact Pattern LTCA Child Window / Contact Element*



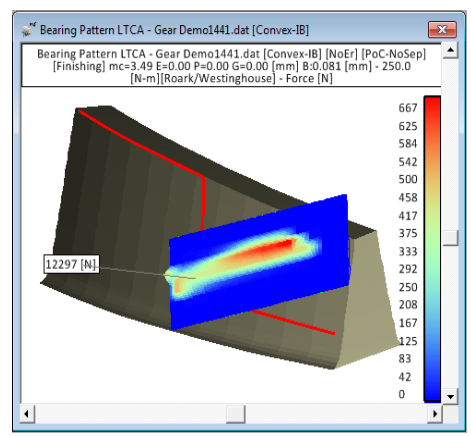

Contact Separation




Contact Pressure



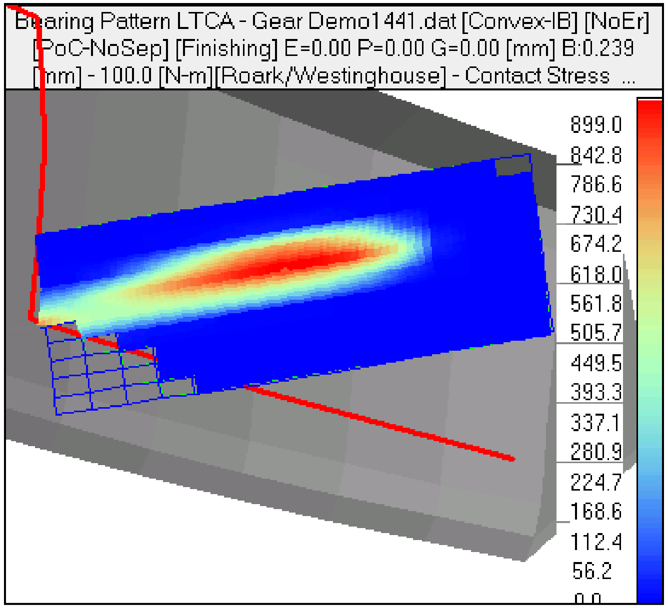

Contact Deformation



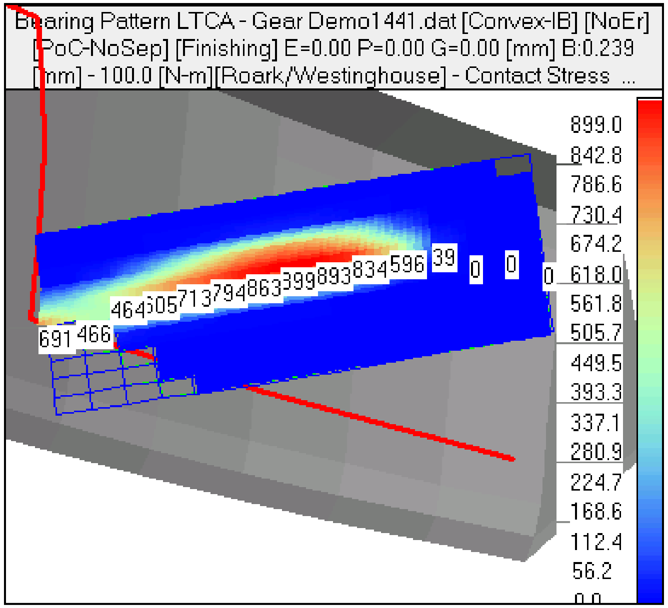

Contact Force

# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window / Contact Element*




Values are hidden




Values are displayed

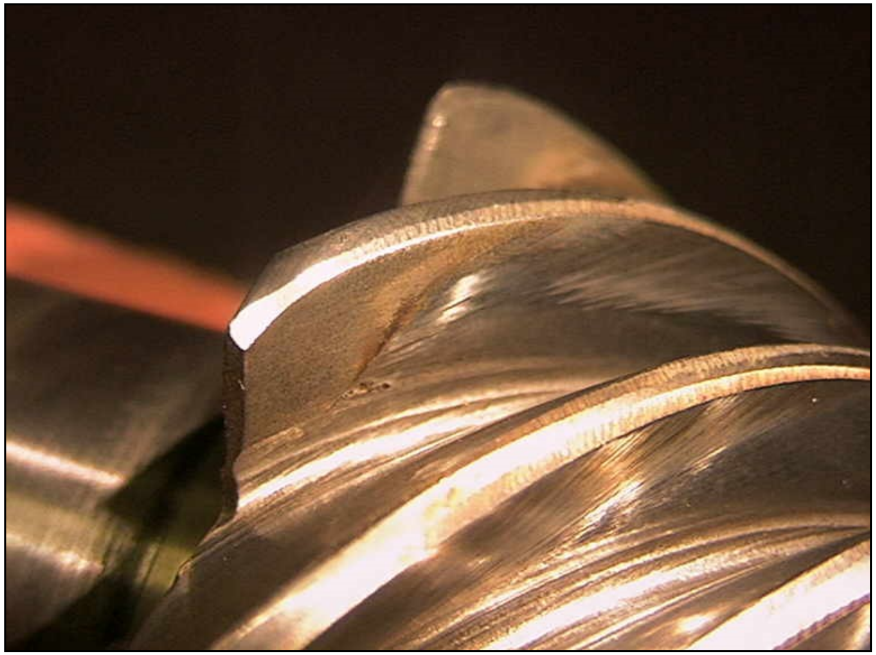
# Example : LTCA Ridging + Pitting

*Kinematics -> Contact Pattern LTCA Child Window / Contact Element*

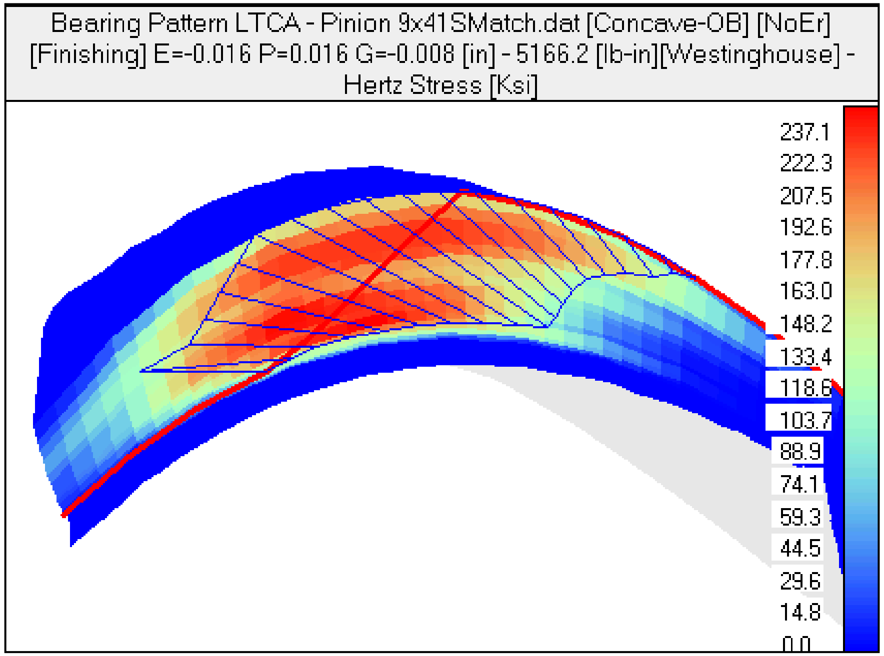
Ridging + Pits present on pinion tooth after initial run in:

- Gleason Summary was entered in HyGEARS
- LTCA run at expected operating position

Pinion tooth shows ridging + pits



HyGEARS simulation (Hertz)

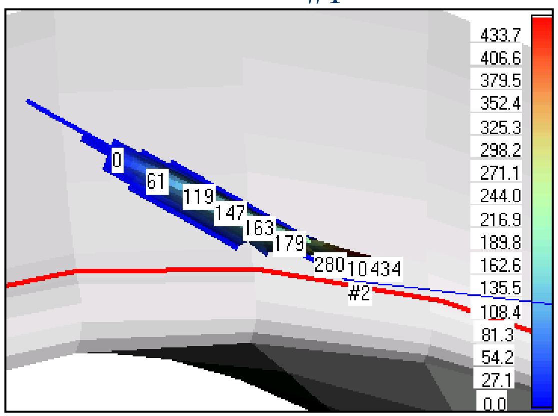


# Example : LTCA Ridging + Pitting

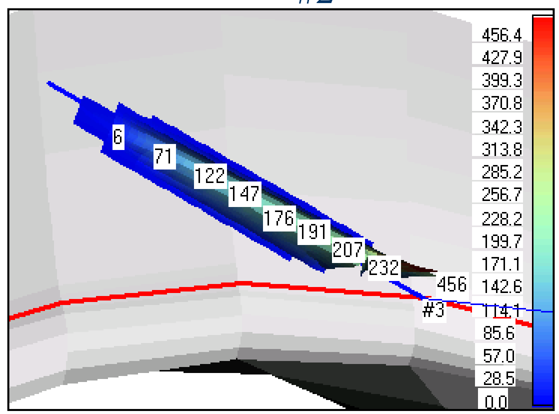
Pinion + Gear teeth measured

- Pinion + gear teeth R.E.
- LTCA run with Error Surface
- Use of Error Surface with Contact Elements analysis

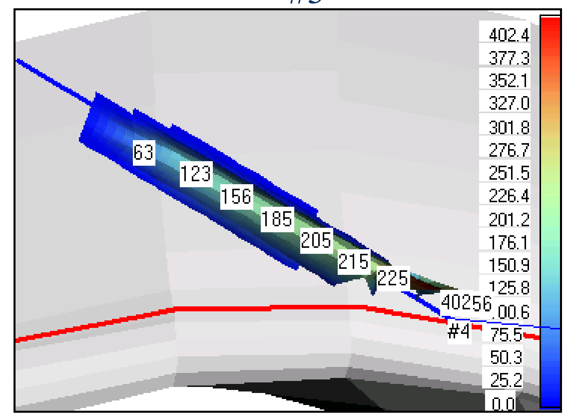
#1



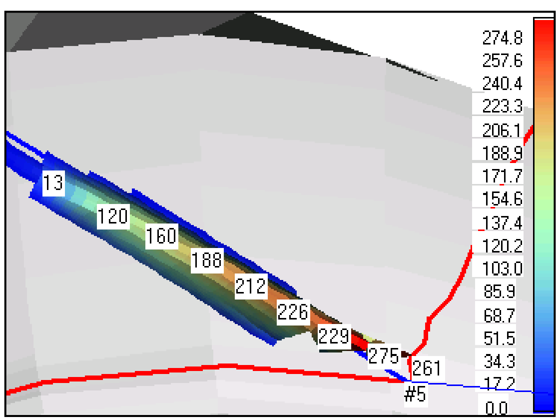

#2



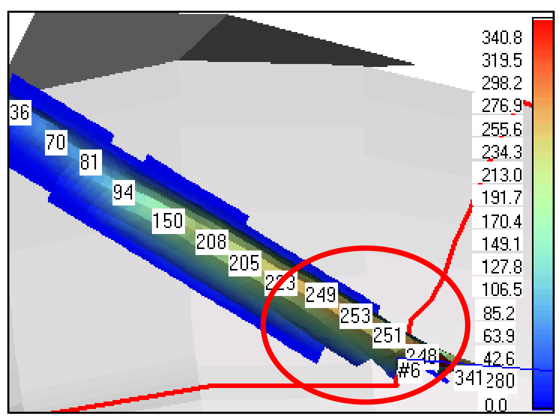

#3



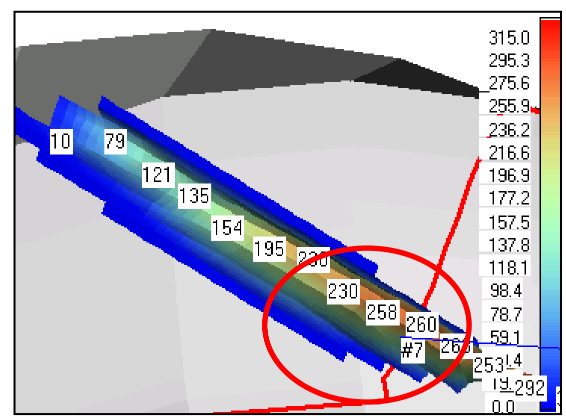

#4




***#5***




***#6***

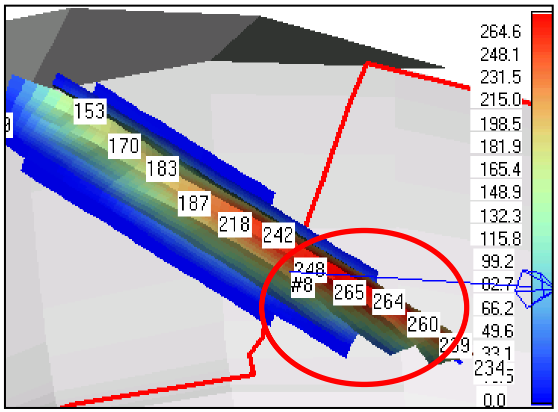


# Example : LTCA Ridging + Pitting

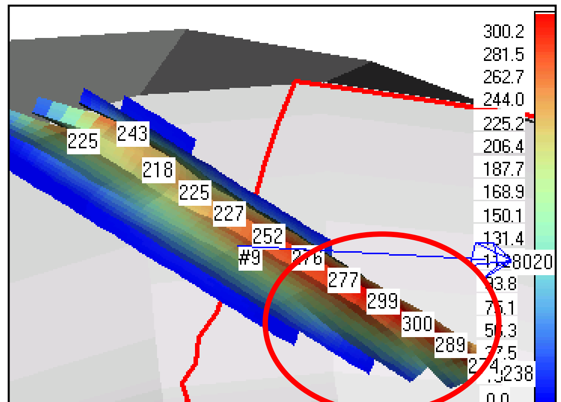
Pinion + Gear teeth measured

- Pinion + gear teeth R.E.
- LTCA run with Error Surface
- Use of Error Surface with Contact Elements analysis

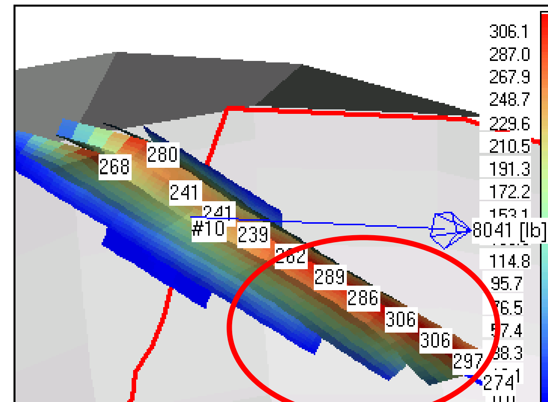
*#7*



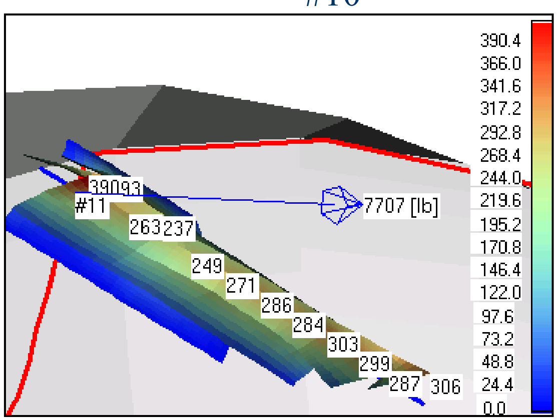

*#8*



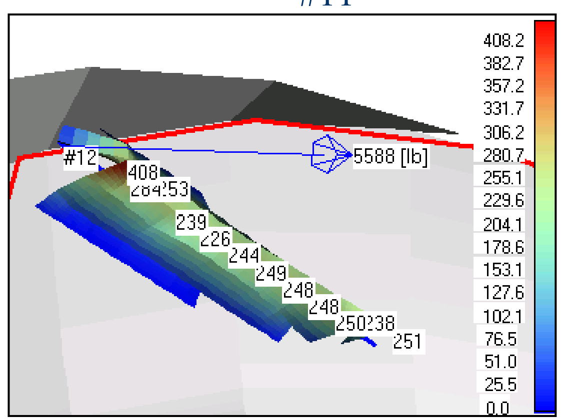

*#9*



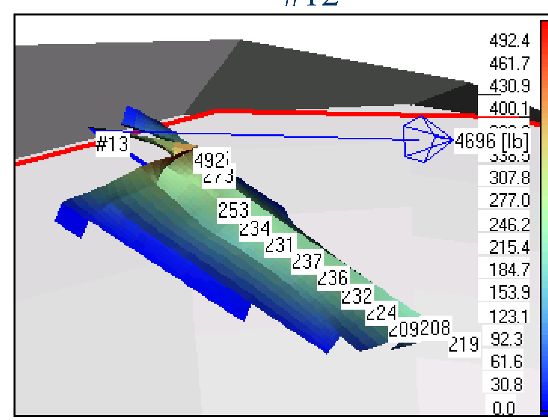

#10




#11




#12

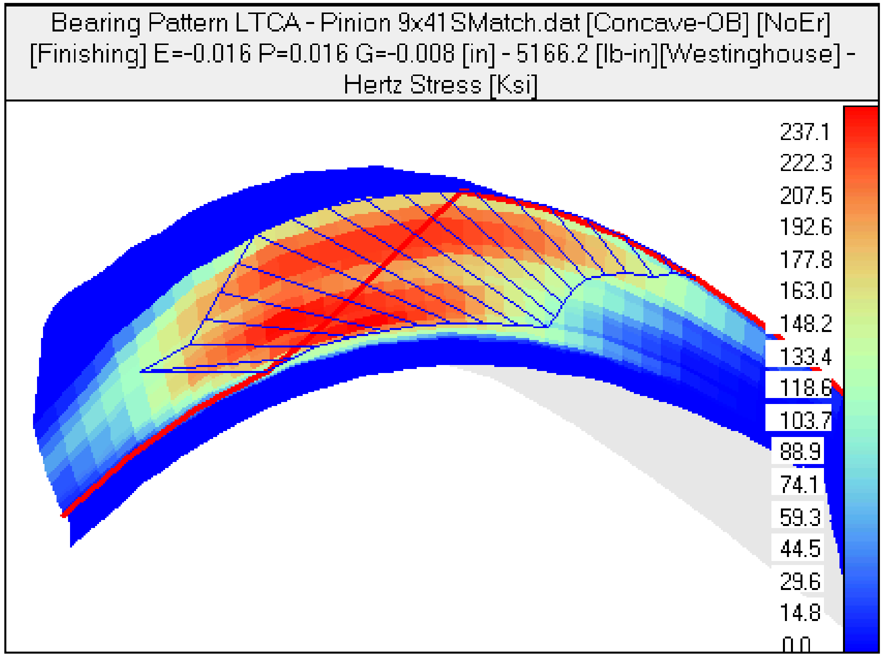


# Example : LTCA Ridging + Pitting

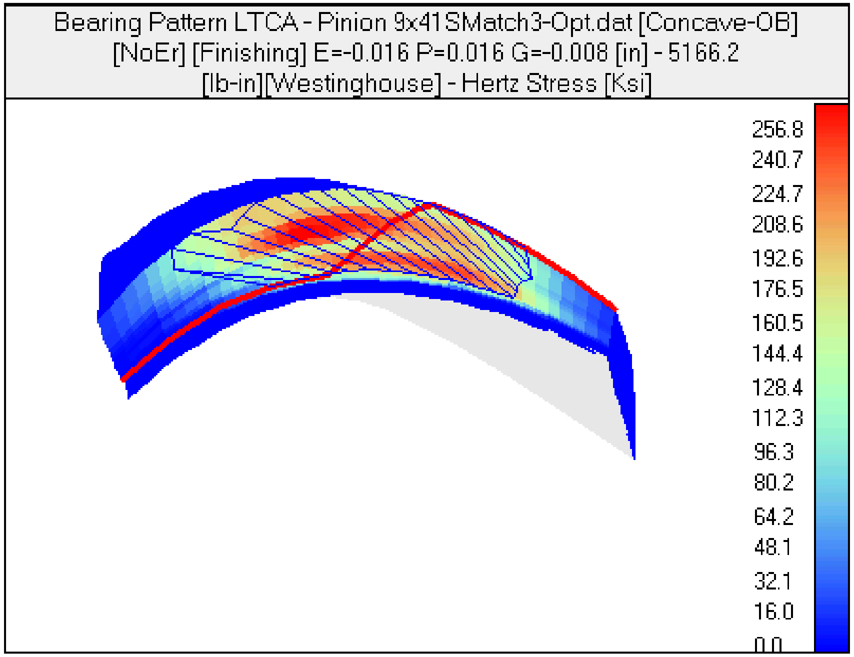
Pinion redesigned:

- Moved the CP away from fillet at heel
- Kept same blank, cutter, etc.
- Lower Hertz stresses at contact entry

Original




Redesigned

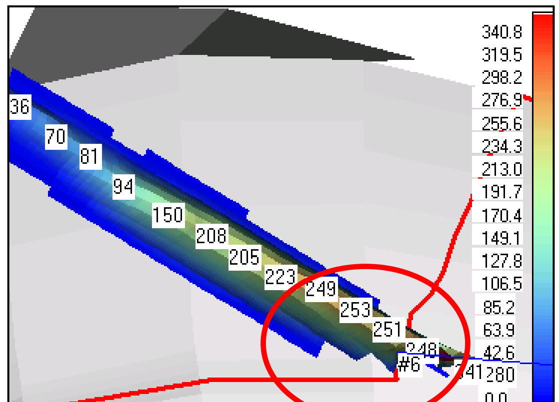


# Example : LTCA Ridging + Pitting

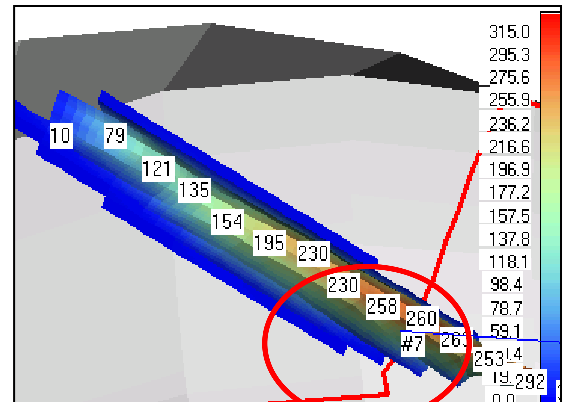
Comparative Contact Element Analysis:

Original

**#5**

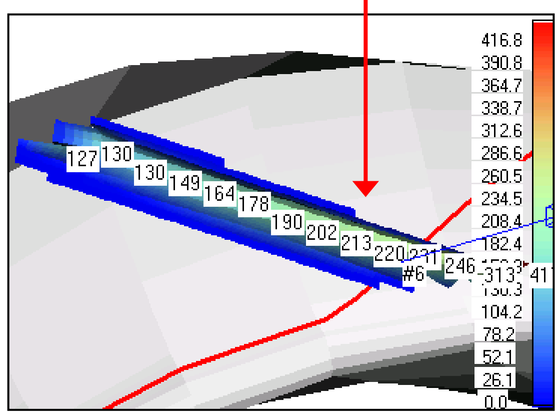



**#6**

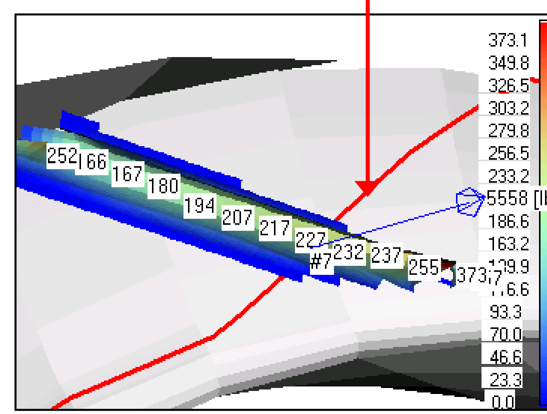



Redesigned

**#5**



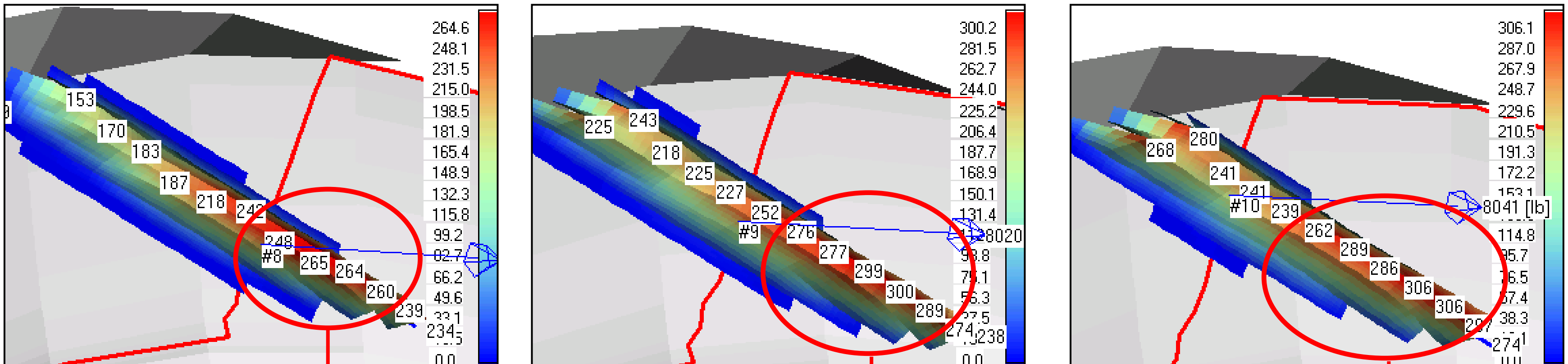

**#6**



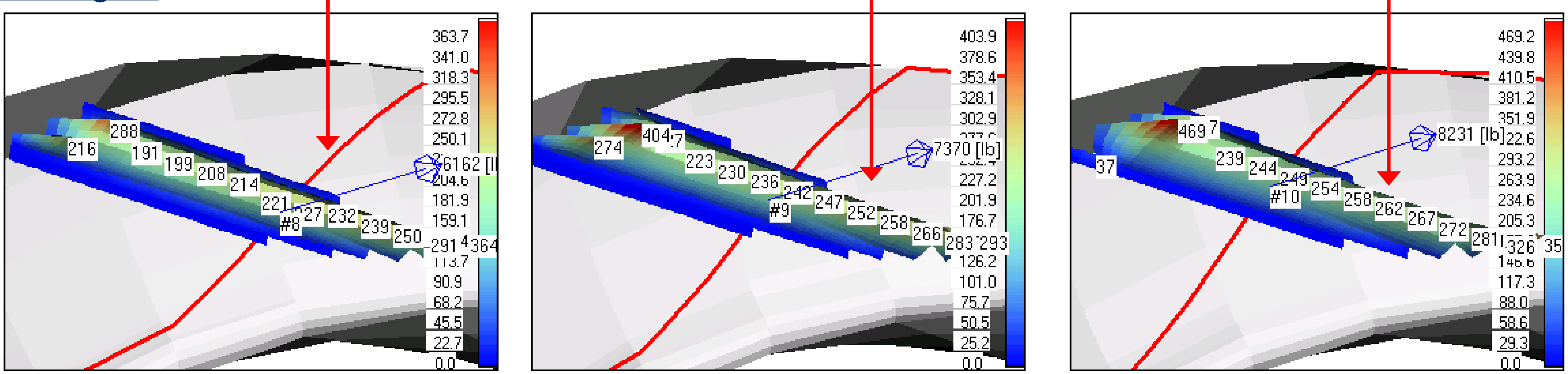
# Example : LTCA Ridging + Pitting

Comparative Contact Element Analysis:

Original #7 #8 #9



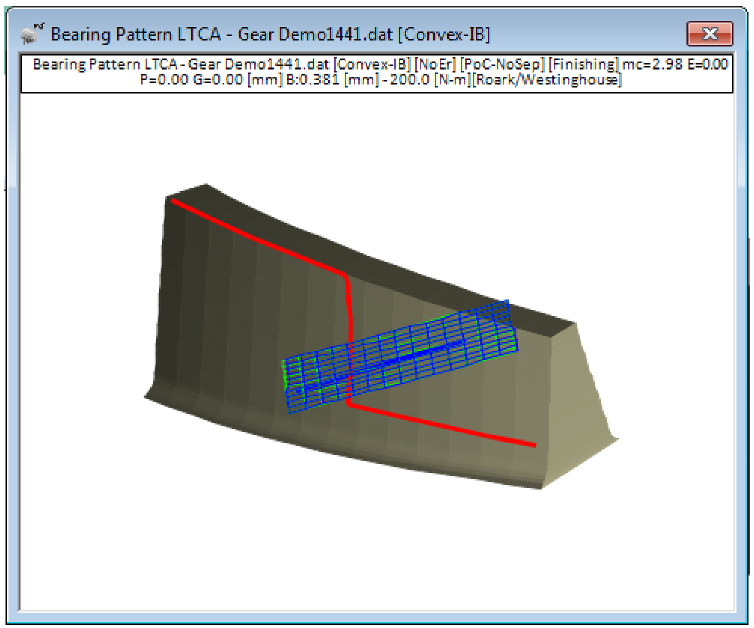

Redesigned #7 #8 #9

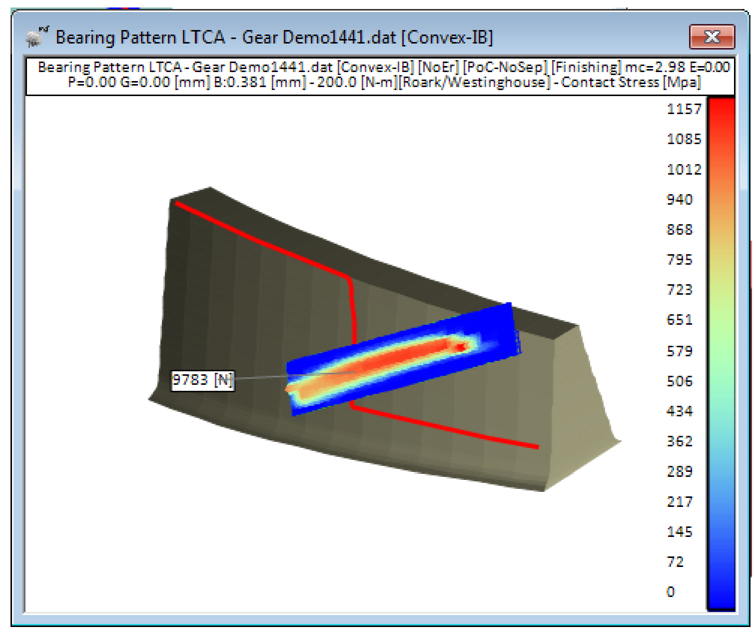


# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*

- "NoCE" – toggle into Contact Element display
- "^Z" – zoom onto the desired tooth area
- "Opt" – select "Contact Pressure"

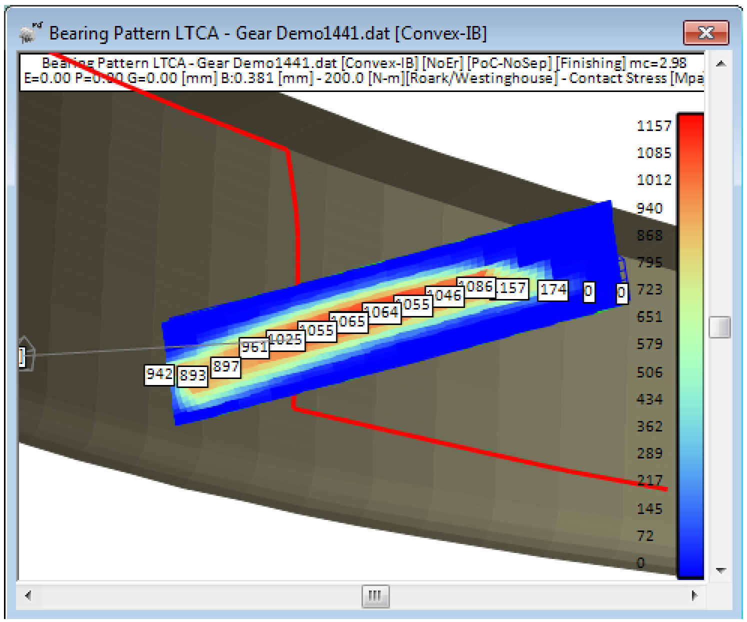


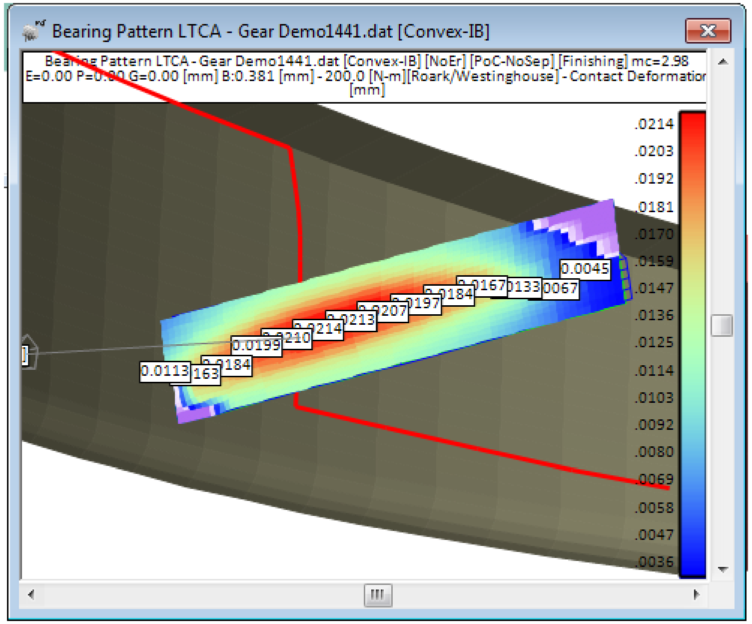



# Graphic Display Functions

*Kinematics -> Contact Pattern LTCA Child Window*

- "NoDi" – toggle in dimension display
- "Opt" – select "Contact Deformation"
- +/- - scan through the PoC

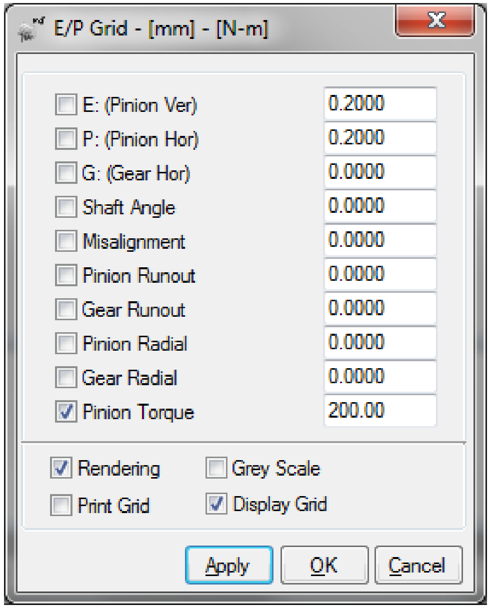


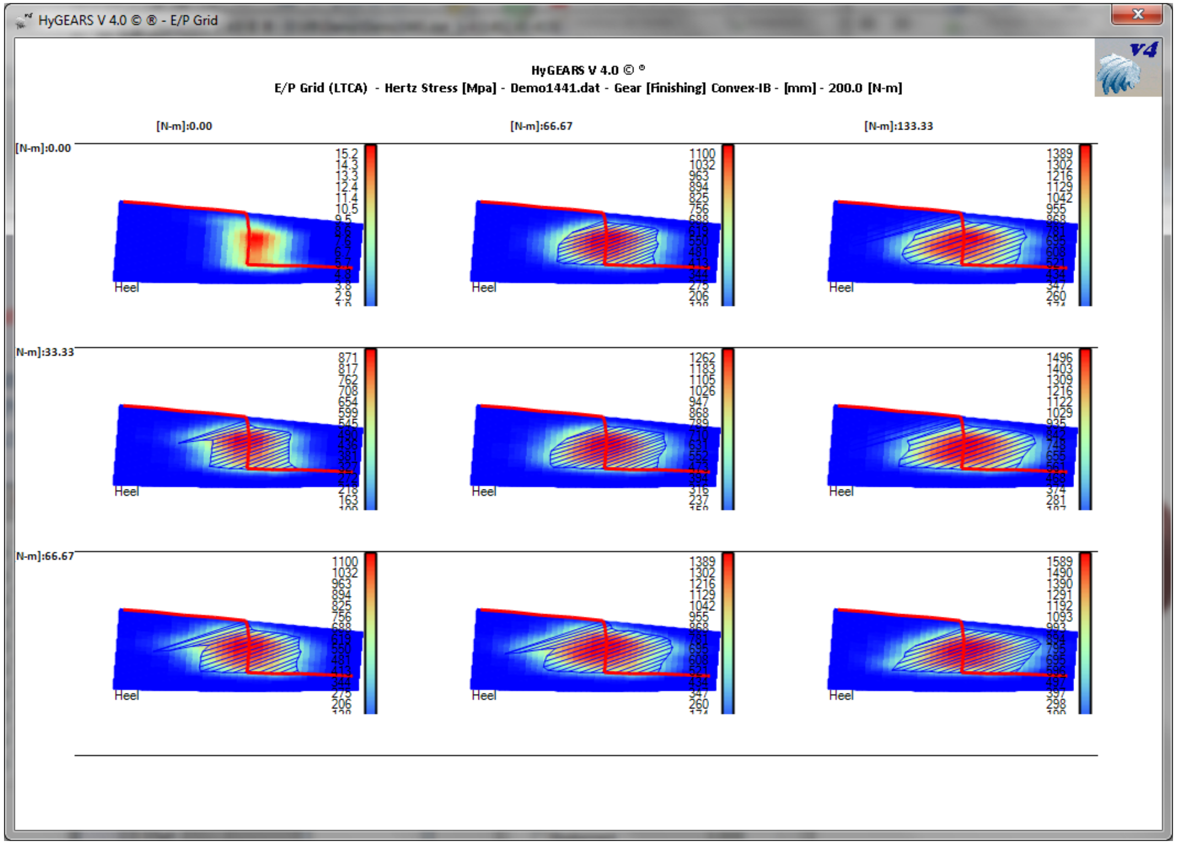



# Graphic Display Functions

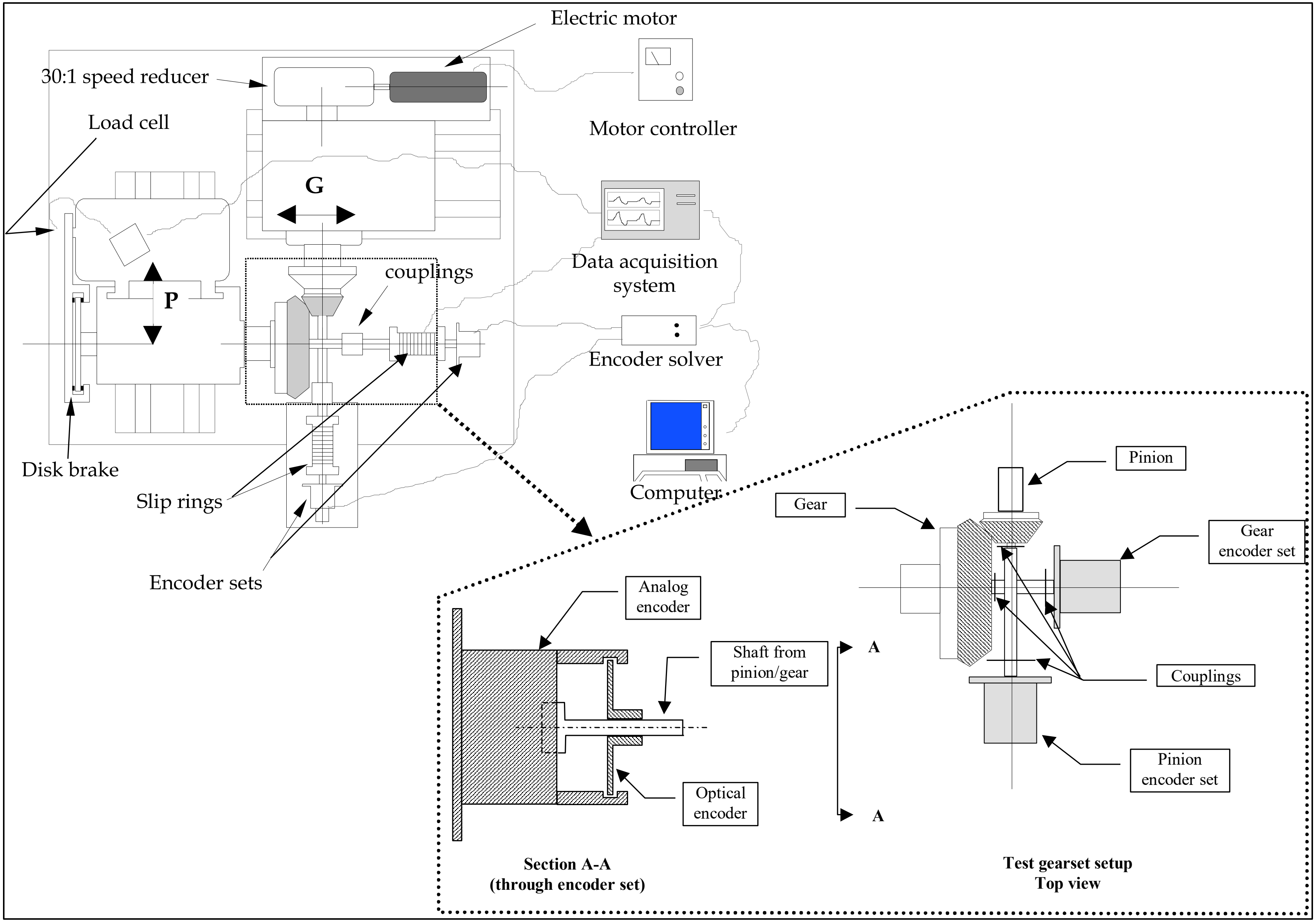
*Kinematics -> Contact Pattern LTCA Child Window*

- Close the Contact Pattern LTCA child window
- Create a new Contact Pattern LTCA child window
- Click on “Grid” – select Torque and leave inputted value – click “Ok”

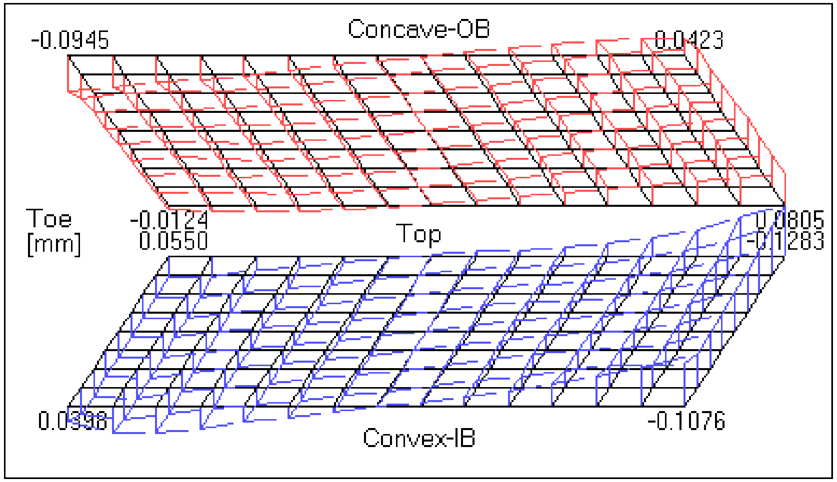


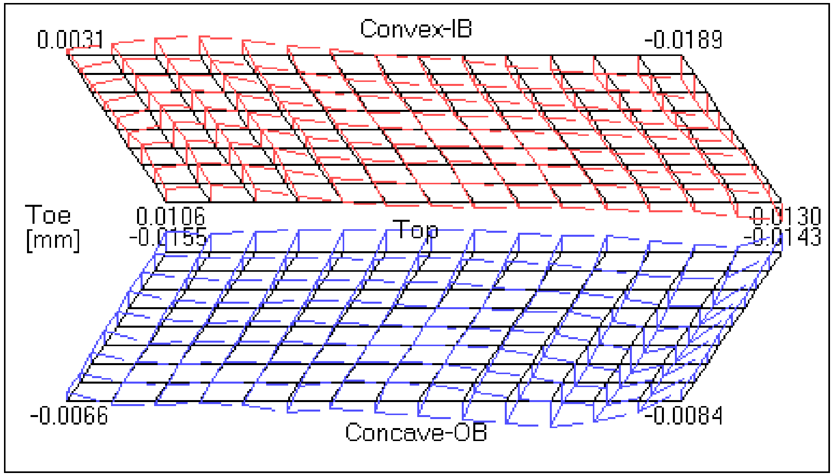



# LTCA Testing: Fixed Setting Hypoid Gear Set

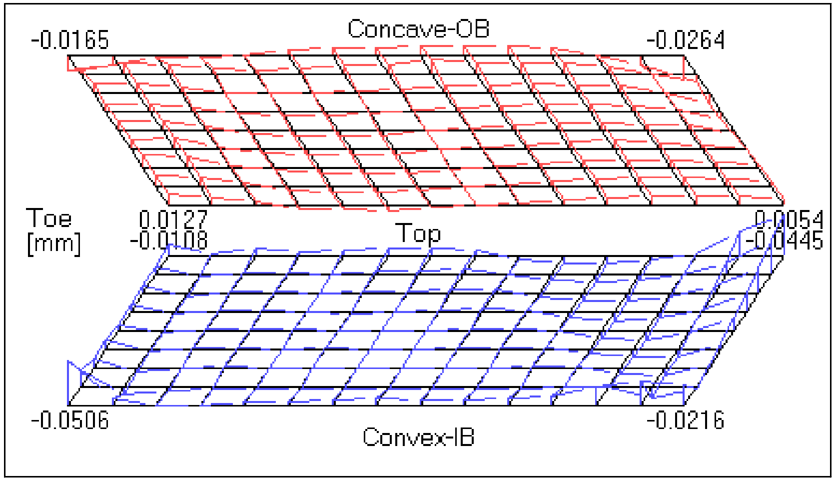


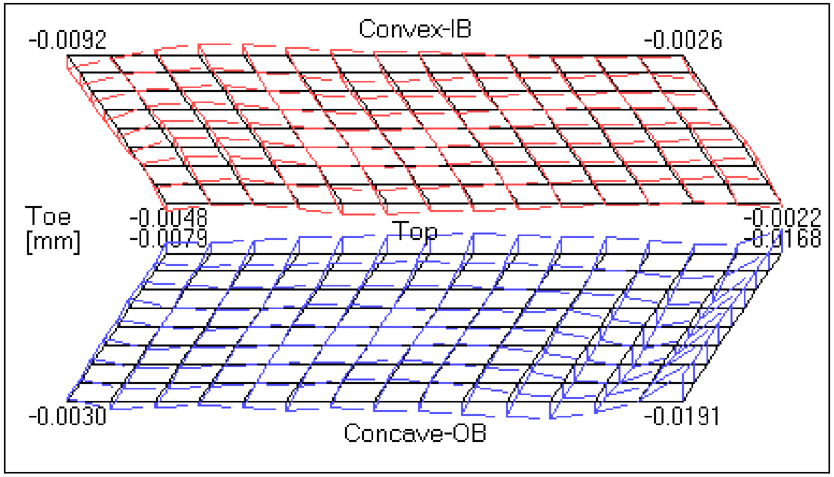
# LTCA Testing: Fixed Setting Hypoid Gear Set




Reverse Engineering

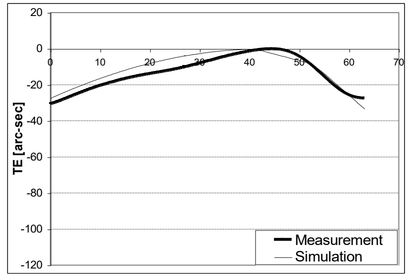
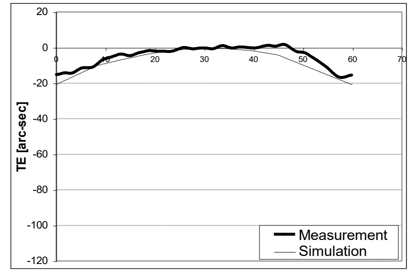
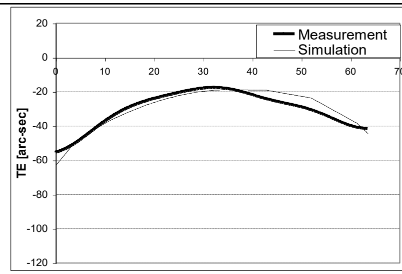
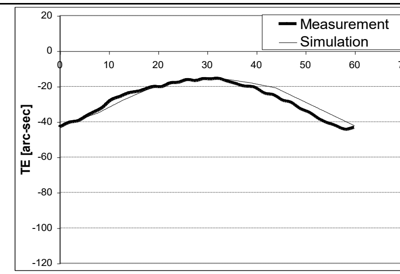
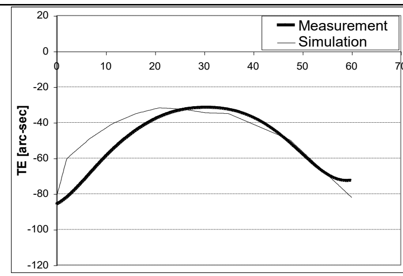
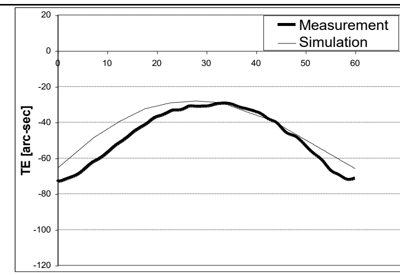
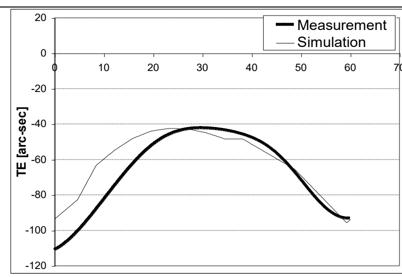
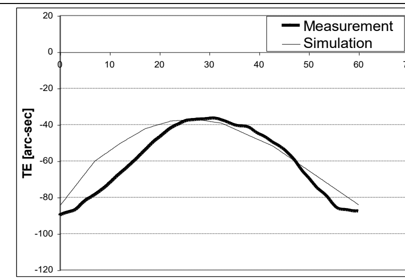



Pinion

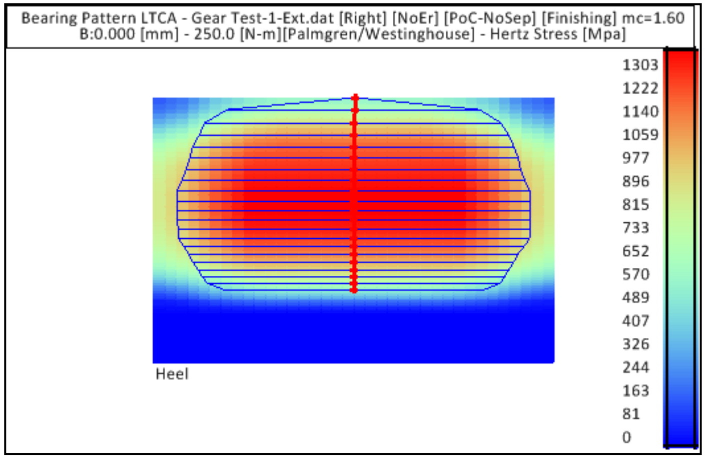
Gear

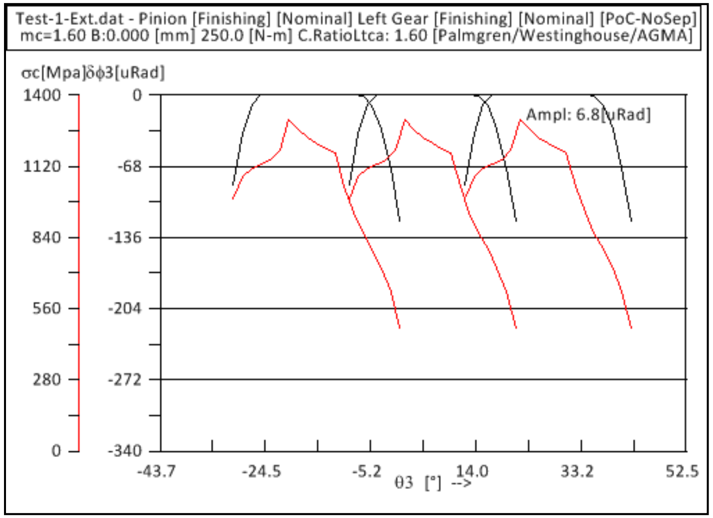
# Fixed Setting LTCA Testing: TE

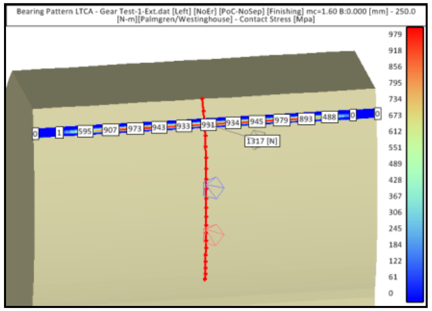
| Output Torque [N-m] | Transmission Error P01-G28 | Transmission Error P04-G01 |
|---|---|---|
| 0 |   |   |
| 300 |   |   |
| 600 |   |   |
| 900 |   |   |

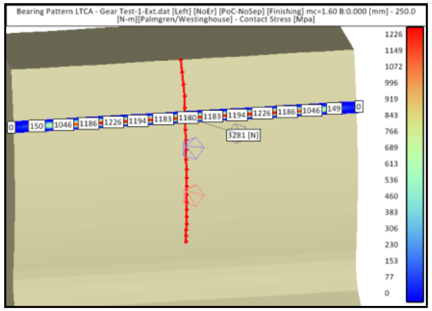
# LTCA Comparison – Spur HyGEARS

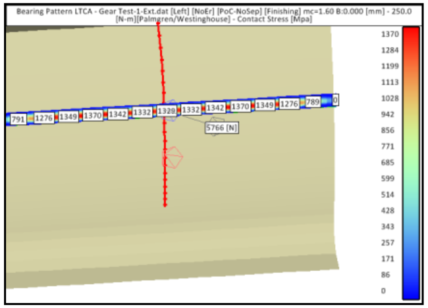
## LTCA - Compressive Stress - MPa - Gear:

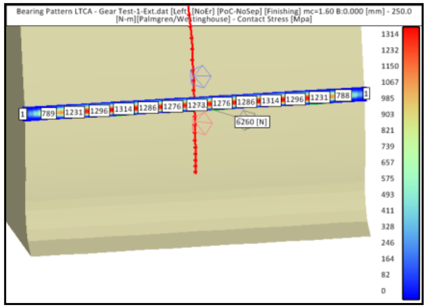


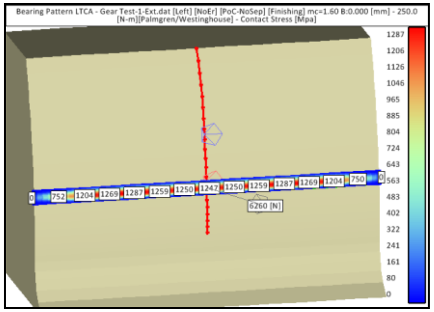



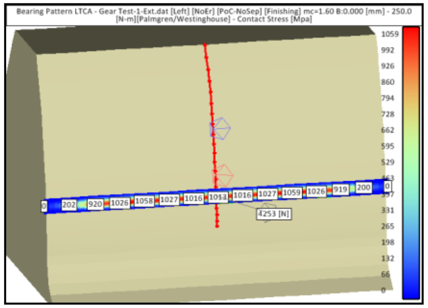







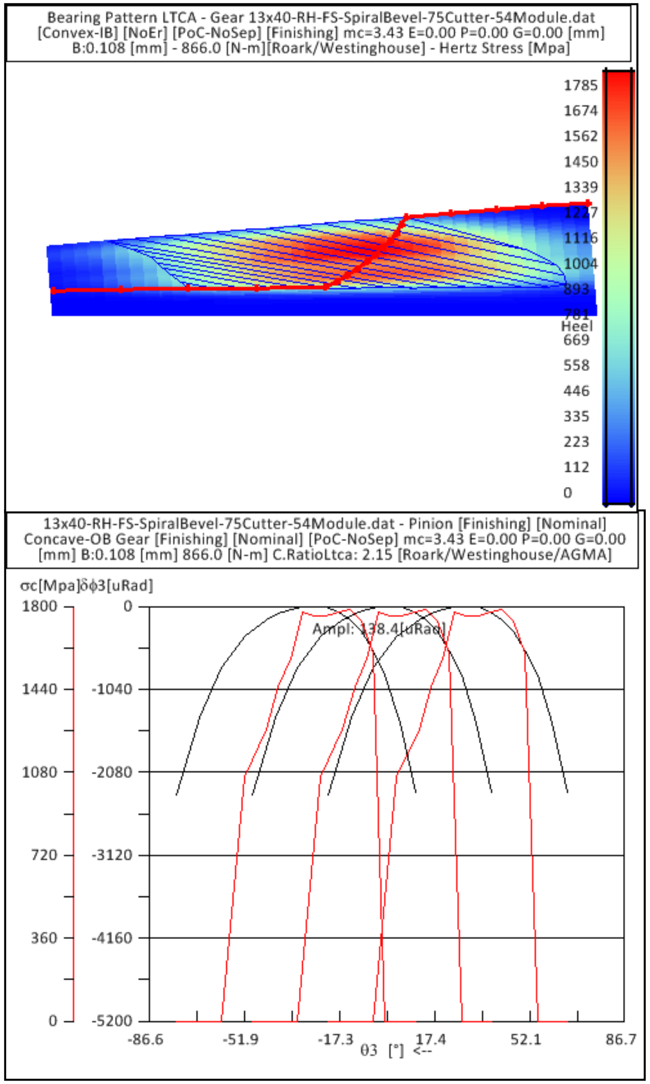


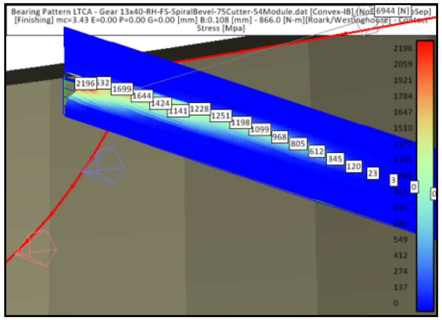


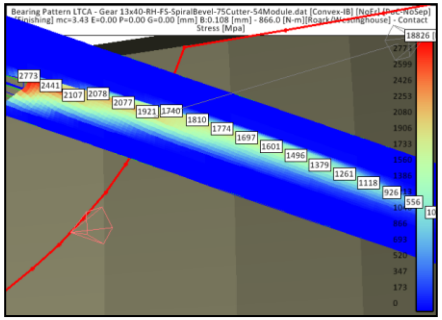


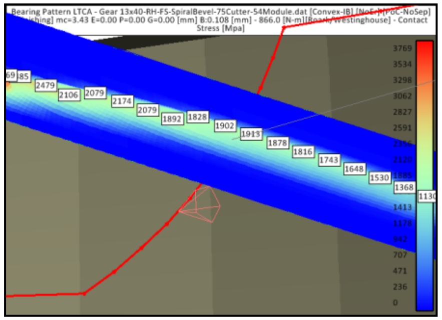
# LTCA Comparison – Spiral-Bevel FM HyGEARS

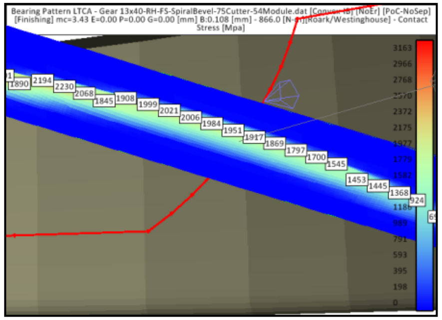
LTCA - Compressive Stress - MPa - Gear Convex:

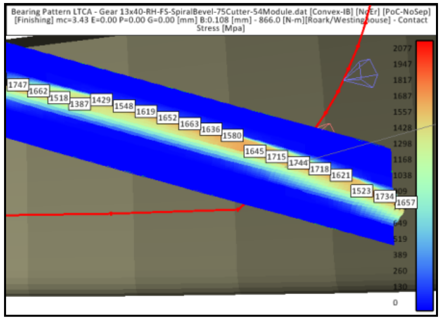


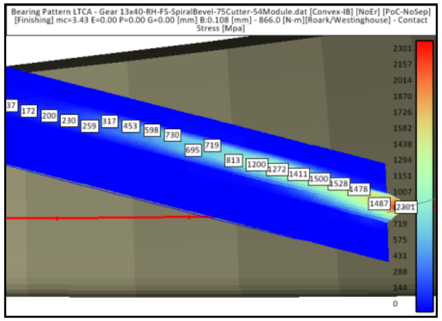







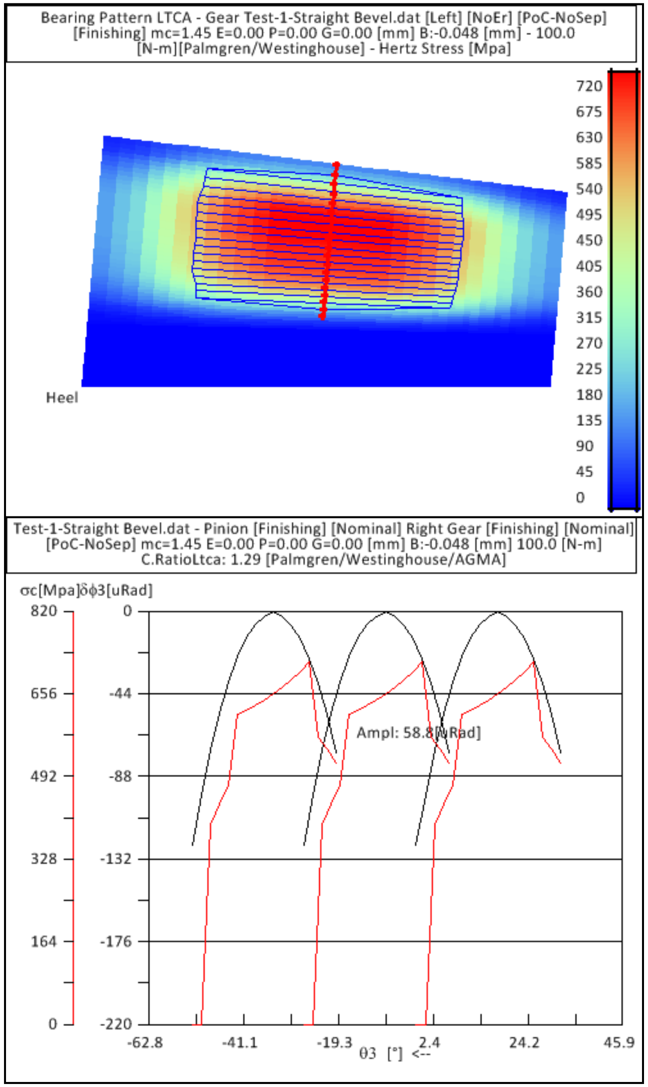


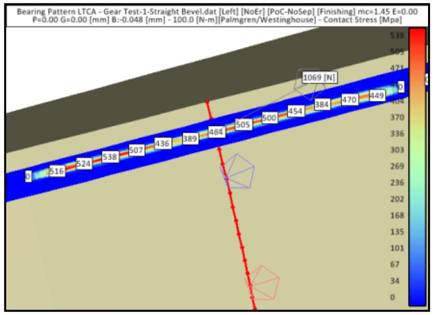


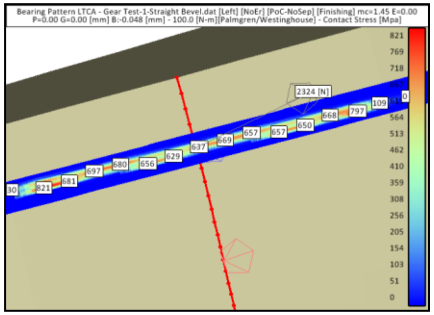


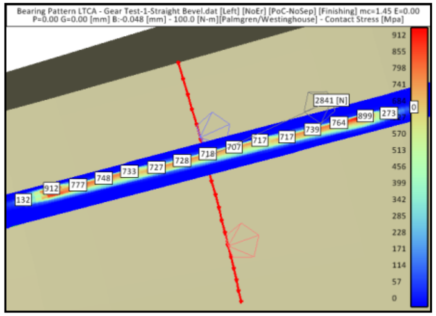
# LTCA Comparison – Straight-Bevel (MRoll) HyGEARS

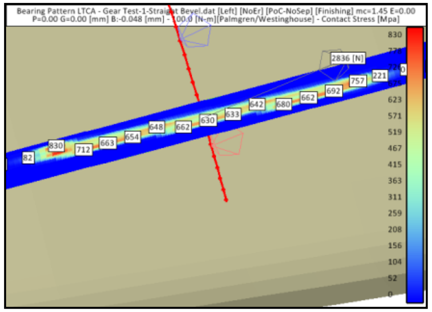
## LTCA - Compressive Stress - MPa - Gear:

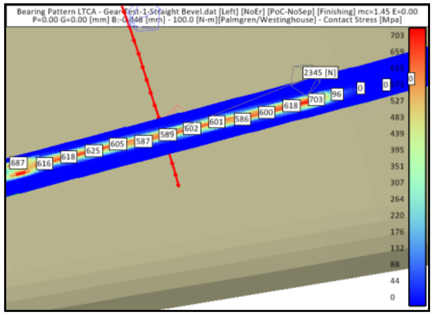


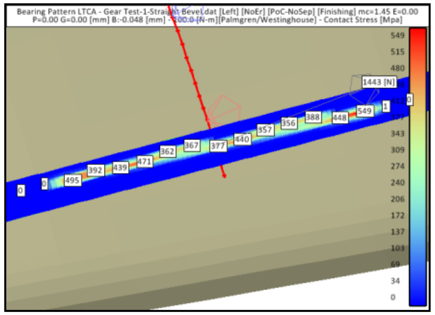







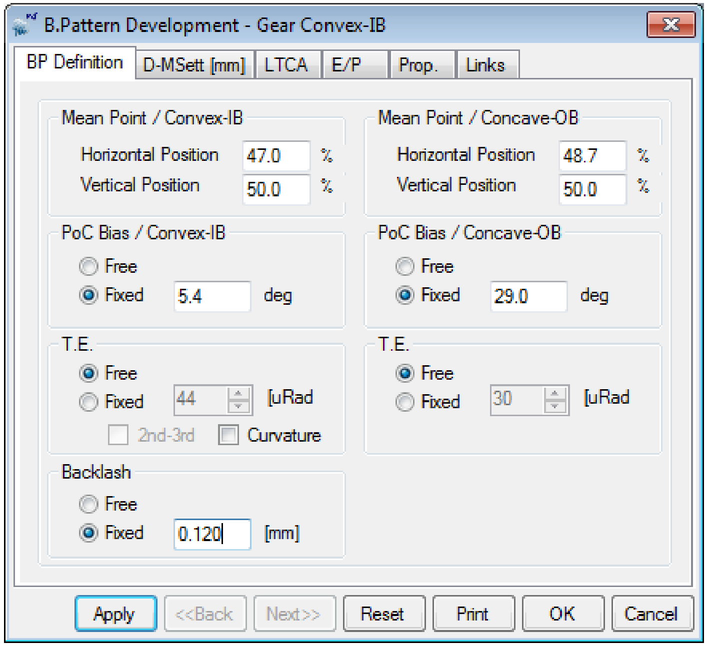


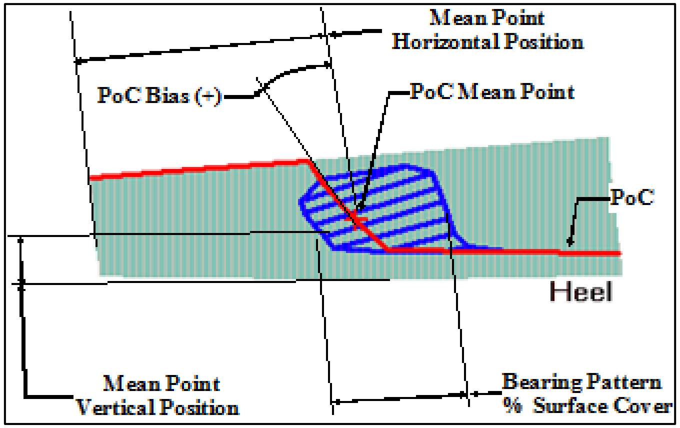


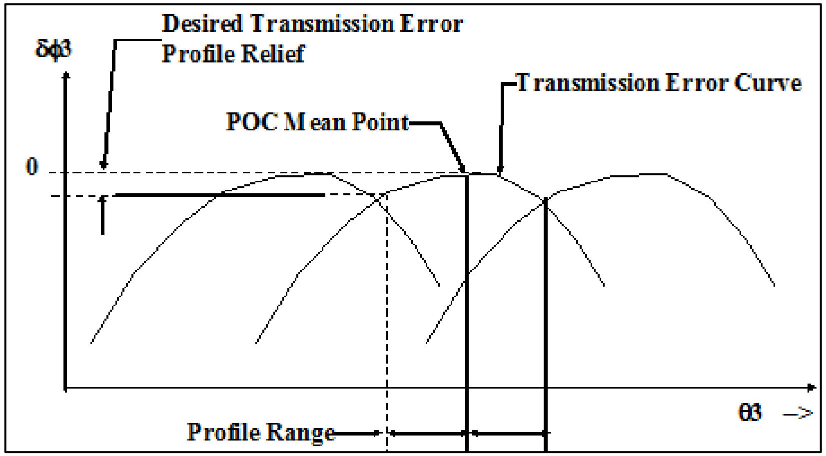


# Graphic Display Functions

*Kinematics -> Contact Pattern Development Child Window*

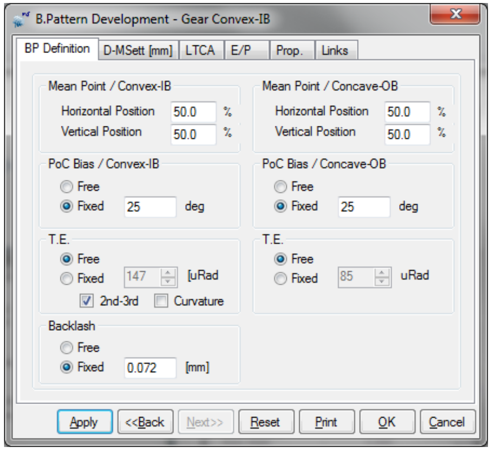


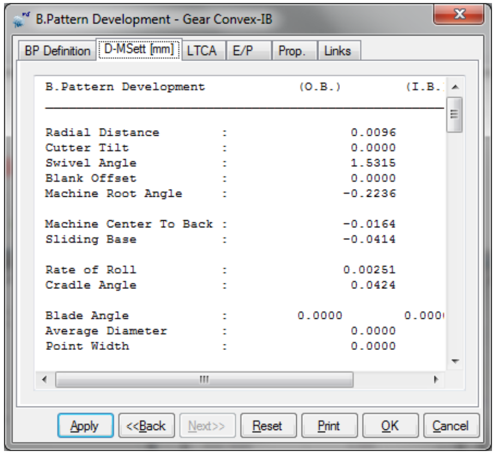



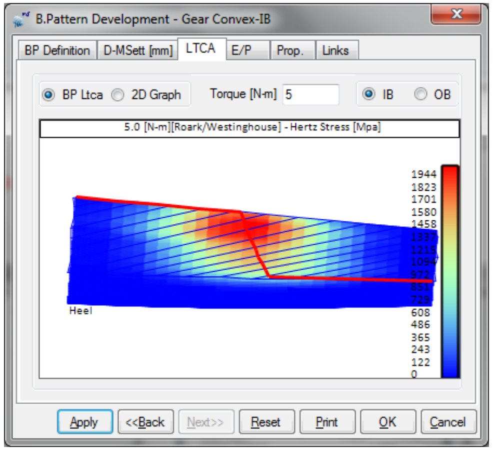



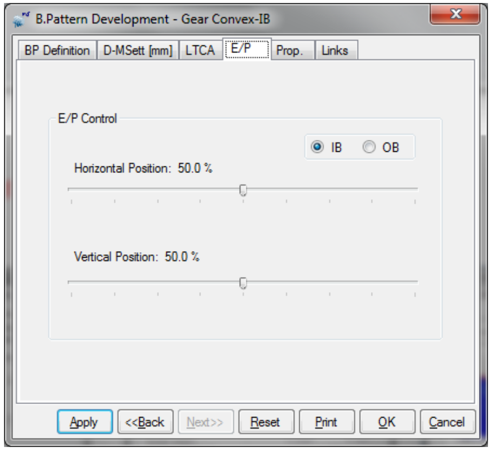
# Graphic Display Functions

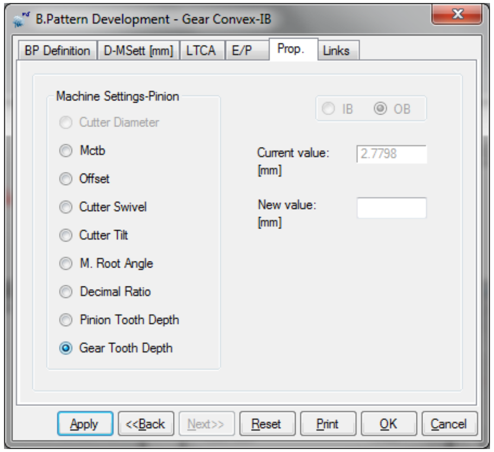
*Kinematics -> Contact Pattern Development Child Window*

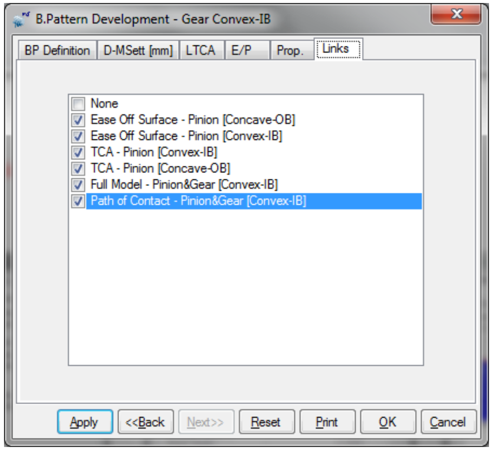










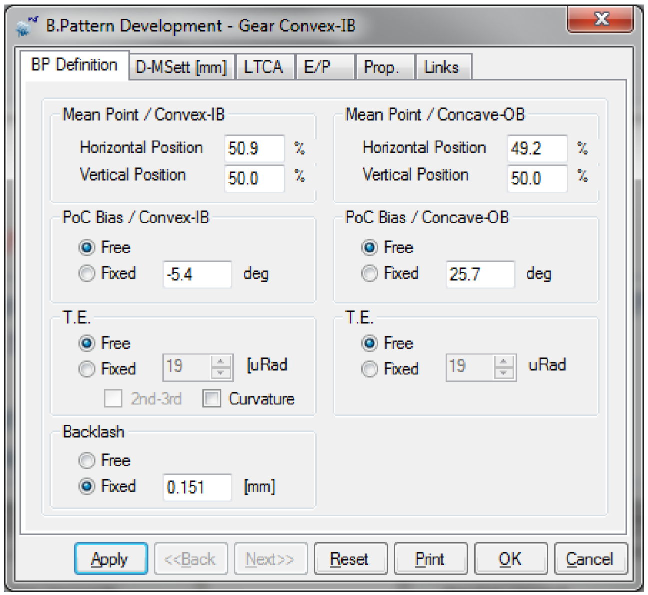


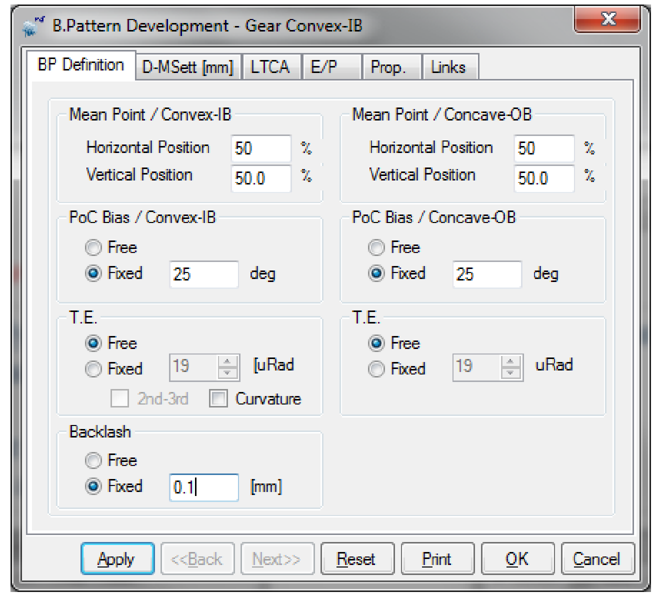
# Graphic Display Functions

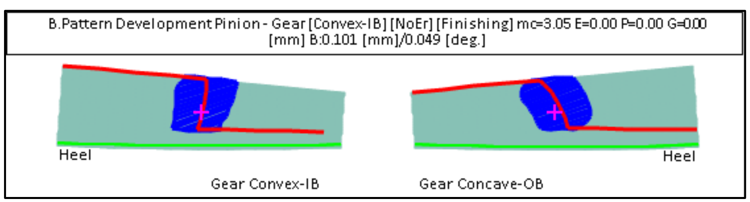
*Kinematics -> Contact Pattern Development Child Window*

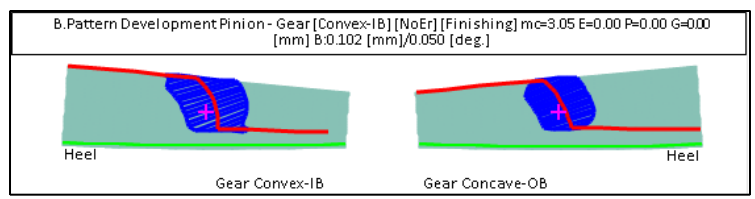
Use the 11x45a.HyG geometry, for the Gear. Test the following Contact Pattern Development (Pinion) child window function buttons, one by one :

- "CPat" – call the Contact Pattern Development selection window
- Input the values as displayed below



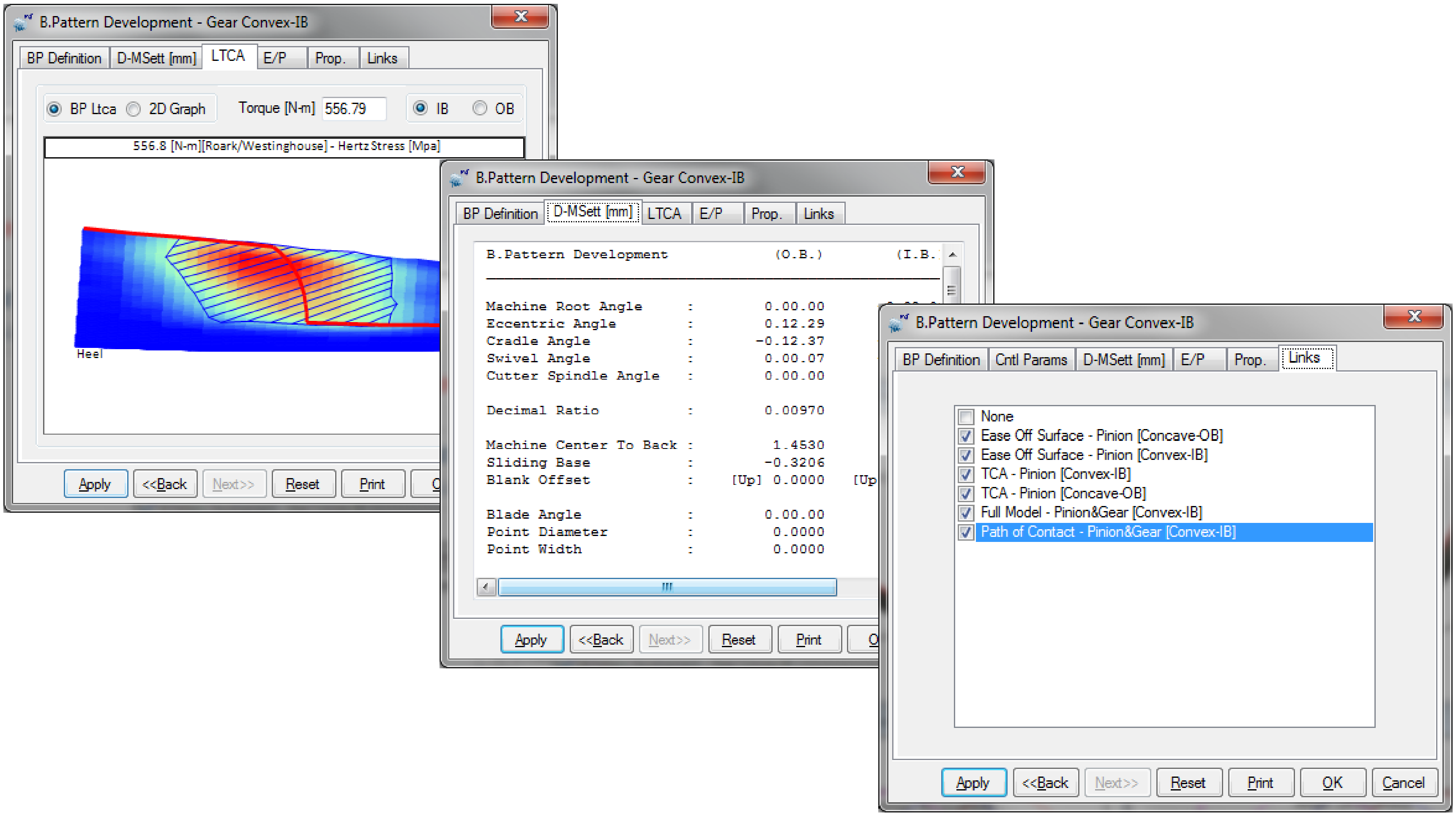



# Graphic Display Functions

*Kinematics -> Contact Pattern Development Child Window*

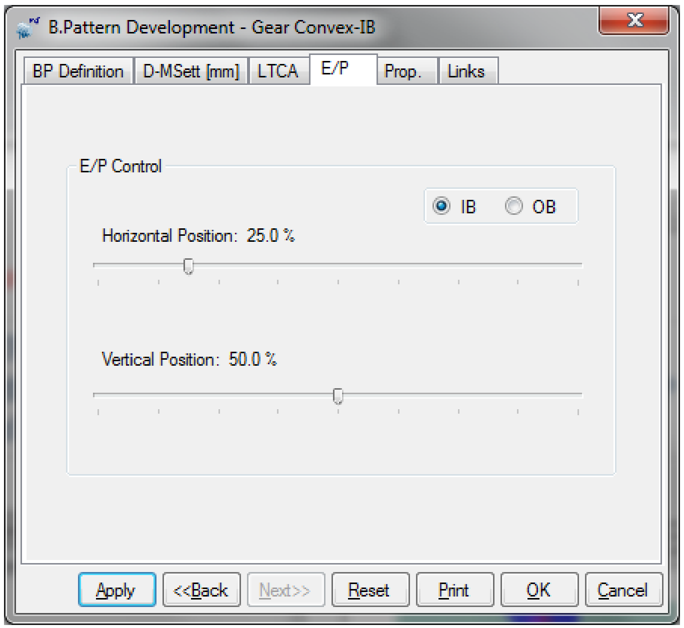
- Scan through the various Tabs to see the displays
- Input the values as displayed below

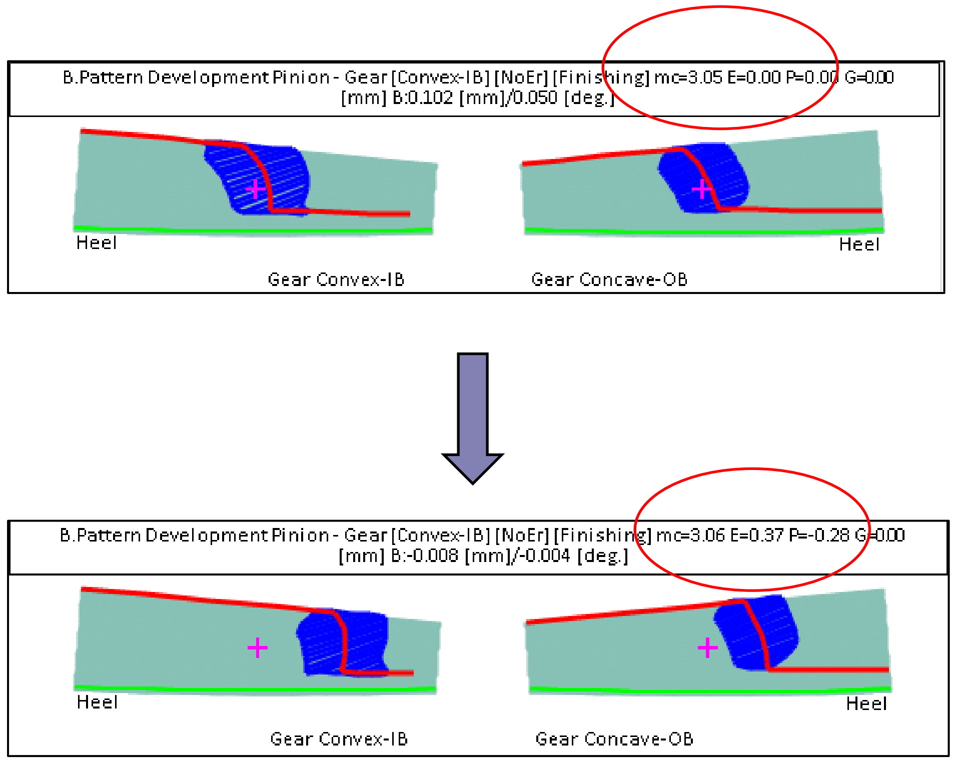


# Graphic Display Functions

*Kinematics -> Contact Pattern Development Child Window*

- Click on the “E/P” tab
- Select 25% for the Horizontal and click on “Apply”; watch the EP values
- Click on “Cancel”



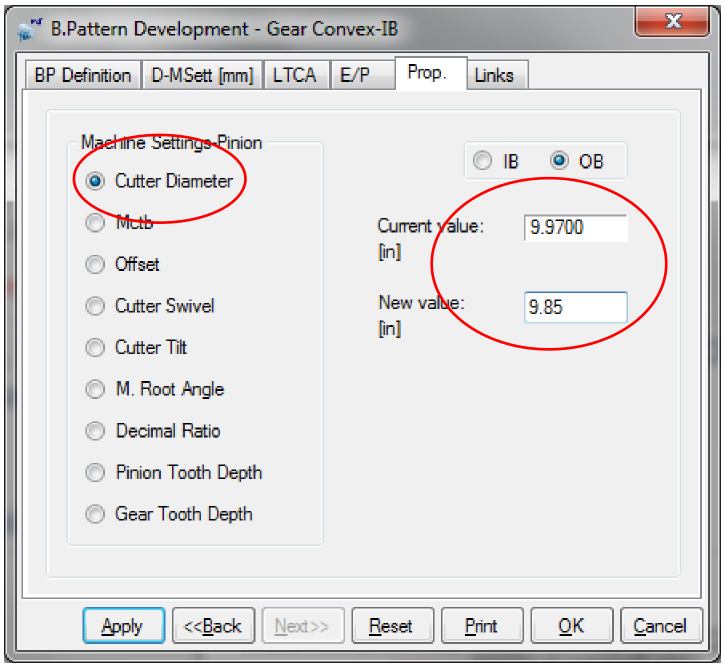



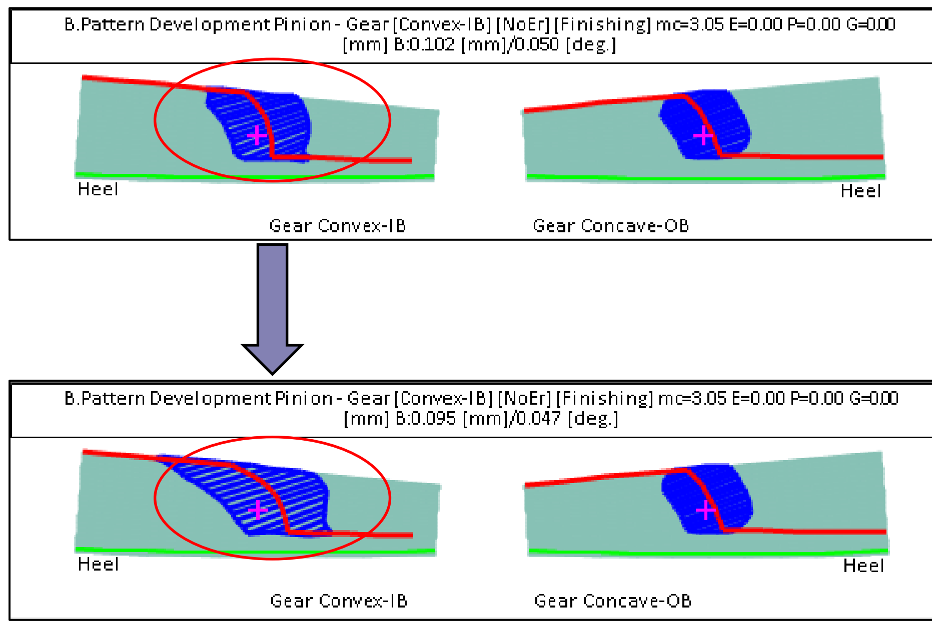
# Graphic Display Functions

*Kinematics -> Contact Pattern Development Child Window*

Use the 11x45a.dat geometry, for the Gear. Test the following Contact Pattern Development (Pinion) child window function buttons, one by one :

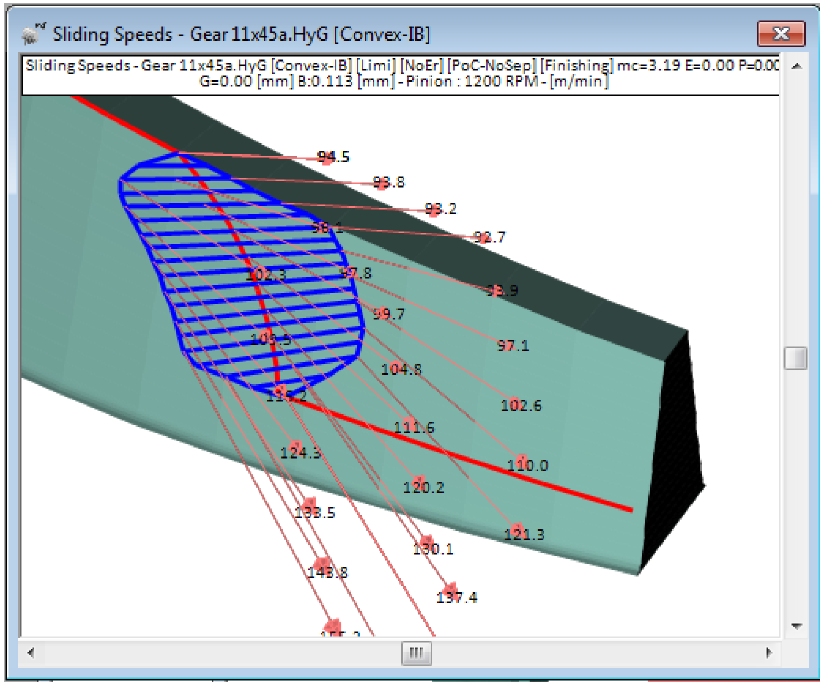
- Click on the “Prop” tab
- Input the values as displayed below – click on “Apply”



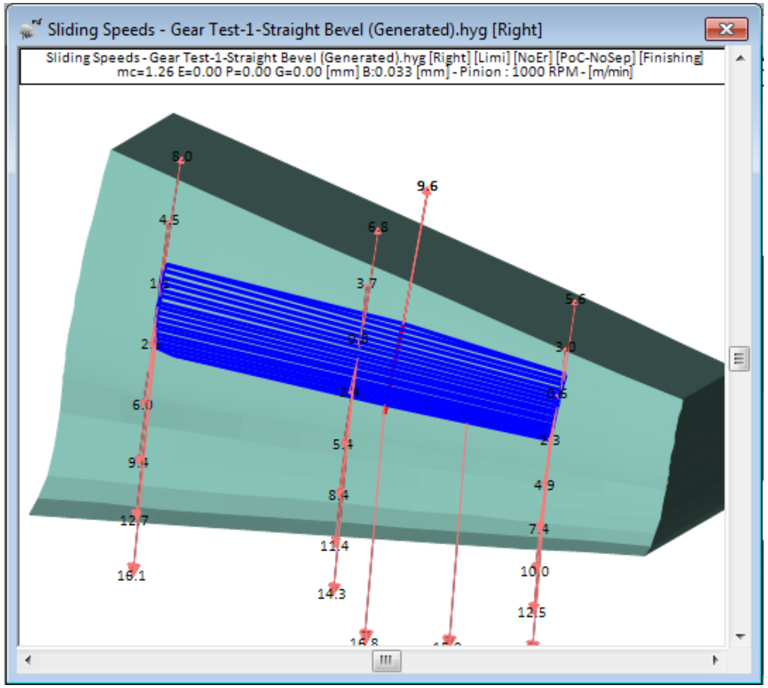



# Graphic Display Functions

*Kinematics -> Sliding Speeds Child Window*



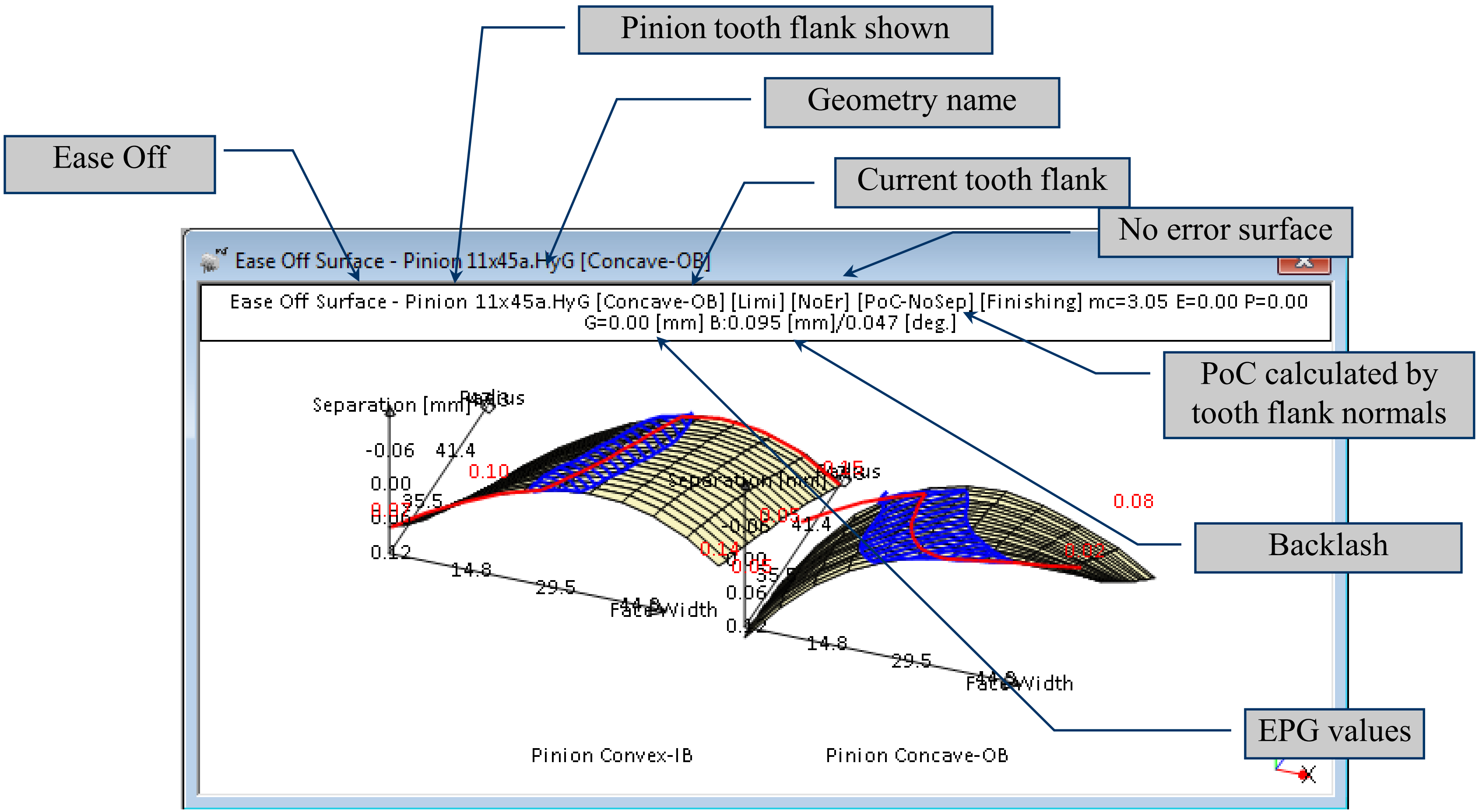

Hypoid gear




Straight Bevel gear

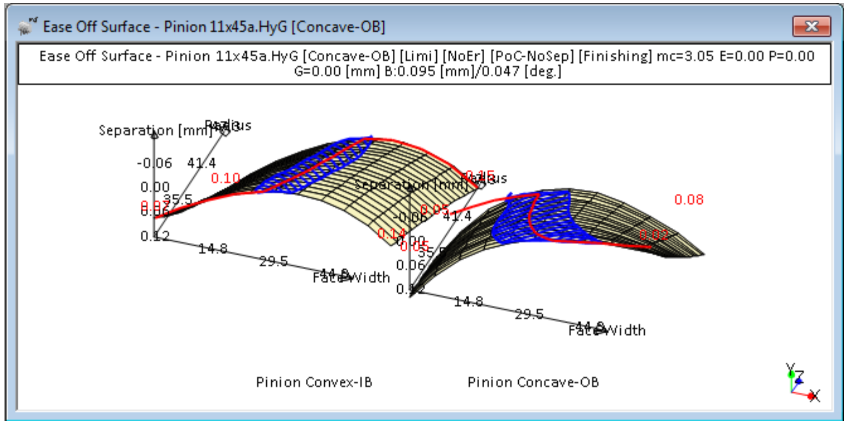
# Graphic Display Functions

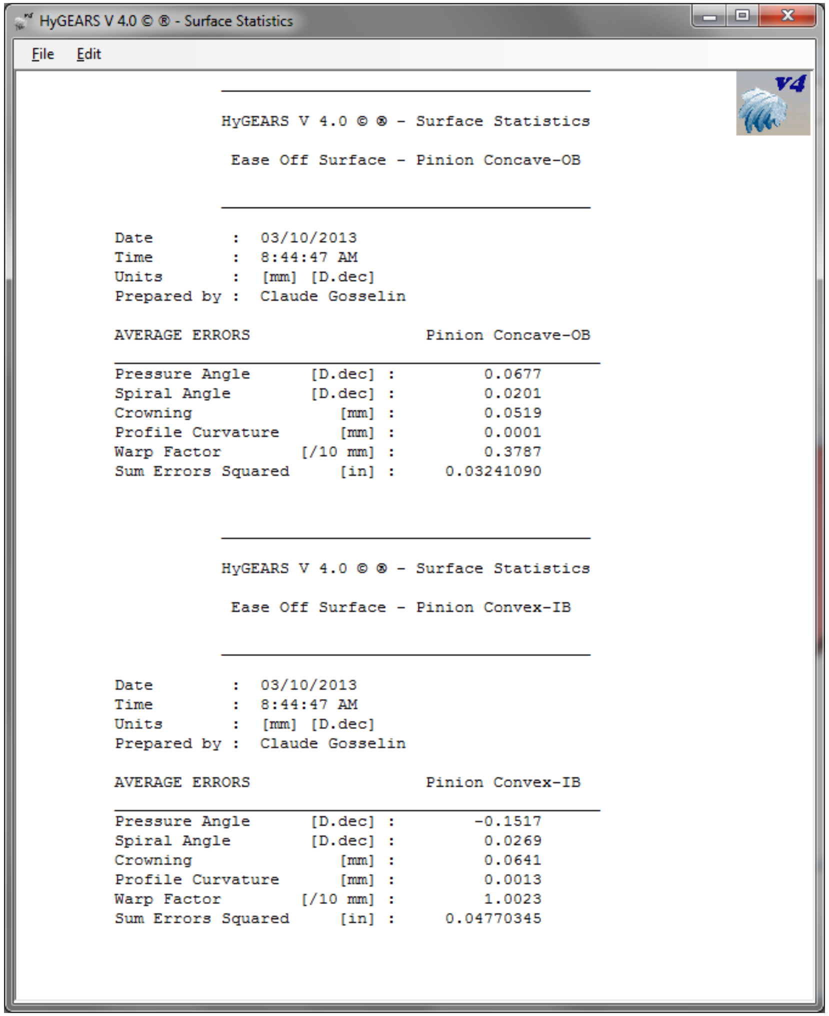
*Kinematics -> Ease Off Child Window*



# Graphic Display Functions

*Kinematics -> Ease Off Child Window*





HyGEARS V 4.0 © ® - Surface Statistics

File Edit

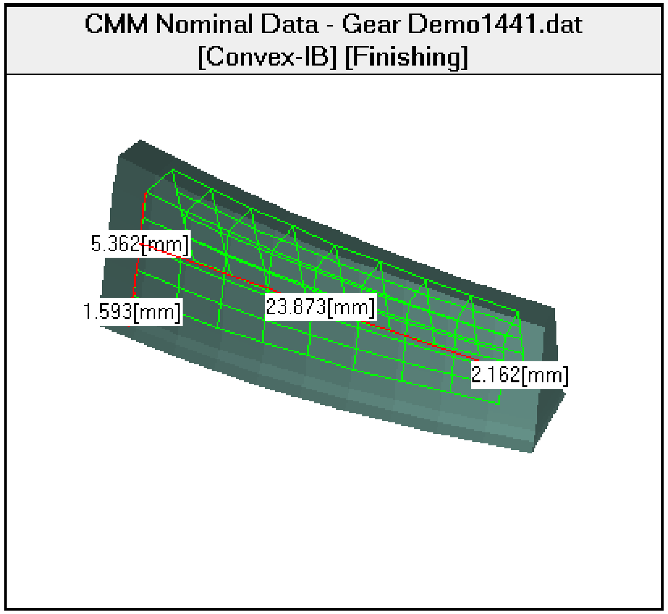
```
HyGEARS V 4.0 © ® - Surface Statistics

Ease Off Surface - Pinion Concave-OB

Date          :  03/10/2013
Time          :  8:44:47 AM
Units         :  [mm]  [D.dec]
Prepared by   :  Claude Gosselin

AVERAGE ERRORS                        Pinion Concave-OB

Pressure Angle        [D.dec] :          0.0677
Spiral Angle          [D.dec] :          0.0201
Crowning                 [mm] :          0.0519
Profile Curvature        [mm] :          0.0001
Warp Factor          [/10 mm] :          0.3787
Sum Errors Squared       [in] :      0.03241090

HyGEARS V 4.0 © ® - Surface Statistics

Ease Off Surface - Pinion Convex-IB

Date          :  03/10/2013
Time          :  8:44:47 AM
Units         :  [mm]  [D.dec]
Prepared by   :  Claude Gosselin

AVERAGE ERRORS                        Pinion Convex-IB

Pressure Angle        [D.dec] :         -0.1517
Spiral Angle          [D.dec] :          0.0269
Crowning                 [mm] :          0.0641
Profile Curvature        [mm] :          0.0013
Warp Factor          [/10 mm] :          1.0023
Sum Errors Squared       [in] :      0.04770345
```

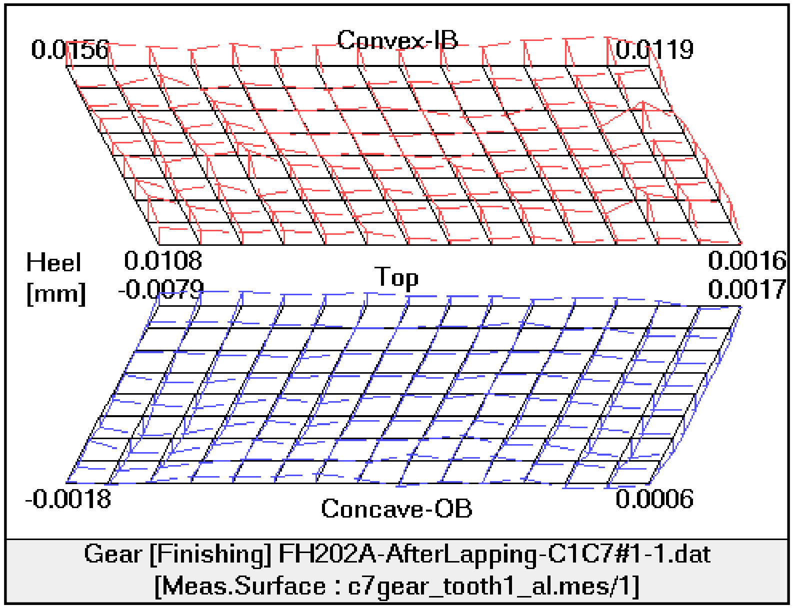
Ease off Surface statistics

# HyGEARS Production Control Functions

HyGEARS offers several tools for Production control. For Spiral-Bevel and Hypoid gears, CMM functions have been developed to:

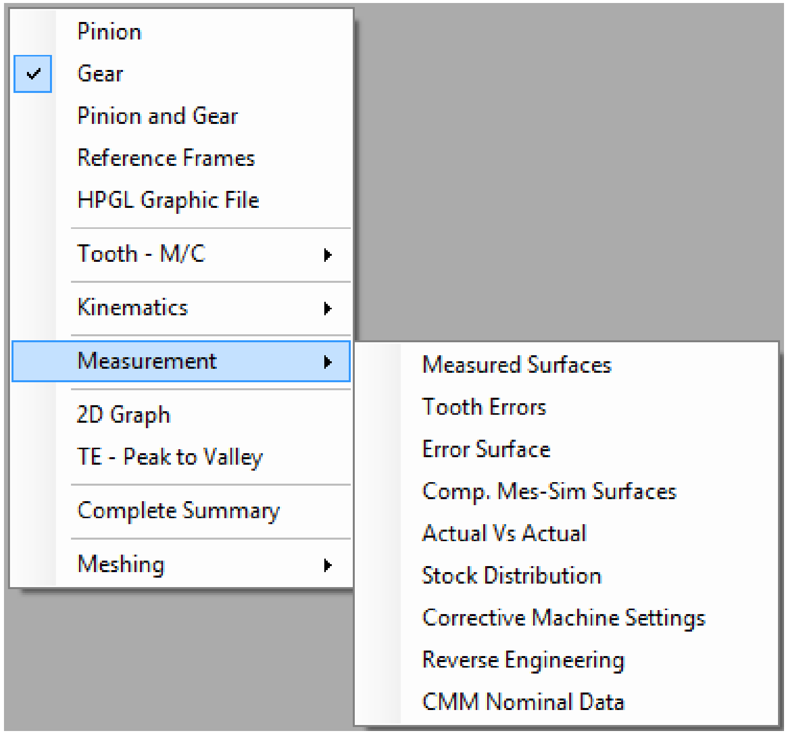
- define *where measurement* on the tooth flank is to be performed;
- *convert and display* surface measurement (from *any* CMM) for quality control check;
- calculate *Corrective Machine Settings*; deviations can be added to pre-compensate for heat treat. deformations;
- *Reverse-Engineer* measured surfaces using the proprietary Surface Match algorithm.



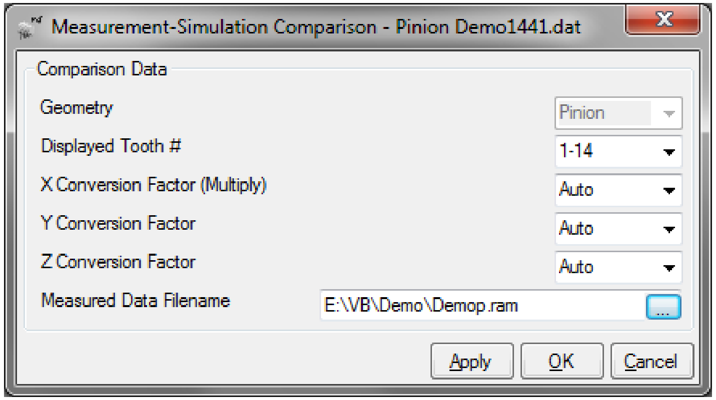
# HyGEARS Production Control Functions

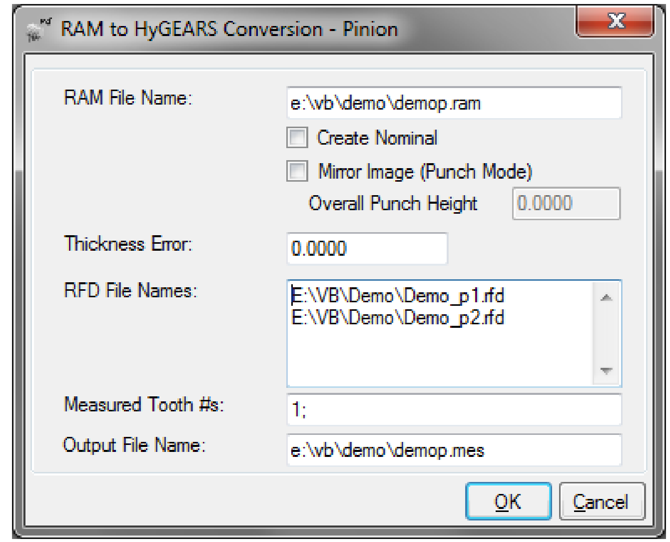
*Measurement, Corrective Machine Settings and Reverse Engineering*



# HyGEARS Production Control Functions

*Measurement -> CMM Data selection and conversion*




Test if the data file is of :

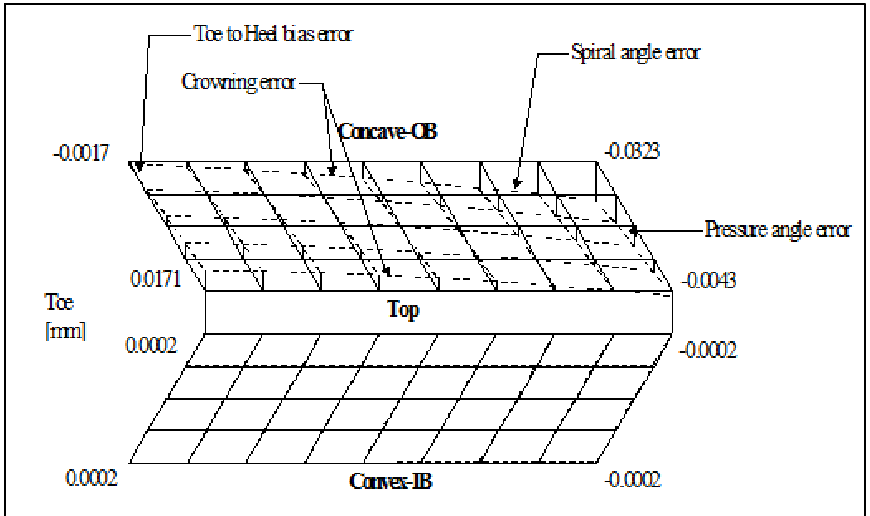
- “Ram” type;
- “Rfd” type;
- “Gleason-Zeiss” type;
- “Hoeffler” type;
- “MdM” type;
- “Klingelnberg-P” type;
- “GAGE” type;
- “Zeiss Gear Pro” type;
- “HyGEARS” type.

# HyGEARS Production Control Functions

*Measurement -> Surface Match Algorithm for Correction / R.E.*

The *Surface Match* algorithm (1994) :

- Changes the machine settings of the selected member until the *measurement surface statistics* are within given tolerances;
- Uses the sensitivity of the error surface (difference between measurement and simulation) to chosen control parameters to iterate until the desired tolerances are met;



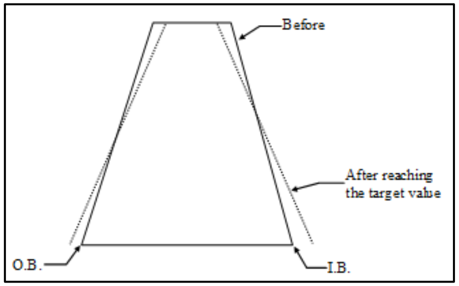

0.200 [mm] Offset change

- Applies a Newton-Raphson based iterative process to solve the objective functions.

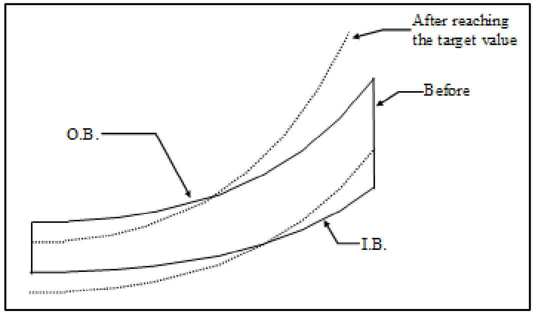
# HyGEARS Production Control Functions

*Measurement -> Surface Match Algorithm for Correction / R.E.*

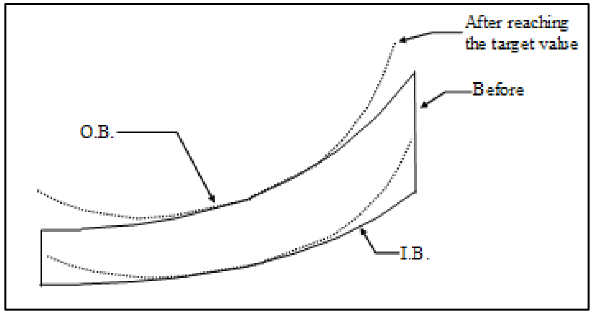
Pressure Angle Error:




Spiral Angle Error:



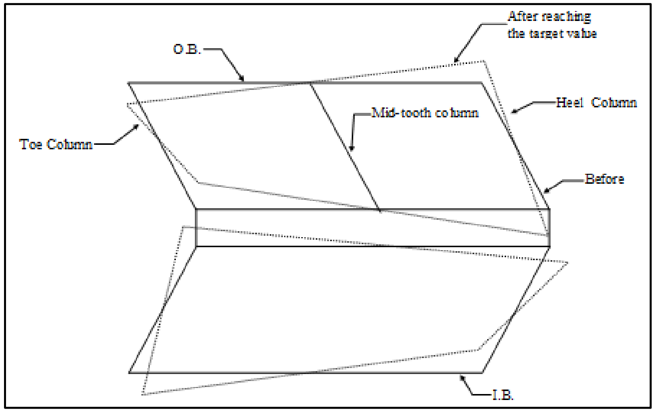

Crowning Error:



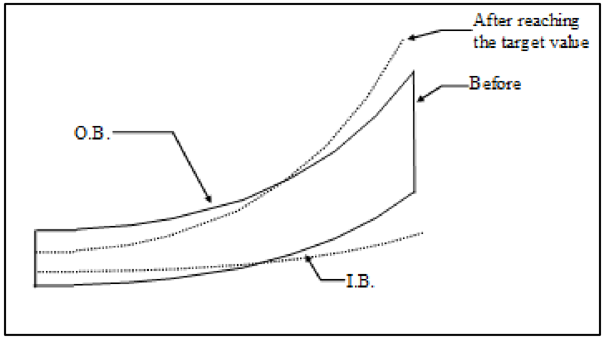
# HyGEARS Production Control Functions

*Measurement -> Surface Match Algorithm for Correction / R.E.*

Warp Error:




Taper Error:



# HyGEARS Production Control Functions

*Measurement -> Surface Match Algorithm for Correction / R.E.*

## 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:

$$\zeta = \Phi_i - \Phi_j$$

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.

# HyGEARS Production Control Functions

*Measurement -> Surface Match Algorithm for Correction / R.E.*

Objective Functions:

1st Order:

$$\Phi(\tau, \kappa, SlBase) - T_1 \le L_1$$
$$\Psi(\kappa, \psi, SlBase) - T_2 \le L_2$$

$\Phi$ is the average *pressure angle error;*
$\Psi$ is the average *spiral angle error*;

2nd Order

$$\Xi(\tau, \kappa, \psi, SlBase, Offset) - T_3 \le L_3$$
$$\zeta(\tau, \kappa, \psi, SlBase, Mctb) - T_4 \le L_4$$

$\Xi$ is the averaged *crowning error;*
$\zeta$ is the averaged *warp (bias) error;*

$T_i$ are the requested *deviations*;
$L_i$ are the *tolerance limits*;

# HyGEARS Production Control Functions

*Measurement -> Surface Match Algorithm for Correction / R.E.*

Jacobian (or 1st order sensitivity) matrix:

1st Order:

$$\begin{Bmatrix} \frac{\partial\Phi}{\partial\tau} & \frac{\partial\Phi}{\partial\kappa} \\ \frac{\partial\Psi}{\partial\tau} & \frac{\partial\Psi}{\partial\kappa} \end{Bmatrix} \begin{Bmatrix} \Delta\tau \\ \Delta\kappa \end{Bmatrix} = \begin{Bmatrix} -\Phi \\ -\Psi \end{Bmatrix}$$

2nd Order:

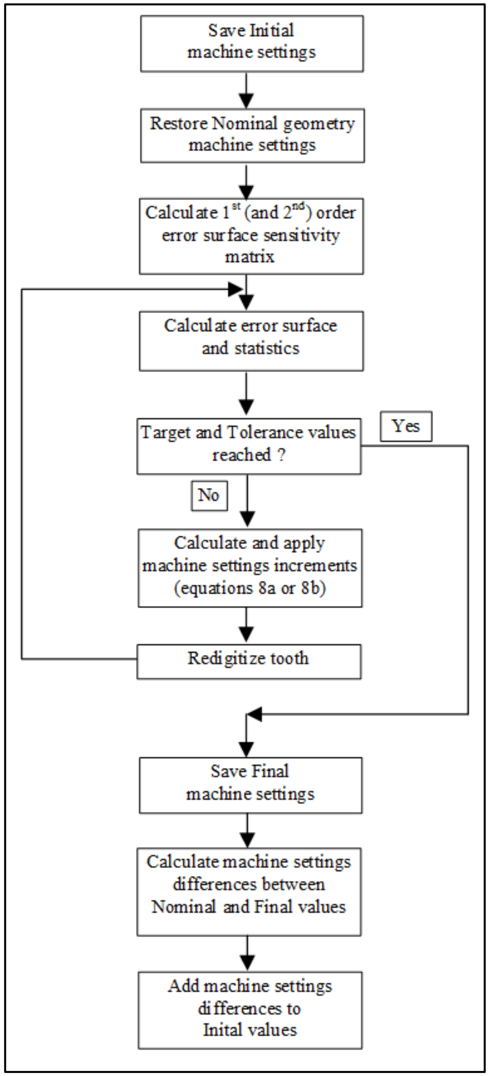
$$\begin{Bmatrix} \frac{\partial\Phi}{\partial\tau} & \frac{\partial\Phi}{\partial\kappa} & \frac{\partial\Phi}{\partial Mctb} & \frac{\partial\Phi}{\partial DRatio} \\ \frac{\partial\Psi}{\partial\tau} & \frac{\partial\Psi}{\partial\kappa} & \frac{\partial\Psi}{\partial Mctb} & \frac{\partial\Psi}{\partial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

$\Phi$ is the average *pressure angle error;*
$\Psi$ is the average *spiral angle error*;
$\Xi$ is the averaged *crowning error;*
$\zeta$ is the averaged *warp (bias) error;*

# HyGEARS Production Control Functions

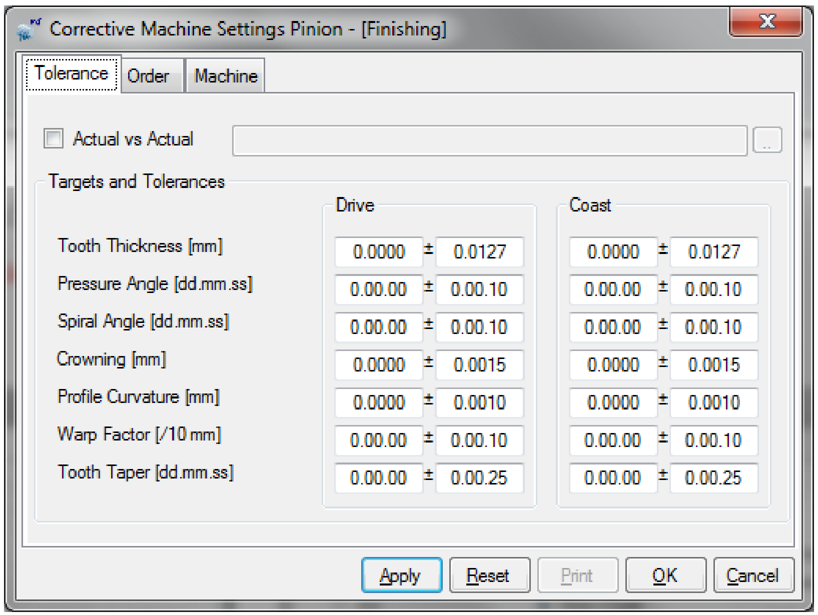
*Measurement -> Surface Match Algorithm for Correction / R.E.*

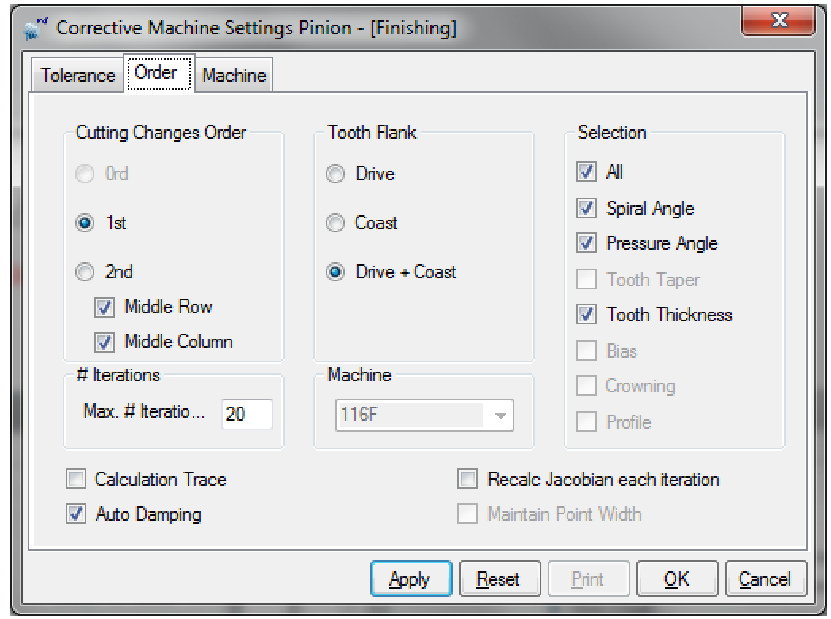
Algorithm flow chart:



# HyGEARS Production Control Functions

*Measurement -> Corrective Machine Settings and R.E. selection window*

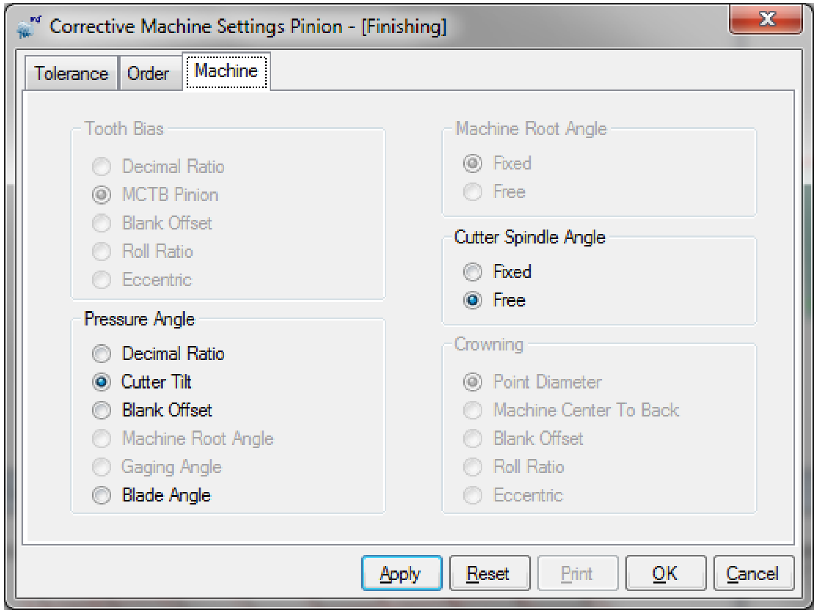


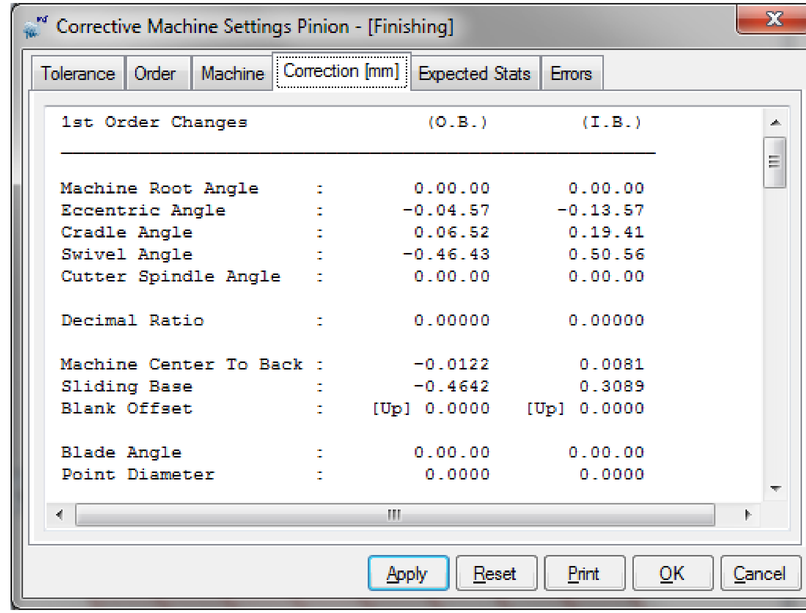




| | |
|---|---|
| Tolerance | options on target values and tolerances; |
| Order | options on what is to be corrected; |
| Machine | options on control parameters constraints; |
| Correction | calculated changes in machine settings; |
| Expected Stats | what HyGEARS hopes to achieve after correction; |
| Errors | point by point differences |

# HyGEARS Production Control Functions

*Measurement -> Corrective Machine Settings and R.E. selection window*

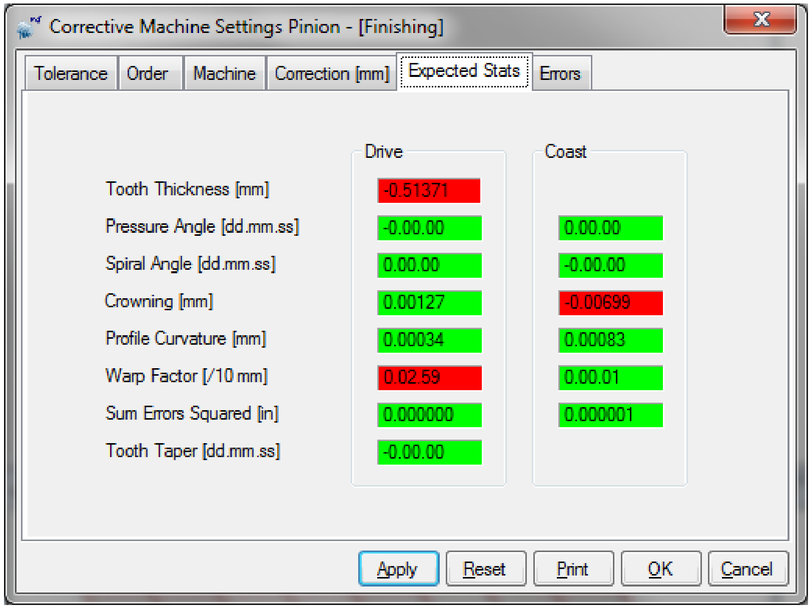


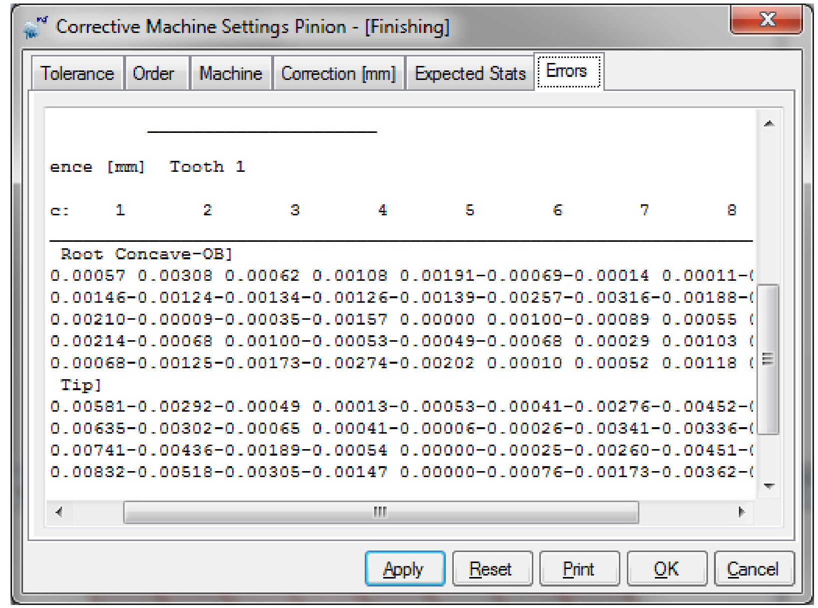




| | |
|---|---|
| Tolerance | options on target values and tolerances; |
| Order | options on what is to be corrected; |
| Machine | options on control parameters constraints; |
| Correction | calculated changes in machine settings; |
| Expected Stats | what HyGEARS hopes to achieve after correction; |
| Errors | point by point differences |

# HyGEARS Production Control Functions

*Measurement -> Corrective Machine Settings and R.E. selection window*




| | |
|---|---|
| Tolerance | options on target values and tolerances; |
| Order | options on what is to be corrected; |
| Machine | options on control parameters constraints; |
| Correction | calculated changes in machine settings; |
| Expected Stats | what HyGEARS hopes to achieve after correction; |
| Errors | point by point differences |

# HyGEARS Production Control Functions

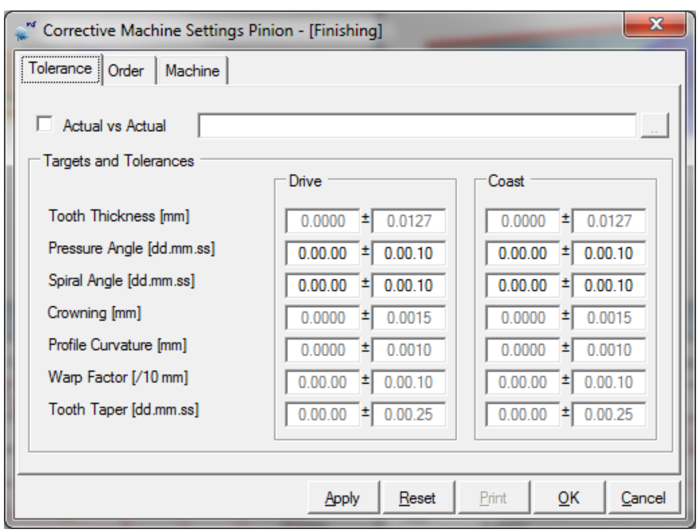
*Measurement -> Corrective Machine Settings*

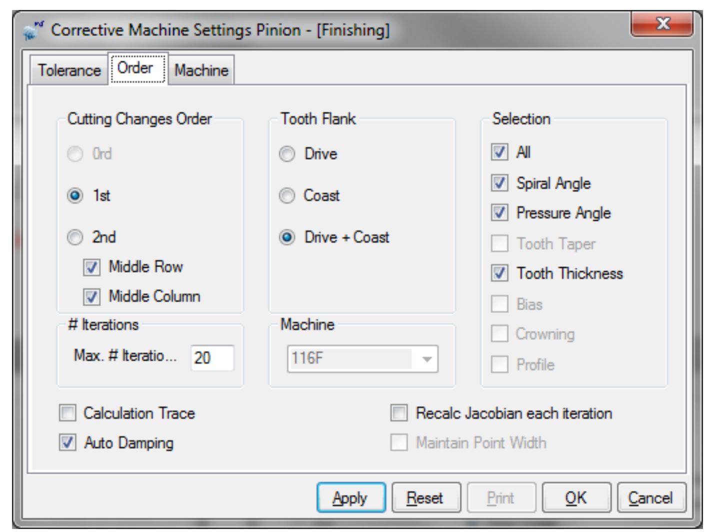
HyGEARS offers Corrective Machine Settings (similar to Gleason's GAGE)

CMM data is used to calculate changes in machine settings needed for the actual tooth surface to match the theoretical tooth surface.

Corrective Machine Settings support:

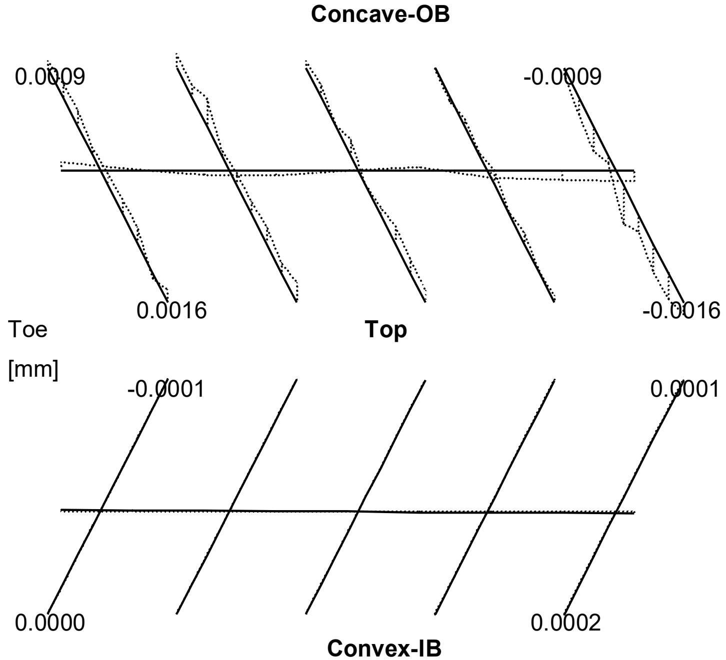
- 1$^{st}$ order errors: spiral angle, pressure angle, tooth taper;
- 2$^{nd}$ order errors: crowning and tooth warp (bias);
- Roughing and Finishing;
- All FM and FH cutting processes



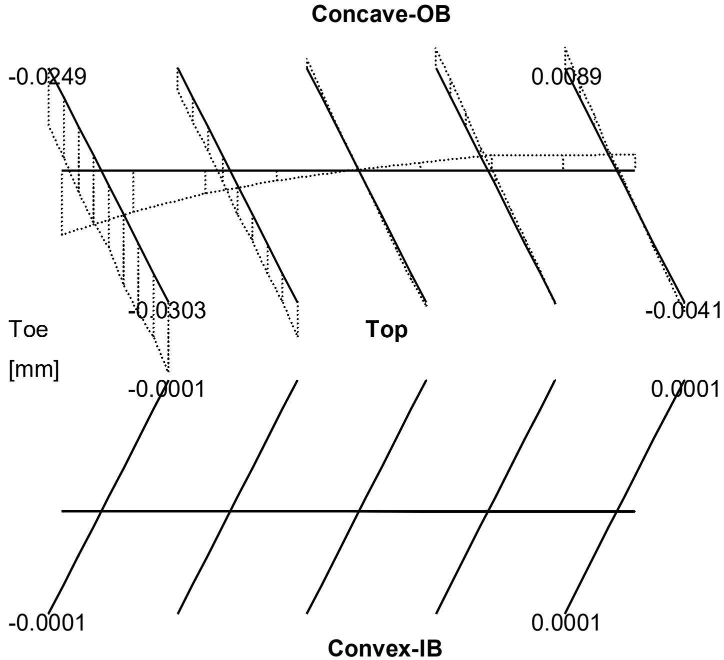



# Corrective Machine Settings: Fixed Setting Example

*Measurement -> Corrective Machine Settings*



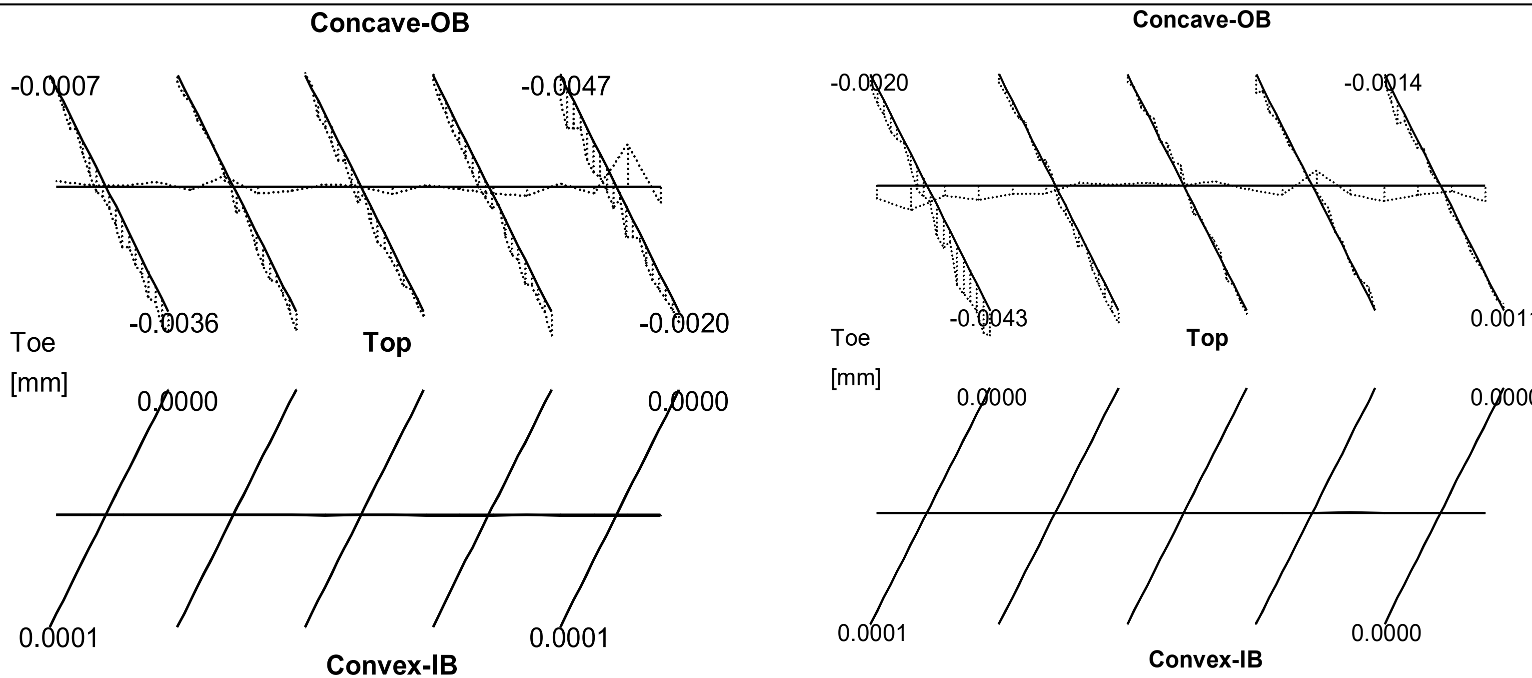

Theoretical and
target pinion tooth surface




Theoretical and
30’ bias-out tooth surface

# Corrective Machine Settings: Fixed Setting Example

*Measurement -> Corrective Machine Settings*

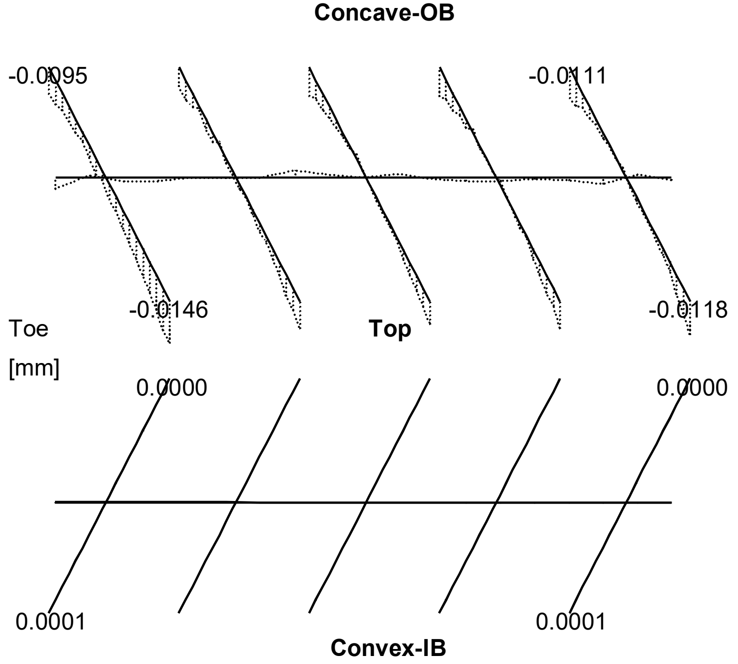



-2 µm profile deviation

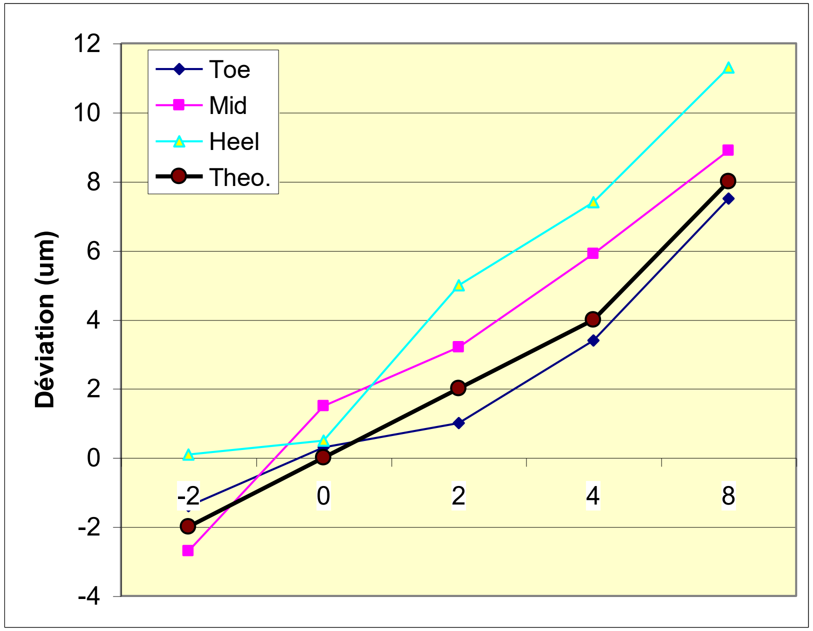
0 µm profile deviation

# Corrective Machine Settings: Fixed Setting Example

*Measurement -> Corrective Machine Settings*



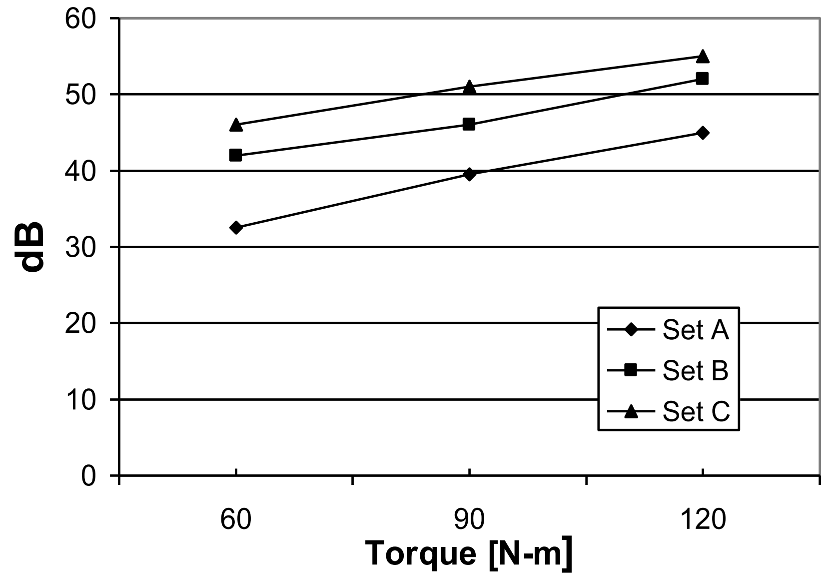

**+8 µm profile deviation**



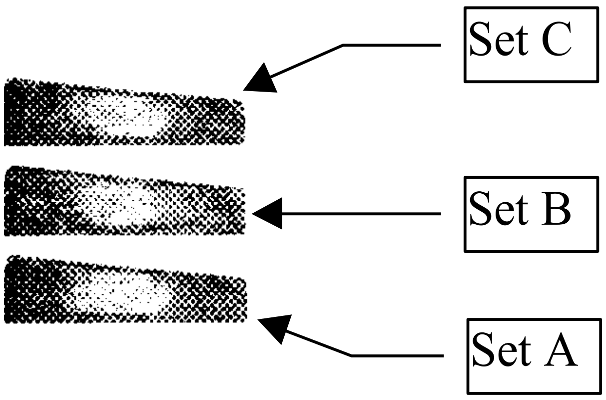

**Requested vs Obtained profile deviations**

# Corrective Machine Settings: Fixed Setting Example

*Measurement -> Corrective Machine Settings*



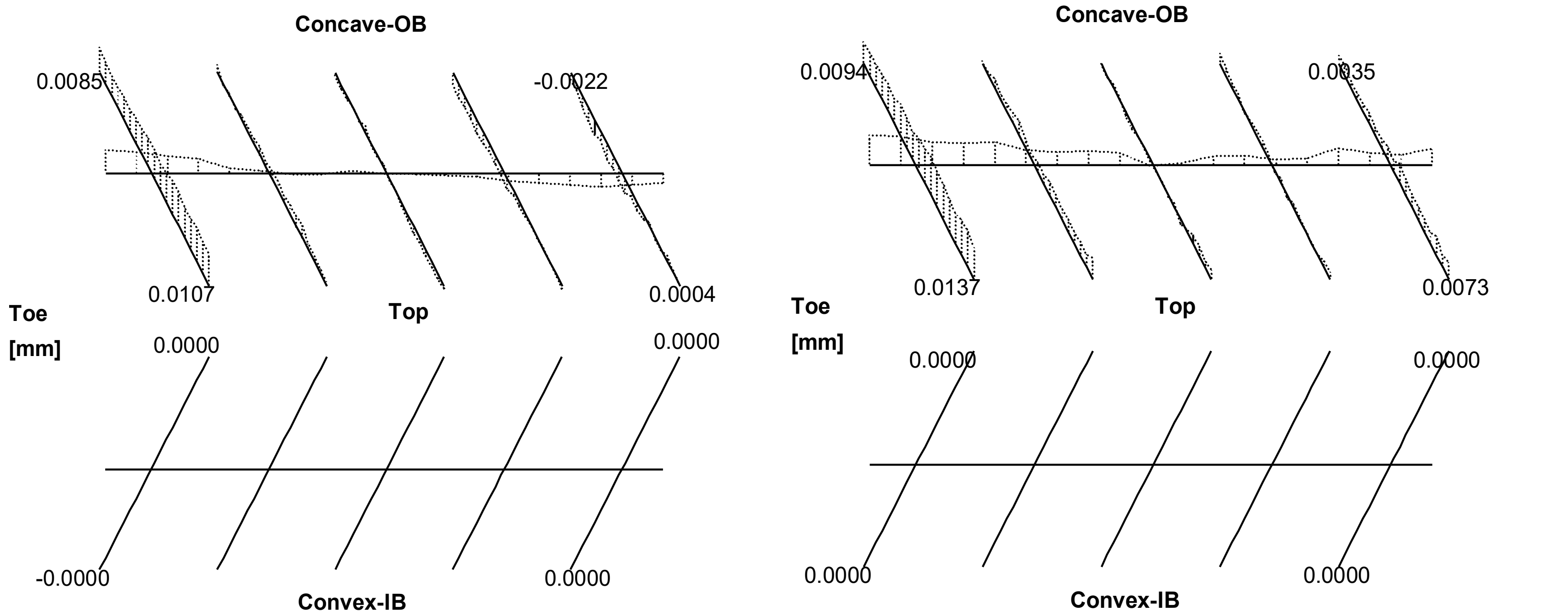

Vibration Levels Before Correction




BPs Before Correction

# Corrective Machine Settings: Fixed Setting Example

*Measurement -> Corrective Machine Settings*

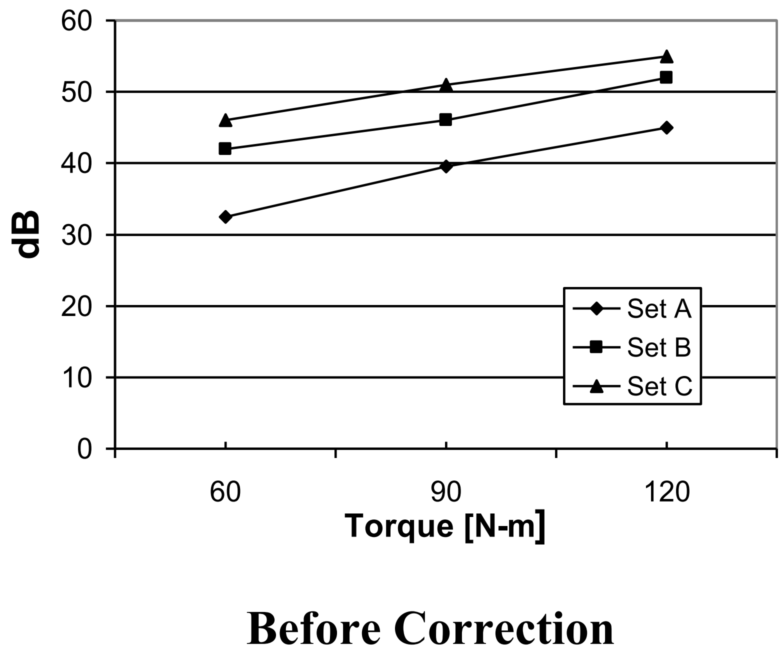


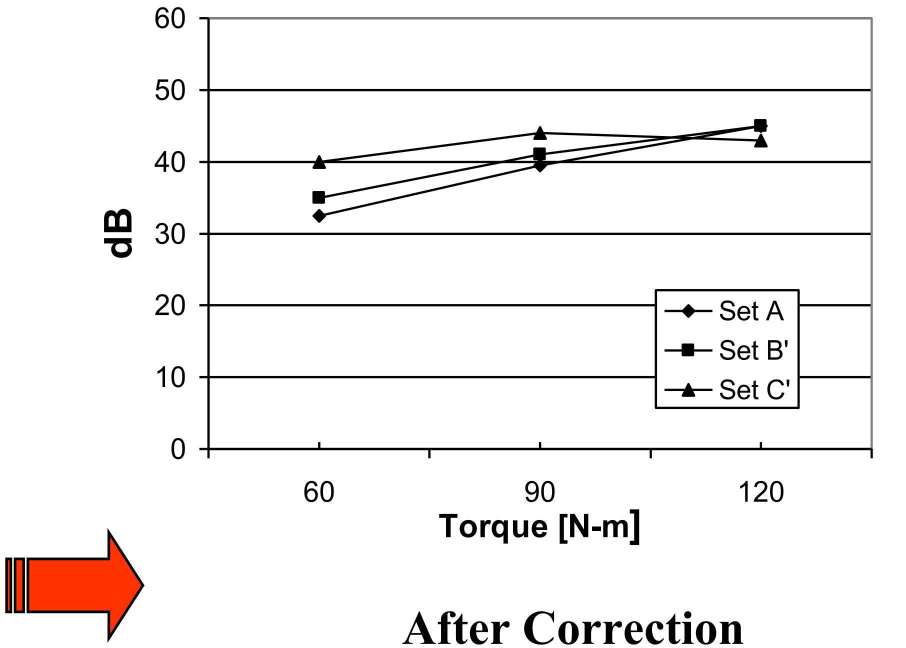

**Differences between Pinions A and B**

**Differences between Pinions A and C**

# Corrective Machine Settings: Fixed Setting Example

*Measurement -> Corrective Machine Settings*



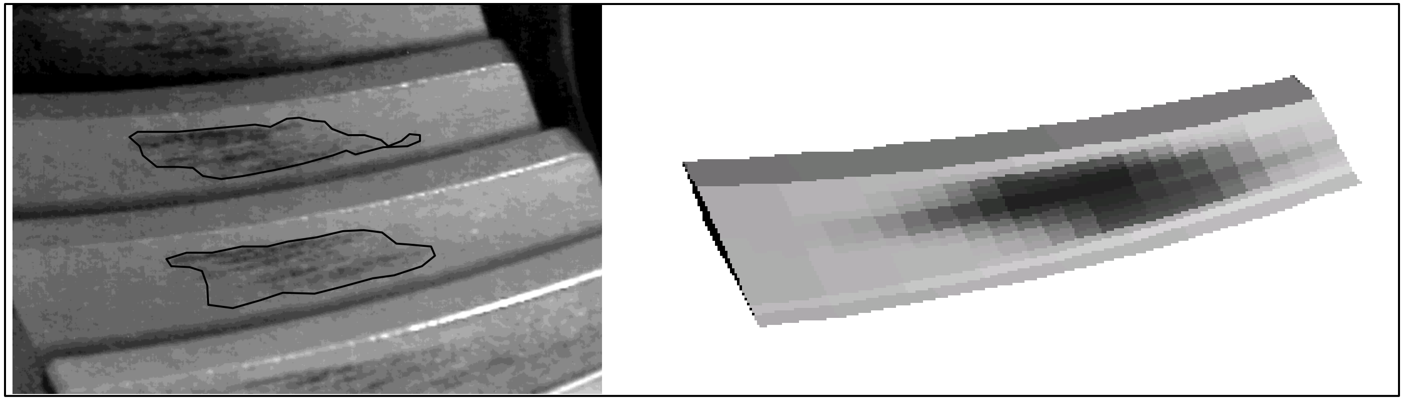
# HyGEARS Production Control Functions

*Measurement -> Reverse Engineering*

HyGEARS uses the Surface Match algorithm to *Reverse Engineer* existing tooth surfaces.

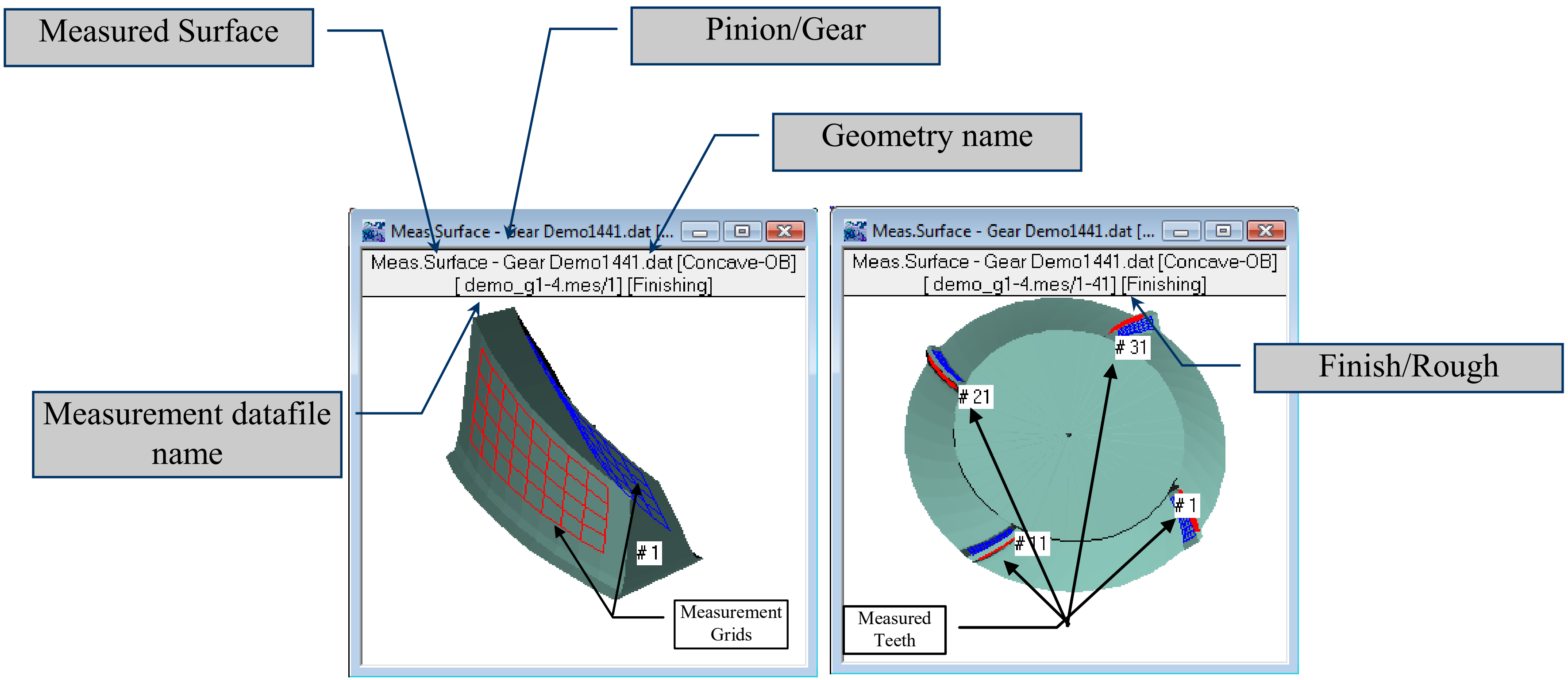
Reverse Engineering is useful to:

- identify the machine settings of existing gear sets for which the *summaries are lost*;
- *analyze existing gear sets* and identify the machine settings or provide a reference surface leading to quietness;
- *diagnose the reason for a failure* by simulating meshing and load sharing;
- optimize the Stock Distribution;
- *use different cutters* on a given geometry (Fixed Setting only);
- *calibrate mechanical machines* to pre-compensate for their inaccuracies;
- etc.



# HyGEARS Production Control Functions

*Measurement -> Measured Surfaces Child Window*

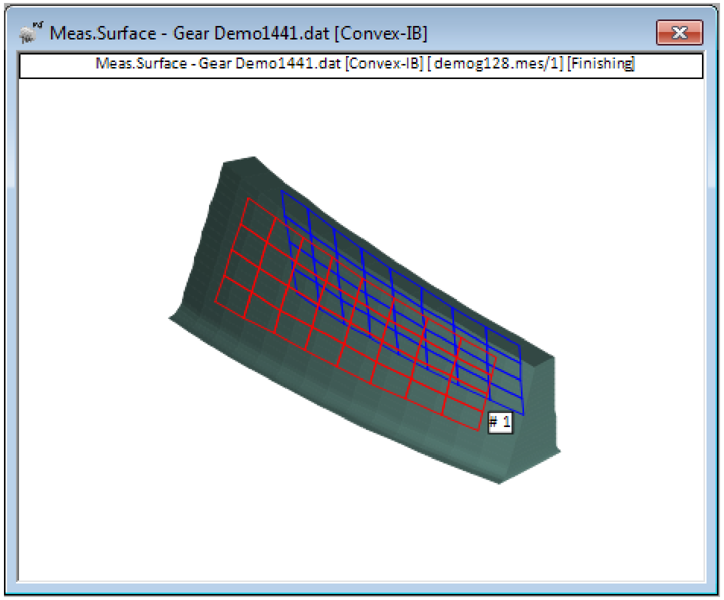


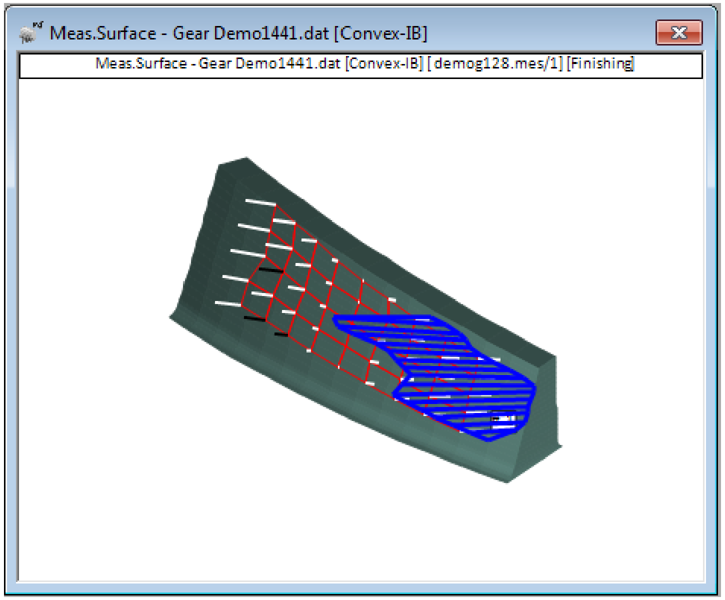
# HyGEARS Production Control Functions

*Measurement -> Measured Surfaces Child Window*

Use the Demo1441.HyG geometry. Test the following Measured Surfaces child window function buttons, one by one :

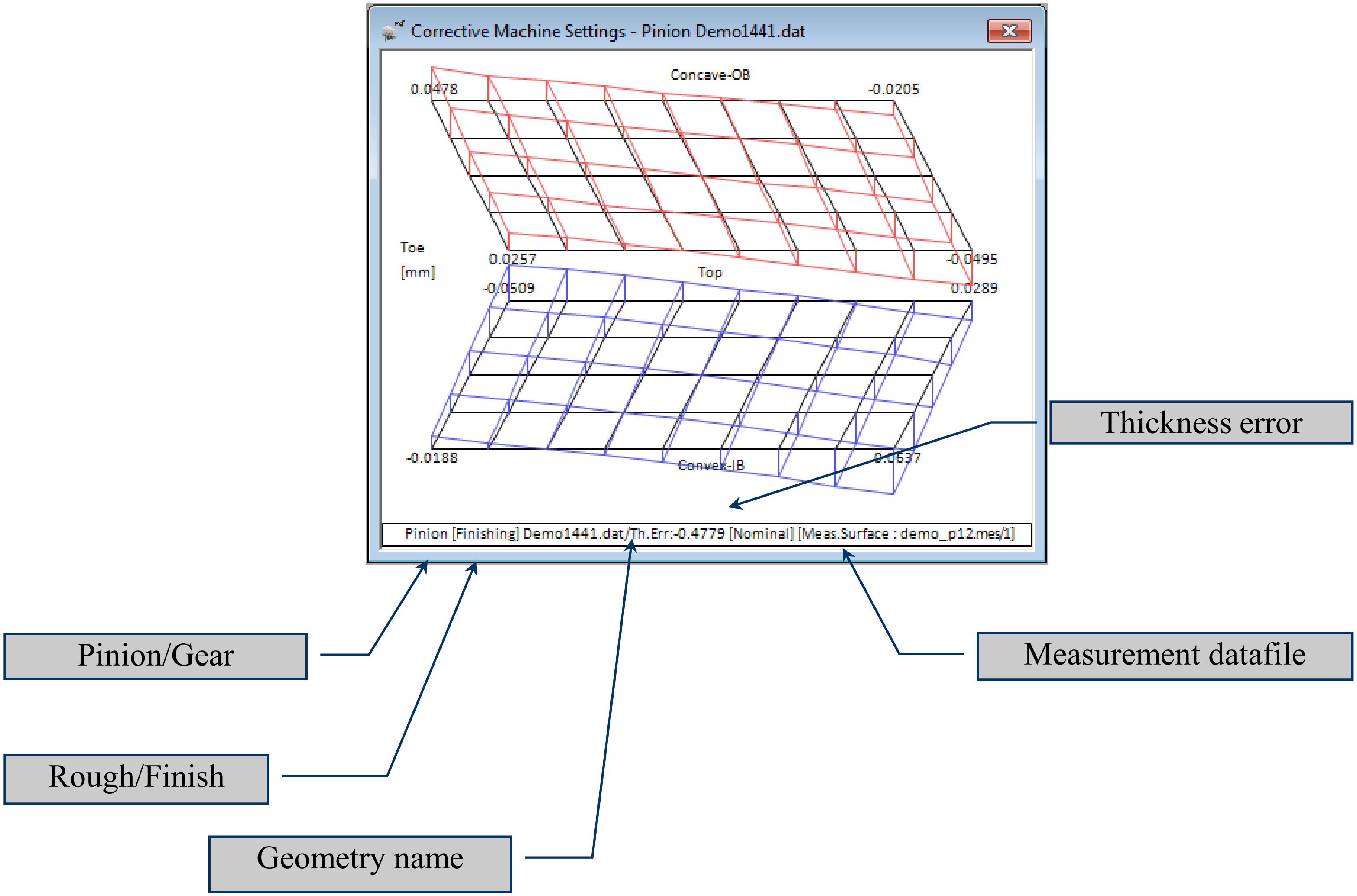
- Create a Measured Surfaces Child window for the Gear
-“3D” – toggle in and out of 3D mode
- “XYZ” to select which tooth to display (use #1)
- “NoPo” – toggle in the display of the Contact Pattern
- “ErrS” – toggle the CP into using the Error Surface – use “Linear” in “Opt”
- “Scal” – change the scale such as to view the Error Surface deviations



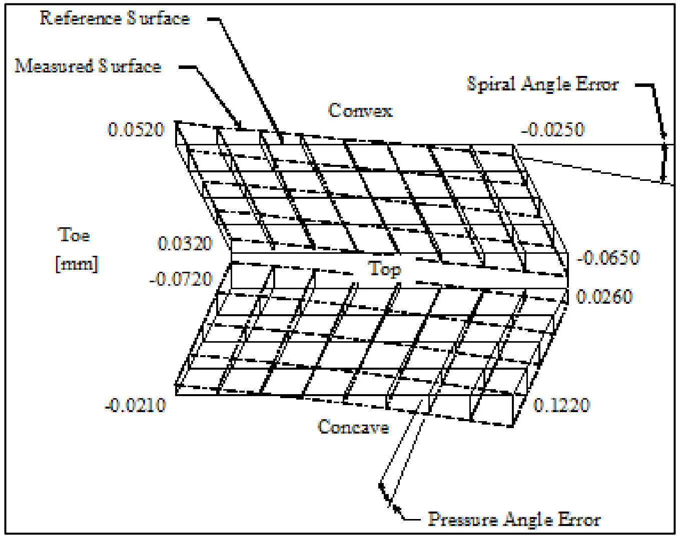
# HyGEARS Production Control Functions

*Measurement -> Compare Meas-Sim Surfaces Child Window*

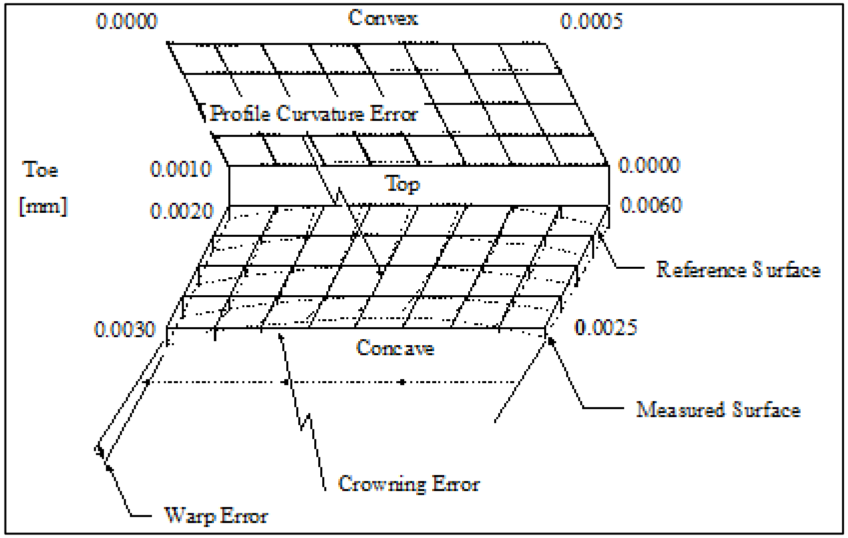


# HyGEARS Production Control Functions

*Measurement -> Compare Meas-Sim Surfaces Child Window*




1st order errors



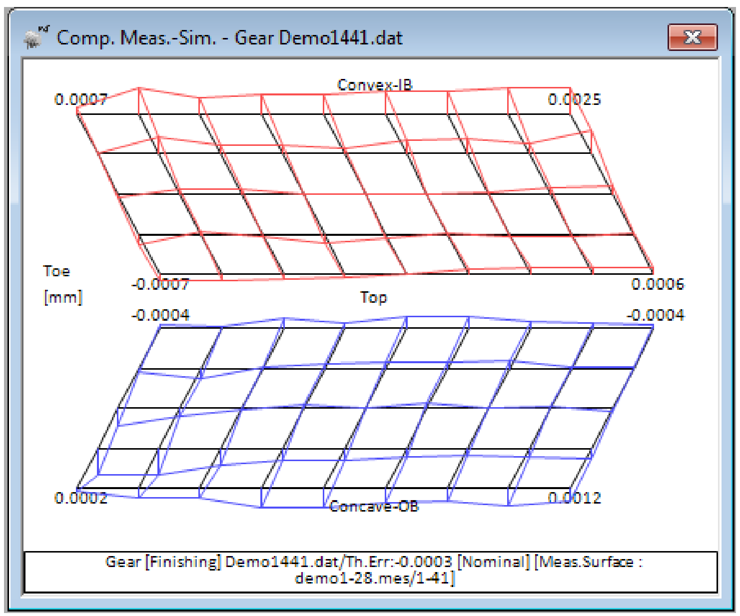

2nd order errors

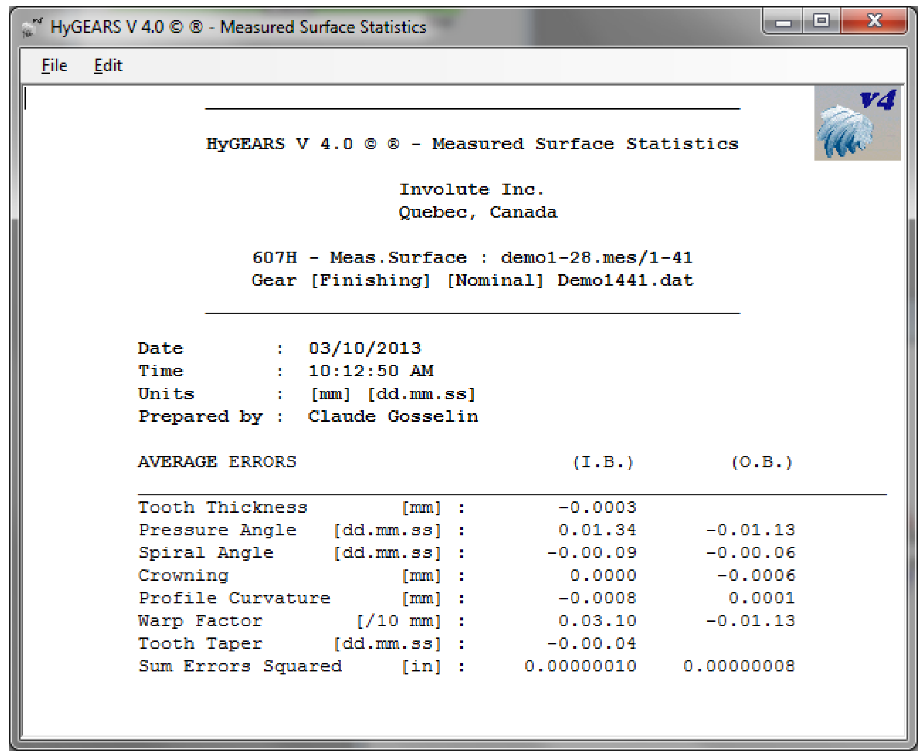
# HyGEARS Production Control Functions

*Measurement -> Compare Meas-Sim Surfaces Child Window*

Use the Demo1441.HyG geometry. Test the following Comp Meas-Sim Surfaces Child window function buttons, one by one :

- Create a Comp Meas-Sim Surfaces child window for the Pinion
- “Stat” – call the Surface Statistics Output – compare with the Error Surface




HyGEARS V 4.0 © ® - Measured Surface Statistics

Involute Inc.
Quebec, Canada

607H - Meas.Surface : demo1-28.mes/1-41
Gear [Finishing] [Nominal] Demo1441.dat

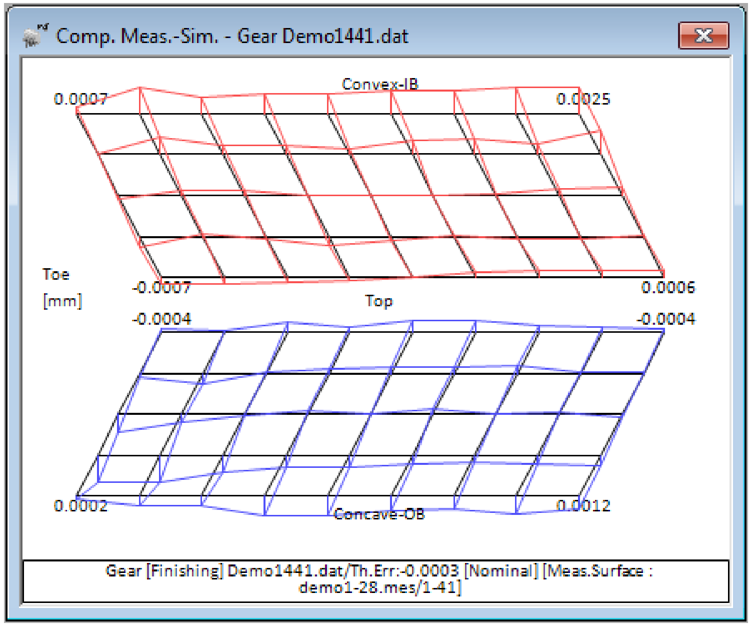
Date : 03/10/2013
Time : 10:12:50 AM
Units : [mm] [dd.mm.ss]
Prepared by : Claude Gosselin

| AVERAGE ERRORS | | (I.B.) | (O.B.) |
|---|---|---|---|
| Tooth Thickness | [mm] : | -0.0003 | |
| Pressure Angle | [dd.mm.ss] : | 0.01.34 | -0.01.13 |
| Spiral Angle | [dd.mm.ss] : | -0.00.09 | -0.00.06 |
| Crowning | [mm] : | 0.0000 | -0.0006 |
| Profile Curvature | [mm] : | -0.0008 | 0.0001 |
| Warp Factor | [/10 mm] : | 0.03.10 | -0.01.13 |
| Tooth Taper | [dd.mm.ss] : | -0.00.04 | |
| Sum Errors Squared | [in] : | 0.00000010 | 0.00000008 |

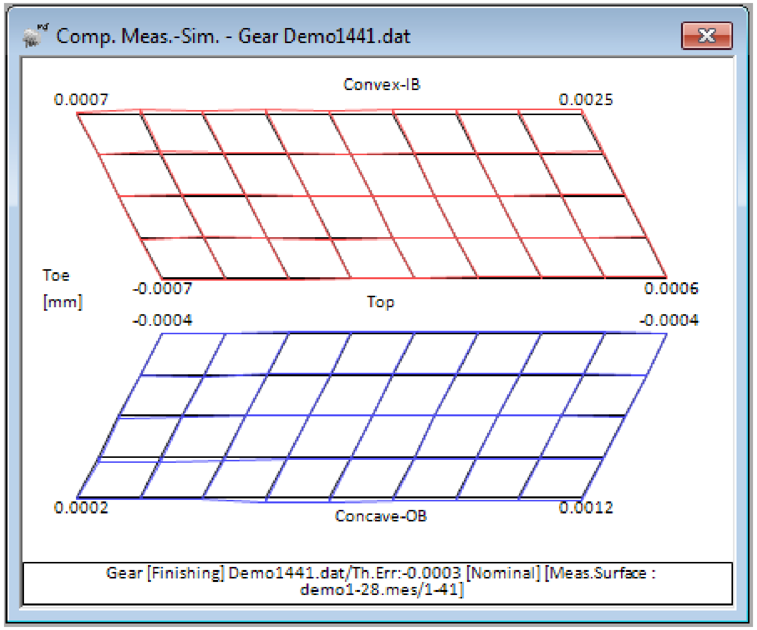
# HyGEARS Production Control Functions

*Measurement -> Compare Meas-Sim Surfaces Child Window*

- "Scal" – experiment changing the scale from Auto to any available value




Auto-Scale




Scale = 10 um

# HyGEARS Production Control Functions

*Measurement -> Compare Meas-Sim Surfaces Child Window*

- "Outp" – call the Error Surface Output

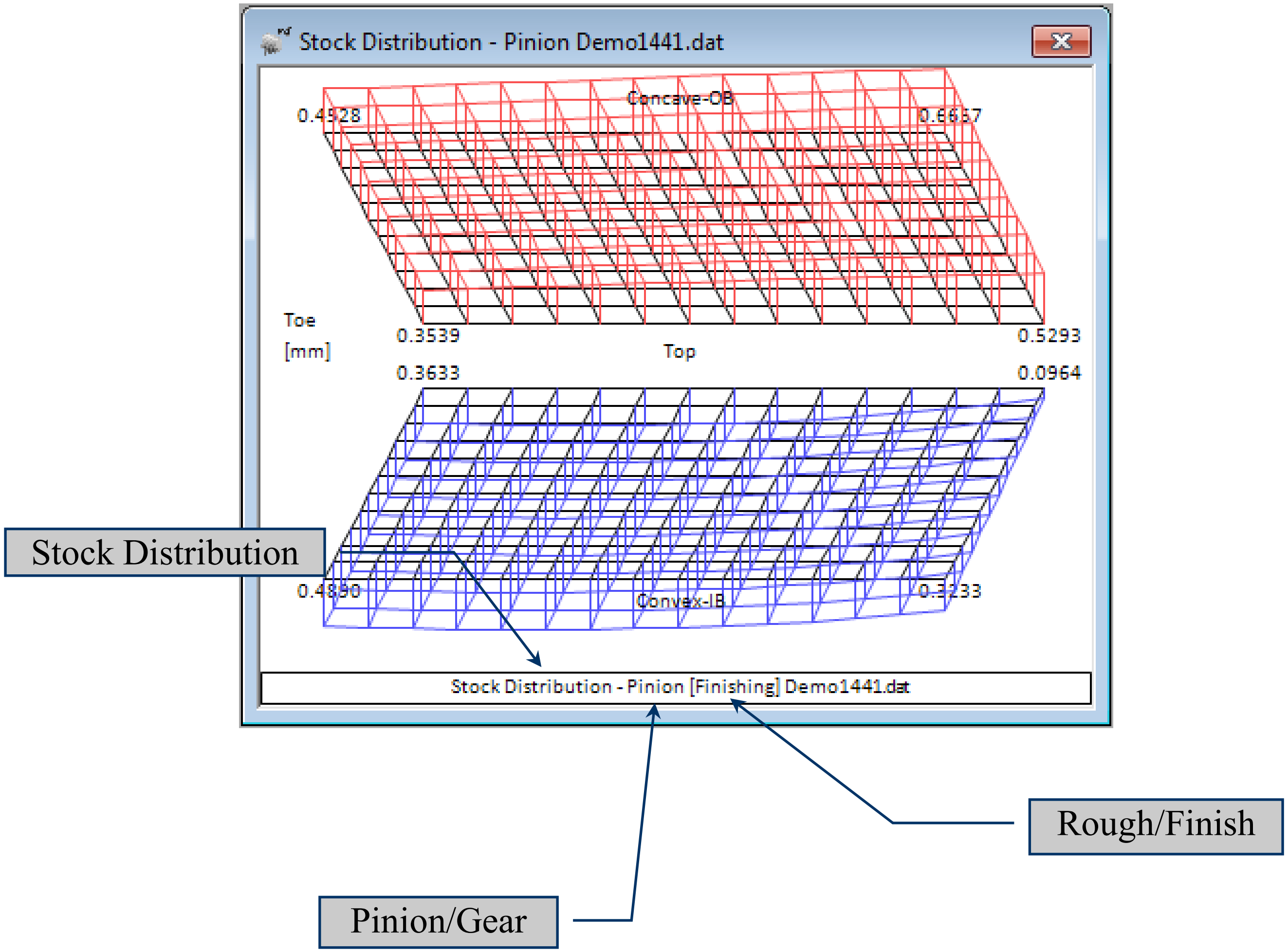
Comp. Meas.-Sim. - Gear [Finishing] - Demo1441.dat

File Edit

```
                         HyGEARS V 4.0 © ®

      Comp. Meas.-Sim. Gear [Finishing] [mm] - Demo1441.dat

      Date / Time         : 03/10/2013 / 10:16:45 AM
      General Units       : [mm] [dd.mm.ss]
      Cutter  Units       : [in]
      Prepared by         : Claude Gosselin
      Version             : 4.0.402.40

      Measured data file  : e:\vb\demo\demo1-28.mes

Difference [mm]  Tooth 1 - 4

Ia3\Iac:    1       2       3       4       5       6       7       8       9

[Tooth Root Concave-OB]
  1    0.00023 0.00086 0.00089 0.00194 0.00189 0.00140 0.00120 0.00175 0.00122
  2    0.00273 0.00263 0.00166 0.00114 0.00113 0.00082 0.00071 0.00090 0.00107
  3    0.00183 0.00072 0.00019-0.00034 0.00000-0.00045 0.00003-0.00026 0.00034
  4    0.00032 0.00114-0.00018-0.00048-0.00052-0.00065-0.00082-0.00014-0.00002
  5   -0.00038-0.00018-0.00095-0.00053-0.00121-0.00109-0.00062-0.00045-0.00036
[Tooth Tip]
  5   -0.00067-0.00055-0.00040-0.00024 0.00008 0.00061 0.00063 0.00066 0.00064
  4   -0.00109 0.00033-0.00023-0.00086-0.00046 0.00007-0.00021-0.00024 0.00010
  3   -0.00025 0.00050 0.00045-0.00005 0.00000 0.00006 0.00016 0.00070 0.00083
  2    0.00007 0.00171 0.00097 0.00092 0.00062 0.00142 0.00150 0.00105 0.00239
  1    0.00070 0.00259 0.00161 0.00202 0.00197 0.00221 0.00236 0.00258 0.00255
[Tooth Root Convex-IB]
```

# HyGEARS Production Control Functions

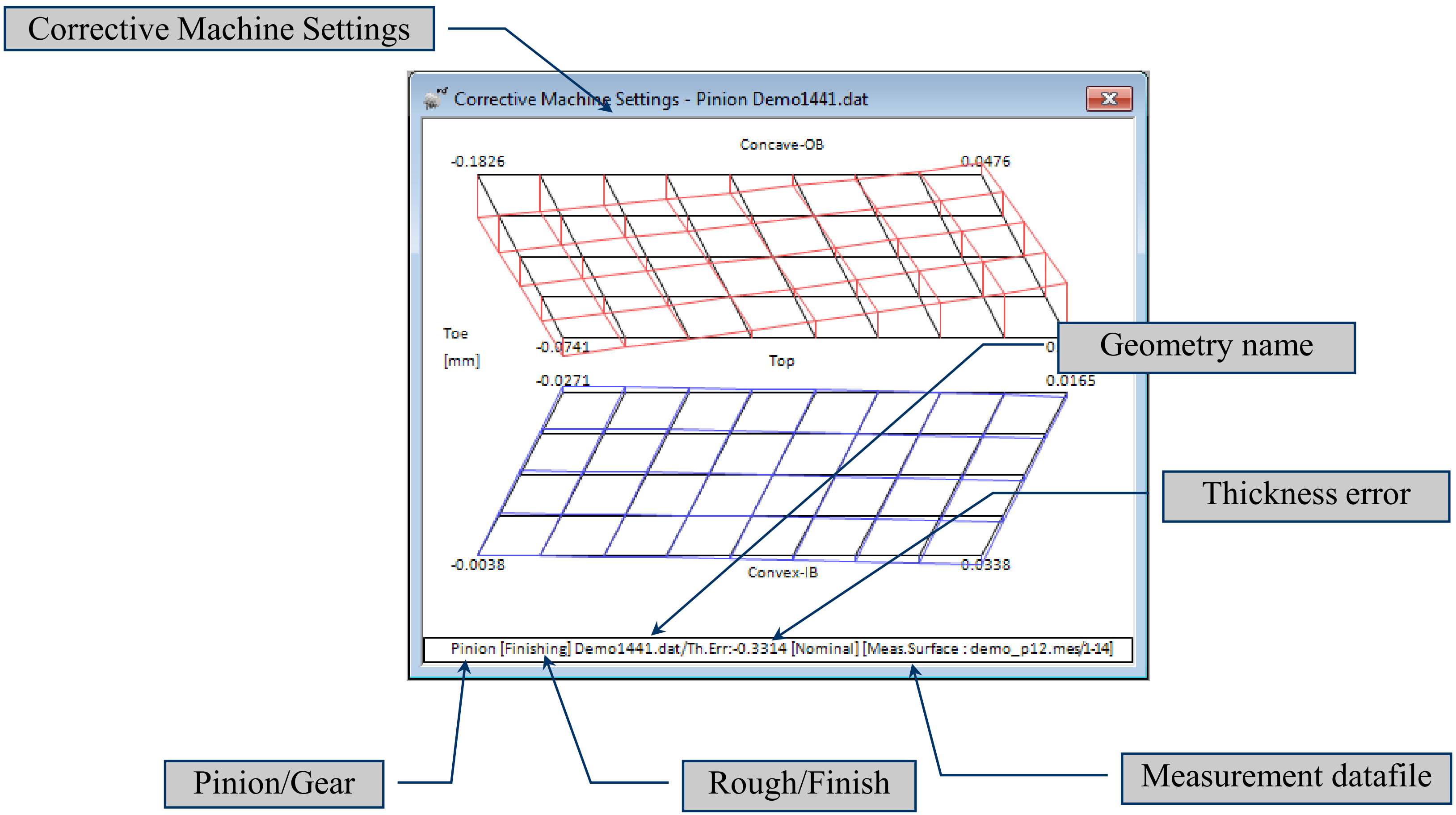
*Measurement -> Stock Distribution Child Window*



# HyGEARS Production Control Functions

*Measurement -> Corrective Machine Settings Child Window*

Corrective M/C Settings: machine changes for the manufactured tooth to match the design tooth

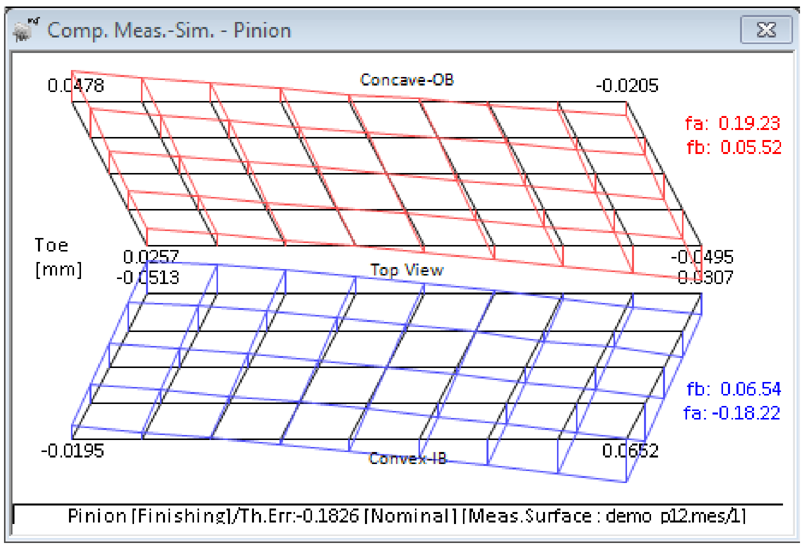


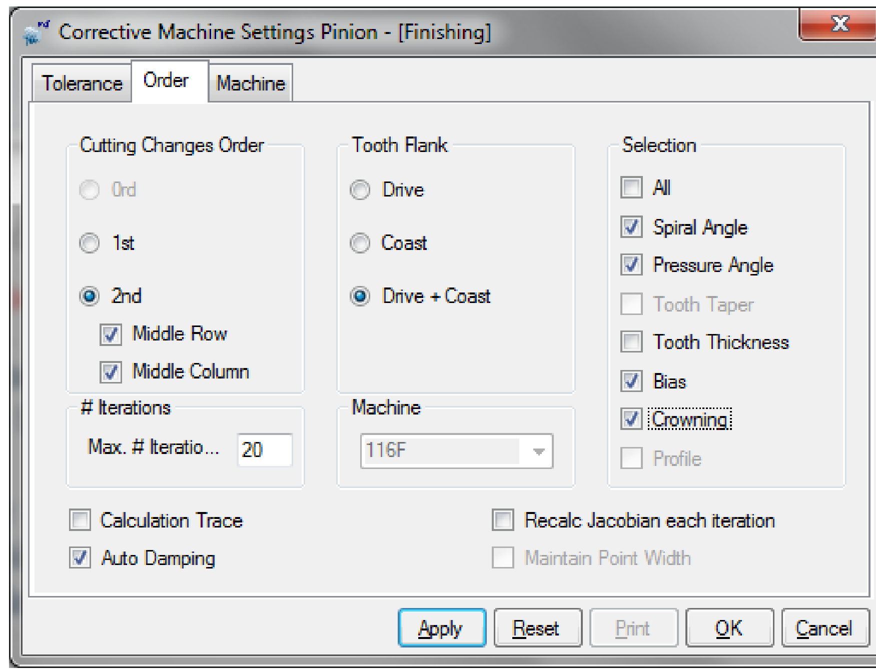
# HyGEARS Production Control Functions

*Measurement -> Corrective Machine Settings Child Window*

Use the Demo1441.HyG geometry. Test the following Corrective Machine Settings child window function buttons, one by one :

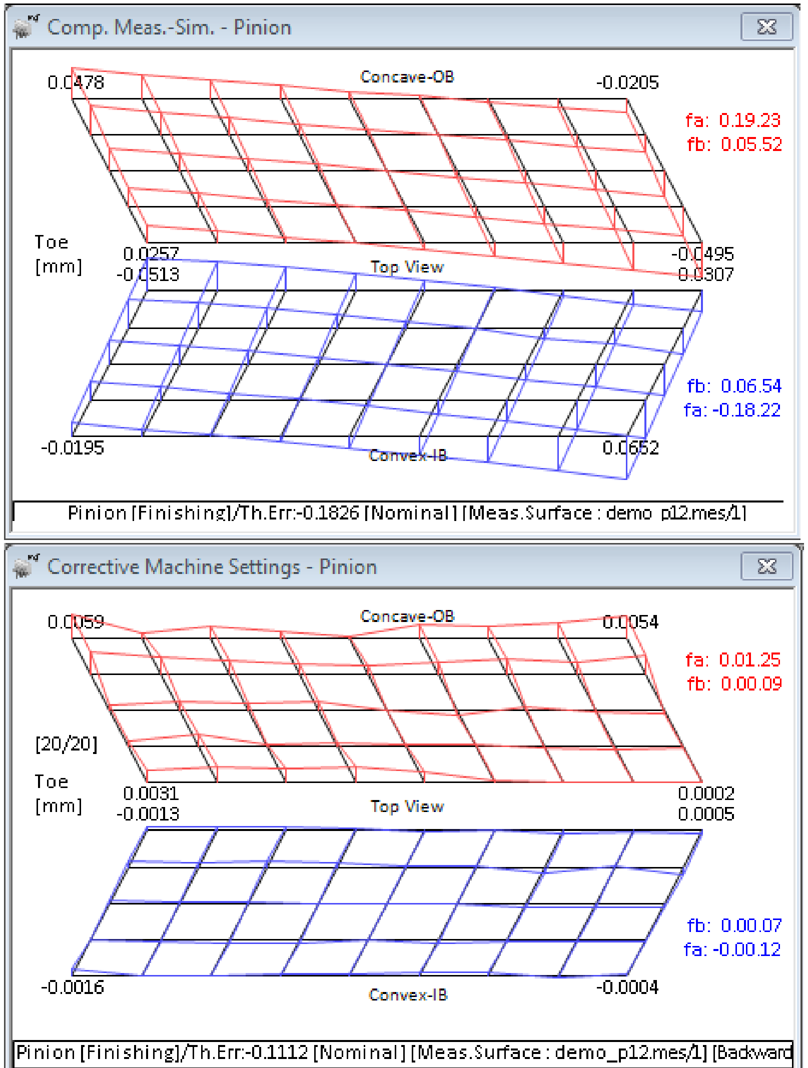
- Create a Corrective Machine Settings child window for the Pinion
- "Sett" – call the Corrective Machine Settings selection
- "Order" Tab – select 2nd Order

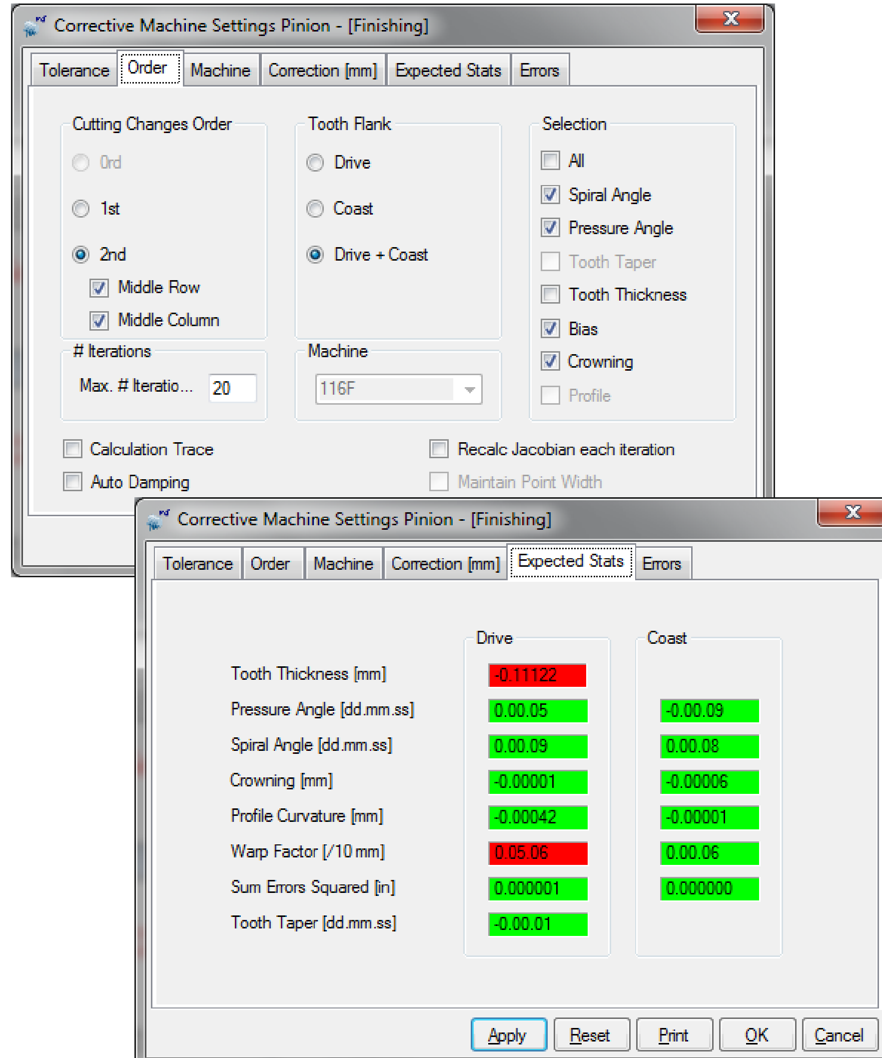


# HyGEARS Production Control Functions

*Measurement -> Corrective Machine Settings Child Window*

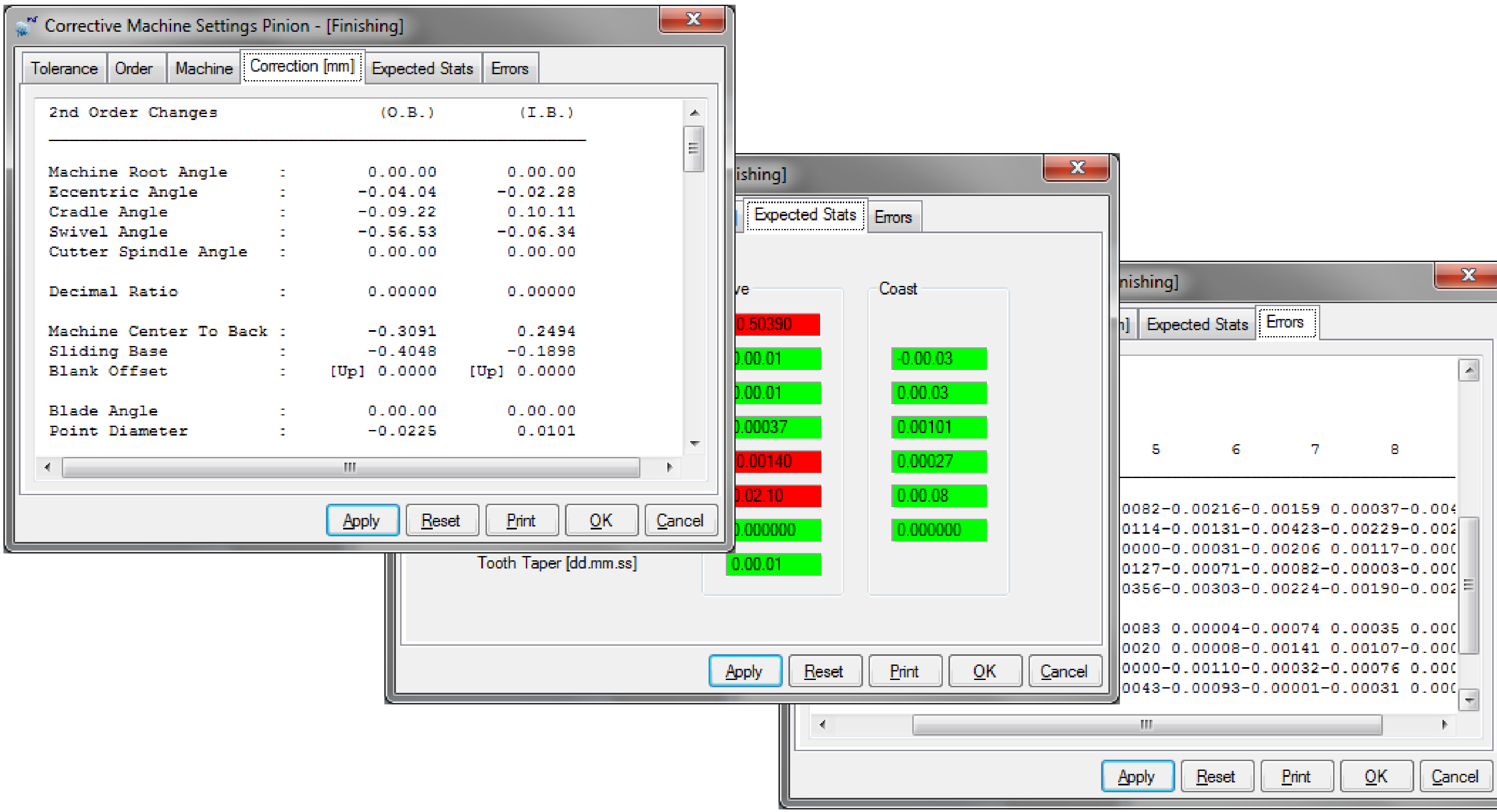


# HyGEARS Production Control Functions

*Measurement -> Corrective Machine Settings Child Window*

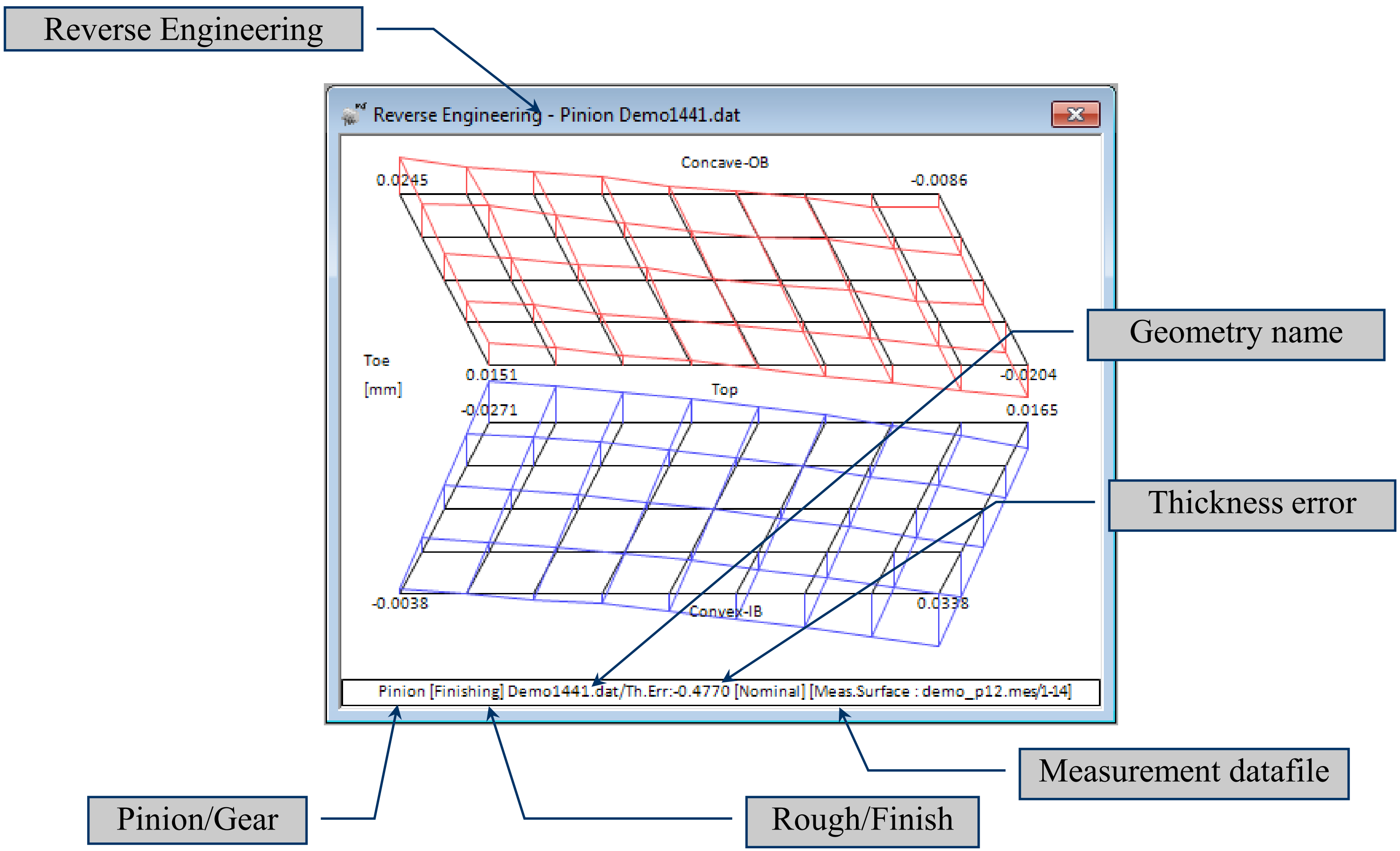
- Check the displays in all other Tabs
- Click on “Ok” to keep, “Cancel” to dump



# HyGEARS Production Control Functions

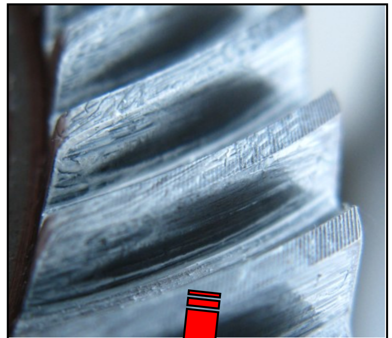
*Measurement -> Reverse Engineering Child Window*

Reverse Engineering: machine changes for the design tooth to match the manufactured tooth

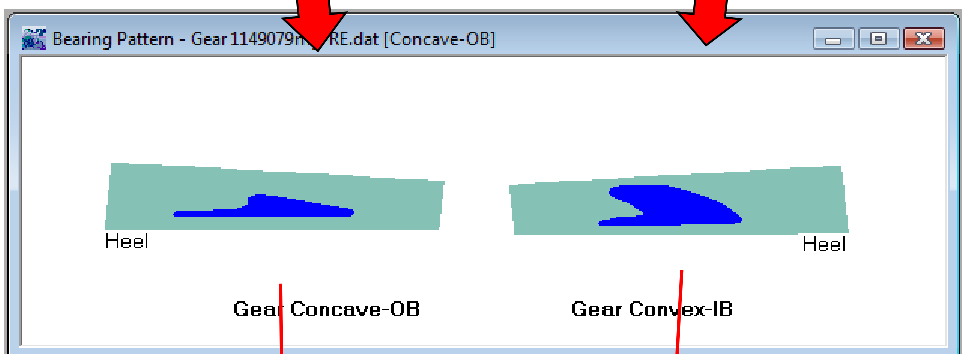


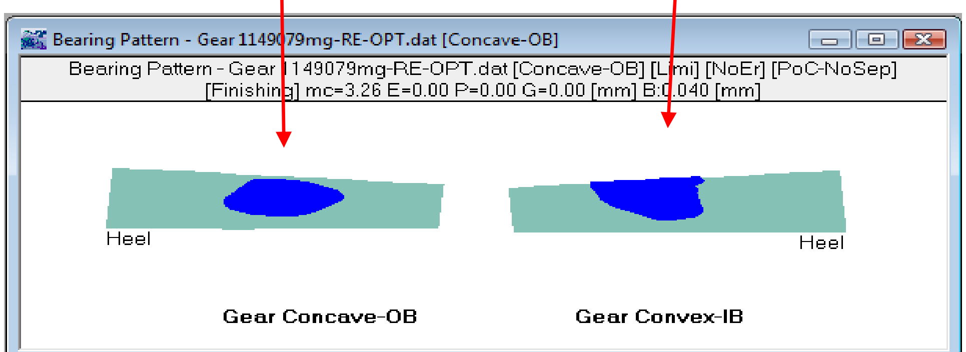
# Reverse Engineering : Duplex Helical Example

*Measurement -> Reverse Engineering*

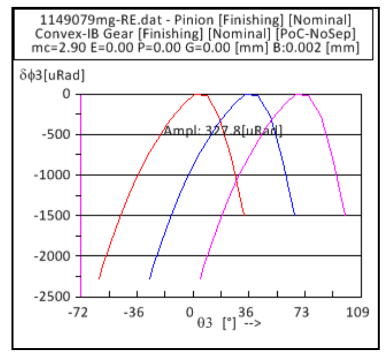


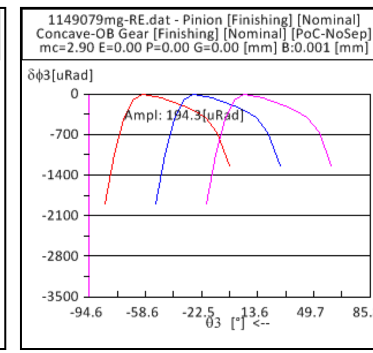
Actual gears + CPs



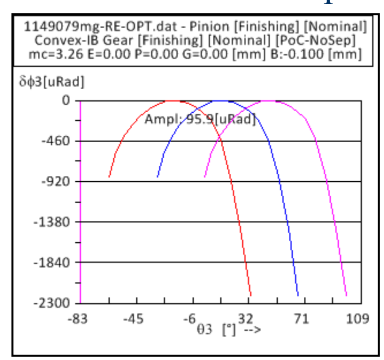



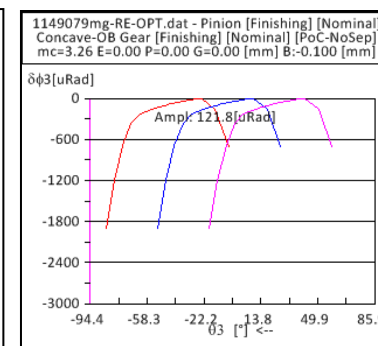

Simulated CPs after R.E. based on CMM data (noisy- whining)



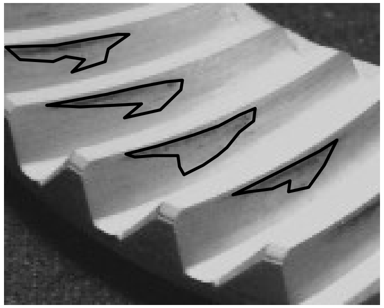

CPs after re-development based on R.E. Gear

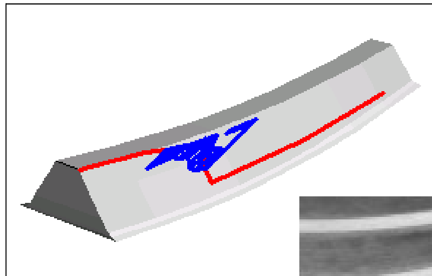


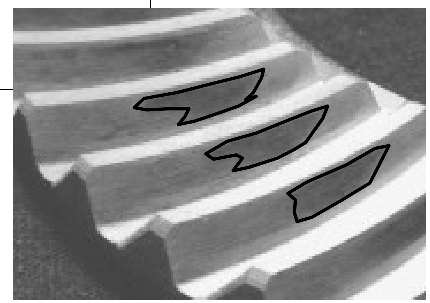



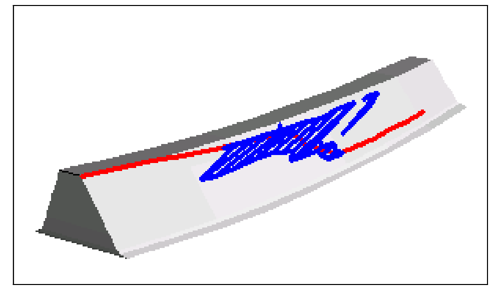
# Reverse Engineering : Fixed Setting Examples

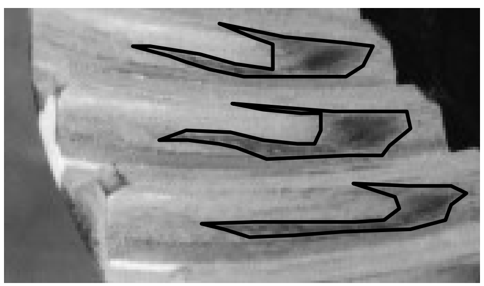
*Measurement -> Reverse Engineering*

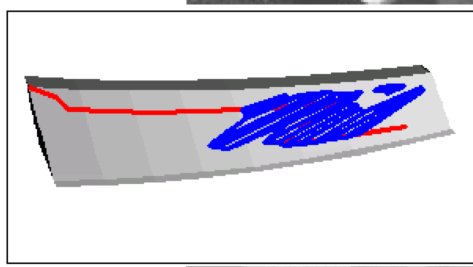


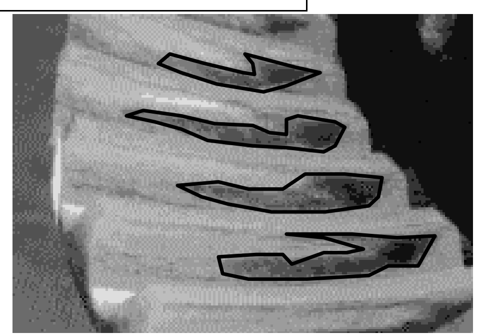


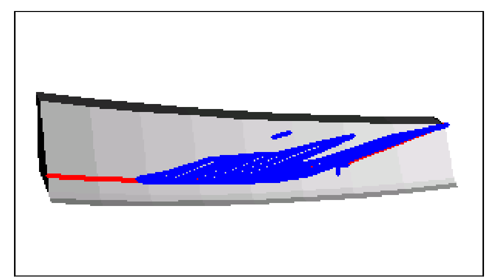






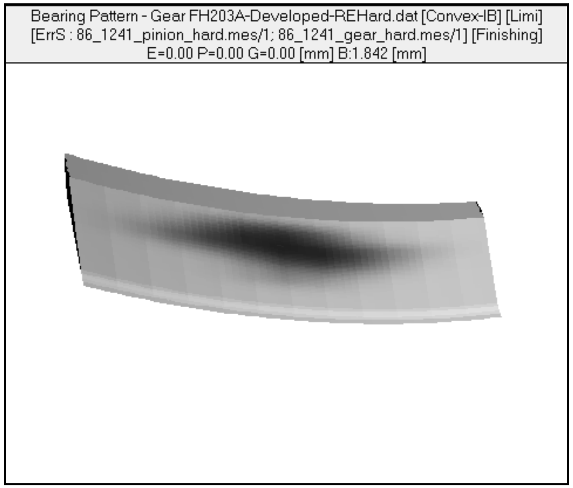


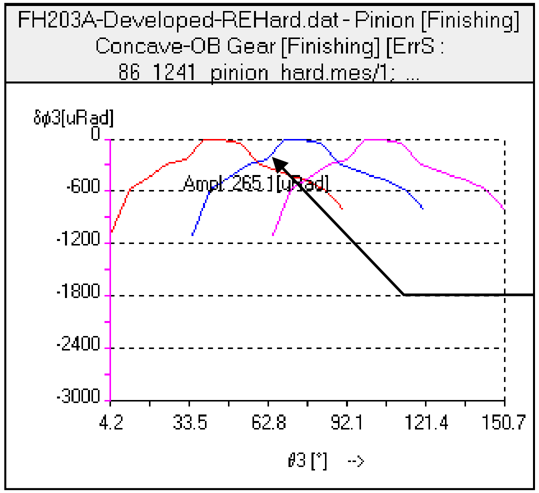


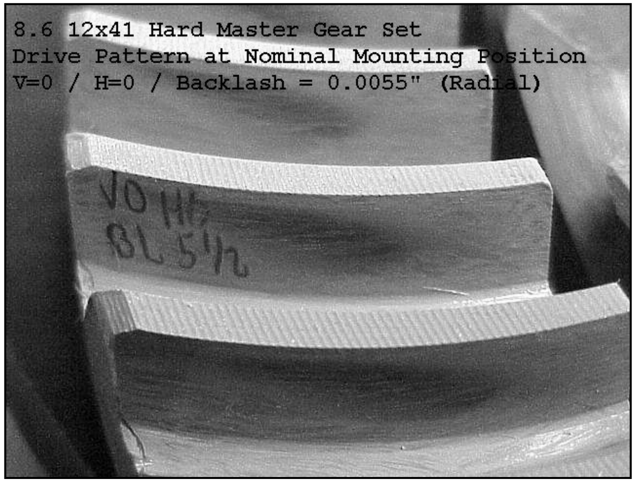


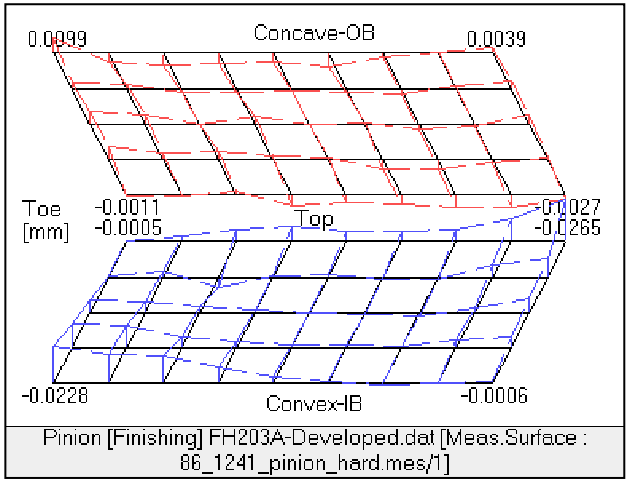
# Reverse Engineering : Face Hobbed Example - Quiet Drive Side

*Measurement -> Reverse Engineering*



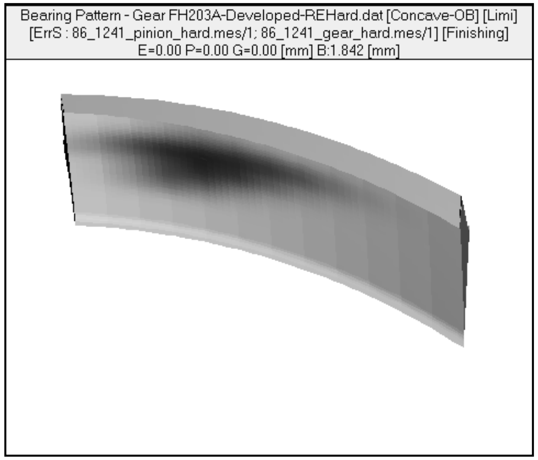



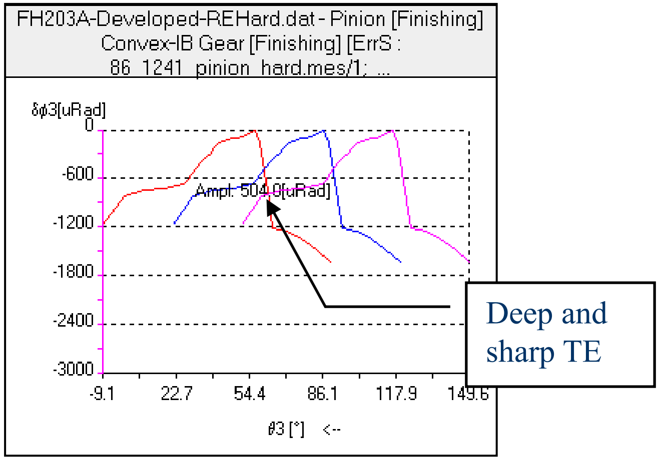



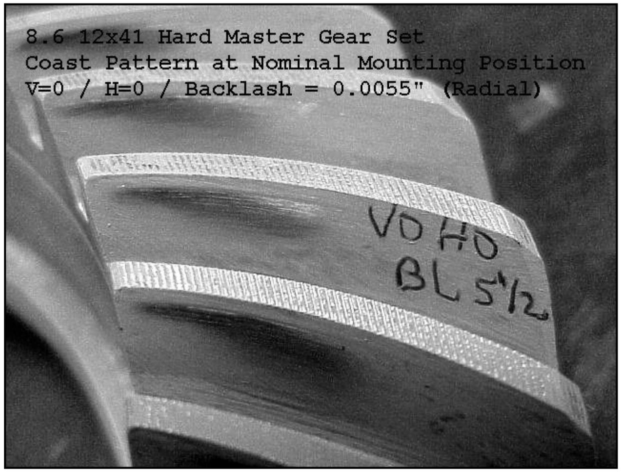



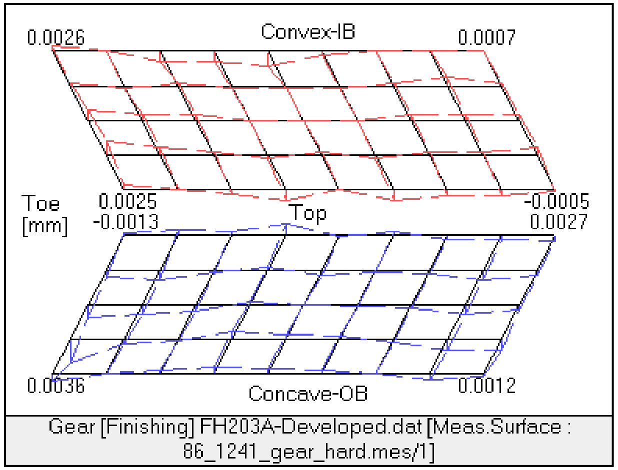
# Reverse Engineering : Face Hobbed Example - Noisy Coast Side

*Measurement -> Reverse Engineering*



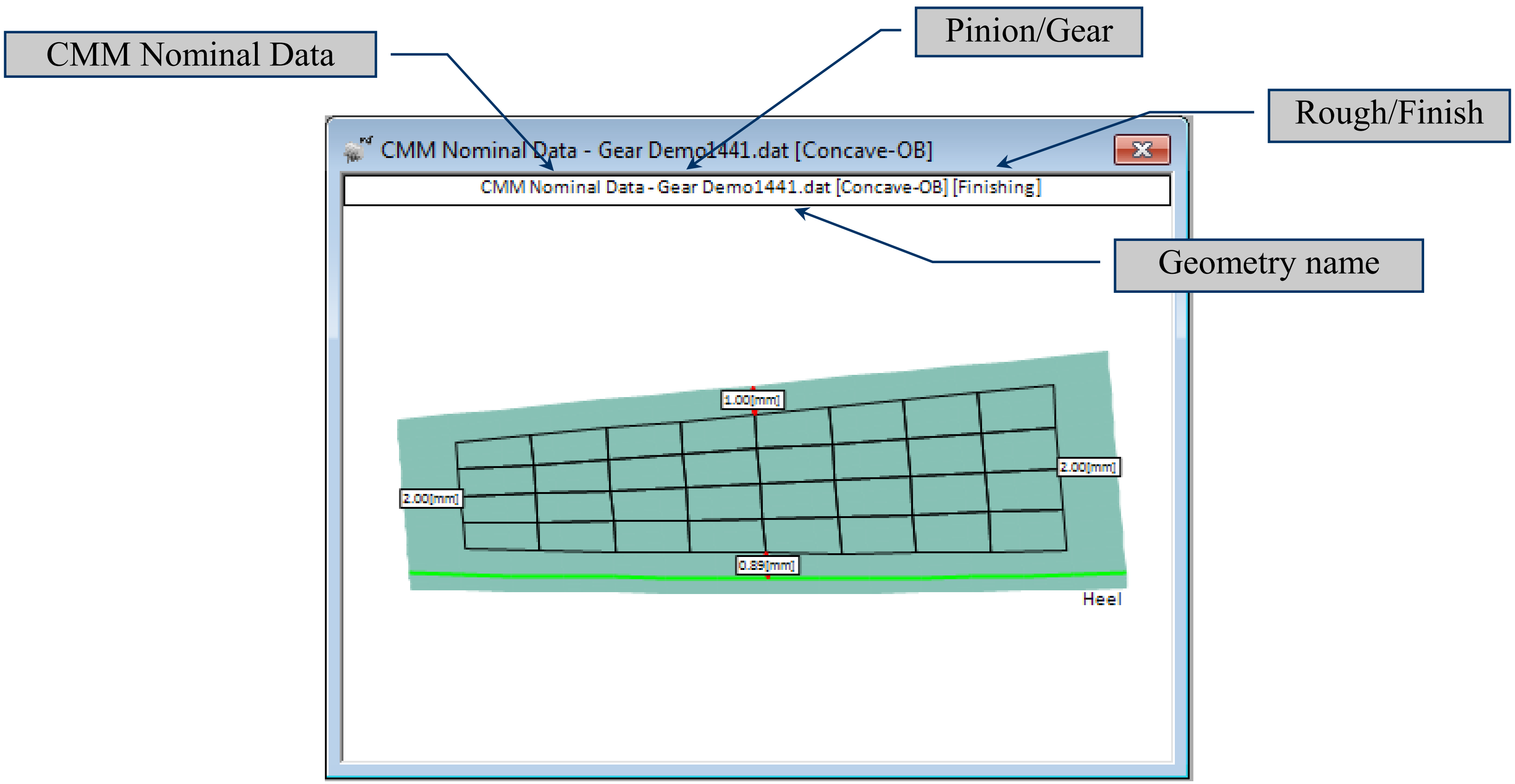



# HyGEARS Production Control Functions

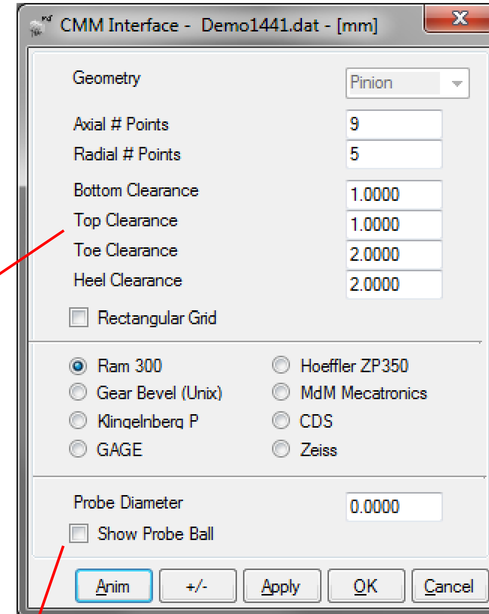
*Measurement -> CMM Nominal Data Child Window*



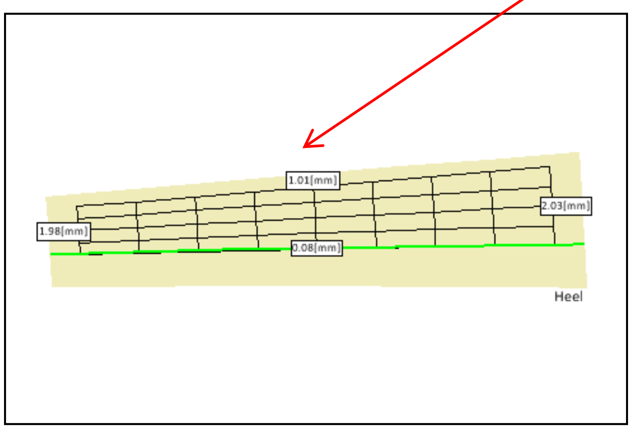
# HyGEARS Production Control Functions

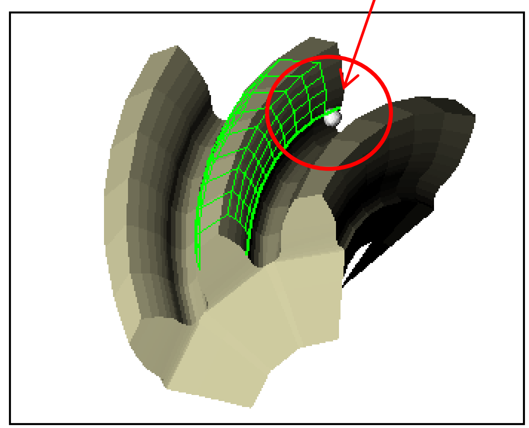
*Measurement -> CMM Nominal Data Child Window*

HyGEARS allows the definition of the *Target CMM* grid.




- Output can be done for several popular CMMs
- Edge reductions can be inputted at tooth Bottom, Top, Toe and Heel;
- After measurement, the CMM output file is converted into a HyGEARS specific format for fast access;
- Probe ball can be displayed and moved at target points to visualize potential interference;

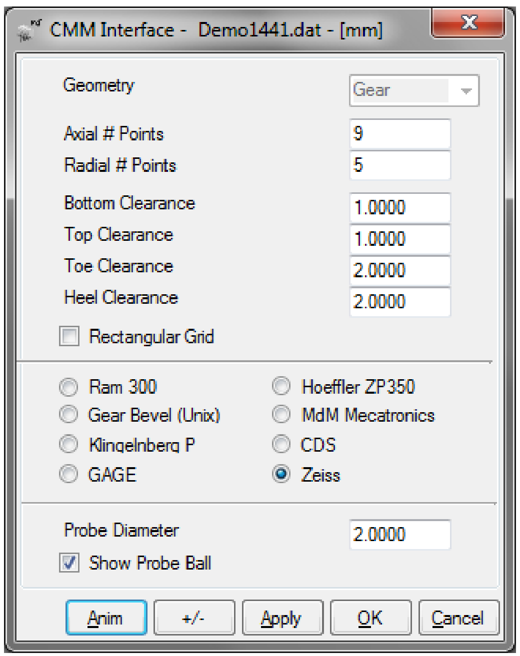


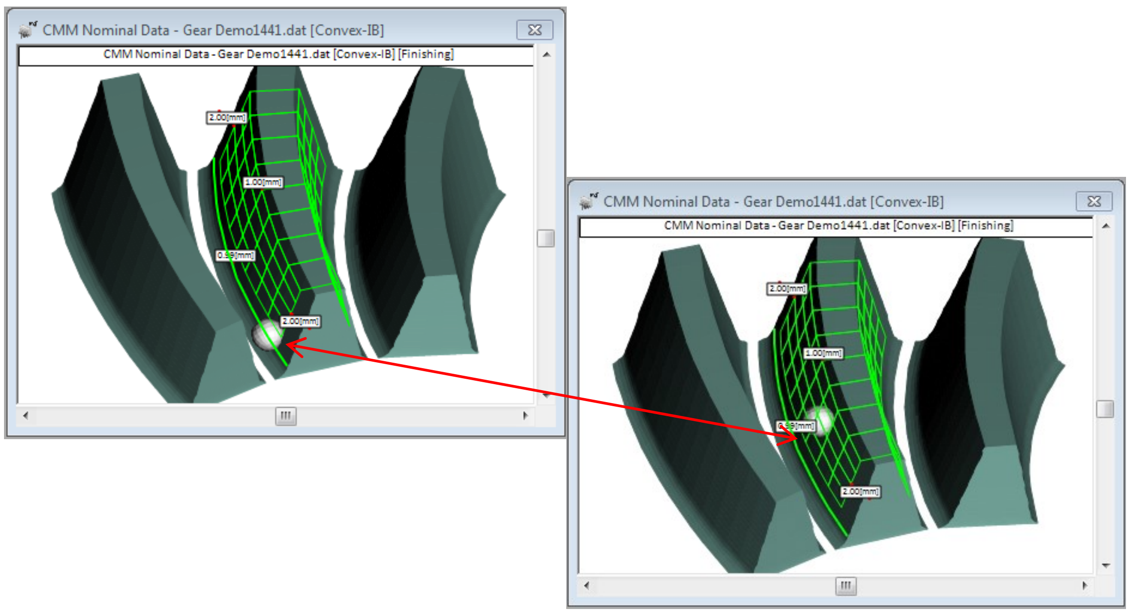



# HyGEARS Production Control Functions

*Measurement -> CMM Nominal Data Child Window*

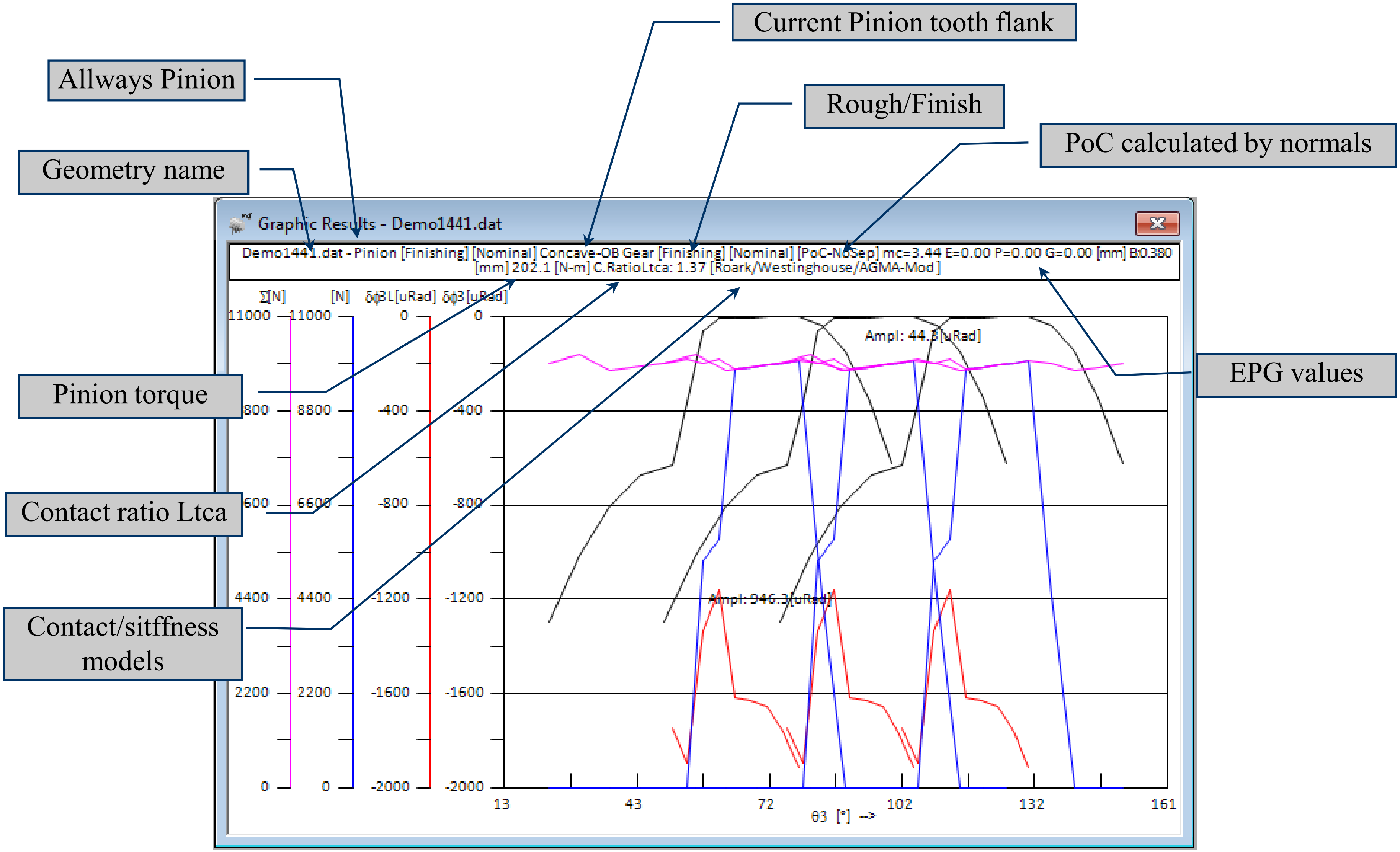
- "2D" to change to 3D view;
- Rotate the display until a proper viewing angle is obtained;
- "Dims" to hide the CMM grid dimensions;
- "^Z" to toggle into Manual Zoom; zoom onto the Grid area;
- "Ram" function button – check the "Show Probe Ball" and enter 2.0 mm as the Probe Diameter; click on the "Apply" button;
- "+/-" with the left and right mouse buttons to move the probe along the tooth flank;



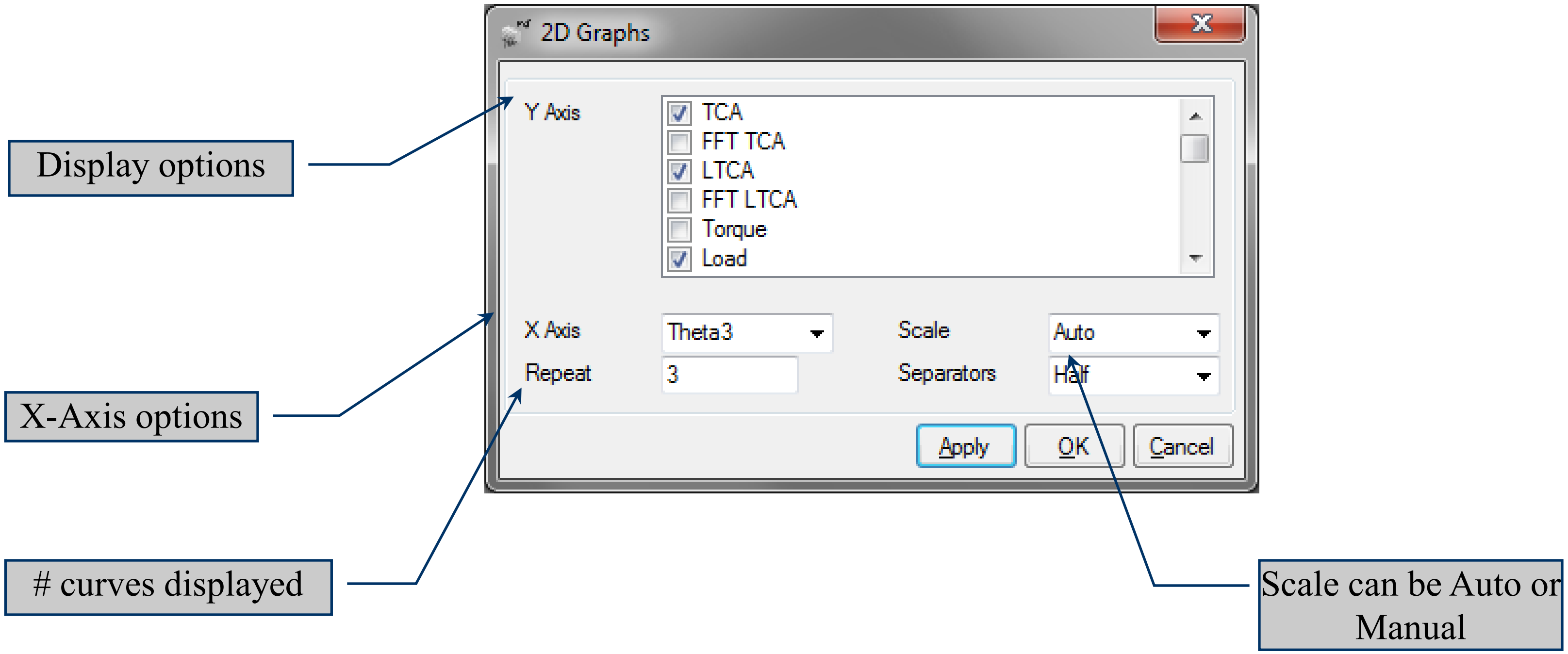
# Graphic Display Functions

*2D Graphs Child Window*



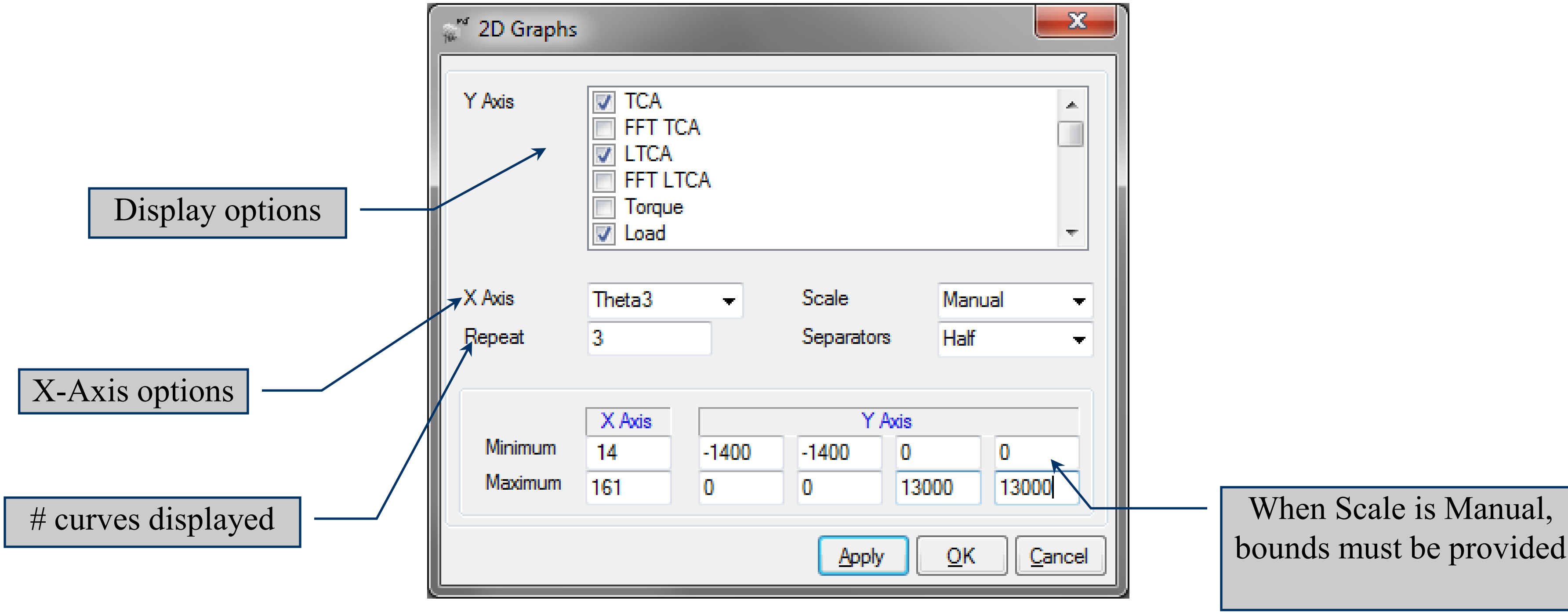
# Graphic Display Functions

*2D Graphs Child Window*



# Graphic Display Functions

*2D Graphs Child Window*



# Graphic Display Functions

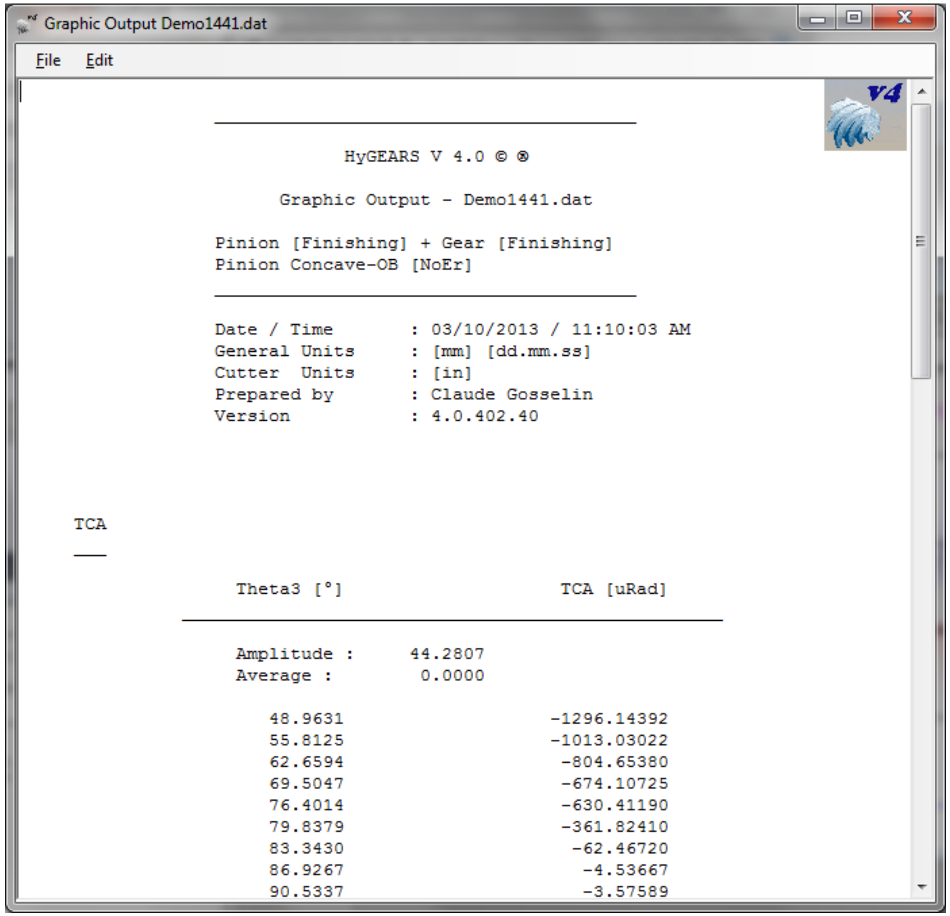
*2D Graphs Child Window*

Display Options

- TCA:
- LTCA:
- Torque:
- Transm. Force:
- Bending Def.:
- Contact Def.:
- Lamda:
- Efficiency Ltca:
- Temp Increase:
- B. Stress Gear:
- J Factor-Gear:
- Kt - G:
- #1… Gage Gear:
- K-Flex:
- Tooth Separation
- FFT TCA:
- FFT LTCA:
- Load:
- Sum Load:
- Contact Stress:
- Min. Oil Film:
- Efficiency:
- Frict. Coef. Ltca:
- B. Stress Pinion:
- J Factor-Pinion:
- Kt - P:
- #1… Gage Pinion
- %:
- K-Mesh:
- Sliding Speeds:

# Graphic Display Functions

*2D Graphs Child Window*


Graphic Output Demo1441.dat

File Edit

HyGEARS V 4.0 © ®

Graphic Output - Demo1441.dat

Pinion [Finishing] + Gear [Finishing]
Pinion Concave-OB [NoEr]

| | |
|---|---|
| Date / Time | : 03/10/2013 / 11:10:03 AM |
| General Units | : [mm] [dd.mm.ss] |
| Cutter Units | : [in] |
| Prepared by | : Claude Gosselin |
| Version | : 4.0.402.40 |

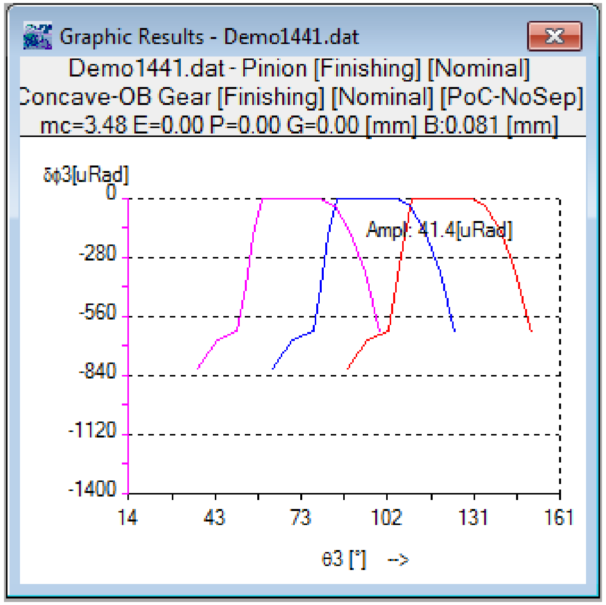
TCA

| Theta3 [°] | TCA [uRad] |
|---|---|
| Amplitude : | 44.2807 |
| Average : | 0.0000 |
| 48.9631 | -1296.14392 |
| 55.8125 | -1013.03022 |
| 62.6594 | -804.65380 |
| 69.5047 | -674.10725 |
| 76.4014 | -630.41190 |
| 79.8379 | -361.82410 |
| 83.3430 | -62.46720 |
| 86.9267 | -4.53667 |
| 90.5337 | -3.57589 |

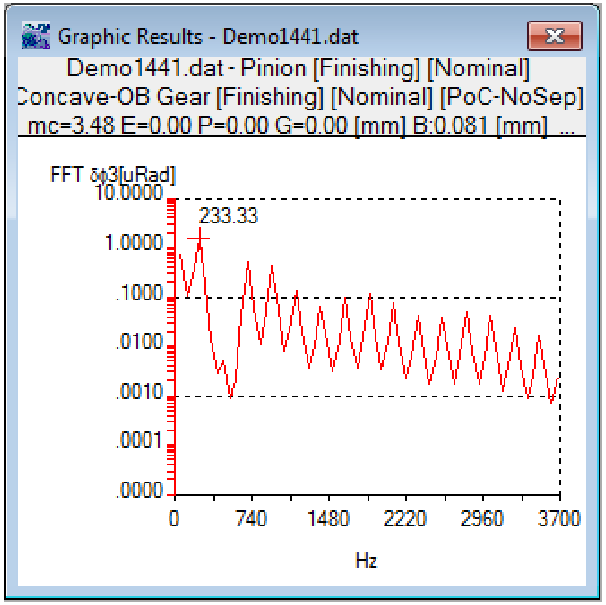
Text output of a 2D graph

# Graphic Display Functions

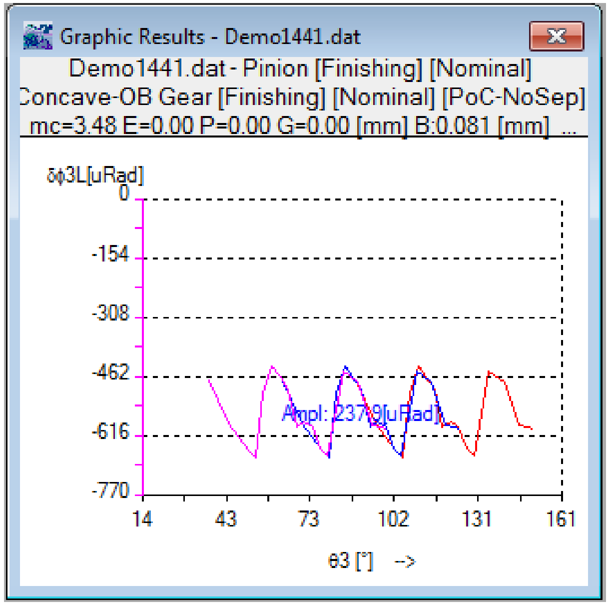
*2D Graphs Child Window*




TCA curve




FFT TCA curve

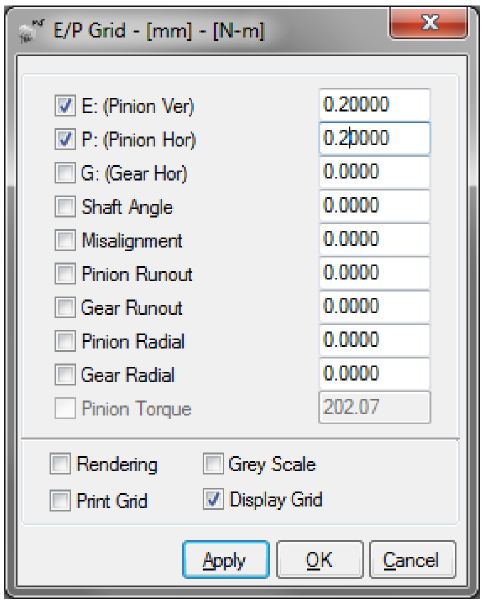


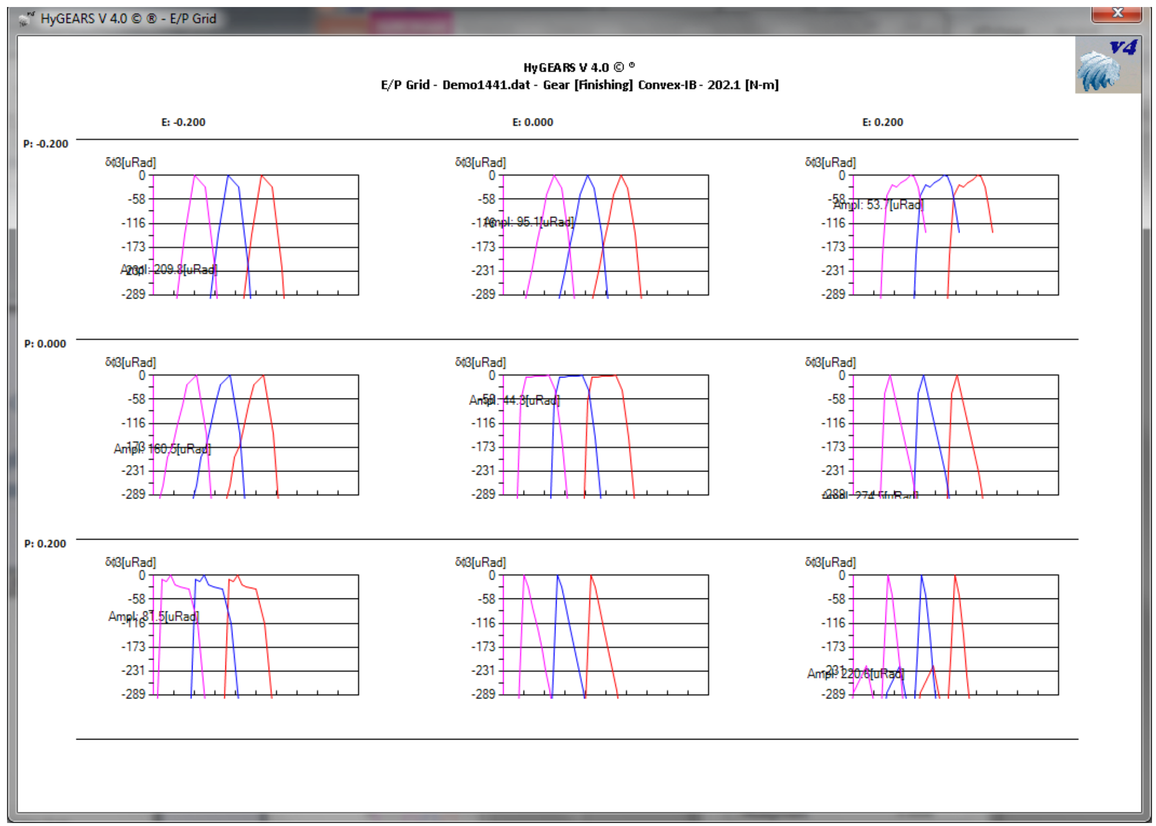

LTCA curve

# Graphic Display Functions

*2D Graphs Child Window*

- "2D Graph" - Create a 2D Graph child window; select "TCA", click on "Ok";
- "Grid" function button – enter E and P as 0.200 mm; click on "Ok"



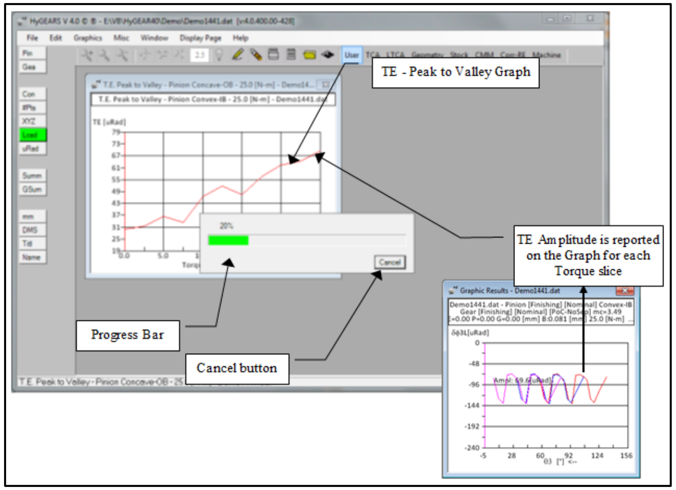



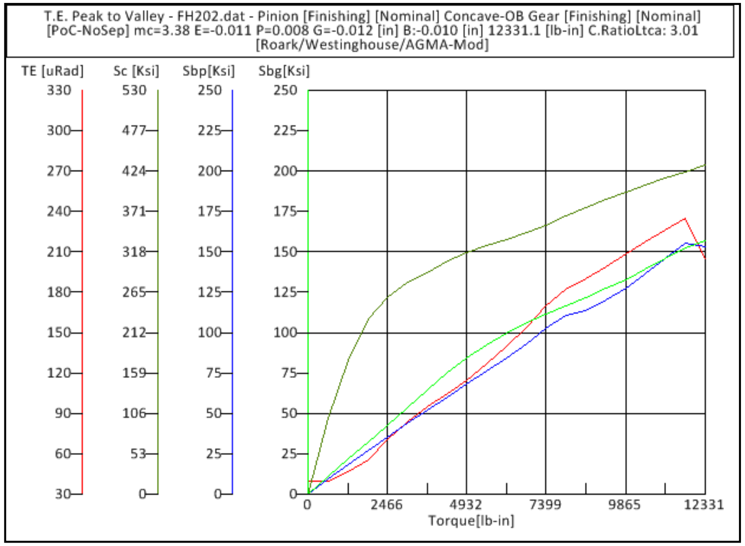
# Graphic Display Functions

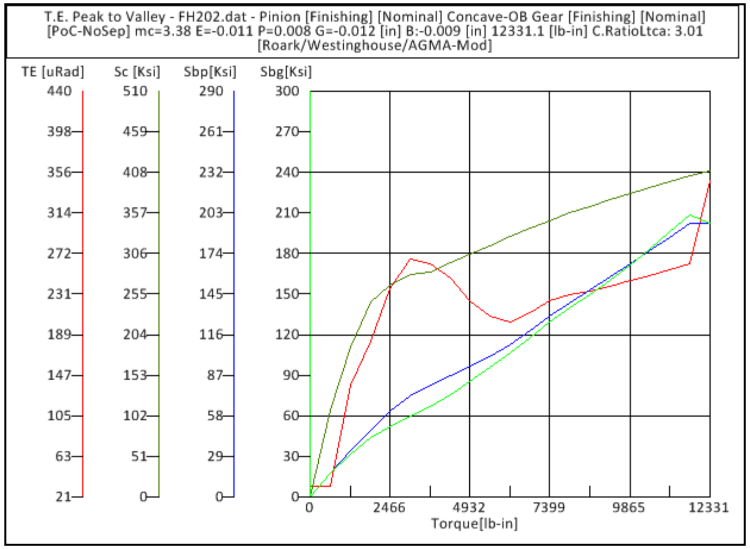
*LTCA TE-P2V Child Window*

Need to see how some LTCA metrics evolve with torque;

- Display TE under load *f*(Torque)
- Display Sc *f*(Torque)
- Display SCP, SbG *f*(Torque)



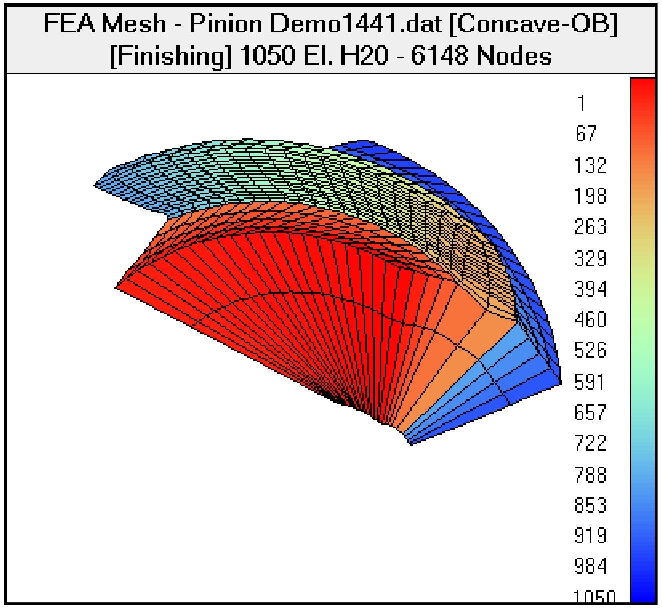



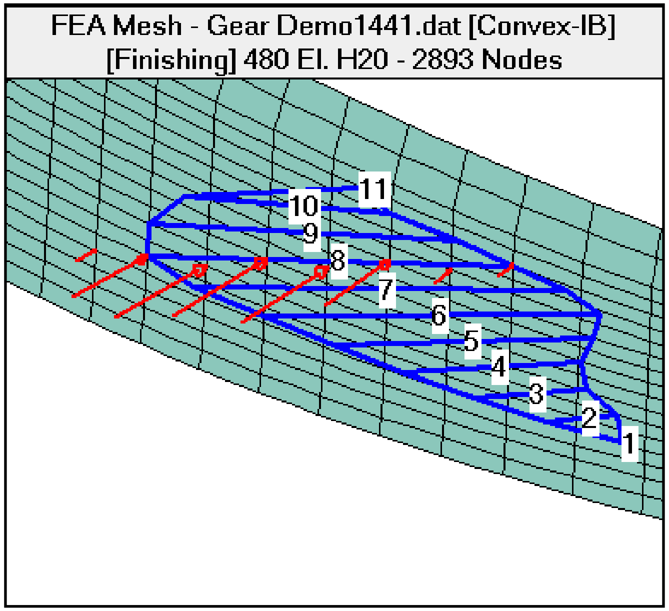
# Graphic Display Functions

*Meshing -> FEA Model Child Window*

HyGEARS offers an advanced meshing interface in which a FEA mesh can be defined and outputted *in a matter of seconds*.

- An FEA mesh is based on the same tooth surface as that obtained by the machine settings.
- *Loads* can be applied, in different manners, *anywhere on the tooth surface*.
- Export in *Patran Neutral* file format



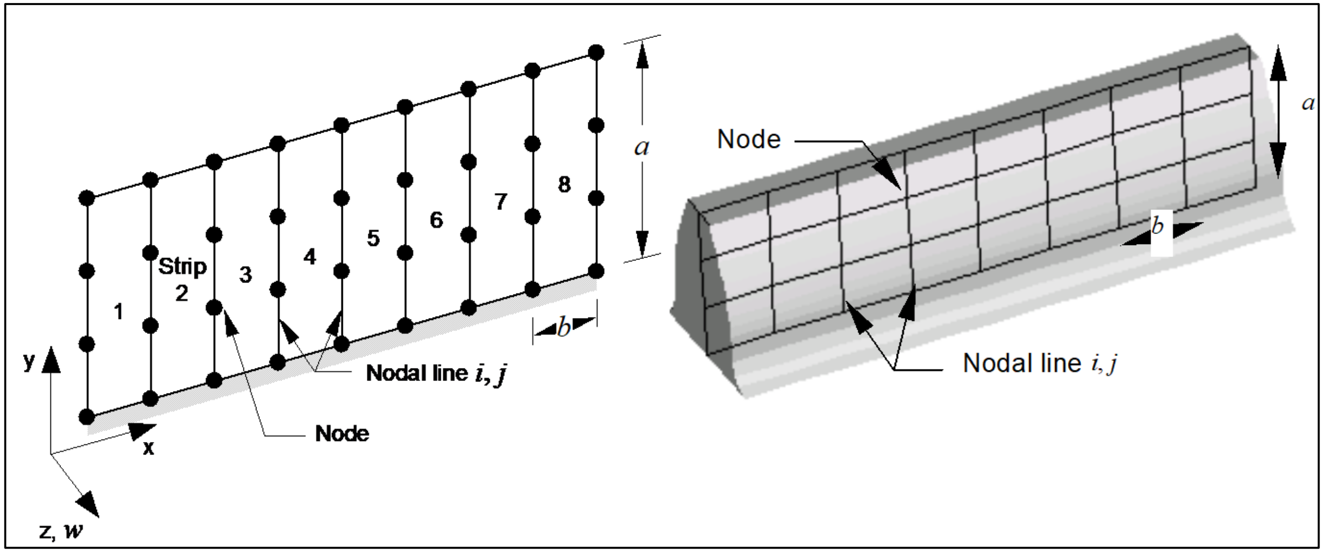
# Graphic Display Functions

*Meshing -> Finite Strips Child Window*

HyGEARS offers a proprietary solution to bending stiffness and stresses: *the Finite Strips*.

In short, the Finite Strips are a *subset of the Finite Elements*.

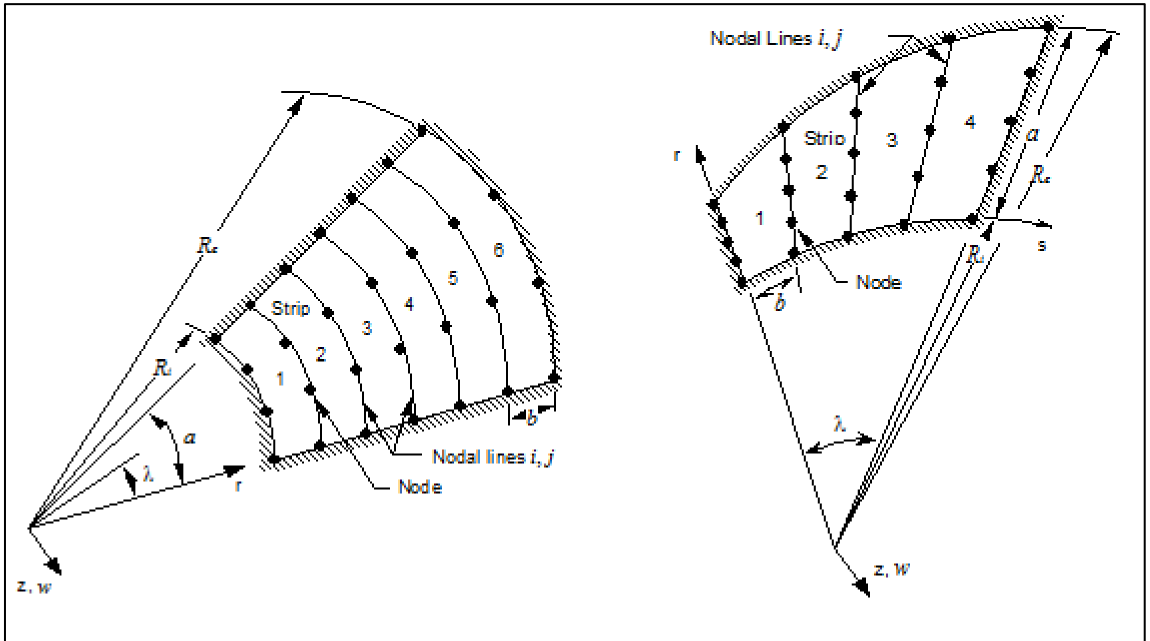
Using *thick plate* theory combined to smooth series, *accurate tooth stiffness and bending stresses* can be obtained in a matter of seconds.



# Graphic Display Functions

*Meshing -> Finite Strips Child Window*

Strips of width $b$ and length (or height) $a$ are parallel to the $\lambda$-axis and connected by nodal lines; the nodes are used to define the displacement function.




Straight bevel-gear tooth

Spiral-bevel / Hypoid gear tooth

# Graphic Display Functions

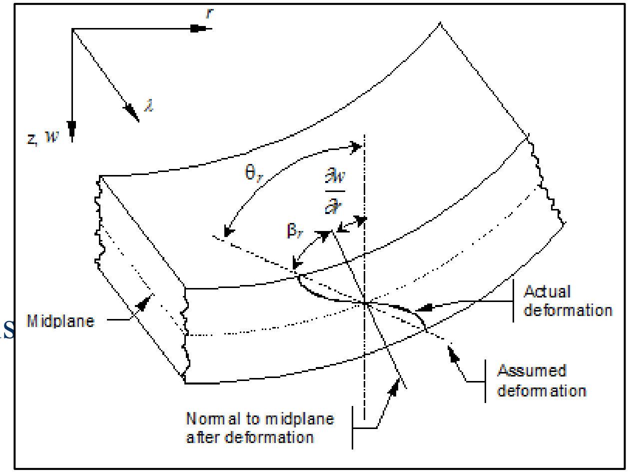
*Meshing -> Finite Strips Child Window*

The displacement function δ 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 $\Phi_i^m$ is a combination of polynomial $N_i$ and series $\phi_m^w$ , $\phi_m^{\theta_r}$ 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, the mid-plane displacement vector of a strip is

$$\delta = [w, \quad \theta_r, \quad \theta_\lambda]^T$$

The vector of nodal parameters of node *i* for the $m^{th}$ function is:

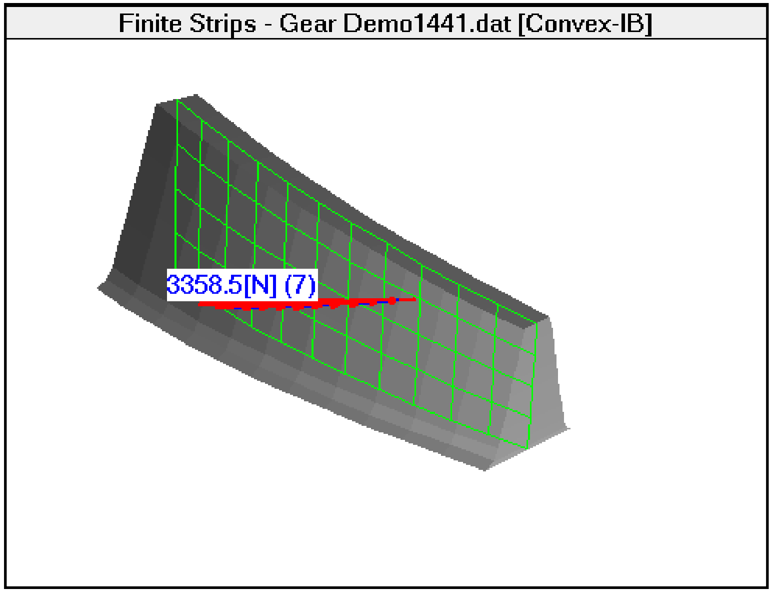
$$a_i^m = [w_i^m, \quad \theta_{ri}^m, \quad \theta_{\lambda i}^m]^T$$

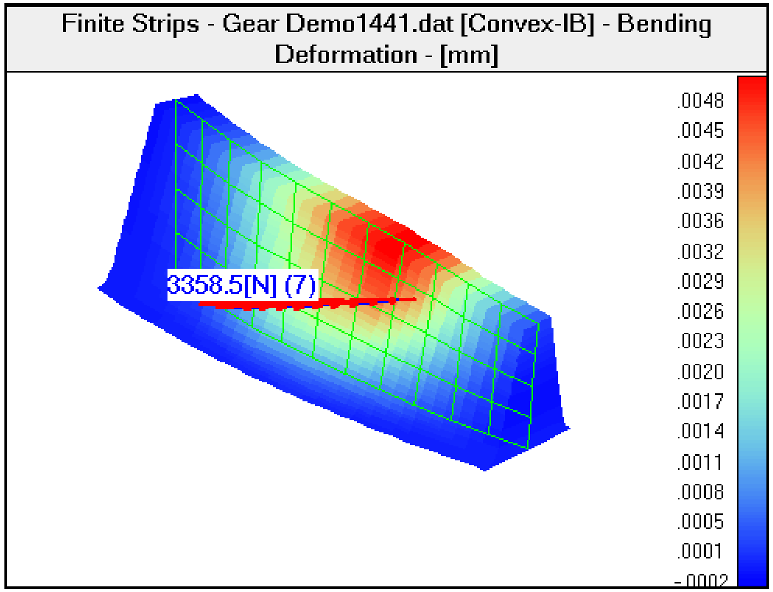
The Finite Strip stiffness matrix for functions *m*, *n* and nodal lines *i*, *j* is written as:

$$[k_{i,j}^{m,n}] = \iint [B_i^m][D][B_j^n] \, r \, d\lambda \, dr$$

# Graphic Display Functions

*Meshing -> Finite Strips Child Window*



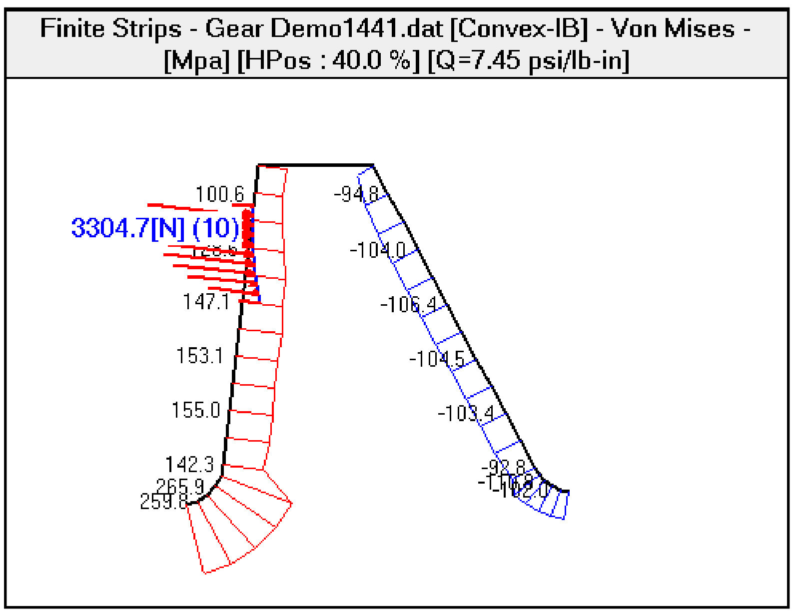



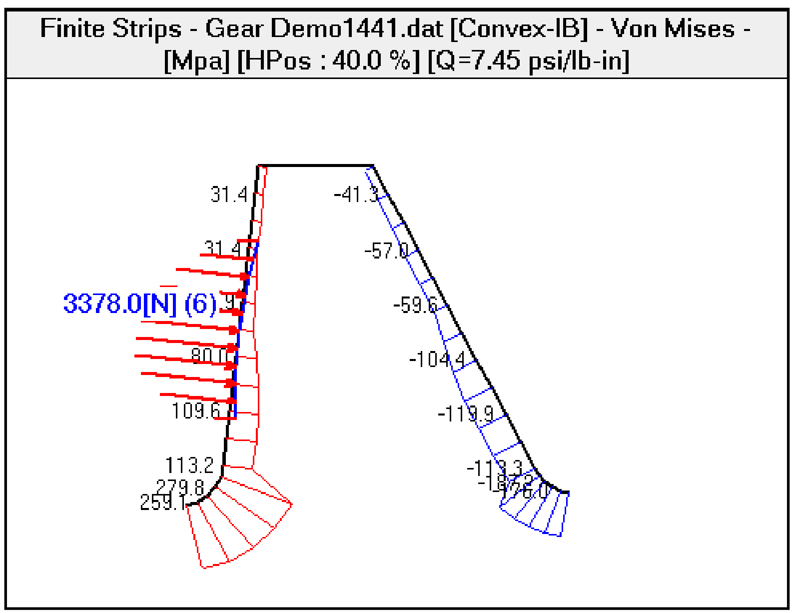
# Graphic Display Functions

*Meshing -> Finite Strips Child Window*

The figures below show the bending stresses in a Helical gear tooth, in two different contact positions using the results of the Loaded Tooth Contact Analysis for applied load and extent of the Contact Pattern.

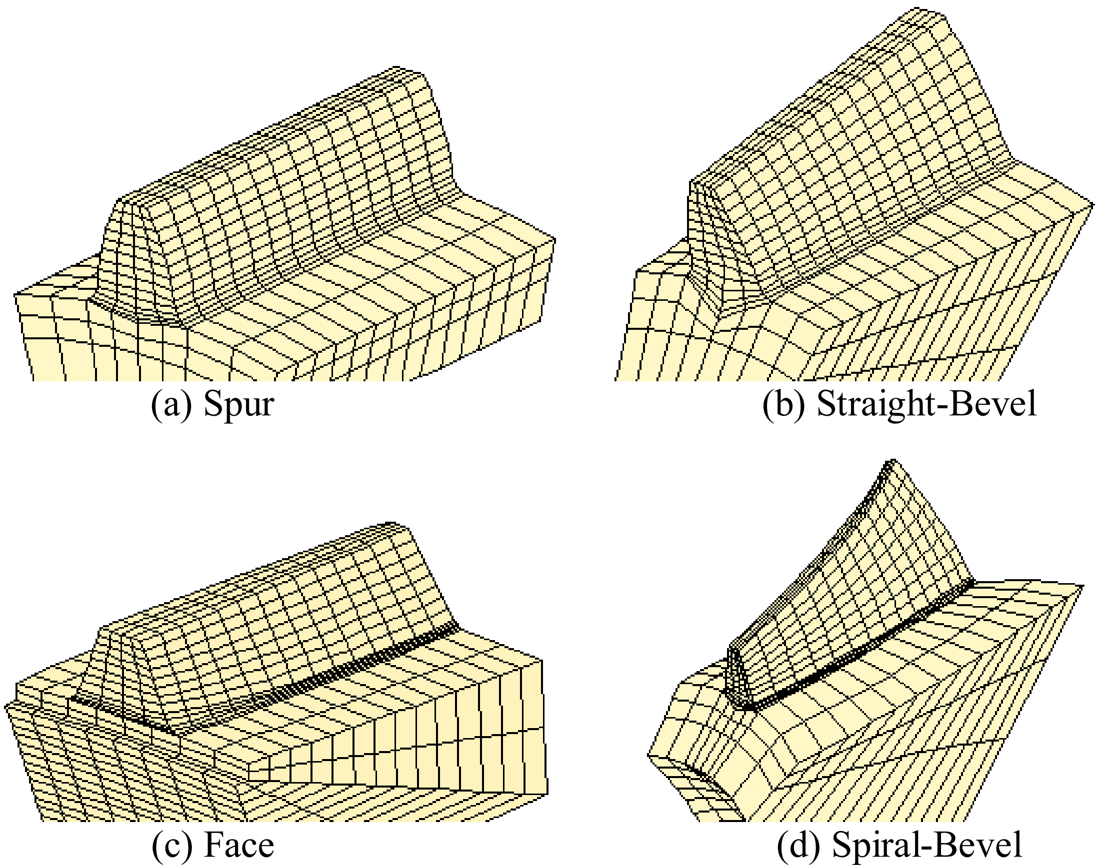
Typical pre-processing and *solution times < 0.3 sec*. on standard 2.4 GHz computer. The Finite Strips are therefore an *excellent tool to design and optimize a geometry* .



# Graphic Display Functions

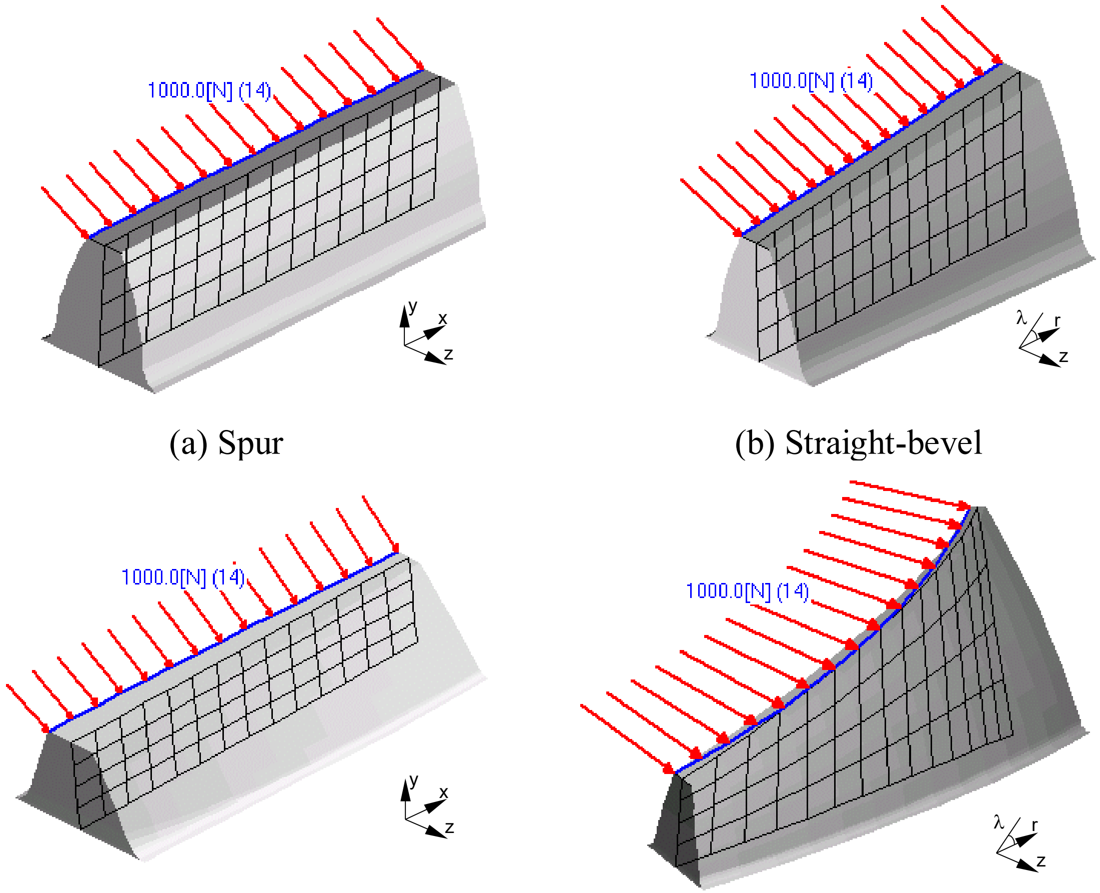
*Meshing -> Finite Strips Child Window*




FEM models

# Graphic Display Functions

*Meshing -> Finite Strips Child Window*




(a) Spur

(b) Straight-bevel

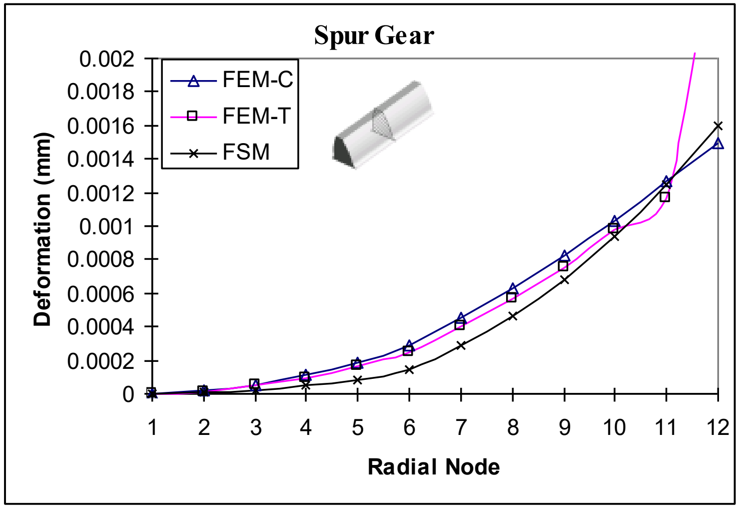
(c) Face

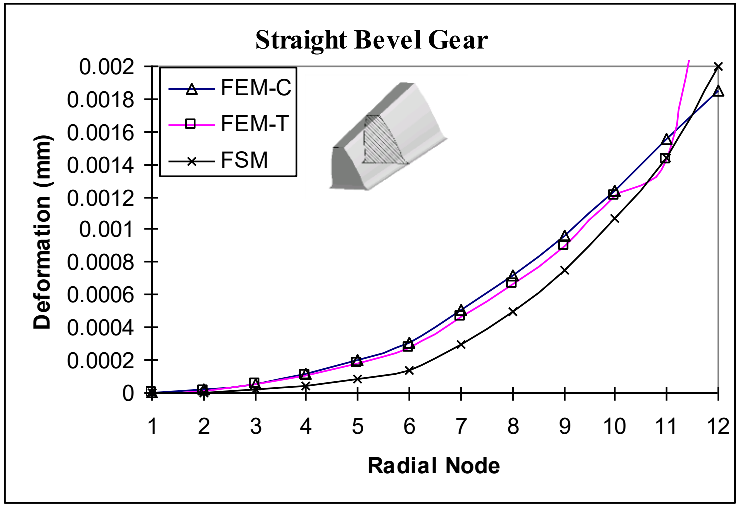
(d) Spiral-bevel

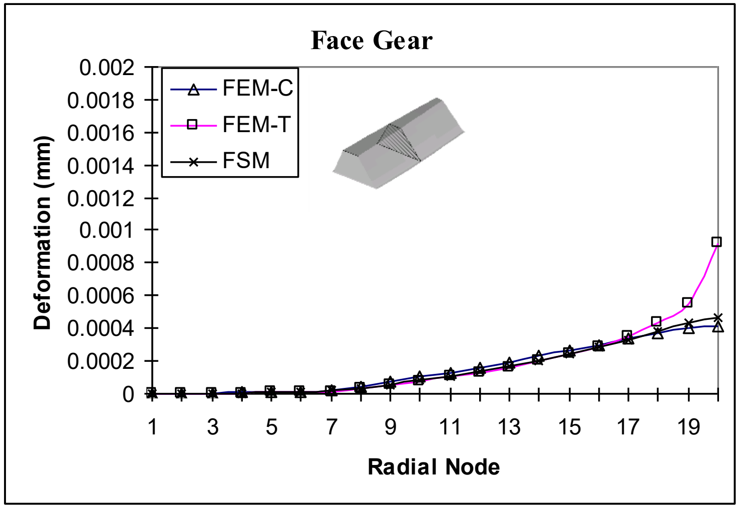
FSM models

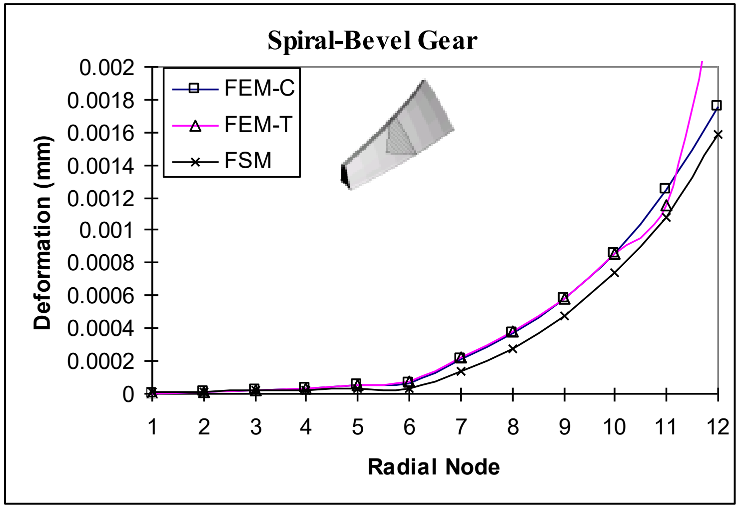
# Graphic Display Functions

*Meshing -> Finite Strips Child Window*



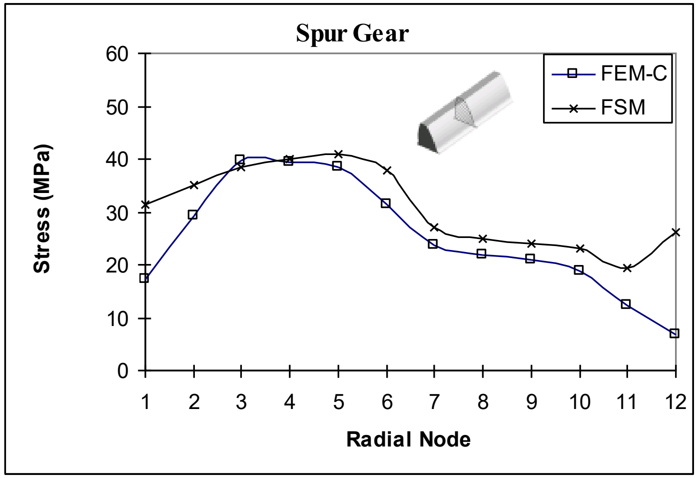



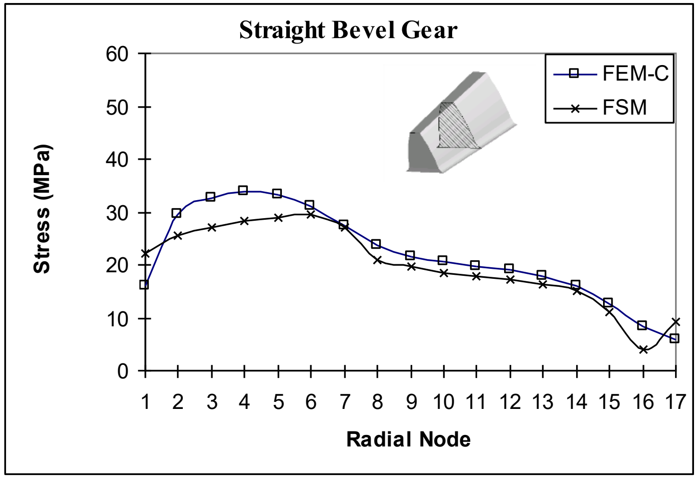



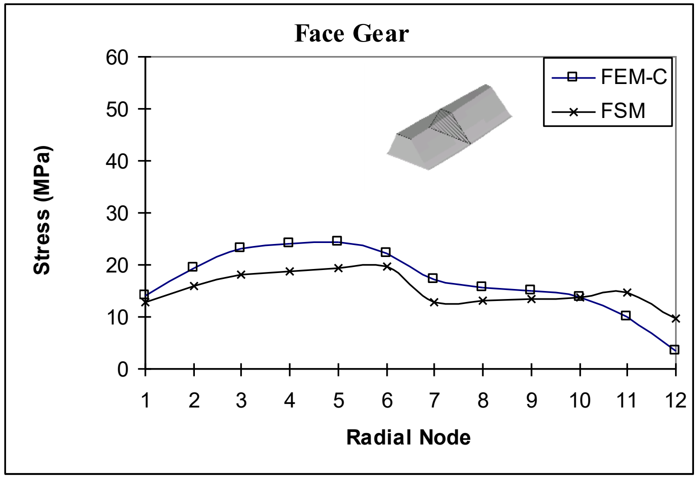



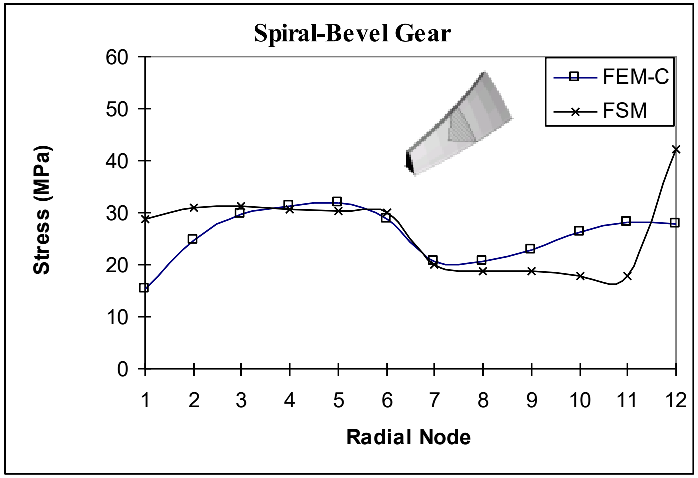
# Graphic Display Functions

*Meshing -> Finite Strips Child Window*

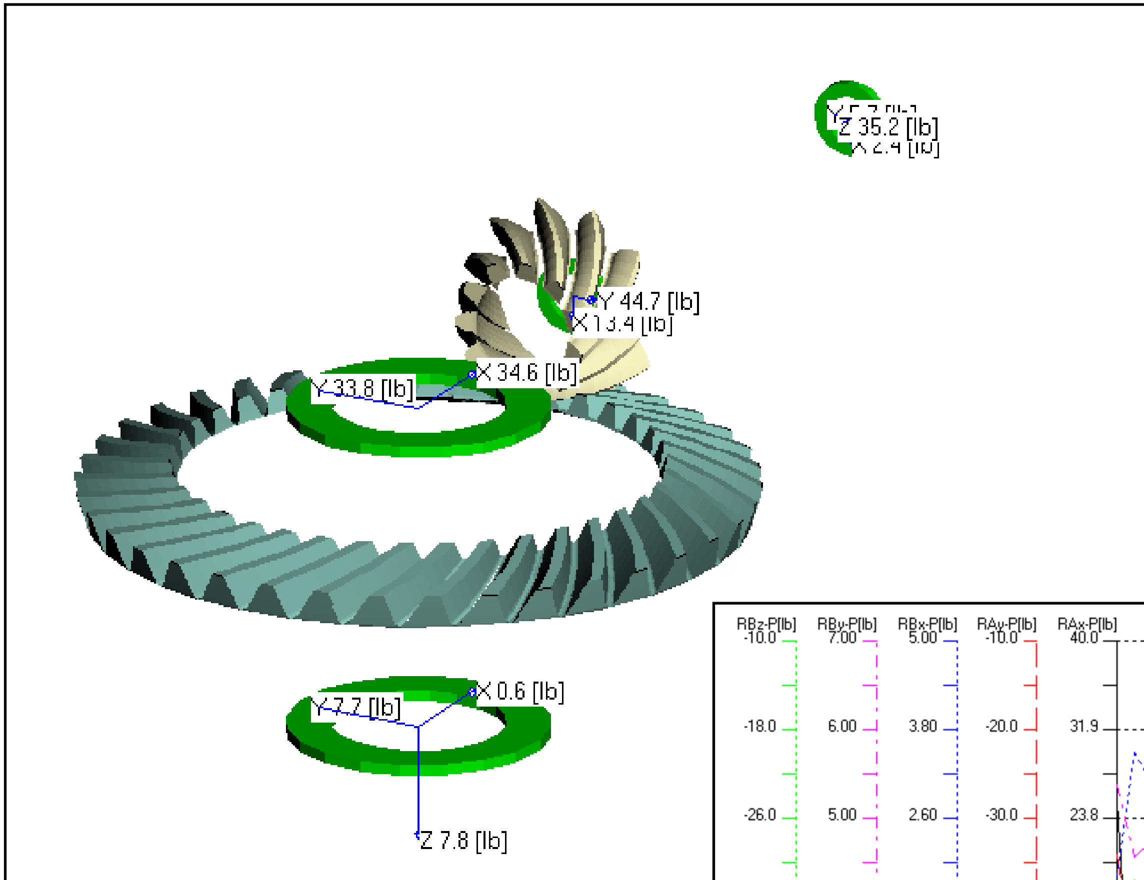


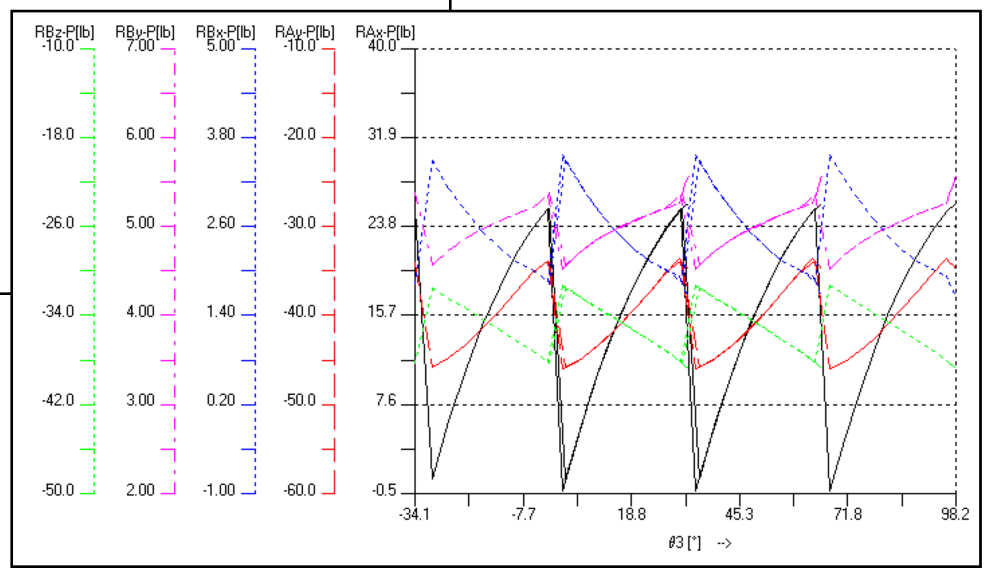



# Addendum 1: Bearing Reactions

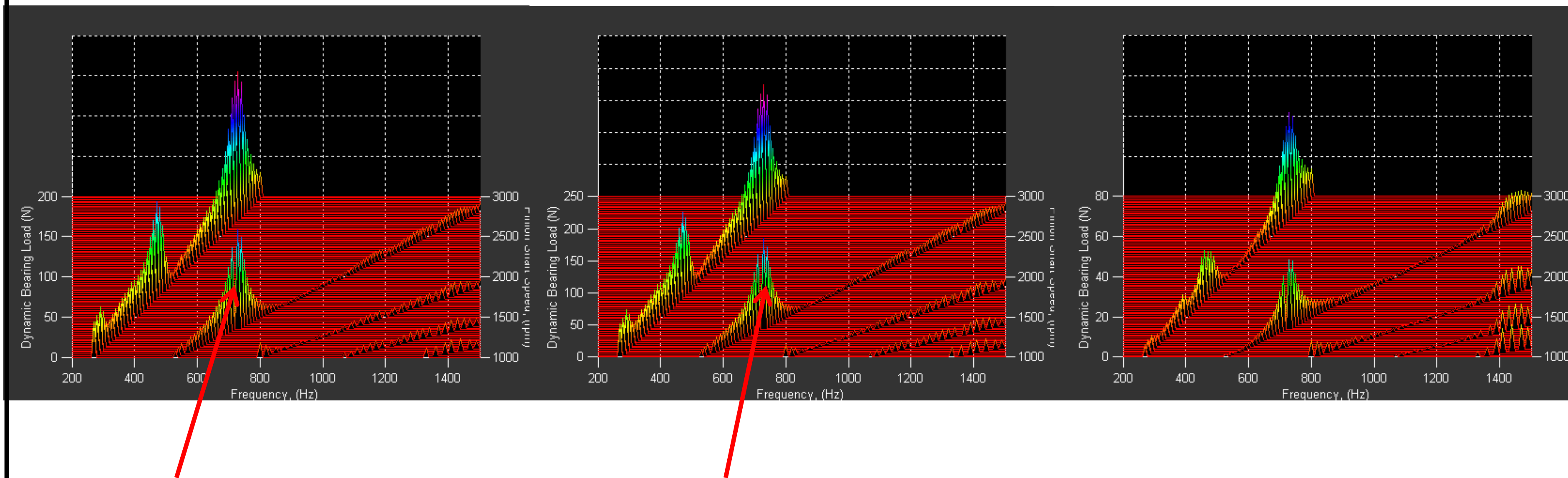


# Addendum 1: Large Bearing Reactions (Romax Designer)

Rear pinion bearing

X : 200N Y : 250N Z: 80N

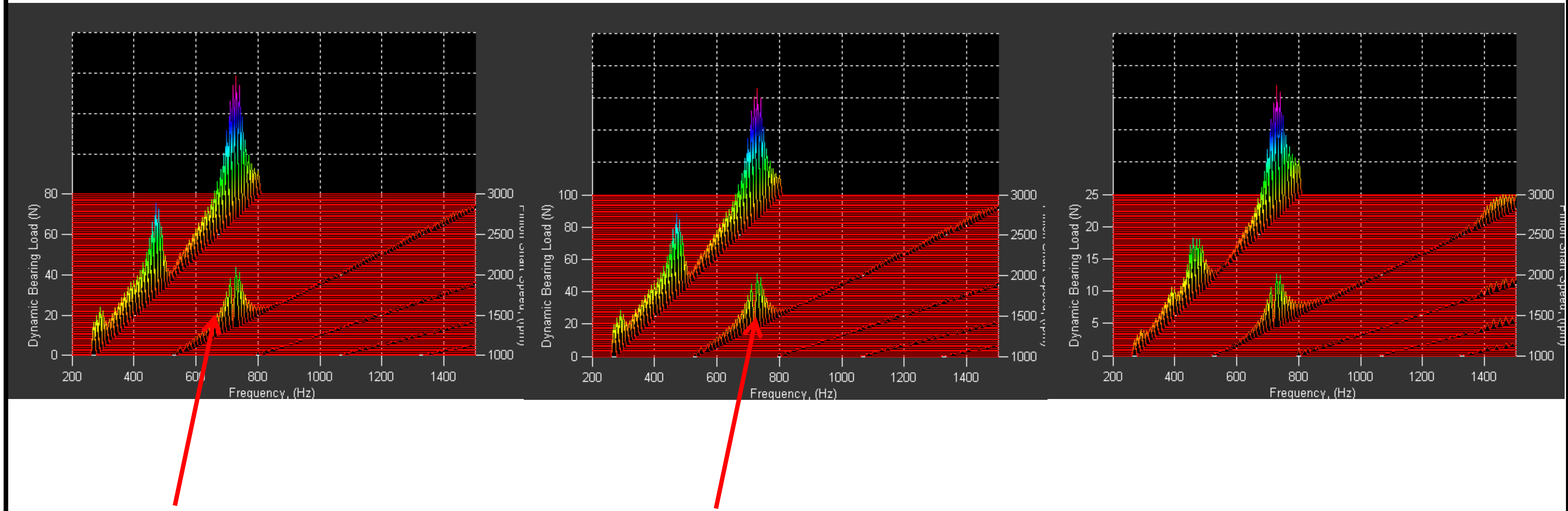



2nd harmonic higher than 1st harmonic, high response at 730 Hz

# Addendum 1: 70% reduction in Bearing Reactions

Rear pinion bearing

X : 80N　　　　Y : 100N　　　　Z: 25N



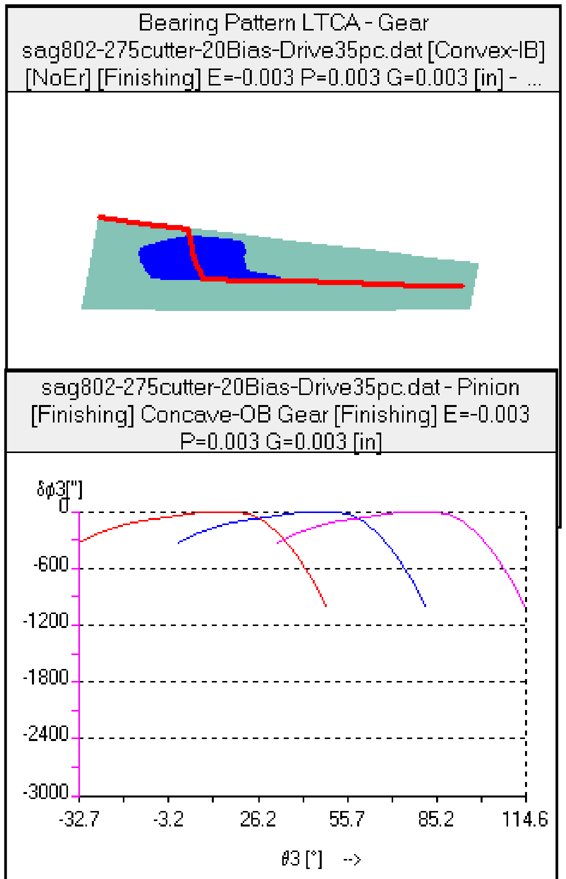

Forces reduced to 30% of green cut due to optimization in TE.

# Addendum 2: Influence of Bearing Stiffness (TCA / LTCA)

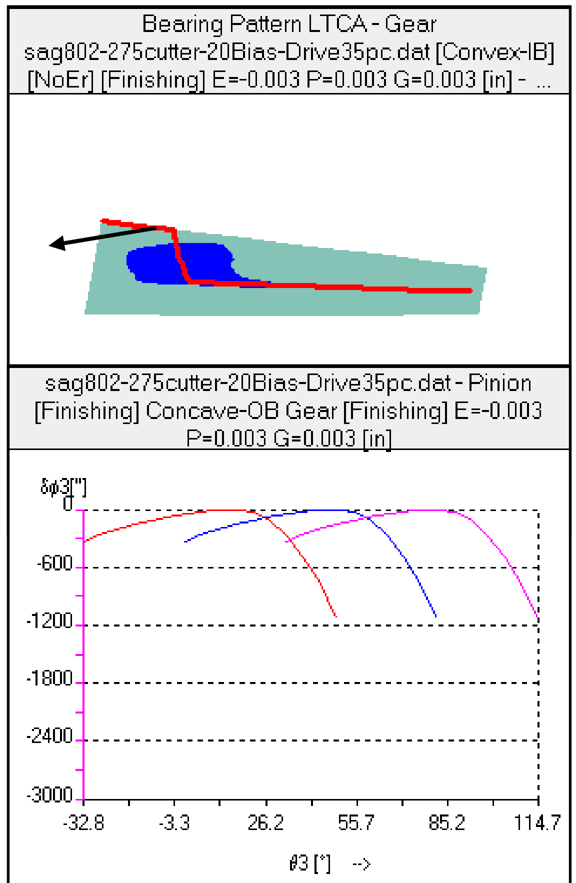
Worst Case Scenario

- –Contact Pattern / Contact Stresses
- –Transmission Error

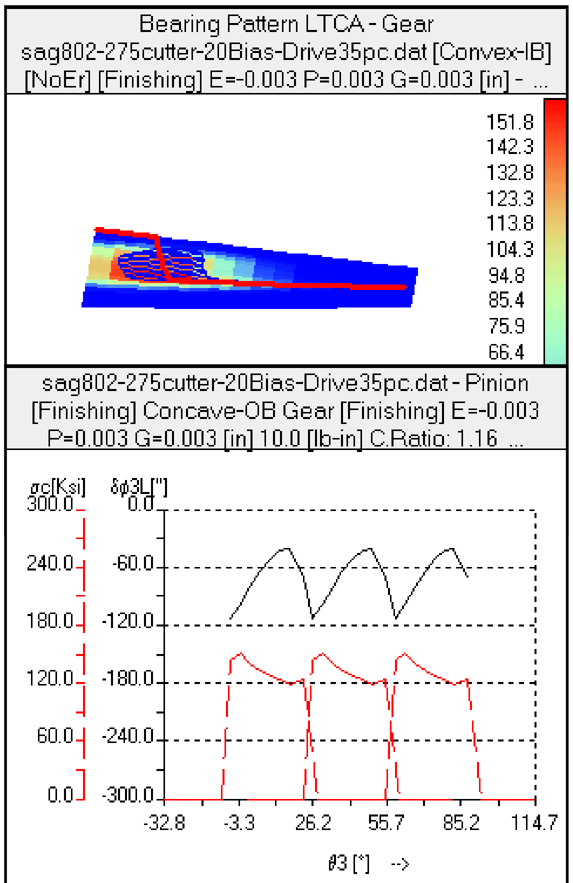
Stiff bearings and supports




Support stiffness = 50 k-lbs/in

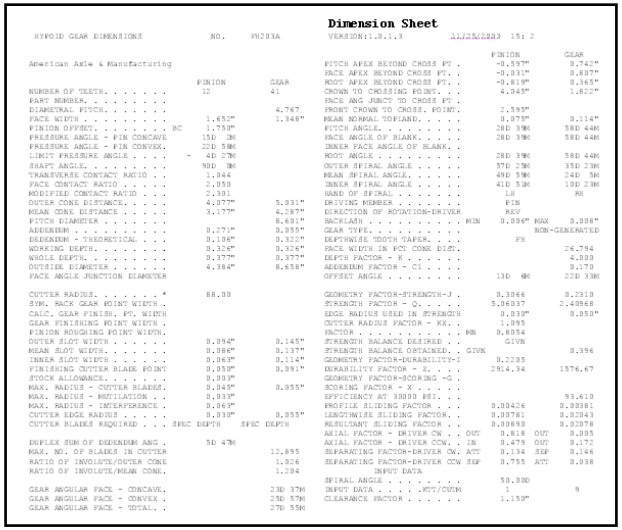



Support stiffness = 50 k-lbs/in



# Addendum 3: Case Analysis – FH Example

## Gleason Summary provided by customer



**Dimension Sheet**

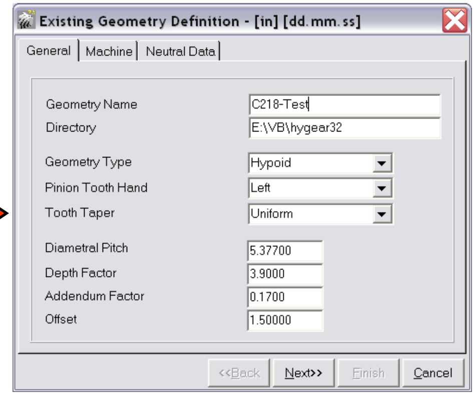
HYPOID GEAR DIMENSIONS    NO.    FH203A    VERSION:1.0.1.3    11/25/2003 15: 2

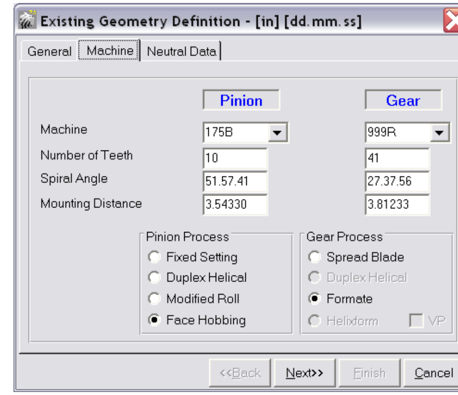
American Axle & Manufacturing

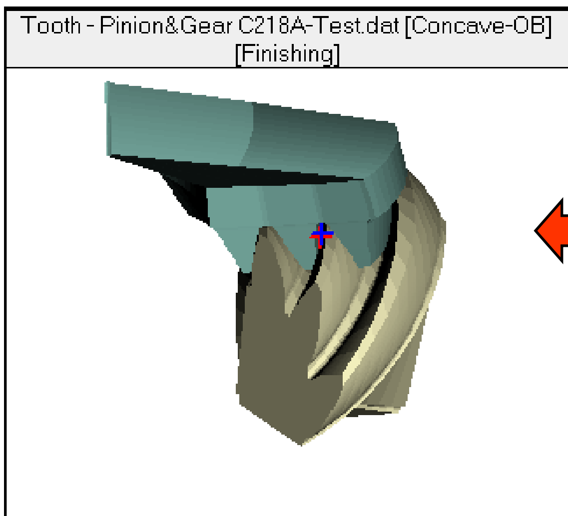
| | | PINION | GEAR |
|---|---|---|---|
| NUMBER OF TEETH. . . . . . . . | | 12 | 41 |
| PART NUMBER. . . . . . . . . | | | |
| DIAMETRAL PITCH. . . . . . . . | | | 4.767 |
| FACE WIDTH . . . . . . . . . . | | 1.652" | 1.348" |
| PINION OFFSET. . . . . . . . . | BC | 1.750" | |
| PRESSURE ANGLE - PIN CONCAVE | | 15D 2M | |
| PRESSURE ANGLE - PIN CONVEX. | | 22D 58M | |
| LIMIT PRESSURE ANGLE . . . . | - | 4D 27M | |
| SHAFT ANGLE. . . . . . . . . . | | 90D 0M | |
| TRANSVERSE CONTACT RATIO . . | | 1.044 | |
| FACE CONTACT RATIO . . . . . . | | 2.050 | |
| MODIFIED CONTACT RATIO . . . | | 2.301 | |
| OUTER CONE DISTANCE. . . . . | | 4.077" | 5.031" |
| MEAN CONE DISTANCE . . . . . . | | 3.177" | 4.287" |
| PITCH DIAMETER . . . . . . . . | | | 8.601" |
| ADDENDUM . . . . . . . . . . . | | 0.271" | 0.055" |
| DEDENDUM - THEORETICAL . . . | | 0.106" | 0.322" |
| WORKING DEPTH. . . . . . . . . | | 0.326" | 0.326" |
| WHOLE DEPTH. . . . . . . . . . | | 0.377" | 0.377" |
| OUTSIDE DIAMETER . . . . . . . | | 4.384" | 8.658" |
| FACE ANGLE JUNCTION DIAMETER | | | |
| CUTTER RADIUS. . . . . . . . | * | 88.00 | |
| SYM. RACK GEAR POINT WIDTH . | | | |
| CALC. GEAR FINISH. PT. WIDTH | | | |
| GEAR FINISHING POINT WIDTH . | | | |
| PINION ROUGHING POINT WIDTH. | | | |
| OUTER SLOT WIDTH . . . . . . . | | 0.094" | 0.145" |
| MEAN SLOT WIDTH. . . . . . . . | | 0.086" | 0.137" |
| INNER SLOT WIDTH . . . . . . . | | 0.063" | 0.114" |
| FINISHING CUTTER BLADE POINT | | 0.050" | 0.091" |
| STOCK ALLOWANCE. . . . . . . . | | 0.003" | |
| MAX. RADIUS - CUTTER BLADES. | | 0.045" | 0.055" |
| MAX. RADIUS - MUTILATION . . | | 0.033" | |
| MAX. RADIUS - INTERFERENCE . | | 0.063" | |
| CUTTER EDGE RADIUS . . . . . | | 0.030" | 0.055" |
| CUTTER BLADES REQUIRED . . . | | SPEC DEPTH | SPEC DEPTH |
| DUPLEX SUM OF DEDENDUM ANG . | | 5D 47M | |
| MAX. NO. OF BLADES IN CUTTER | | | 12.895 |
| RATIO OF INVOLUTE/OUTER CONE | | | 1.026 |
| RATIO OF INVOLUTE/MEAN CONE. | | | 1.204 |
| GEAR ANGULAR FACE - CONCAVE. | | | 23D 37M |
| GEAR ANGULAR FACE - CONVEX . | | | 25D 57M |
| GEAR ANGULAR FACE - TOTAL. . | | | 27D 55M |

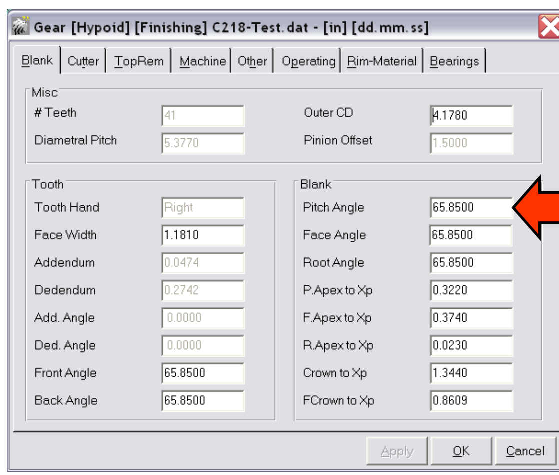
| | | PINION | | GEAR |
|---|---|---|---|---|
| PITCH APEX BEYOND CROSS PT . | | -0.597" | | 0.742" |
| FACE APEX BEYOND CROSS PT. . | | -0.031" | | 0.807" |
| ROOT APEX BEYOND CROSS PT. . | | -0.819" | | 0.365" |
| CROWN TO CROSSING POINT. . . | | 4.045" | | 1.822" |
| FACE ANG JUNCT TO CROSS PT . | | | | |
| FRONT CROWN TO CROSS. POINT. | | 2.595" | | |
| MEAN NORMAL TOPLAND. . . . . | | 0.075" | | 0.114" |
| PITCH ANGLE. . . . . . . . . . | | 28D 39M | | 58D 44M |
| FACE ANGLE OF BLANK. . . . . | | 28D 39M | | 58D 44M |
| INNER FACE ANGLE OF BLANK. . | | | | |
| ROOT ANGLE . . . . . . . . . . | | 28D 39M | | 58D 44M |
| OUTER SPIRAL ANGLE . . . . . | | 57D 25M | | 35D 23M |
| MEAN SPIRAL ANGLE. . . . . . . | | 49D 59M | | 24D 5M |
| INNER SPIRAL ANGLE . . . . . | | 41D 51M | | 10D 23M |
| HAND OF SPIRAL . . . . . . . . | | LH | | RH |
| DRIVING MEMBER . . . . . . . . | | PIN | | |
| DIRECTION OF ROTATION-DRIVER | | REV | | |
| BACKLASH . . . . . . . . . . . | MIN | 0.006" | MAX | 0.008" |
| GEAR TYPE. . . . . . . . . . . | | | | NON-GENERATED |
| DEPTHWISE TOOTH TAPER. . . . | | FH | | |
| FACE WIDTH IN PCT CONE DIST. | | | | 26.794 |
| DEPTH FACTOR - K . . . . . . . | | | | 4.000 |
| ADDENDUM FACTOR - C1 . . . . | | | | 0.170 |
| OFFSET ANGLE . . . . . . . . . | | 13D 6M | | 22D 33M |
| GEOMETRY FACTOR-STRENGTH-J . | | 0.3066 | | 0.2310 |
| STRENGTH FACTOR - Q. . . . . | | 5.06037 | | 2.40968 |
| EDGE RADIUS USED IN STRENGTH | | 0.030" | | 0.050" |
| CUTTER RADIUS FACTOR - KX. . | | 1.095 | | |
| FACTOR . . . . . . . . . . . . | MN | 0.8054 | | |
| STRENGTH BALANCE DESIRED . . | | GIVN | | |
| STRENGTH BALANCE OBTAINED. . | GIVN | | | 0.396 |
| GEOMETRY FACTOR-DURABILITY-I | | 0.2205 | | |
| DURABILITY FACTOR - Z. . . . | | 2914.34 | | 1576.67 |
| GEOMETRY FACTOR-SCORING -G . | | | | |
| SCORING FACTOR - X . . . . . | | | | |
| EFFICIENCY AT 30000 PSI. . . | | | | 93.610 |
| PROFILE SLIDING FACTOR . . . | | 0.00426 | | 0.00381 |
| LENGTHWISE SLIDING FACTOR. . | | 0.00781 | | 0.02043 |
| RESULTANT SLIDING FACTOR . . | | 0.00890 | | 0.02078 |
| AXIAL FACTOR - DRIVER CW . . | OUT | 0.818 | OUT | 0.005 |
| AXIAL FACTOR - DRIVER CCW. . | IN | 0.479 | OUT | 0.172 |
| SEPARATING FACTOR-DRIVER CW. | ATT | 0.134 | SEP | 0.146 |
| SEPARATING FACTOR-DRIVER CCW | SEP | 0.755 | ATT | 0.038 |
| INPUT DATA | | | | |
| SPIRAL ANGLE . . . . . . . . . | | 50.000 | | |
| INPUT DATA . . . . . .KTT/CUTM | | 1 | | 9 |
| CLEARANCE FACTOR . . . . . . | | 1.150" | | |

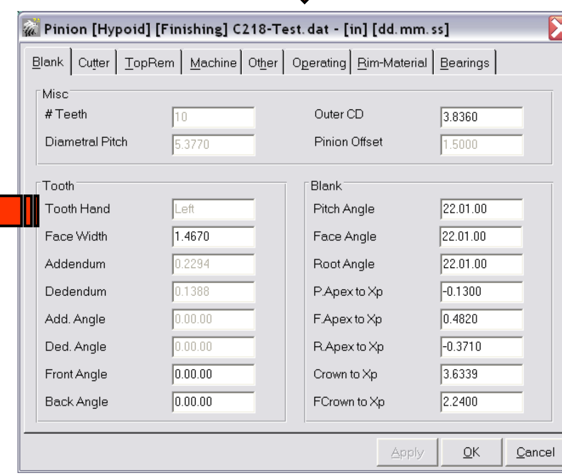
## Data entered in HyGEARS



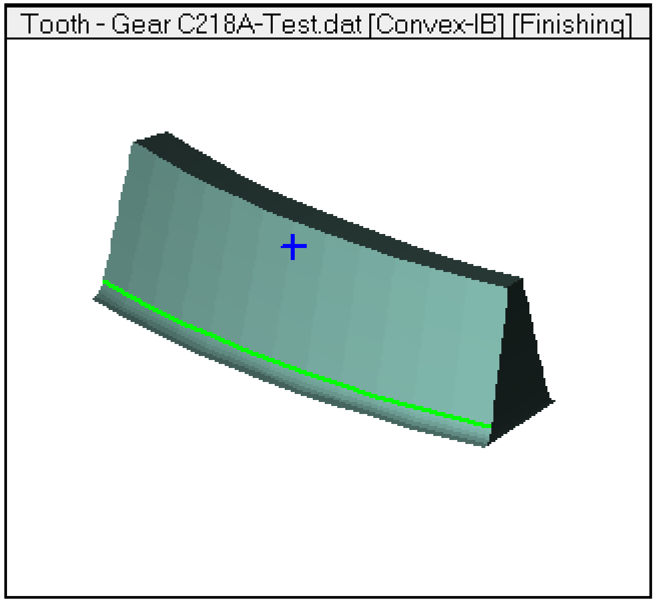



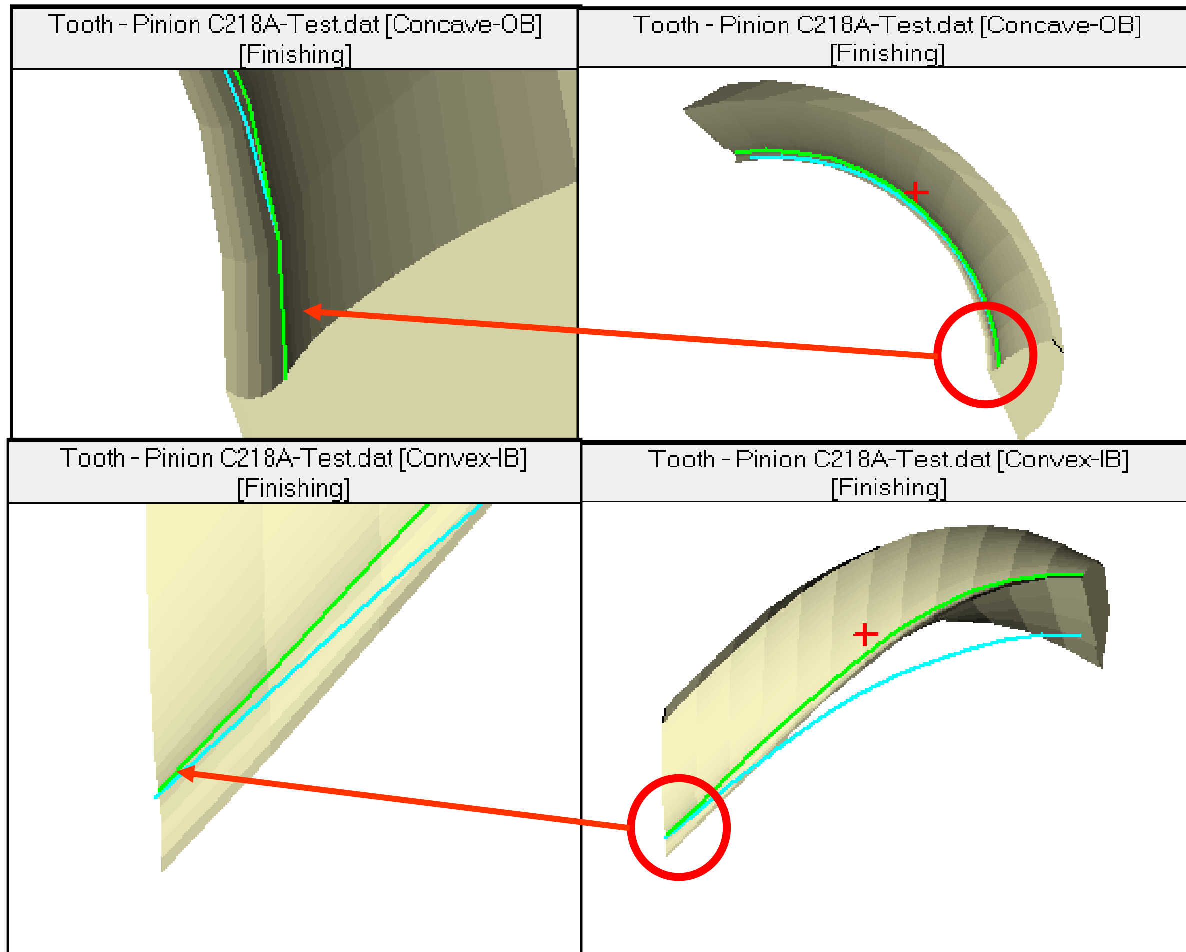
# Addendum 3: Case Analysis – FH Example

Visually verify Pinion and Gear teeth for:

– Insufficient Topland

– Undercutting

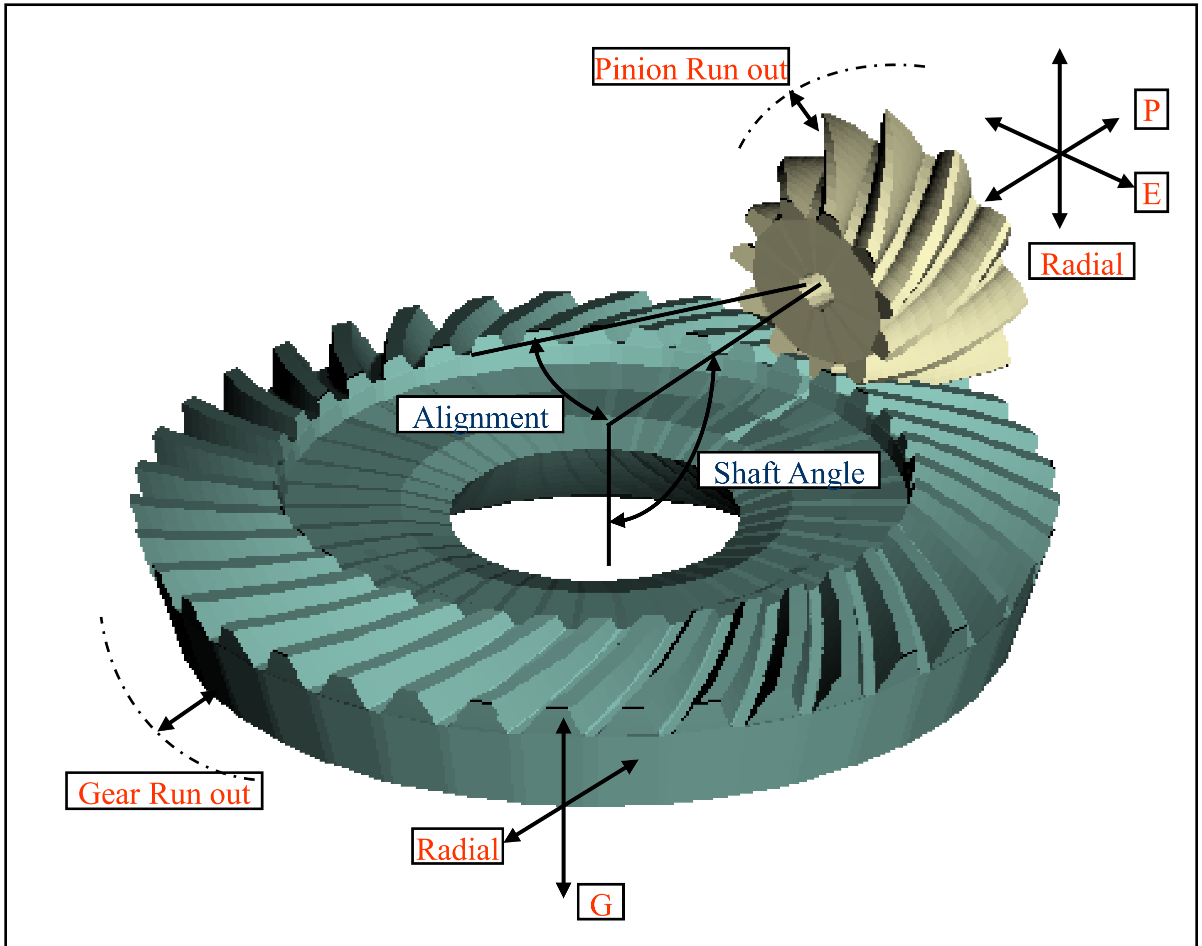


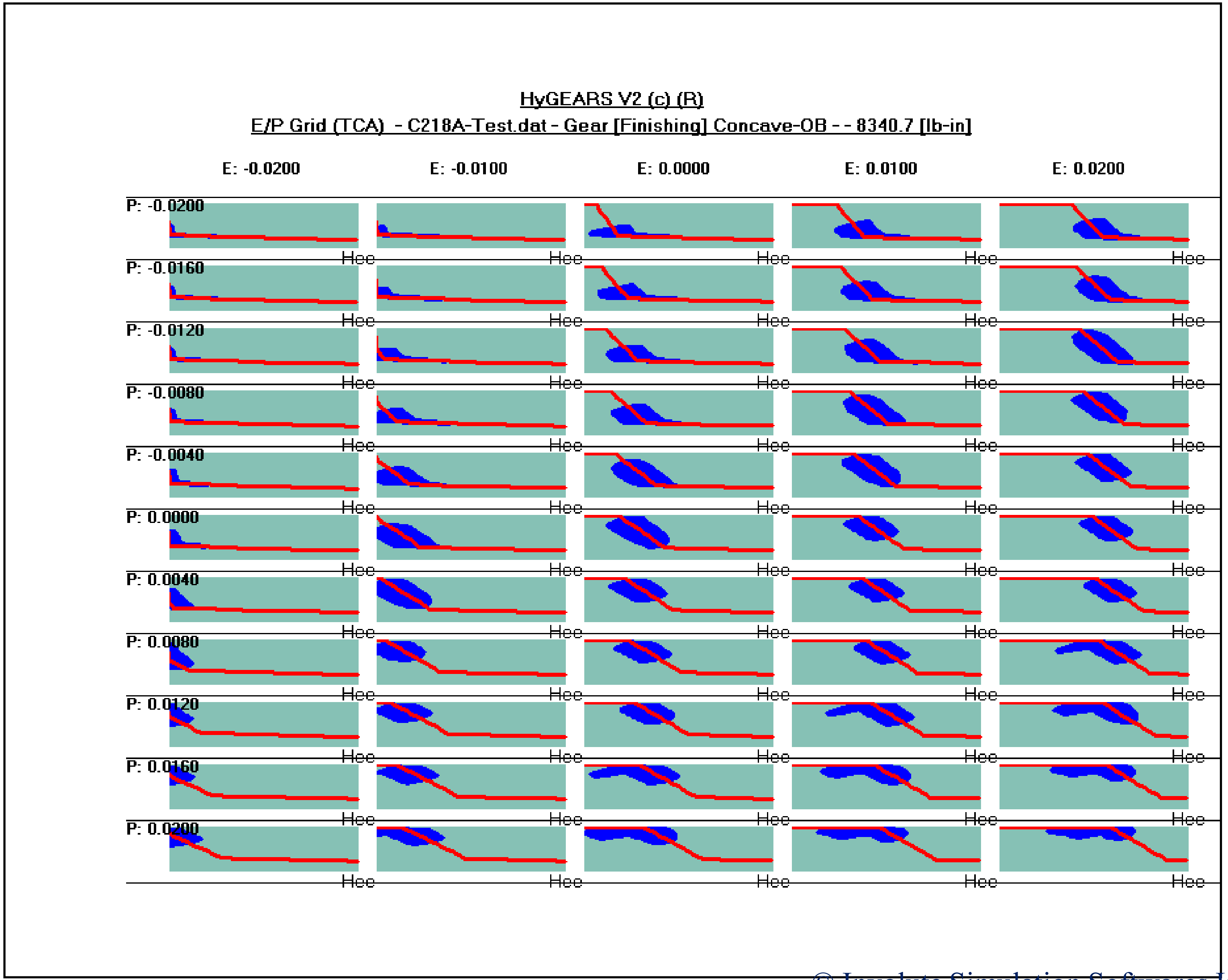
# Addendum 3: Case Analysis – FH Example

Design, is analyzed for:

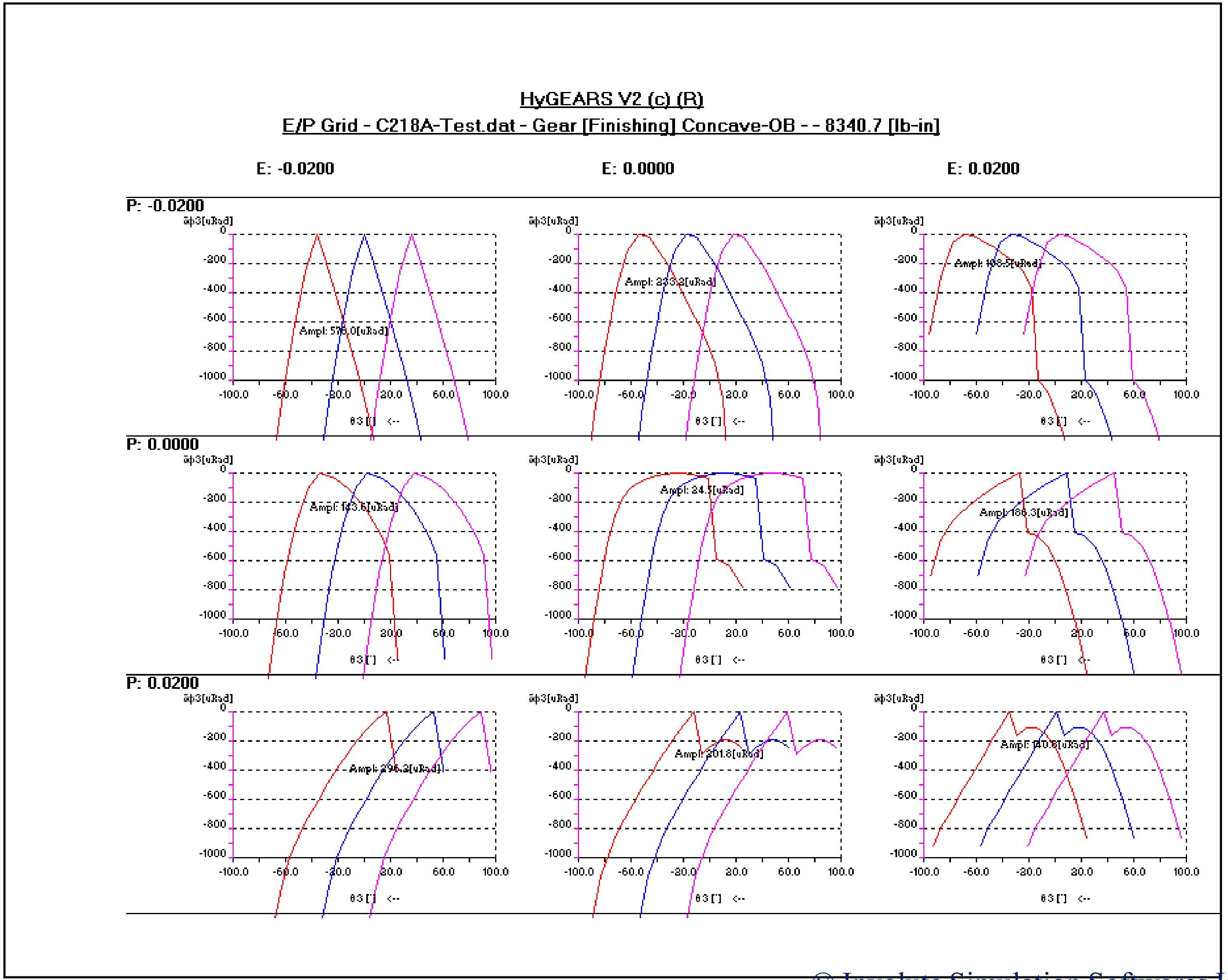
– Position/Alignment sensitivity



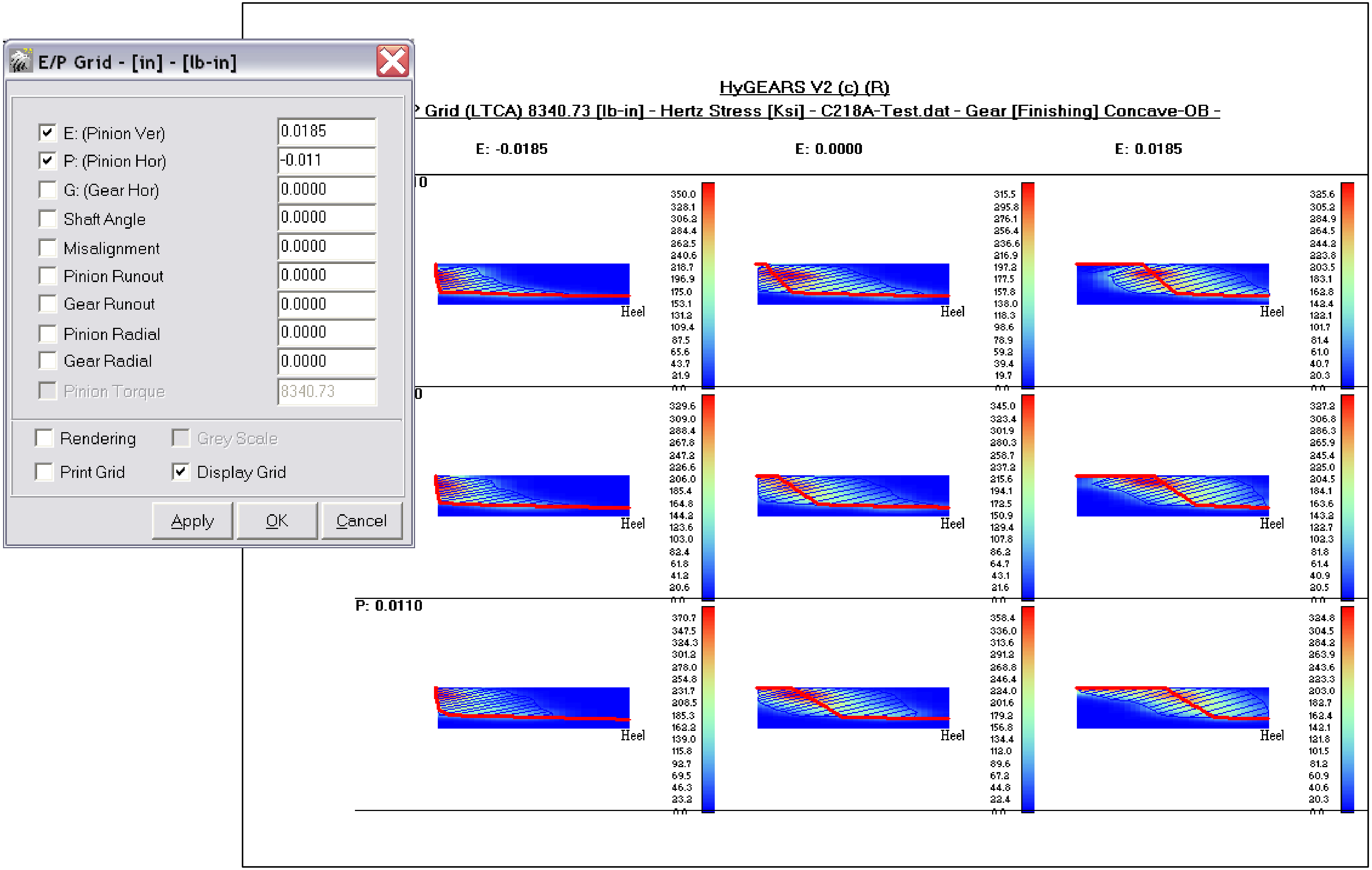
# Addendum 3: Case Analysis – FH Example



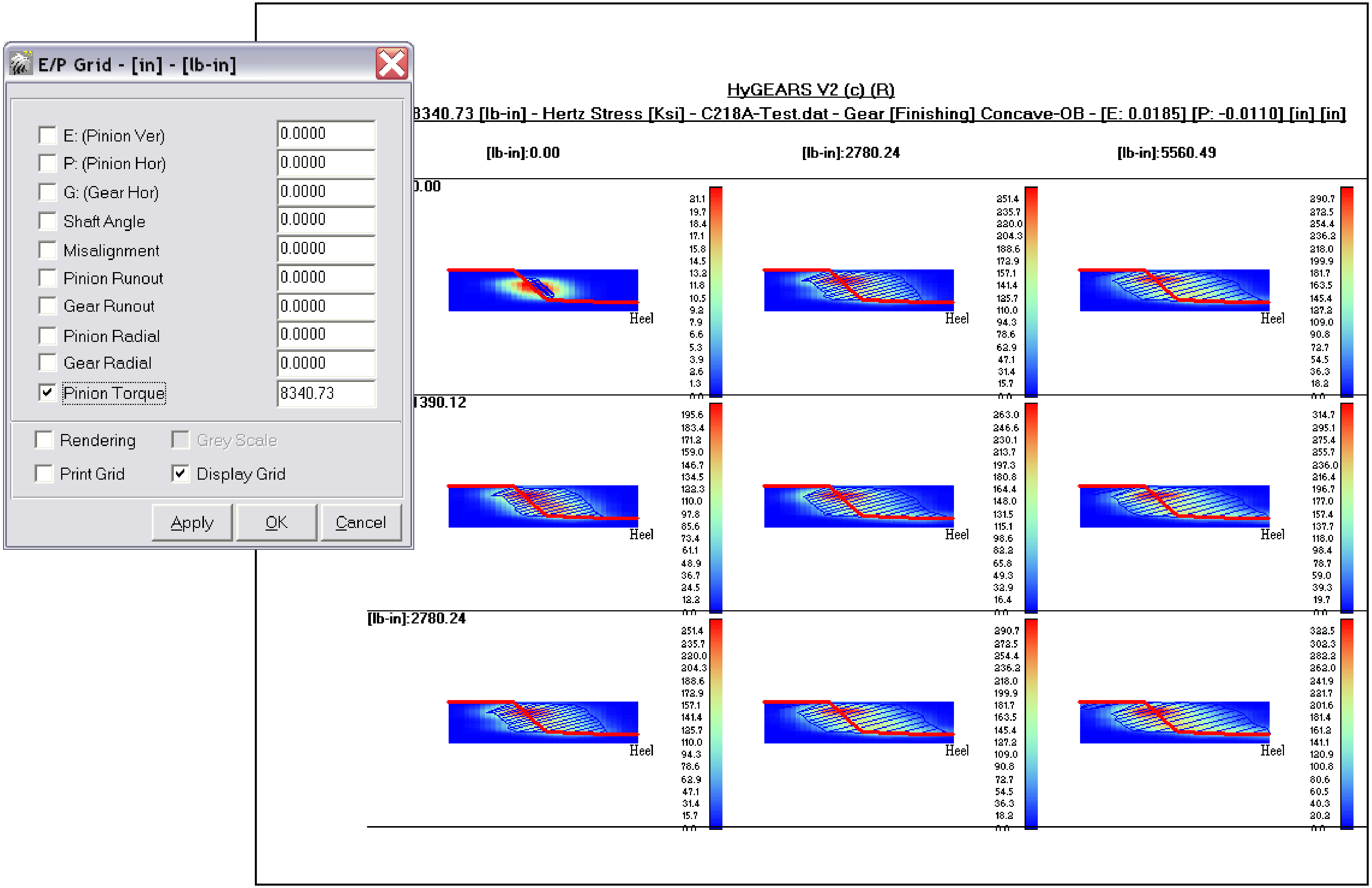
# Addendum 3: Case Analysis – FH Example



# Addendum 3: Case Analysis – FH Example



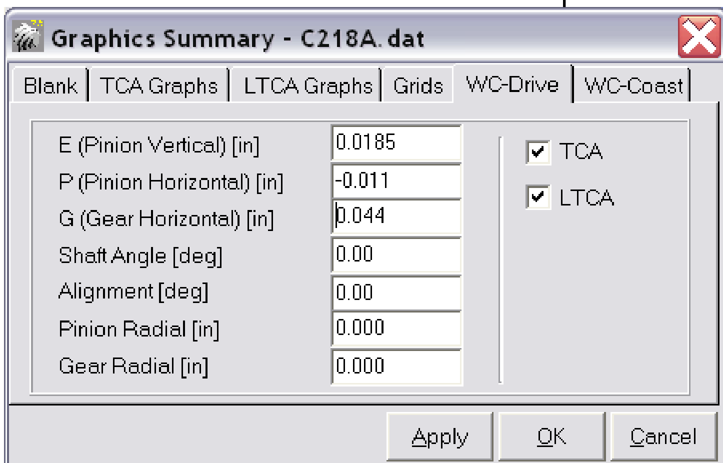
# Addendum 3: Case Analysis – FH Example

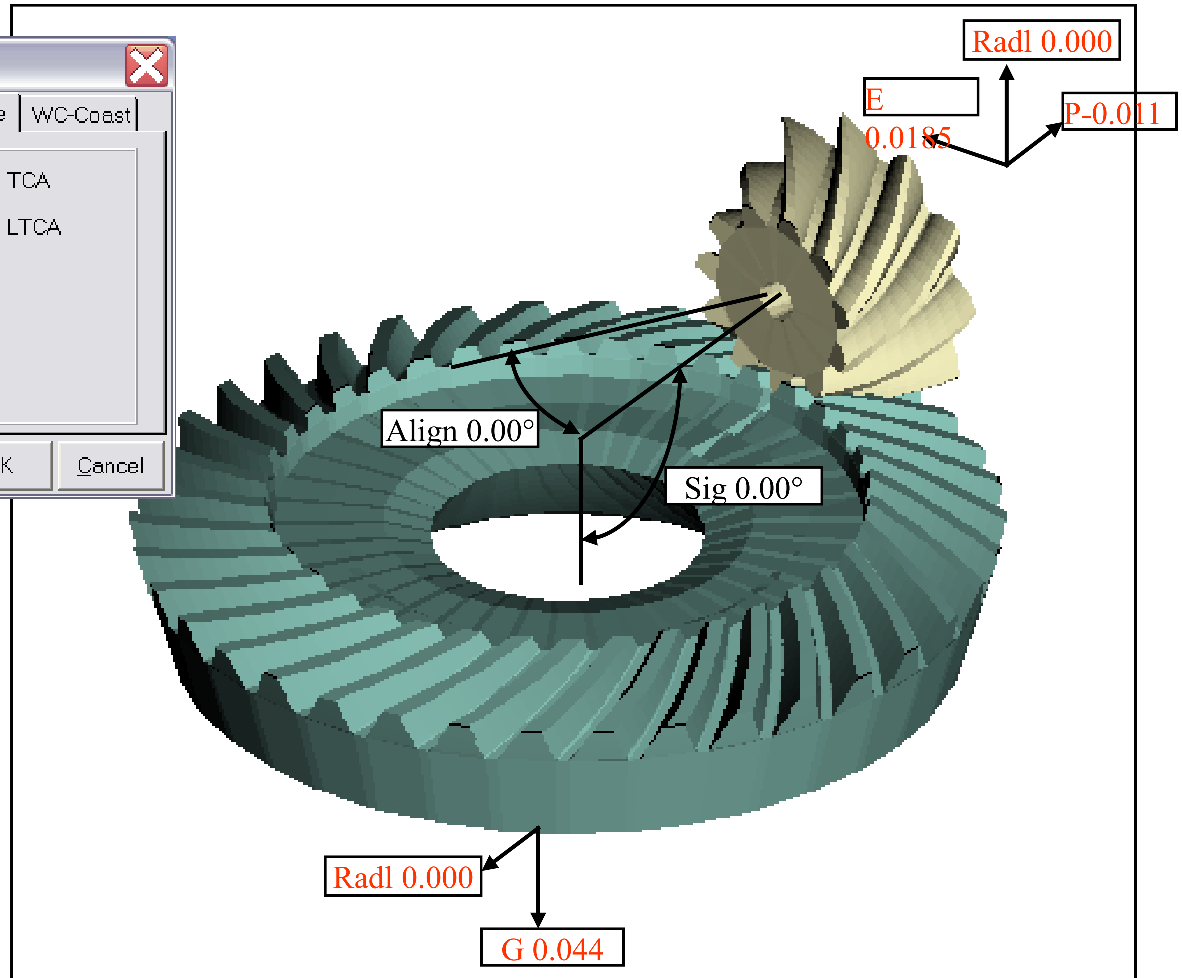


# Addendum 3: Case Analysis – FH Example

Design, is analyzed for:

– Worst case scenario

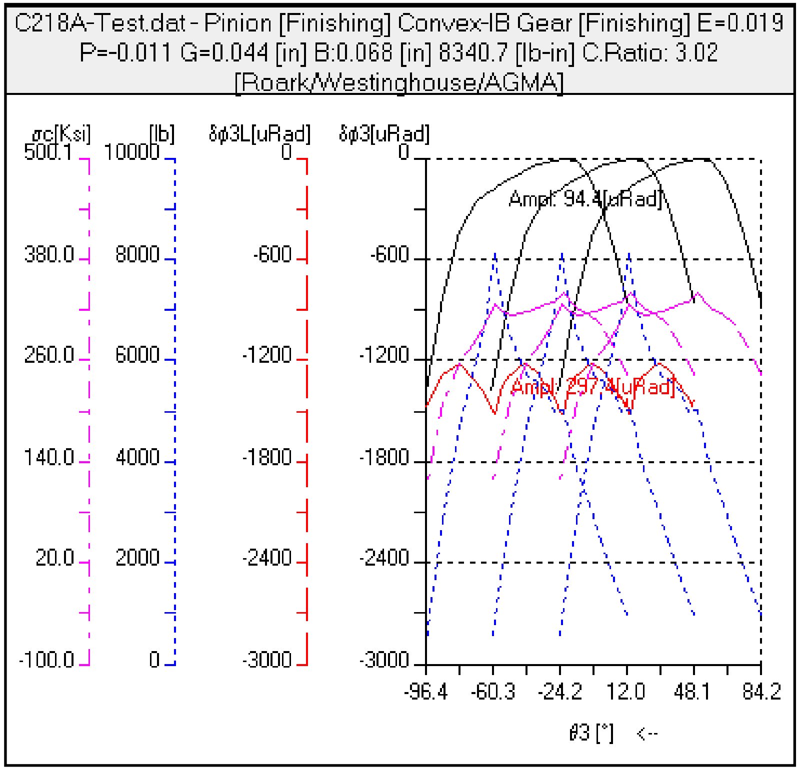


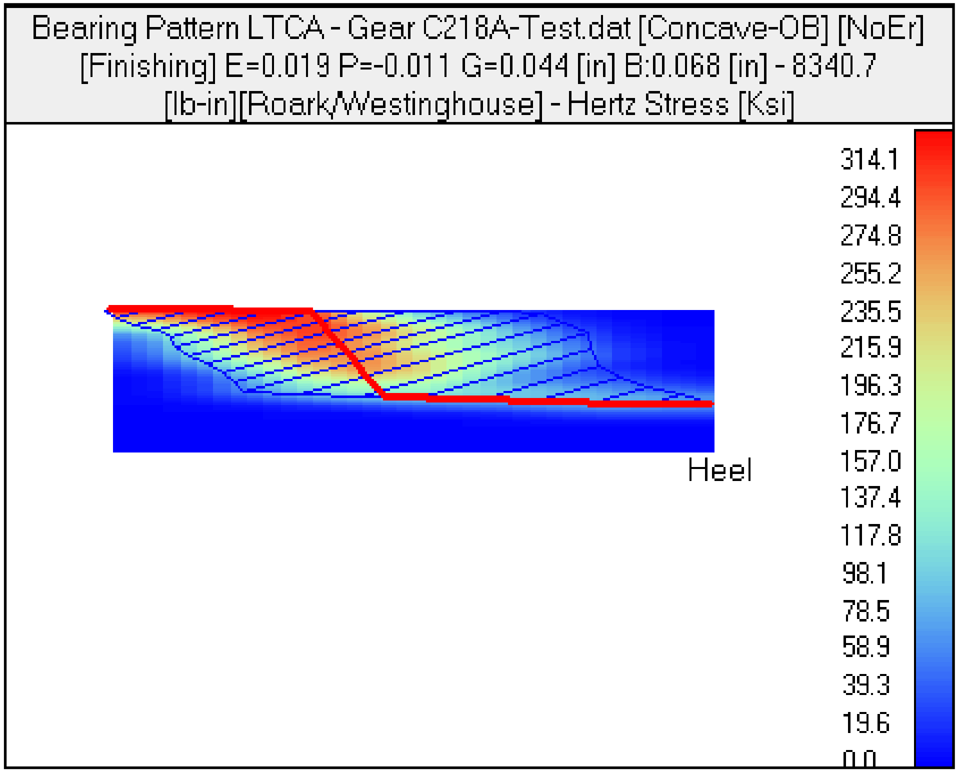



# Addendum 3: Case Analysis – FH Example

## Worst Case Scenario

- Contact Pattern / Contact Stresses
- Transmission Error

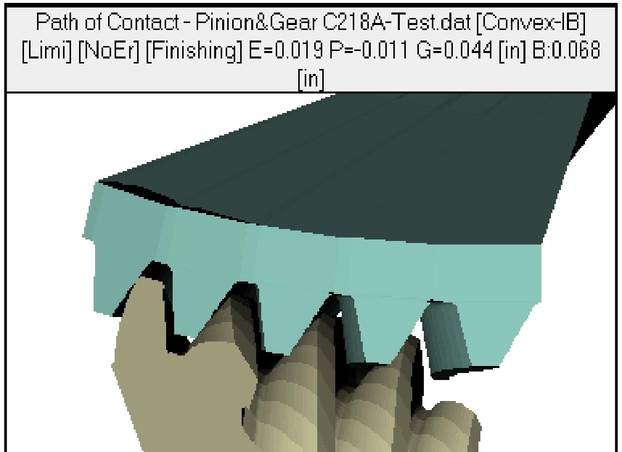


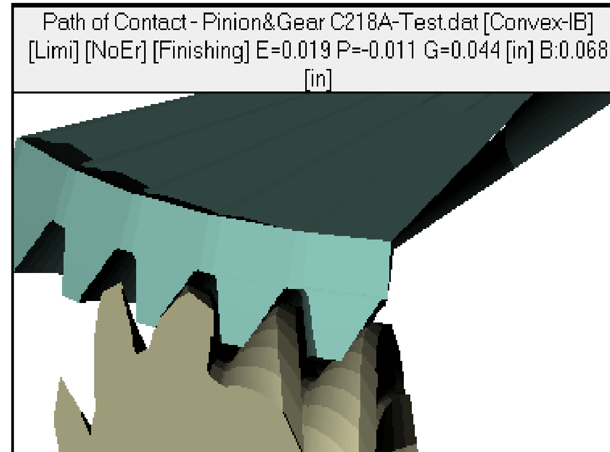



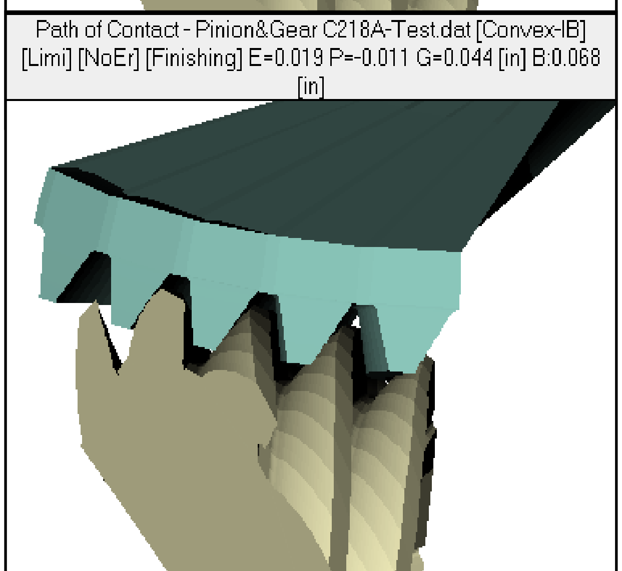
# Addendum 3: Case Analysis – FH Example

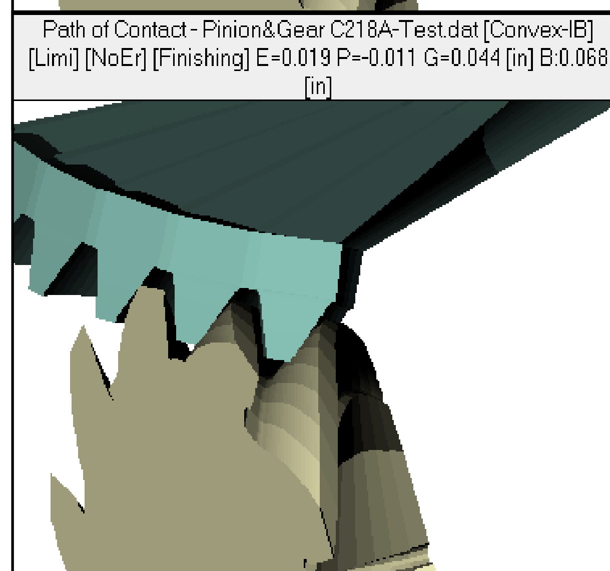
## Worst Case Scenario: Check for Fillet Interference

E=0.0185 P=-0.011 G=0.044 Sigma= 0.00 Align=0.00°



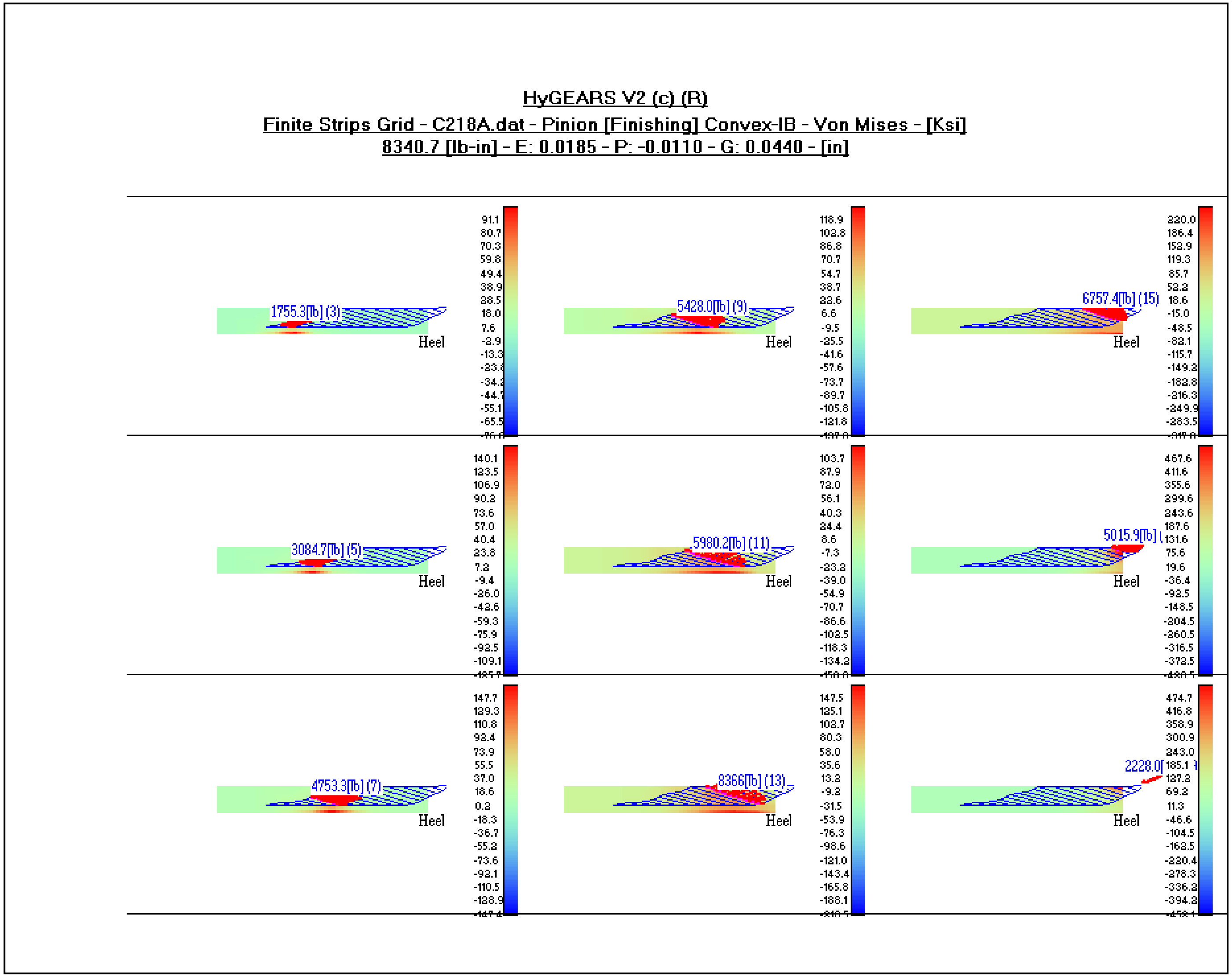



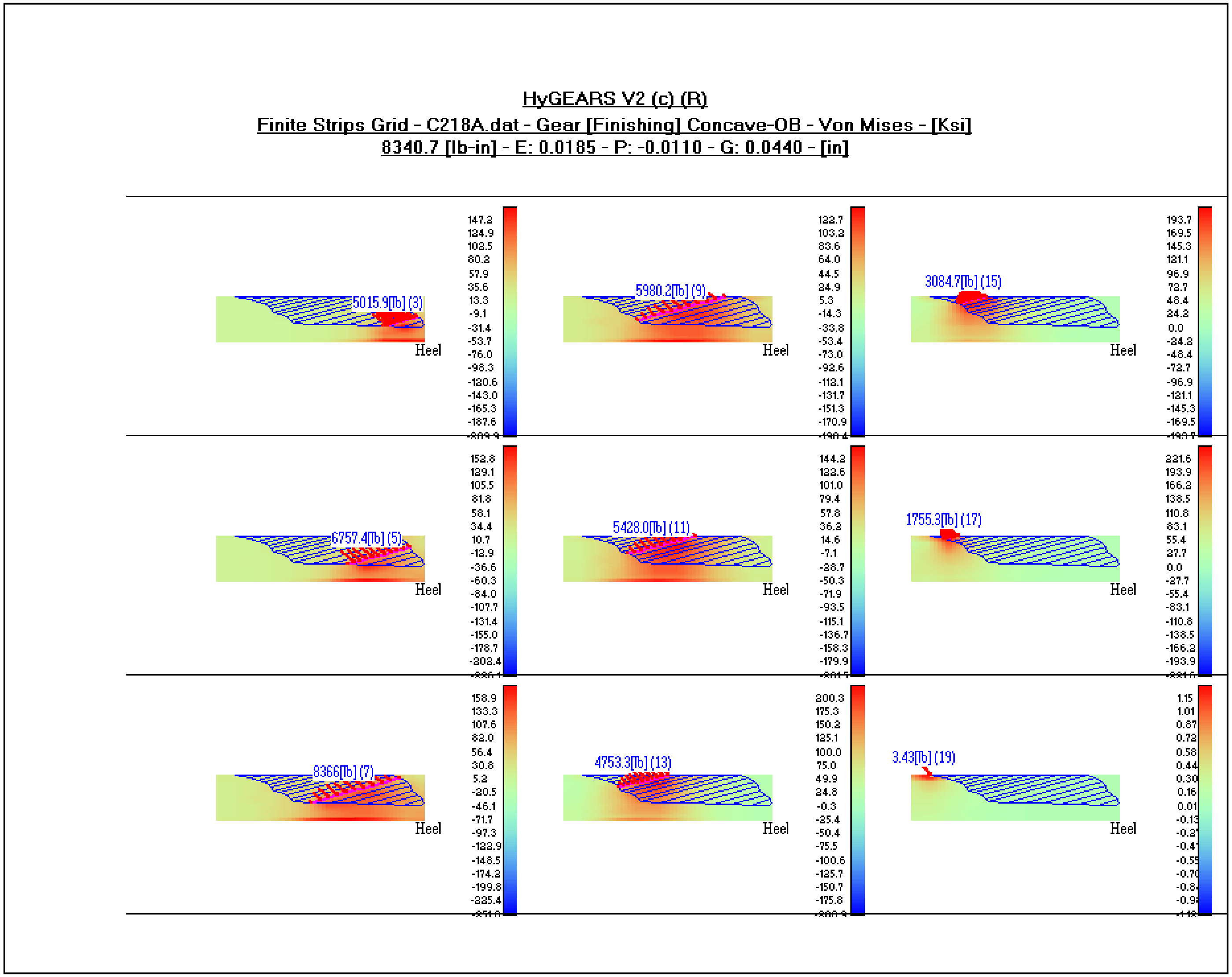
# Addendum 3: Case Analysis – FH Example

Worst Case Scenario: Pinion fillet stresses



# Addendum 3: Case Analysis – FH Example

Worst Case Scenario: Gear fillet stresses



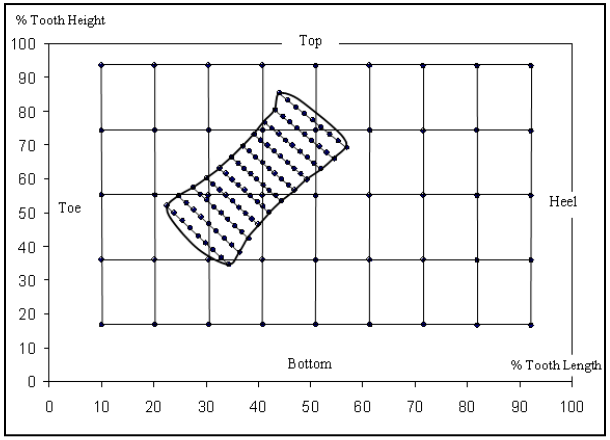
# Addendum 4: Lapping Prediction

Abrasive rate of wear is proportional to:

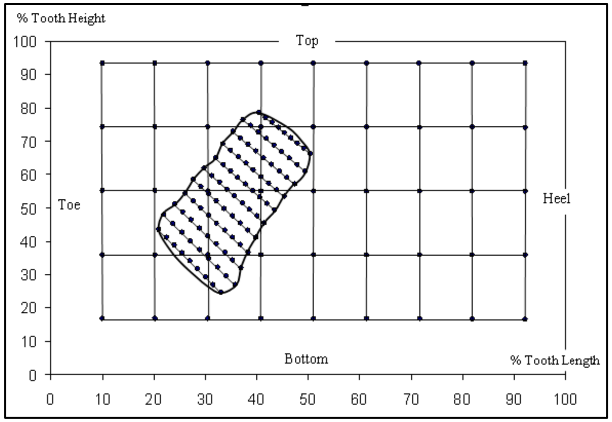
- L  Sliding distance
- W Load
- H  Hardness

$$\boxed{V_m = k\,\frac{W\,L}{H}}$$

Calculated CP before lapping




After lapping



# Addendum 4: Lapping Prediction / 2

Experimental wear coefficients 11x41:

Table 3. Calculated wear coefficients using the error surface in the contact pattern.

| Gear Set | $h_c^p\ (\mu m)$ | $h_c^g\ (\mu m)$ | $k_{bi}^p$ | $k_{bi}^g$ | $k_{ai}^p$ | $k_{ai}^g$ | $k_.$ |
|---|---|---|---|---|---|---|---|
| P1G1 | 17.4 | 9.7 | 0.901 | 0.940 | 0.997 | 1.025 | 0.967 |
| P2G2 | 15.6 | 8.8 | 0.896 | 0.908 | 1.033 | 0.998 | 0.959 |

Table 4. Calculated wear coefficients neglecting the error surface in the contact pattern.

| Gear Set | $h_c^p\ (\mu m)$ | $h_c^g\ (\mu m)$ | $k_{bi}^p$ | $k_{bi}^g$ | $k_{ai}^p$ | $k_{ai}^g$ | $k_.$ |
|---|---|---|---|---|---|---|---|
| P1G1 | 17.4 | 9.7 | 0.912 | 0.967 | 0.912 | 0.967 | 0.939 |
| P2G2 | 15.6 | 8.8 | 0.898 | 0.909 | 0.898 | 0.909 | 0.903 |

# Addendum 4: Lapping Prediction / 3

Experimental wear coefficients 12x41:

**Table 5. Lapping parameters used for wear coefficient determination - 12x41 gear set.**

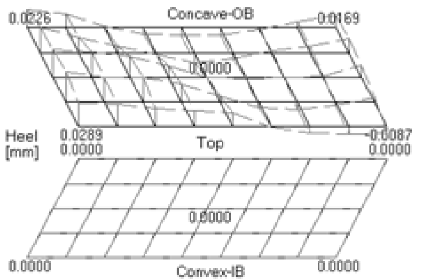
| Torque \ RPM | 1500 RPM | 2000 RPM | 2500 RPM |
|---|---|---|---|
| 5 N-m | Gear set A | Gear set B | Gear set C |
| 10 N-m | Gear set D | Gear set E | Gear set F |

**Table 6. Calculated wear coefficients for gear sets A B C D E F.**

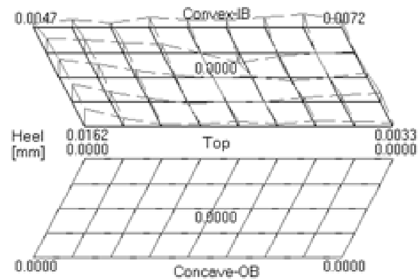
| Gear Set | Reference | *k* | | |
|---|---|---|---|---|
| | | Pinion | Gear | Average |
| **PA-GA** | Before lapping | 0.877 | 0.722 | 0.801 |
| | After lapping | 1.066 | 1.037 | 1.053 |
| | Average | | | *0.930* |
| **PB-GB** | Before lapping | 0.804 | 1.260 | 1.039 |
| | After lapping | 1.155 | 1.404 | 1.273 |
| | Average | | | *1.183* |
| **PC-GC** | Before lapping | 0.871 | 0.823 | 0.846 |
| | After lapping | 1.153 | 1.134 | 1.143 |
| | Average | | | *1.018* |
| **PD-GD** | Before lapping | 0.721 | 0.683 | 0.702 |
| | After lapping | 0.919 | 0.947 | 0.933 |
| | Average | | | *0.843* |
| **PE-GE** | Before lapping | 0.925 | 0.735 | 0.826 |
| | After lapping | 1.266 | 1.129 | 1.197 |
| | Average | | | *1.052* |
| **PF-GF** | Before lapping | 0.716 | 0.746 | 0.732 |
| | After lapping | 1.186 | 1.274 | 1.230 |
| | Average | | | *0.949* |
| **Average A to F** | | | | ***0.996*** |
| **Average A, B, C, E, F** | | | | ***1.026*** |

# Addendum 4: Lapping Prediction / 4

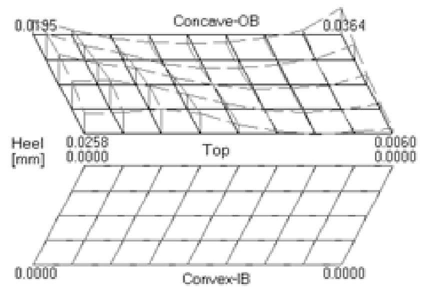
## Prediction and measured …



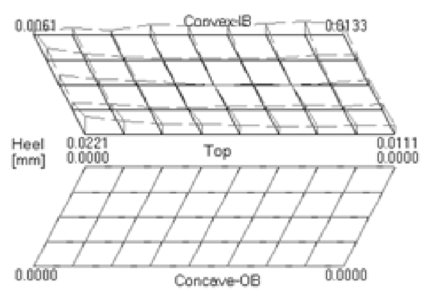
(a) Predicted rror surface after lapping



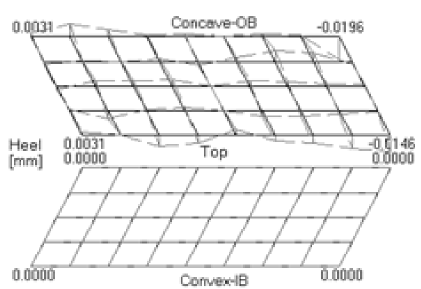
(a) Predicted error surface after lapping



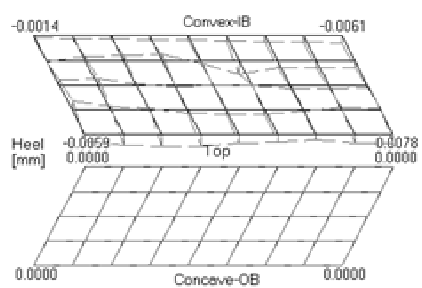
(b) Measured error surface after lapping



(b) Measured error surface after lapping



(c) Difference between (a) and (b)

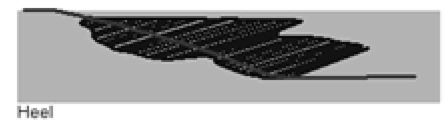


(c) Difference between (a) and (b)

Figure 6.: Predicted and measured error surface - Pinion P3

Figure 7.: Predicted and measured error surface – Gear G3

(a) Contact pattern using pre-lap measurement



(b) Contact pattern using lapping prediction

(c) Contact pattern using post-lap measurement

# 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 machine settings for all HyGEARS supported geometries are calculated and a Summary is created;*

3. *Geometries can be* ***imported from Gleason SPA and KIMoS ND*** *files;*

4. *Spiral bevel cutting processes such as Face Milling and Face Hobbing are* ***integral to HyGEARS****;*

5. *Geometries 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 the many other softwares);*

8. *Part program generation is* ***based on 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 and Fanuc;*

10. *Part programs can be in* ***Machine coordinates, Work piece coordinates*** *with axis angles, or Work piece coordinates with tool axis vector (****Traori, TCPM*** *and* ***TCP****);*

# Summary

11. *Users can **define their own tool box** for Face Mill, CoSIMT, End Mill and Ball Mill tools;*
12. *Cutting Cycles include **Slot by Slot** and **Flank by Flank**, both for tooth flank and fillet; 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;*
15. ***Toe and Heel clearances** allow smooth tool entry and exit;*
16. ***"Stock" allowance** is available for roughing and finishing;*
17. *A **"Roughing mode"** moves the selected tool in the center of the gap to quickly remove as much material as possible;*
18. ***"Operations"**, including all user selections for a given task, may be saved for later re-use;*
19. ***Closed Loop**, also called Corrective Machine Settings, is **integral to HyGEARS** and allows the seamless manufacture of gears to the required tolerances.*