CnC 5Axis Manufacturing of Gears

using

HyGEARS ™ V 4.0

An Overview

Involute Simulation Softwares Inc., Québec, Canada

October 2014

Contents

Introduction

Since its introduction in 1994, HyGEARS has been in constant evolution.

HyGEARS V 4.0 now covers ***all major gear types found in the gear industry****. Its vector simulation model has been extensively tested and confirmed over the years.*

And, notably, a ***5Axis CnC Post-Processor*** *generates, from the* ***exact tooth definition*** *without any interpolation, the part programs to manufacture* ***every gear type*** *of the simulation model on* ***any 5Axis CnC machine*** *available on the market.*

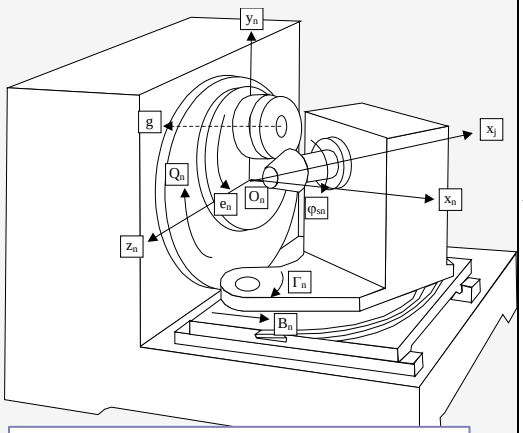
In one single stand alone software, HyGEARS allows users:

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

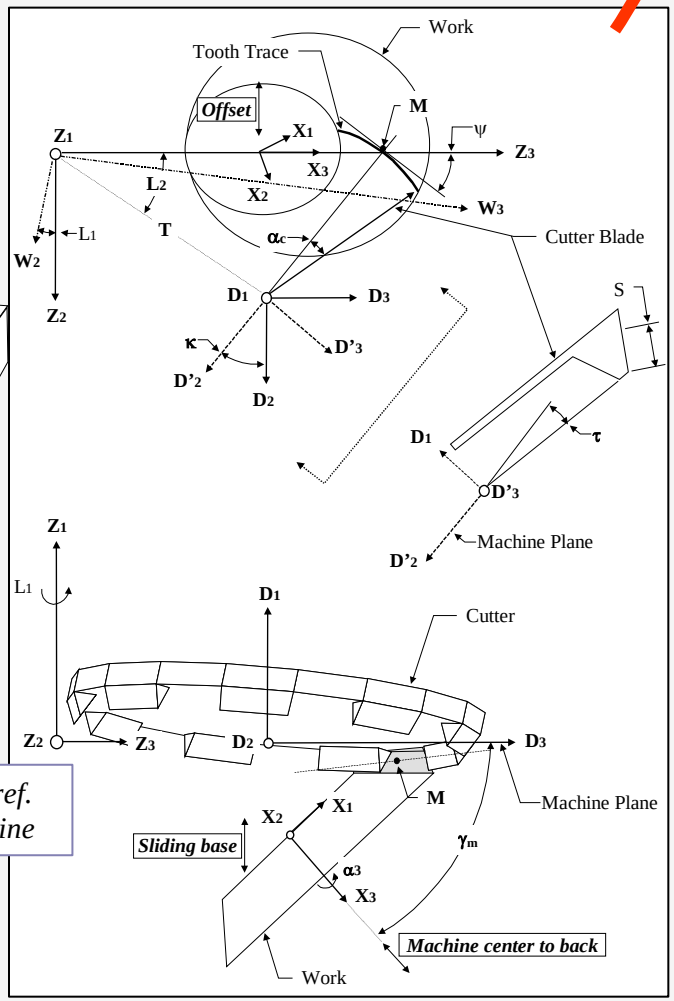
Read on for a brief overview of HyGEARS.

HyGEARS is built on Vector Simulation

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

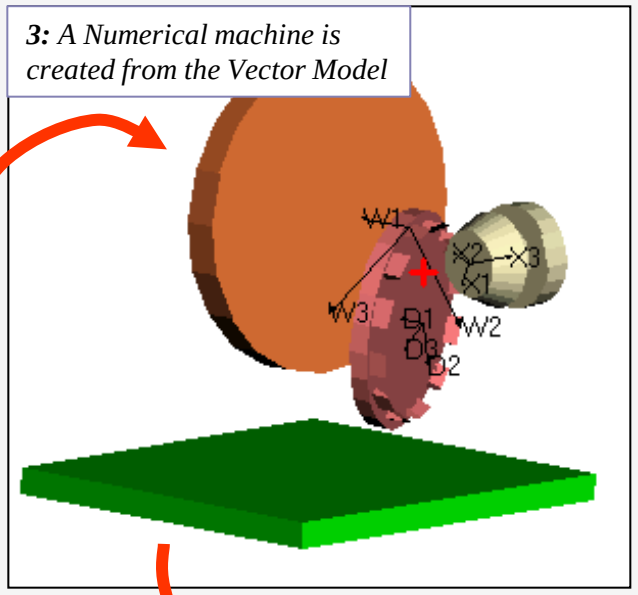


***1:** The reference machine is discretized in a series of ref. frames*

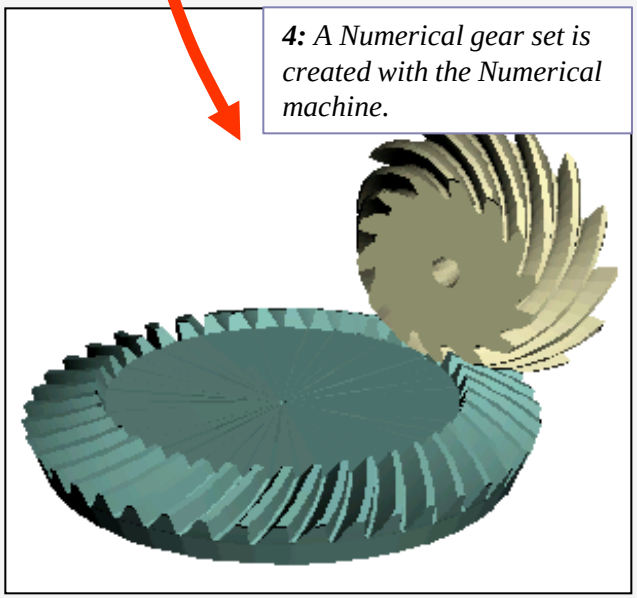


***2:** The Vector Model uses the ref. frames of the discretized machine*

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



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



HyGEARS The Vector Model

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

Point on tooth flank:

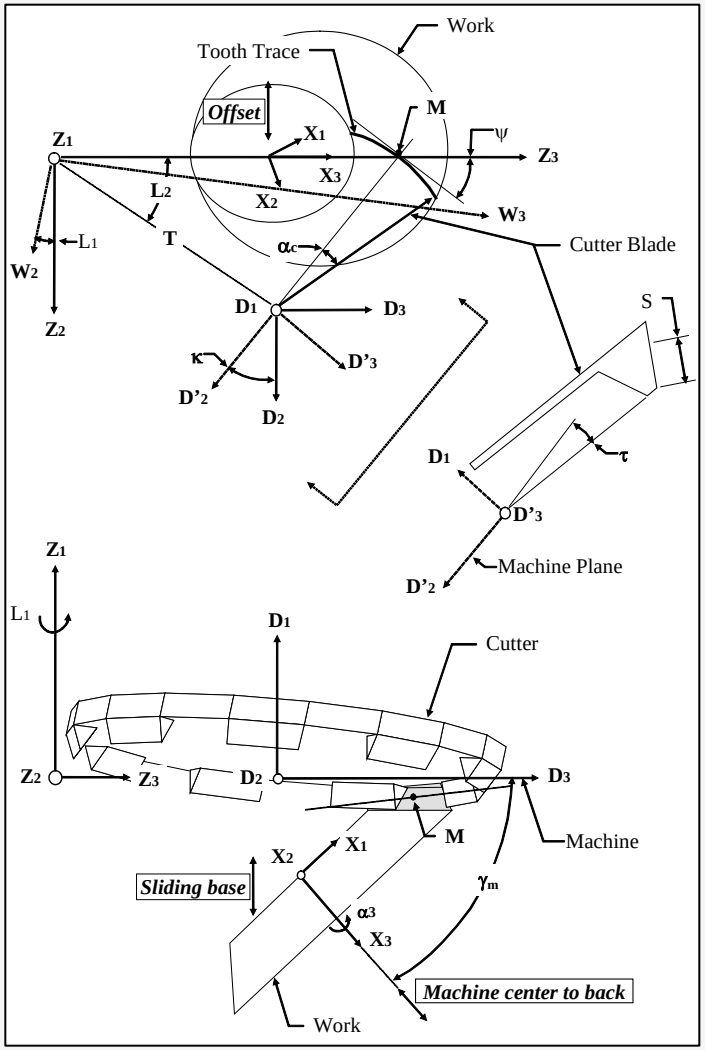
$$D=\begin{bmatrix}1 & 0 & 0\\ 0 & \cos(\alpha c) & \sin(\alpha c)\\ 0 & -\sin(\alpha c) & \cos(\alpha c)\end{bmatrix}\begin{bmatrix}S\cos(\phi)\\ 0\\ (R\pm S\sin(\phi))\end{bmatrix}$$

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

Normal on tooth flank:

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

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



HyGEARS The Vector Model

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

Example 1) Modified Roll higher order change:

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

where:

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

Example 2) Helical Motion higher order change:

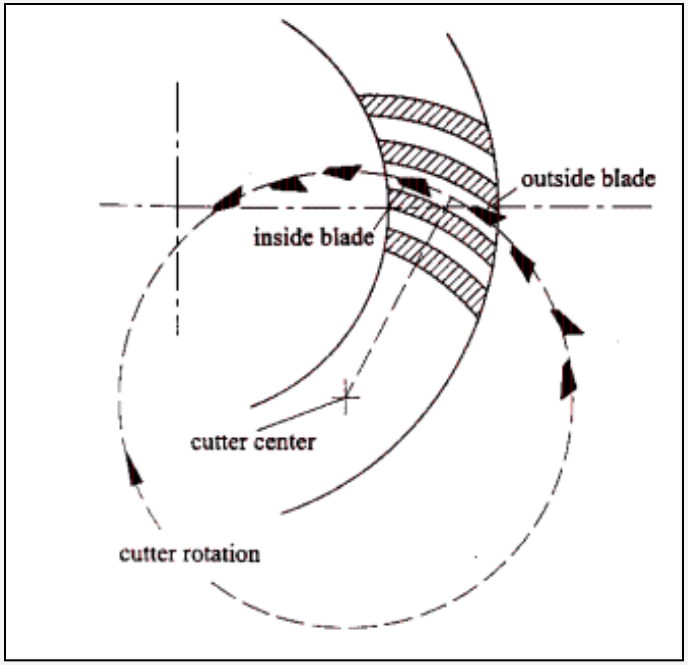
$$X_{bm} = X_b + 1_{st}(C_r - \alpha_3 R_r) + 2_{nd}(C_r - \alpha_3 R_r)^2 + 3_{rd}(C_r - \alpha_3 R_r)^3 + 4_{th}(C_r - \alpha_3 R_r)^4 + 5_{th}(C_r - \alpha_3 R_r)^5 + 6_{th}(C_r - \alpha_3 R_r)^6$$

where:

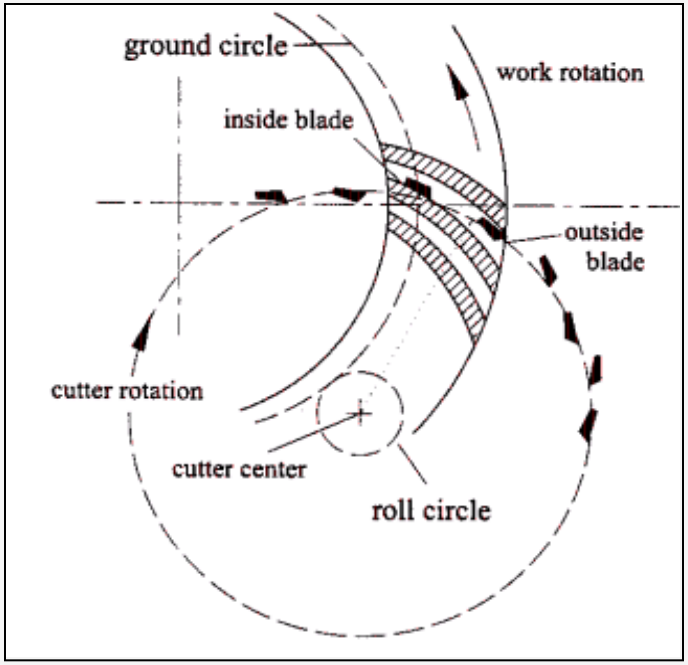
X_{bm}:	modified sliding base
α_3:	work piece roll angle
R_r:	ratio of roll, cradle to work piece
C_r:	cradle ref. position
1st :	1st Order parameter
2nd :	2nd Order parameter
3rd :	3rd Order parameter
4th :	4th Order parameter
5th :	5th Order parameter
6th :	6th Order parameter

HyGEARS – Face Milling and Face Hobbing

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



Face Milling (single indexing)



Face Hobbing (continuous indexing)

HyGEARS – Calibration

Over the years, HyGEARS has been extensively calibrated against Gleason's and Klingelnberg's TCA for Contact Pattern and Transmission Error, CMM output, Corrective Machine Settings (Closed Loop), LTCA Contact Stresses, etc.

Some important milestones:

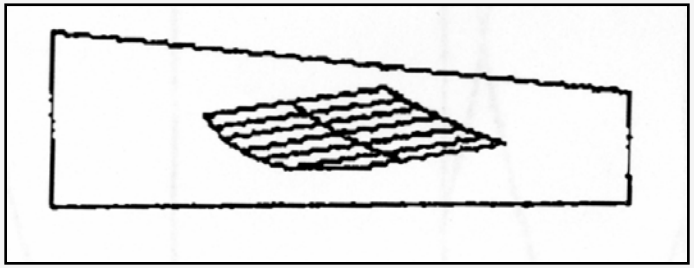
1993-1994:	*Machine Calibration (Gleason and Yutaka machines)*
1994:	*Closed Loop 1st Order*
1995:	*Closed Loop 2nd Order*
1996:	*Experimental TE*
1997:	*Experimental LTCA*
1998:	*Fillet Stress (against FEA)*
2001:	*Contact Stress (against Gleason)*
2004:	*Bending and Contact Stress – Face Hobbing –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

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

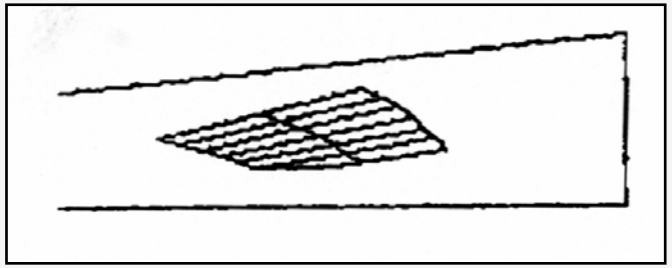
HyGEARS – Calibration

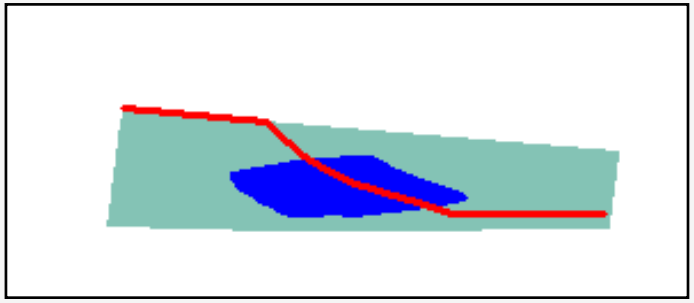
13x24 Face Milled Spiral Bevel gear set: Contact Patterns

Drive Side *Coast Side*

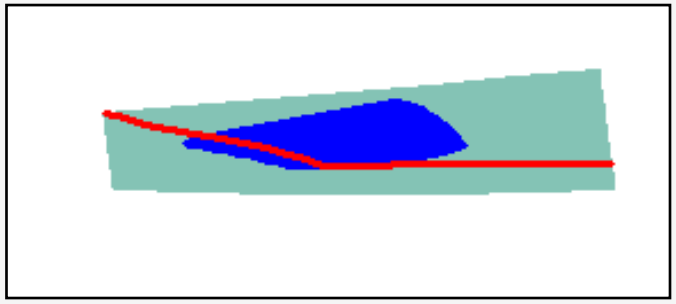


Gleason





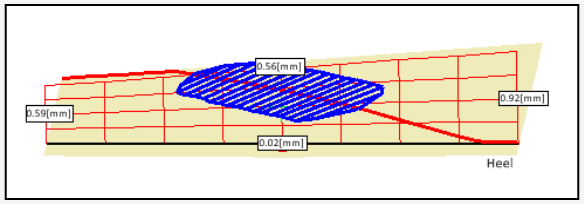
HyGEARS

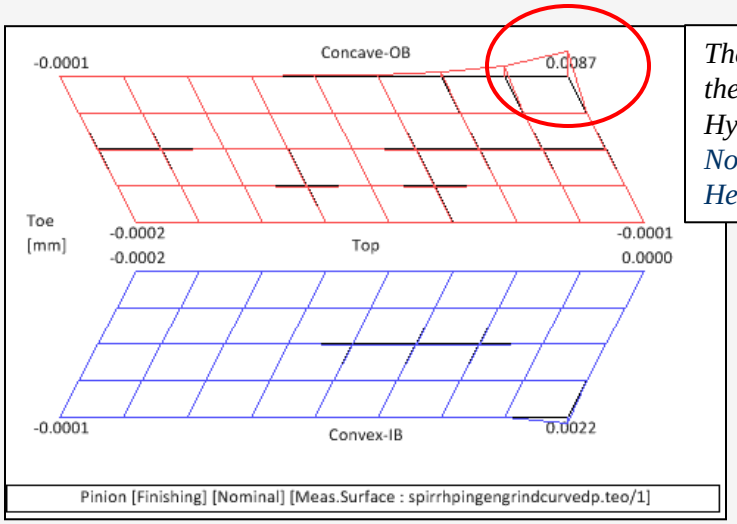


HyGEARS – Calibration

8x39 Face Milled Spiral Bevel gear set: HyGEARS vs Gleason and KIMoS Nominals

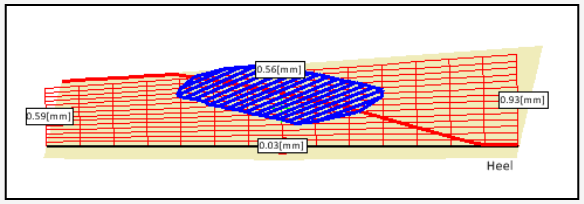
HyGEARS vs. Gleason Nominal

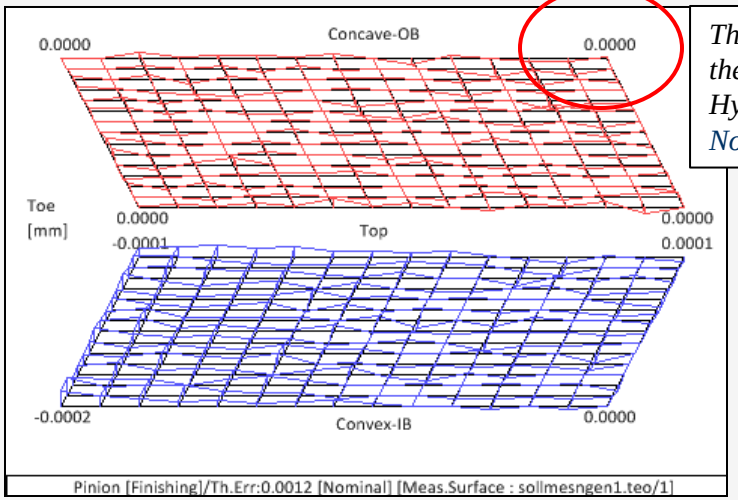




The colored lines are the Gleason nominal; HyGEARS is in black
Note the deviation at Heel-OB

HyGEARS vs. KIMoS Nominal



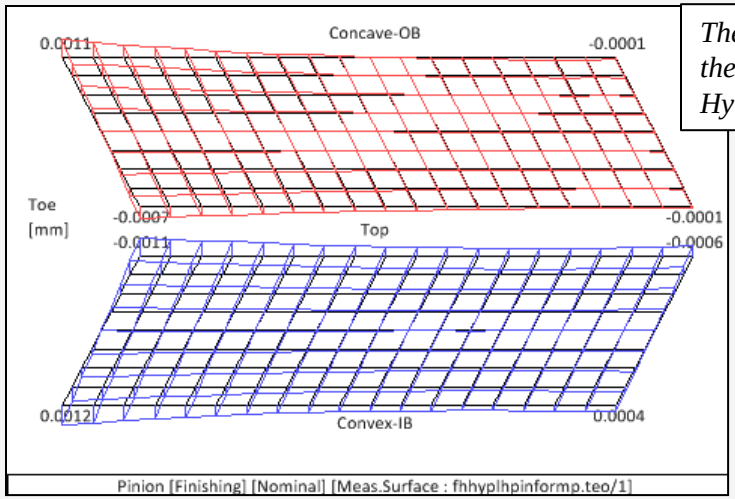


The colored lines are the KIMoS nominal; HyGEARS is in black
No deviation here !

HyGEARS – Calibration

8x39 Face Hobbed Hypoid gear set: HyGEARS vs Gleason and KIMoS Nominals

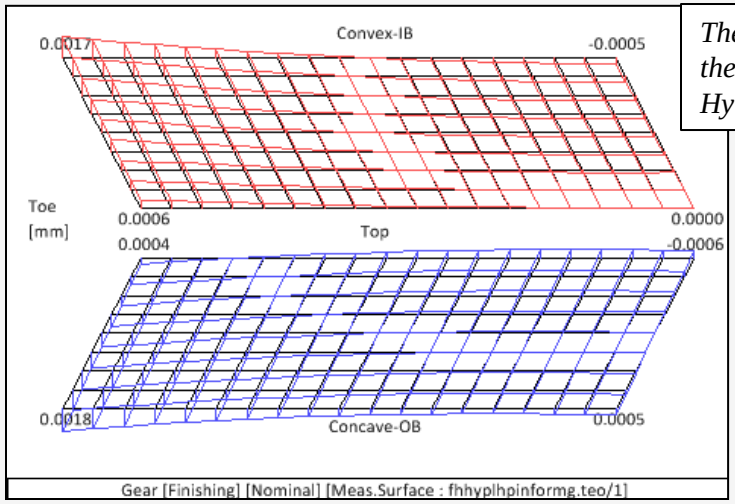
HyGEARS vs. Gleason - Pinion



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

Typical differences are less than 1 µm

HyGEARS vs. Gleason - Gear

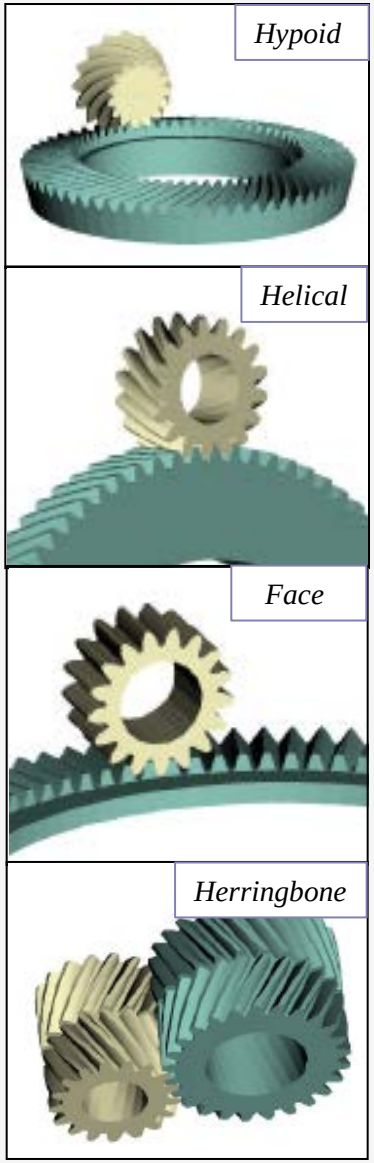


The colored lines are the Gleason nominal; HyGEARS is in black.

HyGEARS – Supported Gear Types

The most popular gear types are supported by HyGEARS.
All can be cut on any 5Axis CnC machines !

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



The HyGEARS 5 Axis CnC Post-Processor

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.

The HyGEARS 5 Axis CnC Post-Processor

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

- *supports "AB", "AC", "BA" and "BC" architecture machines;*
- *supports GCodes, Heidenhain, Siemens and Fanuc controllers;*
- *supports Traori (Siemens), TCPM (Heidenhain) and TCP (Fanuc);*
- *allows creation of specific 5Axis 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 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.*

The HyGEARS 5 Axis CnC Post-Processor

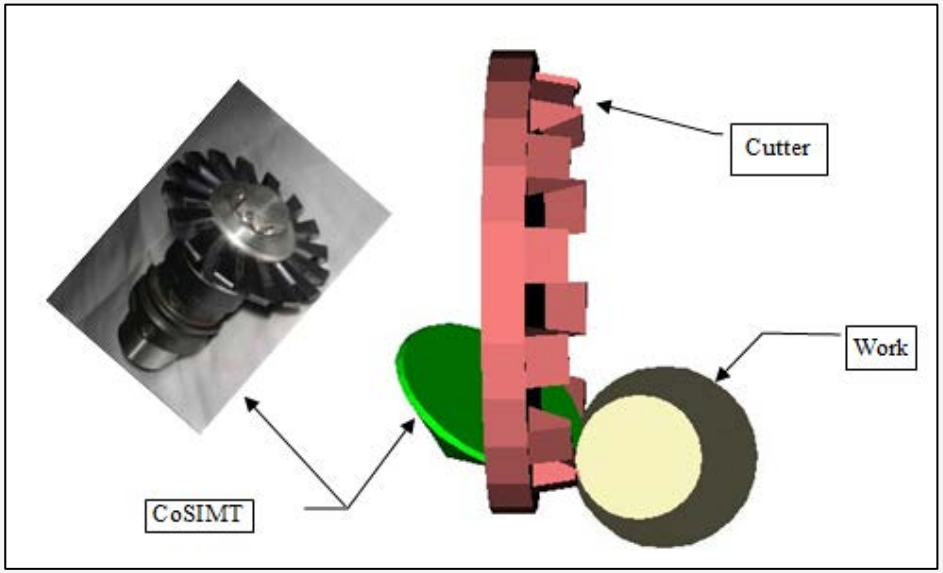
Conversion: *To generate a part program, HyGEARS converts the movements of the conventional cutter in a conventional machine into movements of a Face Mill, Coniflex™ dish, CoSIMT, End Mill or a Ball Mill tool in a 5Axis CnC machine where:*

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

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.

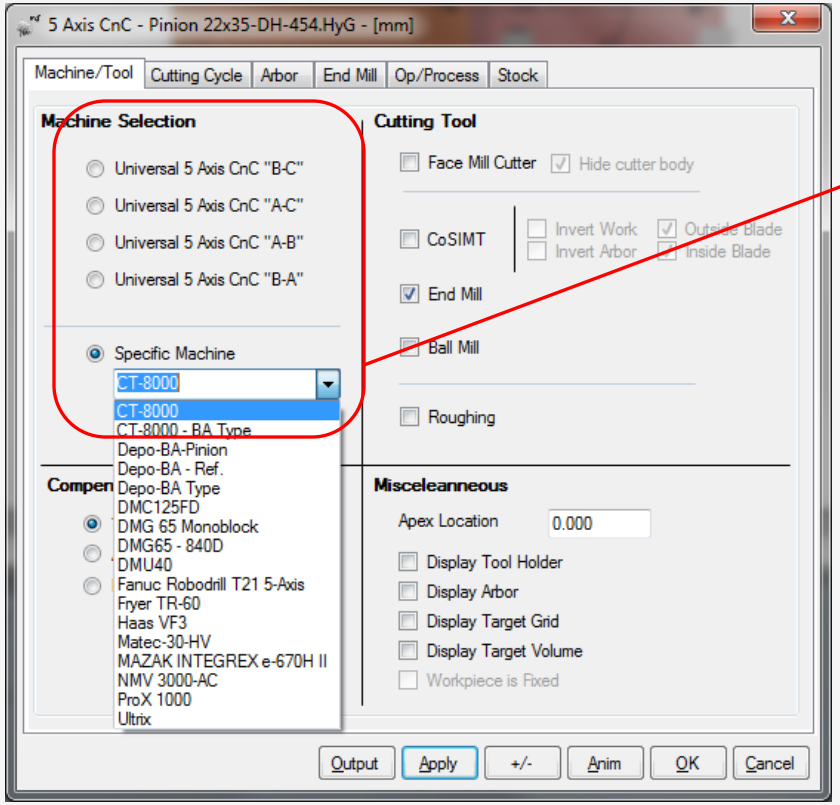
The same approach is applied to all tools and gear types.



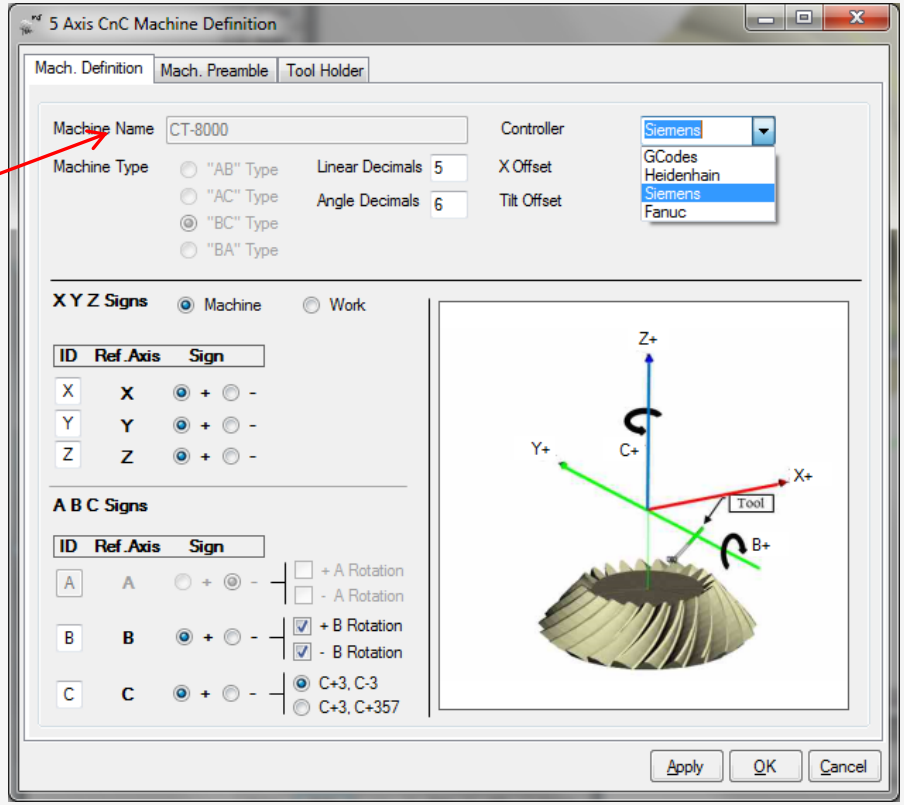
The HyGEARS 5 Axis CnC Post-Processor

***Machines**: 4 basic machines are available: BC, AC, AB and BA (bottom left figure).*

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



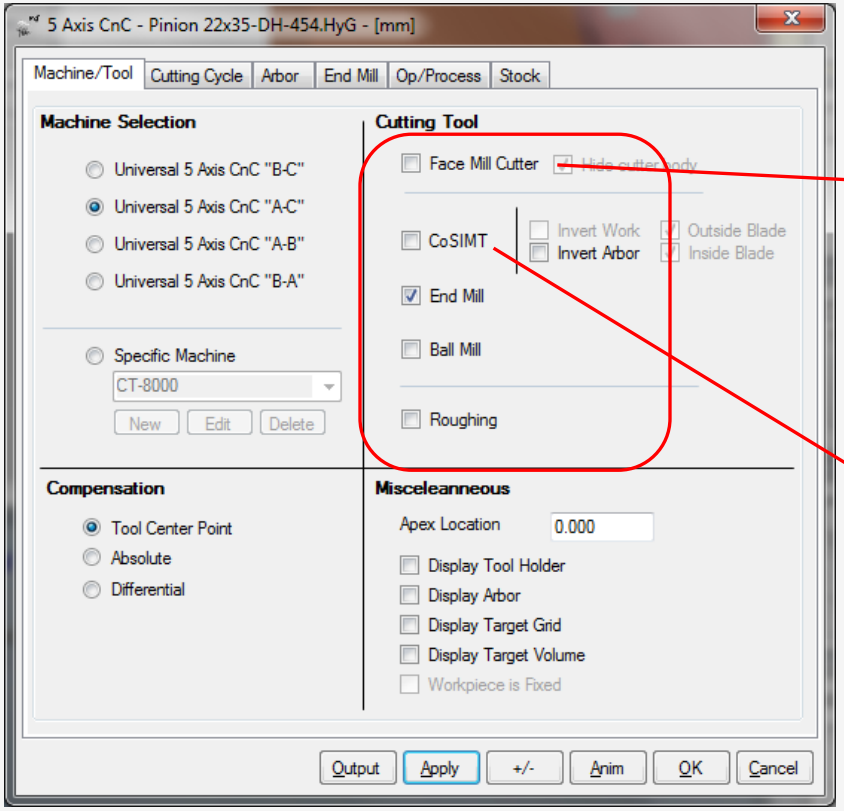
Machine Selection



Machine Editor

The HyGEARS 5 Axis CnC Post-Processor

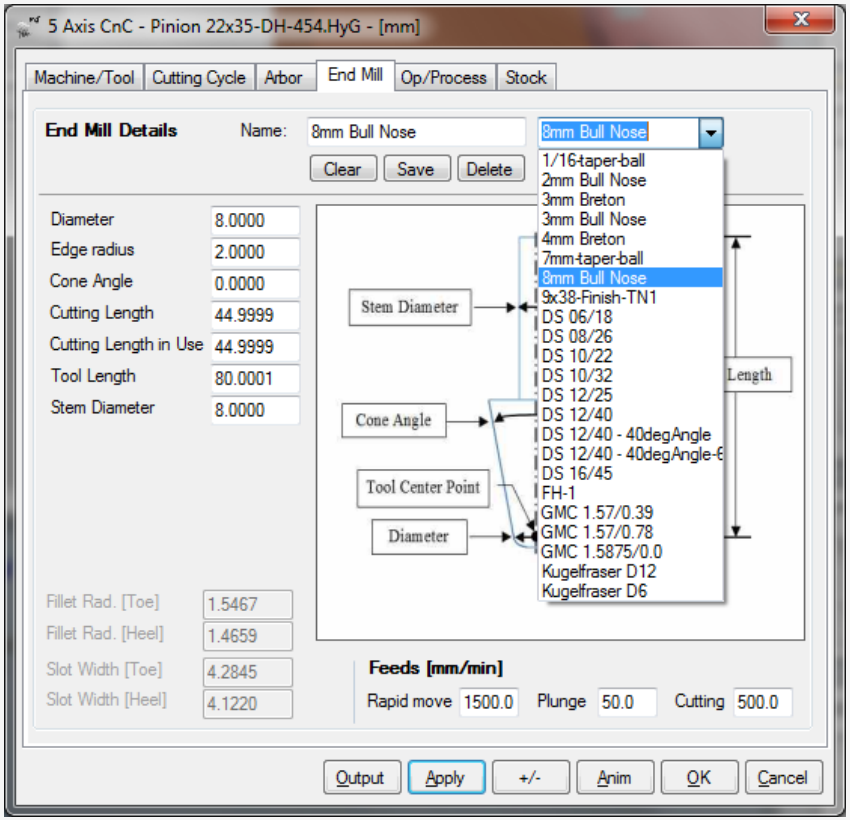
Tools: *HyGEARS offers 5 different tools:*	*Face Mill cutter*	*(for spiral bevel gears)*
	Dish cutter	*(for Coniflex™ gears)*
	CoSIMT	*(for all gear types)*
	End Mill	*(for all gear types)*
	Ball Mill	*(for all gear types)*



The HyGEARS 5 Axis CnC Post-Processor

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.*

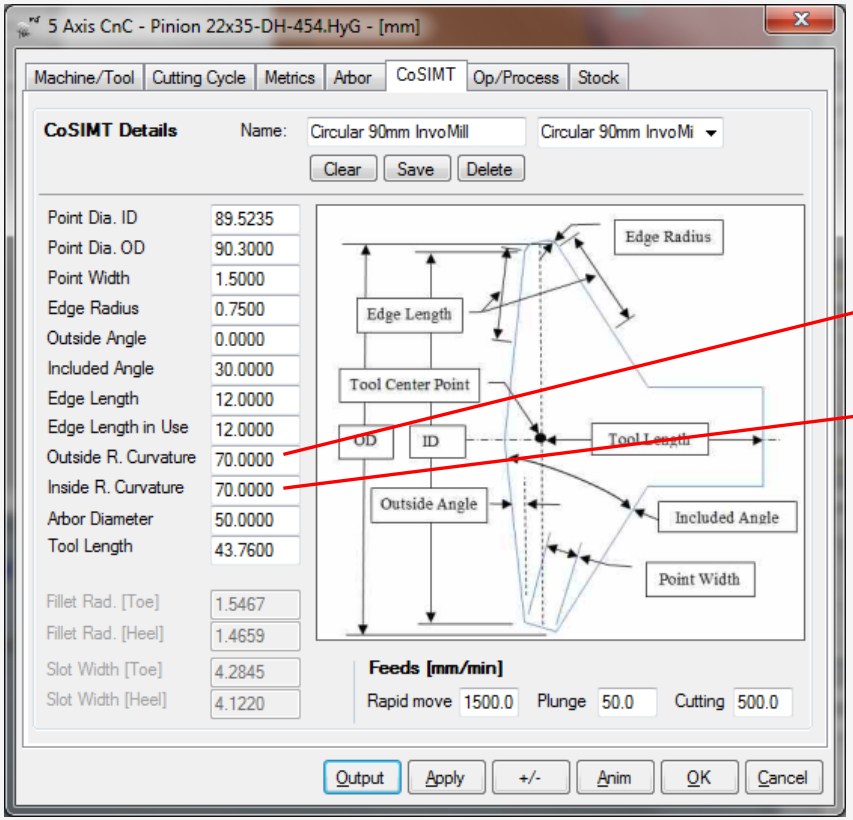
The tools can be saved for re-use and are specific to users, i.e. they are not distributed with HyGEARS. Hence, proprietary information remains proprietary.

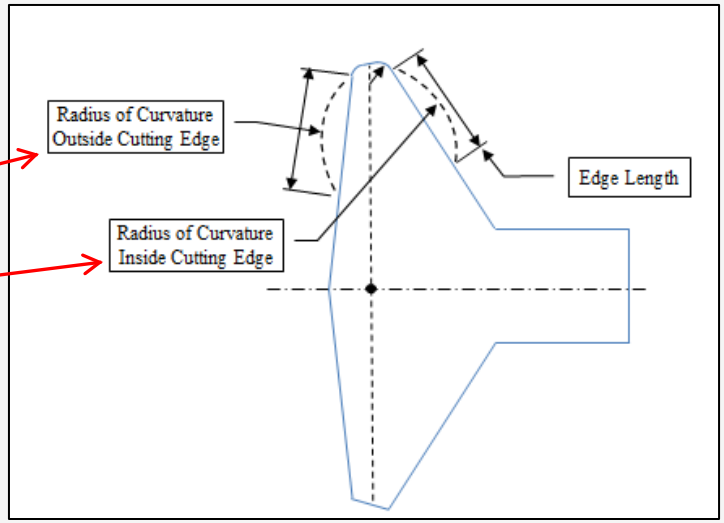


Definition of an 8mm Bull Nose

The HyGEARS 5 Axis CnC Post-Processor

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



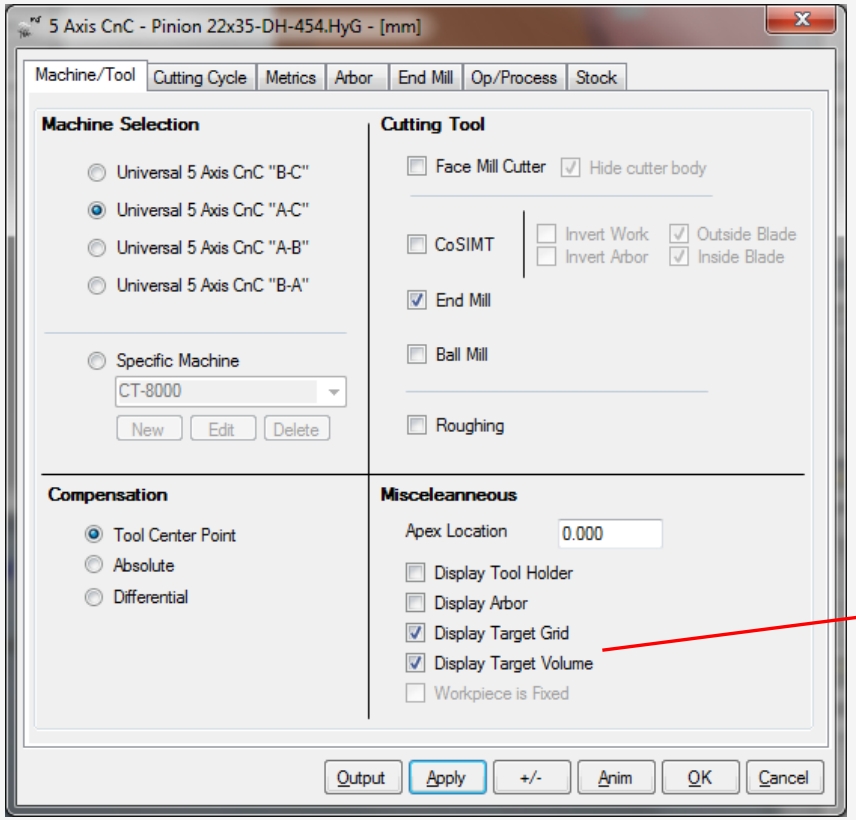


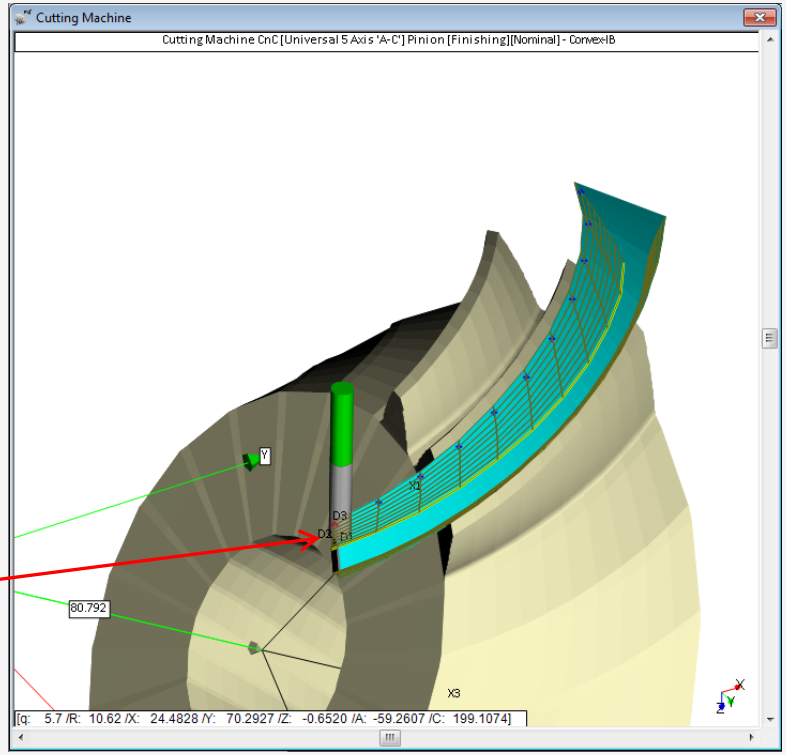
Definition of a CoSIMT

The HyGEARS 5 Axis CnC Post-Processor

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

- *the Tool Holder,*
- *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.*

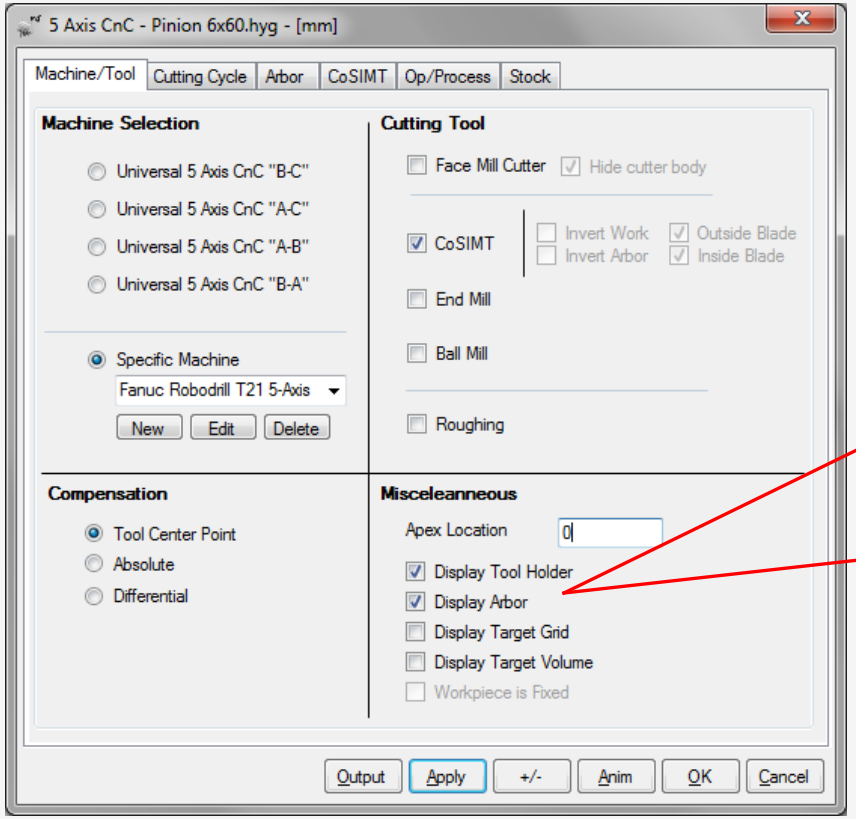


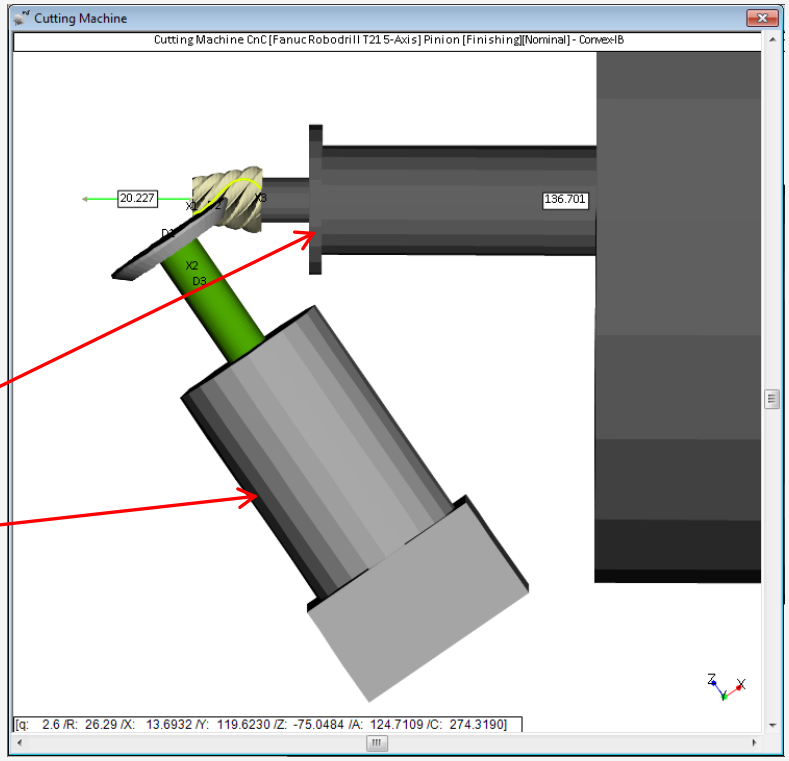


Display of the Target Grid (beige) and Volume (light blue)

The HyGEARS 5 Axis CnC Post-Processor

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

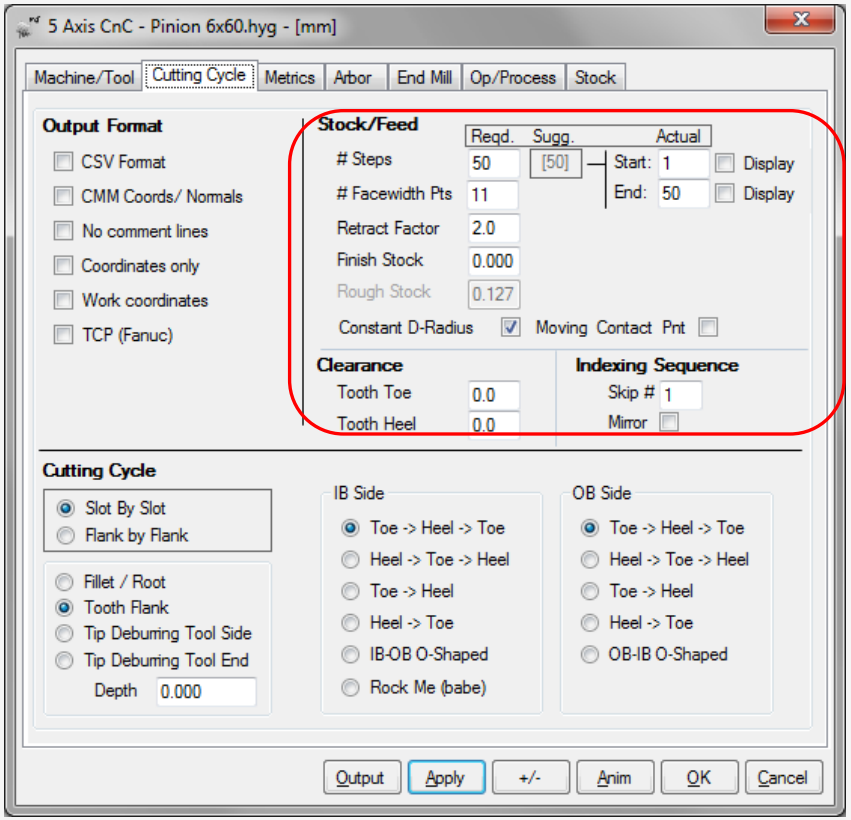




Display of the Arbor and Tool Holder

The HyGEARS 5 Axis CnC Post-Processor

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

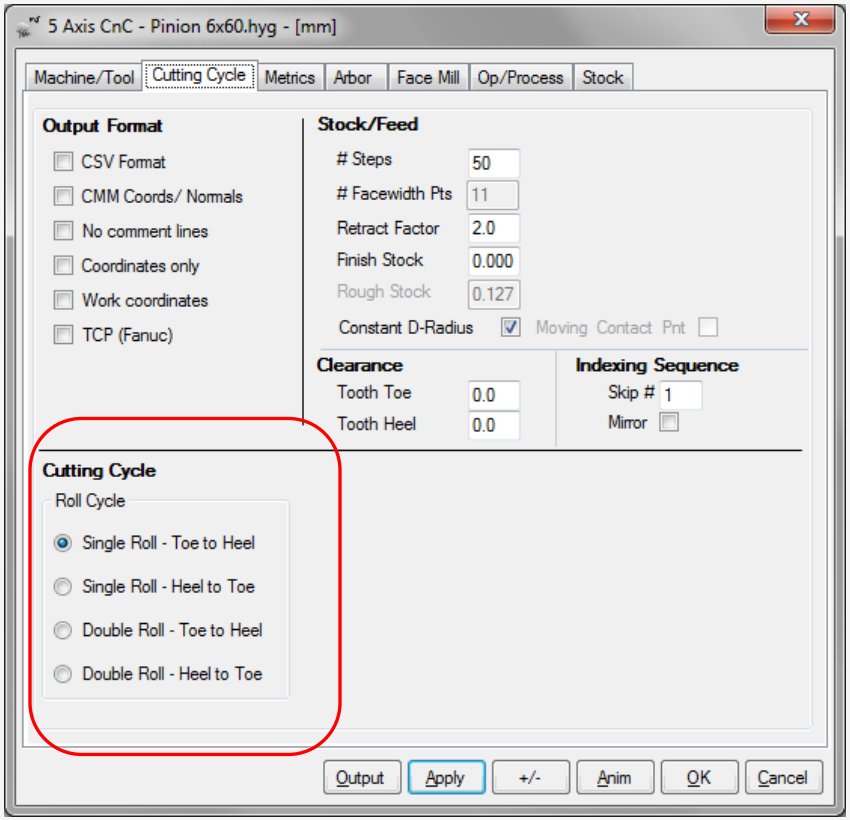


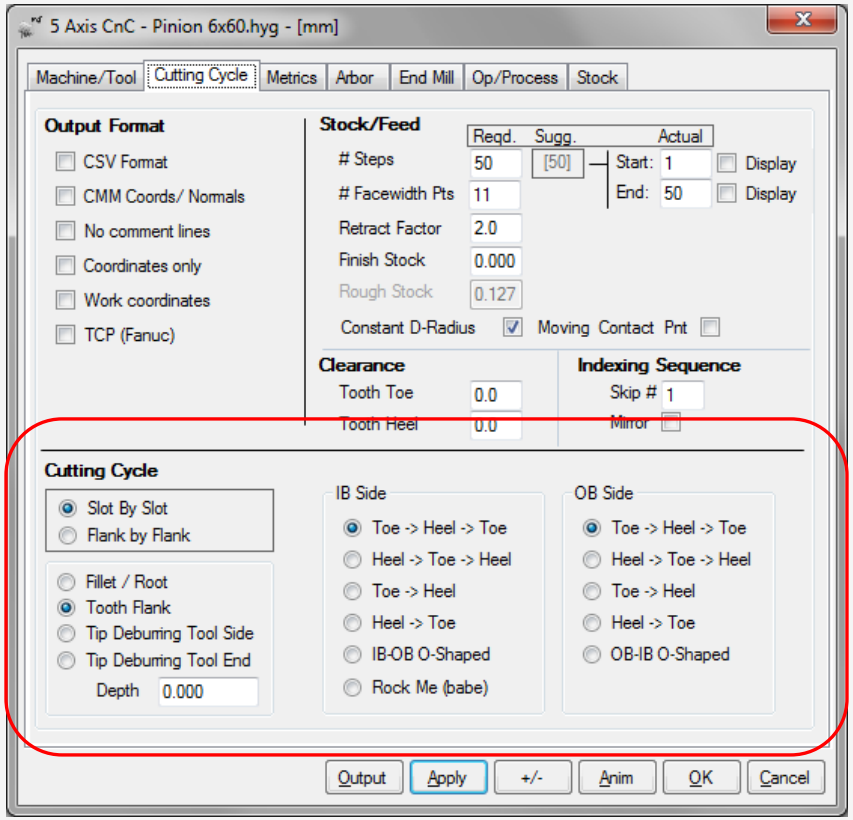
Cycle Options for CoSIMT, End Mill and Ball Mill tools

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

The HyGEARS 5 Axis CnC Post-Processor

Cycles: *HyGEARS offers up to 10 different cutting cycles for CoSIMT, End Mill and Ball Mill tools, 4 cycles for Face Mill cutters and 1 cycle for the Coniflex™ dish cutter.*



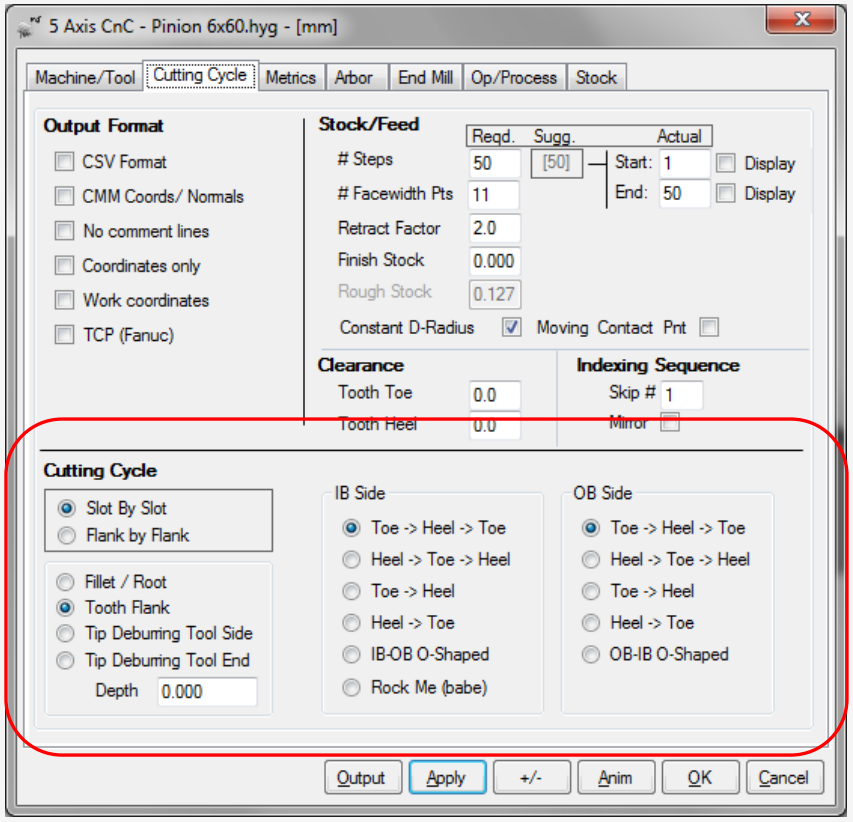


Cycles for Face Mill cutters

Cycles for CoSIMT, End Mill and Ball Mill tools

The HyGEARS 5 Axis CnC Post-Processor

Cycles: *CoSIMT, End Mill and Ball Mill tools.*

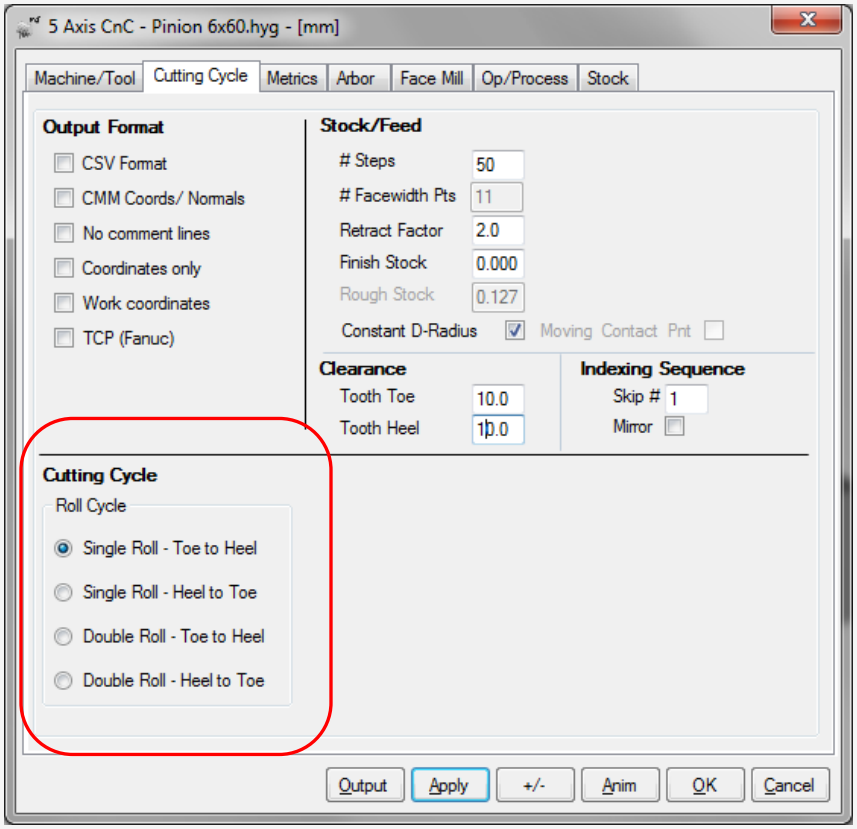


Cycles for CoSIMT, End Mill and Ball Mill tools

- *Fillet, Tooth Flank and Tip Deburring/Chamfering 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;*
- *Cutting cycles need not be the same on both tooth flanks;*

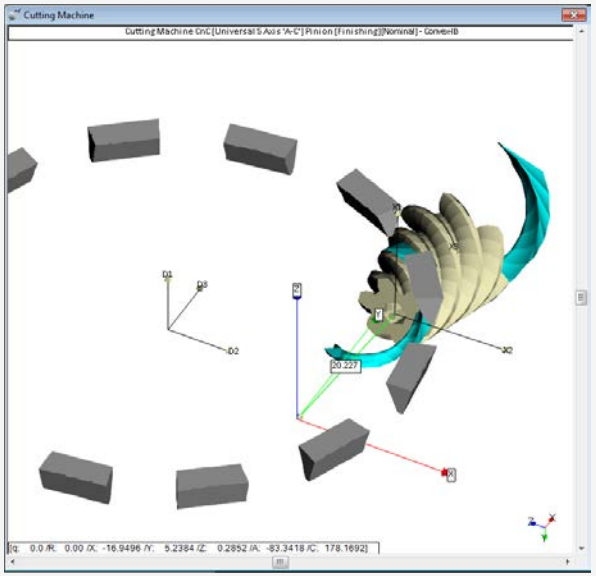
The HyGEARS 5 Axis CnC Post-Processor

Cycles: *Face Mill Cutter*



Cycles for Face Mill cutters

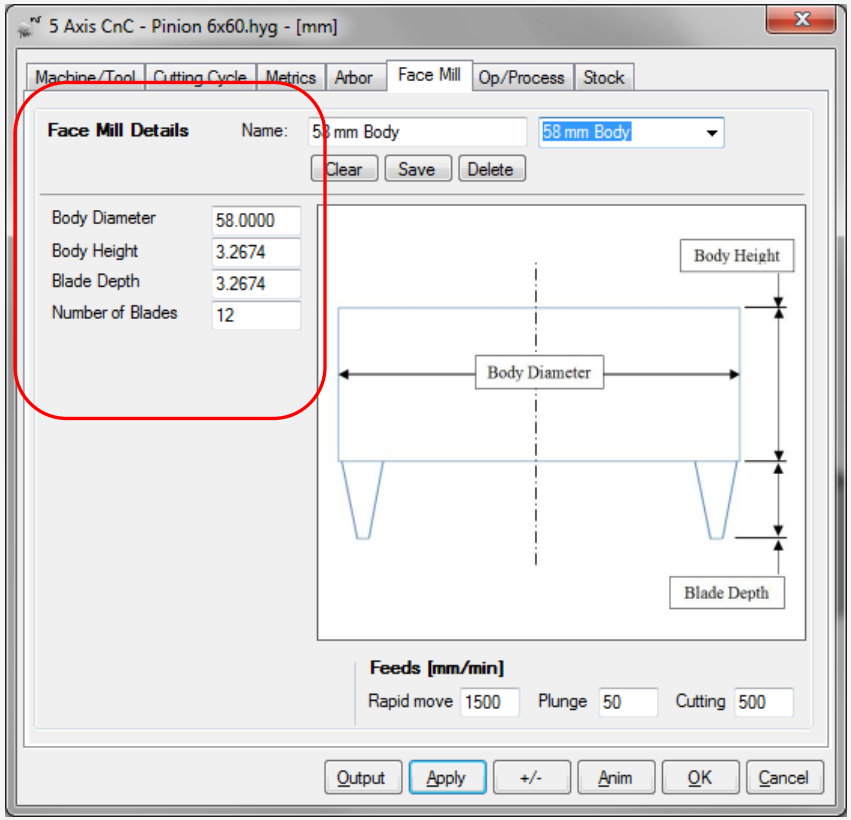
- *can be Single Roll/Double Roll;*
- *Double Roll plunges the cutter to full depth between the start and end of the 1st roll, and then generates full depth on the 2nd roll;*
- *can be Toe to Heel or Heel to Toe;*
- *the use of Toe/Heel clearances allows progressive cutter entry/retract for better tool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

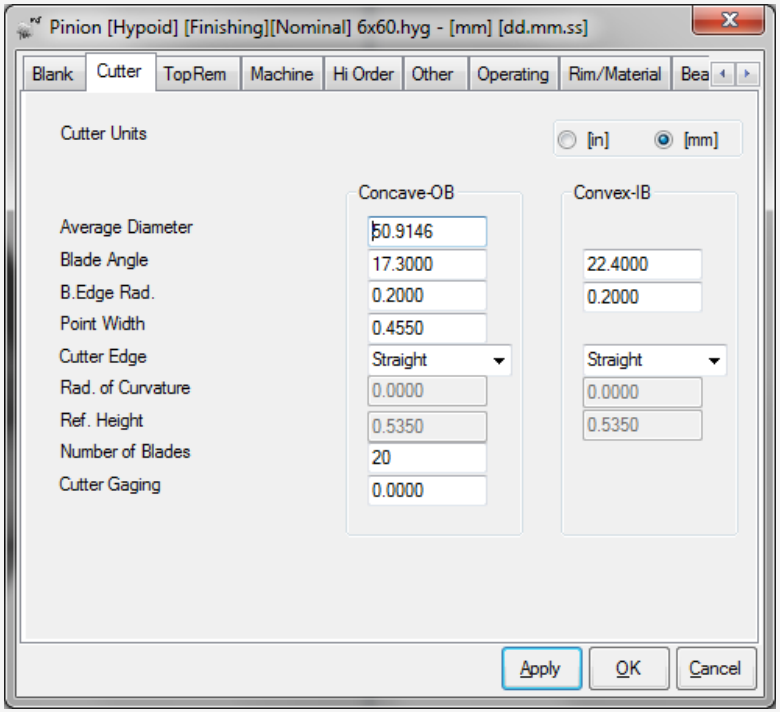


The HyGEARS 5 Axis CnC Post-Processor

Cycles: *Face Mill Cutter*

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



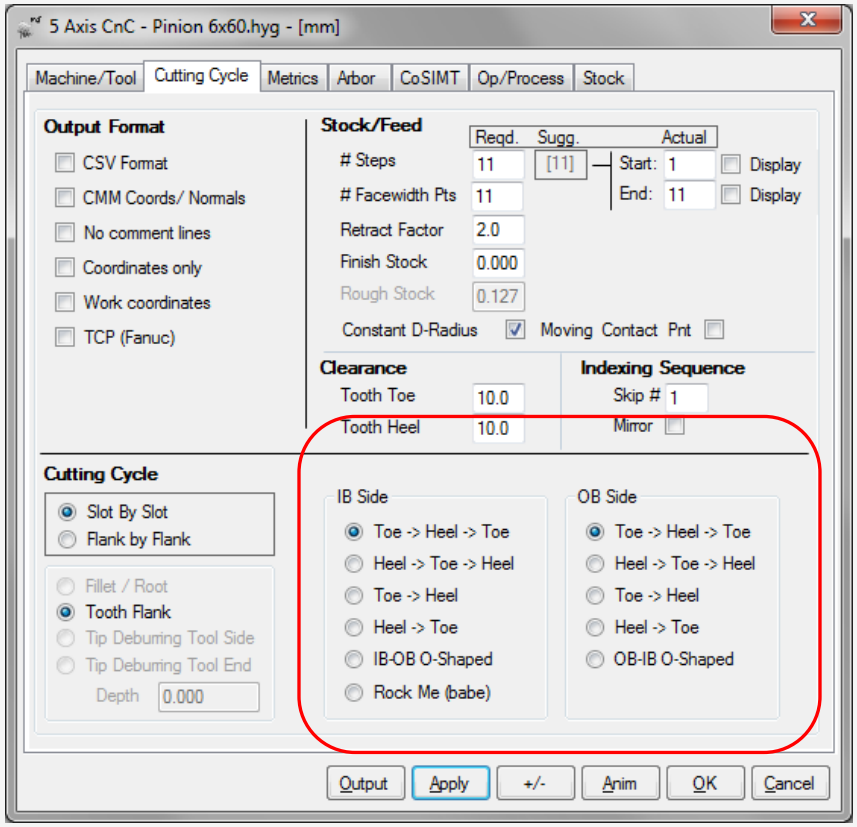


Face Mill cutter definition

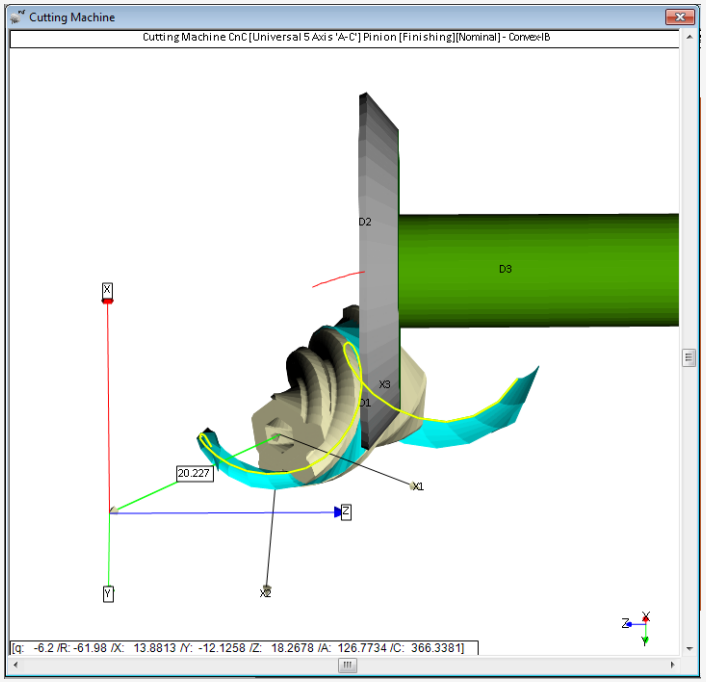
The HyGEARS 5 Axis CnC Post-Processor

Cycles: *CoSIMT, End Mill, Ball Mill*

- *CoSIMT can rough tooth flanks and fillet;*
- *CoSIMT, End Mill and Ball Mill can finish tooth flanks;*
- *Bull Nose End Mill and Ball Mill can finish the fillet, and a protuberance can be imposed in the form of negative Stock;*
- *End Mill can Deburr / Chamfer tooth Tip;*
- *Positive and Negative stock can be used.*

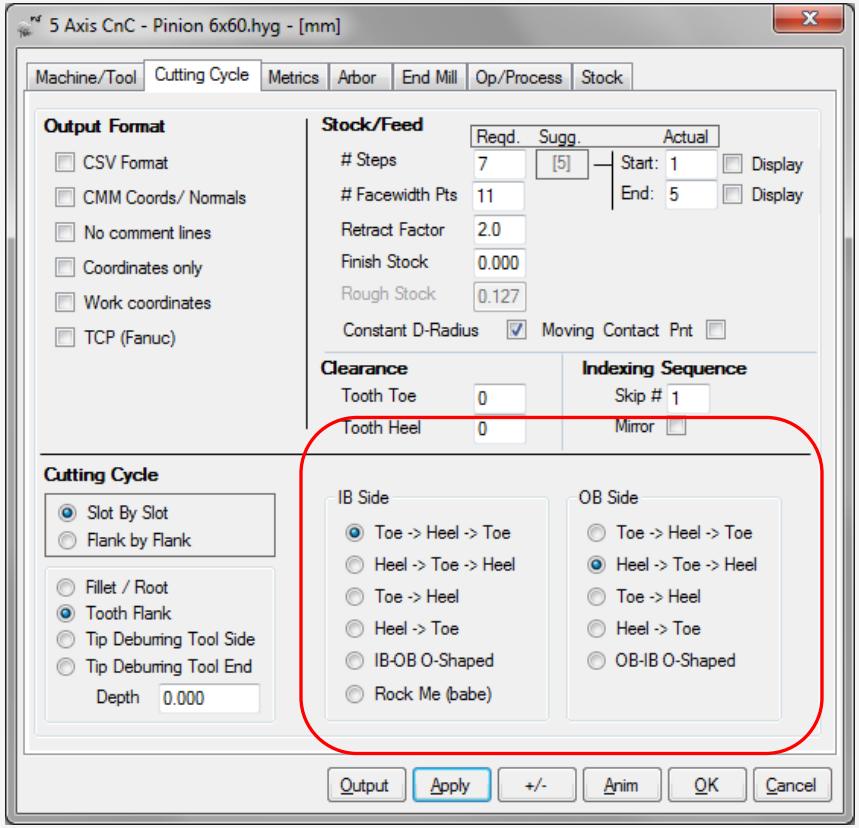


Cycles for CoSIMT, End Mill and Ball Mill tools



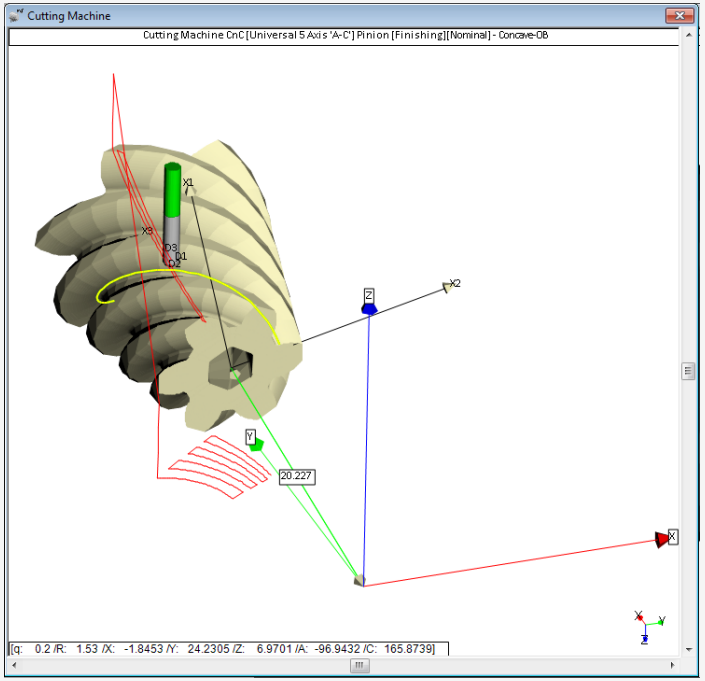
The HyGEARS 5 Axis CnC Post-Processor

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



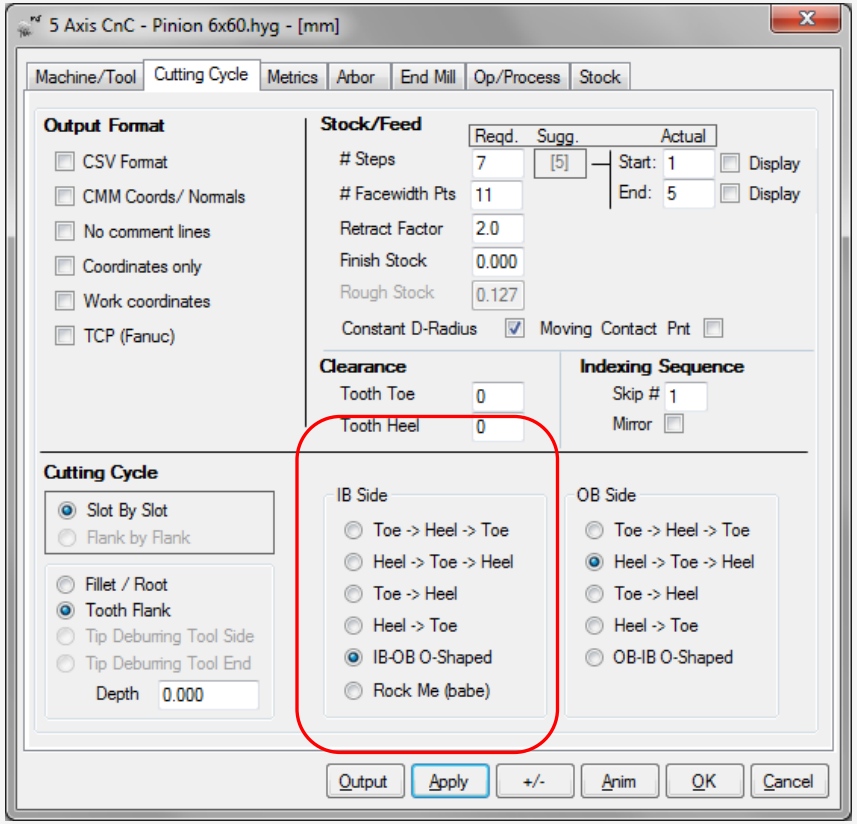
End Mill cycles

- *Cutting cycles can be different for each tooth flank (IB-OB, Left-Right);*
- *a cutting cycle starts on the IB and finishes on the OB (Left-Right flanks 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 would make sense to start the OB cycle at Heel to save cycle time (the tool path is the red line in the figure below).*



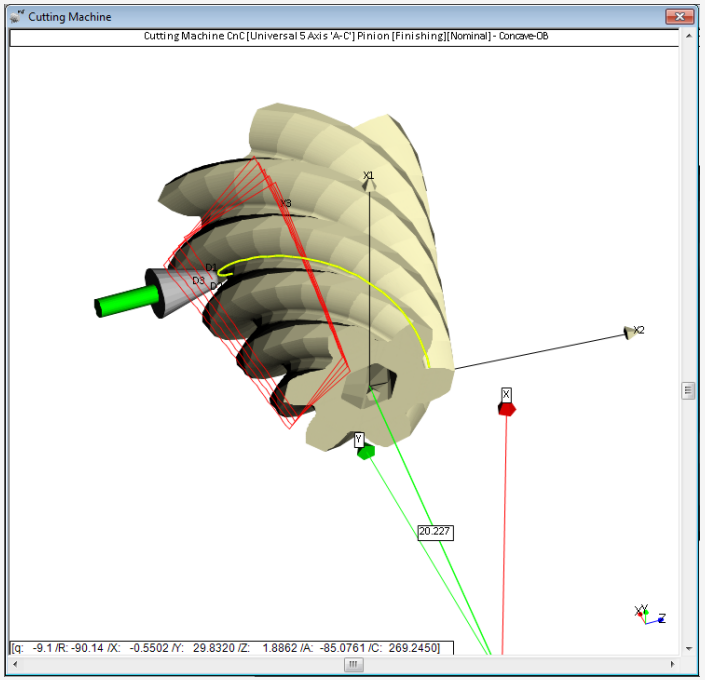
The HyGEARS 5 Axis CnC Post-Processor

Cycles: *IB-OB O-Shaped / OB-IB O-Shaped*



IB-OB O-Shaped cycle

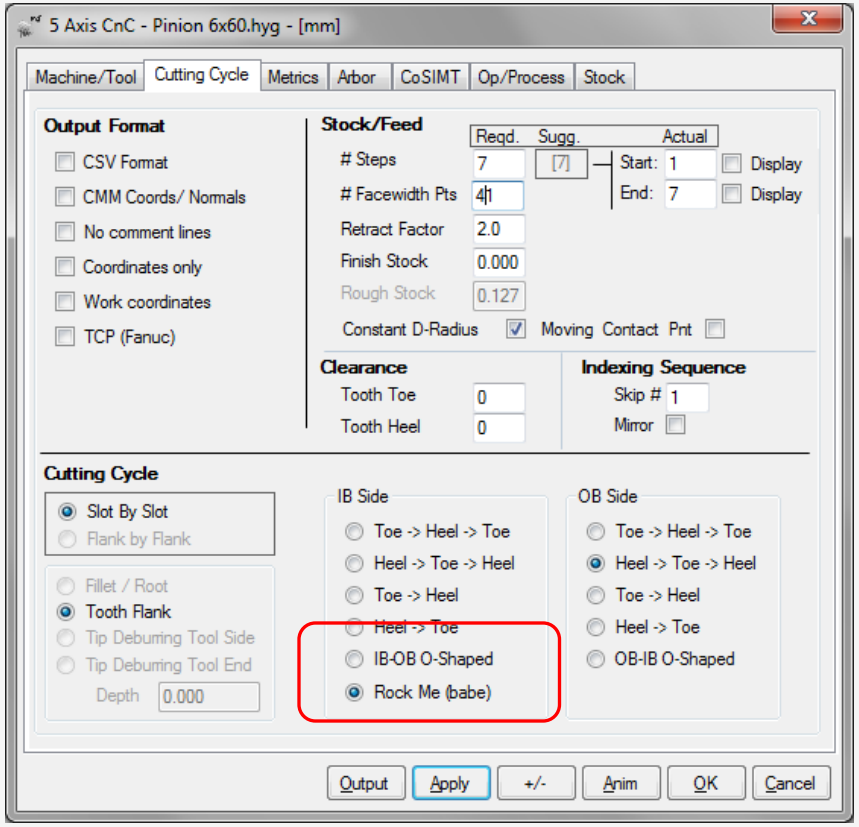
- *only one starting flank can be selected, the other being slave;*
- *for IB-OB, the cutting cycle takes a pass along the face width on the IB and switches to the OB for return; the cycle then switches back to the IB and takes one step depth wise before starting over again;*
- *can be a real time saver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



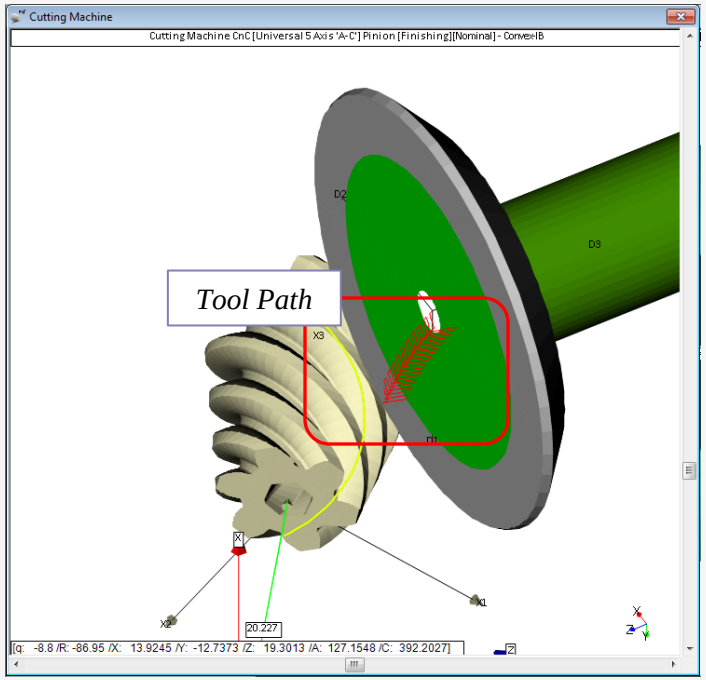
The HyGEARS 5 Axis CnC Post-Processor

Cycles: *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.*



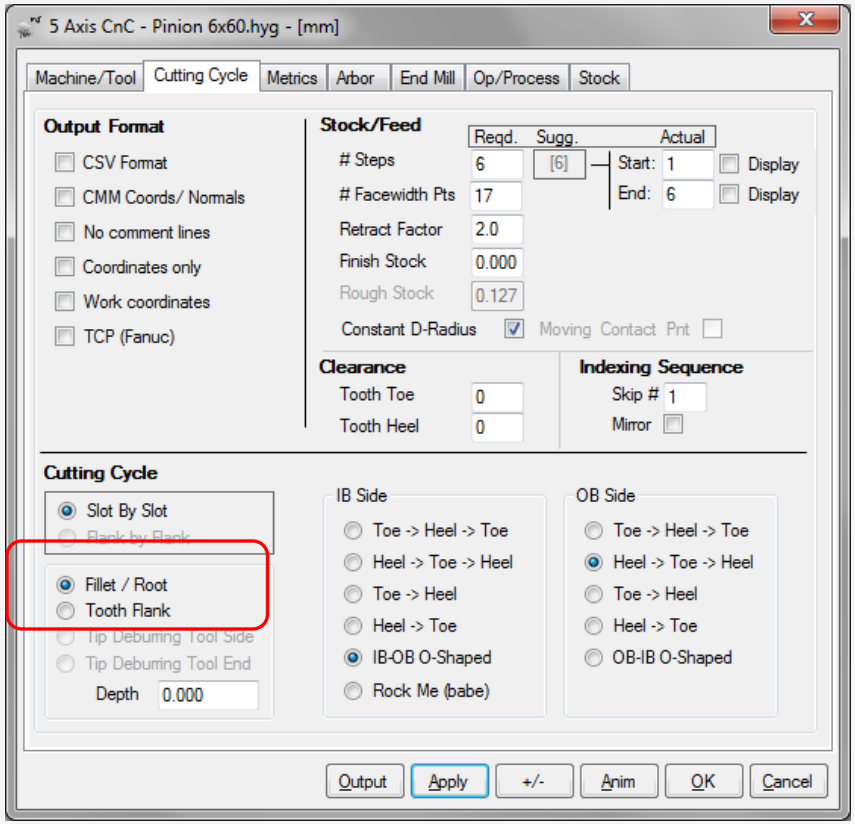
Rock Me (babe) cycle



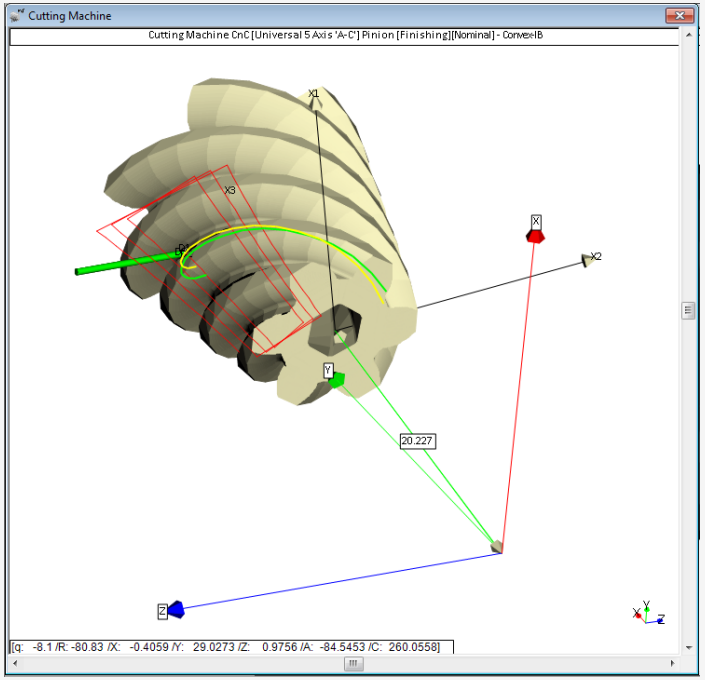
The HyGEARS 5 Axis CnC Post-Processor

Cycles: *Fillet*

- *Fillet finishing is integral to tooth flank finishing when using a Face Mill or CoSIMT tool since the tool sweeping movement generates the fillet;*
- *Fillet finishing can be done in a distinct operation when using an End Mill or Ball Mill tool; in such conditions, negative Stock can be imposed to produce a protuberance;*
- *Fillet finishing uses the same cycles as for Flank finishing (except Rock Me (babe)).*



Fillet cycles

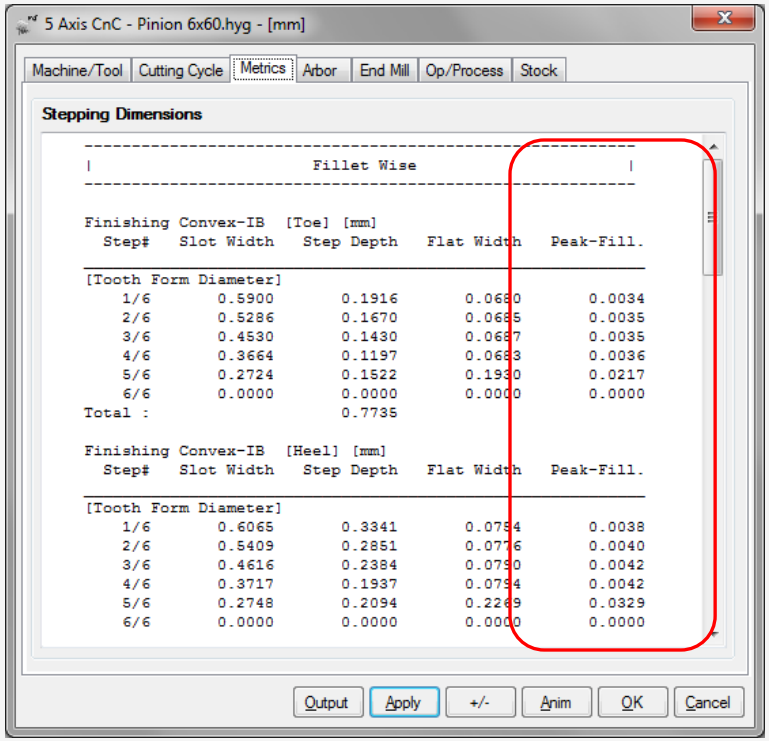


The HyGEARS 5 Axis CnC Post-Processor

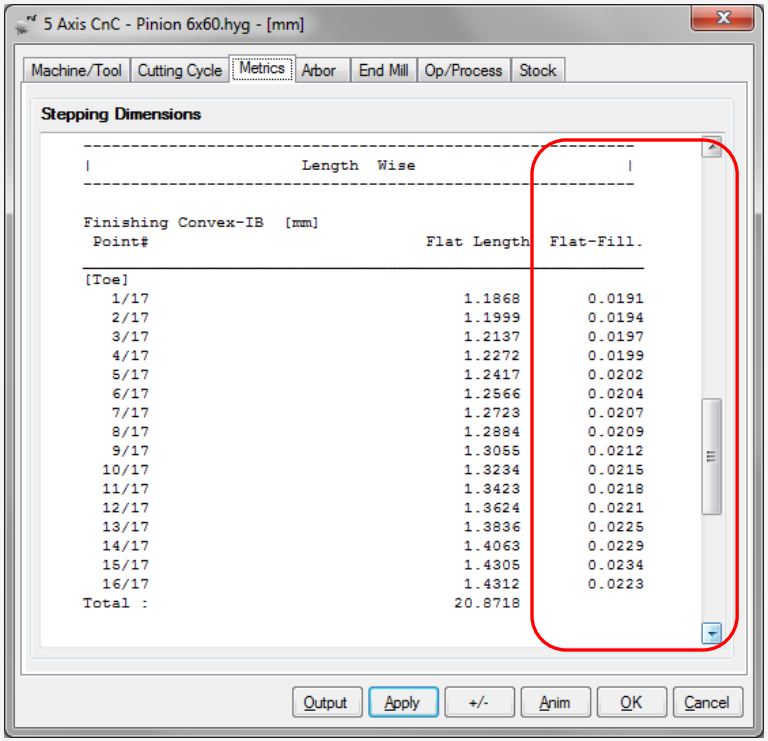
Metrics: *The Metrics page lists, step by step, what are the expected differences between:*

- *the continuous theoretical tooth profile, both depth wise and along the face width, and*
- *the discrete tool paths whose envelope form the tooth flanks.*

It therefore helps the user select an optimal number of Steps Profile and Length wise to have a smooth finish and yet maintain cycle time to a minimum.



Metrics – Profile wise

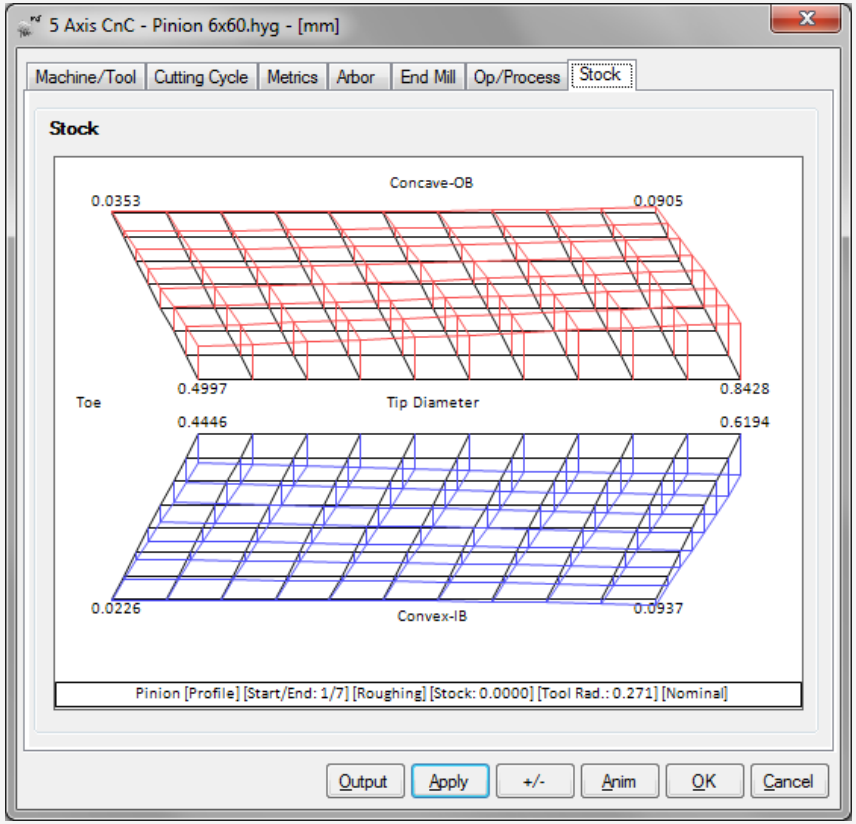


Metrics – Length wise

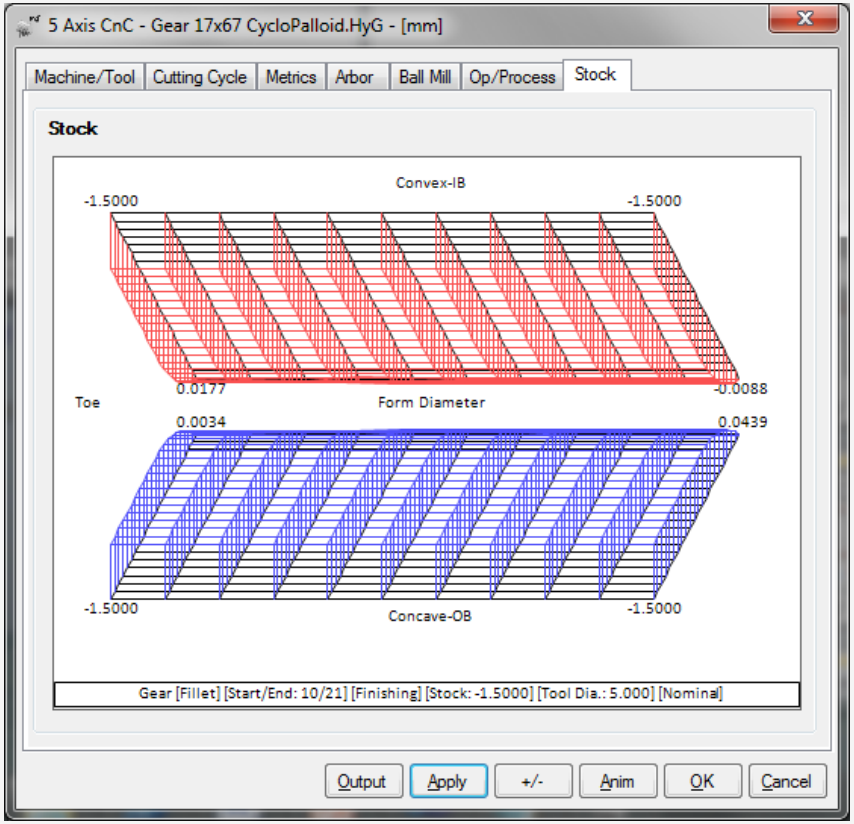
The HyGEARS 5 Axis CnC Post-Processor

Stock: *The Stock page displays the material distribution, after the current operation is completed, in reference to the theoretical profile. This can thus be of great use when :*

- *roughing a slot, where the amount of material left for finishing is known (left below);*
- *finishing the fillet with negative Stock such as to produce a protuberance (right below).*



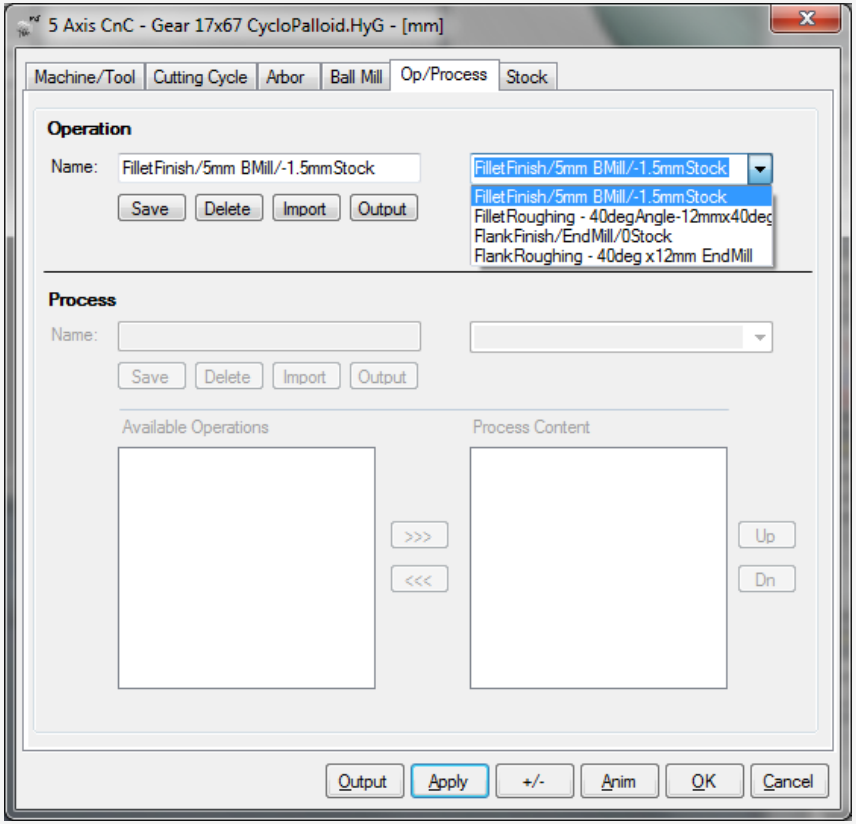
Stock – Pinion single pass roughing with CoSIMT



Stock – Fillet finishing with negative stock

The HyGEARS 5 Axis CnC Post-Processor

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

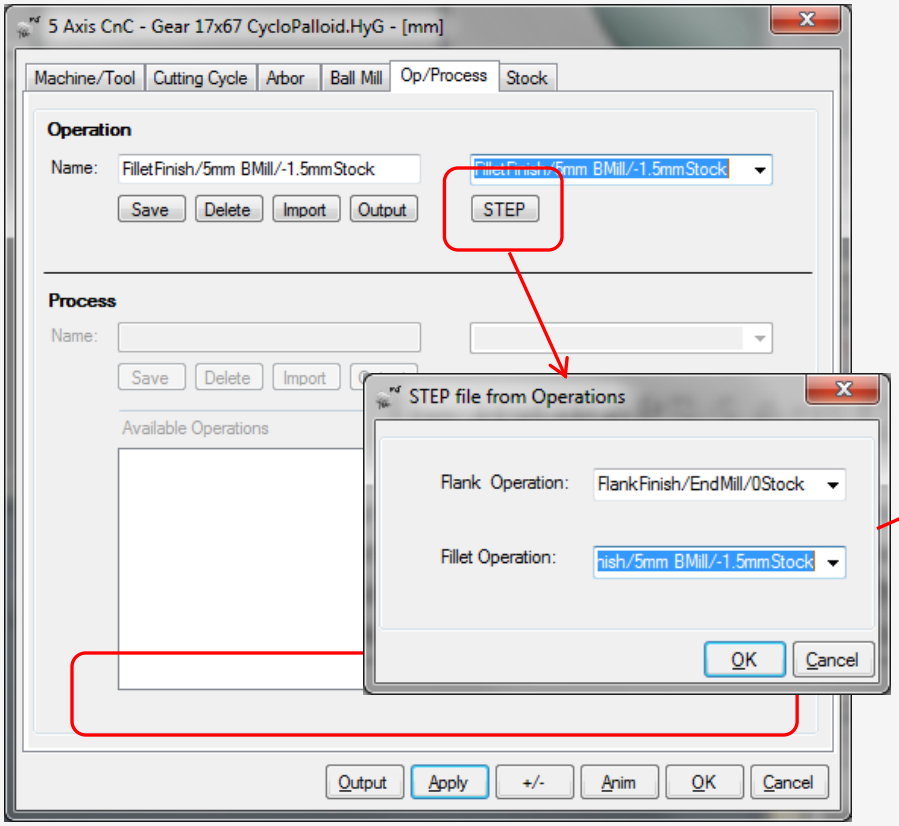


Operations Tab

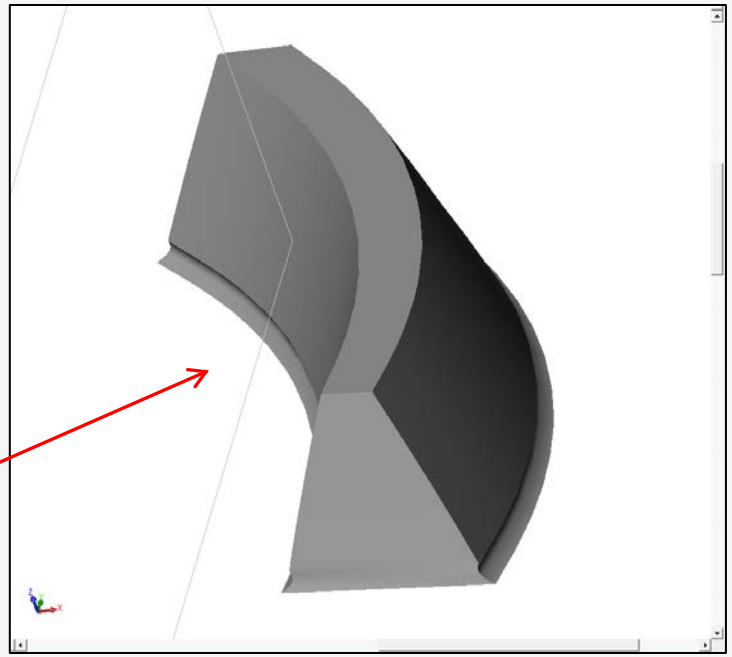
- *an Operation is specific to a geometry, i.e. it is saved in the "Operations.fil" file stored in the current geometry's folder;*
- *the Save / Delete buttons conserve and erase the selected operation;*
- *the Import button allows importing Operations from other geometries; thus, Operations can be re-used;*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

The HyGEARS 5 Axis CnC Post-Processor

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



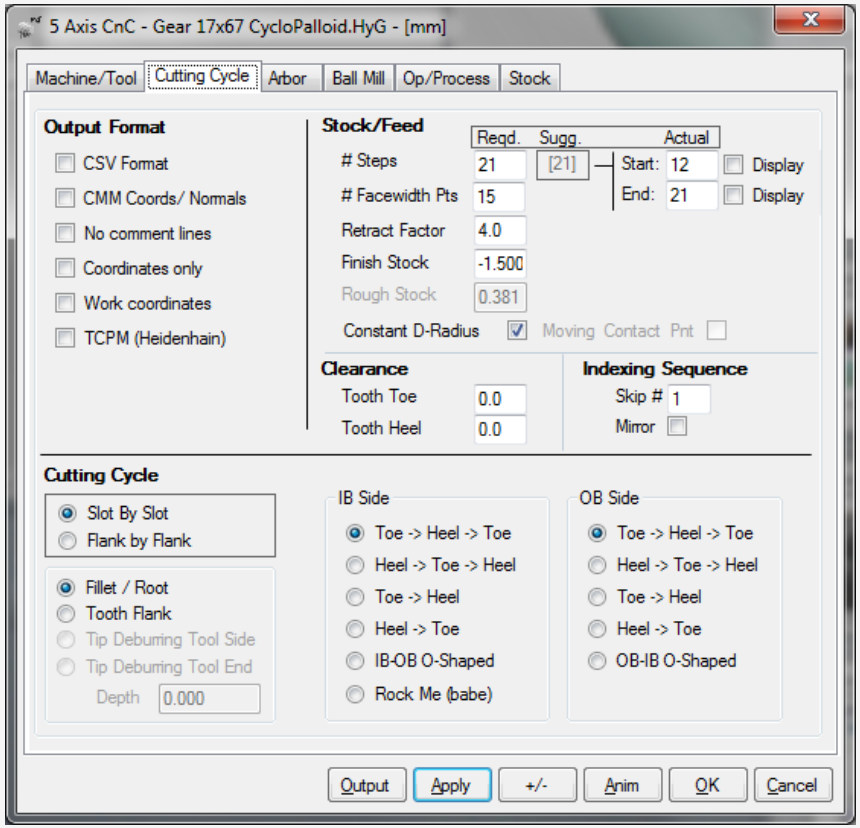
Operations: STEP output



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

The HyGEARS 5 Axis CnC Post-Processor

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



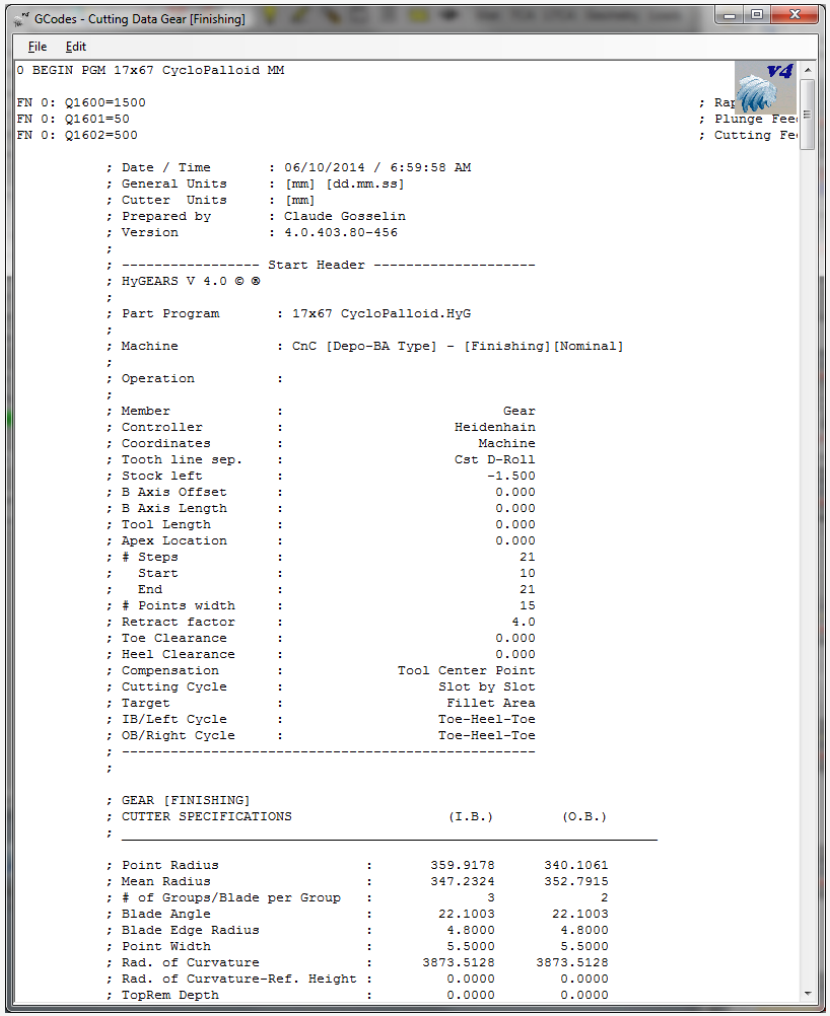
Part program Output

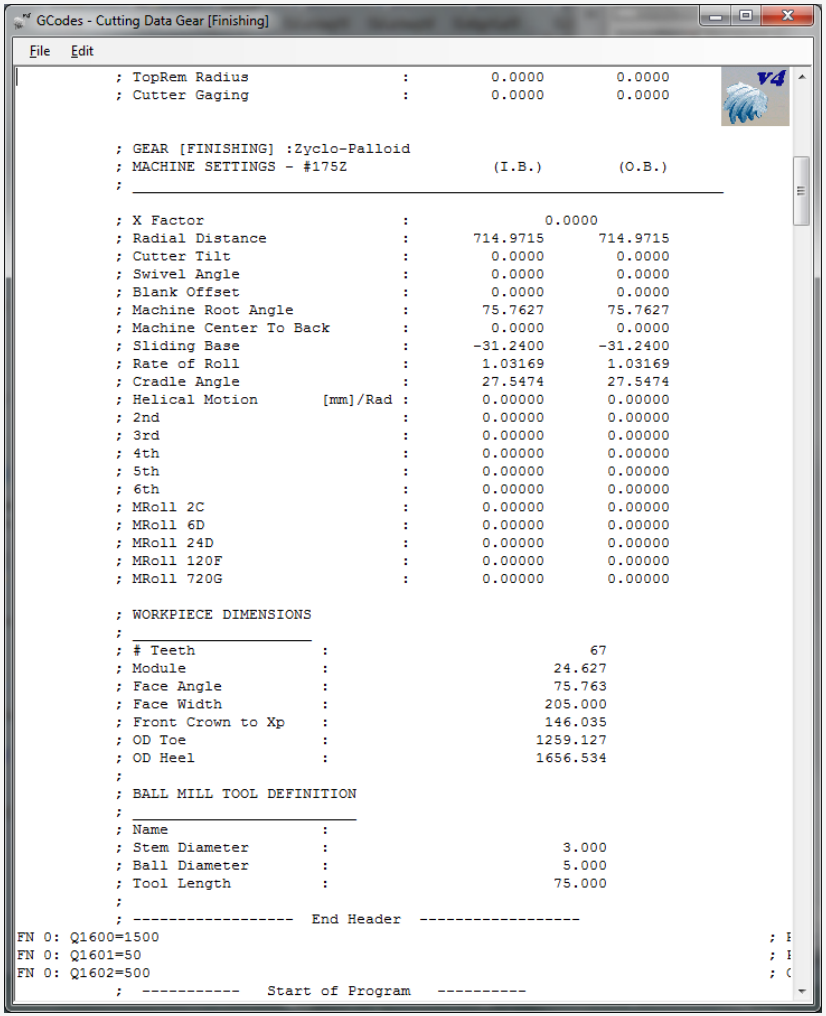
A part program comprises:

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

The HyGEARS 5 Axis CnC Post-Processor

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





Output: Header – 1st part

Output: Header – 2nd part

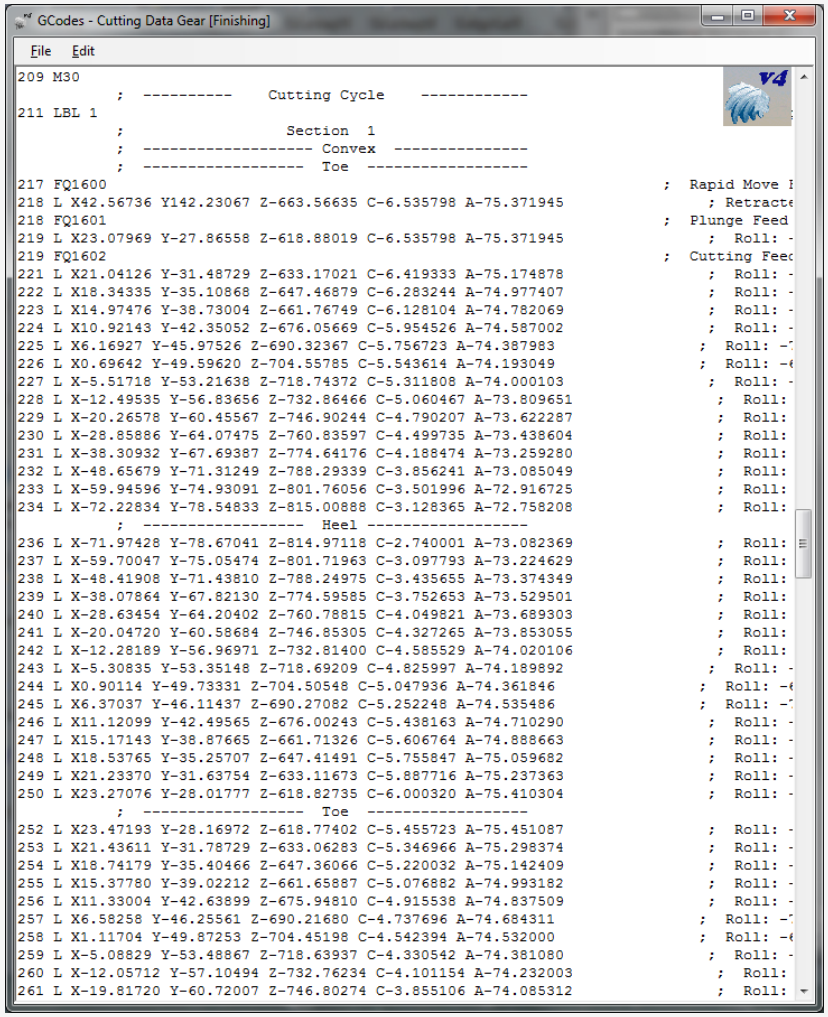
The HyGEARS 5 Axis CnC Post-Processor

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

Output: Header – Indexing Sequence

The HyGEARS 5 Axis CnC Post-Processor

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

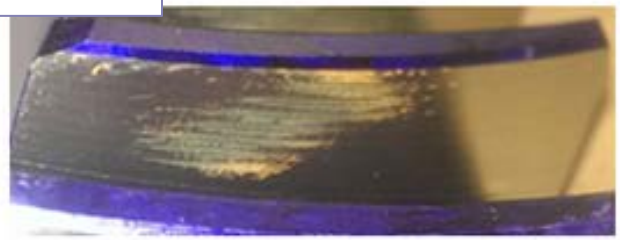


Output: Tool path coordinates (with comments)

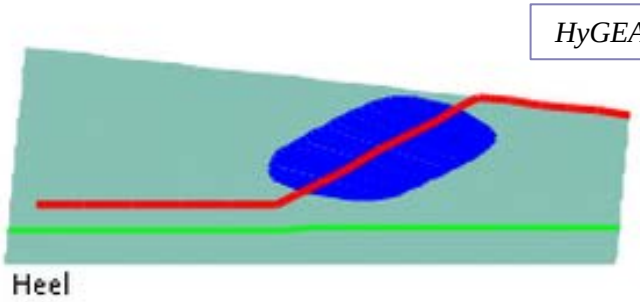
The HyGEARS 5 Axis CnC Post-Processor

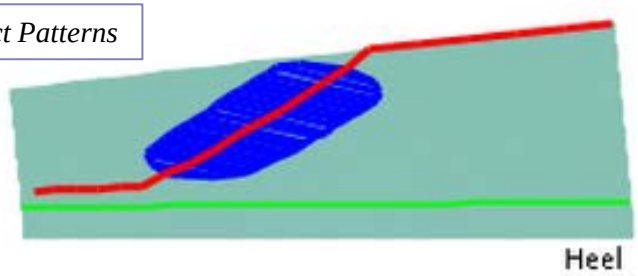
Sample Results: *13x37 6.5 mm module, hypoid gear set:* ***soft-finish****.*
Contact Pattern checks show perfect agreement with HyGEARS' prediction.

Actual Contact Patterns



HyGEARS Contact Patterns





Gear Concave-OB

Gear Convex-IB

The HyGEARS 5 Axis CnC Post-Processor

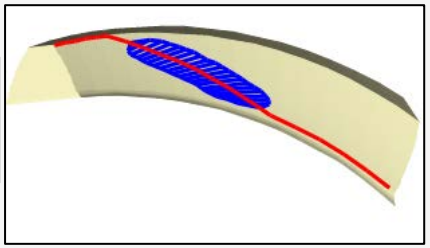
Sample Results: *13x37 6.5 mm module, hypoid gear set:* ***hard-finish****.*
Contact Pattern check shows perfect agreement with HyGEARS' prediction.

13x37 hypoid gear pair on the VH tester

- *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*

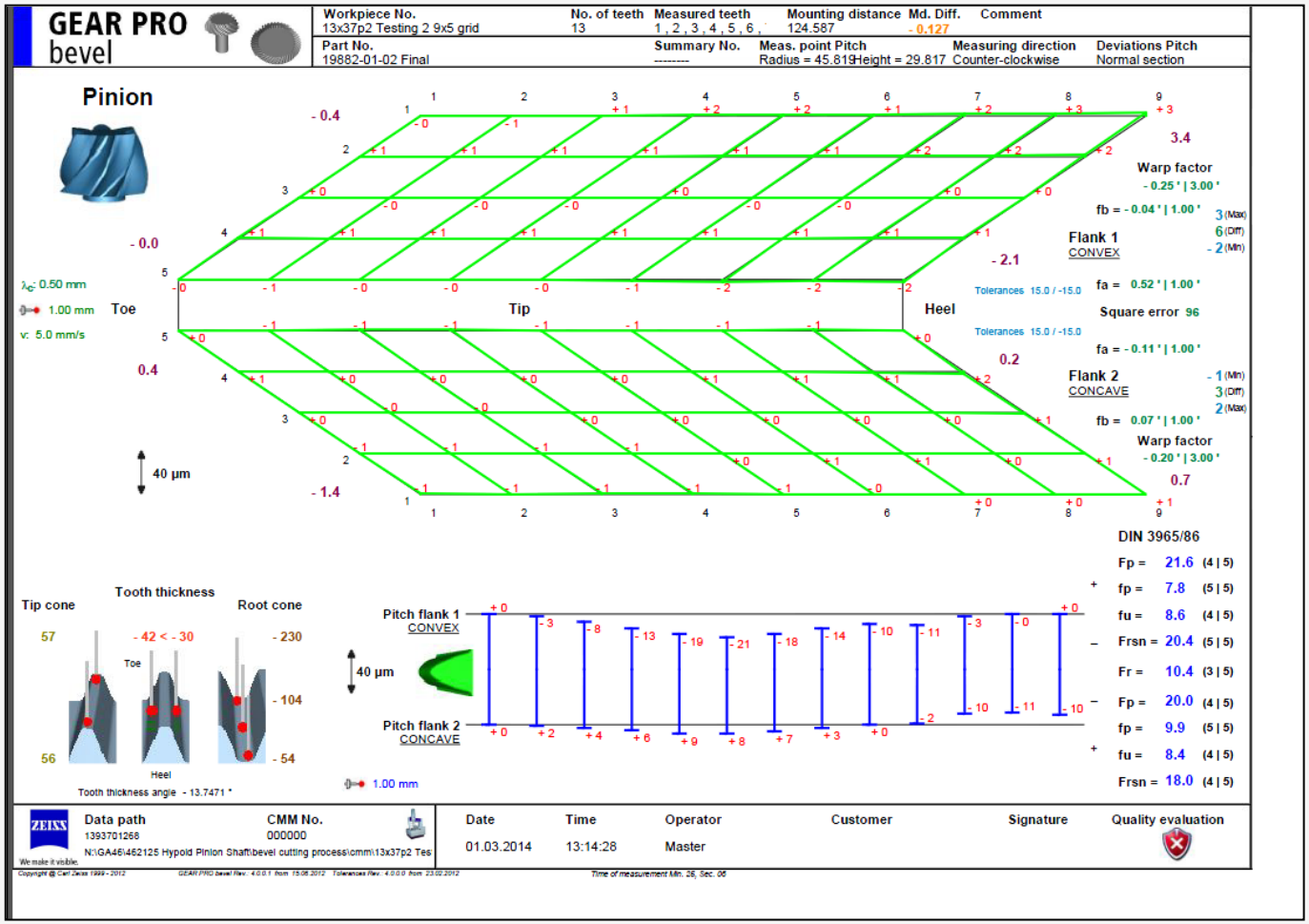
Actual Contact Pattern
Pinion OB

HyGEARS'
Predicted Contact Pattern
Pinion OB



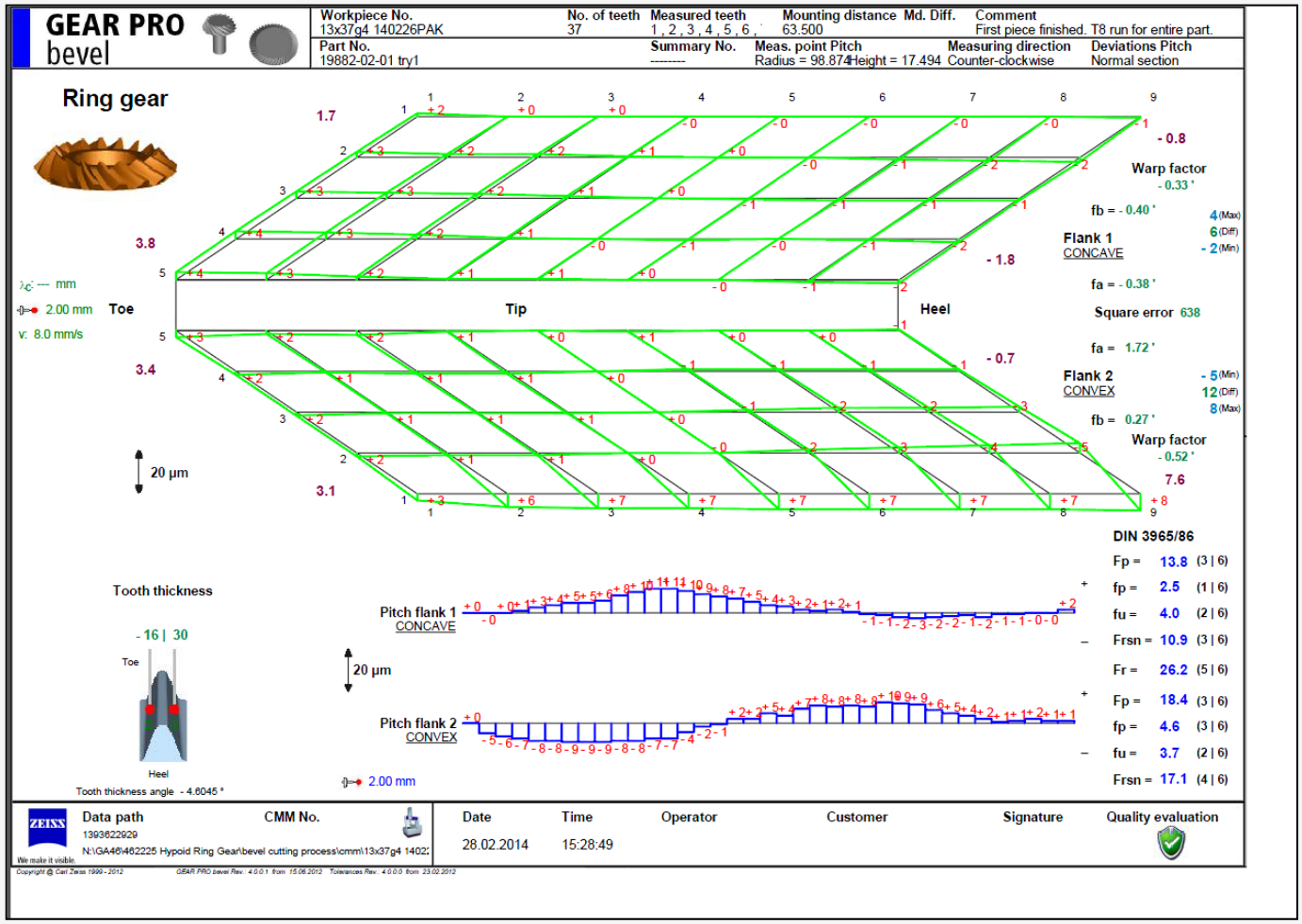
The HyGEARS 5 Axis CnC Post-Processor

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



The HyGEARS 5 Axis CnC Post-Processor

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



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.*

HyGEARS covers every need for the design and manufacture of gears.