



Spur and bevel gear milling on
5-axis machining centres

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EUKLID
GearCAM

Geometriedefinition with GearCAM

The screenshot displays the EUKLID GearCAM 2.3 software interface. The main window shows a 3D model of a gear with a red herringbone gear mesh overlaid on a grey gear. The interface includes a top menu bar with options like Management, Output measure data, Options, Show grid, View, Displays, and Information. A CAD dialog box is open on the right, titled "CAD Dialog", and contains the following sections:

- Description:** Name: Herringbone-1, Comment: (empty)
- Measurement:** mm, inch
- Data input:** 1 / 1,15 / 0,38 ISO 53.2:1997 Profile A, Without reference profile
- Flank Corrections:** Gear data: 28, Reference profile L: 12, Reference profile R: (empty), Calculated: (empty)
- Tolerances / Allowances / Measurement:** Number of teeth: 6, Normale module [mm]: 20, Normal pressure angle [°]: -20, Helix angle [°]: (empty), Profile displacement factor: 0, Tooth thickness deviation [mm]: 0,05, Tooth width [mm]: 60, Addendum coefficient: 1, Dedendum coefficient: 1,15, Tip rounding [mm]: 0, Root blending [mm]: 0,228, Security factor flank: 0, Rotation angle: (empty)
- Herringbone:** Off, Open, Closed, Groove width [mm]: 5, Roundings gap [mm]: 0,04

Two inset diagrams illustrate the helix angle and groove width. The "Helix angle" diagram shows a gear tooth with a red arrow indicating the angle measured on the pitch circle. The "Groove width" diagram shows two gear teeth with a red arrow indicating the distance between them. Below the diagrams, there is explanatory text: "A helical gear is defined by the helix angle. The angle is measured on the pitch circle of the left gear. The sign defines whether it is right or left handed helical gear. For herringbone gears the angle is related to that part of the gear, which starts at the zero point." and "Groove width indicates the distance between both gearing parts. If open herringbone is selected, a groove of size dimension has to be turned into the stock. For closed herringbone there is no groove. A fillet surface will be machined instead."

- 1 / 1,15 / 0,38 ISO 53.2:1997 Profile A
- Without reference profile
- Reference profile - particular input
- 1 / 1,15 / 0,38 ISO 53.2:1997 Profile A
- 1 / 1,15 / 0,3 ISO 53.2:1997 Profile B
- 1 / 1,15 / 0,25 ISO 53.2:1997 Profile C
- 1 / 1,15 / 0,39 ISO 53.2:1997 Profile D
- 1 / 1,15 / 0,3 DIN 867:1986
- 1 / 1,15 / 0,25 DIN 867:1986

Description

Name:

Comment:

Measurement: mm inch

Data input:

Flank Corrections | Tolerances / Allowances / Measurement

Gear data | Reference profile L | Reference profile R | Calculated data

Flank Corrections | Tolerances / Allowances / Measurement

Left Right

0 | 0 | 0 | Profile displacement factor

0 | 0 | 0 | Tooth thickness deviation [mm]

178,78187 | | | Measurement circle [mm]

9,42478 | 9,42478 | 9,42478 | Tooth thickness [mm]

Normal Transverse

Arc Chordal

35 | Diameter of ball/pin [mm]

131,64356 | 131,64356 | 131,64356 | One ball [mm]

263,28709 | 263,28709 | 263,28709 | Two balls [mm]

One ball Two balls

5 | No. of teeth for measurement

82,51656 | 82,51656 | 82,51656 | Base tangent length [mm]

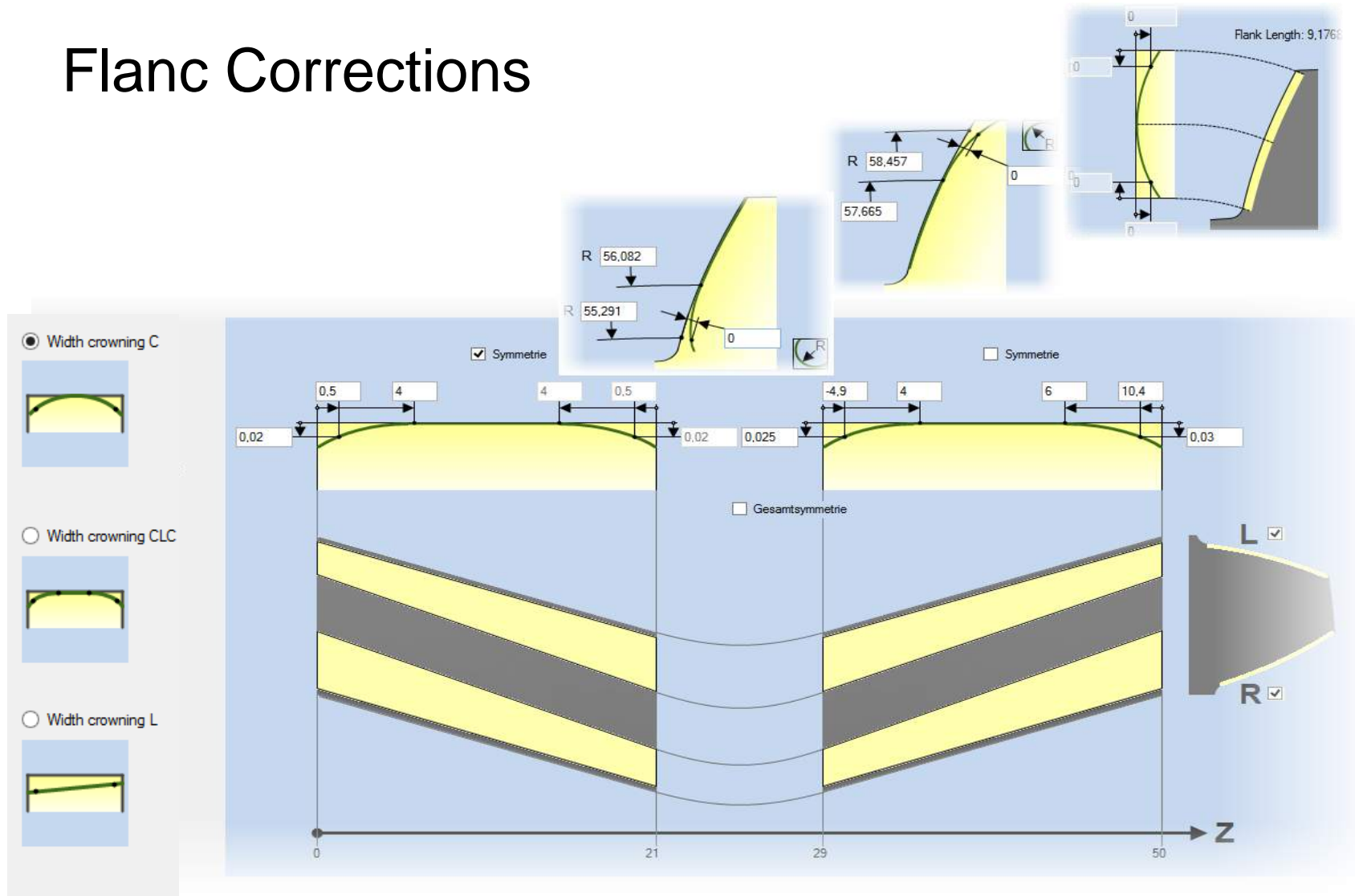
Gear data | Reference profile L | Reference profile R | Calculated data

Flank Corrections | Tolerances / Allowances / Measurement

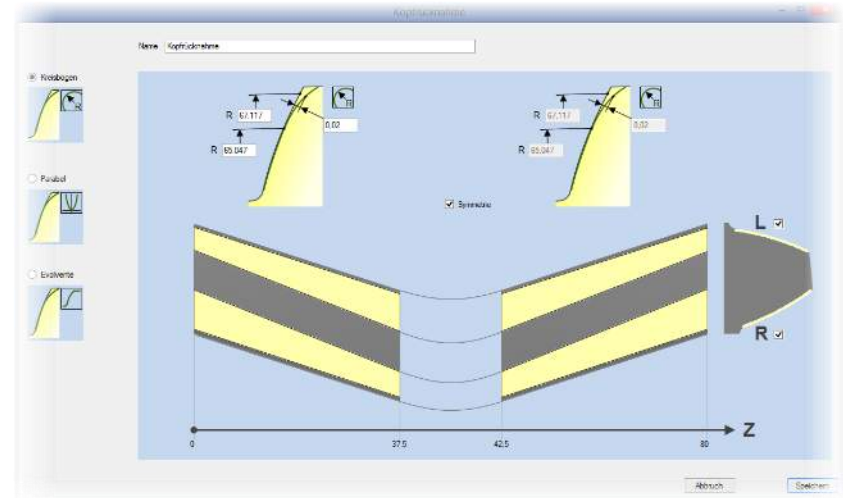
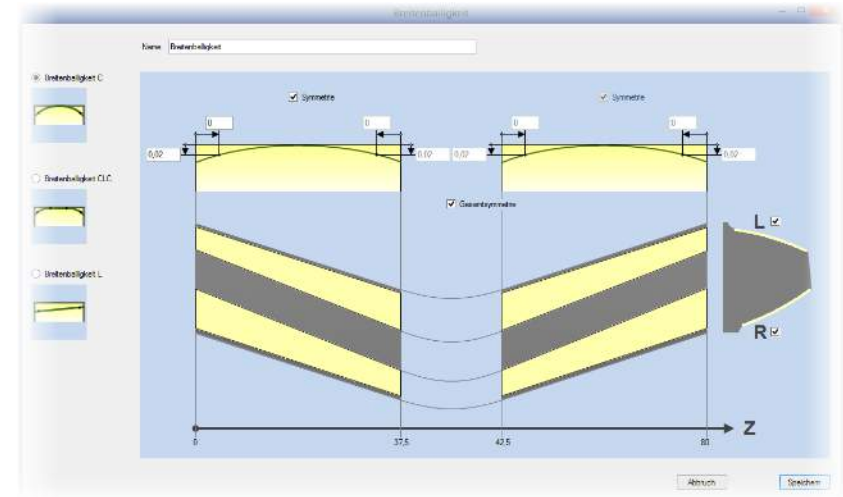
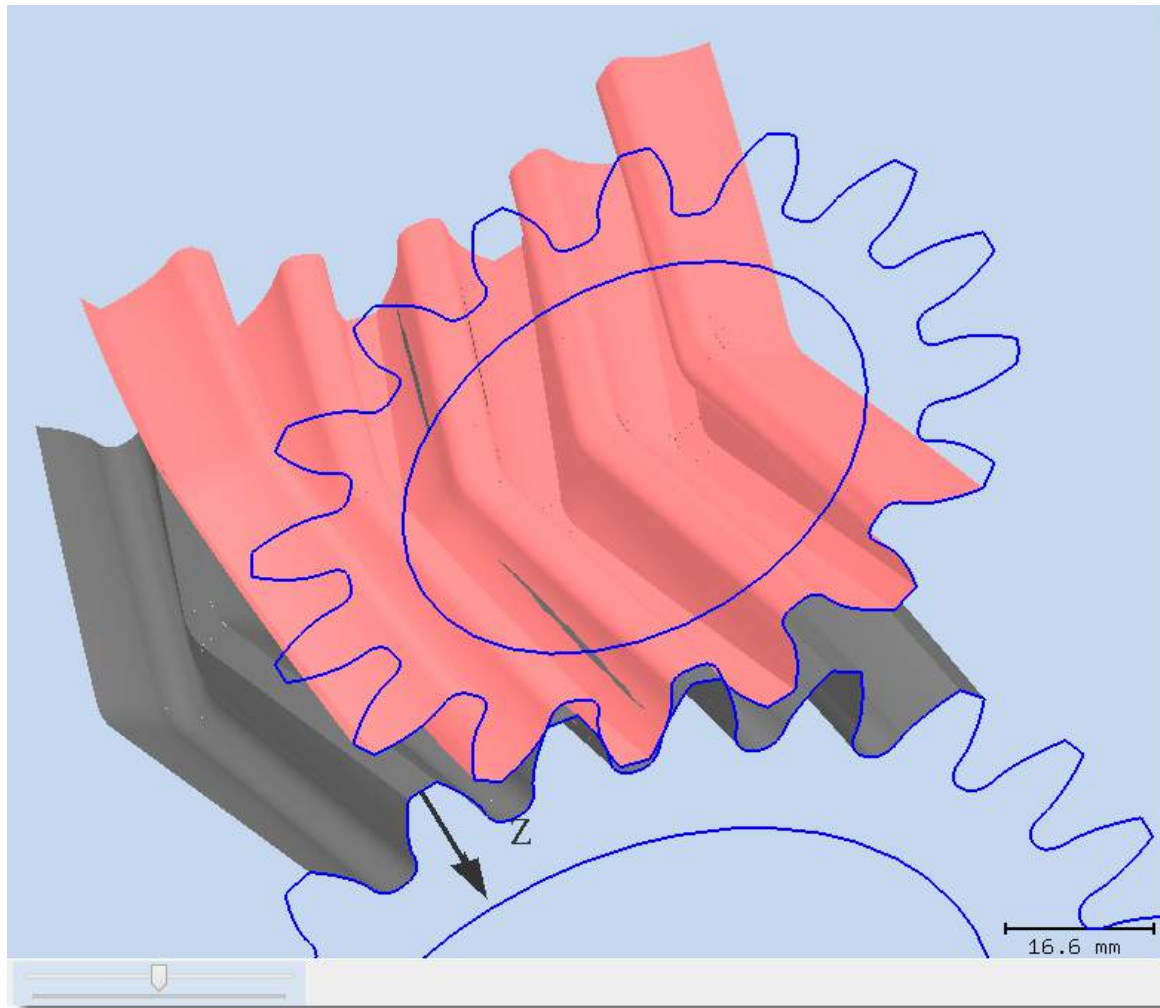
Type	Name	Left	Right
	Width crowning	✓	✓
	Height crowning	✓	✓
	Tip relief	✓	✓
	Foot relief	✓	✓

Protuberance

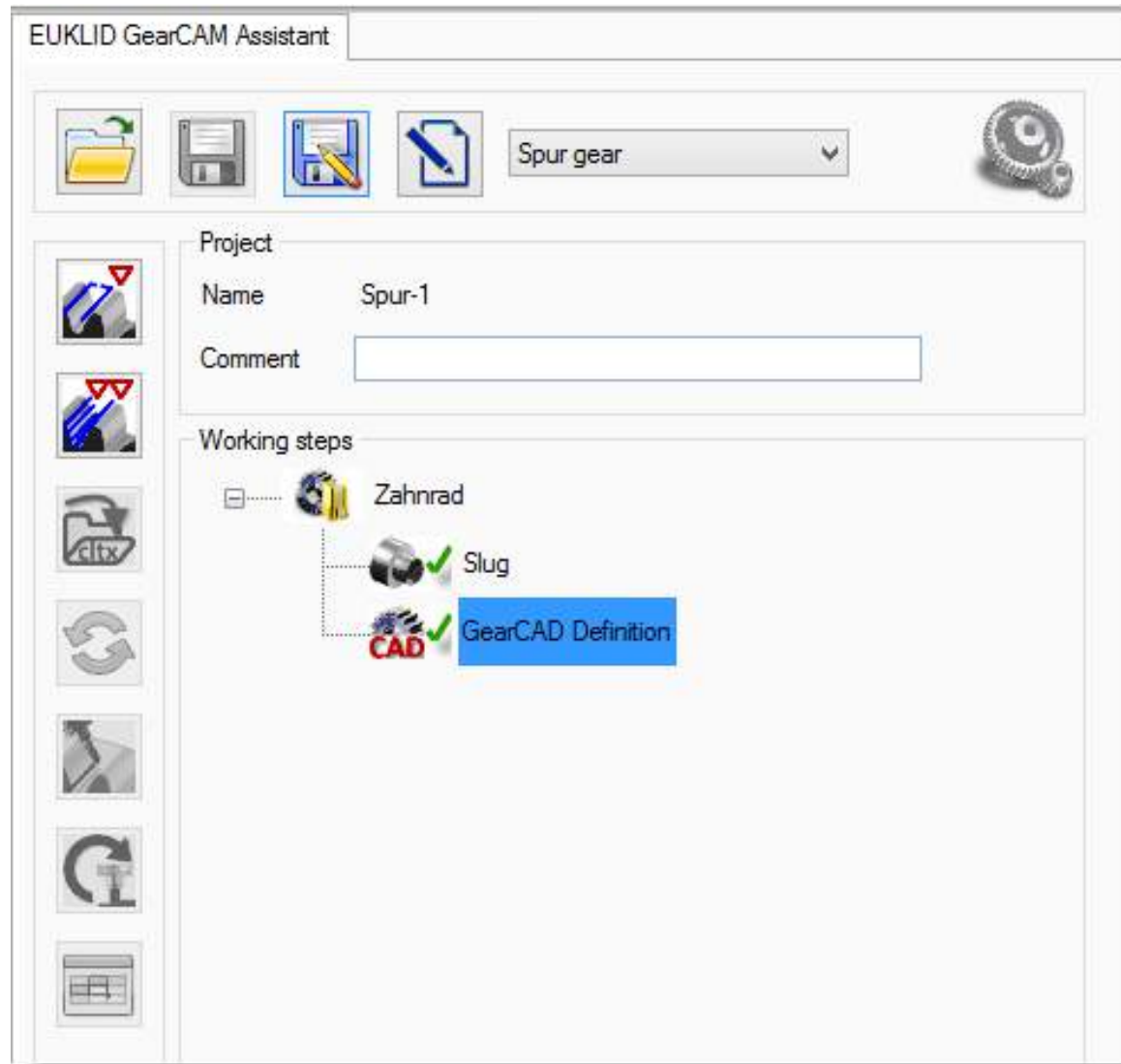
Flanc Corrections



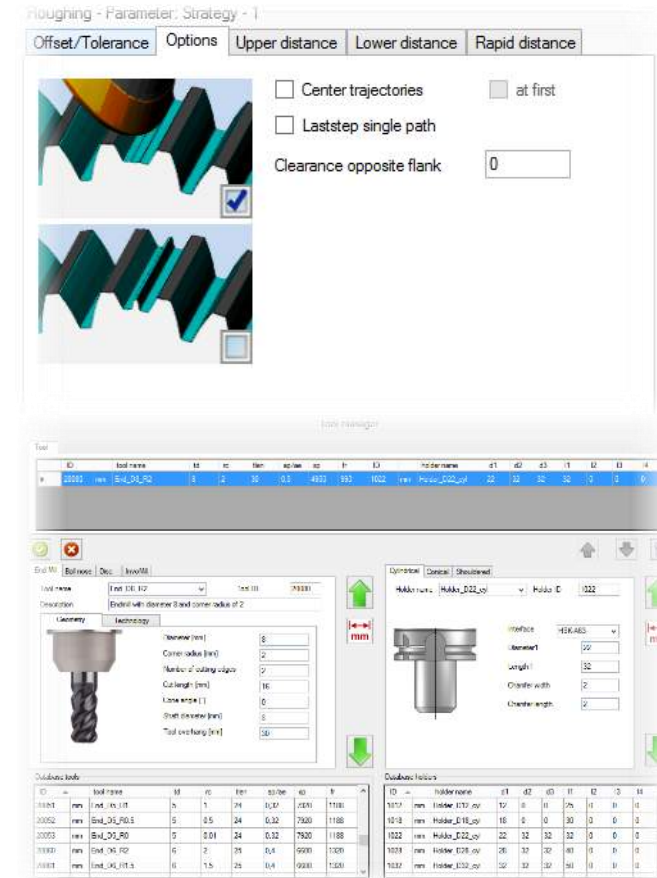
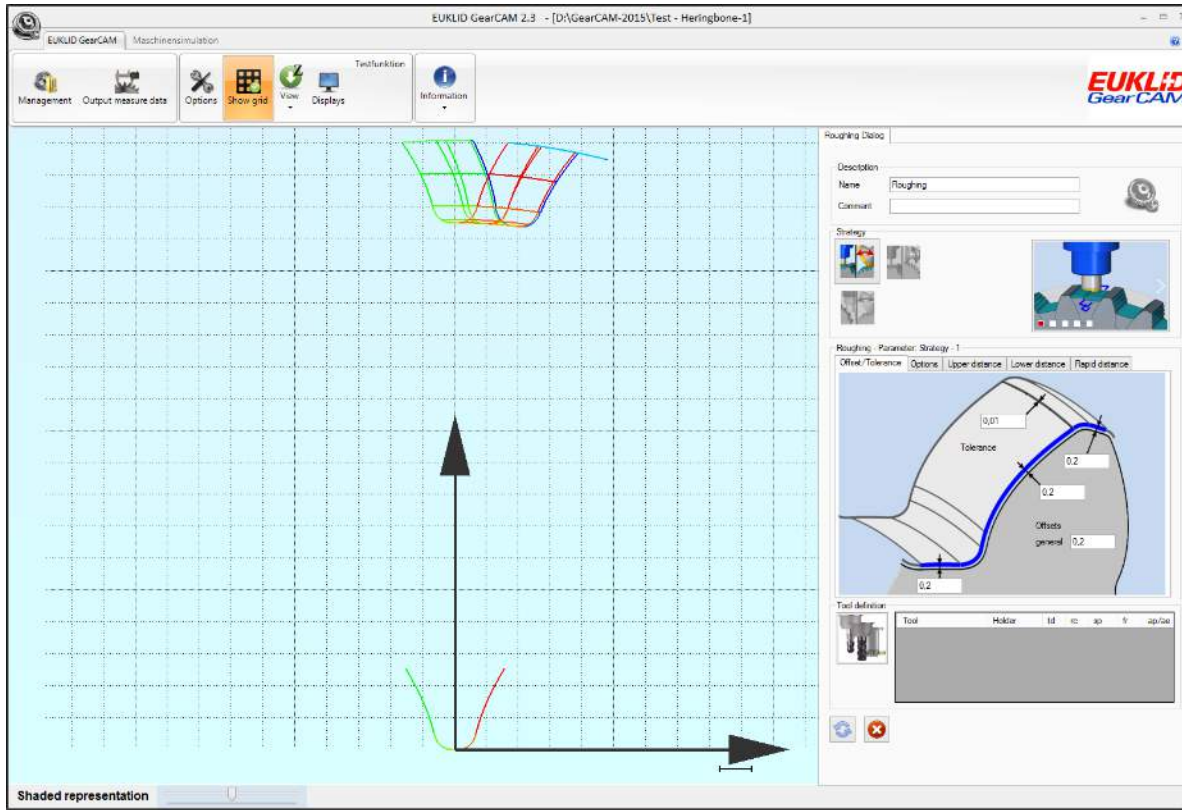
Flanc Correction check



NC-Programming



Roughing



Finishing


Finishing Dialog

Description

Name:

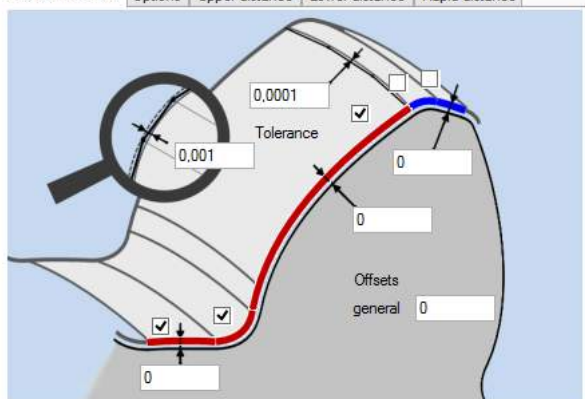
Comment:

Strategy



Finishing - Parameter: Finishing strategy - 3

Offset/Tolerance Options Upper distance Lower distance Rapid distance

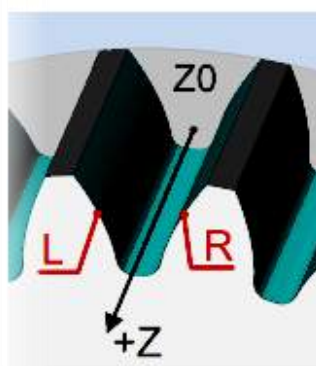


Tool definition

Tool name	Holder name	td	rc	sp	fr
End_D8_R2	Holder_D22_cyl	8	2	4950	990

Finishing - Parameter: Finishing strategy - 3

Offset/Tolerance Options Upper distance Lower distance Rapid distance



Flank selection

both sides

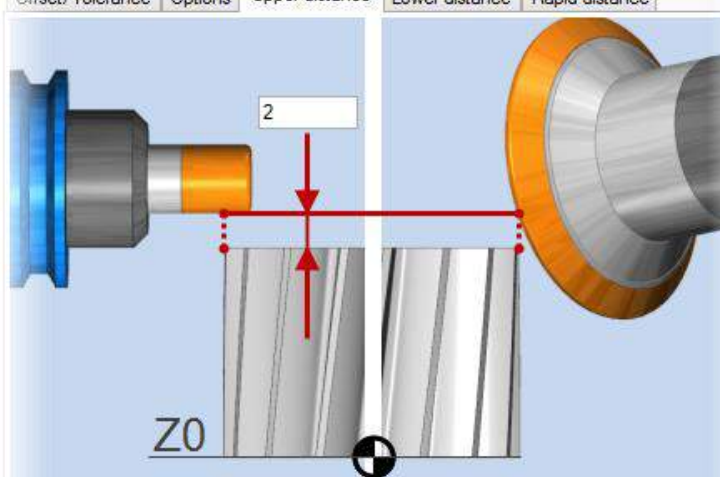
left

right

Use full cutting length

Finishing - Parameter: Finishing strategy - 3

Offset/Tolerance Options Upper distance Lower distance Rapid distance




Deburring

Finishing Dialog

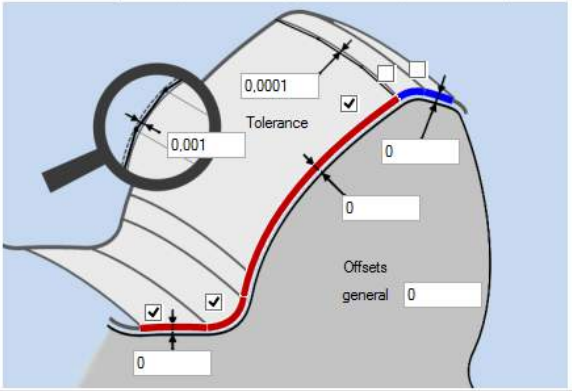
Description
 Name:
 Comment:

Strategy



Finishing - Parameter: Finishing strategy - 5

Offset/Tolerance Options Upper distance Lower distance Rapid distance




Tool definition

Tool name	Holder name	td	rc	sp	fr
End_D4_R1	Holder_D18_cyl	4	1	9900	990

Finishing - Parameter: Finishing strategy - 5

Offset/Tolerance Options Upper distance Lower distance Rapid distance



Chamfer size:

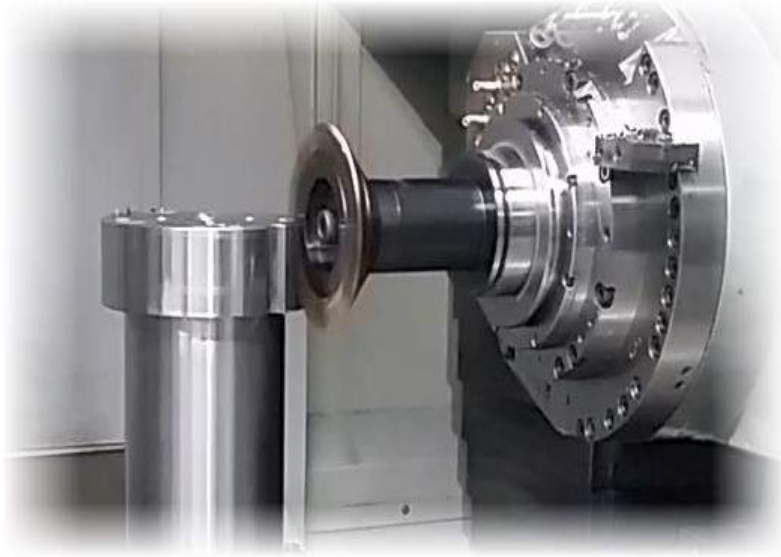
Level selection

- both
- lower (1)
- upper (2)

Side selection

- both
- right
- left

InvoMilling



Finishing Dialog

Description
 Name: Finishing Evolute
 Comment:

Strategy

Finishing - Parameter: Finishing strategy - 1

Offset/Tolerance Options Upper distance Lower distance Rapid distance

Tool definition

Tool name	Holder name	td	rc	sp	fr
CoroMill 162-090	InvoMillHolder50	90	0,8	1230	1353

Finishing - Parameter: Finishing strategy - 1

Offset/Tolerance Options Upper distance Lower distance Rapid distance

Height to line: 2,5 Auto
 Factor collateral overlap: 0,05
 Lead-in as involute path: 3
 Parallel safety clearance: 0,2
 Tangential safety clearance: 1,5
 Collateral protrusion: 2
 Clearance opposite flank: 0,05
 Backside
 Calculate ground paths
 Flank selection: both sides left right

End Mill | Ball nose | Disc | InvoMill

Tool name: CoroMill 162-090 Tool ID: 916211
 Description: CoroMill 162 DC90mm / 176M40-100608E-PM

Geometry Technology

CoroMill 162 SANDVIK Coromant

model : DC 90 mm
 order code : 162-090Q27-40
 inserts
 amount : 11
 type : 176M40-100608E-PM
 order code : 176M40-100608E-PM
 modul : ~ 4,0 - 8,0
 usage : roughing, involute

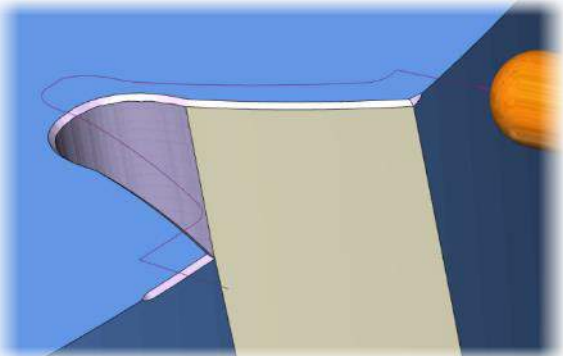
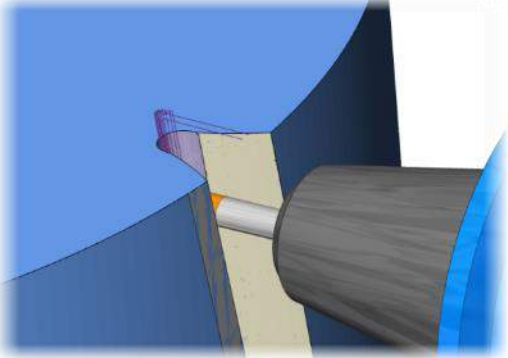
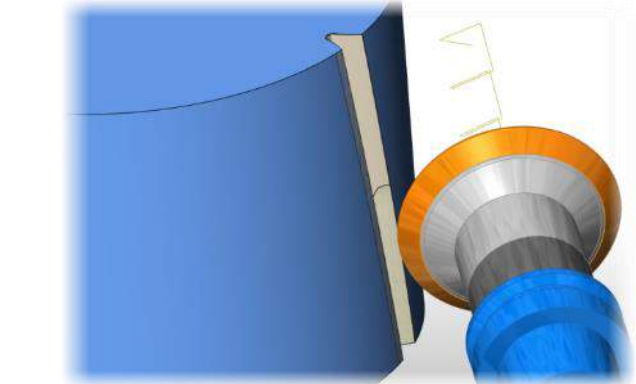
Milling-Simulation

Move List

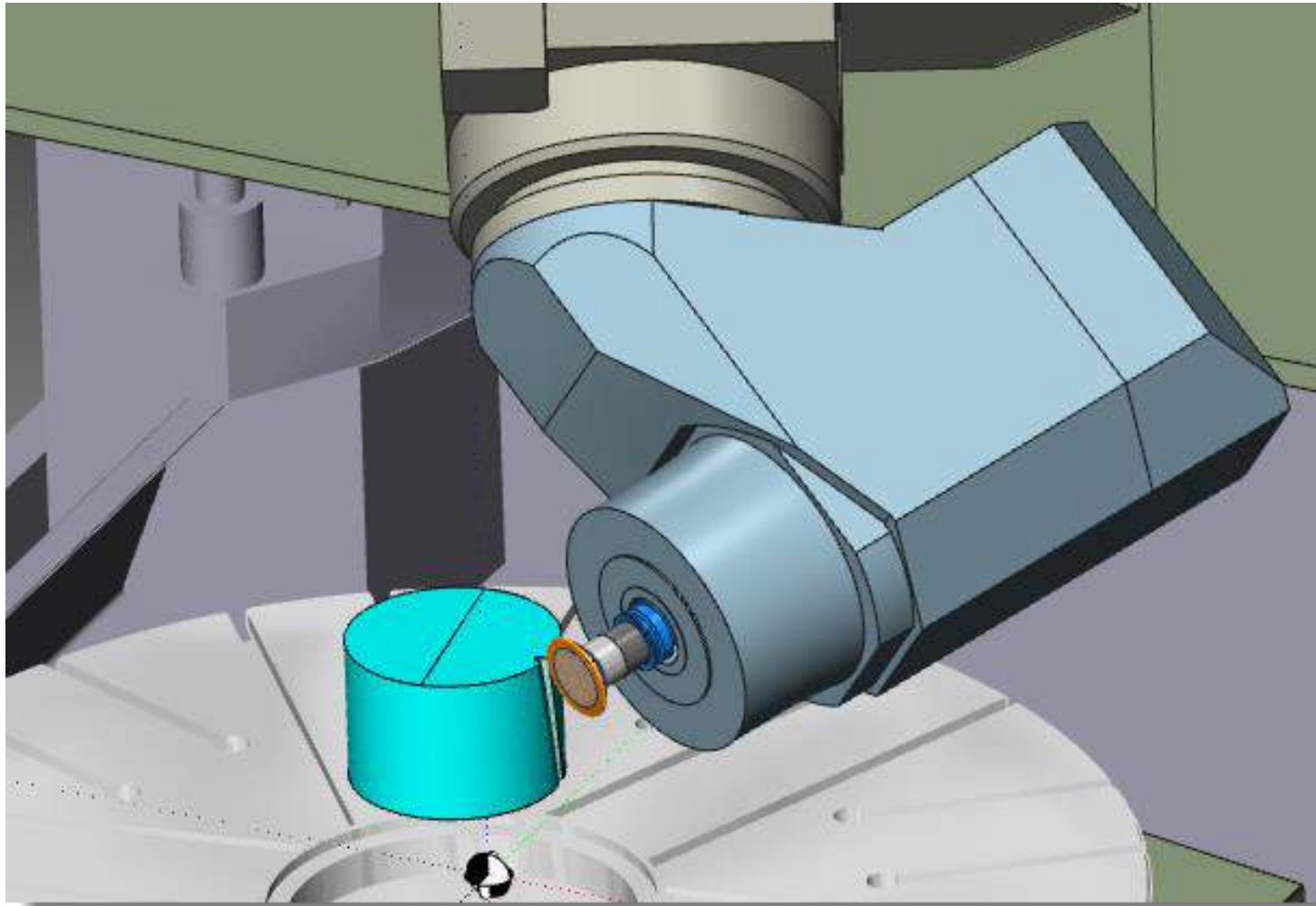
Move	X	Y	Z	C	B
Op. 1 (1): Roughing_1 (CoroMill 162-090)					
Op. 2 (1): Finishing_1 (CoroMill 162-090)					
Op. 3 (1): Finishing_2 (CoroMill 162-090)					
Op. 4 (1): Finishing_Root_1 (Ball_D4)					
Op. 5 (1): Deburring_1 (Ball_D4)					
Op. 6 (1): Deburring_2 (Ball_D4)					
1422	48.192	133.607	123.964	325.488	279.391
1423	48.477	133.505	125.214	325.366	279.391
1424	48.762	133.400	126.464	325.244	279.391
1425	49.046	133.295	127.714	325.121	279.391
1426	49.331	133.191	128.964	324.999	279.391
1427	49.615	133.086	130.214	324.877	279.391
1428	49.898	132.979	131.464	324.755	279.391
1429	50.182	132.872	132.714	324.632	279.391
1430	50.465	132.765	133.964	324.510	279.391
1431	50.749	132.658	135.214	324.388	279.391
1432	51.031	132.548	136.464	324.266	279.391
1433	51.314	132.439	137.714	324.144	279.391
1434	51.596	132.329	138.964	324.021	279.391
1435	51.879	132.220	140.214	323.899	279.391
1436	52.160	132.108	141.464	323.777	279.391
1437	52.442	131.996	142.714	323.655	279.391
1438	52.724	131.884	143.964	323.532	279.391
1439	53.005	131.772	145.214	323.410	279.391

Analysis

G&E	Number	Operation comment
<input type="checkbox"/>	1	Roughing_1 (CoroMill 162-090)
<input checked="" type="checkbox"/>	2	Finishing_1 (CoroMill 162-090)
<input checked="" type="checkbox"/>	3	Finishing_2 (CoroMill 162-090)
<input checked="" type="checkbox"/>	4	Finishing_Root_1 (Ball_D4)
<input checked="" type="checkbox"/>	5	Deburring_1 (Ball_D4)
<input checked="" type="checkbox"/>	6	Deburring_2 (Ball_D4)



Milling Simulation on 5-Axis-machine



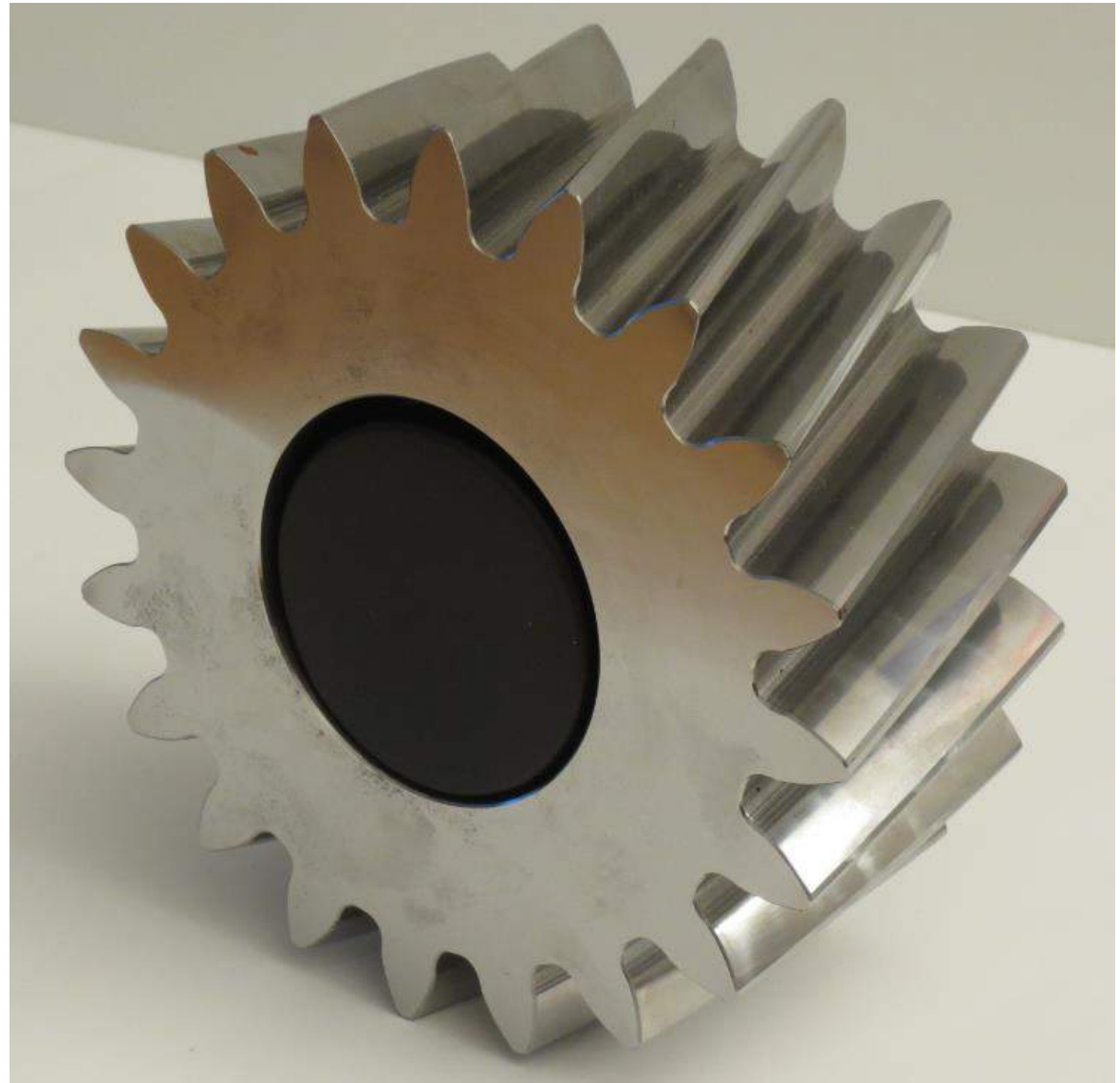
Spur gear:

normal module : 8
helix angle: 20
number of teeth. 20
tooth with: 80 mm
tip circle: 185 mm
material: 42CrMo4

Milling time

Roughing 51 min
Root 27 min
Finishing involute (InvoMill) 20 min
Tip chamfer 6 min
Deburring 3 min

Total 117 min



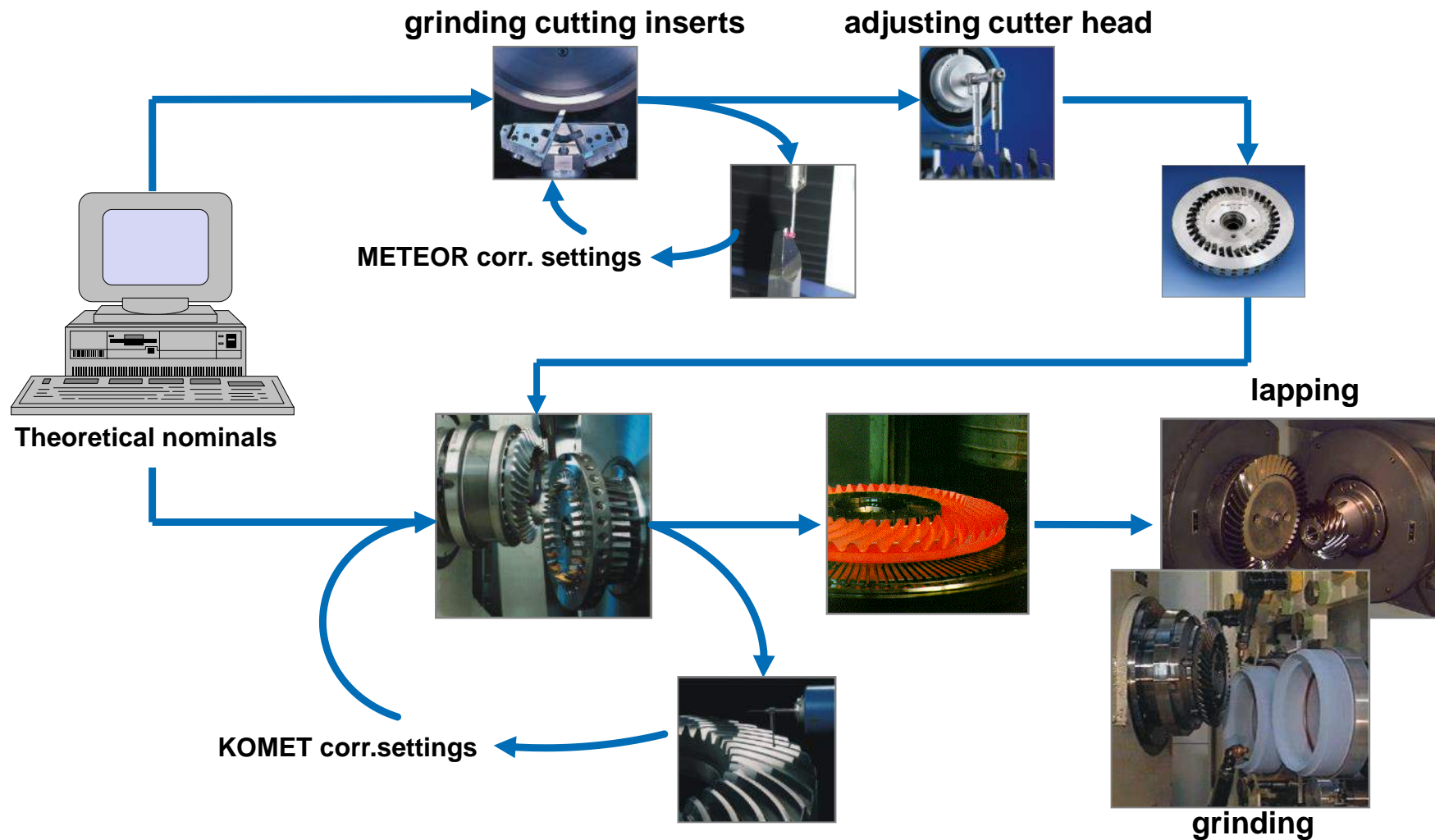
EUKLED
GearCAM

Bevel Gear



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established gearing technics – closed loop



source: Klingelberg / WZL / IPT

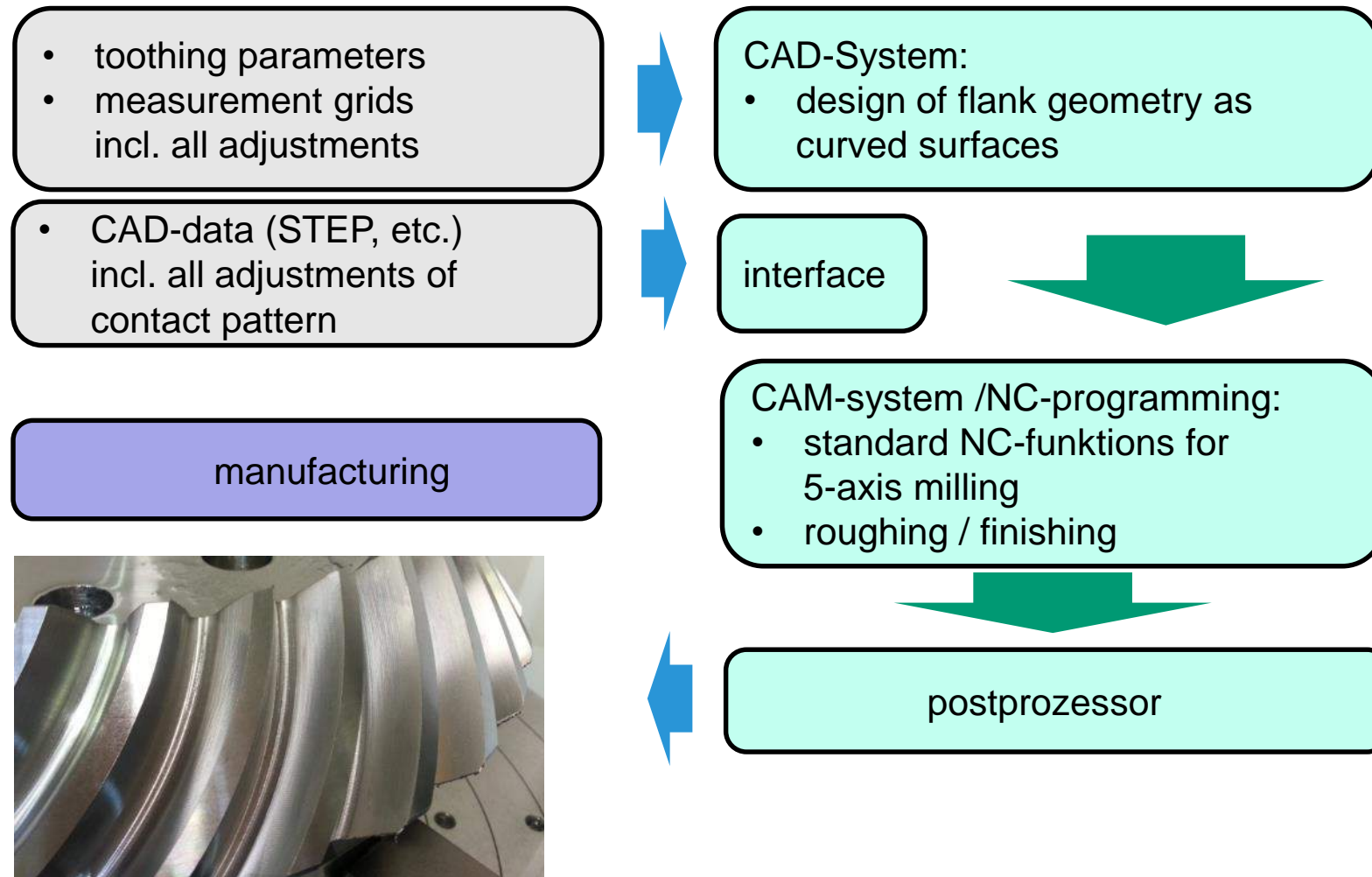
established gearing technology:

- highly productive manufacturing processes
- process specific special machines, in general separate for soft and hardened state machining
- complex product specific cutting tools
- multistage, iterative manufacturing process (closed loop)
- no exact definition of flank topology in detail, characteristics of contact pattern is a result of case specific optimization

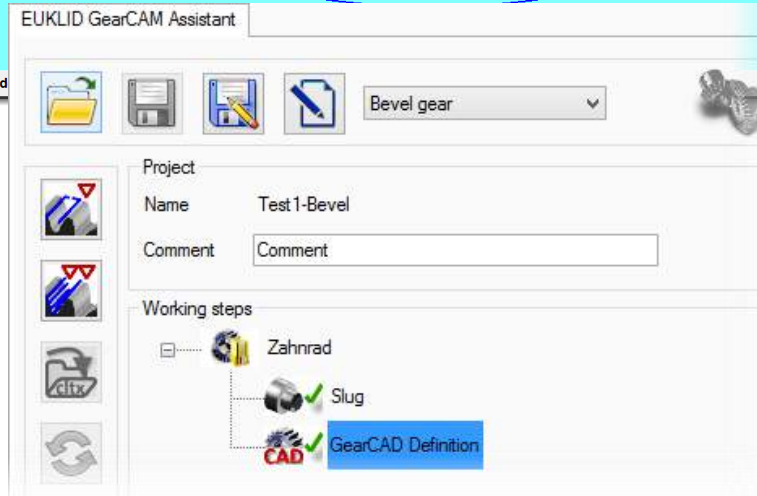
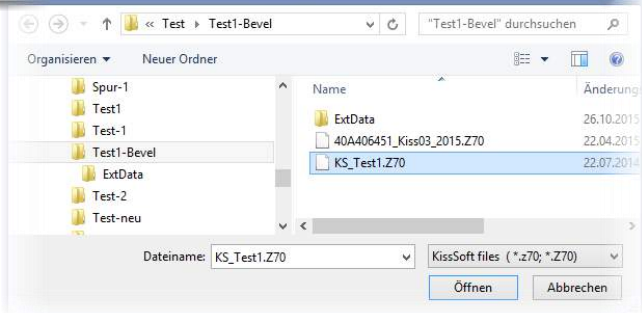
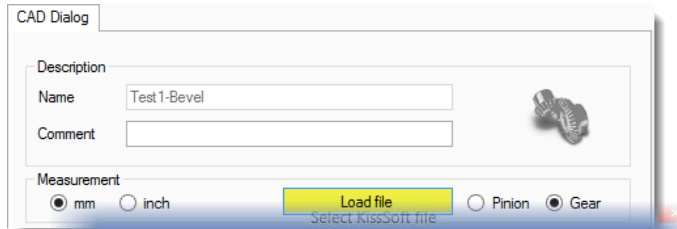
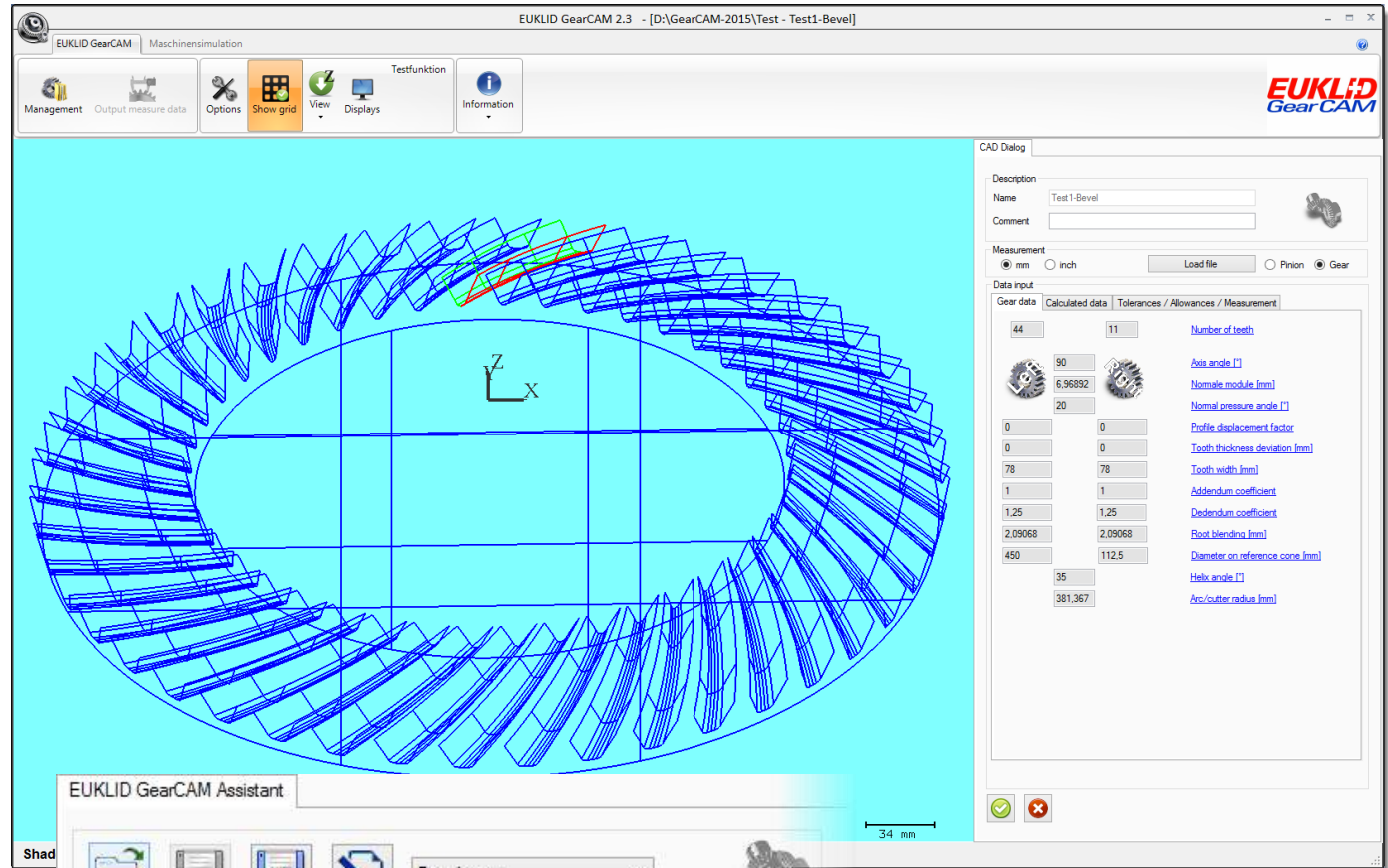
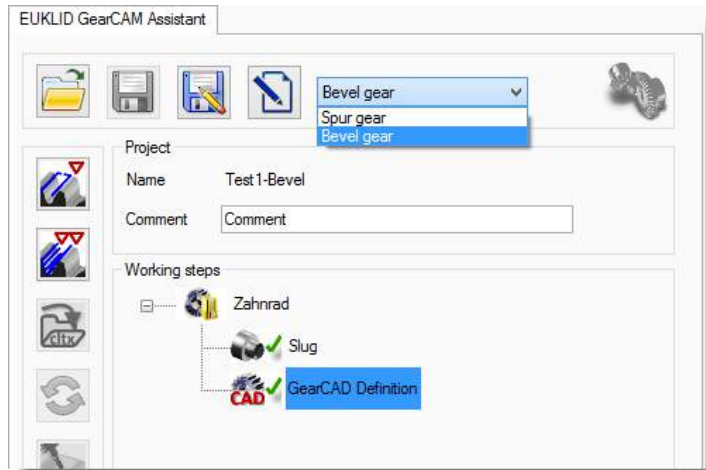
5-axis milling of gears:

- exact definition of flank geometry is basic precondition
- implementing of universal machining centers
- use of standard cutting tools
- any gear design possible – even special materials – no restrictions designing contact patterns hard machining up to 62 HRC
- single-step process with definite targets (incl. all necessary adjustments of flank topology)

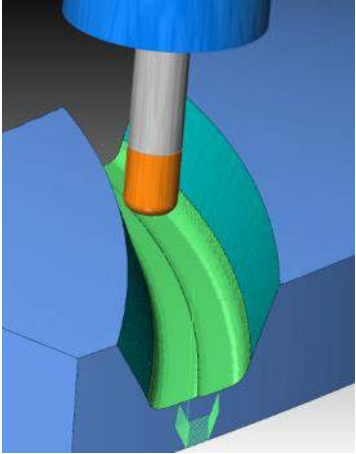
standard process chain for curved surface milling:



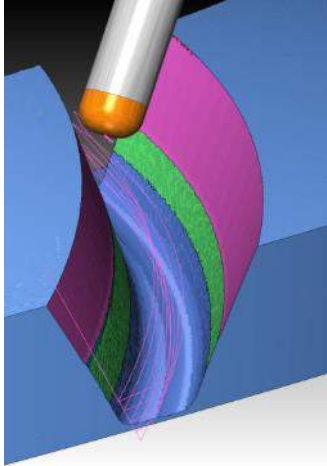
Definition Bevel Gear with GearCAM



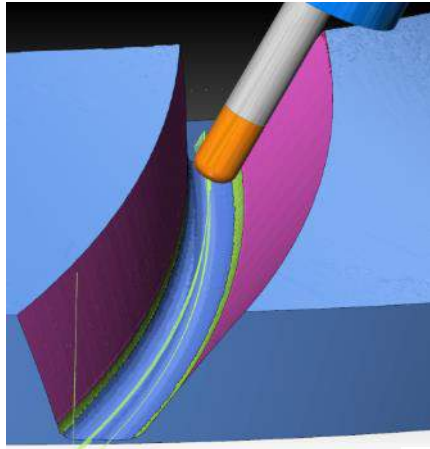
Processing sequence, cutting strategy / cutting conditions – finish milling:



roughing

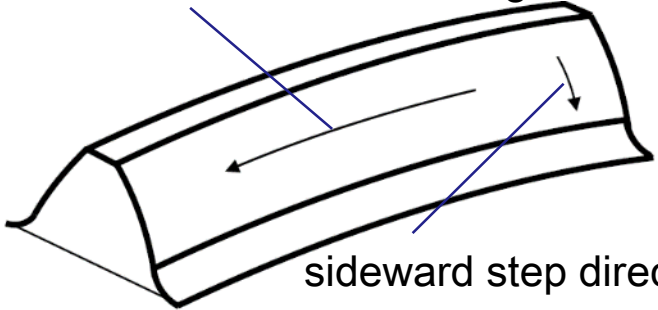


pre-finishing

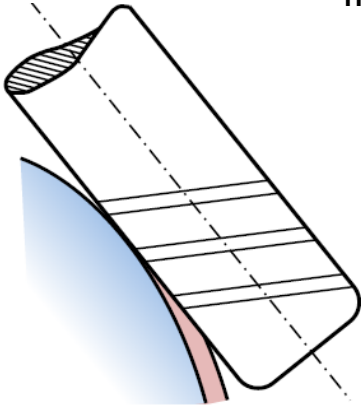


finishing

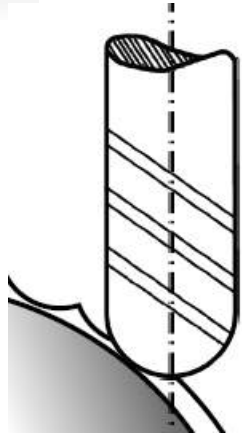
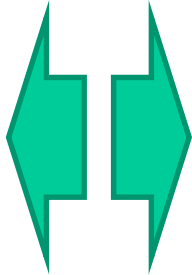
Feed direction / climb cutting



sideward step direction



5-axis swarf milling



curved surface milling
3-axis with
ball end mill cutter

Demands to machining centers:



gear milling on 5-axis milling centers

additional technical equipment:

- laser measurement system for cutting tools
- system for 3D workpiece measurement
- 5-axis calibration function



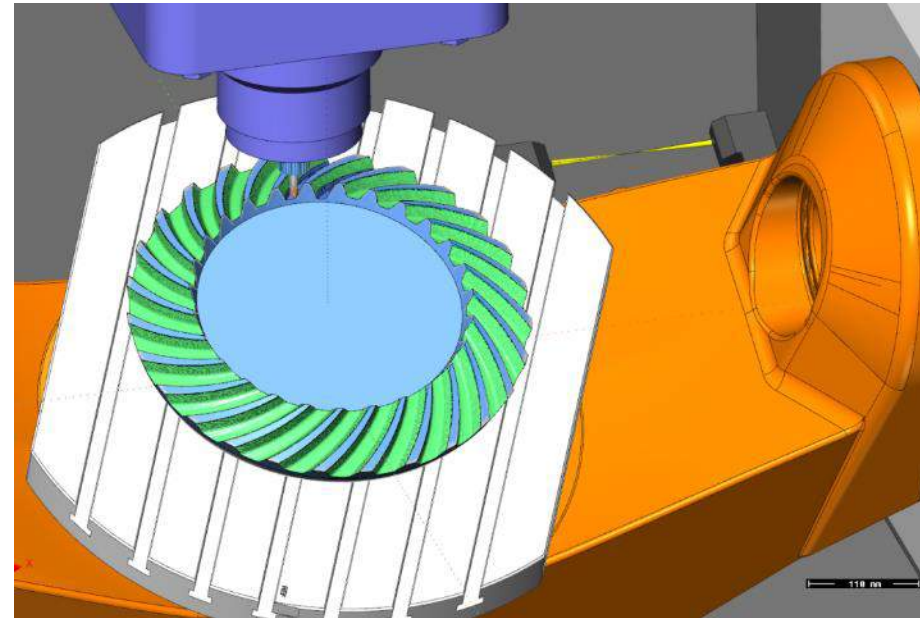
pinion shafts - 5-axis turn-mill centers

tooth quality is preliminary depending on accuracy of machining center:

- axis configuration (rotary axis !)
- pitch accuracy of rotary axis !
- static and dynamic accuracy !
- thermal stability (long term) !
- linear axis of secondary importance

configuration of rotary axis:

- both rotary axis on workpiece side only for limited workpiece weight (< ca. 500 kg)
- heavy/large gears (> dk= ca. 2000 mm, > ca. 4 t) => portal concept advantageous, both rotary axis in z-ram, static precise rotary table exclusively for positioning

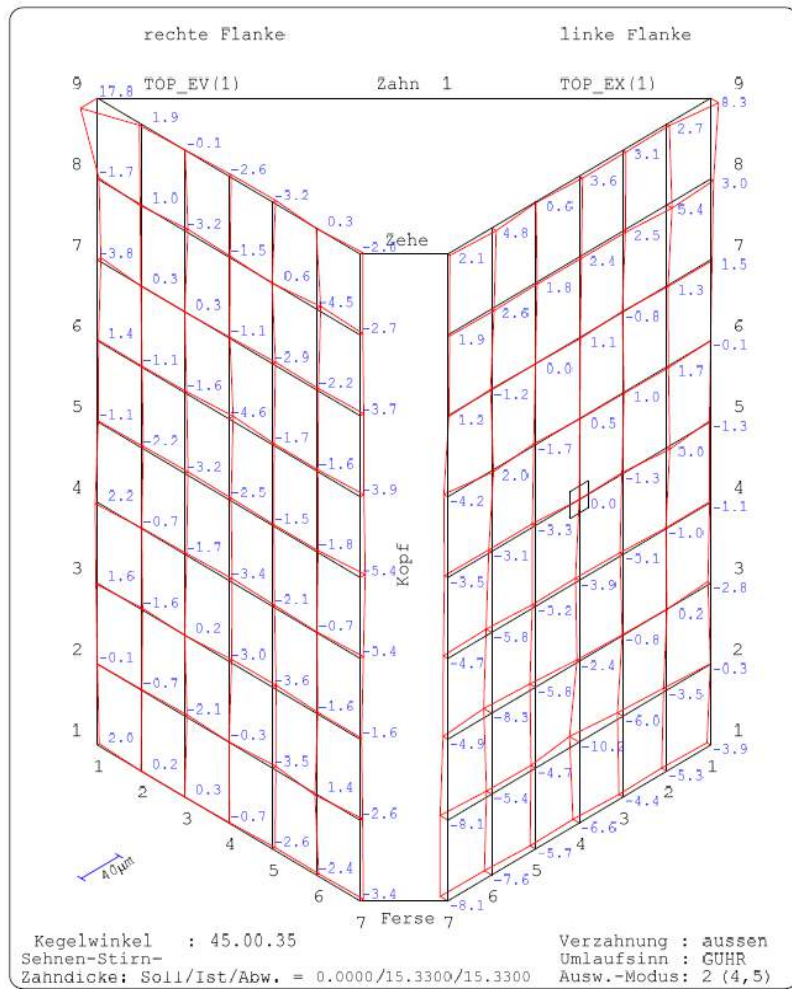


Bevel gear:

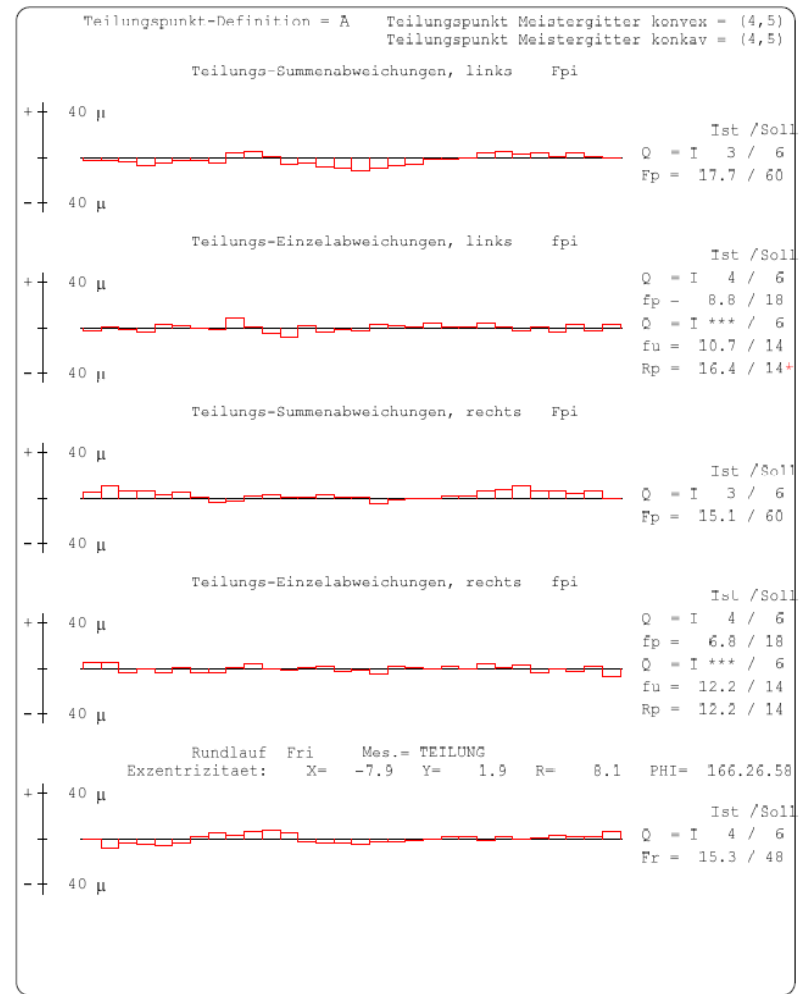
- Klingelnberg
- spiral toothed
- normal modul middle $m_n = 9,481\text{mm}$
- number of teeth $z = 30$
- tooth with $b = 80\text{mm}$
- outer diameter $d_k = 398\text{mm}$



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Qualität:
Soll: 6
Ist: 4



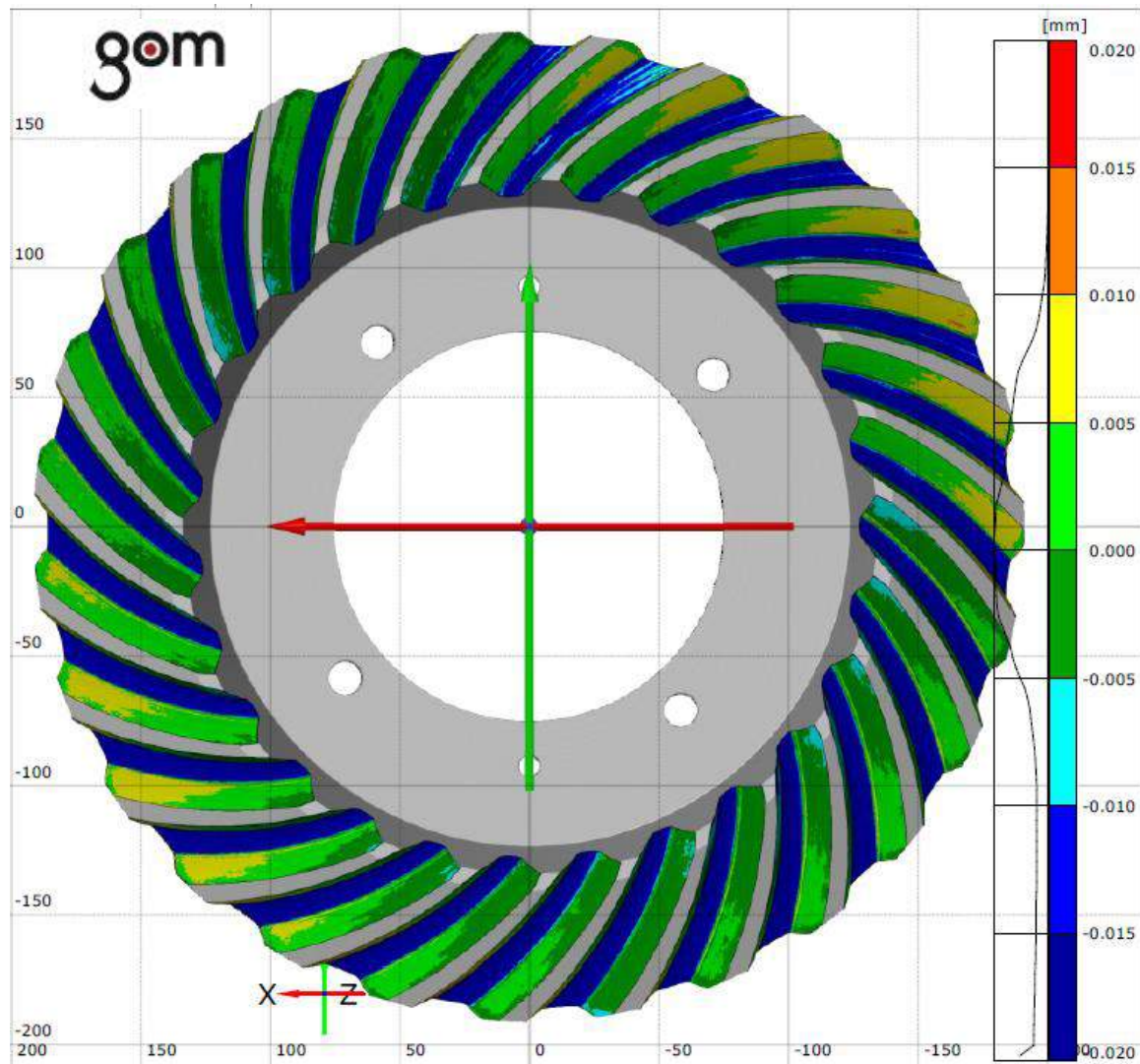
 SPIRAL-KEGELRAD	Bezeichnung : Spiralkegelrad	Mes.	Tol	Sym.	Tol	Mes.
	Zeichn. Nr. :	20.6	30	Pri	30	6.2
	Pruefer : A. Reinus	1.4	30	Pra	30	4.2
	Datum : 12-FEB-2014	0.6	30	Lik	30	10.2
	Bemerkung : Testmessung	19.8	30	Lif	30	12.3
	Masssystem : metrisch	23.1	50	Ges	50	10.5
KSY : Wks						

 SPIRAL-KEGELRAD	Bezeichnung : Spiralkegelrad	Zaehnezahl : 30
	Zeichn. Nr. :	Modul : 12.833
	Pruefer : A. Reinus	Verzahnung : aussen
	Datum : 12-FEB-2014	Messung : Zahn
	Bemerkung : Testmessung	Umlaufsinn : GUHR
	Masssystem : metrisch	Q-Typ: ISO 17485-2006
KSY : Wks		

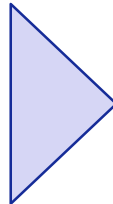


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Optical measuring with



EUKLID
GearCAM

Pair of bevel wheels:

18CrNiMo7-6

Case hardened

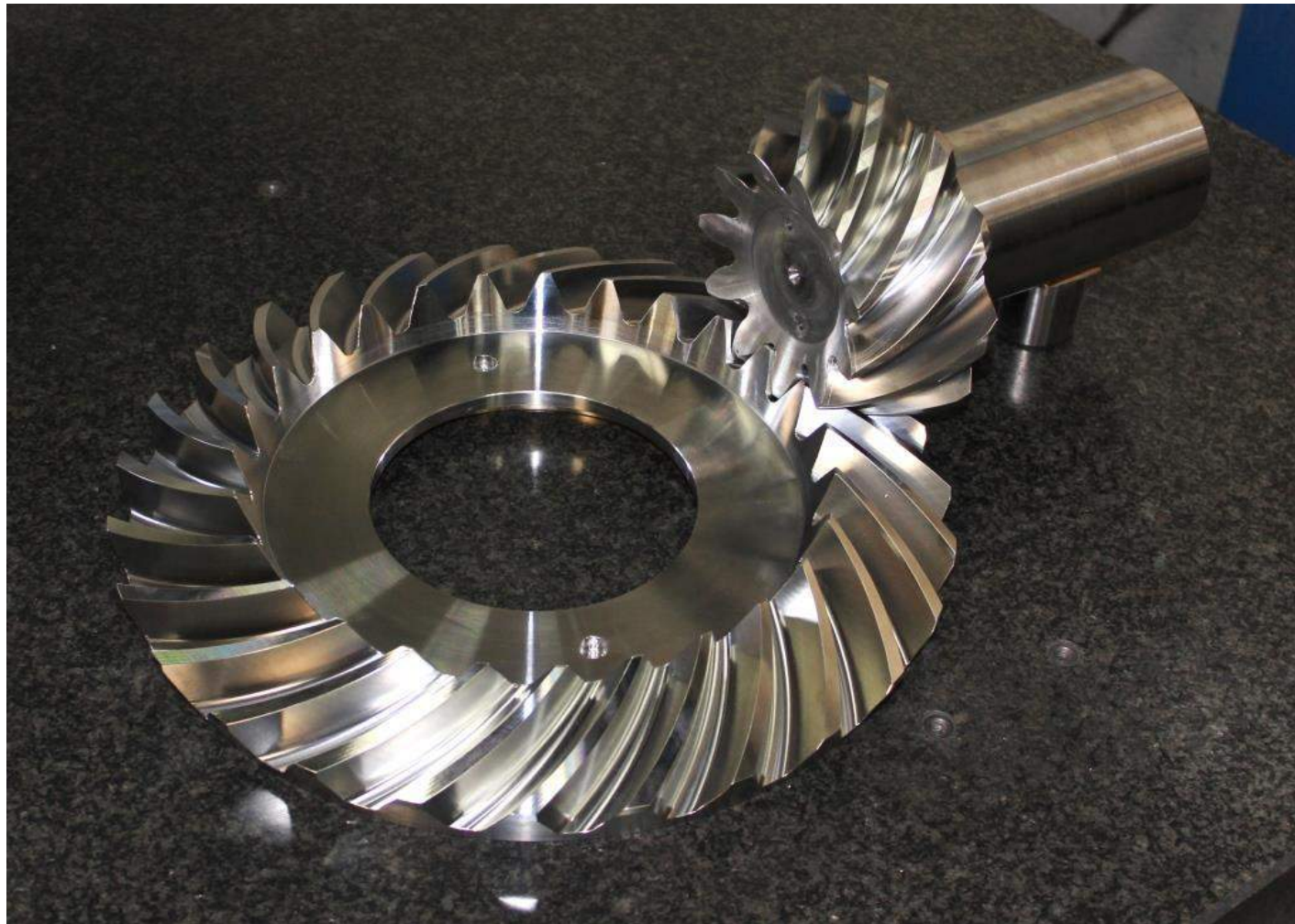
58 HRC

$m_n = 9\text{mm}$

$z_1 = 11 / z_2 = 27$

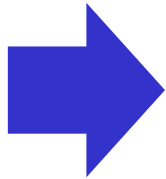
dimensioning:

KISSsoft



Summary and outlook:

- 5-axis milling of gears belongs to state of the art
- 5-axis milling of gears places high demands on CAM-modules, machining centers, cutting tools und process know-how
- under these pre-conditions even higher toothing qualities can be reached by 5-axis milling
- process related the 5-axis milling of gears for series production is subjected to economical restrictions in comparison to established gear technologies.
- in case of small lot sizes, single part production or special gears the 5-axis milling of gears offers significant competitive advantages in terms of delivery time and cost – with nearly no restrictions to profile design.



5-axis milling of gears is no direct competition to the established gear manufacturing technologies, but rather will be an increasingly important complementary alternative.