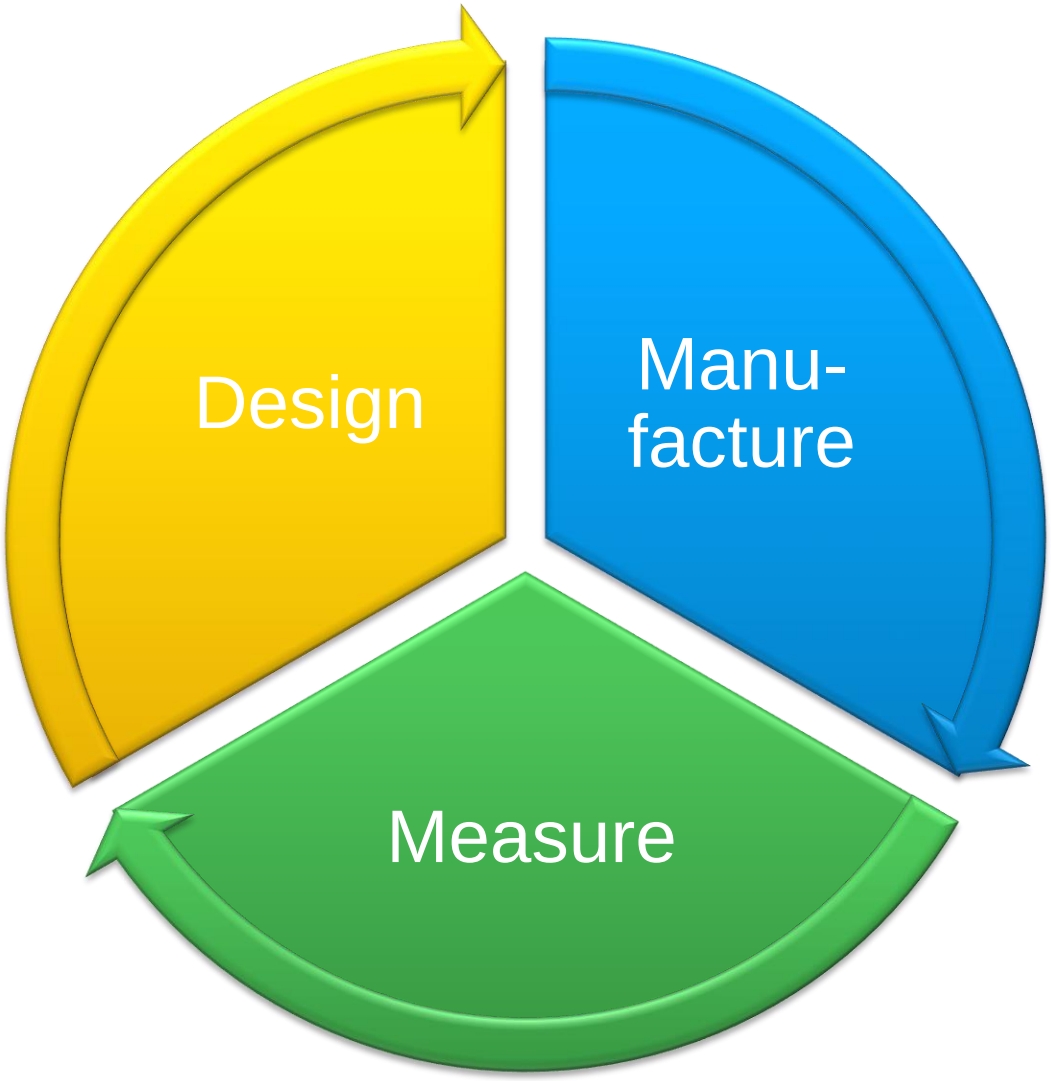
Design – Manufacture – Measure



Dr. Inho Bae, Hanspeter Dinner

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T. +41 55 254 20 50, info@KISSsoft.AG, www.KISSsoft.AG

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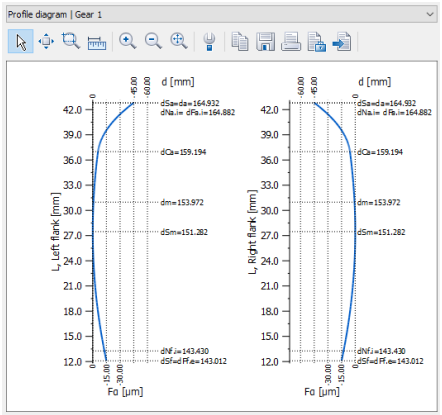
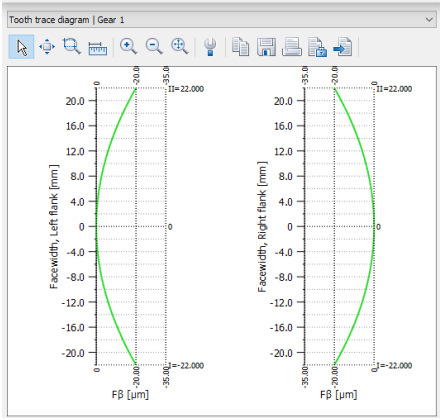
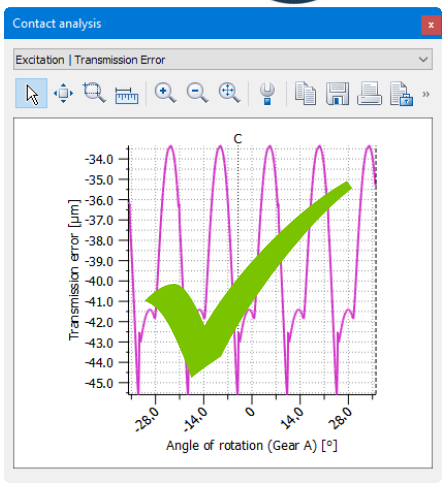
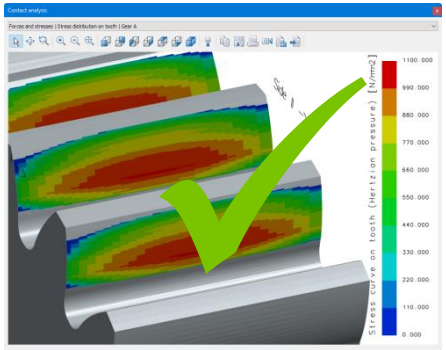
Characteristics of manufactured gear → NOT known

Designed gear / reference





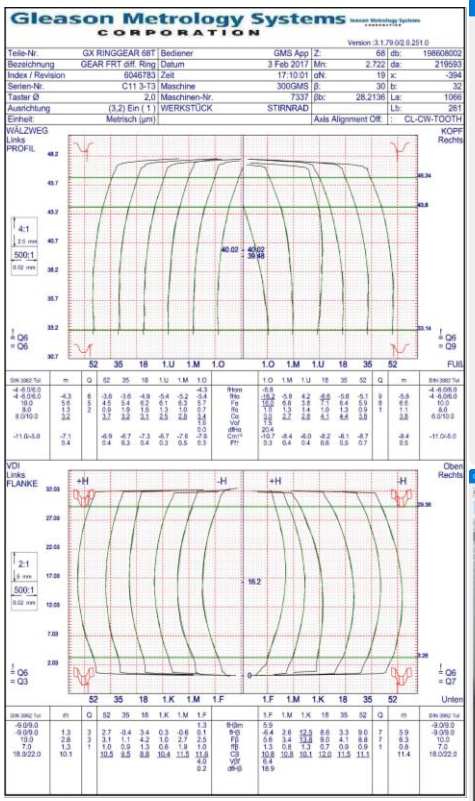


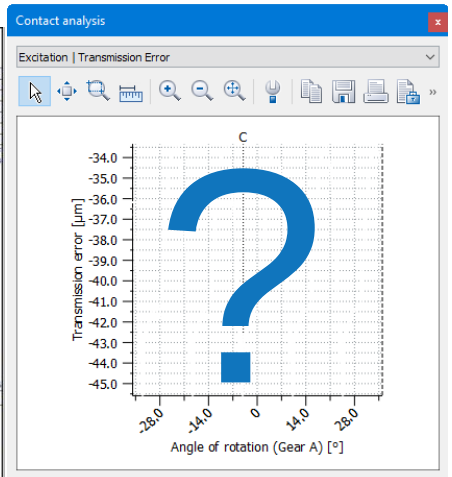


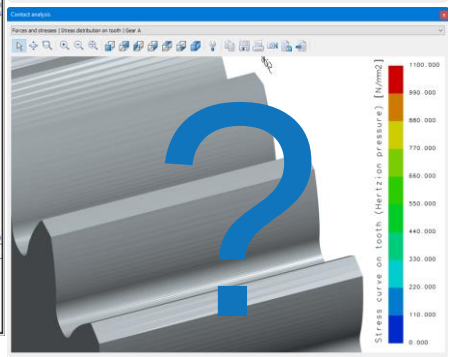
Transmission error = ✓

Load distribution = ✓

Manufactured gear







Transmission error = ?

Load distribution = ?

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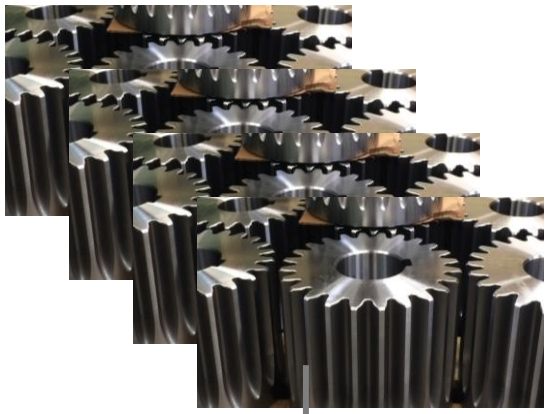
Basic working principle in KISSsoft

Reference + Variants → LTCA

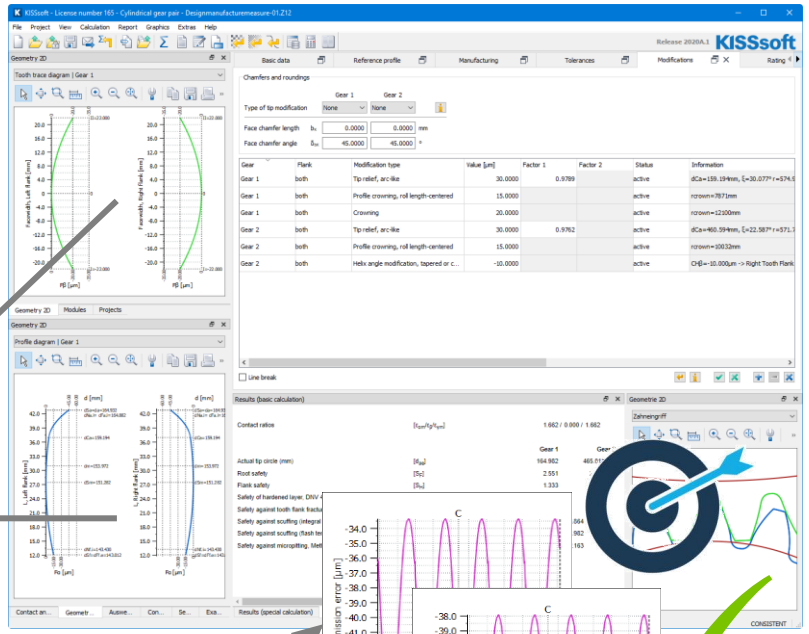


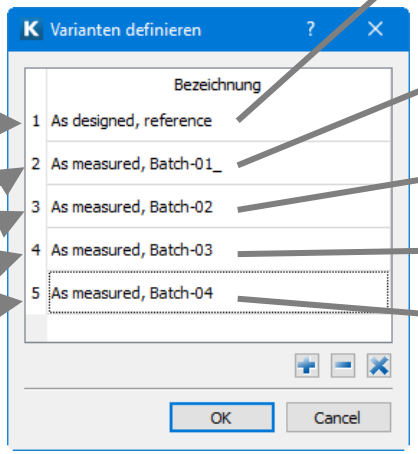
Batch-01-300GM SP-GAMA -

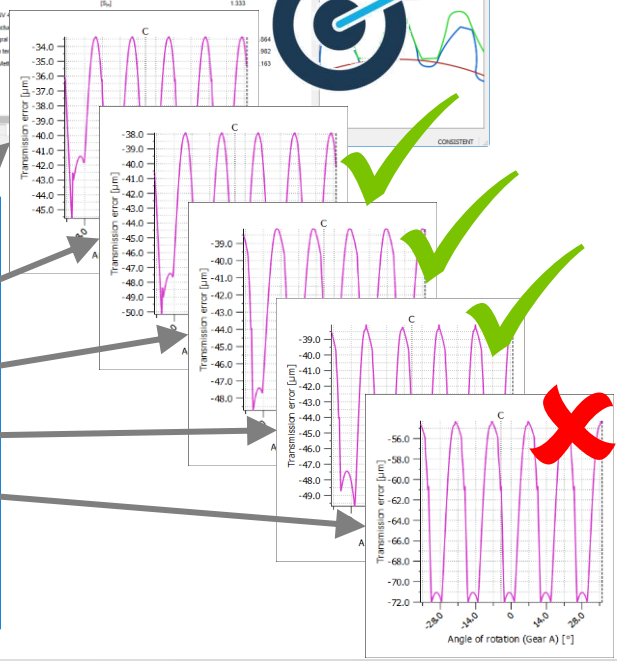
Batch-02-300GM SP-GAMA -

Batch-03-300GM SP-GAMA -

Batch-04-300GM SP-GAMA -



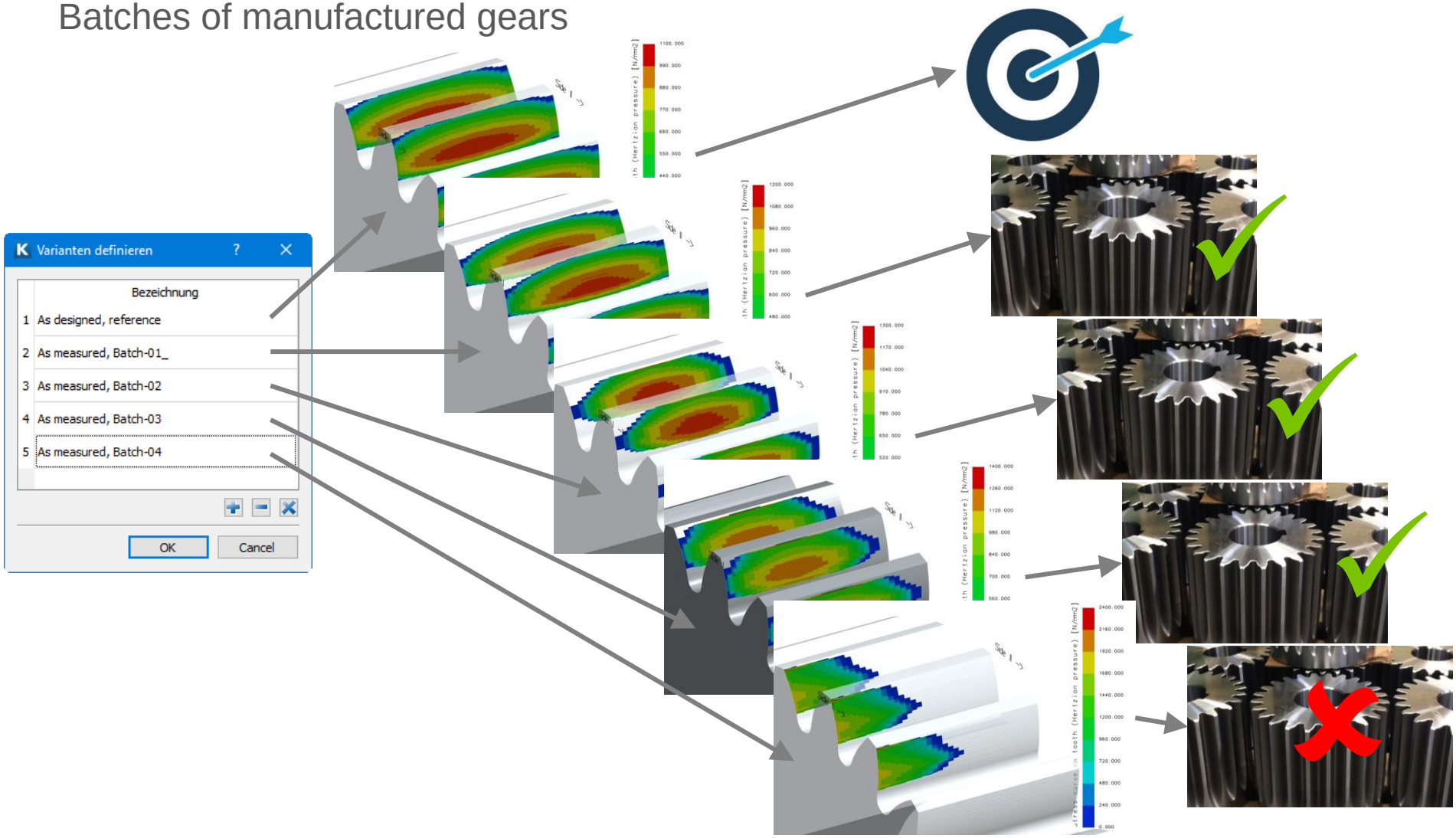




KISSsoft

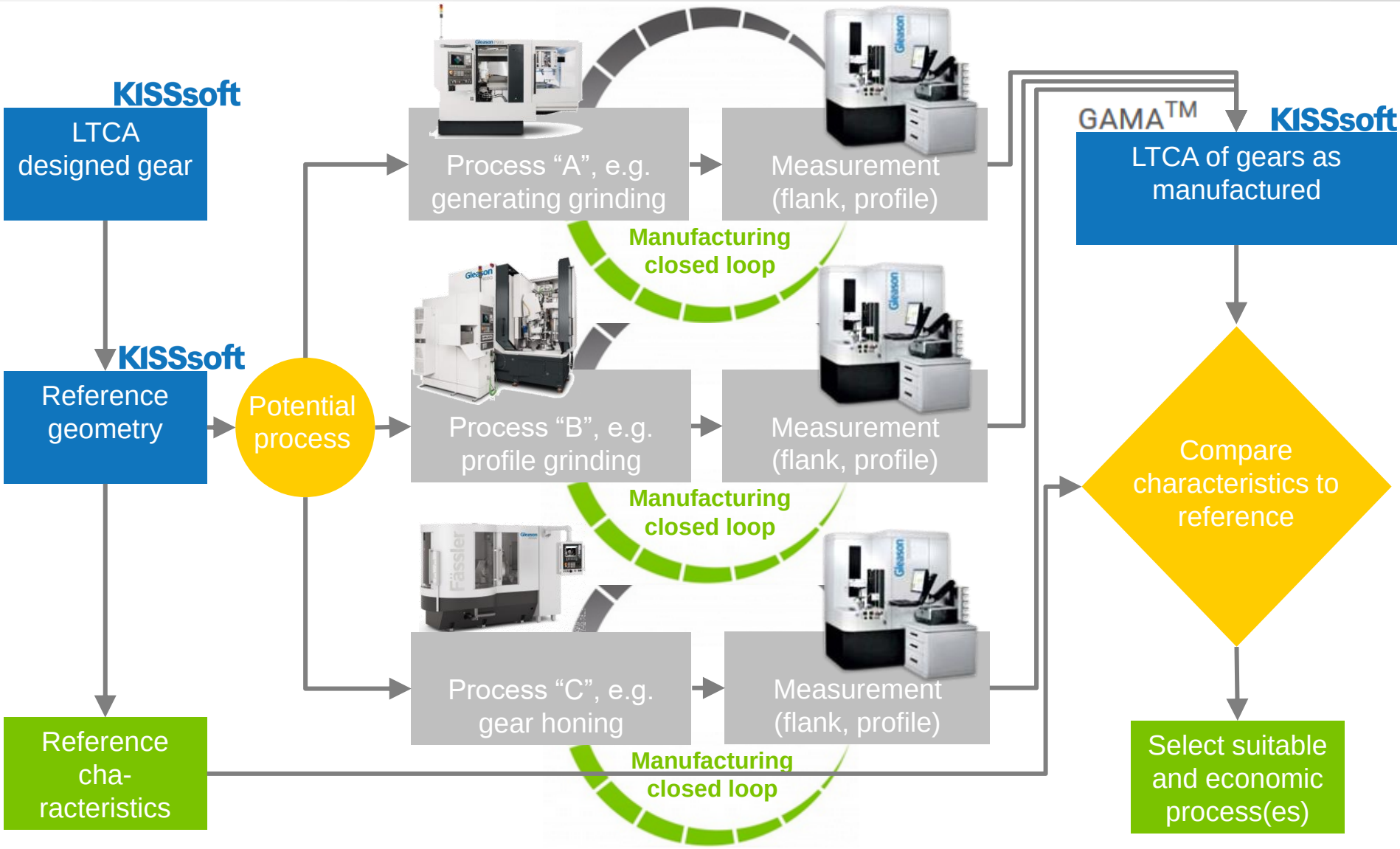
Use case 1: Acceptance of gears

Batches of manufactured gears



KISSsoft

Use case 2: Selection of economical process



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Use case 3: Design or process modification

KISSsoft
Gear design for desired characteristics

KISSsoft
Characteristics variation due to deviations

KISSsoft
Reference geometry

Manufacturing

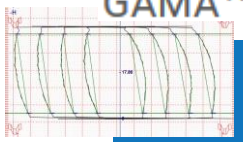
Measured geometry

Manufacturing closed loop

Reference cha-racteristics

KISSsoft
Modify design

Modify process



GAMA™

Export data

Compare characteristics to reference

KISSsoft
Determine characteristics of manufactured gear

KISSsoft
Convert measured geometry to geometry modification

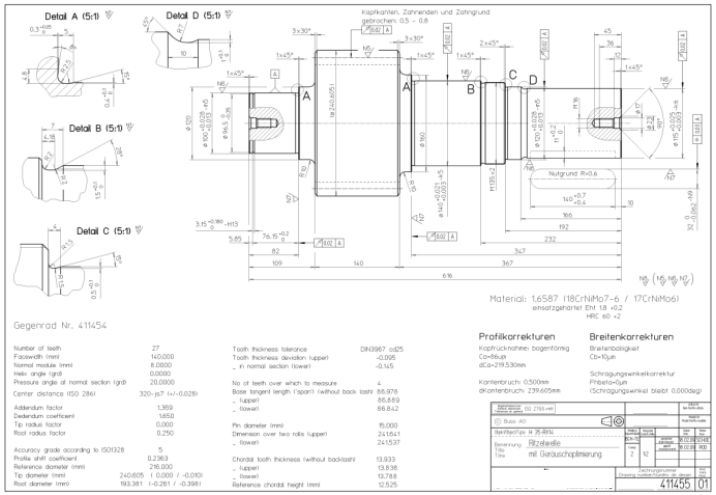
KISSsoft GAMA™
Analyze data, extract significant deviations

Approved design and approved process

KISSsoft

STEP 1: KISSsoft Input: Macro geometry

Macro geometry input of the designed gear



Basic data | Reference profile | Manufacturing | Tolerances | Modifications | Rating | Factors | Contact analysis

Geometry

				Gear 1	Gear 2	
Normal module	m_n	2.6800	mm			Details...
Normal p...re angle	α_n	21.2328	°	Numbe...teeth z	11	40
Gear 1		helix right hand		Facewidth b	23.3000	20.8000 mm
Helix ang...ce circle	β	22.5000	°	Profil...icient x	0.7680	-0.3694
Center distance	a	75.0000	mm ☐	Quali...2013) A	6	6

Material and lubrication

Gear 1	Case-hardening steel	18CrNiMo7-6, case-hardened, ISO 6336-5 Figure 9/10 (MQ), Core hardness >=25HRC Jom	
Gear 2	Case-hardening steel	18CrNiMo7-6, case-hardened, ISO 6336-5 Figure 9/10 (MQ), Core hardness >=25HRC Jom	
Lubrication	Oil: ISO-VG 220		Oil bath lubrication

Basic data | Reference profile | Manufacturing | Tolerances | Modifications | Rating | Factors | Contact analysis

Machining step Gear 1

Selection: Final machining (\

Machining step Gear 2

Selection: Final machining (\

Final machining Gear 1

Tool selection	Reference profile
Input	Factors
Select ref...ce profile	Own Input
Designation	Input...
Dedendum coefficient h^*_{fP}	1.4599
Root radius coefficien ρ^*_{fP}	0.3000
Addendum coefficient h^*_{aP}	0.8722

Final machining Gear 2

Tool selection	Reference profile
Input	Factors
Select ref...ce profile	Own Input
Designation	Input...
Dedendum coefficient h^*_{fP}	1.3345
Root radius coefficien ρ^*_{fP}	0.3000
Addendum coefficient h^*_{aP}	1.2028

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STEP 1: KISSsoft Input: Micro geometry

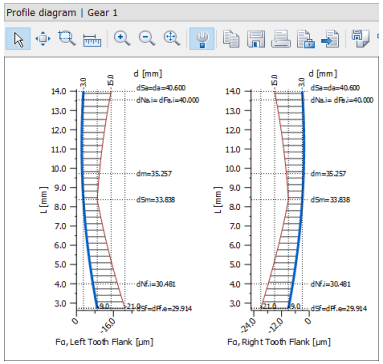
Gear 1

Gear	Flank	Modification type	Value [µm]	Factor 1	Factor 2	Status
Gear 1	left	Crowning	3.0000			active
Gear 1	left	Helix angle modification, tapered or conical	-4.0000			active
Gear 1	left	Pressure angle modification (value)	6.0000			active
Gear 1	left	Profile crowning, roll length-centered	3.0000			active
Gear 1	right	Helix angle modification, tapered or conical	6.0000			active
Gear 1	right	Crowning	3.0000			active
Gear 1	right	Pressure angle modification (value)	6.0000			active
Gear 1	right	Profile crowning, roll length-centered	3.0000			active

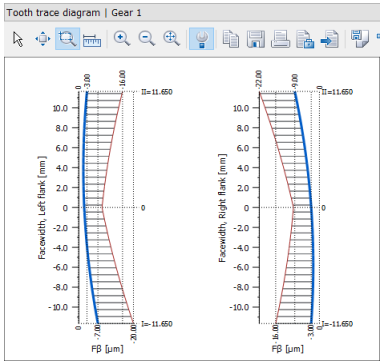
Gear 2

Gear	Flank	Modification type	Value [µm]	Factor 1	Factor 2	Status
Gear 2	left	Crowning	3.0000			active
Gear 2	left	Profile crowning, roll length-centered	6.0000			active
Gear 2	right	Helix angle modification, tapered or conical	20.0000			active
Gear 2	right	Tip relief, linear	25.0000	2.0750		active
Gear 2	right	Profile crowning, roll length-centered	3.0000			active
Gear 2	right	Crowning	3.0000			active

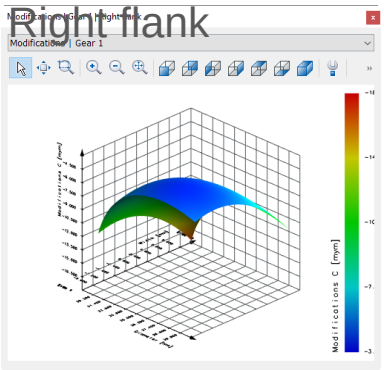
Profile



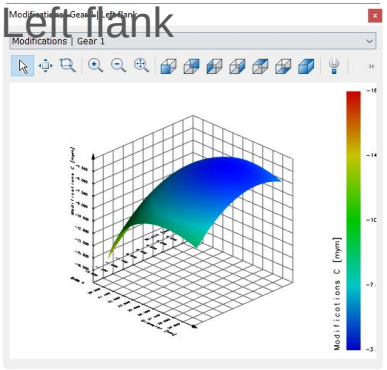
Lead



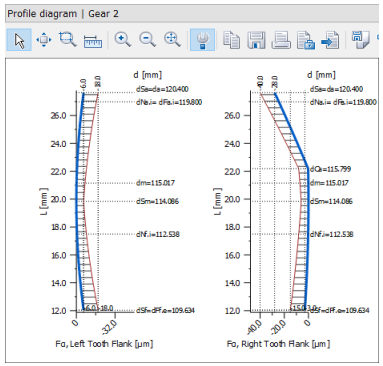
Right flank



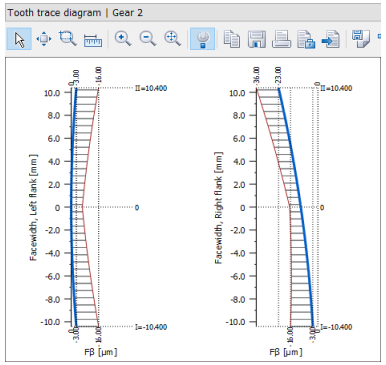
Left flank



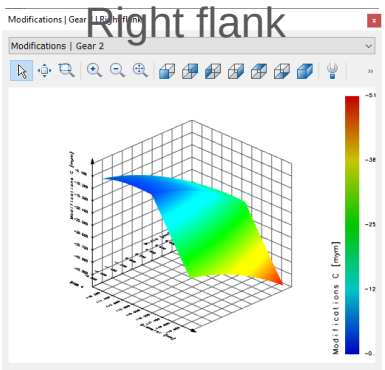
Profile



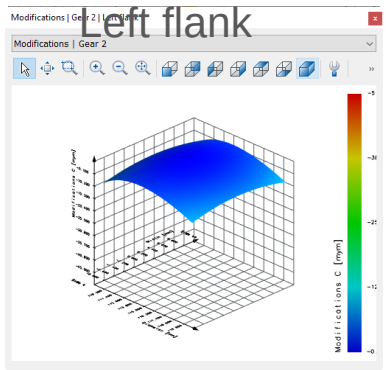
Lead



Right flank



Left flank



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STEP 1: KISSsoft Input: Manufacturing deviations from gear quality

Potentially, 2^n+1 calculations, where n is the number of independent modifications per flank plus one calculation for middle of tolerance field for all modifications, here n=7 → 129 combinations for one single torque level. Analysis can be done for several torque levels simultaneously.

KISSsoft

KISSsoft Release 2020 A.1

KISSsoft-Entwicklungs-Version KISSsoft AG CH-8608 BUBIKON

File

Name : CylGearPair 1 (spur gear)
Description: KISSsoft example
Changed by: hdinner on: 06.10.2020 at: 08:25:27

Manufacturing tolerances

Tolerances for cylindrical gears	ISO 1328-1:2013 (JIS B 1702-1:2016)			
Accuracy grade	(A)	6	6	
Single pitch deviation	(µm)	+- 11.0	+- 11.0	(fpT)
Normal base pitch deviation	(µm)	+- 10.0	+- 10.4	(fpbT)
Total cumulative pitch deviation	(µm)	33.0	41.0	(FpT)
Profile form deviation	(µm)	12.0	12.0	(ffaT)
Profile slope deviation	(µm)	+- 9.5	+- 9.5	(fHaT)
Total profile deviation	(µm)	15.0	15.0	(FaT)
Helix form deviation	(µm)	11.0	12.0	(ffbT)
Helix slope deviation	(µm)	+- 10.0	+- 10.0	(fHbT)
Total helix deviation	(µm)	15.0	16.0	(FbT)
Runout	(µm)	30.0	37.0	(FrT)
Single flank composite, tooth-to-tooth	(µm)	10.0	10.0	(fisT)
Total tangential composite deviation	(µm)	43.0	51.0	(FisT)
Sector pitch deviation	(µm)	+- 21.0	+- 27.0	(Fpz/8T)
Difference between adjacent pitches	(µm)	15.0	16.0	(fuT)

Tolerances for cylindrical gears	ISO 1328-1:1995 (JIS B 1702-1:1998)			
Accuracy grade	(Q)	6	6	
Single pitch deviation	(µm)	+- 10.0	+- 11.0	(fpt)
Normal base pitch deviation	(µm)	+- 9.4	+- 10.3	(fpb)
Total cumulative pitch deviation	(µm)	36.0	47.0	(Fp)

Modifications sizing

Conditions I | Conditions II | Results | Graphic I | Graphic II

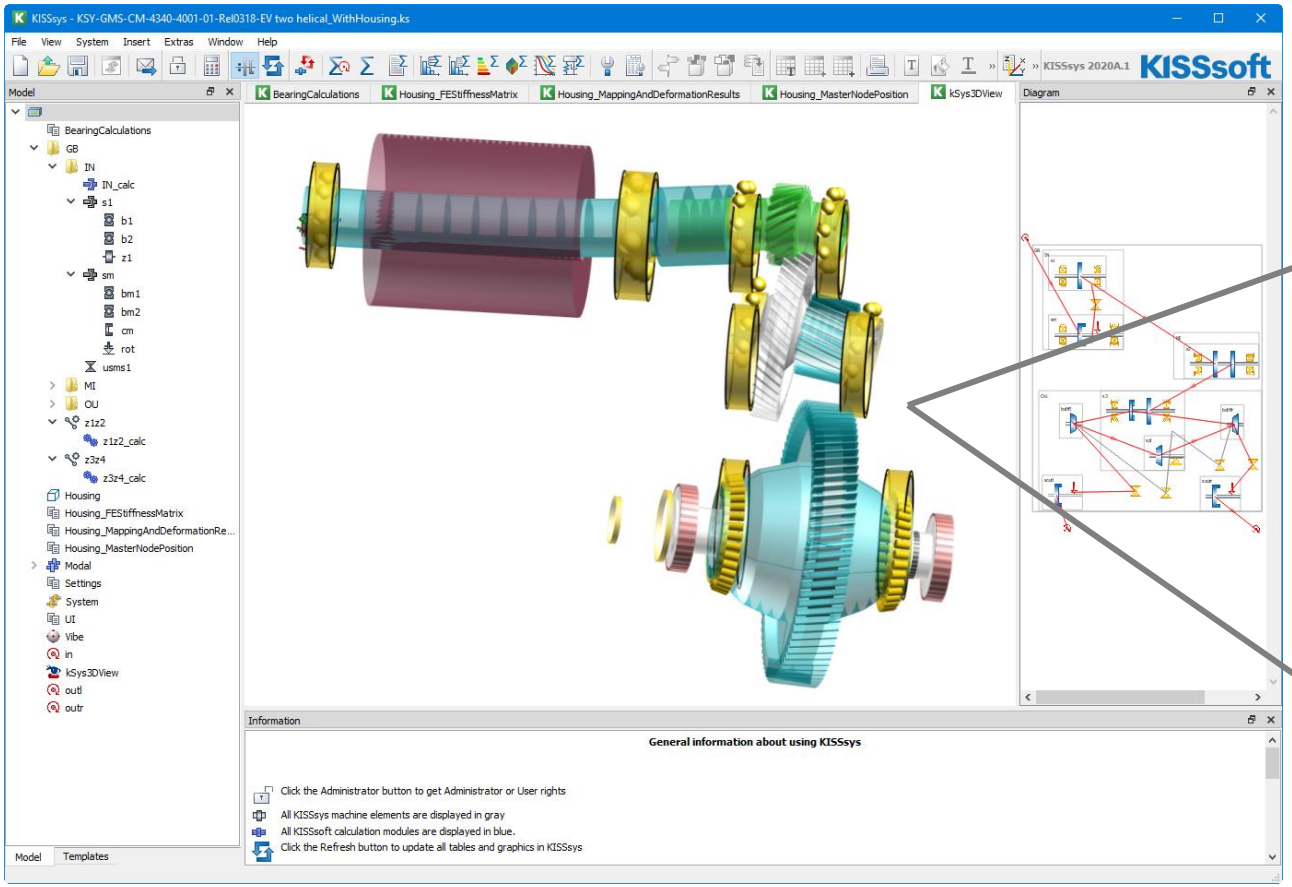
No.	Gear	Synchronize with no.	Flank	Modification type	Number of steps	Value (min) [µm]	Value (max) [µm]
1	Gear 1	1	left	Crowning	3	-11.0000	11.0000
2	Gear 1	2	left	Helix angle modification, tapered or conical	3	-10.0000	10.0000
3	Gear 1	3	left	Pressure angle modification (value)	3	-10.0000	10.0000
4	Gear 1	4	left	Profile crowning, roll length-centered	3	-9.5000	9.5000
5	Gear 1	5	right	Helix angle modification, tapered or conical	3	-10.0000	10.0000
6	Gear 1	6	right	Crowning	3	-12.0000	12.0000
7	Gear 1	7	right	Pressure angle modification (value)	3	-9.5000	9.5000
8	Gear 1	8	right	Profile crowning, roll length-centered	3	-9.5000	9.5000
9	Gear 2	9	left	Crowning	3	-12.0000	12.0000
10	Gear 2	10	left	Profile crowning, roll length-centered	3	-9.5000	9.5000
11	Gear 2	11	left	Helix angle modification, tapered or conical	3	-10.0000	10.0000
12	Gear 2	12	left	Tip relief, linear	3	-12.0000	12.0000
13	Gear 2	13	right	Profile crowning, roll length-centered	3	-9.5000	9.5000
14	Gear 2	14	right	Crowning	3	-12.0000	12.0000

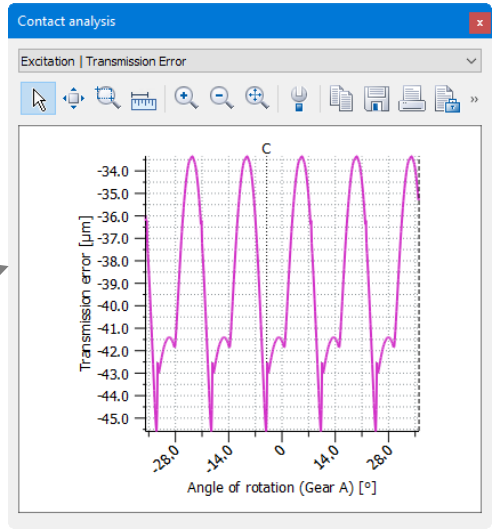
Report length: Short form | Accept | Delete | Report | Calculate | Cancel | Save | Restore

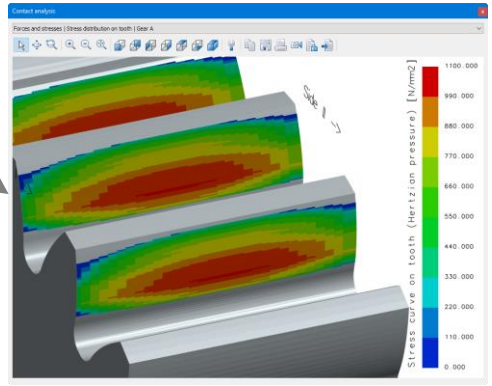
KISSsoft

STEP 2: LTCA of designed gear

Loaded contact analysis for reference geometry, considering system level deformation







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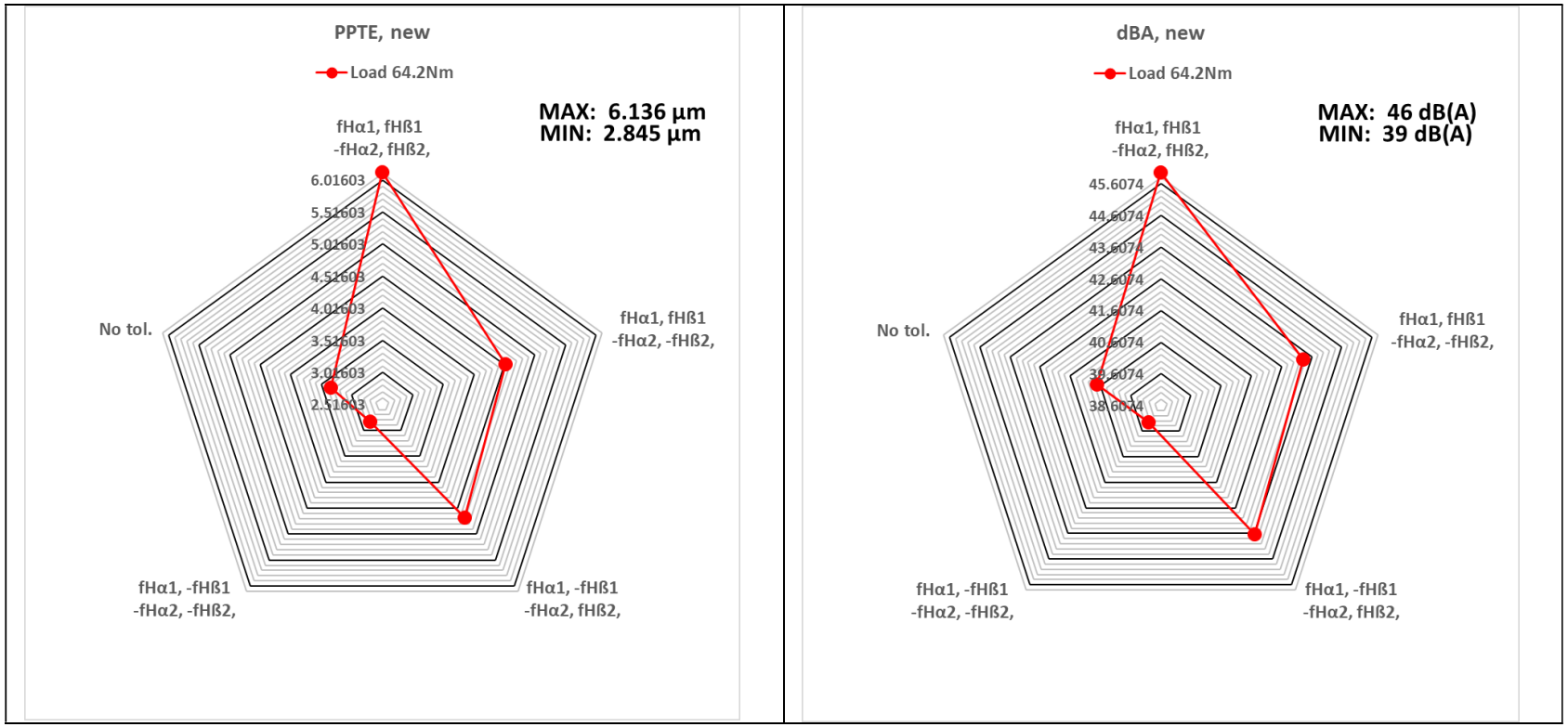
STEP 2: LTCA of designed gear with tolerance variation

Loaded contact analysis for reference geometry with manufacturing tolerances / deviations superimposed, considering system level deformation



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Resulting characteristics

without manufacturing deviation

Results (Contact analysis)

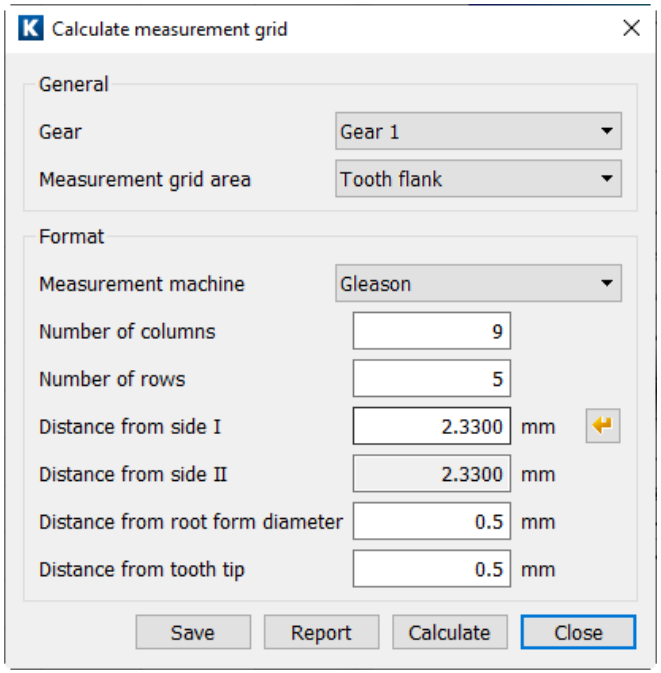
		min	max	Δ	μ
Transmission error	(μm)	-29.8907	-26.5268	3.3639	-27.6108
Excitation force	(N)	3773.9648	4619.4325	845.4677	4357.9199
Tangents Stiffness curve	(N/μm)	190.1098	287.3960	97.2862	255.2770
Secants stiffness curve	(N/μm)	142.2260	158.9537	16.7277	152.8458
Line load	(N/mm)	0.0000	908.4017	908.4017	210.1171
Torque Gear 1	(Nm)	64.1451	64.1575	0.0124	64.1510
Torque Gear 2	(Nm)	224.1770	227.8568	3.6798	225.5483
Speed, gear 2	(1/min)	273.8453	275.9028	2.0575	274.9989
Power loss	(W)	155.8756	267.0384	111.1628	223.8706
Efficiency	(%)	96.0250	97.6797	1.6547	96.6676
Contact temperature	(°C)	74.5472	211.7577	137.2106	99.8802
Thickness of lubrication film	(μm)	0.0697	0.4525	0.3828	0.1493
Active flank area of usage (diameter) Gear 1	(mm)	15.4062	20.1640	4.7578	
Active flank area of usage (diameter) Gear 2	(mm)	56.3091	59.7814	3.4722	
Hertzian pressure	(N/mm²)		2116.2030		809.0912
Tooth root stress gear 1 (graphical method)	(N/mm²)		377.8748		155.4234
Tooth root stress gear 1 (at 30° tangents)	(N/mm²)		375.2064		154.3937
Tooth root stress gear 2 (graphical method)	(N/mm²)		309.0625		173.8598
Tooth root stress gear 2 (at 30° tangents)	(N/mm²)		298.7796		166.2276

Safety against scuffing		1.9668
Transverse contact ratio under load	[εα]	1.1789
	min	0.6316
	μ	0.9845
	max	1.1789
	side I, II	1.1789 / 0.6316
Overlap ratio under load	[εβ]	0.4316
Total contact ratio under load (max)	[εγ]	1.6105
Sound pressure level (according to Masuda)	[dB(A)]	40.7

KISSsoft

STEP 3: KISSsoft output: Measurement grid

Export measurement grid report to be used in GAMA

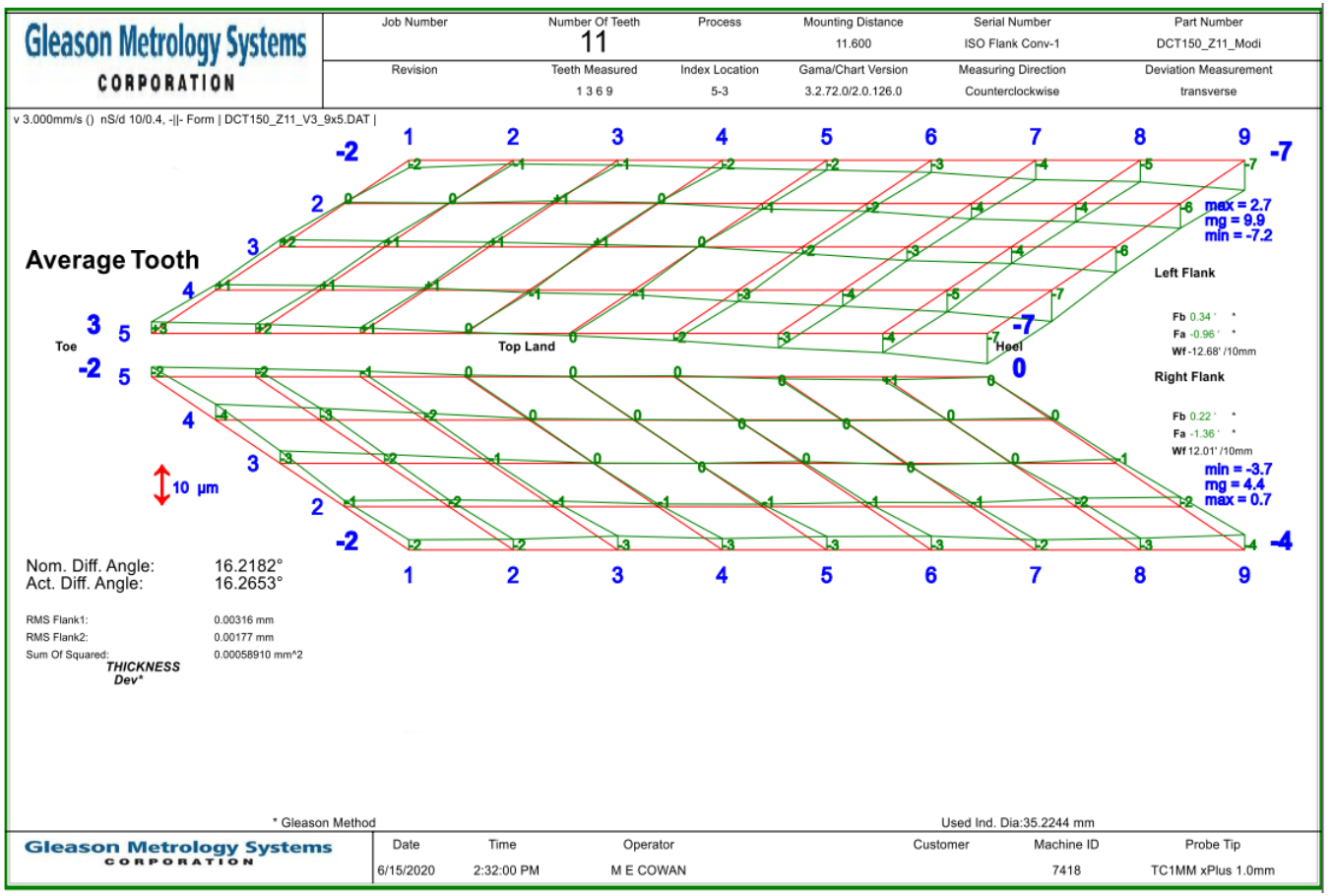



```
*************************************************************************
*                      NOMINAL - COORDINATE - LIST                      *
*                      *** PINION CONCAVE ***                           *
*-----------------------------------------------------------------------*
* PART # :                          NUMBER OF TEETH % Z ! 11            *
* DCT150_Z11_Modi                   PINION  THEORETICAL 23 Apr 2020     *
* DIFF. ANG: % DEDI ! -16.2182      REF. PT.: ! (5, 3)                  *
*-----------------------------------------------------------------------*
* NUMBER COLUMNS: ! 9               NUMBER LINES: ! 5                   *
*-----------------------------------------------------------------------*
* DATE:  23 Apr 2020          TIME: 09:47:39          UNITS: mm         *
*************************************************************************
* J  I      X         Y         Z         XN        YN        ZN      *
*=======================================================================*
 1  1    14.8311   -4.6709   -9.3200    .3045    -.9334    -.1895
 1  2    15.9476   -4.5383   -9.3200    .3679    -.9102    -.1896
 1  3    17.1005   -4.2145   -9.3200    .4201    -.8874    -.1894
 1  4    18.2695   -3.7167   -9.3200    .4744    -.8599    -.1882
 1  5    19.4370   -3.0522   -9.3200    .5137    -.8372    -.1875
 2  1    15.0860   -3.7673   -6.9900    .2906    -.9381    -.1879
 2  2    16.1924   -3.5675   -6.9900    .3543    -.9159    -.1880
 2  3    17.3237   -3.1747   -6.9900    .4069    -.8939    -.1878
 2  4    18.4605   -2.6072   -6.9900    .4616    -.8672    -.1866
 2  5    19.5858   -1.8735   -6.9900    .5012    -.8450    -.1859
 3  1    15.2859   -2.8496   -4.6600    .2766    -.9424    -.1877
 3  2    16.3783   -2.5834   -4.6600    .3407    -.9212    -.1878
 3  3    17.4838   -2.1230   -4.6600    .3935    -.8999    -.1876
 3  4    18.5842   -1.4880   -4.6600    .4486    -.8740    -.1864
 3  5    19.6631    -.6876   -4.6600    .4885    -.8525    -.1857
 4  1    15.4301   -1.9213   -2.3300    .2625    -.9465    -.1874
 4  2    16.5044   -1.5896   -2.3300    .3269    -.9262    -.1876
 4  3    17.5801   -1.0633   -2.3300    .3801    -.9057    -.1874
 4  4    18.6402    -.3629   -2.3300    .4355    -.8806    -.1862
 4  5    19.6688     .5010   -2.3300    .4758    -.8597    -.1855
 5  1    15.5180    -.9856     .0000    .2484    -.9503    -.1872
 5  2    16.5703    -.5897     .0000    .3131    -.9310    -.1873
 5  3    17.6122     .0005     .0000    .3665    -.9113    -.1872
 5  4    18.6280     .7636     .0000    .4224    -.8870    -.1860
 5  5    19.6026    1.6883     .0000    .4629    -.8667    -.1853
 6  1    15.5492    -.0462    2.3300    .2342    -.9540    -.1870
 6  2    16.5756     .4125    2.3300    .2992    -.9356    -.1871
 6  3    17.5800    1.0648    2.3300    .3529    -.9167    -.1870
 6  4    18.5479    1.8879    2.3300    .4091    -.8933    -.1858
 6  5    19.4648    2.8696    2.3300    .4500    -.8736    -.1851
 7  1    15.5236     .8936    4.6600    .2200    -.9574    -.1868
 7  2    16.5204    1.4136    4.6600    .2852    -.9400    -.1869
 7  3    57.4622   -1.7056    4.1600    .3392    -.9219    -.1868
 7  4    58.5045   -1.2912    4.1600    .3958    -.8993    -.1856
```


KISSsoft

STEP 5: GAMA measurement

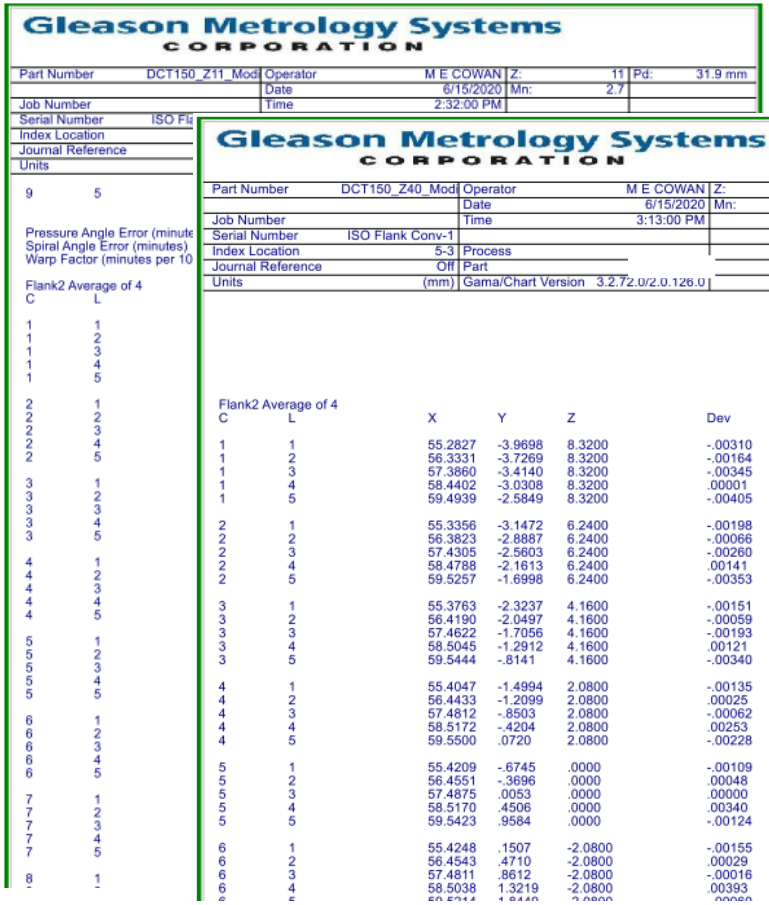
Measurement of manufacturing deviation of pinion and gear



KISSsoft

Measurement of manufacturing deviation of pinion and gear

Left flank



Gleason Metrology Systems
CORPORATION

Part Number	DCT150_Z11_Mod	Operator	M E COWAN	Z:	11	Pd:	31.9 mm
		Date	6/15/2020	Mn:	2.7		
Job Number		Time	2:32:00 PM				
Serial Number	ISO Fl						
Index Location							
Journal Reference							
Units							

Pressure Angle Error (minute
Spiral Angle Error (minutes)
Warp Factor (minutes per 10

Flank2 Average of 4

C	L
9	5
1	1
1	2
1	3
1	4
1	5
2	1
2	2
2	3
2	4
2	5
3	1
3	2
3	3
3	4
3	5
4	1
4	2
4	3
4	4
4	5
5	1
5	2
5	3
5	4
5	5
6	1
6	2
6	3
6	4
6	5
7	1
7	2
7	3
7	4
7	5
8	1

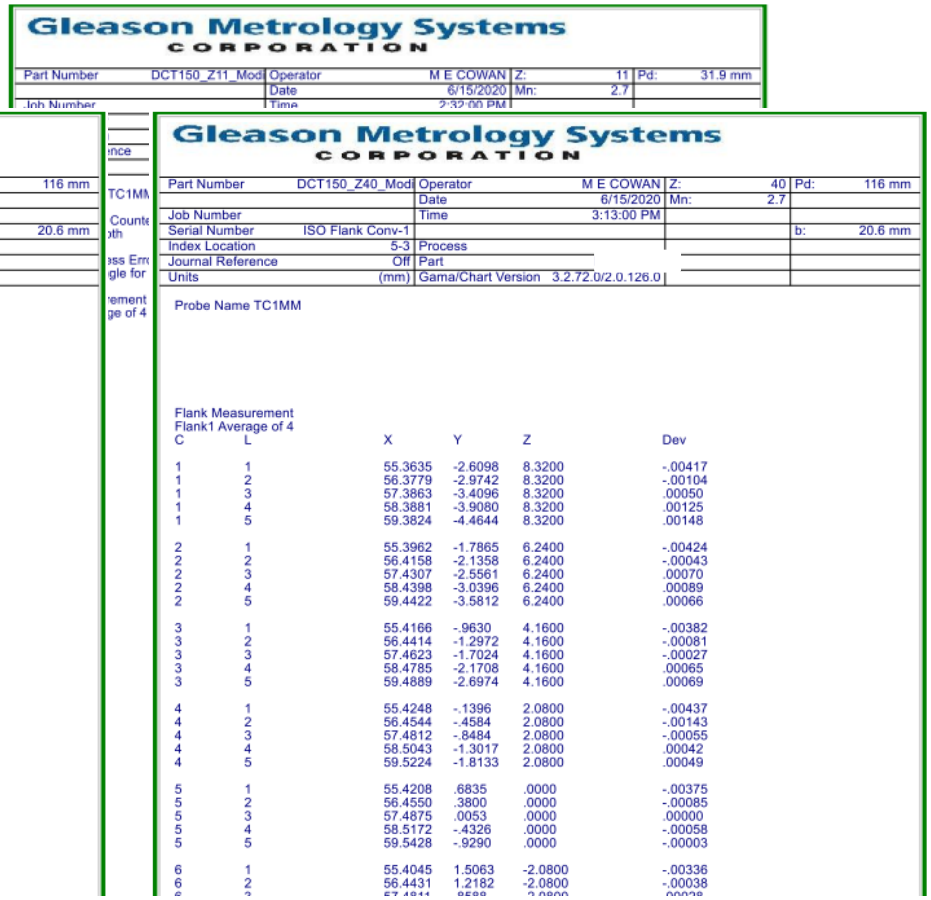
Gleason Metrology Systems
CORPORATION

Part Number	DCT150_Z40_Mod	Operator	M E COWAN	Z:	40	Pd:	116 mm
		Date	6/15/2020	Mn:	2.7		
Job Number		Time	3:13:00 PM				
Serial Number	ISO Flank Conv-1					b:	20.6 mm
Index Location	5-3	Process					
Journal Reference	Off	Part					
Units	(mm)	Gama/Chart Version	3.2.72.0/2.0.126.0				

Flank2 Average of 4

C	L	X	Y	Z	Dev
1	1	55.2827	-3.9698	8.3200	-.00310
1	2	56.3331	-3.7269	8.3200	-.00164
1	3	57.3860	-3.4140	8.3200	-.00345
1	4	58.4402	-3.0308	8.3200	.00001
1	5	59.4939	-2.5849	8.3200	-.00405
2	1	55.3356	-3.1472	6.2400	-.00198
2	2	56.3823	-2.8887	6.2400	-.00066
2	3	57.4305	-2.5603	6.2400	-.00260
2	4	58.4788	-2.1613	6.2400	.00141
2	5	59.5257	-1.6998	6.2400	-.00353
3	1	55.3763	-2.3237	4.1600	-.00151
3	2	56.4190	-2.0497	4.1600	-.00059
3	3	57.4622	-1.7056	4.1600	-.00193
3	4	58.5045	-1.2912	4.1600	.00121
3	5	59.5444	-.8141	4.1600	-.00340
4	1	55.4047	-1.4994	2.0800	-.00135
4	2	56.4433	-1.2099	2.0800	.00025
4	3	57.4812	-.8503	2.0800	-.00062
4	4	58.5172	-.4204	2.0800	.00253
4	5	59.5500	.0720	2.0800	-.00228
5	1	55.4209	-.6745	.0000	-.00109
5	2	56.4551	-.3696	.0000	.00048
5	3	57.4875	.0053	.0000	.00000
5	4	58.5170	.4506	.0000	.00340
5	5	59.5423	.9584	.0000	-.00124
6	1	55.4248	.1507	-2.0800	-.00155
6	2	56.4543	.4710	-2.0800	.00029
6	3	57.4811	.8612	-2.0800	-.00016
6	4	58.5038	1.3219	-2.0800	.00393

Right flank



Gleason Metrology Systems
CORPORATION

Part Number	DCT150_Z11_Mod	Operator	M E COWAN	Z:	11	Pd:	31.9 mm
		Date	6/15/2020	Mn:	2.7		
Job Number		Time	2:32:00 PM				

Gleason Metrology Systems
CORPORATION

Part Number	DCT150_Z40_Mod	Operator	M E COWAN	Z:	40	Pd:	116 mm
		Date	6/15/2020	Mn:	2.7		
Job Number		Time	3:13:00 PM				
Serial Number	ISO Flank Conv-1					b:	20.6 mm
Index Location	5-3	Process					
Journal Reference	Off	Part					
Units	(mm)	Gama/Chart Version	3.2.72.0/2.0.126.0				

Probe Name TC1MM

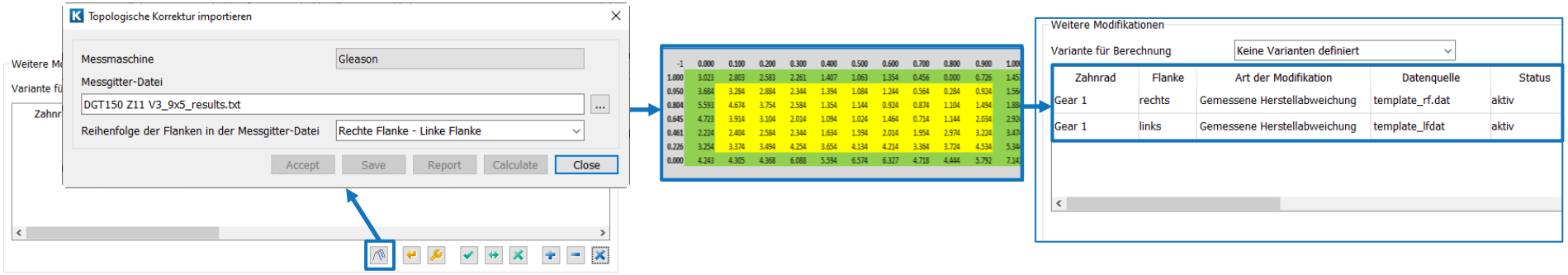
Flank Measurement
Flank1 Average of 4

C	L	X	Y	Z	Dev
1	1	55.3635	-2.6098	8.3200	-.00417
1	2	56.3779	-2.9742	8.3200	-.00104
1	3	57.3863	-3.4096	8.3200	.00050
1	4	58.3881	-3.9080	8.3200	.00125
1	5	59.3824	-4.4644	8.3200	.00148
2	1	55.3962	-1.7865	6.2400	-.00424
2	2	56.4158	-2.1358	6.2400	-.00043
2	3	57.4307	-2.5561	6.2400	.00070
2	4	58.4398	-3.0396	6.2400	.00089
2	5	59.4422	-3.5812	6.2400	.00066
3	1	55.4166	-.9630	4.1600	-.00382
3	2	56.4414	-1.2972	4.1600	-.00081
3	3	57.4623	-1.7024	4.1600	-.00027
3	4	58.4785	-2.1708	4.1600	.00065
3	5	59.4889	-2.6974	4.1600	.00069
4	1	55.4248	-.1396	2.0800	-.00437
4	2	56.4544	-.4584	2.0800	-.00143
4	3	57.4812	-.8484	2.0800	-.00055
4	4	58.5043	-1.3017	2.0800	.00042
4	5	59.5224	-1.8133	2.0800	.00049
5	1	55.4208	.6835	.0000	-.00375
5	2	56.4550	.3800	.0000	-.00085
5	3	57.4875	.0053	.0000	.00000
5	4	58.5172	-.4326	.0000	-.00058
5	5	59.5428	-.9290	.0000	-.00003
6	1	55.4045	1.5063	-2.0800	-.00336
6	2	56.4431	1.2182	-2.0800	-.00038

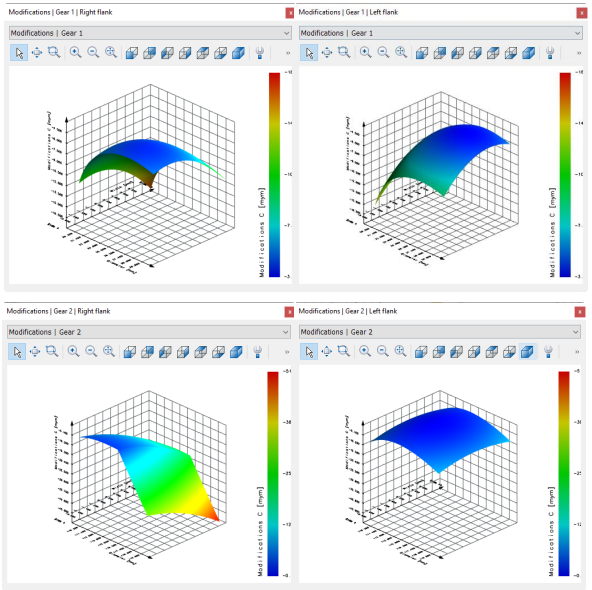
KISSsoft

STEP 6: Import measurement data to KISSsoft

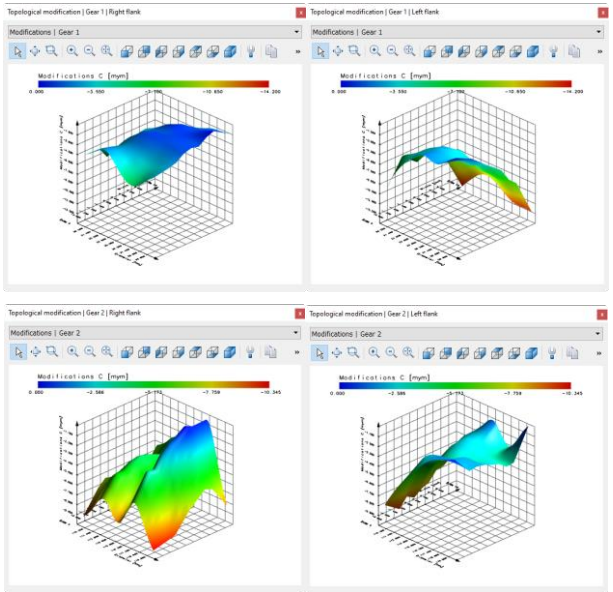
Import the topological modification of manufacturing deviation into KISSsoft



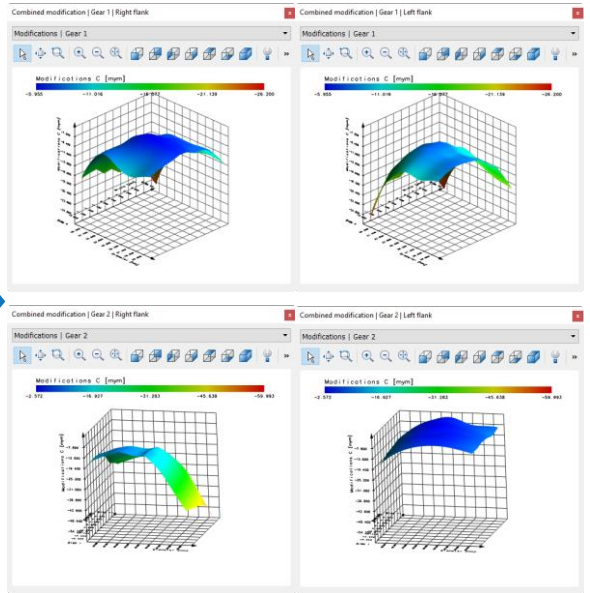
Designed modification



Manufacturing deviation



Combined modification



KISSsoft

STEP 6: Import measurement data to KISSsoft

Convert measured manufacturing deviation into topological modification

Flank2 Average of 4

C	L	X	Y	Z	Dev
1	1	15.3022	2.7609	9.3200	-.00235
1	2	16.2290	3.3974	9.3200	-.00138
1	3	17.0991	4.2202	9.3200	-.00289
1	4	17.9026	5.2044	9.3200	-.00365
1	5	18.6272	6.3355	9.3200	-.00226
2	1	15.4412	1.8305	6.9900	-.00247
2	2	16.4047	2.4098	6.9900	-.00156
2	3	17.3230	3.1784	6.9900	-.00208
2	4	18.1845	4.1123	6.9900	-.00273
2	5	18.9762	5.1975	6.9900	-.00186
3	1	15.5236	.8936	4.6600	-.00323
3	2	16.5204	1.4136	4.6600	-.00132
3	3	17.4835	2.1253	4.6600	-.00099
3	4	18.3999	3.0054	4.6600	-.00156
3	5	19.2557	4.0408	4.6600	-.00132
4	1	15.5492	-.0462	2.3300	-.00263
4	2	16.5756	.4125	2.3300	-.00061
4	3	17.5800	1.0648	2.3300	-.00007
4	4	18.5479	1.8879	2.3300	-.00033
4	5	19.4648	2.8696	2.3300	-.00037
5	1	15.5180	-.9856	.0000	-.00311
5	2	16.5703	-.5897	.0000	-.00057
5	3	17.6122	.0005	.0000	.00000
5	4	18.6280	.7636	.0000	-.00012
5	5	19.6026	1.6883	.0000	-.00006
6	1	15.4301	-1.9213	-2.3300	-.00319
6	2	16.5044	-1.5896	-2.3300	-.00099
6	3	17.5801	-1.0633	-2.3300	-.00044
6	4	18.6402	-.3629	-2.3300	.00010
6	5	19.6688	.5010	-2.3300	-.00022
7	1	15.2859	-2.8496	-4.6600	-.00234
7	2	16.3783	-2.5834	-4.6600	-.00093
7	3	17.4838	-2.1230	-4.6600	.00031
7	4	18.5842	-1.4880	-4.6600	.00015
7	5	19.6631	-.6876	-4.6600	.00046
8	1	15.0860	-3.7673	-6.9900	-.00270
8	2	16.1924	-3.5675	-6.9900	-.00195
8	3	17.3237	-3.1747	-6.9900	-.00012

- Read in deviation values for each grid node (yellow area)
- Estimate the edge values using extrapolation (green area)

COLUMNS=13
DATA

	1	-1	0.000	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000
2	1.000	-1.999	-1.779	-1.559	-1.237	-0.384	-0.039	-0.331	0.567	1.024	0.297	-0.430
3	0.950	-2.660	-2.260	-1.860	-1.320	-0.370	-0.060	-0.220	0.460	0.240	0.100	-0.540
4	0.804	-4.570	-3.650	-2.730	-1.560	-0.330	-0.120	0.100	0.150	-0.080	-0.470	-0.860
5	0.645	-3.700	-2.890	-2.080	-0.990	-0.070	0.000	-0.440	0.310	-0.220	-1.010	-1.900
6	0.461	-1.200	-1.380	-1.560	-1.320	-0.610	-0.570	-0.990	-0.930	-1.950	-2.200	-2.450
7	0.226	-2.230	-2.350	-2.470	-3.230	-2.630	-3.110	-3.190	-2.340	-2.700	-3.510	-4.320
8	0.000	-3.220	-3.282	-3.344	-5.065	-4.571	-5.550	-5.303	-3.695	-3.421	-4.768	-6.117

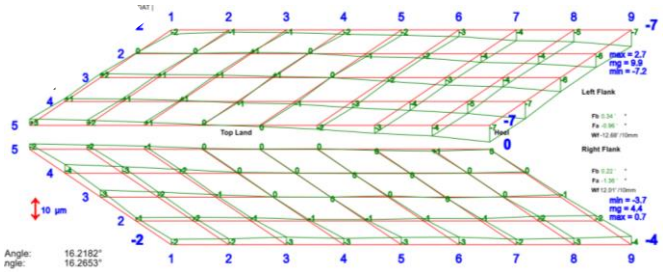
END

- Subtract the maximum for all values to transform into negative values
- Tooth thickness change is ignored

COLUMNS=13
DATA

	1	-1	0.000	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000
2	1.000	-3.023	-2.803	-2.583	-2.261	-1.407	-1.063	-1.354	-0.456	0.000	-0.726	-1.453
3	0.972	-3.684	-3.284	-2.884	-2.344	-1.394	-1.084	-1.244	-0.564	-0.284	-0.924	-1.564
4	0.806	-5.593	-4.674	-3.754	-2.584	-1.354	-1.144	-0.924	-0.874	-1.104	-1.494	-1.884
5	0.622	-4.723	-3.914	-3.104	-2.014	-1.094	-1.024	-1.464	-0.714	-1.144	-2.034	-2.924
6	0.403	-2.224	-2.404	-2.584	-2.344	-1.634	-1.594	-2.014	-1.954	-2.974	-3.224	-3.474
7	0.093	-3.254	-3.374	-3.494	-4.254	-3.654	-4.134	-4.214	-3.364	-3.724	-4.534	-5.344
8	0.000	-4.243	-4.305	-4.368	-6.088	-5.594	-6.574	-6.327	-4.718	-4.444	-5.792	-7.141

END



- Convert the values into positive as per KISSsoft format (positive value removes the material)

COLUMNS=13
DATA

	1	-1	0.000	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000
2	1.000	3.023	2.803	2.583	2.261	1.407	1.063	1.354	0.456	0.000	0.726	1.453
3	0.950	3.684	3.284	2.884	2.344	1.394	1.084	1.244	0.564	0.284	0.924	1.564
4	0.804	5.593	4.674	3.754	2.584	1.354	1.144	0.924	0.874	1.104	1.494	1.884
5	0.645	4.723	3.914	3.104	2.014	1.094	1.024	1.464	0.714	1.144	2.034	2.924
6	0.461	2.224	2.404	2.584	2.344	1.634	1.594	2.014	1.954	2.974	3.224	3.474
7	0.226	3.254	3.374	3.494	4.254	3.654	4.134	4.214	3.364	3.724	4.534	5.344
8	0.000	4.243	4.305	4.368	6.088	5.594	6.574	6.327	4.718	4.444	5.792	7.141

END

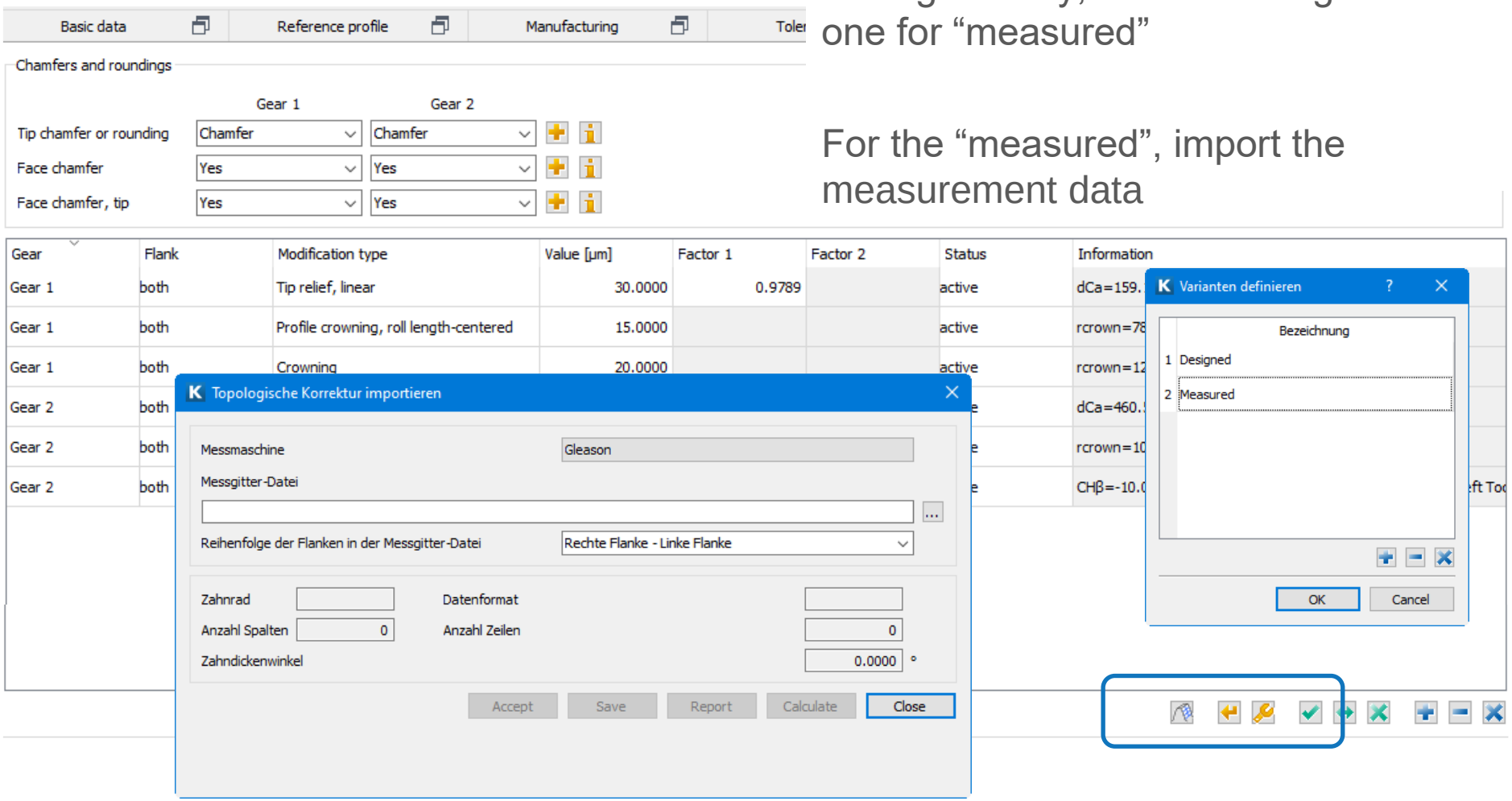
KISSsoft

STEP 6: Import measurement data to KISSsoft

User interface, tab «Modifications»

Create two variants of the microgeometry, one for “designed” and one for “measured”

For the “measured”, import the measurement data



KISSsoft

STEP 7: Contact analysis results of designed & manufactured gear

Based on design / reference

Weitere Modifikationen

Variante für Berechnung: Ohne Modifikationen rechnen

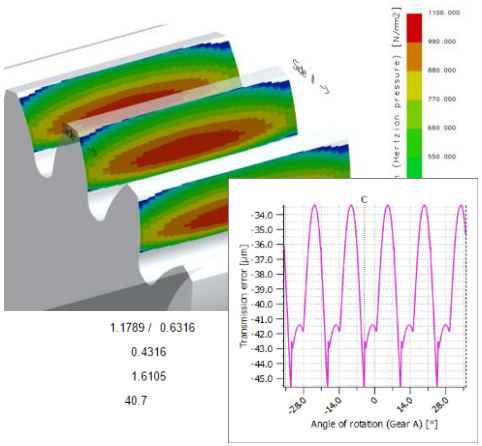
Alle Varianten anzeigen

Ohne Modifikationen rechnen
Designed
Measured

Variante | Zahnrad | Flanke | Art der Modifikation

Results (Contact analysis)

		min	max	Δ	μ
Transmission error	(μm)	-29.8907	-26.5268	3.3639	-27.6108
Excitation force	(N)	3773.9648	4619.4325	845.4677	4357.9199
Tangents Stiffness curve	(N/μm)	190.1098	287.3960	97.2862	255.2770
Secants stiffness curve	(N/μm)	142.2260	158.9537	16.7277	152.8458
Line load	(N/mm)	0.0000	908.4017	908.4017	210.1171
Torque Gear 1	(Nm)	64.1451	64.1575	0.0124	64.1510
Torque Gear 2	(Nm)	224.1770	227.8568	3.6798	225.5483
Speed, gear 2	(1/min)	273.8453	275.9028	2.0575	274.9989
Power loss	(W)	155.8756	267.0384	111.1628	223.8706
Efficiency	(%)	96.0250	97.6797	1.6547	96.6676
Contact temperature	(°C)	74.5472	211.7577	137.2106	99.8802
Thickness of lubrication film	(μm)	0.0697	0.4525	0.3828	0.1493
Active flank area of usage (diameter) Gear 1	(mm)				
Active flank area of usage (diameter) Gear 2	(mm)				
Hertzian pressure	(N/mm²)				
Tooth root stress gear 1 (graphical method)	(N/mm²)				
Tooth root stress gear 1 (at 30° tangents)	(N/mm²)				
Tooth root stress gear 2 (graphical method)	(N/mm²)				
Tooth root stress gear 2 (at 30° tangents)	(N/mm²)				
Safety against scuffing					
Transverse contact ratio under load	[εα]				
	min				
	μ				
	max				
	side I, II		1.1789 / 0.6316		
Overlap ratio under load	[εβ]		0.4316		
Total contact ratio under load (max)	[εγ]		1.6105		
Sound pressure level (according to Masuda)	[dB(A)]		40.7		



As manufactured / measured

Weitere Modifikationen

Variante für Berechnung: Ohne Modifikationen rechnen

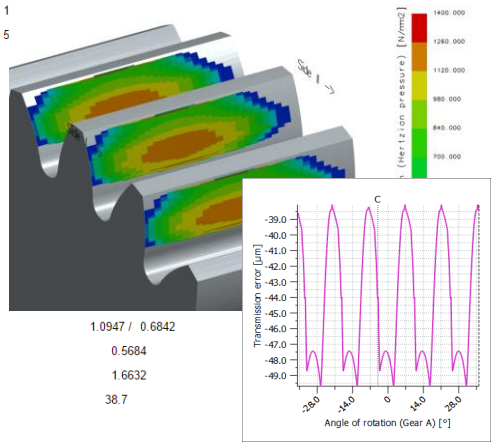
Alle Varianten anzeigen

Ohne Modifikationen rechnen
Designed
Measured

Variante | Zahnrad | Flanke | Art der Modifikation

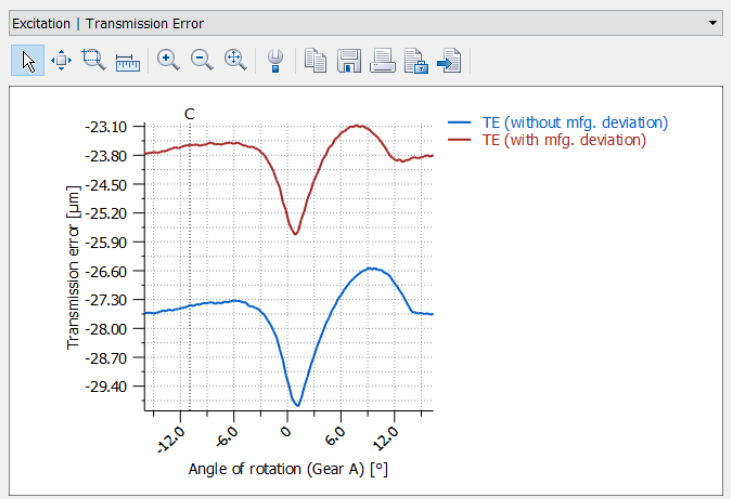
Results (Contact analysis)

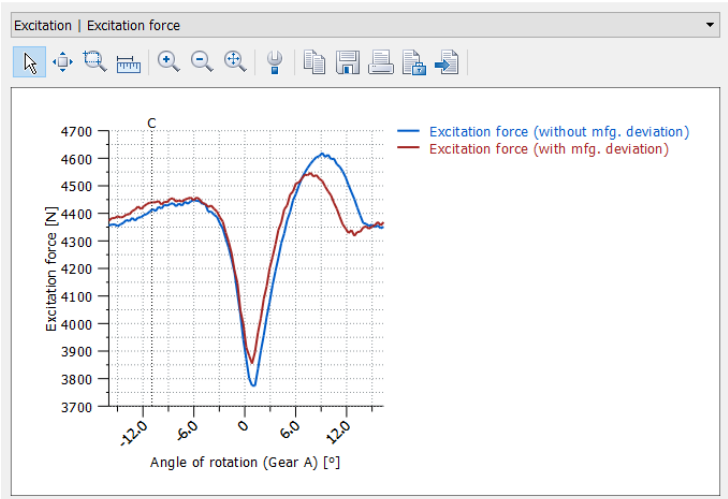
		min	max	Δ	μ
Transmission error	(μm)	-25.7335	-23.0592	2.6743	-23.8161
Excitation force	(N)	3854.8716	4547.4769	692.6054	4361.9107
Tangents Stiffness curve	(N/μm)	206.5104	277.5245	71.0141	257.3214
Secants stiffness curve	(N/μm)	165.2830	182.9532	17.6702	177.2691
Line load	(N/mm)	0.0000	766.9575	766.9575	210.1003
Torque Gear 1	(Nm)	64.1451	64.1571	0.0120	64.1505
Torque Gear 2	(Nm)	224.3581	227.8073	3.4493	225.6672
Speed, gear 2	(1/min)	273.9194	275.9095	1.9901	274.9990
Power loss	(W)	158.4293	261.2482	102.8188	220.3079
Efficiency	(%)	96.1112	97.6417	1.5305	96.7206
Contact temperature	(°C)	74.5472	196.8750	122.3278	99.8131
Thickness of lubrication film	(μm)	0.0498	0.4790	0.4292	0.1502
Active flank area of usage (diameter) Gear 1	(mm)	1			
Active flank area of usage (diameter) Gear 2	(mm)	5			
Hertzian pressure	(N/mm²)				
Tooth root stress gear 1 (graphical method)	(N/mm²)				
Tooth root stress gear 1 (at 30° tangents)	(N/mm²)				
Tooth root stress gear 2 (graphical method)	(N/mm²)				
Tooth root stress gear 2 (at 30° tangents)	(N/mm²)				
Safety against scuffing					
Transverse contact ratio under load	[εα]				
	min				
	μ				
	max				
	side I, II		1.0947 / 0.6842		
Overlap ratio under load	[εβ]		0.5684		
Total contact ratio under load (max)	[εγ]		1.6632		
Sound pressure level (according to Masuda)	[dB(A)]		38.7		

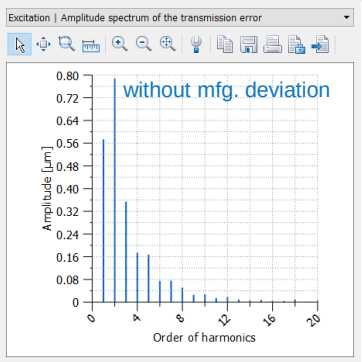


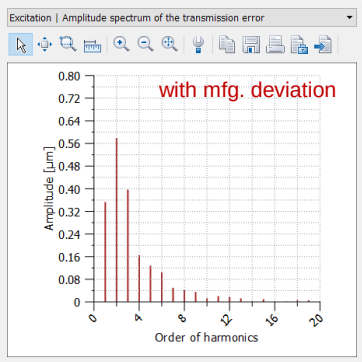
KISSsoft

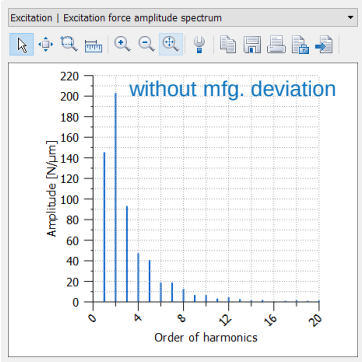
Example case, heavy truck transmission gear set

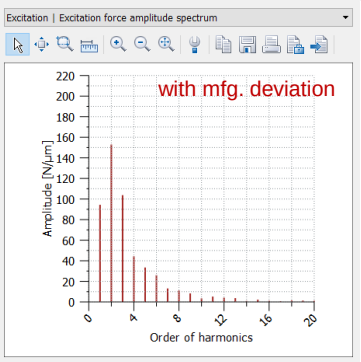












	Min	Max	Δ	µ
	Without mfg. deviation / With mfg. deviation			
Transmission error (µm)	-29.8907 / -25.7335	-26.5268 / -23.0592	3.3639 / 2.6743	-27.6108 / -23.8161
Excitation force (N)	3773.96 / 3854.87	4619.43 / 4547.48	845.47 / 692.61	4357.92 / 4361.91

PPTE and excitation force are lower with manufacturing deviation. This is rather exceptional and might be happening as the manufacturing deviation is very small.

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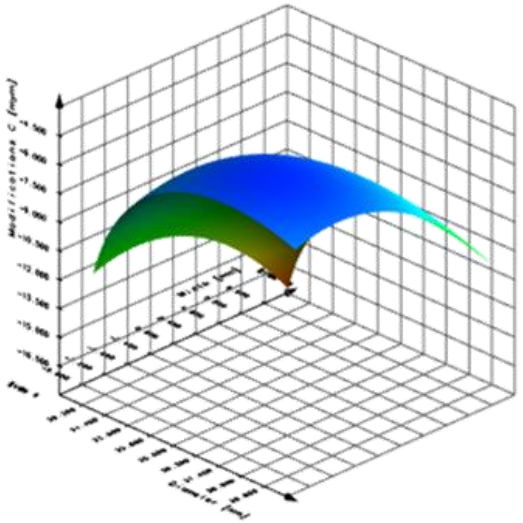
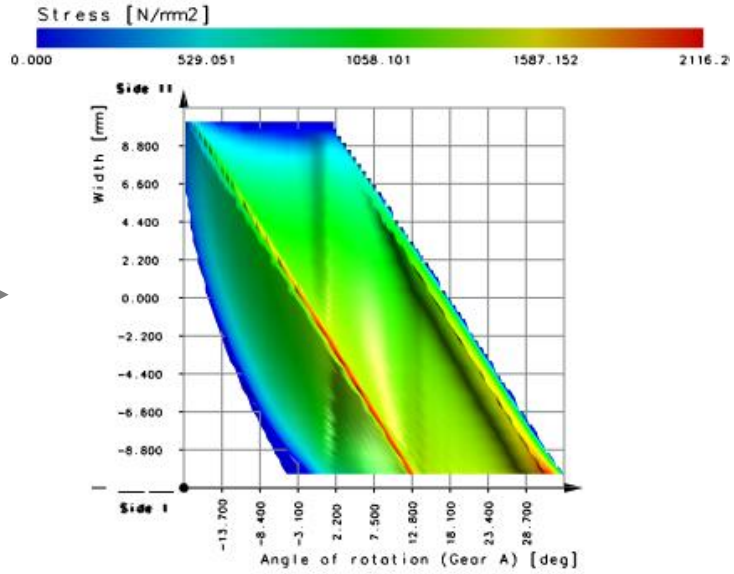
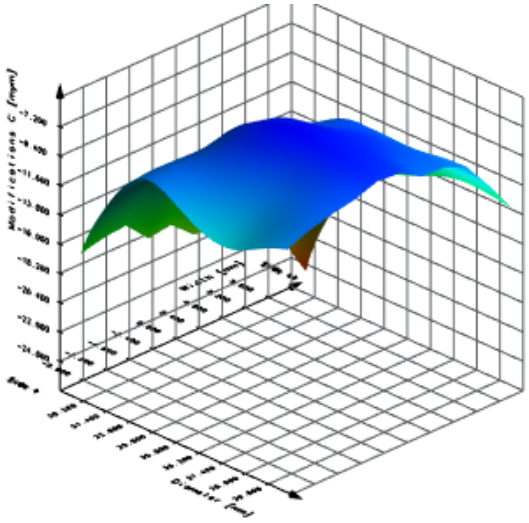
Example case, heavy truck transmission gear set

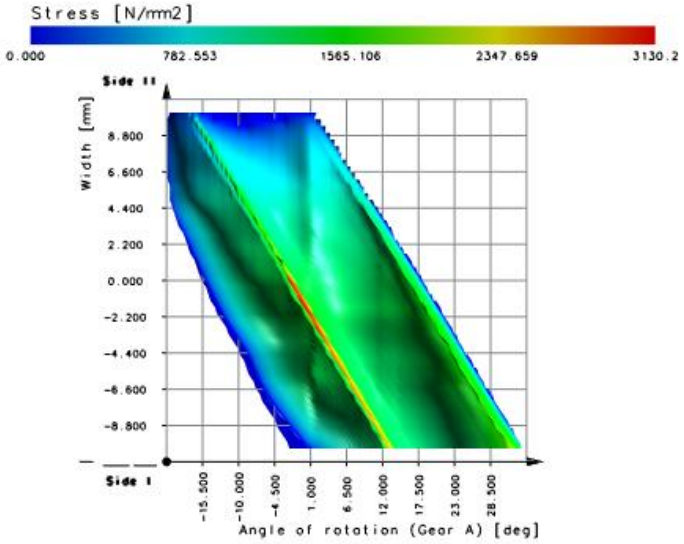


Reference, as designed





Based on as manufactured / measured



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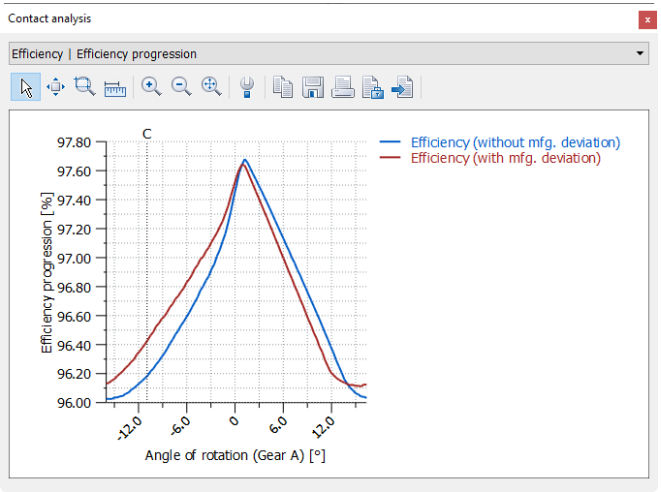
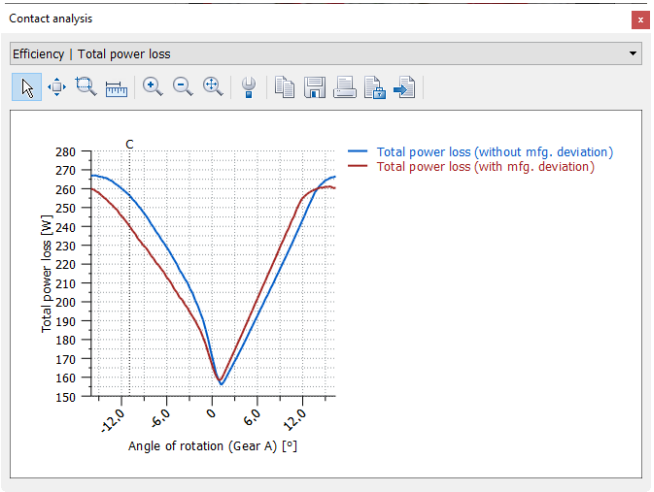
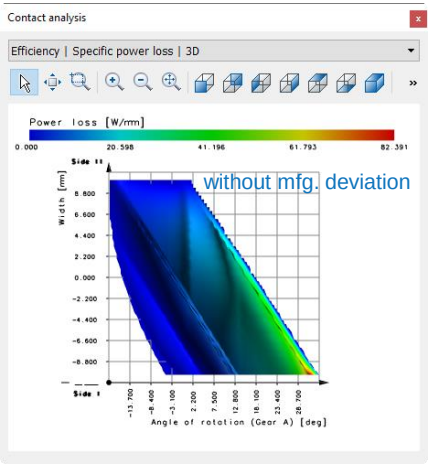
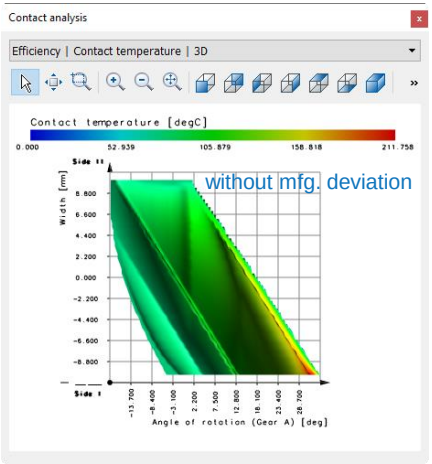
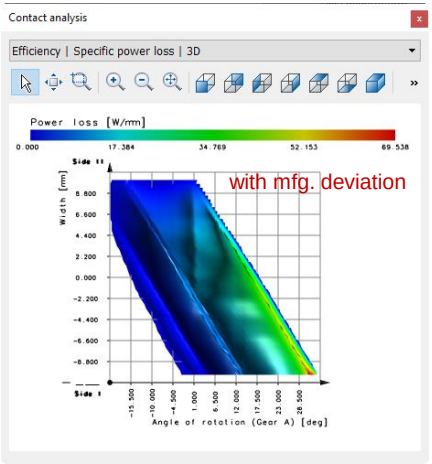
Example case, heavy truck transmission gear set

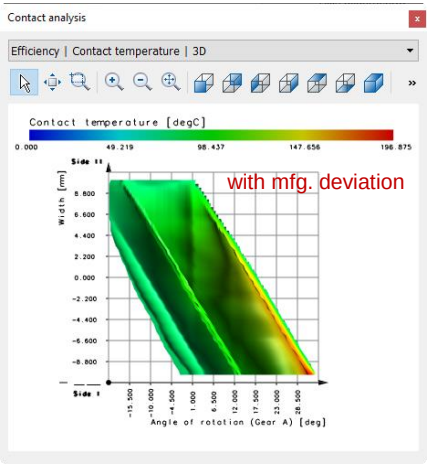












	Min	Max	Δ	μ
	Without mfg. deviation / With mfg. deviation			
Power loss (W)	155.8756 / 158.4293	267.0384 / 261.2482	111.1628 / 102.8188	223.8706 / 220.3079
Efficiency (%)	96.0250 / 96.1112	97.6797 / 97.6417	1.6547 / 1.5305	96.6676 / 96.7206

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Example case, heavy truck transmission gear set

Topic	Parameters	Units	Theoretical gear	Theoretical gear with tolerance (Quality ISO 6)	Manufactured gear	Behavior of Mfg. to Theo. (*)
Noise / Vibration	Transmission error (PPTE)	µm	3.36	2.85 – 6.14	2.67	+
	1st Harmonic (PPTE)	µm	0.573	0.573 – 1.946	0.353	+
	2nd Harmonic/ 1st Harmonic (PPTE)	-	1.373	0.627 – 1.373	1.642	-
	Sound pressure level (Masuda)	dB(A)	40.7	39.3 – 45.9	38.7	+
	Excitation force (Peak to Peak)	N	845.47	727.19 – 1480.28	692.61	+
Strength	Contact stress, mean	N/mm²	809	768 – 877	844	-
	Bending stress, Pinion, max / mean	N/mm²	377 / 155	344 – 538 / 155 – 195	342 / 161	~
	Bending stress, Gear, max / mean	N/mm²	309 / 174	254 – 355 / 174 – 191	283 / 173	~
	Scuffing safety	-	1.97	1.53 – 1.97	2.20	+
Efficiency	Power loss	W	224	224 – 249	220	+
	Efficiency	%	96.67	96.29 – 96.67	96.72	+
(*)	Manufactured gear has (+: better, ~: same, -: lower) performance.					

The manufactured gear has

- Lower transmission error and excitation force
- Lower sound pressure level because of the lower transmission error
- Slightly higher contact stress
- Almost same bending stress
- Slightly better efficiency

Note: In this example, the manufactured gear shows better behavior than the theoretical gear. This is rather exceptional but happens.

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Summary

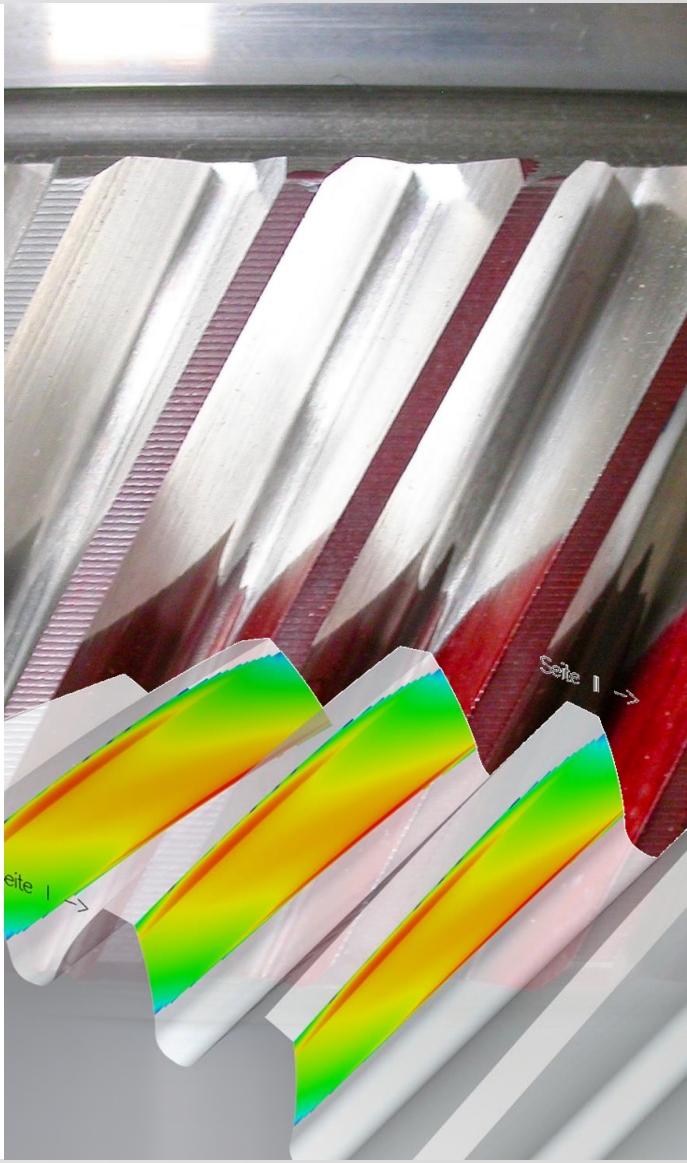
Performance characteristics of manufactured gear

Approach

- Design, manufacture, measure gear
- Designed gear geometry → reference characteristics
- Manufactured gear geometry is measured and imported to KISSsoft → as is characteristics

Use cases

- Accept / reject batches of gears manufactured
- Selection of economical manufacturing process(es)
- Change design and / or manufacturing process for required performance characteristics



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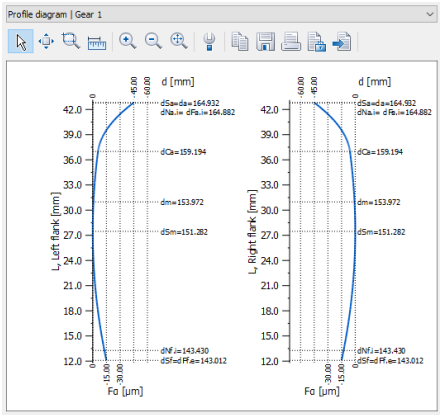
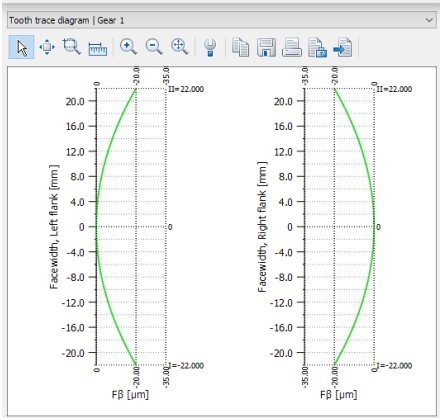
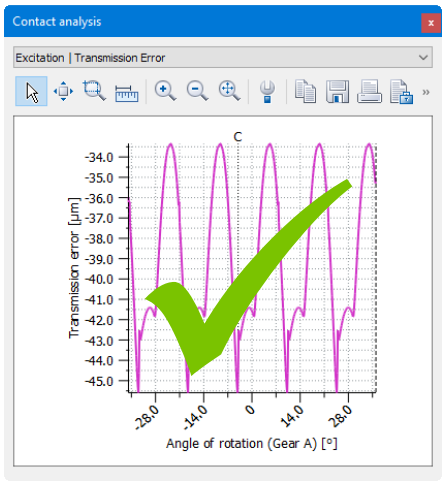
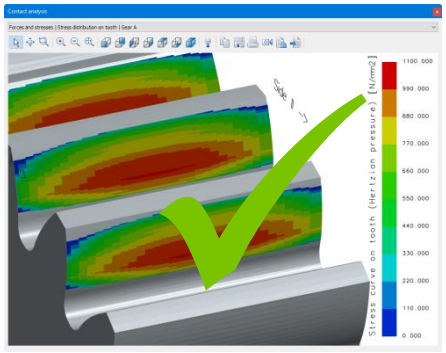
Characteristics of manufactured gear → known

Designed gear / reference

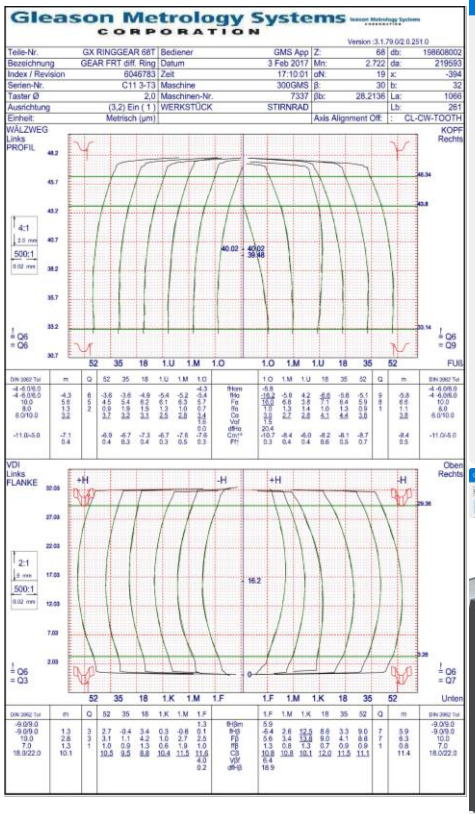


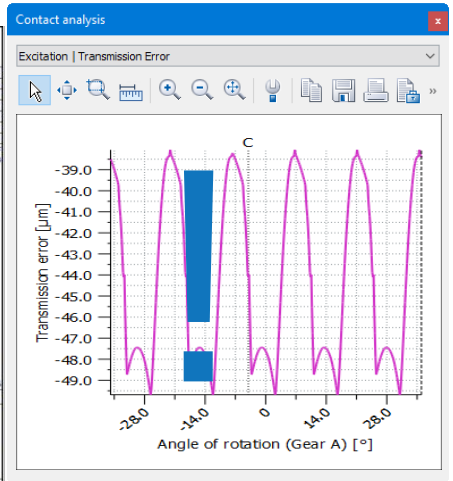


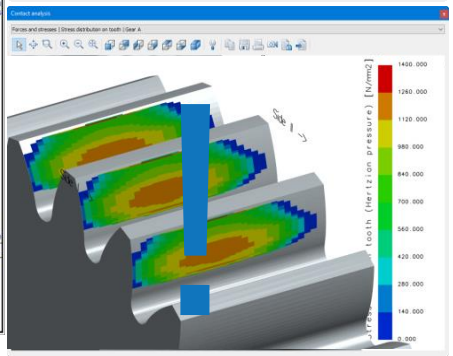




Manufactured gear







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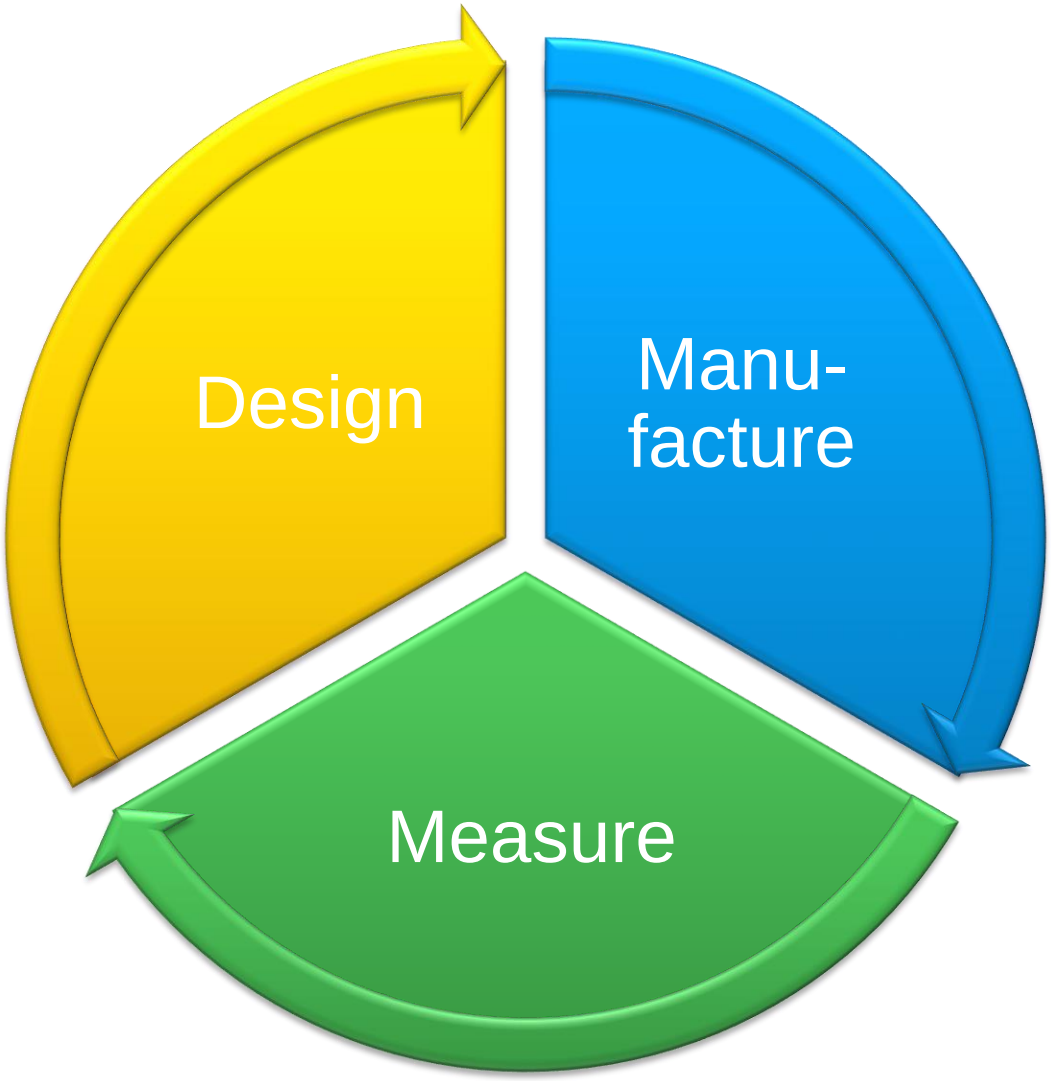
Thank you for your attention!



Sharing Knowledge

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