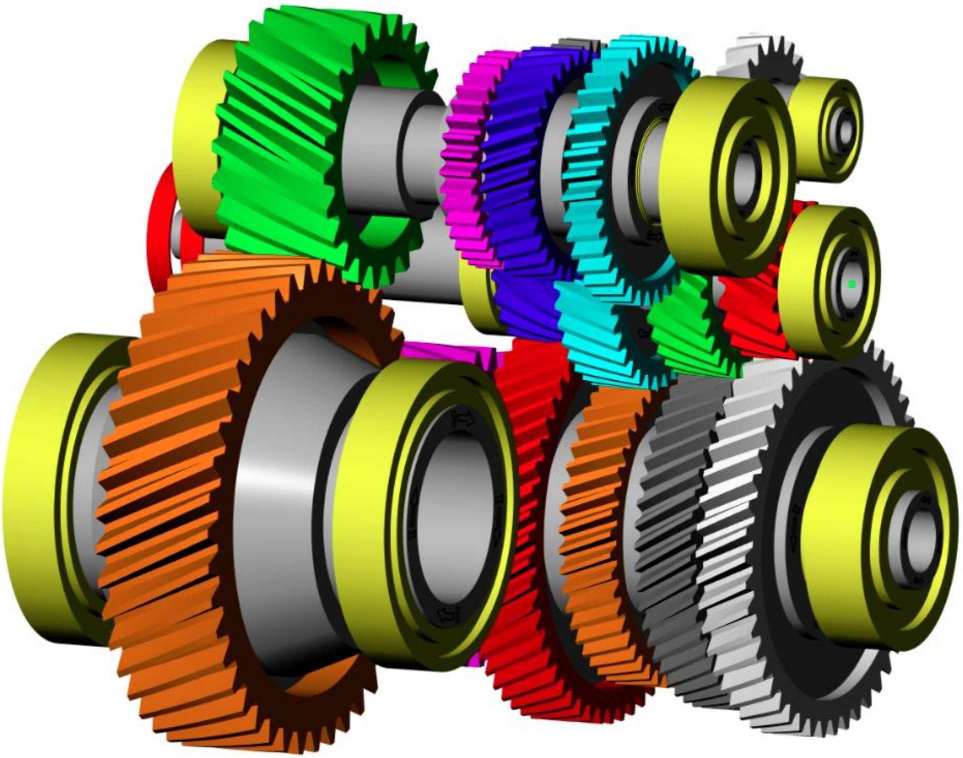
Efficient layout procedure of cylindrical gears with manufacturing constraints



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KISSsoft

Cylindrical gear strength can be calculation according to different standards:

ISO 6336, DIN 3990, AGMA 2001, AGMA 2101, VDI 2736, GOST 21354-87…

The main idea is to compare permissible values with calculated values:

$$Safety\ factor\ (Pitting) = \frac{permissible\ Stress}{calculated\ Stress}$$

$$Safety\ factor\ (Bending) = \frac{permissible\ Stress}{calculated\ Stress}$$

$$Safety\ factor\ (Scuffing) = \frac{permissible\ scuffing\ Temperature}{calculated\ contact\ Temperature}$$

$$Safety\ factor\ (Micropitting) = \frac{calculated\ minimum\ lubricant\ film\ Thickness}{permissible\ lubricant\ film\ Thickness}$$

The following condition has to hold:

$$S \geq S_{min}$$

Condition:

calculated contact stress ≤ permissible contact stress

$$\sigma_H \leq \sigma_{HP}$$

$$\sigma_H = Z_B \cdot \sigma_{HO} \cdot \sqrt{K_A \cdot K_v \cdot K_{H\beta} \cdot K_{H\alpha}} \leq \sigma_{HP}$$

$$\sigma_{HO} = Z_H \cdot Z_E \cdot Z_\varepsilon \cdot Z_\beta \cdot \sqrt{\frac{F_t}{d_1 \cdot b} \cdot \frac{u+1}{u}}$$

$$\sigma_{HP} = \frac{\sigma_{H\lim} \cdot Z_{NT}}{S_{H\min}} \cdot Z_L \cdot Z_V \cdot Z_R \cdot Z_W \cdot Z_X = \frac{\sigma_{HG}}{S_{H\min}}$$

Figure 29 – Initial pitting

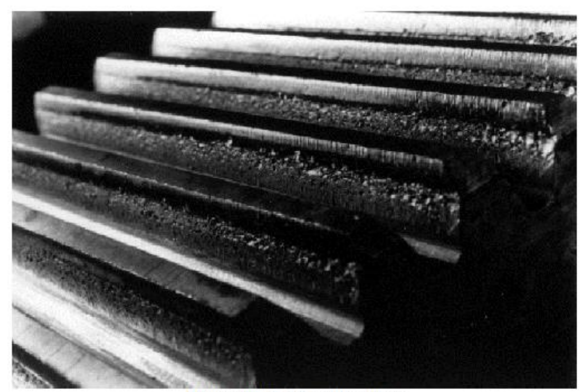
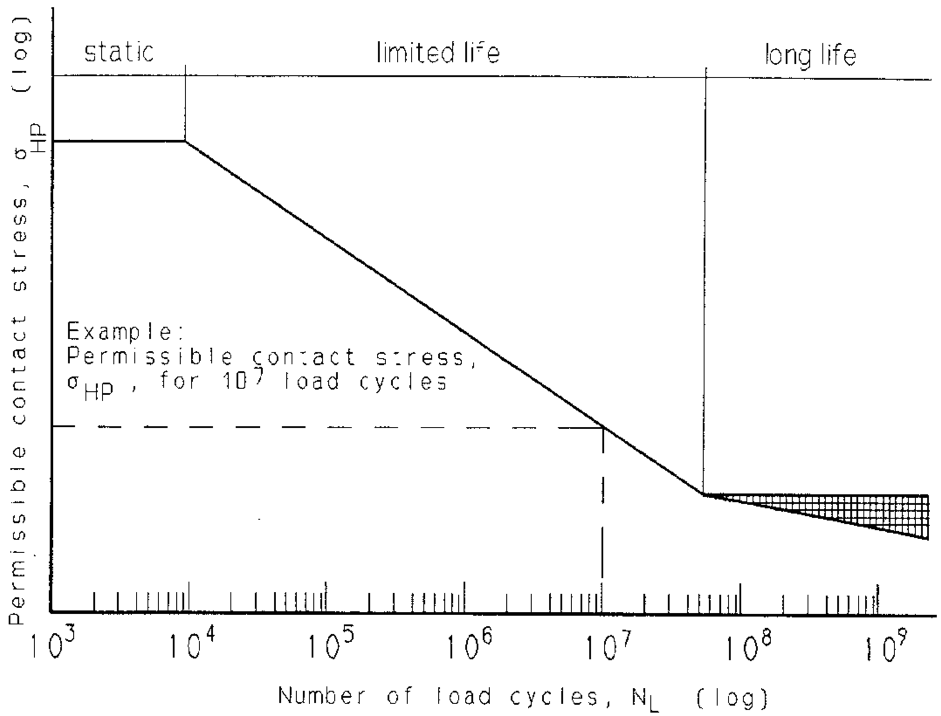


Figure 30 – Progressive pitting

Introduction: permissible contact stress (ISO 6336)



$$\sigma_{HP} = \frac{\sigma_{H\lim} \cdot Z_{NT}}{S_{H\min}} \cdot Z_L \cdot Z_V \cdot Z_R \cdot Z_W \cdot Z_X = \frac{\sigma_{HG}}{S_{H\min}}$$

Condition:

calculated root stress ≤ permissible root stress

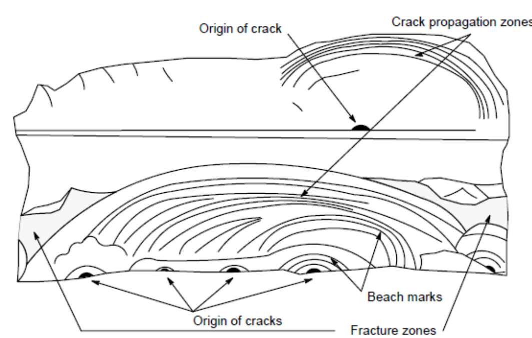
$$\sigma_F \leq \sigma_{FP}$$

$$\sigma_F = \sigma_{FO} \cdot K_A \cdot K_V \cdot K_{F\beta} \cdot K_{F\alpha}$$

$$\sigma_{FP} = \frac{\sigma_{F\lim} \cdot Y_{ST} \cdot Y_{NT}}{S_{F\min}} \cdot Y_{\delta relT} \cdot Y_{RrelT} \cdot Y_X = \frac{\sigma_{FG}}{S_{F\min}}$$

$$\sigma_{FO-B} = \frac{F_t}{b \cdot m_n} \cdot Y_F \cdot Y_S \cdot Y_\beta \cdot Y_B \cdot Y_{DT}$$

Figure 43 – Bending fatigue crack



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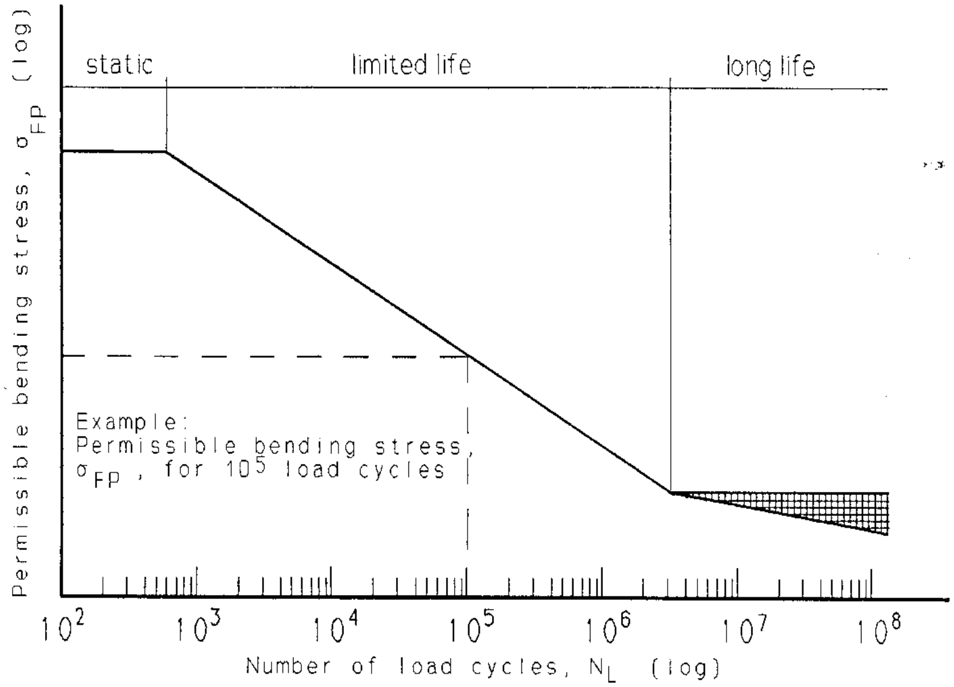
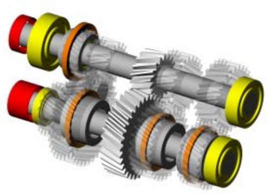
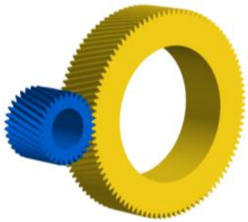
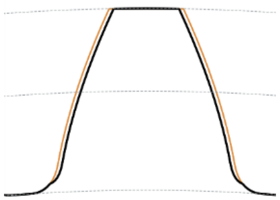
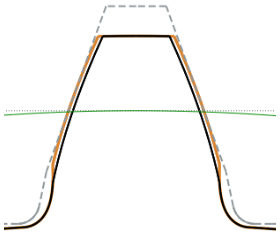
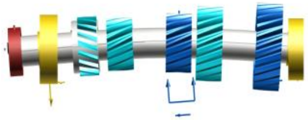
Introduction: permissible root stress (ISO 6336)



$$\sigma_{FP} = \frac{\sigma_{F\lim} \cdot Y_{ST} \cdot Y_{NT}}{S_{F\min}} \cdot Y_{\delta relT} \cdot Y_{RrelT} \cdot Y_X = \frac{\sigma_{FG}}{S_{F\min}}$$

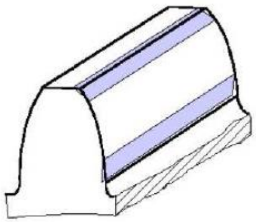
Rough Sizing

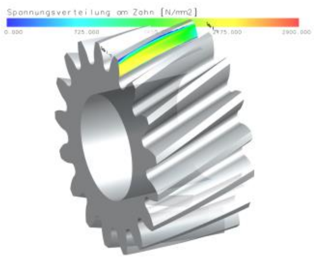
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

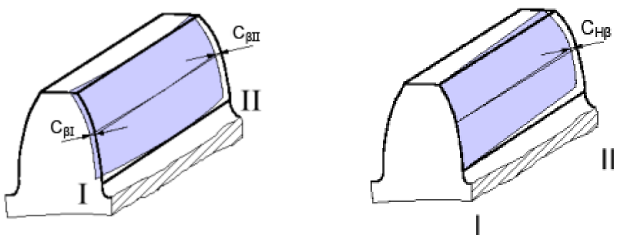
↓

Manufacture Measure ← Profile Modifications ← Contact Analysis ← Crowning ← Helix Angle Modifications



Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur

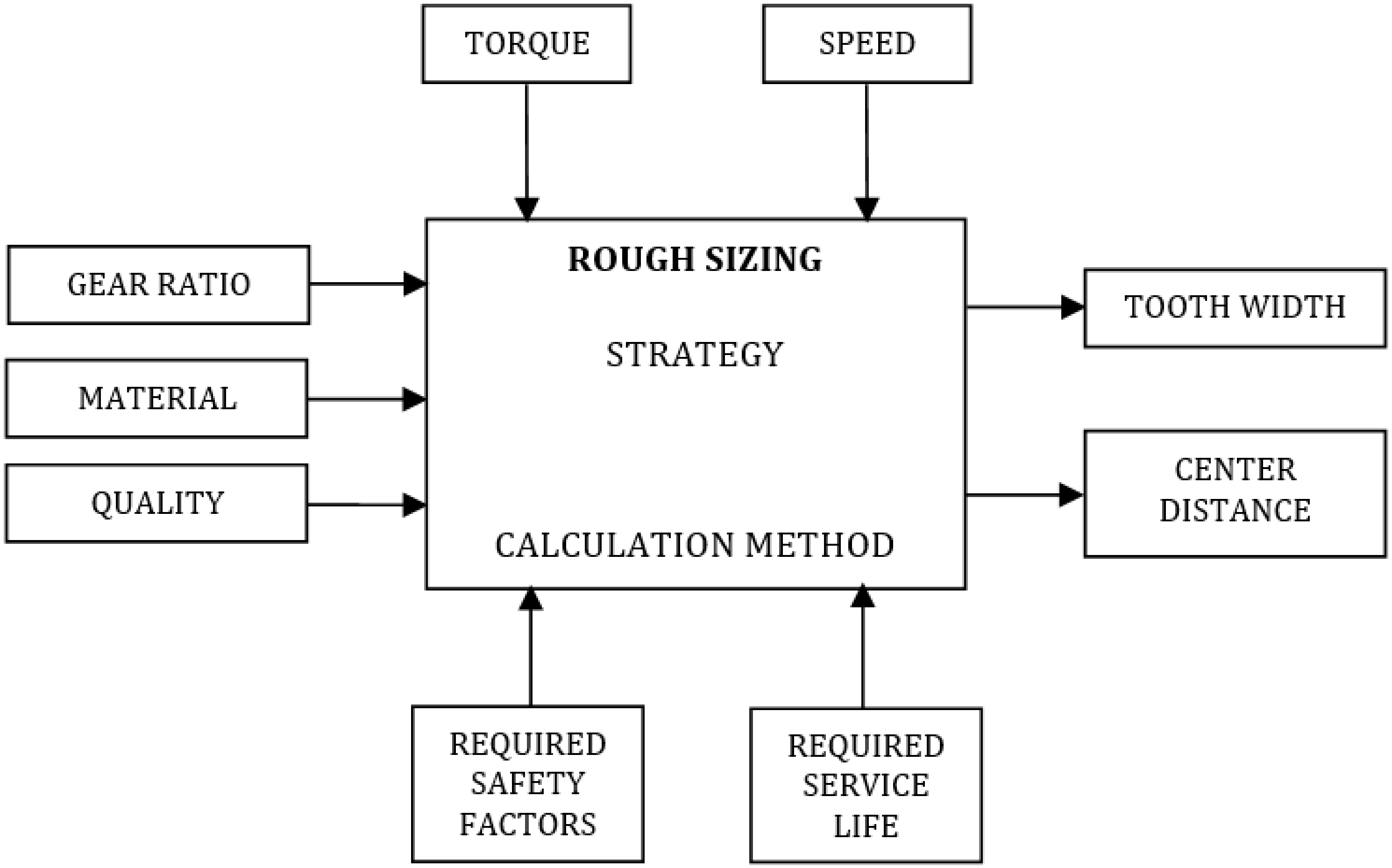




Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

KISSsoft

Rough Sizing



Goal: find optimal **center distance** and **face width**. This will define the gearbox dimensions.

The choice of optimal solution depends on the defined target(s):

- Low weight
- Low size
- Max. Torque
- Max. Power density

a [mm]	b_1 [mm]	b_2 [mm]	m_n [mm]	z_1	z_2	i	$SF_{smallest}$	$SH_{smallest}$	P_{max} [kW]	W [kg]	T_{max}/W [Nm/kg]	dB(A)
97.660	60.930	59.440	2.972	16	49	3.063	2.330	1.000	49.952	8.547	37.205	77.413
100.000	61.232	59.482	3.000	16	50	3.125	2.322	1.000	49.970	9.026	35.246	77.997
106.000	49.540	48.040	2.500	21	62	2.952	1.692	1.002	50.176	8.139	39.247	78.171
106.000	50.497	48.997	2.750	19	56	2.947	1.871	1.001	50.059	8.282	38.477	78.382
106.000	50.408	48.908	2.500	21	64	3.048	1.801	1.001	50.069	8.334	38.246	77.533
106.000	51.000	49.500	2.750	19	58	3.053	1.958	1.001	50.107	8.417	37.897	77.659
106.000	52.974	51.474	3.000	17	52	3.059	2.135	0.998	49.786	8.763	36.167	78.341
106.000	52.951	51.451	3.000	17	53	3.118	2.174	0.998	49.790	8.785	36.083	77.960
106.000	54.602	53.102	3.000	17	54	3.176	2.242	1.000	49.962	9.090	34.992	77.691
106.000	55.972	54.472	2.750	18	57	3.167	1.954	0.999	49.944	9.394	33.846	78.568
106.000	55.997	54.497	2.750	19	59	3.105	2.282	0.994	49.445	9.367	33.605	77.251
106.000	61.196	59.696	3.000	16	52	3.250	2.309	0.999	49.894	10.359	30.662	79.068
111.292	43.990	42.920	2.146	25	78	3.120	1.492	1.000	49.987	8.162	38.987	77.012
112.000	42.797	41.484	2.250	25	74	2.960	1.471	0.999	49.925	7.868	40.396	77.661
112.000	43.813	42.500	3.000	19	56	2.947	2.057	0.999	49.945	7.975	39.869	77.469
112.000	44.781	43.468	2.750	20	61	3.050	1.832	1.000	49.998	8.270	38.488	77.761
112.000	45.130	43.817	2.250	24	74	3.083	1.456	0.998	49.827	8.416	37.693	78.094
112.000	45.307	43.994	2.250	24	75	3.125	1.509	0.998	49.805	8.472	37.424	77.783
112.000	46.554	45.241	3.000	18	55	3.056	2.012	1.000	49.969	8.610	36.949	78.304
112.000	46.485	45.172	2.750	20	62	3.100	1.916	0.998	49.794	8.617	36.787	77.521
112.000	47.845	46.532	3.000	18	57	3.167	2.129	1.000	49.955	8.904	35.716	77.668
112.000	48.688	47.375	2.500	23	68	2.957	2.025	0.999	49.903	9.027	35.193	76.962
112.000	48.116	46.803	2.500	21	67	3.190	1.663	0.999	49.946	9.056	35.113	78.253
112.000	48.239	46.926	2.500	21	68	3.238	1.713	0.999	49.946	9.104	34.927	77.924
112.000	49.552	48.239	2.750	19	60	3.158	1.846	0.999	49.932	9.298	34.186	78.712
112.000	52.968	51.655	3.000	17	55	3.235	2.150	0.999	49.899	10.008	31.741	78.996
118.000	41.232	39.919	2.250	25	79	3.160	1.423	0.999	49.928	8.575	37.065	77.918
118.000	41.764	40.451	2.250	25	78	3.120	1.383	0.999	49.400	8.666	36.288	78.256
118.000	41.782	40.469	2.250	25	80	3.200	1.474	0.993	49.330	8.715	36.033	77.669
118.000	44.976	43.663	2.250	24	78	3.250	1.443	0.999	49.881	9.472	33.524	78.792
118.000	45.662	44.349	2.250	25	81	3.240	1.744	1.001	50.105	9.632	33.115	77.328
141.955	28.080	25.920	4.320	16	49	3.063	2.266	1.000	50.009	7.923	40.184	77.413
161.648	20.260	18.700	3.117	25	78	3.120	1.447	1.000	50.014	7.545	42.201	77.012

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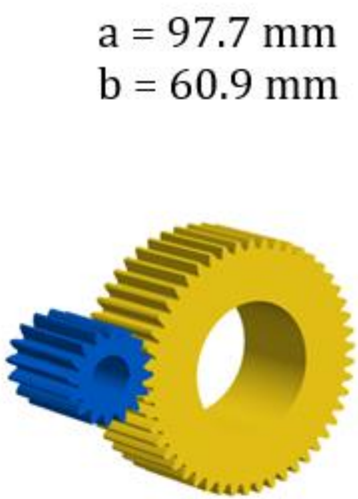
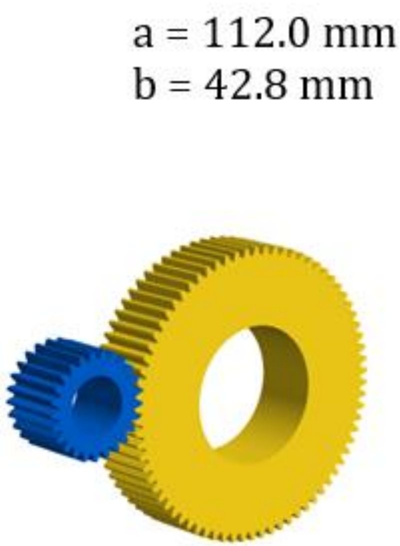
Combination of goals: high power density at low size

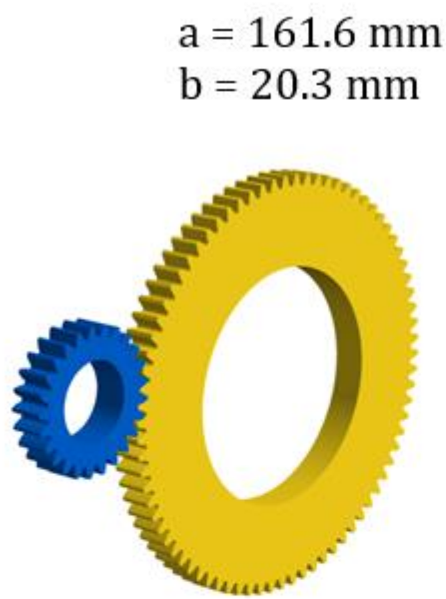
Smallest size



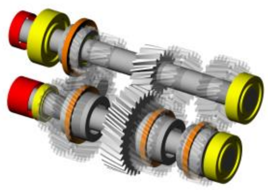
High power density
low size

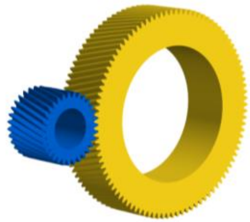


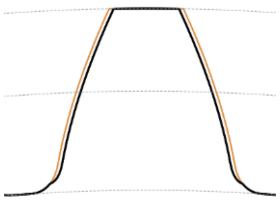
Smallest weight

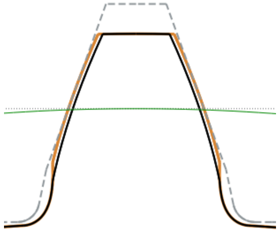


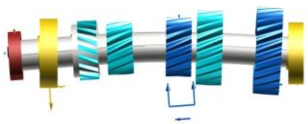
Rough Sizing







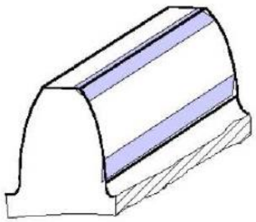




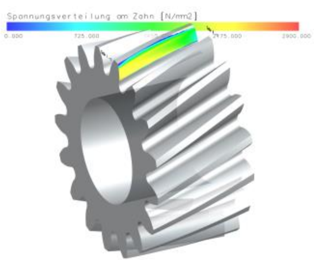
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

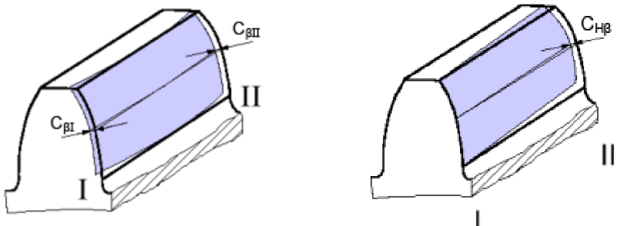
↓

Manufacture Measure ← Profile Modifications ← Contact Analysis ← Crowning ← Helix Angle Modifications



Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur

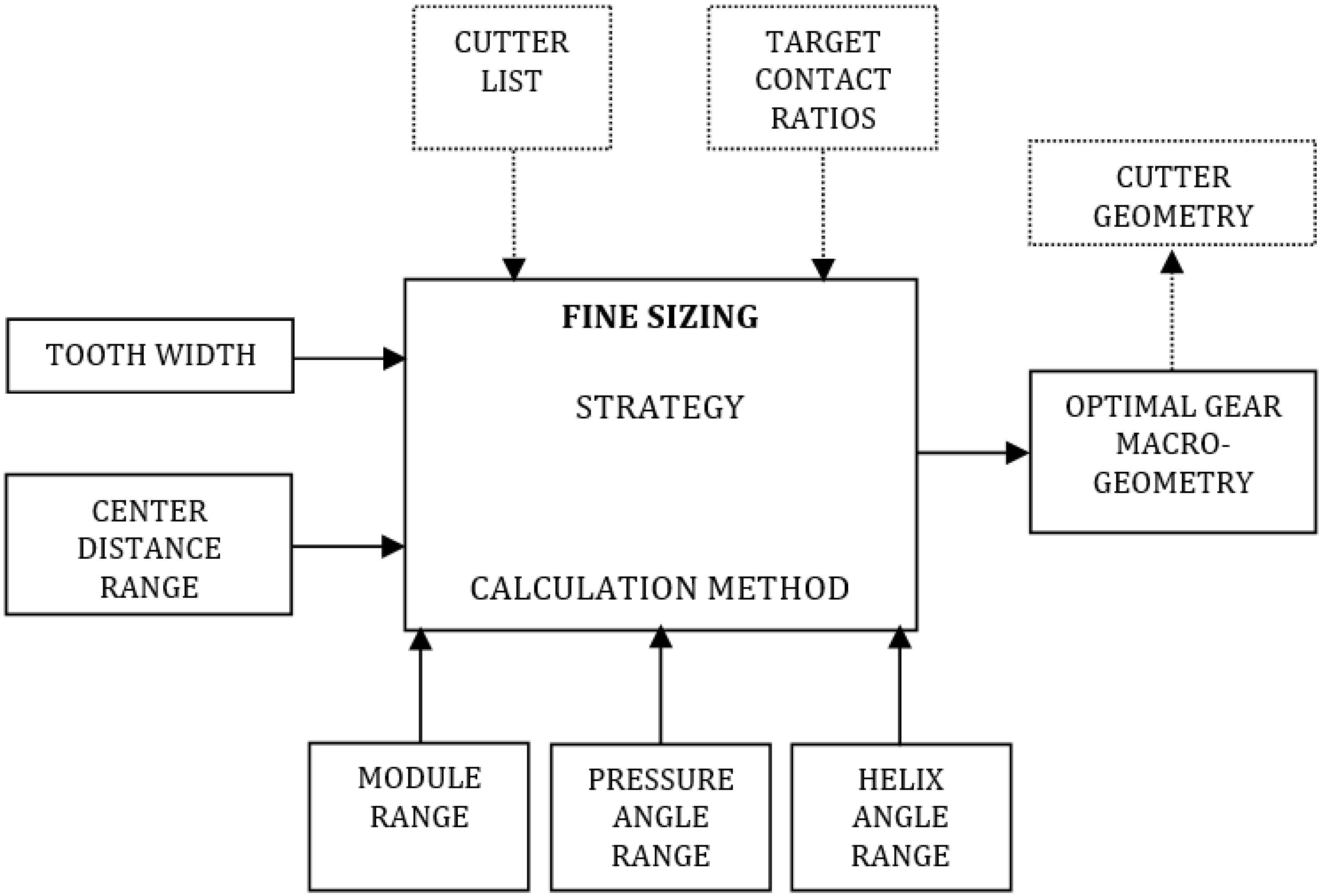




Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

KISSsoft

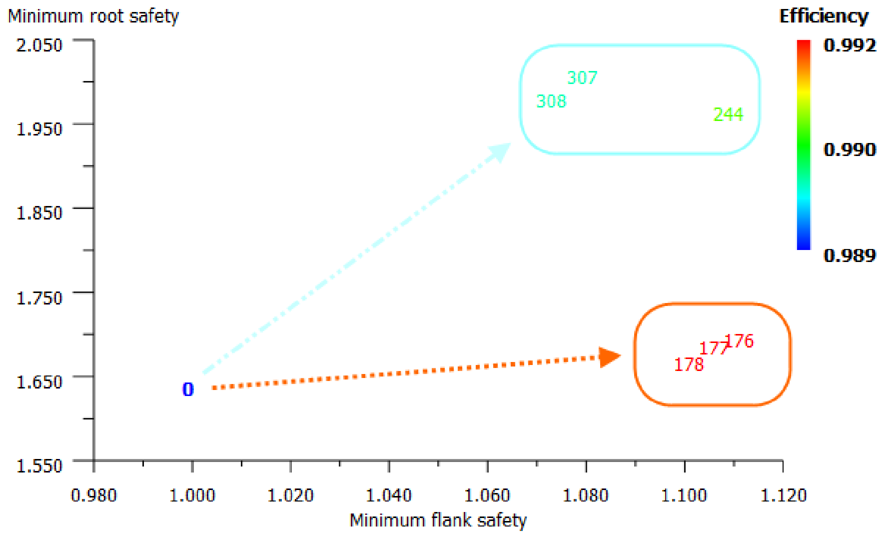
Fine Sizing

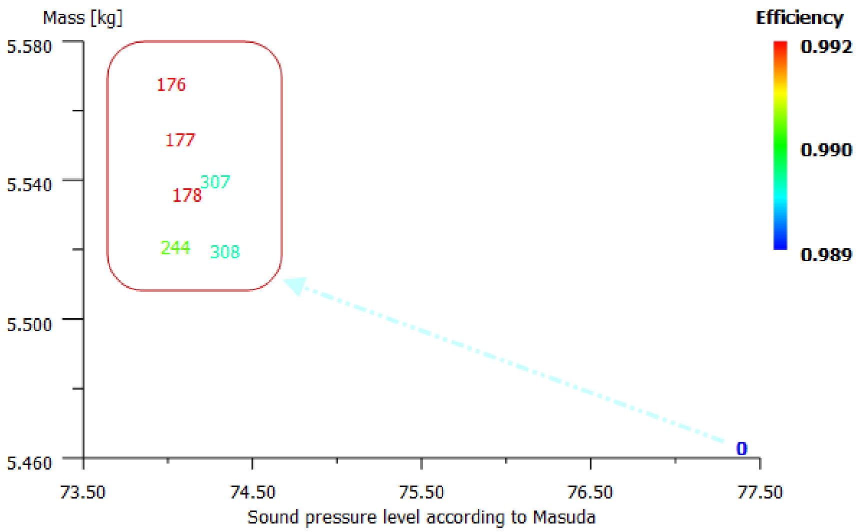

CUTTER LIST
TARGET CONTACT RATIOS
CUTTER GEOMETRY
FINE SIZING
STRATEGY
CALCULATION METHOD
TOOTH WIDTH
CENTER DISTANCE RANGE
OPTIMAL GEAR MACRO-GEOMETRY
MODULE RANGE
PRESSURE ANGLE RANGE
HELIX ANGLE RANGE

Goal: optimal gear macro-geometry

Possible Target:

Find a solution with high **Safety Factors**, low **Weight**, low **Noise Excitation** (high contact ratio) and high **Efficiency.**

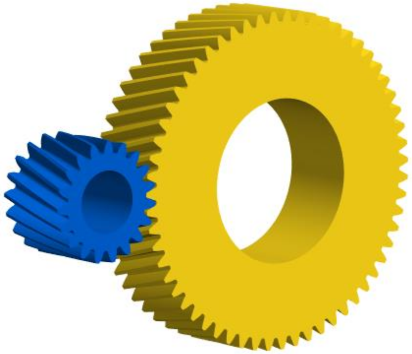




The consideration of available cutters in the early design process can save a lot of effort in further design steps.

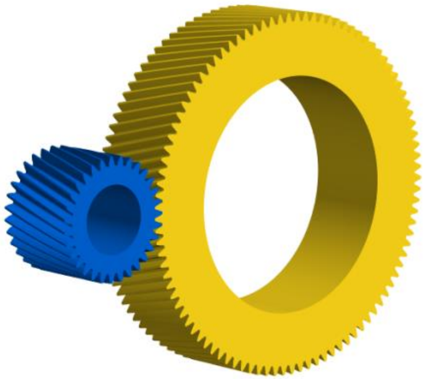
Standard cutter profile: **ISO 53 Profil A**

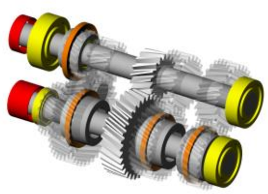
- Standard cutter (lower costs)
- Lower contact ratio
- Lower root stresses
- Higher noise excitiation

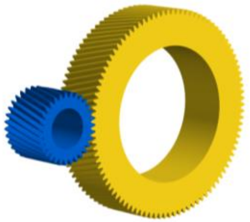


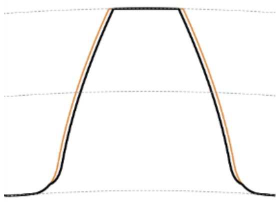
Deep Tooth Form

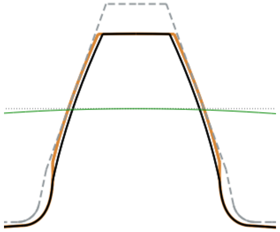
- Special cutter (higher costs)
- Higher contact ratio
- Higher root stresses
- Lower noise excitation

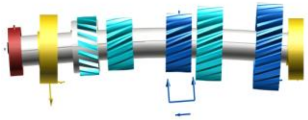








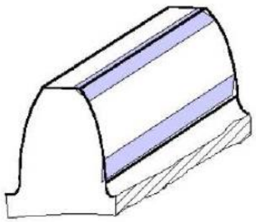




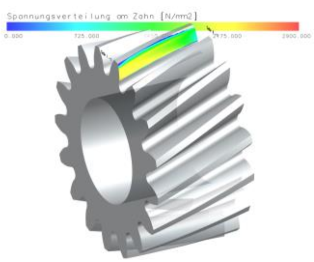
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

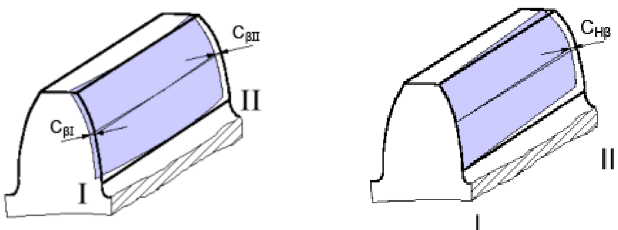
↓

Helix Angle Modifications → Crowning → Contact Analysis → Profile Modifications → Manufacture Measure



Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur





Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

Sizing of grinding stock

$$q = q_1/4 + \sqrt{(q_2/4)^2 + V_E^2 + (F_\alpha/2)^2 + (F_\beta/2)^2 + (F_p/2)^2}$$

- q = Nennwert des anzustrebenden Aufmaßes pro Flanke
- q_1 = Zahnweitentoleranz der Fertigbearbeitung (Wkmax. – Wkmin.)
- q_2 = Zahnweitentoleranz der Vorbearbeitung (Wkmax. – Wkmin.)
- V_E = angenommener Versatz der Links- zu Rechtsflanken (für Honprozess hier keine Eingabe / für Schleifprozess sollten ca. 15µm angesetzt werden)
- F_α = Profil – Gesamtabweichung der Vorbearbeitung)*
- $F_ß$ = Flankenlinien – Gesamtabweichung der Vorbearbeitung)*
- F_p = Teilungs – Gesamtabweichung der Vorbearbeitung)*

  für Schleifprozess wird 100% des Fp-Betrages angesetzt, für Honprozess wird je nach Bearbeitungsstrategie 30 bis 60% des Fp-Betrages der Vorbearbeitung angesetzt

)* wenn keine IST-Werte bekannt, dann DIN Q 9,5 ansetzen

Alle Werte in µm

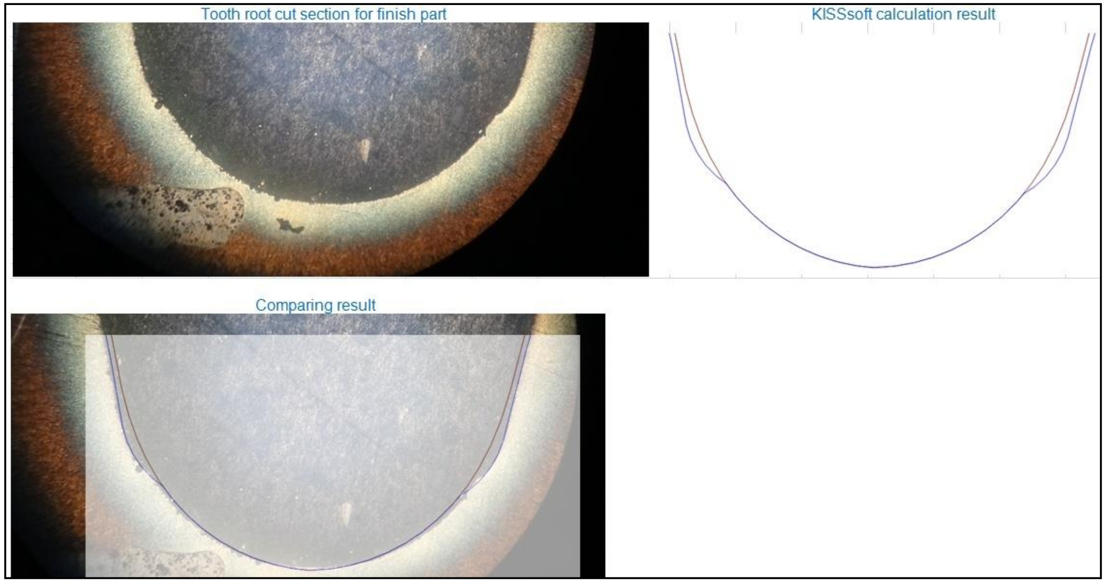
KISSsoft

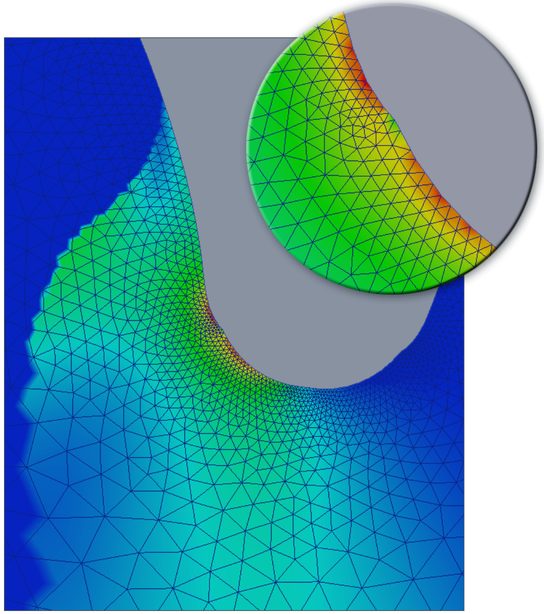
Sizing of grinding stock

If the flank is ground and the root not, a **grinding notch** will appear in the root area.

Due to the notch effect, the root stresses will increase.

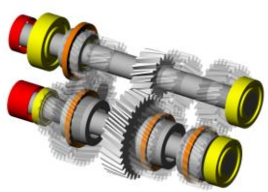
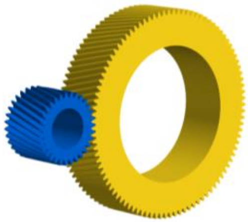
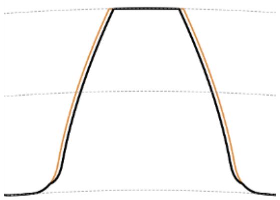
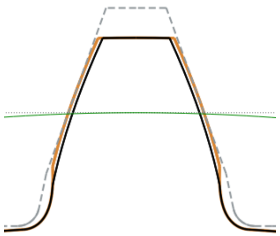
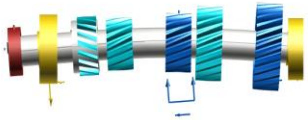
In order to avoid the grinding notch, a **protuberance cutter** is designed.





KISSsoft

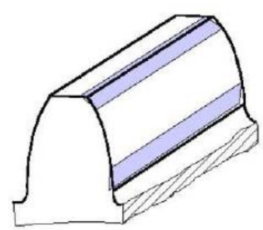
Rough Sizing

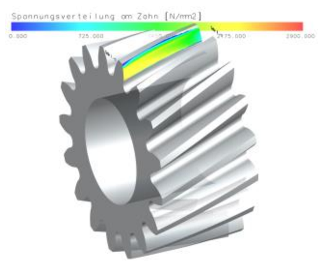
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

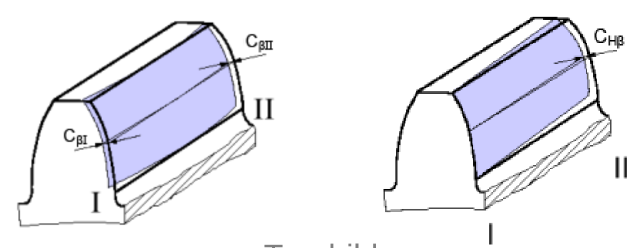
↓

Manufacture Measure ← Profile Modifications ← Contact Analysis ← Crowning ← Helix Angle Modifications

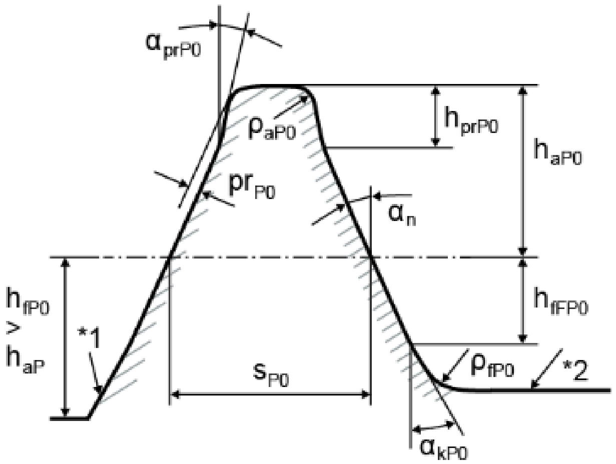


Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur





Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation



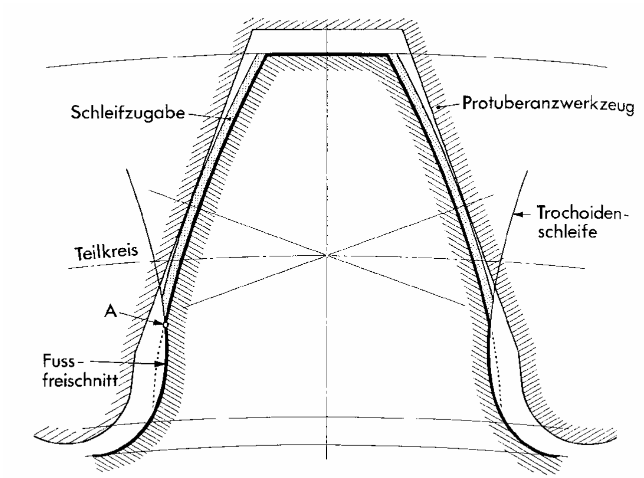
Addendum	h_{aP0}
Tip radius	ρ_{aP0}
Dedendum	h_{fP0}
Root radius	ρ_{fP0}
Protuberance height	h_{prP0}
Protuberance angle	α_{prP0}
Root form height	h_{FfP0}
Ramp angle	α_{KP0}

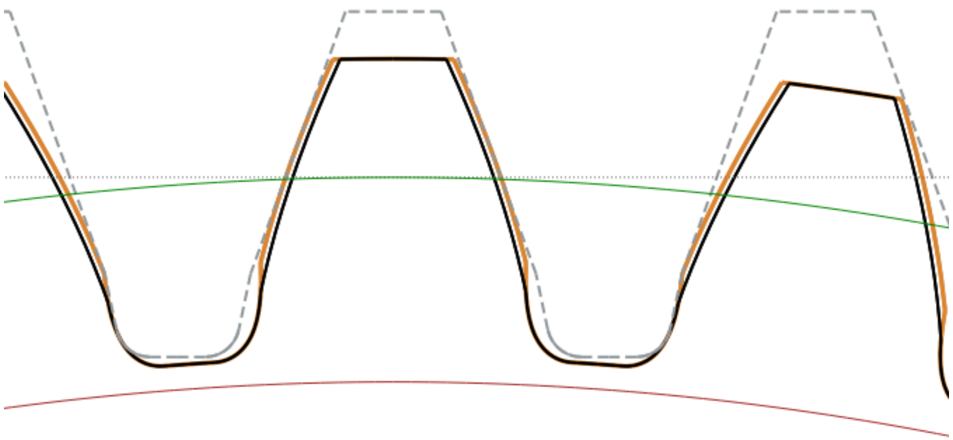
Protuberance	pr_{P0}
Protuberance angle	α_{prP0}
Protuberance height	h_{prP0}

$$pr_{po} \geq q$$

α_{prP0} defined

h_{pfP0} calculated



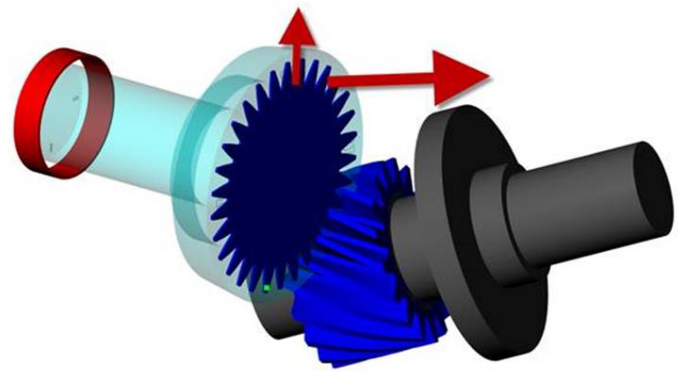


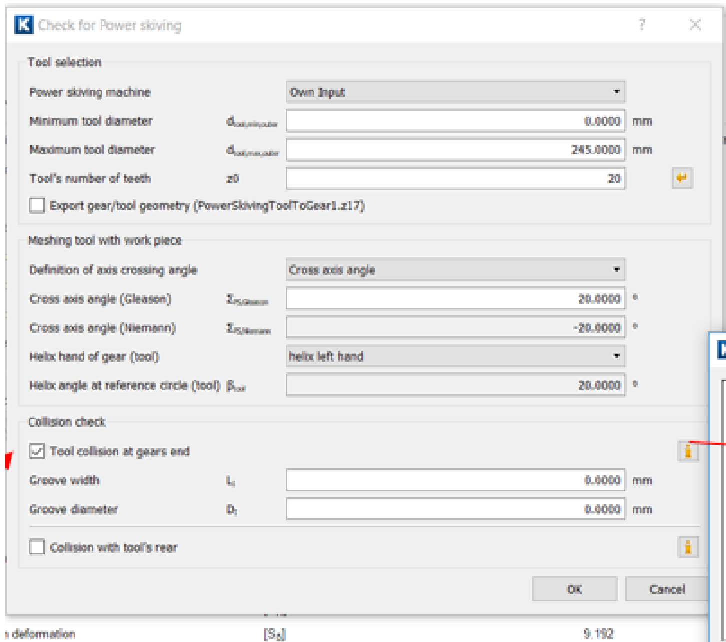
KISSsoft

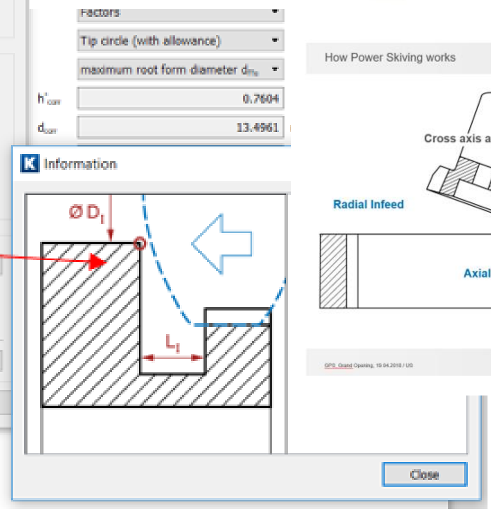
Feasibility assessment for Power-Skiving

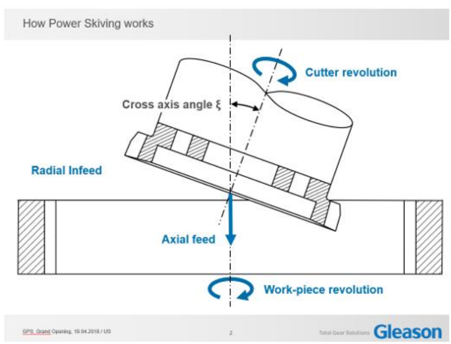
KISSsoft performs a feasibility assessment for manufacturing Power-Skiving

- Checks if a given gear can be manufacturing by Power-Skiving
- Sizing of tool’s number of teeth
- First collision check
- For external and internal gears



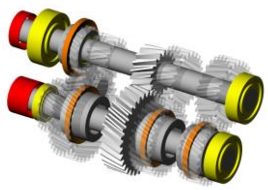


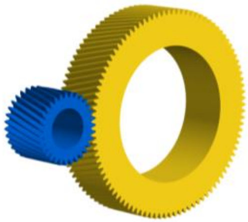


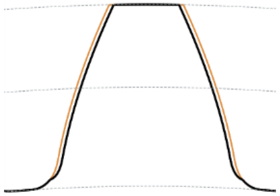


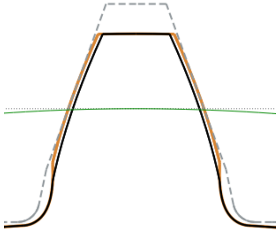
KISSsoft

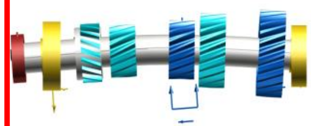
Rough Sizing







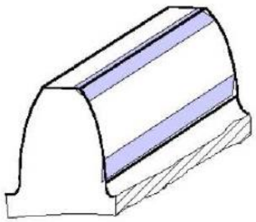




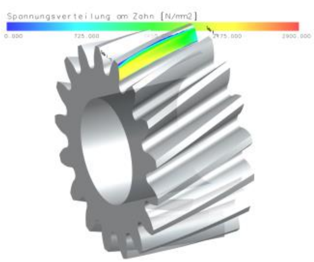
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

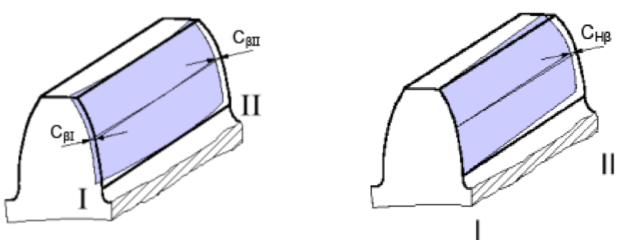
↓

Helix Angle Modifications → Crowning → Contact Analysis → Profile Modifications → Manufacture Measure



Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur

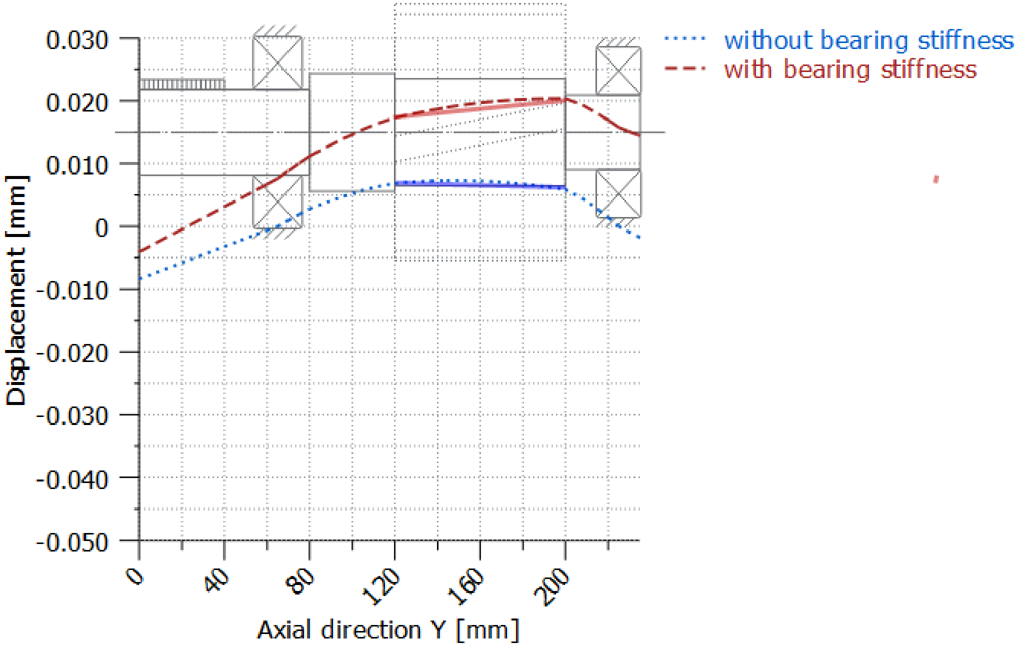




Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

KISSsoft

Example: Influence of **Bearing Stiffness** on shaft **Displacement**

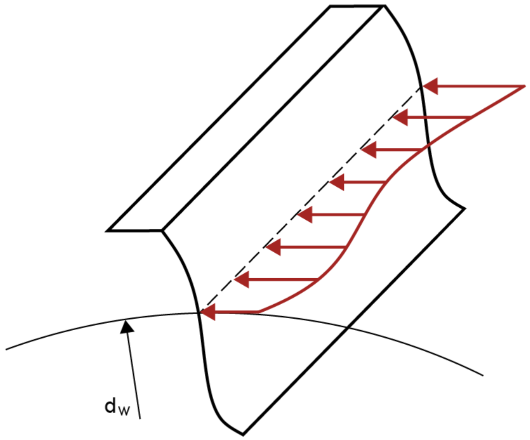


The gear **inclines** due to shaft deformation. If not compensated by lead modifications, this will result in an **uneven load distribution** on the tooth flank.

KISSsoft

Definition of the **Face Load Factor $\mathbf{K_{H\beta}}$** (ISO 6336−1)

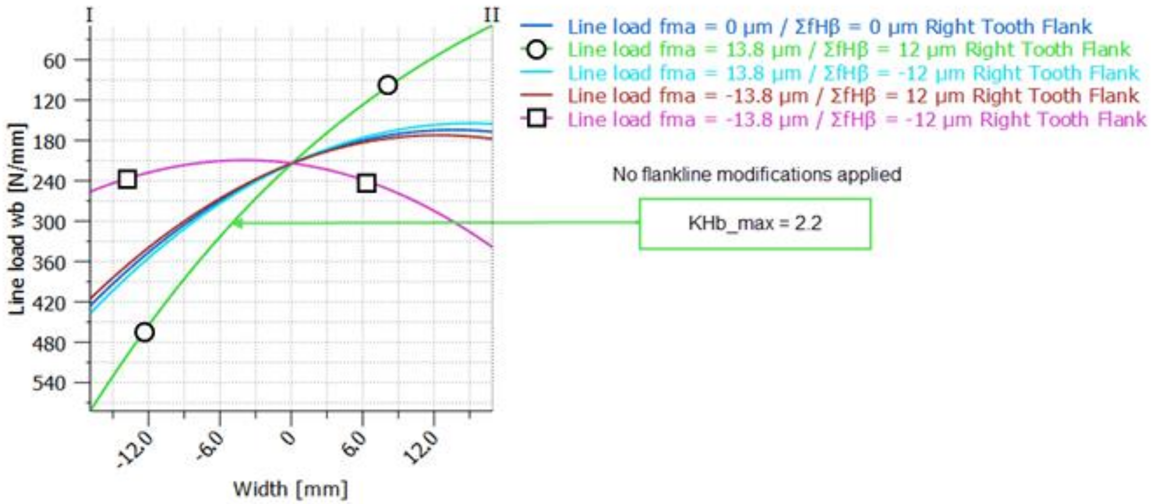
$$K_{H\beta} = \frac{maximum\ line\ load}{average\ line\ load}$$



ISO 6336-1 Annex E: Considers shaft deformation and flankline modifications

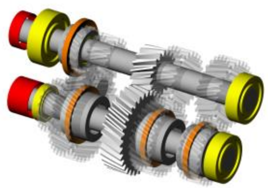
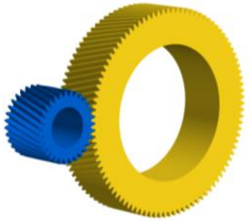
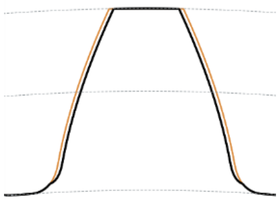
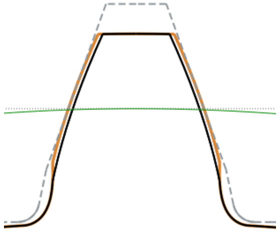
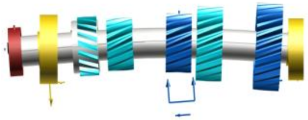
Manufacturing errors like axis non-parallelism (f_{ma}) und helix slope deviation ($f_{H\beta}$) can be considered in the calculation. Since manufacturing errors can have either a positive or a negative sign, several scenarios must be analysed.

- $f_{ma} = 0$ and $f_{H\beta} = 0$
- f_{ma} (+) and $f_{H\beta}$ (+)
- f_{ma} (+) and $f_{H\beta}$ (-)
- f_{ma} (-) and $f_{H\beta}$ (+)
- f_{ma} (-) and $f_{H\beta}$ (-)



According to ISO 6336, Annex E, the strength calculation must be performed with the highest face load factor (in this example, KHβ =2.2) that results from the above 5 cases.

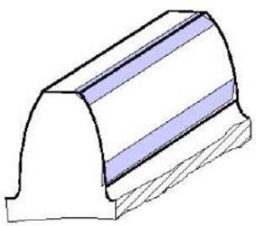
Rough Sizing

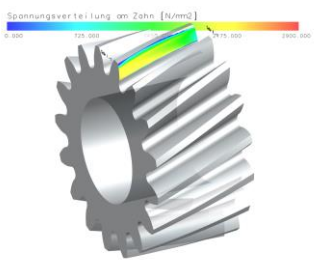
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

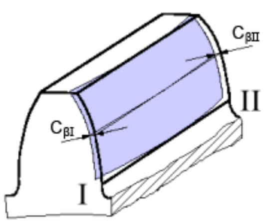
↓

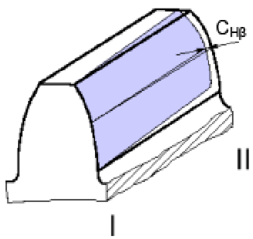
Manufacture Measure ← Profile Modifications ← Contact Analysis ← Crowning ← Helix Angle Modifications



Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur



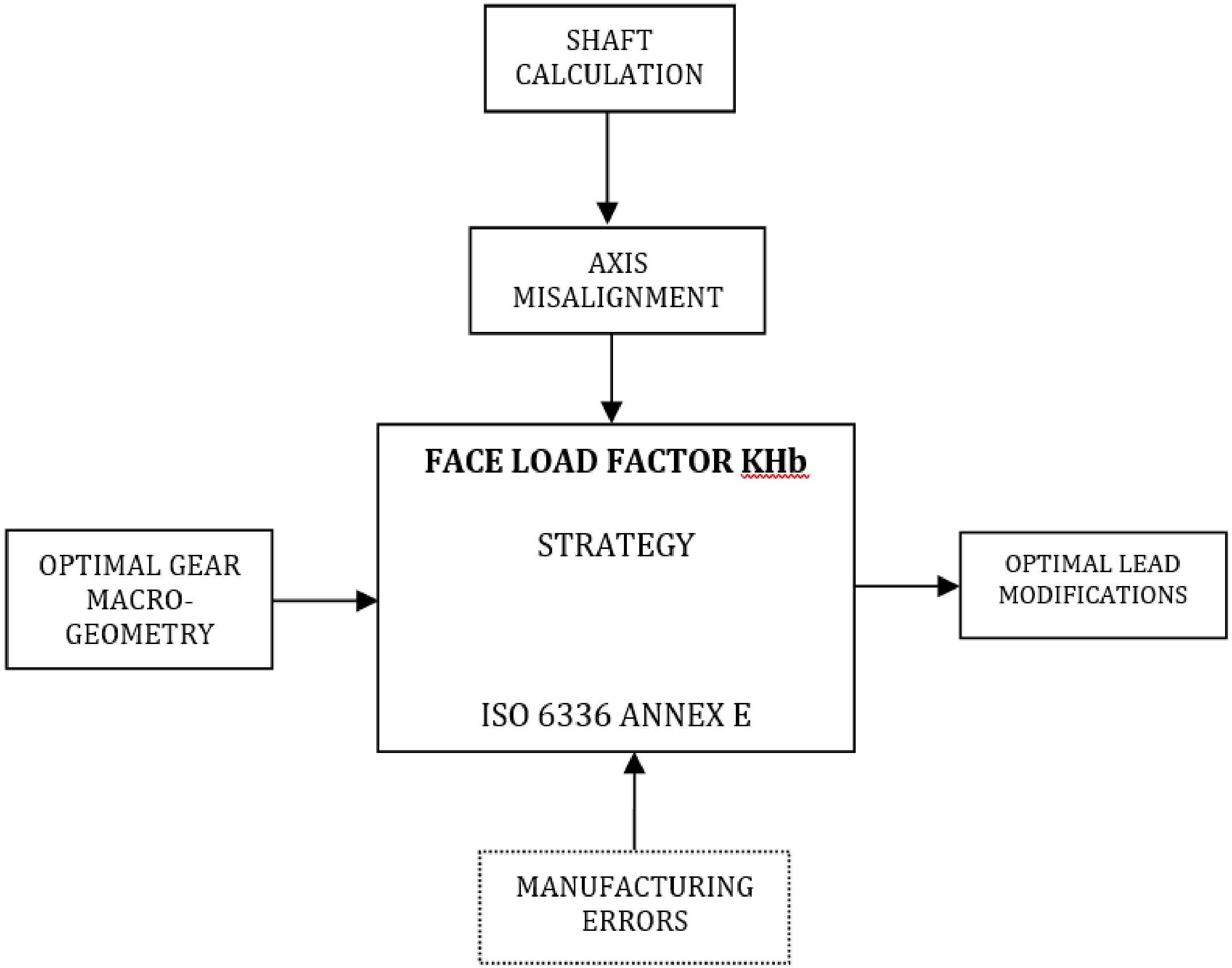




Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

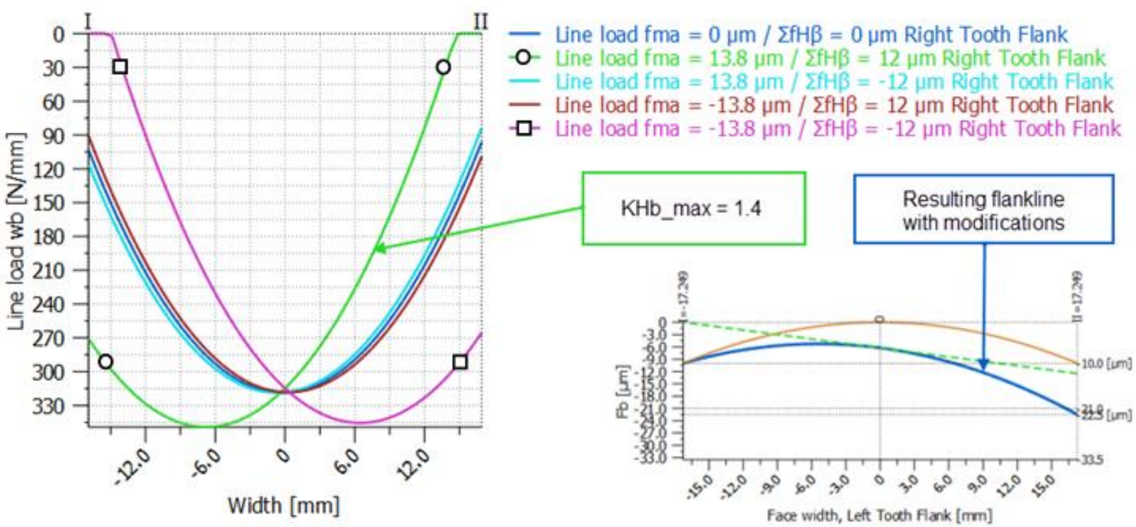
KISSsoft

Sizing of flankline (lead) modifications with manufacturing constraints



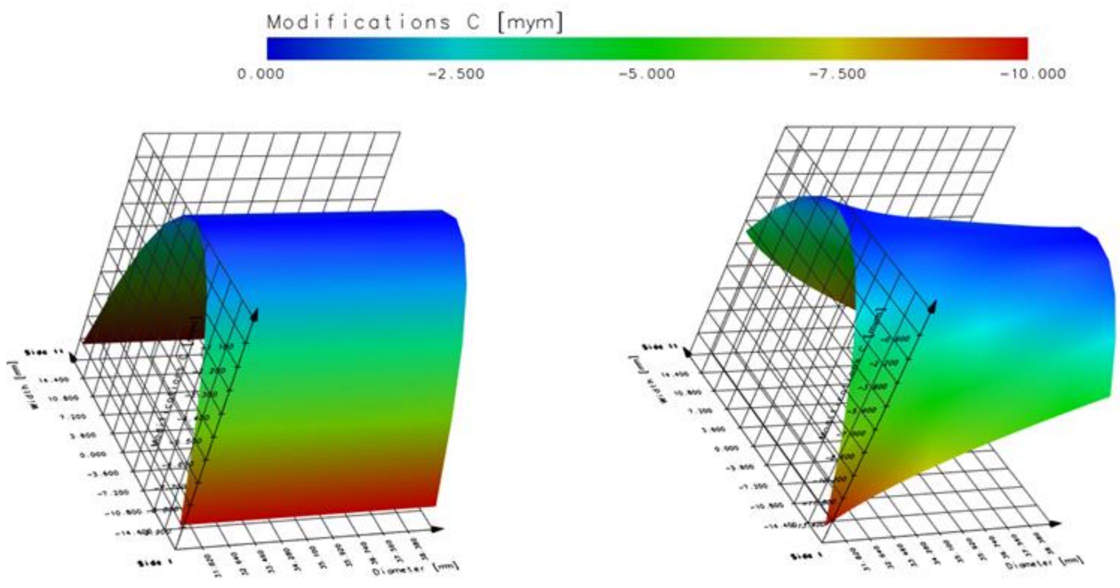
KISSsoft

In order to optimize the load distribution along the face width with manufacturing errors, often a crowning C_β and a helix angle modification $C_{H\beta}$ is introduced.



Conclusion: Flankline modifications are used to optimize the line load distribution. In this example, the face load factor was reduced from 2.2 down to 1.4. Applying the resulting face load factor in the strength calculation resulted in 45% higher root safety and 20% higher flank safety.

When using generation grinding to produce crowning in helical gears, a twist may appear due to the grinding motion of the tool. If not compensated, this may lead to a higher effective line load.

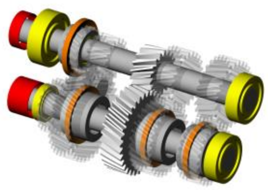


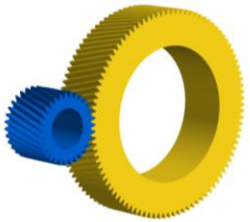
Theoretical crowning

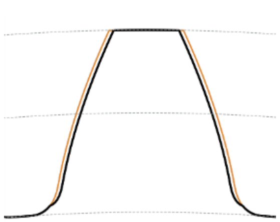
Resulting crowning with manufacturing twist

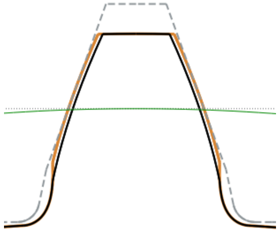
The twist due to manufacturing can be estimated in KISSsoft and applied for a detailed contact analysis.

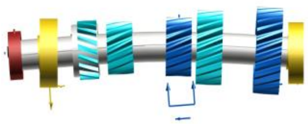
Rough Sizing







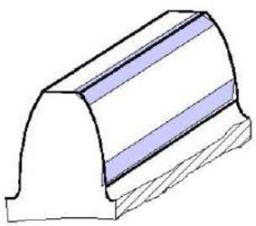




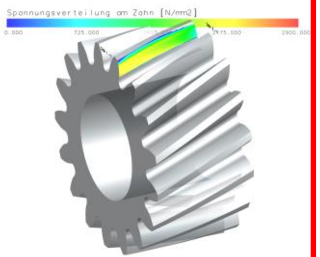
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

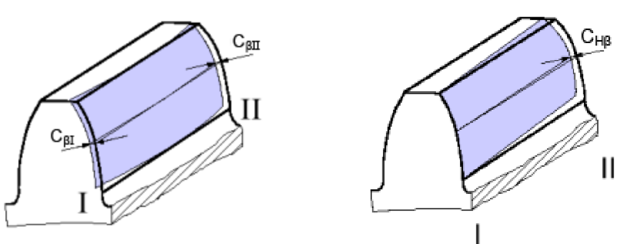
↓

Manufacture Measure ← Profile Modifications ← Contact Analysis ← Crowning ← Helix Angle Modifications



Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur

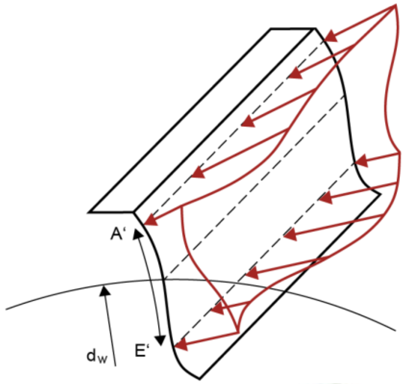


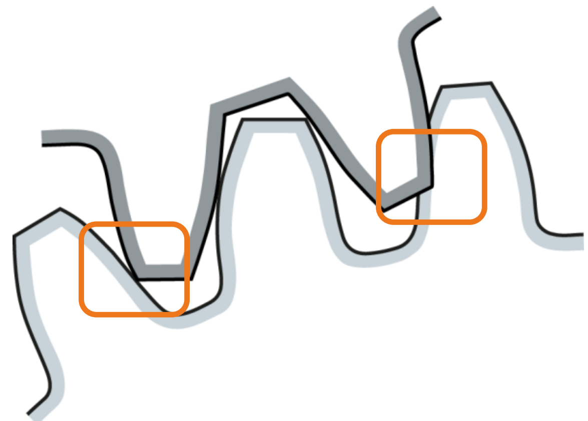


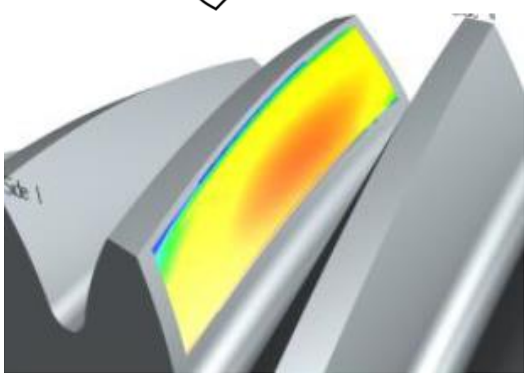
Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

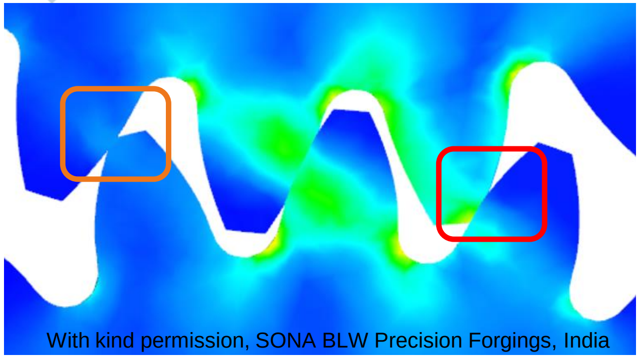
Loaded Tooth Contact Analysis (LTCA)

Die Kontaktanalyse rechnet die Zahndeformation unter Last und die Spannungen über den gesamten Eingriff und Zahnbreite. Die Berechnung basiert auf dem FVA-Bericht 129 und 134 nach Weber und Banaschek und ist ein alternativer Ansatz zu einer FE-Berechnung.









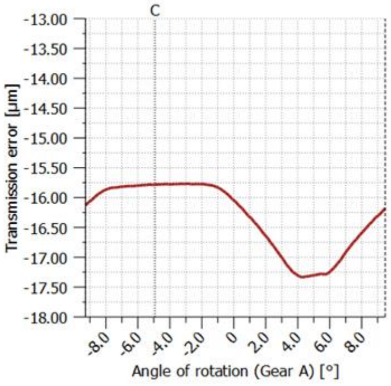
KISSsoft

A loaded tooth contact analysis evaluates the meshing under loaded conditions. Important parameters such as:

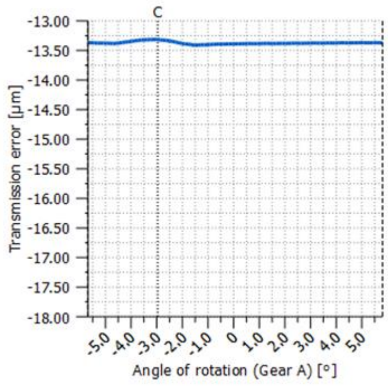
- Contact Shocks
- Transmission error (TE)
- Amplitude spectrum of TE
- Contact ratio under load

are calculated.

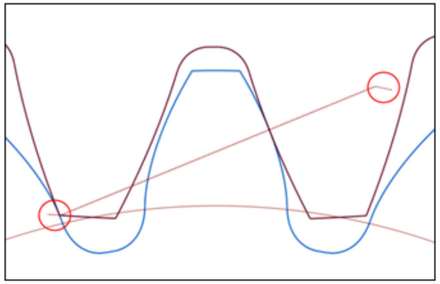
What is the optimal profile modification?



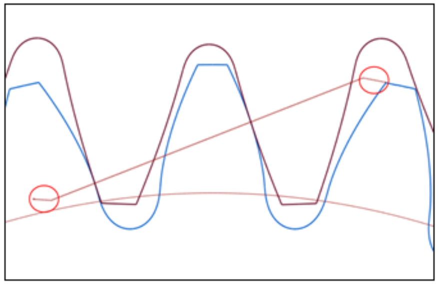
TE (example Profile C)



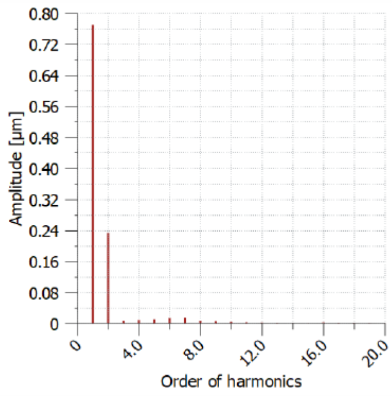
TE (example deep tooth form)



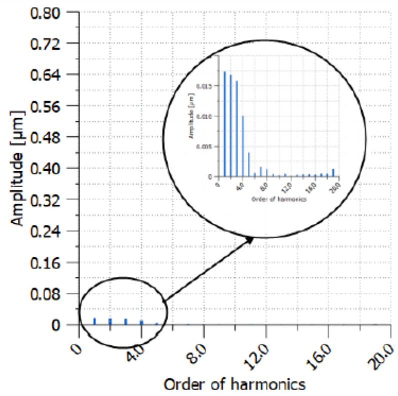
Contact shock (example profile C)



Contact shock (example deep tooth form)



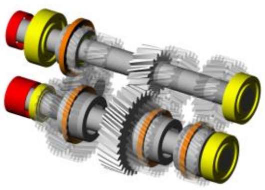
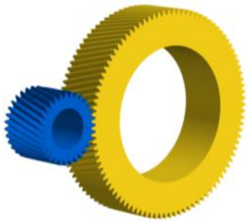
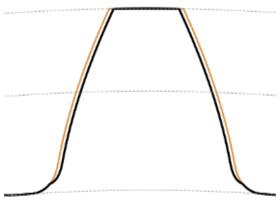
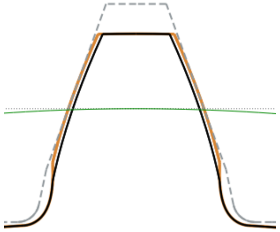
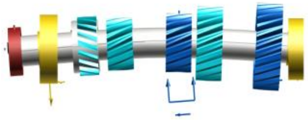
TE Harmonics (example Profile C)



TE Harmonics (example deep tooth form)

KISSsoft

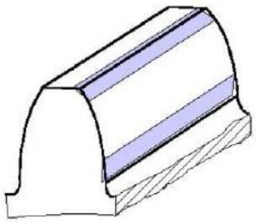
Rough Sizing

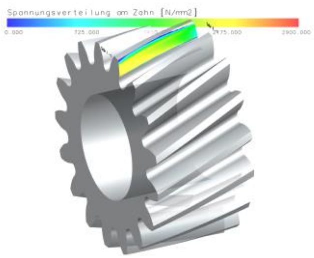
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

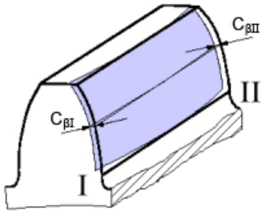
↓

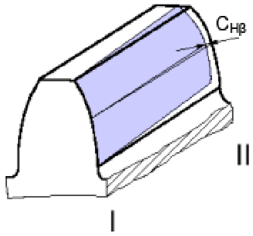
Helix Angle Modifications → Crowning → Contact Analysis → Profile Modifications → Manufacture Measure



Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur



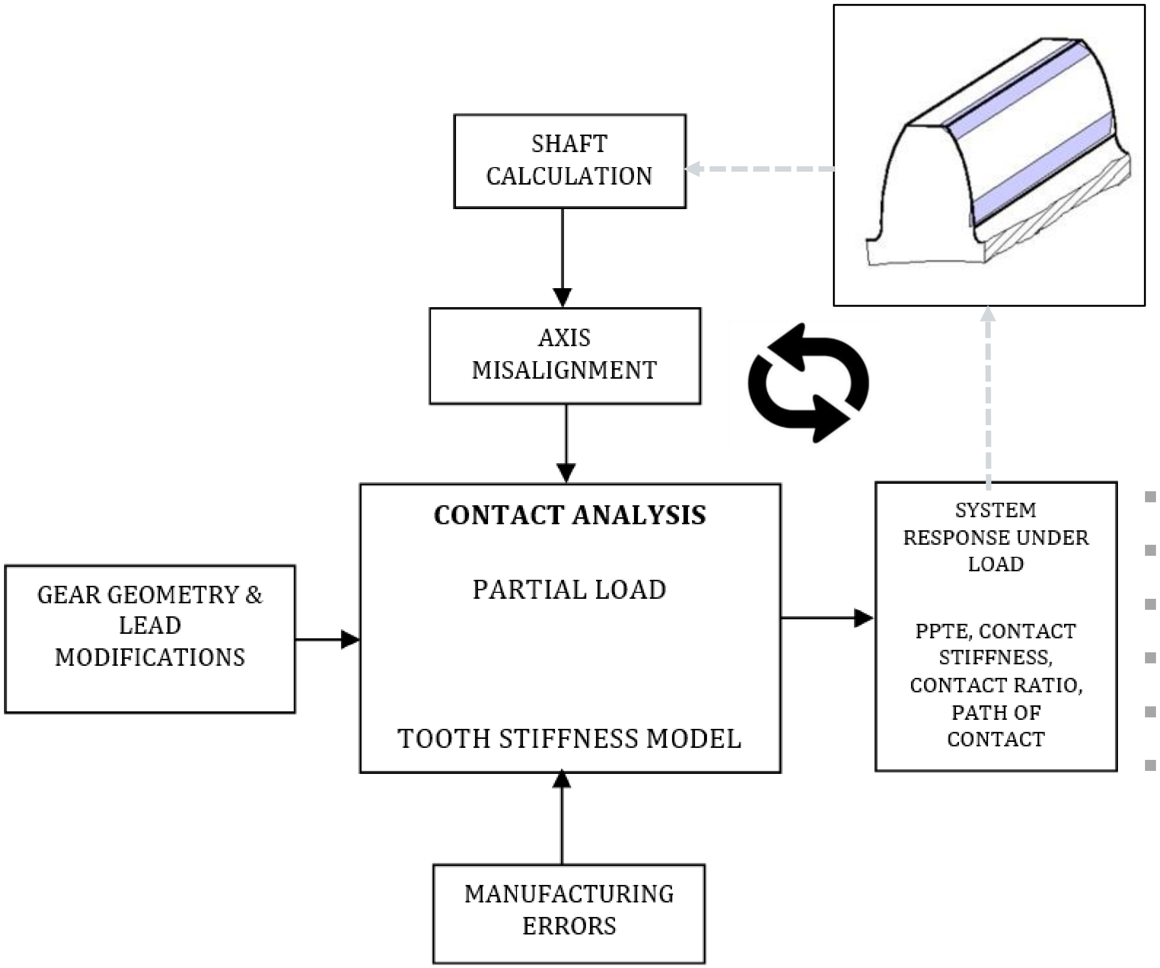




Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

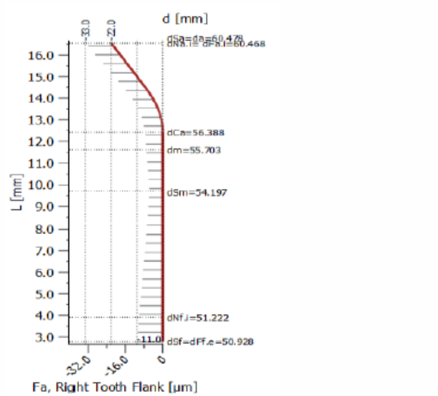
KISSsoft

Sizing of profile modifications

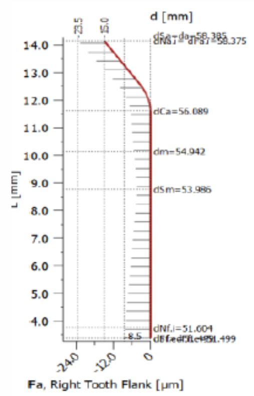


- Transmission error (TE)
- Amplitude of TE (PPTE)
- Harmonics of TE
- Force excitation
- Path of contact under load
- Contact ratio under load

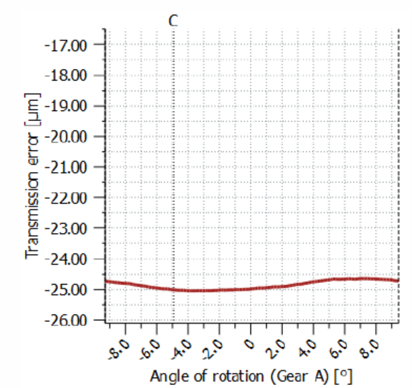
An optimal profile modification eliminates contact shocks, reduces the peak-to-peak transmission error and eliminates higher orders of harmonics, to ensure a smooth transmission error curve that is similar to a sin-wave.



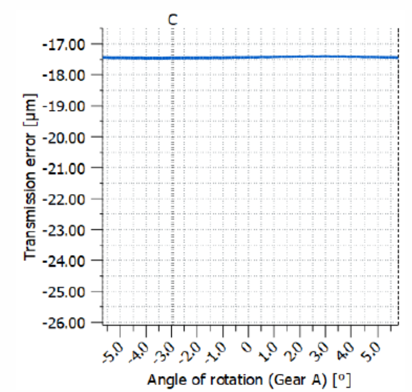
Tip Relief: Caα = 22 µm



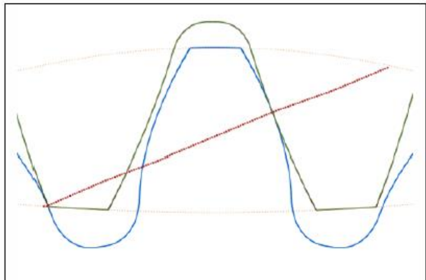
Tip Relief: Caα = 15 µm



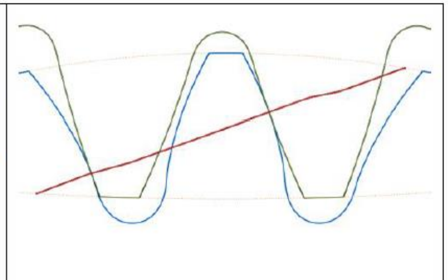
TE (example Profile C with tip relief)



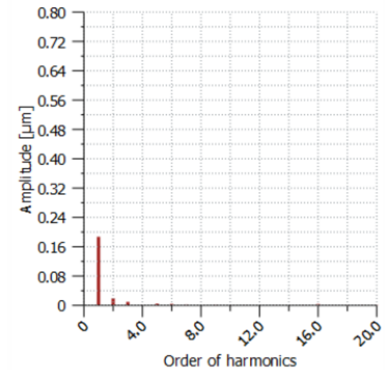
TE (example deep tooth form with tip relief)

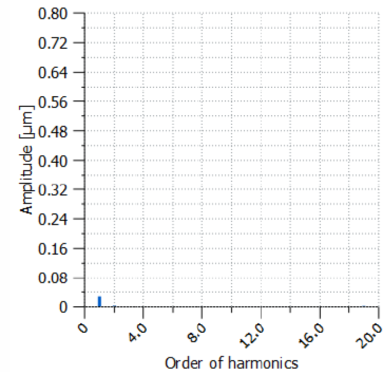


Path of contact with Tip Relief, Profile C



Path of contact with Tip Relief, deep tooth form

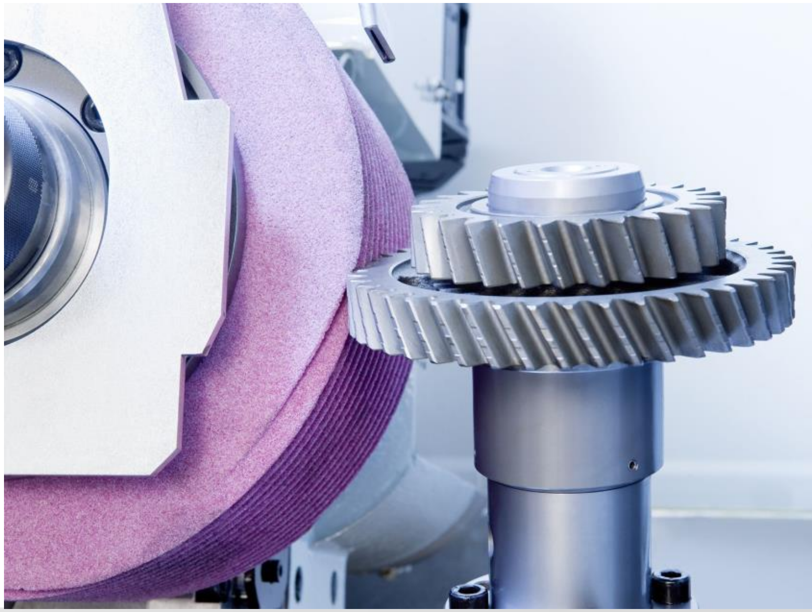


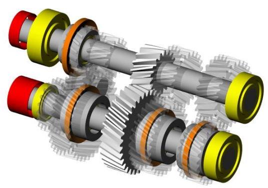


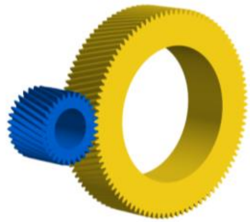
KISSsoft

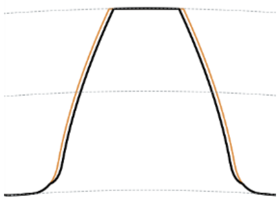
In KISSsoft, it is possible to assess which modifications can be manufacturing by a list of available **Dressing Wheels** or **Grinding Worms**.

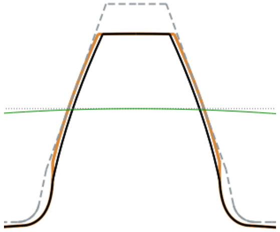
Considering existing tools in the design process may further reduce manufacturing costs during the grinding process.

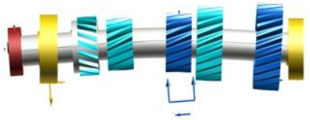








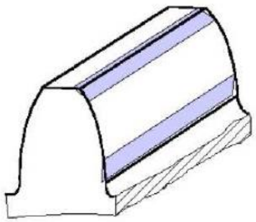




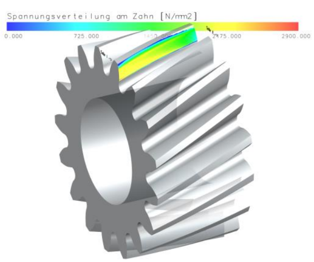
Rough Sizing → Fine Sizing → Grinding Stock Sizing → Cutter Sizing → Deformation Face Load Factor

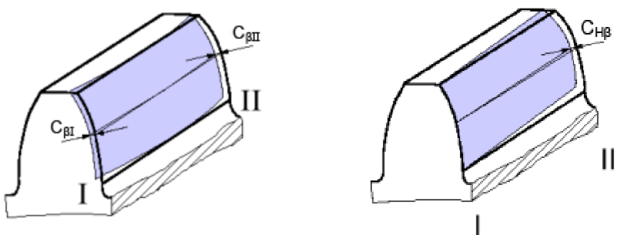
↓

Manufacture Measure ← Profile Modifications ← Contact Analysis ← Crowning ← Helix Angle Modifications



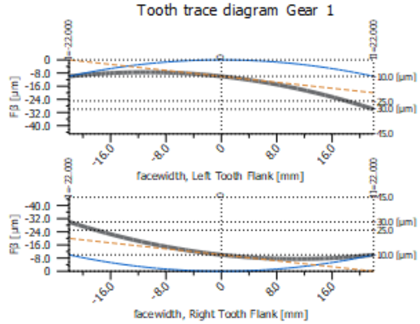
Geräusch
Fressen
Wirkungsgrad
Kontakttemperatur

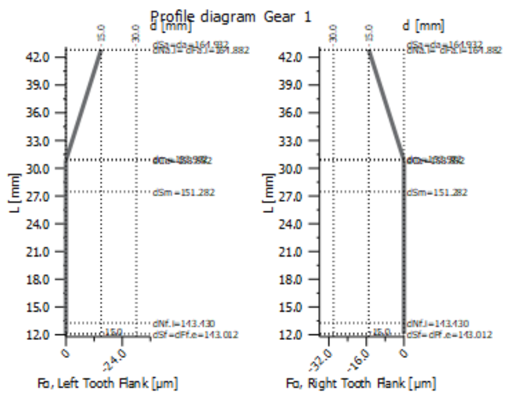




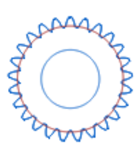
Tragbild
Lebensdauer
Kompensation Herstellfehler / Lagerluft
Variable Deformation

Manufacturing Data



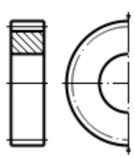


Tooth form Gear 1



Scale 1 : 5

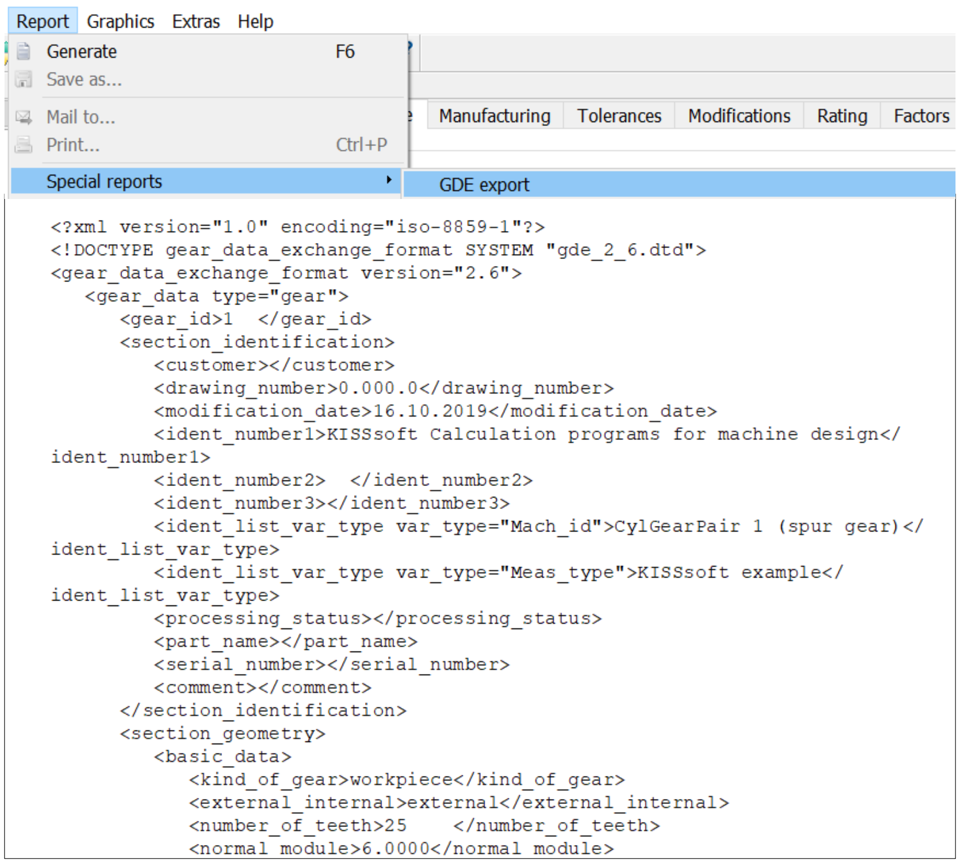
Drawing Gear 1

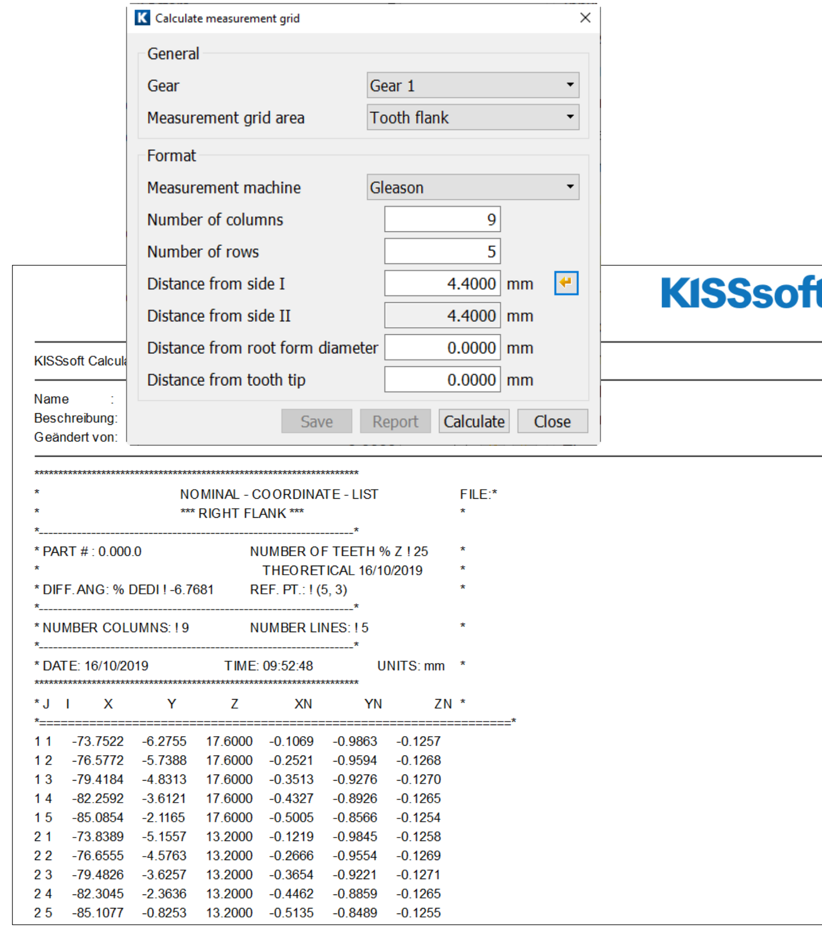


Scale 1 : 5

Manufacturing data for cylindrical gears		
Drawing or article number		0.000.0
Number of teeth	[z]	25
Facewidth (mm)	[b]	44.000
Normal module (mm)	[mn]	6.000
Helix angle (°)	[β]	0.000 (0°0'0'')
Hand of gear	Spur gear	
Normal pressure angle (°)	[αn]	20.000 (20°0'0'')
Material	18CrNiMo7-6	
Cutter/Tool: Hobbing cutter		
Addendum coefficient	[haP0*]	1.250
Dedendum coefficient	[hfP0*]	1.200
Tip radius factor	[ρaP0*]	0.380
Root radius factor	[ρfP0*]	0.001
Root form height coefficient	[hFfP0*]	0.000
Protuberance angle (°)	[αprP0]	0.000
Protuberance height coefficient	[hprP0*]	0.000
Ramp angle (°)	[αKP0]	0.000
Tooth thickness factor reference line	[sP0*]	1.571
not topping		
Addendum coeff. ref. profile	[haP*]	1.000
Accuracy grade according to ISO 1328:2013		A
6		
Profile shift coefficient	[x]	0.248
Reference diameter (mm)	[d]	150.000
Tip diameter (mm)	[da]	164.982 , 0.000 / -0.100
Root diameter (mm)	[df]	137.982 , -0.261 / -0.398
Tooth thickness tolerance	DIN 3967 cd25	
Tooth thickness allowance (normal section) (mm)	[As.e/i]	-0.095 / -0.145
Number of teeth spanned	[k]	4
Base tangent length (no backlash) (mm)	[Wk]	65.115
Actual base tangent length (span) (mm)	[Wk.e/i]	65.026 / 64.979
Effective diameter of ball/pin (mm)	[DMeff]	11.000
Measurement over pins according to DIN 3960 (mm)	[MdR.e/i]	168.394 / 168.289
Measurement over 3 pins (axial) according to AGMA 2002 (mm)		
[MdR.e/i]168.394 /168.289		
Normal chordal tooth thickness, no backlash (mm)	[sc]	10.502
Actual chordal tooth thickness (mm)	[sc.e/i]	10.409 / 10.360
Reference chordal height (mm)	[ha]	7.650
Profile and tooth trace modifications		
Symmetric (both flanks)		
- flankline crowning	Cb =	10.000 μm (rcrown=24200mm)
- Helix angle modification, parallel	CHb=	-20.000 μm
- Tip relief, linear	Caa=	15.000 μm LCa = 2.000 *mn dCa = 153.882 mm

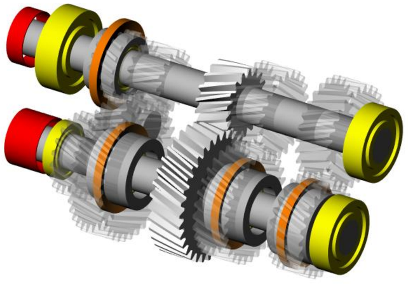
Measurement Data (GDE / Measurement Grid)

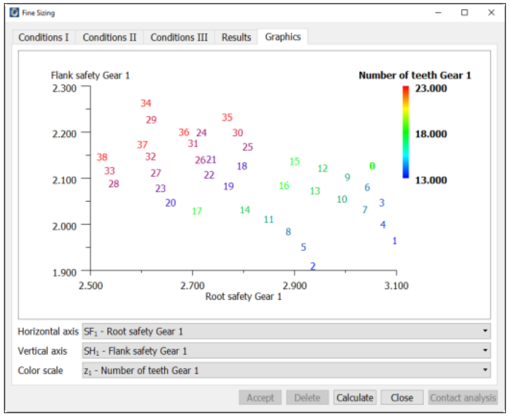




Summary

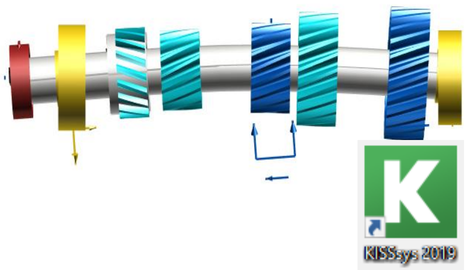
Rough Sizing



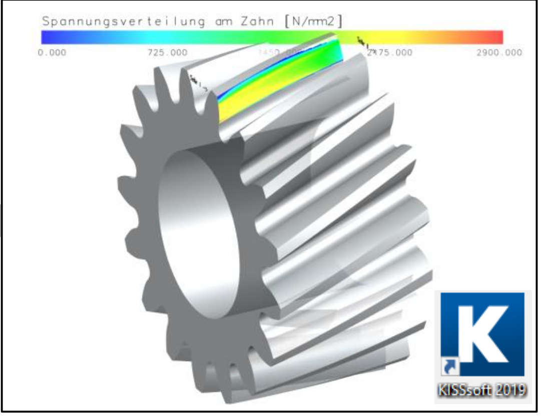


Fine Sizing

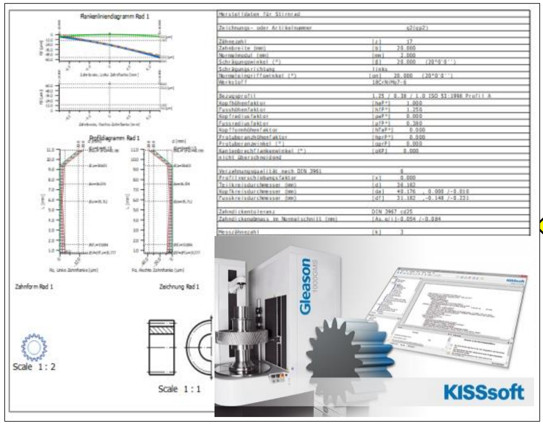
Deformation



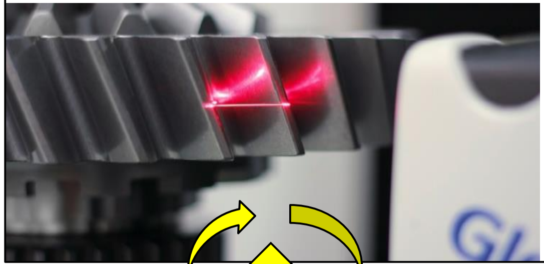
Contact Analysis
Micro-Geometry

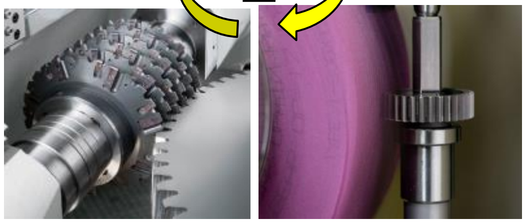


Manufacturing & Measurement Data



Measuring





Manufacturing

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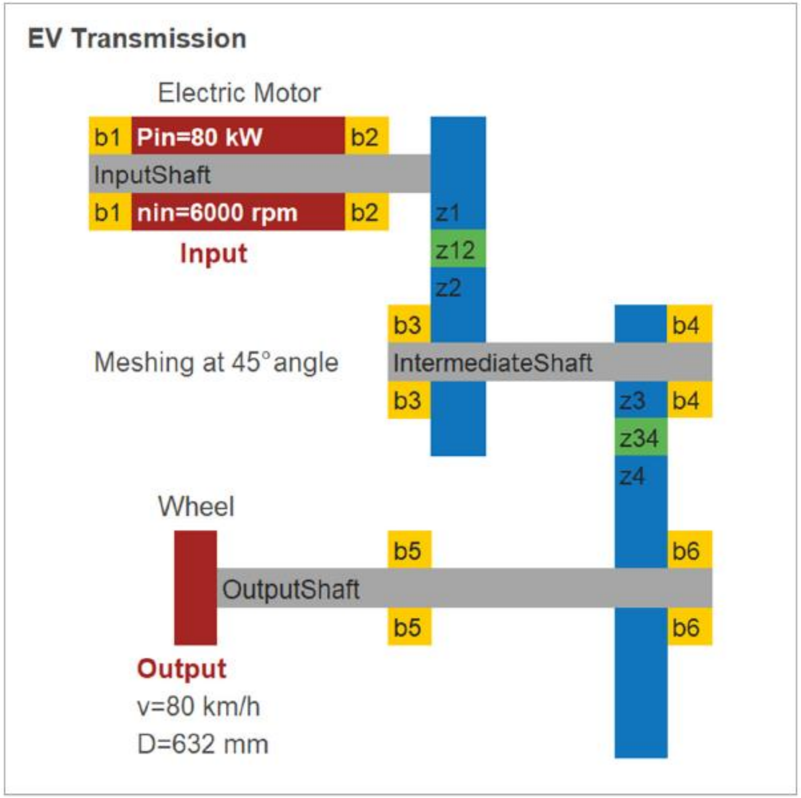
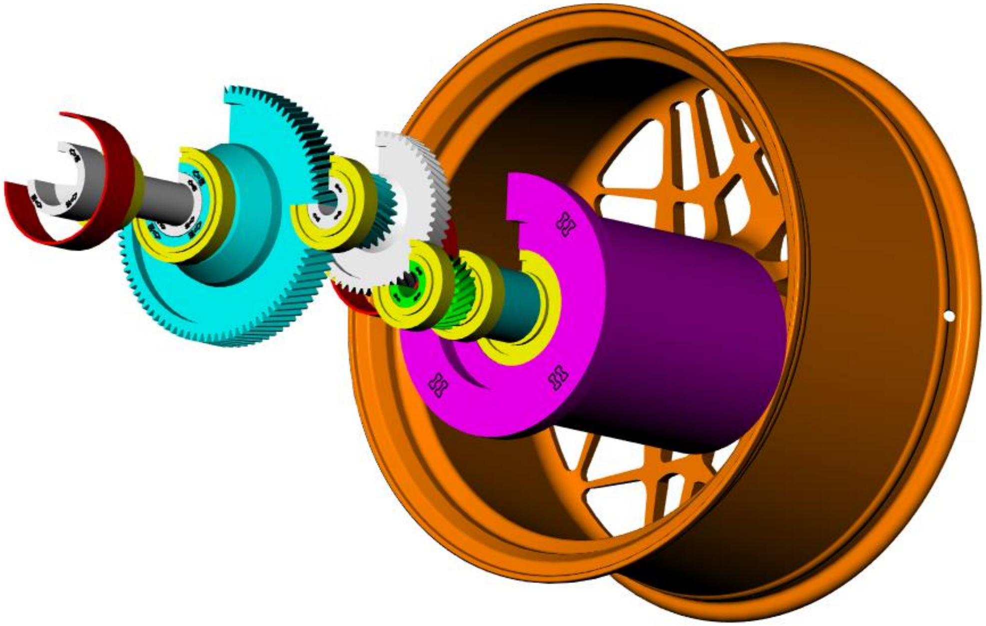
Calculation Example





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Calculation Methods

Gears: ISO 6336	SHmin = 1.1	SFmin = 1.6
Shafts: DIN 743	SSmin = 1.2	SDmin = 1.2
Bearings: ISO 16281	Hmin = 5000h	

Materials

Gears: 18 CrNiMo7-6 Case Hardened
Shafts: C45
Housing: Aluminium

Lubrication

Oil Injection, ISO VG 46, 80°

$$i = \frac{n_{motor} \cdot D \cdot \pi}{v}$$

i … Transmission ratio, n_{motor} … Optimal motor RPM [1/min],
D … Outer tire diameter [m], v … Average vehicle speed [m/min]

Example: $i = \frac{6000\ rpm \cdot 0.632\ m \cdot 3.14}{1333 \cdot \frac{m}{min}} = 8.9$

$i_{12} = 2.3$ $i_{34} = 3.7$

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References

[1] ISO 6336, *Calculation of load capacity of spur and helical gears*, Part 1,2,3 and 6, 2006.

[2] ISO 53, *Cylindrical gears for general and heavy engineering — Standard basic rack tooth profile*, 1998.

[3] ISO/TS 16281, *Rolling bearings - Methods for calculating the modified reference rating life for universally loaded bearings*, 2008.

[4] Kissling, U.: *Layout of the Gear Micro Geometry*, Gearsolutions, 2008.

[5] Masuda, T.: *Prediction Method of Gear Noise Considering the Influence of the Tooth Flank Finishing Method*, Japan, 1986.

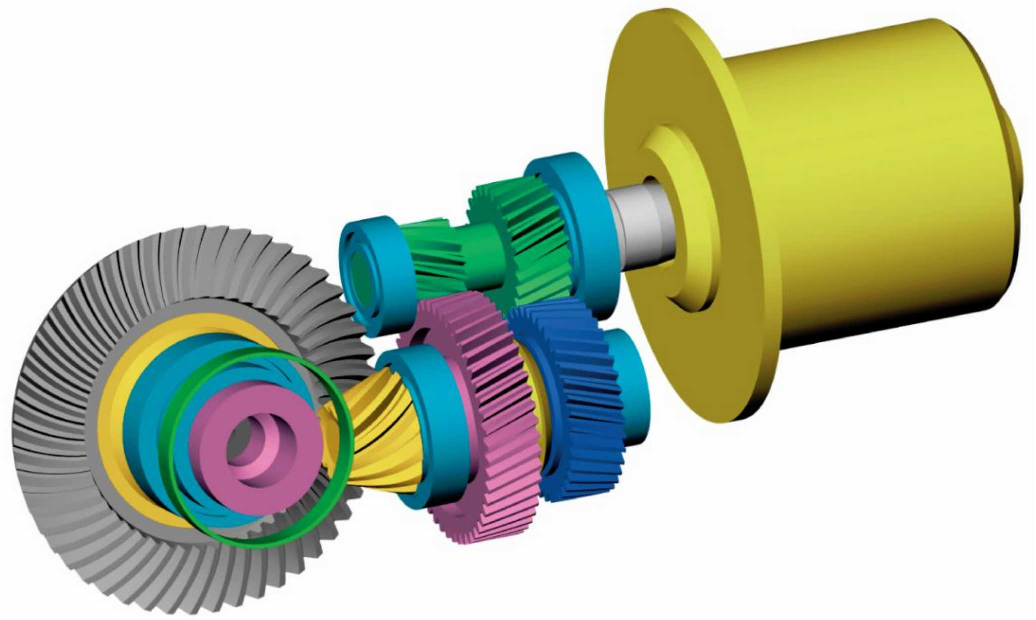
[6] Weber C., Banaschek K.: FVA-Bericht 129 und 134, *Elastische Formänderung der Zähne und der anschliessenden Teile der Radkörper von Zahnradgetrieben*, FVA 1955.

[7] FVA-Bericht Nr. 487, 2011.

[8] Nicholas Bugliarello, Biji George, Don Giessel, Dan McCurdy, Ron Perkins, Steve Richardson & Craig Zimmerman: *Heat Treat Processes for Gears, Gear Solutions*, July 2010.

[9] ISO 21771 *Gears - Cylindrical involute gears and gear pairs - Concepts and geometry*.

Thank you for your attention!



Sharing Knowledge

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