Plastic Gears

An overview and introduction

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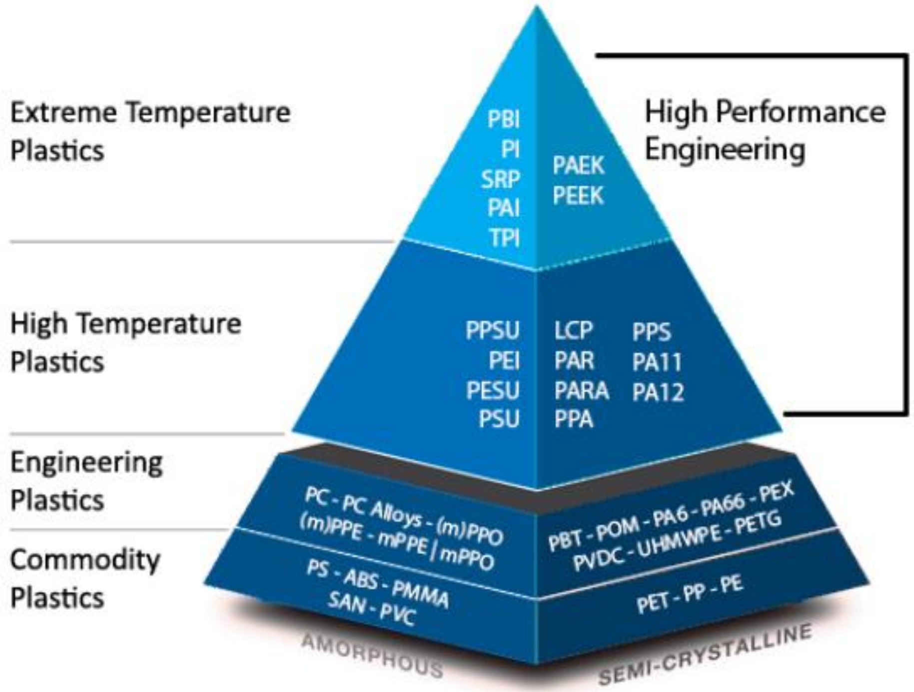
Plastic gears – Introduction



Advantages

- Low mass and inertia
- No lubrication required
- Corrosion resistance
- Sound and vibration damping
- Lower cost for serial production
- Design freedom

Drawbacks

- Inferior mechanical properties
- Inferior thermal properties
- Lower manufacturing tolerances
- Lower operating temperatures
- Moisture absorption

SOURCE: http://polymers.com.au/thermoplastics/, 9.6.2017.

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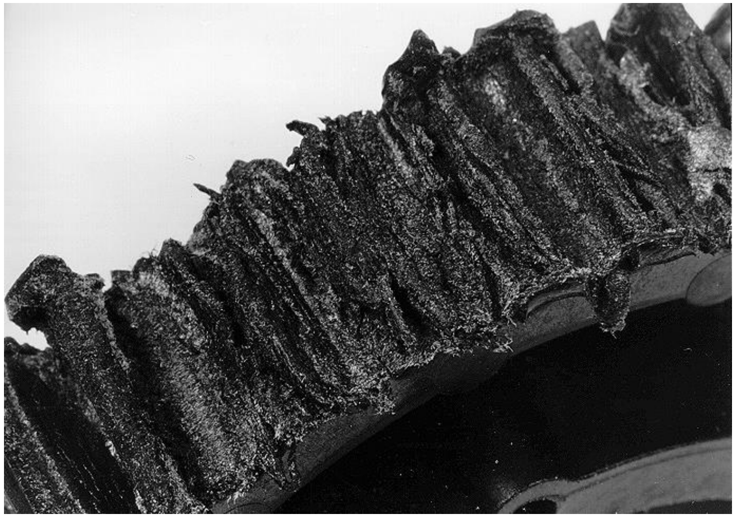
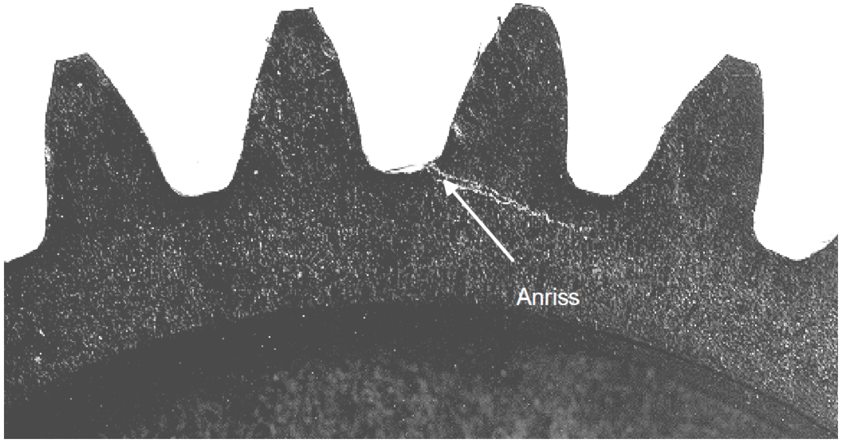
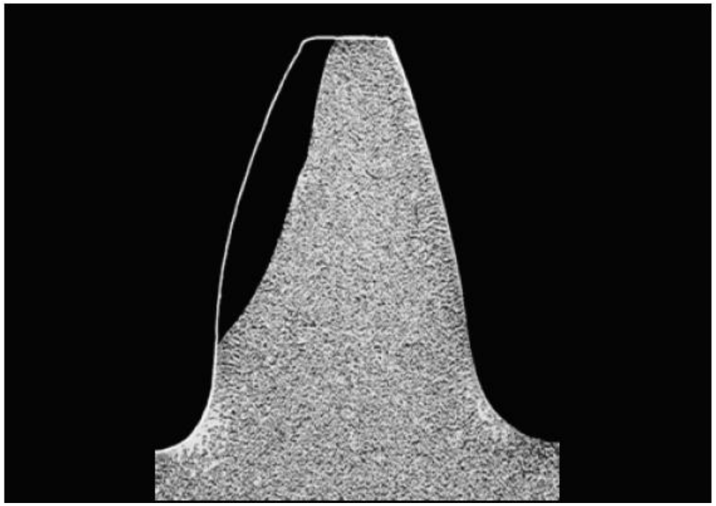
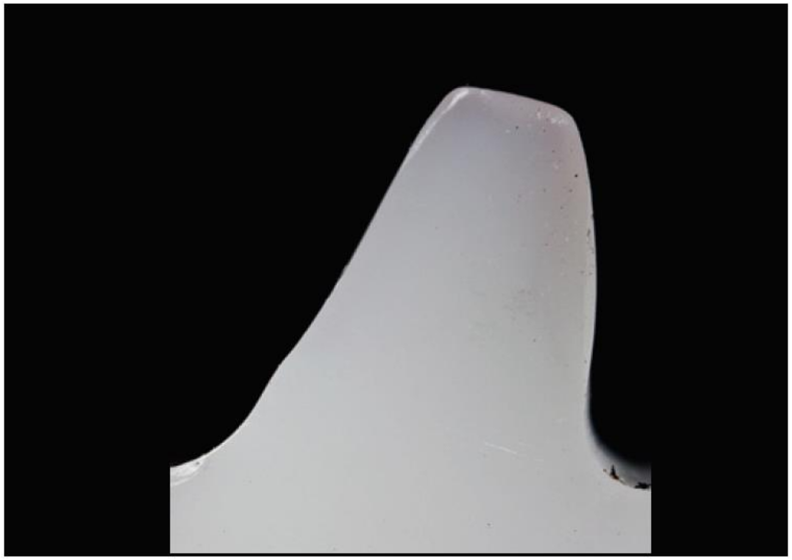
Failure modes









SOURCE: Rösler J.: Zur Tragfähigkeitssteigerung thermoplastischer Zahnräder mit Füllstoffen, Diss.TU Berlin 2005.

Material data – General

Guidelines and data for the design of plastic gears in KISSsoft:

1981 - 1996	Guideline VDI 2545 (PA12, PA66, POM)
1996 - 2008	Nothing valid …
2008	Material data measured by Victrex, Sabic, DSM
2013	Guideline VDI 2736

Required data for the calcualtion

- **Poisson ratio** and **elasticity modulus** (temperature dependent)
- Static strength calculation: **Yield** and **ultimate** tensile strength (temperature dependent)
- Wear calculation: **Wear factor** (material combination, lubrication, ...)
- Temperature calculation: **Coefficient of friction** (material combination, lubrication, ...)
- Lifetime calculation: **S-N curves** for root and flank (temperature dependent)
- Other: **Coefficient of thermal expansion**, **water absorption**, …

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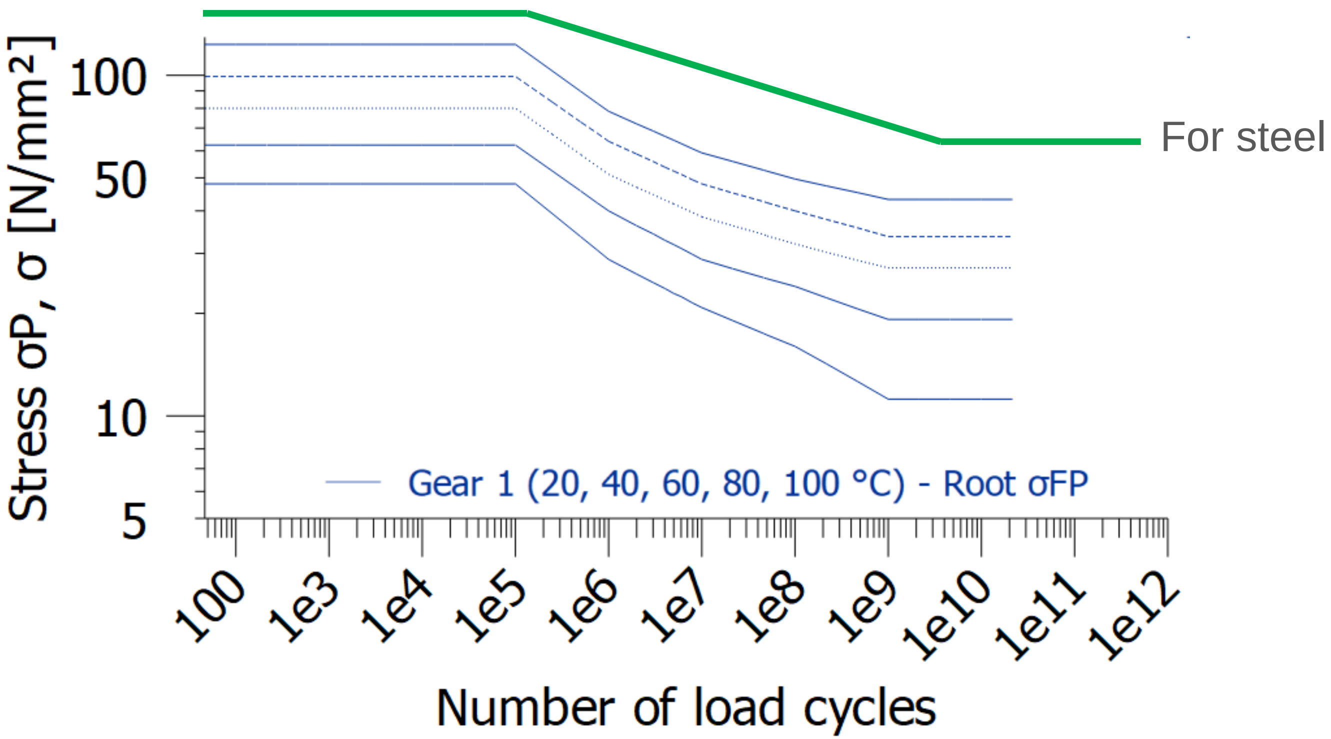
Material data – S-N curves (Wöhler line)

- S-N curves strongly depend on the actual root/flank temperatures
- S-N curves required as a function of temperature
- Measuring the S-N curves is very time consuming and expensive



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Overview of the current materials in the KISSsoft database

OPEN SOURCE: 34 general materials (PA6, POM, PA46, ...)

- from standards and industry measurements
- from plastics manufacturers (Kuraray, DuPont, ...)

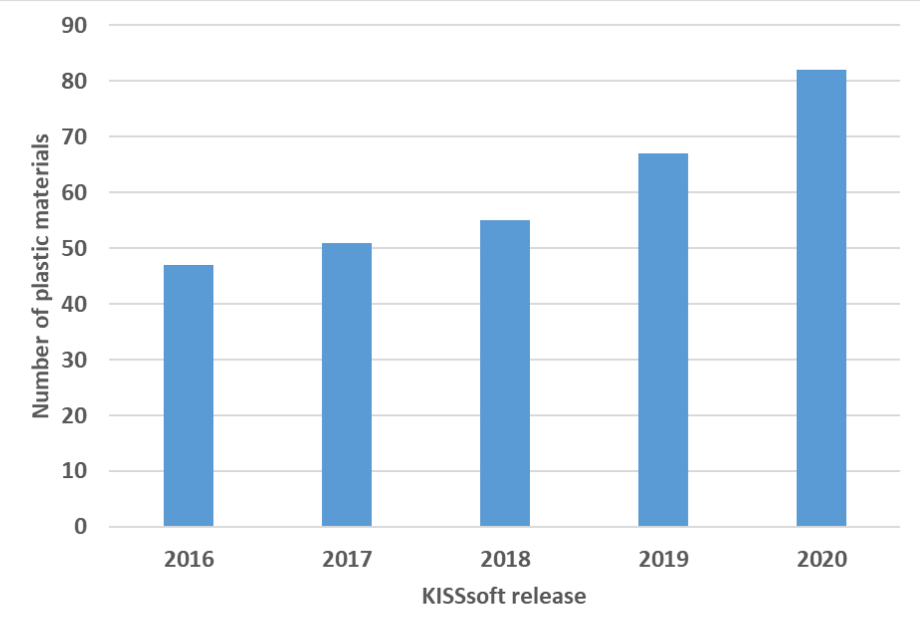
ON REQUEST: 33 specific materials

- 22 from Sabic Innovative Plastic
- 5 from Alcom (no fatigue data available)
- 3 from DSM Performance Material
- 1 from Victrex
- 1 from DuPont

10491	179 PA66 (VDI2736)
10492	180 POM (VDI2736)
10493	181 PBT (VDI2736)
10494	182 PET (VDI2736)
10495	183 PA46 (VDI2736)
10496	184 PEEK (VDI2736)
10500	185 Laminated fabric
10510	186 PA 12 (VDI2545)
10531	187 Hostaform C9021G (Celanese) POM
10540	188 Laminated wood
19001	189 PEEK (Victrex)
19151	190 LUBRICOMP UCL-4036A HS/UCL36AS
19152	191 LUBRICOMP UFL-4036A HS/UFL36AS
19153	192 THERMOCOMP UFM-3249HSS/UFW49RS
19154	193 LUBRICOMP KA/KA000M
19155	194 LUBRICOMP KL-4040/KL004
19156	195 LUBRILOY R/R2000
19157	196 LUBRICOMP DFL-4036/DFL36
19158	197 LUBRICOMP EFL-4036/EFL36
19159	198 LUBRICOMP OFL-4036/OFL36A
19160	199 LUBRICOMP OCL-4036/OCL36A
19161	200 LUBRICOMP RFL-4036/RFL36
19162	201 VERTON RFL-8029/RVL29ESS
19163	202 LUBRICOMP WFL-4036/WFL36
19164	203 LUBRICOMP LCL-4033/LCL33
19165	204 LUBRICOMP DL-4020FR/DL0029E
19166	205 LUBRICOMP WL-4040/WL004
19167	206 LUBRICOMP RL-4040/RL004
19168	207 LUBRICOMP RFL-8036/RVL36
19169	208 LUBRICOMP ECL-4036/ECL36

Summary

Open source:	34 materials
On request:	33 materials
Total:	**67 materials**
Root fatigue:	41 materials
Flank fatigue:	10 materials
Wear data:	44 materials



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VDI 2736 – General

VDI 2736 is the most recent calculation method for plastic gears. **It is a guideline and not a standard!**

It consists of 4 parts:
VDI 2736, Part 1: General recommendations, material properties, drawings
VDI 2736, Part 2: Strength assessment of cylindrical gears
VDI 2736, Part 3: Strength assessment of worm gears (crossed helical gears)
VDI 2736, Part 4: Measurements of material properties

Possible calculations:

- An approximate **rough calculation** for cylindrical gears
- Calculation of **temperatures**
- Calculation of **fatigue failure (root, flank)**
- Calculation of **wear**
- Calculation of **static failure**
- Calculation of **deformation**
- Calculation of **shear** (for crossed helical gears)
- Calculation of **efficiency** (for crossed helical gears)

Required safety factors

- Possible **fatigue safety factors** for different modules are shown in the table below

Module m	Root	Flank	Wear	Deformation
m ≥ 2.0	1.4	1	1.0	1.1
m = 1.0	1.2	0.9	1	1.1
m ≤ 0.5	0.6	0.6	1	1.1

- Inbetween, linear interpolation is used.

- Possible **static safety factors** are shown in the table below (VDI 2736)

	Safety factor
Yield strength	1.5
Ultimate strength	2.0

Calculation Method + Experience (know how) = Optimal Results

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Required safety factors

An important note concerning the use of data from the existing design

- If the existing design is over dimensioned, then also the new design will be over dimensioned!

- We recommend therefore, that if you test a gearbox on the test rig and if the required life time is achieved without any problem, to repeat the test with a higher load.

- If with the higher torque failure of the gears occurs after a certain number of hours X, this is exactly the information you are looking for: Repeat the calculation with the higher torque and lifetime X and you will get exactly the minimum required safety factors!

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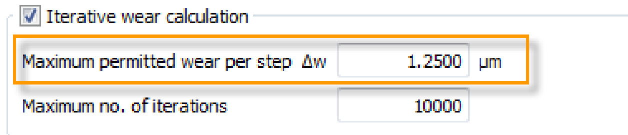
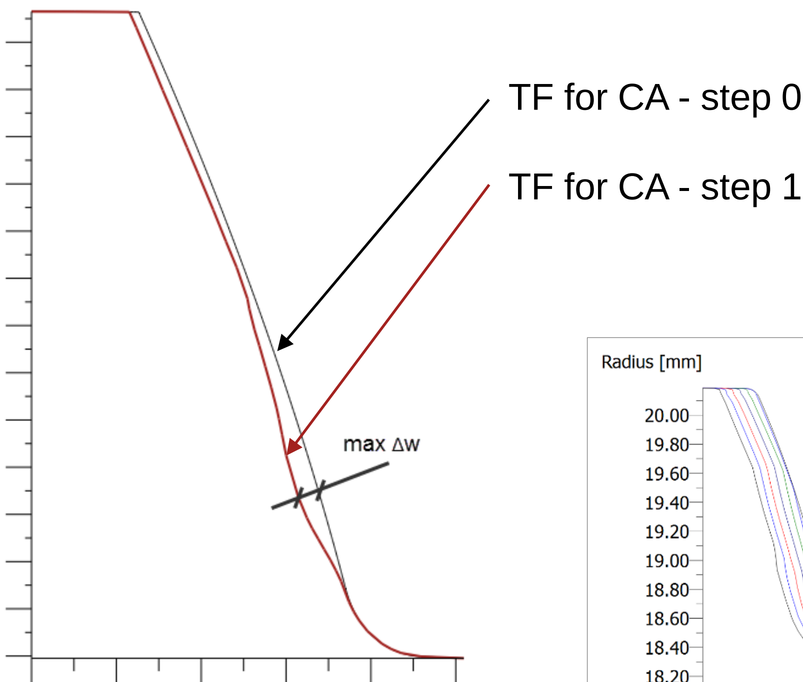
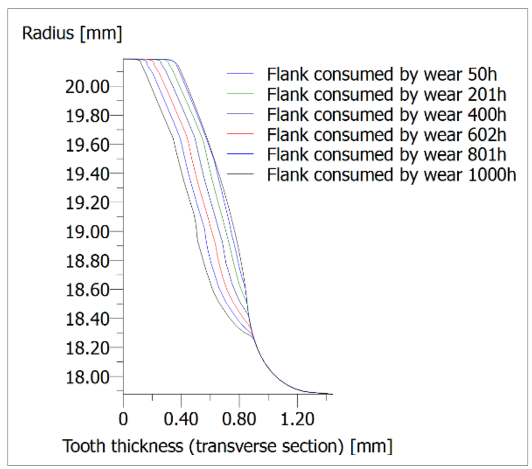
Wear calculation methods in KISSsoft – method A (with iteration)

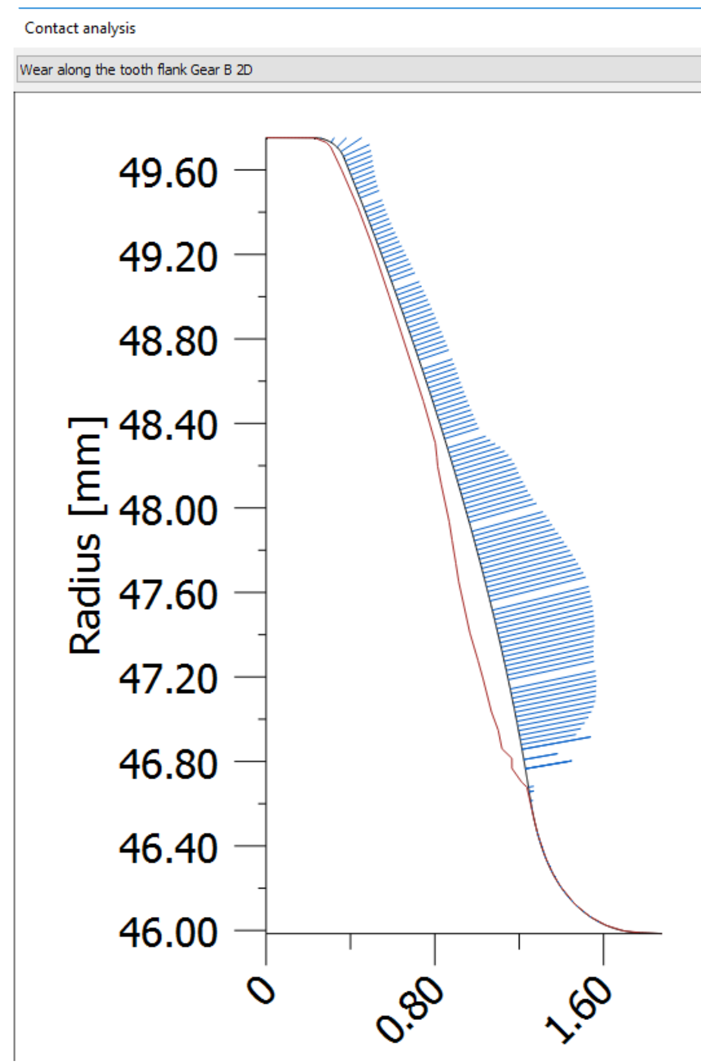
Additional output:

- Wear progress









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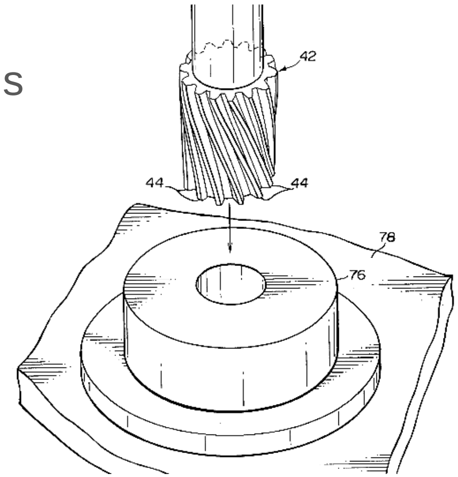
Tooth Form

Tooth form

- For plastic and sinter gears, tooth form is not limited by the classic manufacturing processes
- “Any“ tooth form can be produced without additional costs (wire erosion, ...)
- For instance, by adding material at the root (full rounding, elliptical root modification), root strength can be improved
- High deformations of the plastic gear teeth must be compensated with modifications (usually long tip relief)
- Usually no flankline modifications



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Modifications for mold making – General

- Shrinkage of plastic materials
- Different in radial and circumferential direction
- Different at root and tip
- Effect of injection points
- Expansion of sintered materials*

SOURCE: www.kleissgears.com

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Operating backlash and Tolerances

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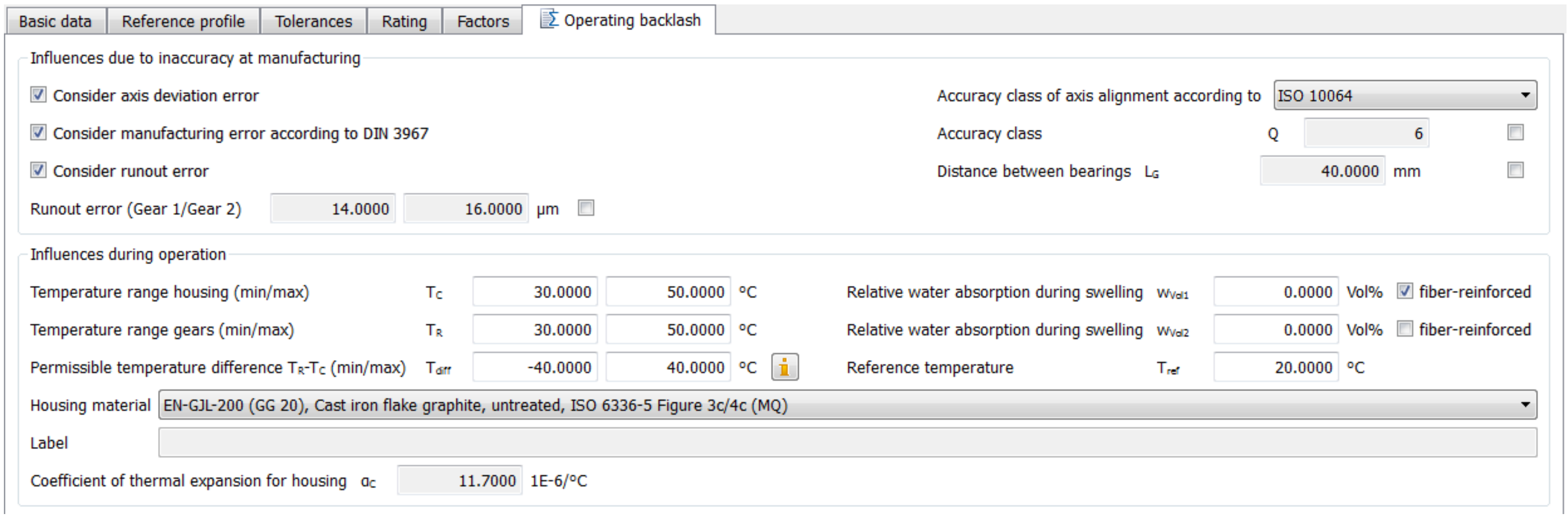
Backlash calculation – Use in KISSsoft

In KISSsoft, all three backlash calculations are available:

- **Theoretical backlash** (always calculated, documented in general report)
- **Acceptance backlash**
- **Operating backlash** (most relevant for plastic gears)

The Acceptance Backlash and the Operating Backlash are calculated in the tab „Operating Backlash“ as shown below.



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Backlash calculation – Operating backlash

For the calculation of the **operating backlash**, the following is considered

- Acceptance backlash
- Effects changing the centre distance and tooth thickness
  - Housing temperature change
  - Housing water absorption (Not included)
  - Housing material
  - Gears temperature change
  - Gears water absorption

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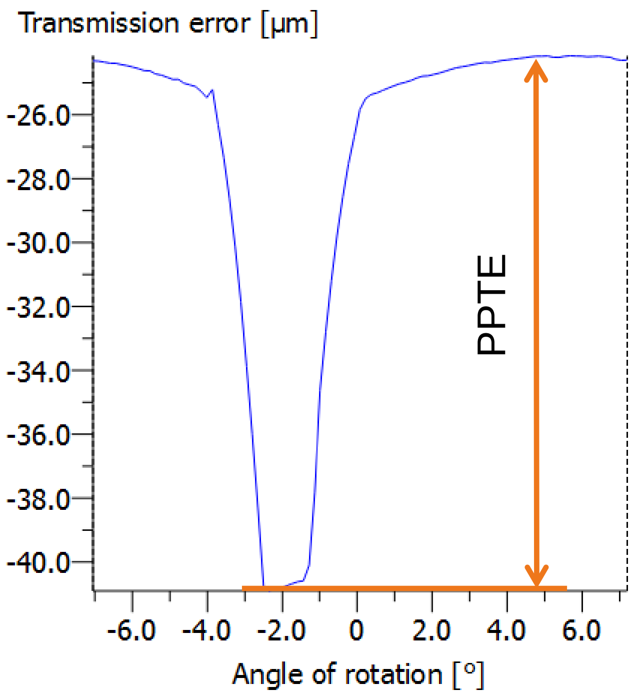
Transmission error

Transmission error is the amount by which the contact point is displaced on the path of contact (length at path of contact) in μm. This is an outcome of varying contact stiffness. The amplitude of the transmission error is a decisive criterion in determining how quietly a gear unit runs.

(PPTE = Peak to Peak Transmission Error)



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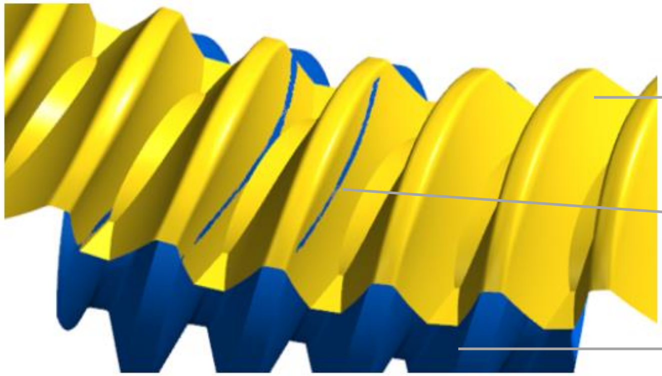
Crossed helical gears

Contact pattern – Worm gear vs. Crossed helical gear

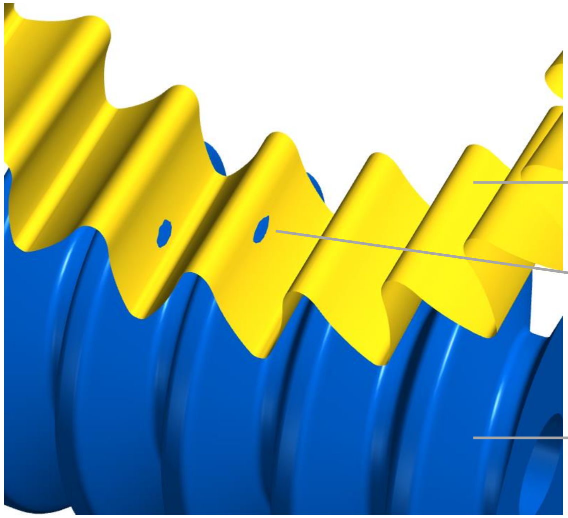


Enveloping worm wheel

Contact **lines**

Cylindrical worm gear

Worm gears



Worm wheel

Contact **points**

Cylindrical worm gear

Crossed helical gears

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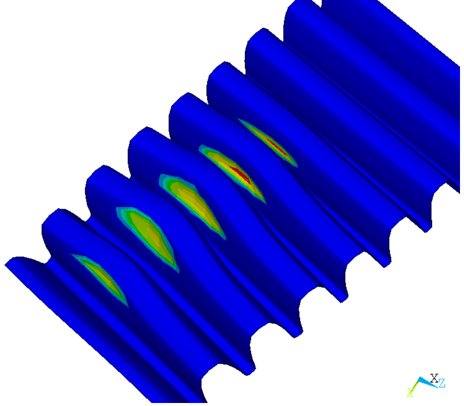
Contact pattern – Crossed helical gear

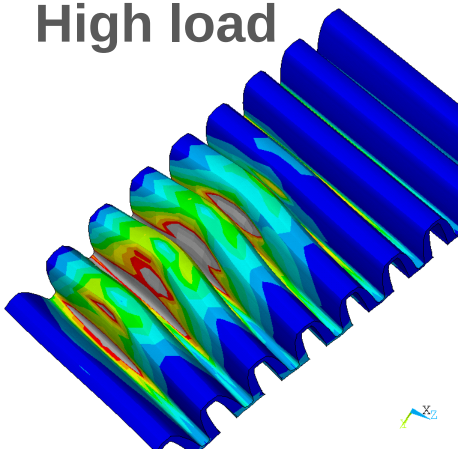
As the load increases, the contact **point** extends to a contact **ellipse**.

Running in wear also helps to increase the contact surface.

Low load



High load



Difference in load carying capacity:

Steel/bronze	Steel/plastic
1 : **4**	1.0 : **1.2***

*Due to running in, flank pressure lowers and conditions become similar to globoidal worm gears

SOURCE: Barton, P.: Tragfähigkeit von Schraubrad- und Schneckengetrieben der Werkstoffpaarung Stahl/Kunststoff, Ruhr Universität Bochum, Deutschland, 2000.

VDI 2736-3 – General

Limitations for the geometry:

- Material combination **metal worm/plastic worm wheel**
- Shaft angle Σ of 90°
- $m \geq 0.3$ mm, $Z_{worm} < 6$ (better efficiency, strength)

Possible calculations

- Tooth **root** load-carrying capacity (shear strength)
- Tooth **flank** load-carrying capacity
- Efficiency

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VDI 2545 – General

- VDI 2545 has no calculation for crossed helical gears
- KISSsoft adapted the calculation, so that it can also be used for crossed helical gears
- Also possible for plastic/plastic combinations

- Possible calculations
  - Tooth **root** load-carrying capacity
  - Tooth **flank** load-carrying capacity

General remarks: calculated safety factors could be too low, depending on the elongated eliptical contact under load or wear.

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Wear – According to Pech

- Wear calculation of the plastic **worm gear** according to Pech
- Calculation of **plastic deformation**, **wear intensity** and **total wear** (in the normal section at the operating pitch circle diameter).
- Calculation of **COF**, **efficiency**, **lubricant** and **gear temperatures**

- The following limitations apply for the calculation:
  - Shaft angle of 90°
  - Grease lubrication
  - Material of worm: steel
  - Material of worm gear: POM, PEEK, PEEK+30% CF or PA46
  - Driving gear: worm

4a. Wear according to Pech

		GEAR
Plastic deformation (µm)	[λpln]	8.457
Permitted plastic deformation (µm)	[λpln0]	85.000
Safety against deformation	[SPdef]	10.051
Running-in wear (µm)	[δW0n]	49.162
Wear intensity (µm/mm)	[JwP]	1.005e-006
Wear removal (mm)	[δWn]	0.107
Permissible wear removal (tooth tip) (mm)	[δWnp0]	2.650
Safety against wear (tooth tip)	[SWPs]	24.718
Permissible wear removal (permitted backlash) (mm)	[δWnf0]	0.510
Safety against wear (permitted backlash)	[SWPf]	4.757

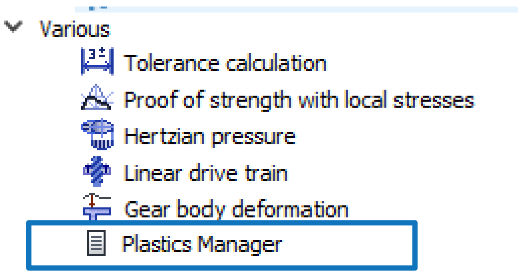
GEOMETRY LIMITS	
Number of teeth: worm gear	$16 \le Z_2 \le 80$
Centre distance	$10\ \text{mm} \le a \le 80\ \text{mm}$
Axial module: worm gear	$0.5\ \text{mm} \le m_x \le 3\ \text{mm}$
Gear ratio	$10 \le u \le 80$
Pressure angle	$10 \le \alpha_n \le 22^\circ$
Profile shift coefficient: worm gear	$-0.2 \le x_2 \le 1.5$

SOURCE: Pech M.: Tragfähigkeit und Zahnverformung von Schraubradgetrieben der Werkstoffpaarung Stahl/Kunststoff, Lehrstuhl für Maschinenelemente, Getriebe und Kraftfahrzeuge, Bochum, 2011.

Plastics Manager

General

Located under various



Functionality

- Adding new plastic materials to the KS database
- Automatic generation of the corresponding DAT files

If fatigue data from gear testing is available

- Calculation of permissible tooth root/flank stresses for different lubrication regimes
- Statistical evaluation of cycles to failure

2 calculation cases possible

- Identical test gears for all tests (testing on the test bench)
- Different test gears used (Z12, Z14, Z15, Z16) – mainly testing in actual applications

Possible to calculate wear factors and heat transfer coeffcients acc. to the VDI 2736

Thank you for your attention!

Sharing Knowledge

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