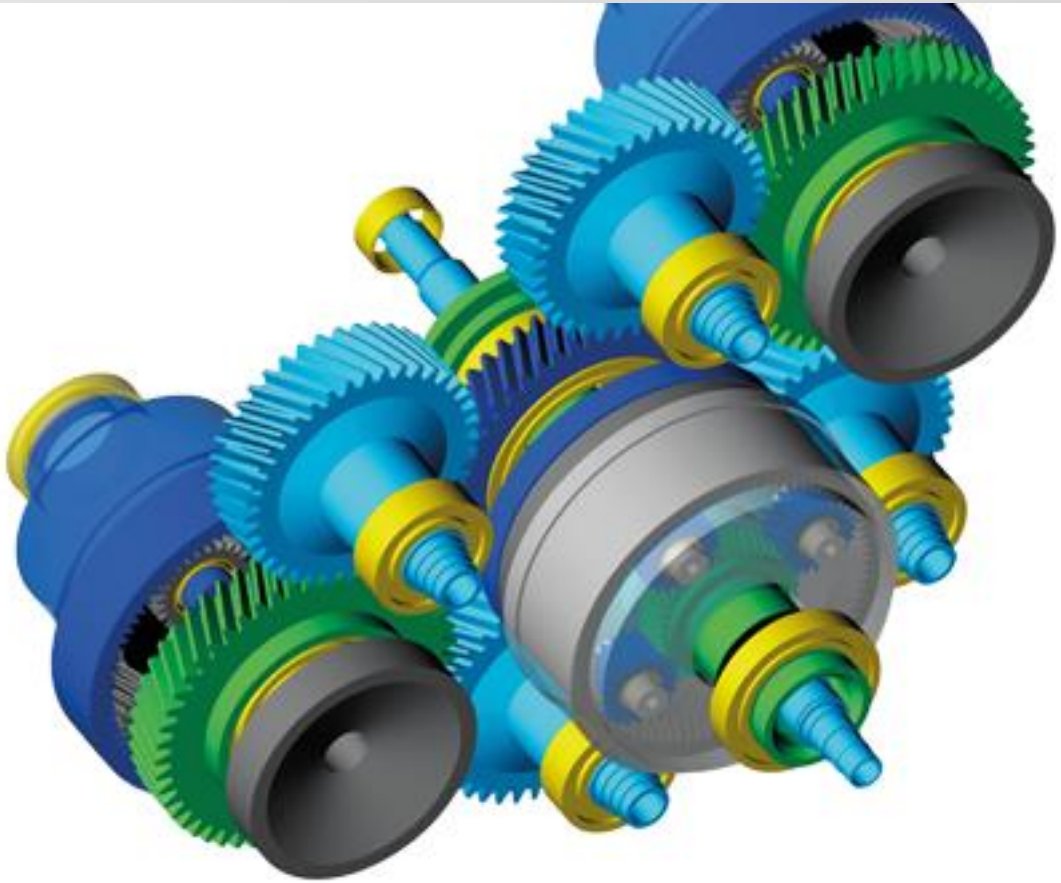
Layout of profile modifications for symmetric and asymmetric plastic gears



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Content

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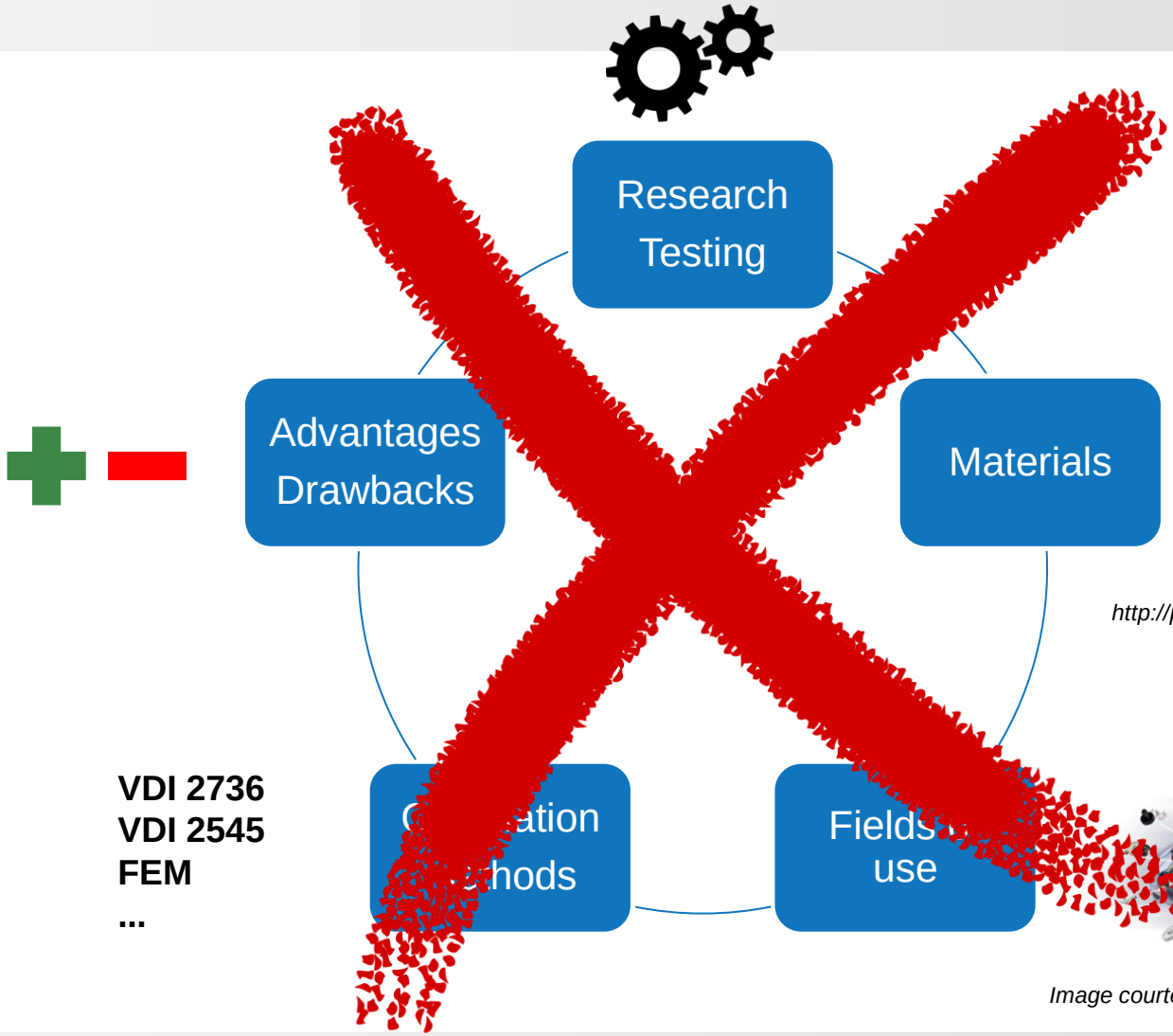
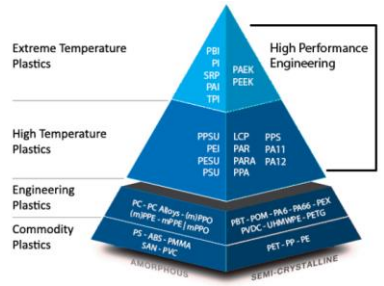
Introduction





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

Image courtesy of Winzeler Gear and DuPont

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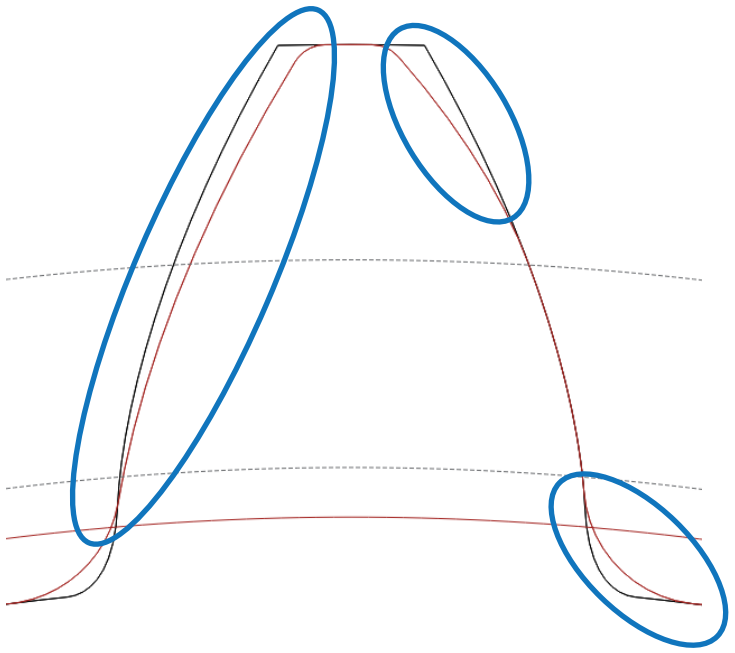
Introduction

- Plastic and sintered gears tooth form not limited by:
  - “traditional“ manufacturing processes
  - standardised tool geometries (m_n, α_n, h_{aP}, ...)

- As a consequence:
  - profile modifications can be defined freely
  - root geometry can be defined freely

Important note:

- VDI 2736 calculation is not considering any modifications!
- VDI 2736 assumes infinitely stiff teeth



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Applying profile modifications

Rule of thumb for **steel** gears:

- profile modifications -> only for high quality gears (Q6 or better)
- profile modifications usually small -> small effect for low Q gears

Do profile modifications make sense for plastic/sintered gears?

	POM-POM gear (80°C)			CH Steel Gear
Torque (Pinion), Nm	3.3	3.3	3.3	37.2
Bending safety S_F (Pinion)	1.35	1.35	1.35	1.35
Calculation method	VDI 2736	VDI 2736	VDI 2736	ISO 6336-3
Young modulus, MPa	2080	2080	2080	206000
Quality acc. DIN 3961	**10**	**11**	**12**	**6**
Tooth tip bending C_a (by LTCA), µm	**101.5**	**101.5**	**101.5**	**9.1**
Profile slope deviation $f_{H\alpha}$, µm	23	37	59	5
Bending/Slope deviation ($C_a/f_{H\alpha}$)	101/23 = **4.4**	101/37 = **2.7**	101/59 = **1.7**	9.1/5 = **1.8**

m_n = 1.375 mm, z = 23/85

Yes they do!

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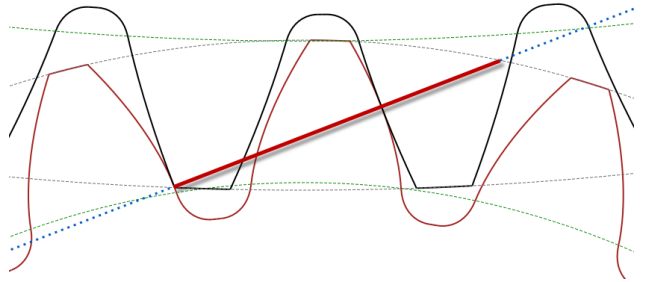
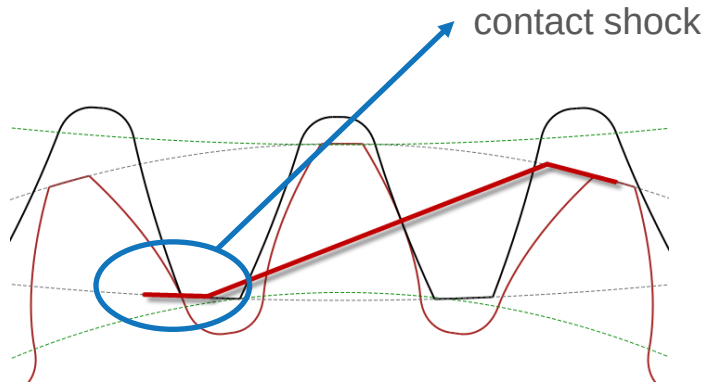
Applying profile modifications

- Comparison between VDI 2736 and LTCA

	VDI 2736	LTCA	LTCA
Stiffness calculation	Infinite	Infinite	Weber-Banaschek
Root stress 1, MPa	16.3	15.1	11.3
Root stress 2, MPa	16.1	16.4	9.8
Hertzian pressure, MPa	22.7	24.2	19.2
Contact ratio	1.587	1.582	2.110
Transmission error, µm	0	0	9.31





- Transmission error has an effect on the NV behaviour
- Specific sliding, load distribution, wear, ...

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Typical profile modifications

- Modification values are defined in a profile diagram

Tip and root relief

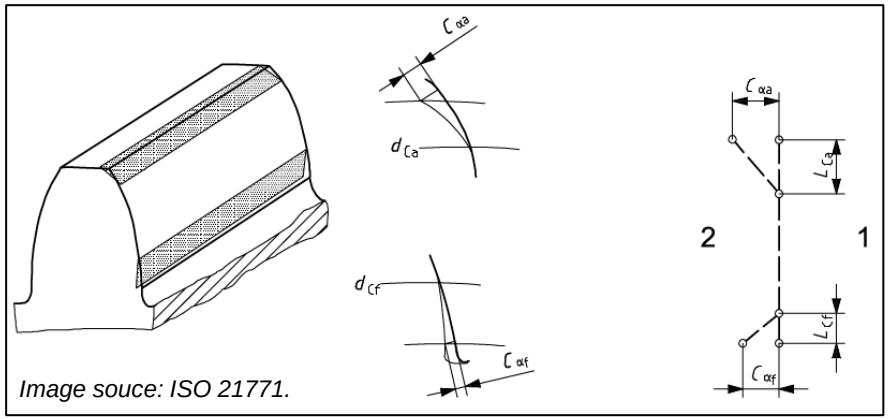


Image souce: ISO 21771.

Profile crowning

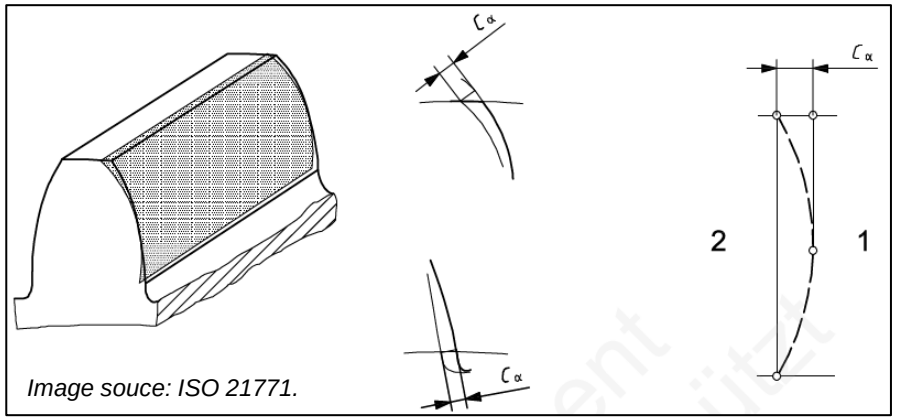


Image souce: ISO 21771.

Transverse slope modification

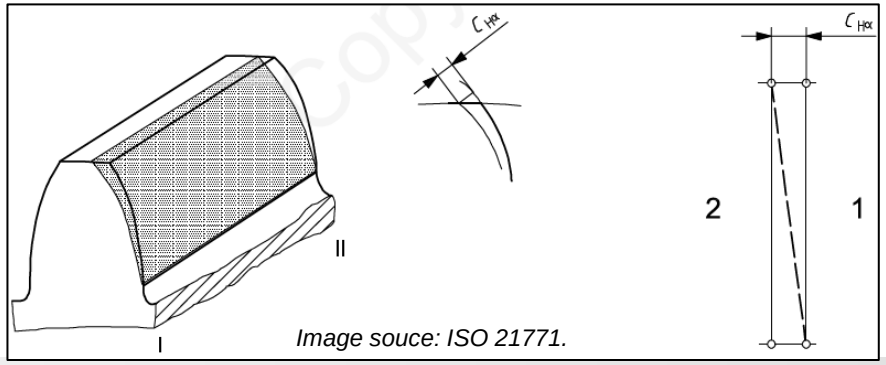


Image souce: ISO 21771.

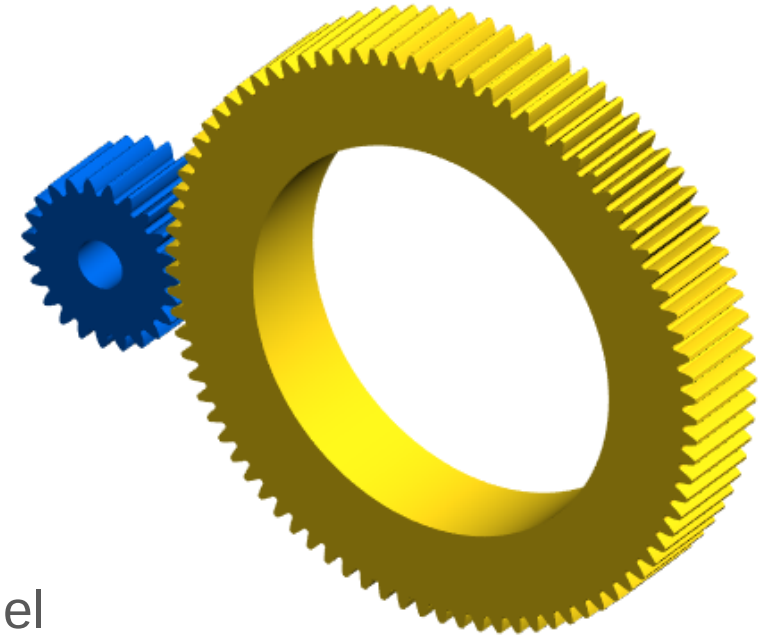
C_α – amount of modification
L_C – roll length

Effect of profile modifications

Gear configuration

Normal module:	1.375 mm
Pressure angle:	20 °
Number of teeth:	23/85
Profile shift:	0.37/0.029
Center distance:	74.79 mm
Reference profile:	1.25/0.38/1.0 ISO
Material:	POM/PA66
Temperature:	20° C
Wear factor (both):	$1 \cdot 10^{-6}$ mm^3/Nm
Input torque:	2.4 Nm
Calculation:	LTCA using Weber-Banaschek model

d_a = 35 mm d_a = 120 mm



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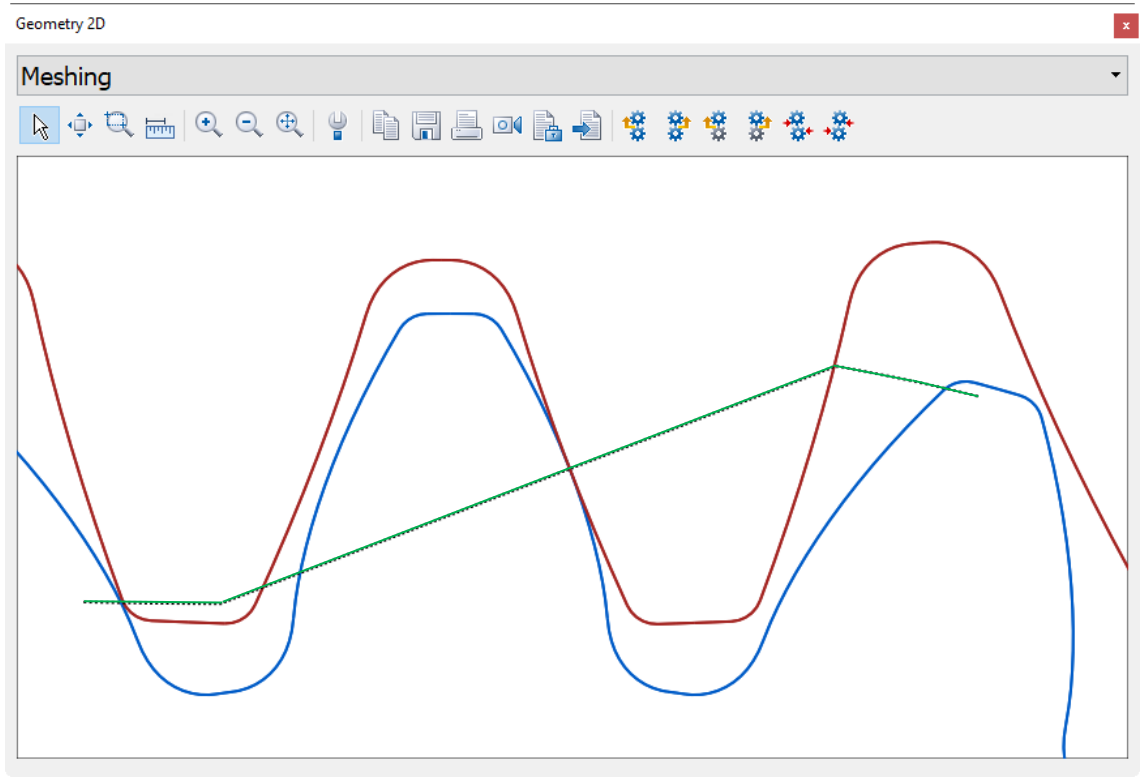
Effect of profile modifications

Gear	Flank	Type of modification	Value [µm]	Factor 1
		No modifications		



Results

PPTE:	15.6 µm
Wear per tooth 1:	1.58 mm^3
Wear per tooth 2:	0.52 mm^3
Hertz pressure:	26.6 MPa
Root stress 1:	12.6 MPa
Root stress 2:	13.4 Mpa
Contact ratio:	1.95

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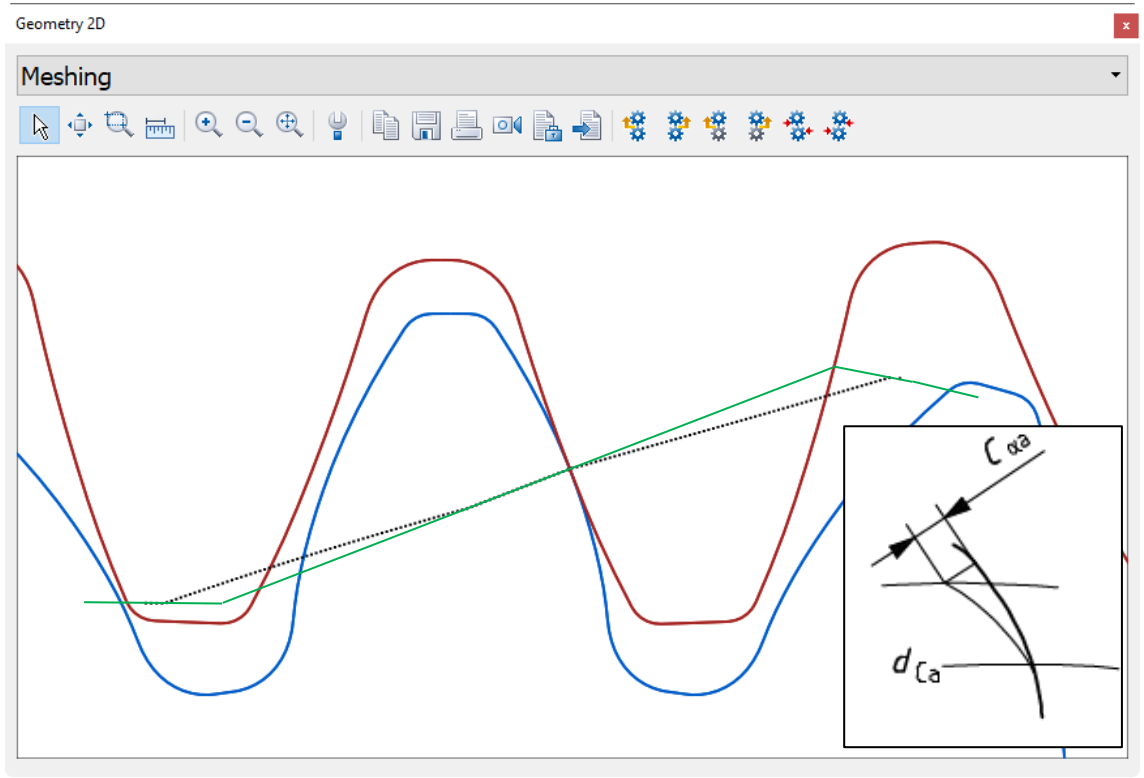
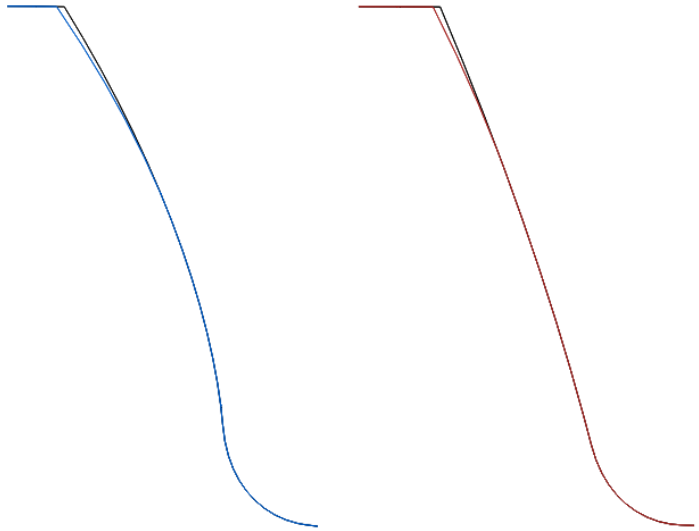
Effect of profile modifications

Gear	Flank	Type of modification	Value [µm]	Factor 1
Gear 1	both	Tip relief, arc-like	41.0000	2.0000
Gear 2	both	Tip relief, arc-like	41.0000	2.0000



Results

PPTE:	8.39 µm
Wear per tooth 1:	1.24 mm^3
Wear per tooth 2:	0.33 mm^3
Hertz pressure:	31.6 MPa
Root stress 1:	13.6 MPa
Root stress 2:	15.9 Mpa
Contact ratio:	1.69



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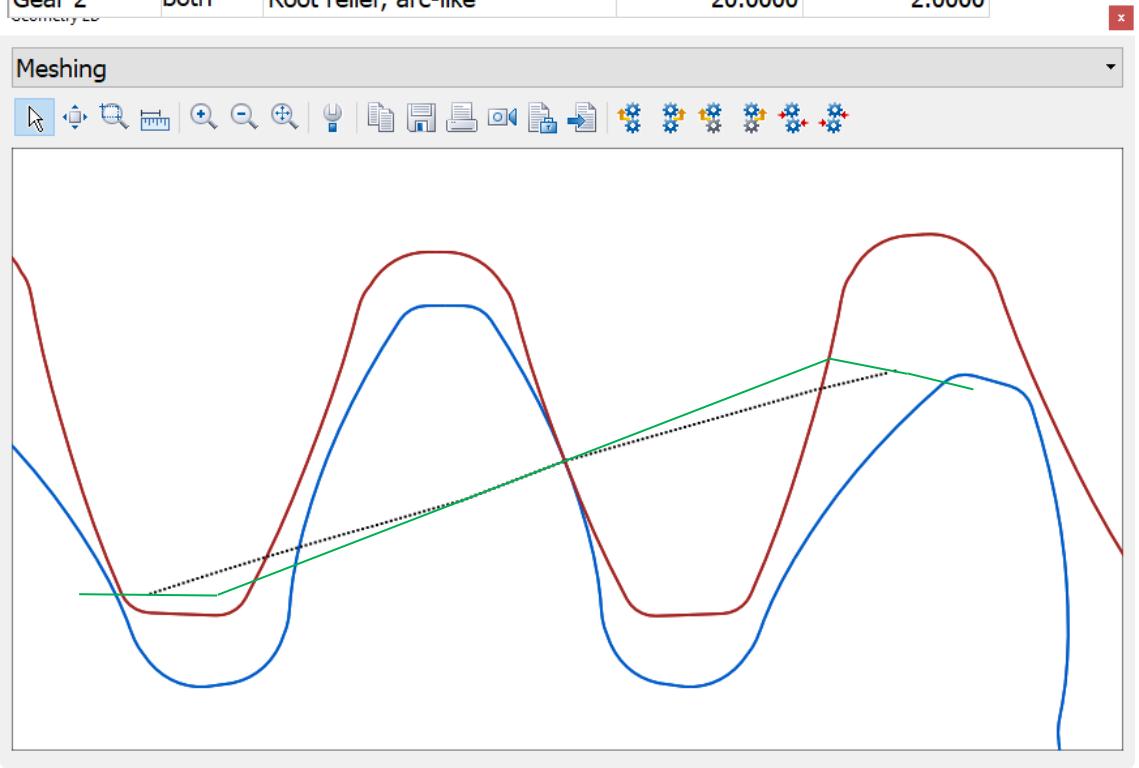
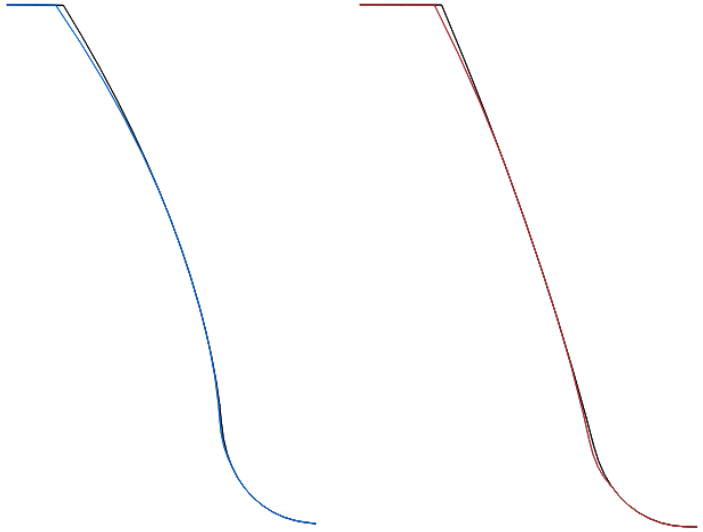
Effect of profile modifications

Gear	Flank	Type of modification	Value [µm]	Factor 1
Gear 1	both	Tip relief, arc-like	41.0000	2.0000
Gear 2	both	Tip relief, arc-like	41.0000	2.0000
Gear 1	both	Root relief, arc-like	10.0000	2.0000
Gear 2	both	Root relief, arc-like	20.0000	2.0000



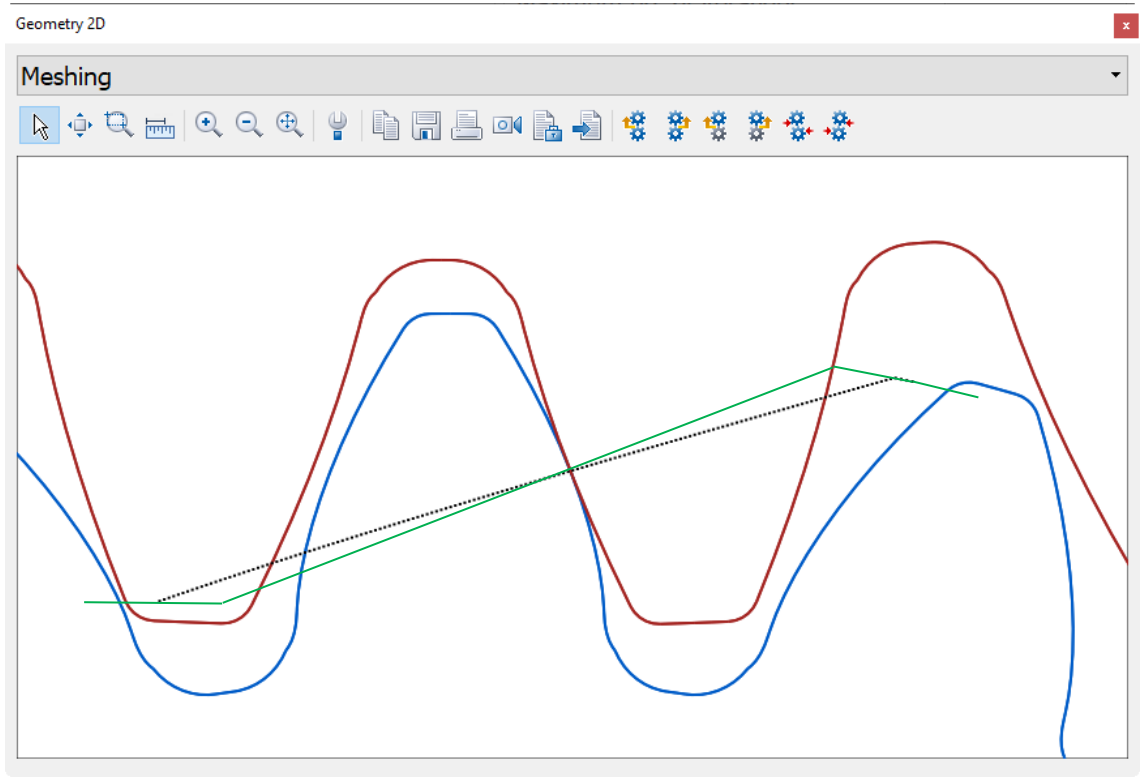
Results

PPTE:	8.37 µm
Wear per tooth 1:	1.22 mm^3
Wear per tooth 2:	0.32 mm^3
Hertz pressure:	31.6 MPa
Root stress 1:	13.7 MPa
Root stress 2:	16.0 Mpa
Contact ratio:	1.67



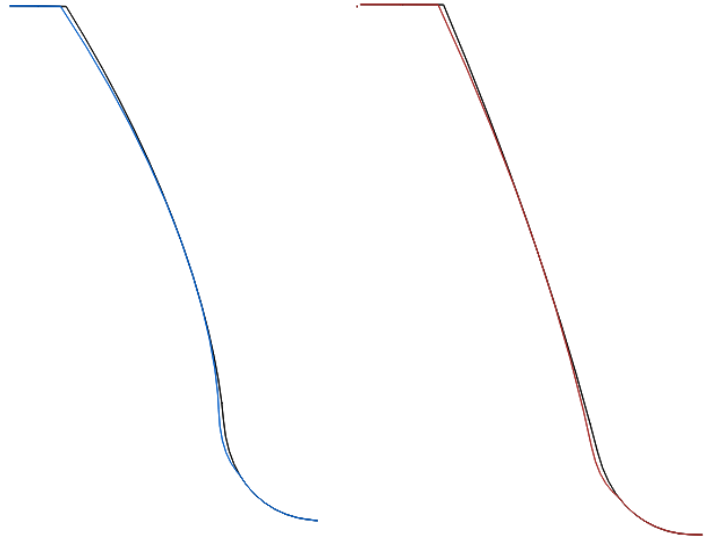
Effect of profile modifications

Gear	Flank	Type of modification	Value [µm]
Gear 1	both	Profile crowning (barreling)	30.0000
Gear 2	both	Profile crowning (barreling)	30.0000



Results

PPTE:	3.33 µm
Wear per tooth 1:	1.27 mm^3
Wear per tooth 2:	0.33 mm^3
Hertz pressure:	29.8 MPa
Root stress 1:	16.0 MPa
Root stress 2:	20.2 Mpa
Contact ratio:	1.68



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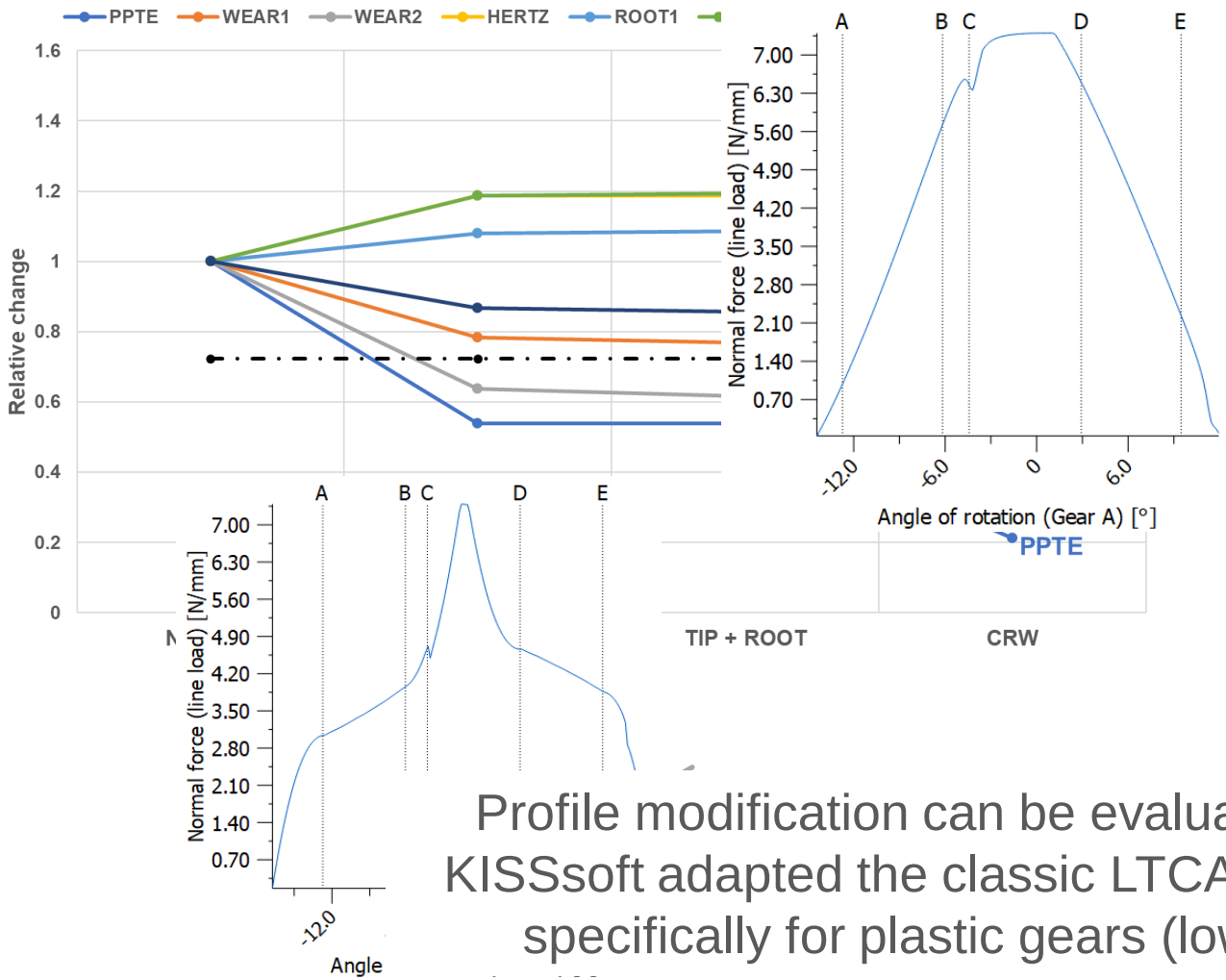
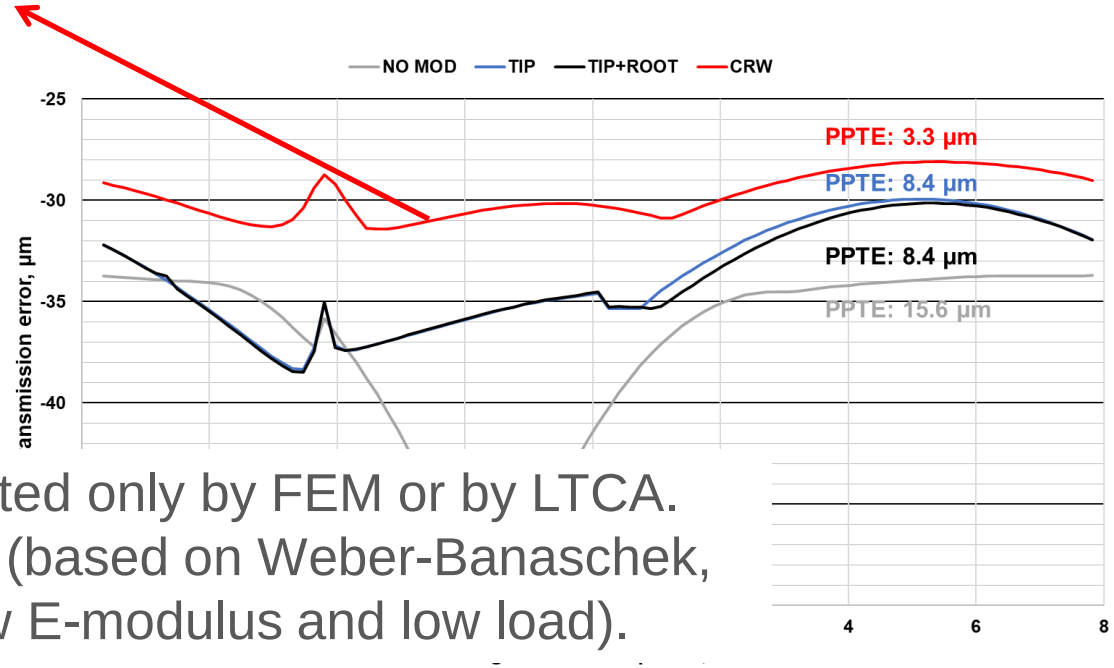
Effect of profile modifications





Profile modification can be evaluated only by FEM or by LTCA. KISSsoft adapted the classic LTCA (based on Weber-Banaschek, specifically for plastic gears (low E-modulus and low load).

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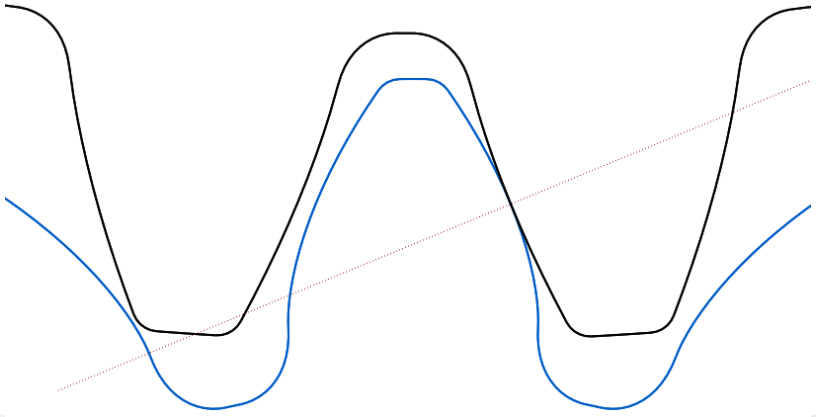
Effect of profile modifications – (a)symmetric gears

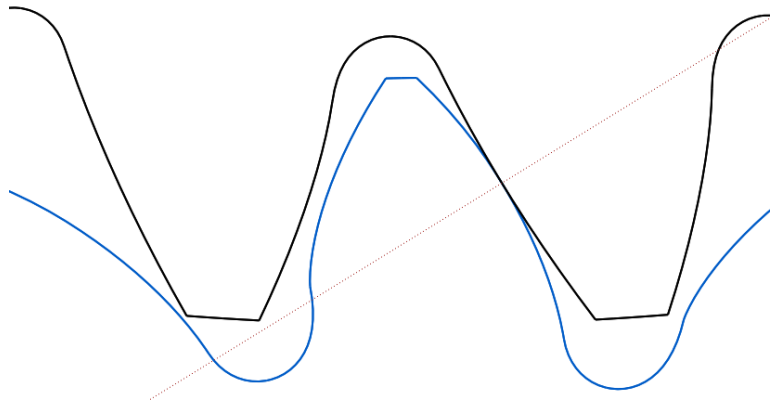
Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value, µm Length factor	/ / /	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value, µm Length factor	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	43.5	43.9	44.4	44.9	44.2	44.2	44.1	43.9	44.4	44.9	**44.3**
Root stress 2, MPa	43.1	43.1	43.1	43.1	43.4	46.6	46.7	43.4	46.5	46.7	**45.5**
Hertzian pr., MPa	83.4	83.4	83.4	83.4	83.4	83.7	86.5	83.4	83.7	86.4	**90.4**
Contact ratio ε_{α_eff}	1.75	1.73	1.72	1.70	1.73	1.72	1.70	1.71	1.68	1.65	**1.67**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.44	0.42	0.41	0.39	0.42	0.41	0.39	0.40	0.37	0.34	**0.36**
PPTE, µm	27.0	27.0	27.0	27.0	23.6	23.3	26.5	23.5	22.8	25.3	**16.8**
Max wear, µm	60.8	60.5	60.1	61.2	57.7	52.6	40.7	55.9	49.6	44.2	**46.0**



SYMMETRIC

ASYMMETRIC

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value Length	/	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value Length	/	Arc 10 1	Arc 20 1	Arc 30 1	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	48.1	49.0	50.4	51.8	48.1	48.1	48.1	49.0	49.6	50.5	**45.6**
Root stress 2, MPa	45.3	44.2	44.2	44.2	44.9	45.6	46.2	44.9	45.5	46.2	**46.8**
Hertzian pr., MPa	84.8	84.9	85.0	85.2	77.6	78.0	78.3	77.6	78.6	84.3	**81.9**
Contact ratio ε_{α_eff}	1.58	1.55	1.53	1.48	1.57	1.55	1.53	1.53	1.50	1.45	**1.50**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.43	0.40	0.38	0.33	0.42	0.40	0.38	0.38	0.35	0.30	**0.35**
PPTE, µm	26.8	26.5	26.3	26.1	23.5	23.3	23.7	22.3	20.2	19.0	**17.4**
Wear, µm	47.2	48.2	47.2	48.9	41.9	35.3	24.7	41.7	35.3	28.0	**35.1**



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Effect of profile modifications – (a)symmetric gears

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value, µm Length factor	/ / /	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value, µm Length factor	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	43.5	43.9	44.4	44.9	44.2	44.2	44.1	43.9	44.4	44.9	**44.3**
Root stress 2, MPa	43.1	43.1	43.1	43.1	43.4	46.6	46.7	43.4	46.5	46.7	**45.5**
Hertzian pr., MPa	83.4	83.4	83.4	83.4	83.4	83.7	86.5	83.4	83.7	86.4	**90.4**
Contact ratio ε_{α_eff}	1.75	1.73	1.72	1.70	1.73	1.72	1.70	1.71	1.68	1.65	**1.67**
ε_{α_eff} - ε_{α_th}	0.44	0.42	0.41	0.39	0.42	0.41	0.39	0.40	0.37	0.34	**0.36**
PPTE, µm	27.0	27.0	27.0	27.0	23.6	23.3	26.5	23.5	22.8	25.3	**16.8**
Max wear, µm	60.8	60.5	60.1	61.2	57.7	52.6	40.7	55.9	49.6	44.2	**46.0**

+2%
+5%
+8%
-5%

-38%
-25%

SYMMETRIC

ASYMMETRIC

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value Length	/	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value Length	/	Arc 10 1	Arc 20 1	Arc 30 1	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	48.1	49.0	50.4	51.8	48.1	48.1	48.1	49.0	49.6	50.5	**45.6**
Root stress 2, MPa	45.3	44.2	44.2	44.2	44.9	45.6	46.2	44.9	45.5	46.2	**46.8**
Hertzian pr., MPa	84.8	84.9	85.0	85.2	77.6	78.0	78.3	77.6	78.6	84.3	**81.9**
Contact ratio ε_{α_eff}	1.58	1.55	1.53	1.48	1.57	1.55	1.53	1.53	1.50	1.45	**1.50**
ε_{α_eff} - ε_{α_th}	0.43	0.40	0.38	0.33	0.42	0.40	0.38	0.38	0.35	0.30	**0.35**
PPTE, µm	26.8	26.5	26.3	26.1	23.5	23.3	23.7	22.3	20.2	19.0	**17.4**
Wear, µm	47.2	48.2	47.2	48.9	41.9	35.3	24.7	41.7	35.3	28.0	**35.1**

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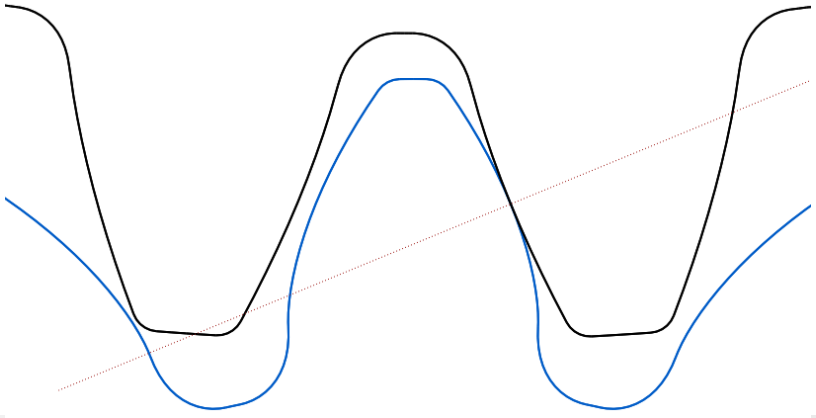
Effect of profile modifications – (a)symmetric gears

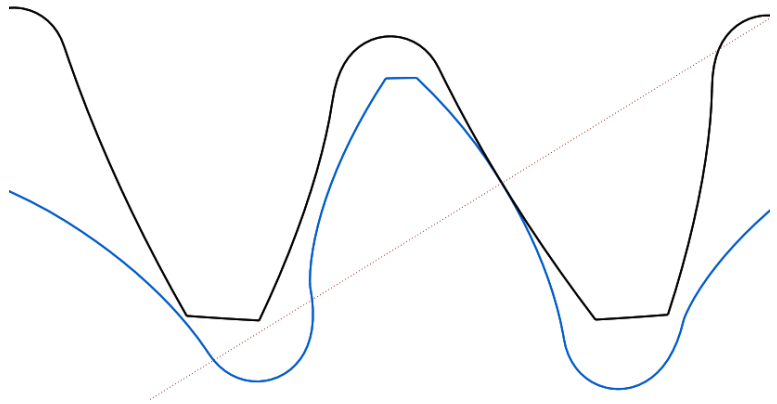
Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value, µm Length factor	/ / /	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value, µm Length factor	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	43.5	43.9	44.4	44.9	44.2	44.2	44.1	43.9	44.4	44.9	**44.3**
Root stress 2, MPa	43.1	43.1	43.1	43.1	43.4	46.6	46.7	43.4	46.5	46.7	**45.5**
Hertzian pr., MPa	83.4	83.4	83.4	83.4	83.4	83.7	86.5	83.4	83.7	86.4	**90.4**
Contact ratio ε_{α_eff}	1.75	1.73	1.72	1.70	1.73	1.72	1.70	1.71	1.68	1.65	**1.67**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.44	0.42	0.41	0.39	0.42	0.41	0.39	0.40	0.37	0.34	**0.36**
PPTE, µm	27.0	27.0	27.0	27.0	23.6	23.3	26.5	23.5	22.8	25.3	**16.8**
Max wear, µm	60.8	60.5	60.1	61.2	57.7	52.6	40.7	55.9	49.6	44.2	**46.0**



SYMMETRIC

ASYMMETRIC

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value Length	/	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value Length	/	Arc 10 1	Arc 20 1	Arc 30 1	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	48.1	49.0	50.4	51.8	48.1	48.1	48.1	49.0	49.6	50.5	**45.6**
Root stress 2, MPa	45.3	44.2	44.2	44.2	44.9	45.6	46.2	44.9	45.5	46.2	**46.8**
Hertzian pr., MPa	84.8	84.9	85.0	85.2	77.6	78.0	78.3	77.6	78.6	84.3	**81.9**
Contact ratio ε_{α_eff}	1.58	1.55	1.53	1.48	1.57	1.55	1.53	1.53	1.50	1.45	**1.50**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.43	0.40	0.38	0.33	0.42	0.40	0.38	0.38	0.35	0.30	**0.35**
PPTE, µm	26.8	26.5	26.3	26.1	23.5	23.3	23.7	22.3	20.2	19.0	**17.4**
Wear, µm	47.2	48.2	47.2	48.9	41.9	35.3	24.7	41.7	35.3	28.0	**35.1**



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Effect of profile modifications – (a)symmetric gears

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value, µm Length factor	/ / /	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value, µm Length factor	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	43.5	43.9	44.4	44.9	44.2	44.2	44.1	43.9	44.4	44.9	**44.3**
Root stress 2, MPa	43.1	43.1	43.1	43.1	43.4	46.6	46.7	43.4	46.5	46.7	**45.5**
Hertzian pr., MPa	83.4	83.4	83.4	83.4	83.4	83.7	86.5	83.4	83.7	86.4	**90.4**
Contact ratio ε_{α_eff}	1.75	1.73	1.72	1.70	1.73	1.72	1.70	1.71	1.68	1.65	**1.67**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.44	0.42	0.41	0.39	0.42	0.41	0.39	0.40	0.37	0.34	**0.36**
PPTE, µm	27.0	27.0	27.0	27.0	23.6	23.3	26.5	23.5	22.8	25.3	**16.8**
Max wear, µm	60.8	60.5	60.1	61.2	57.7	52.6	40.7	55.9	49.6	44.2	**46.0**

SYMMETRIC

ASYMMETRIC

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value Length	/	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value Length	/	Arc 10 1	Arc 20 1	Arc 30 1	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	48.1	49.0	50.4	51.8	48.1	48.1	48.1	49.0	49.6	50.5	**45.6**
Root stress 2, MPa	45.3	44.2	44.2	44.2	44.9	45.6	46.2	44.9	45.5	46.2	**46.8**
Hertzian pr., MPa	84.8	84.9	85.0	85.2	77.6	78.0	78.3	77.6	78.6	84.3	**81.9**
Contact ratio ε_{α_eff}	1.58	1.55	1.53	1.48	1.57	1.55	1.53	1.53	1.50	1.45	**1.50**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.43	0.40	0.38	0.33	0.42	0.40	0.38	0.38	0.35	0.30	**0.35**
PPTE, µm	26.8	26.5	26.3	26.1	23.5	23.3	23.7	22.3	20.2	19.0	**17.4**
Wear, µm	47.2	48.2	47.2	48.9	41.9	35.3	24.7	41.7	35.3	28.0	**35.1**

-5%
+3%
-3%
-5%

-35%
-25%

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Effect of profile modifications – (a)symmetric gears

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value, µm Length factor	/ / /	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value, µm Length factor	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	/ / /	/ / /	/ / /	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	43.5	43.9	44.4	44.9	44.2	44.2	44.1	43.9	44.4	44.9	**44.3**
Root stress 2, MPa	43.1	43.1	43.1	43.1	43.4	46.6	46.7	43.4	46.5	46.7	**45.5**
Hertzian pr., MPa	83.4	83.4	83.4	83.4	83.4	83.7	86.5	83.4	83.7	86.4	**90.4**
Contact ratio ε_{α_eff}	1.75	1.73	1.72	1.70	1.73	1.72	1.70	1.71	1.68	1.65	**1.67**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.44	0.42	0.41	0.39	0.42	0.41	0.39	0.40	0.37	0.34	**0.36**
PPTE, µm	27.0	27.0	27.0	27.0	23.6	23.3	26.5	23.5	22.8	25.3	**16.8**
Max wear, µm	60.8	60.5	60.1	61.2	57.7	52.6	40.7	55.9	49.6	44.2	**46.0**

Root stress 1, MPa	43.5	**44.3**	+2%
Root stress 2, MPa	43.1	**45.5**	+5%
Hertzian pr., MPa	83.4	**90.4**	+8%
Contact ratio ε_{α_eff}	1.75	**1.67**	-5%
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.44	**0.36**	
PPTE, µm	27.0	**16.8**	-38%
Max wear, µm	60.8	**46.0**	-25%

ASYMMETRIC

SYMMETRIC

Solution nr.	1	2	3	4	5	6	7	8	9	10	**11**
Tip relief gear 1 Value Length	/	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Tip relief gear 2 Value Length	/	Arc 10 1	Arc 20 1	Arc 30 1	/	/	/	Arc 10 1	Arc 20 1	Arc 30 1	**Arc 23 2**
Root stress 1, MPa	48.1	49.0	50.4	51.8	48.1	48.1	48.1	49.0	49.6	50.5	**45.6**
Root stress 2, MPa	45.3	44.2	44.2	44.2	44.9	45.6	46.2	44.9	45.5	46.2	**46.8**
Hertzian pr., MPa	84.8	84.9	85.0	85.2	77.6	78.0	78.3	77.6	78.6	84.3	**81.9**
Contact ratio ε_{α_eff}	1.58	1.55	1.53	1.48	1.57	1.55	1.53	1.53	1.50	1.45	**1.50**
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.43	0.40	0.38	0.33	0.42	0.40	0.38	0.38	0.35	0.30	**0.35**
PPTE, µm	26.8	26.5	26.3	26.1	23.5	23.3	23.7	22.3	20.2	19.0	**17.4**
Wear, µm	47.2	48.2	47.2	48.9	41.9	35.3	24.7	41.7	35.3	28.0	**35.1**

+3%
+3%
-10%
-10%

+4%
-25%

Root stress 1, MPa	48.1	**45.6**	-5%
Root stress 2, MPa	45.3	**46.8**	+3%
Hertzian pr., MPa	84.8	**81.9**	-3%
Contact ratio ε_{α_eff}	1.58	**1.50**	-5%
$\varepsilon_{\alpha\_eff} - \varepsilon_{\alpha\_th}$	0.43	**0.35**	
PPTE, µm	26.8	**17.4**	-35%
Wear, µm	47.2	**35.1**	-25%

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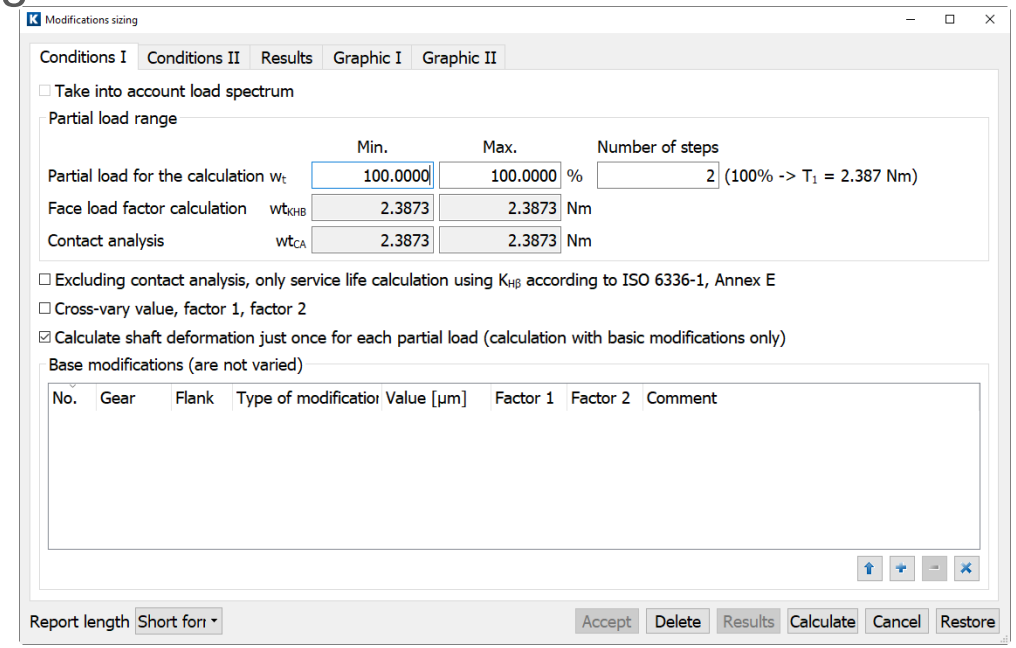
Profile modification sizing tool in KISSsoft

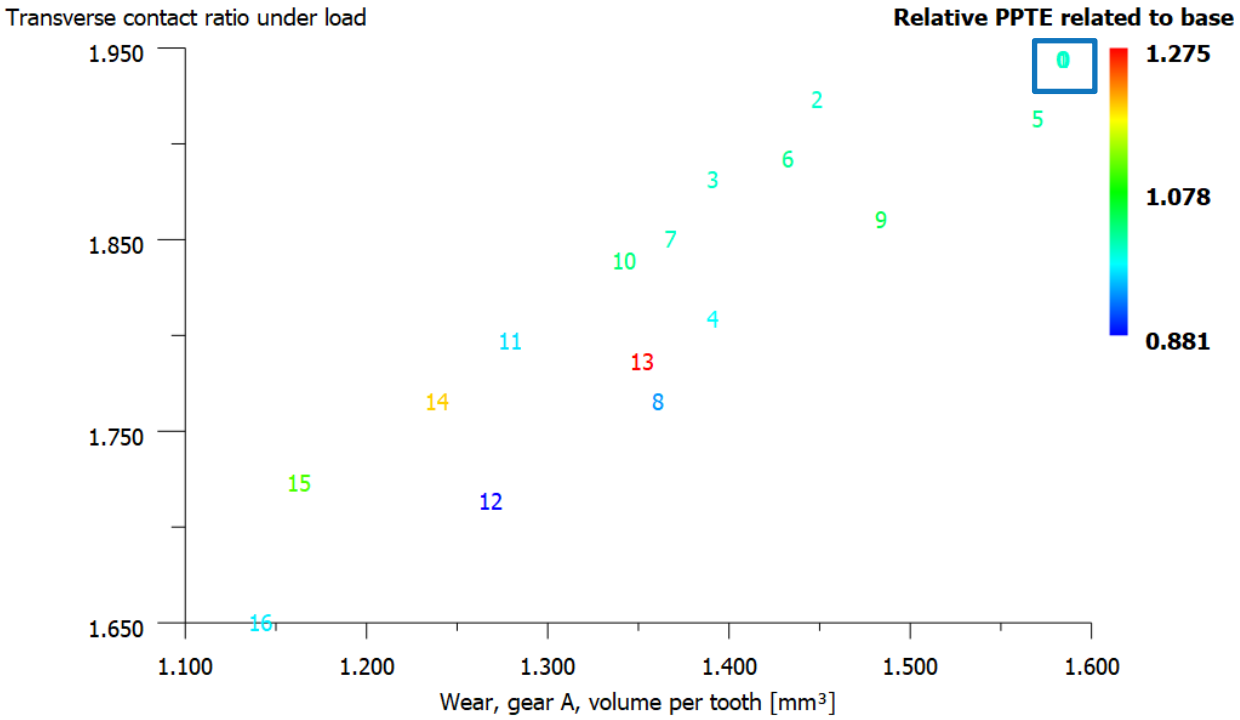
- All modifications shown selected with trial and error algorithm
- Countless different combinations possible
- Modifications sizing functionality within KISSsoft

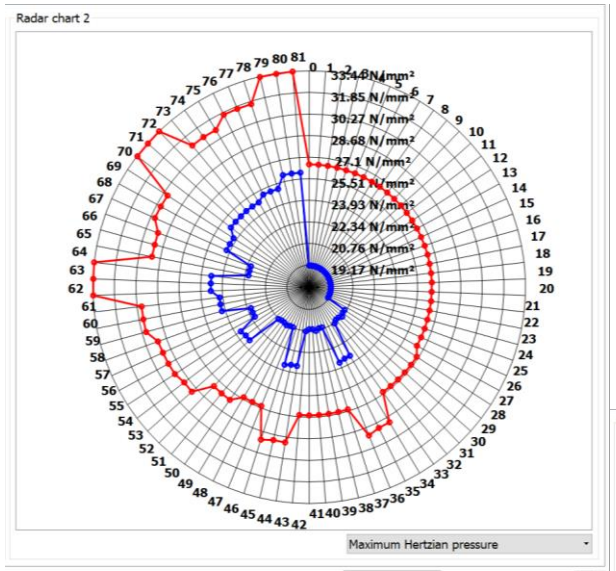


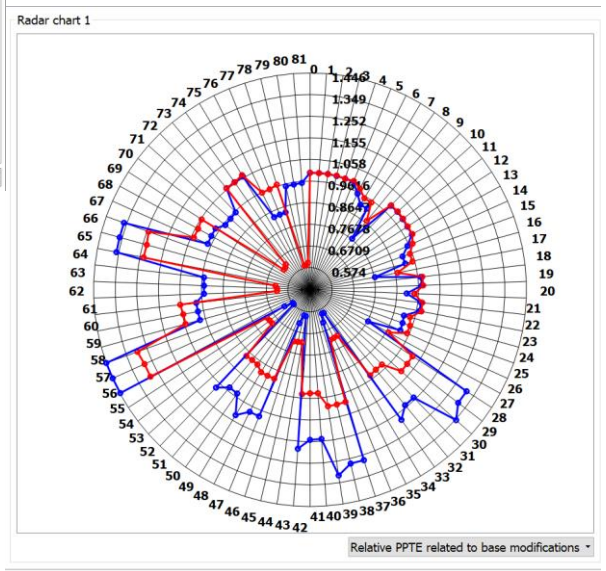
Conditions I | Conditions II | Results | Graphic I | Graphic II

No.	Gear	Synchronize with no.	Flank	Type of modification	Number of steps	Value (min) [µm]	Value (max) [µm]
1	Gear 1	1	both	Profile crowning (barreling)	8	0.0000	80.0000
2	Gear 2	2	both	Profile crowning (barreling)	8	0.0000	80.0000

Profile modification sizing tool in KISSsoft

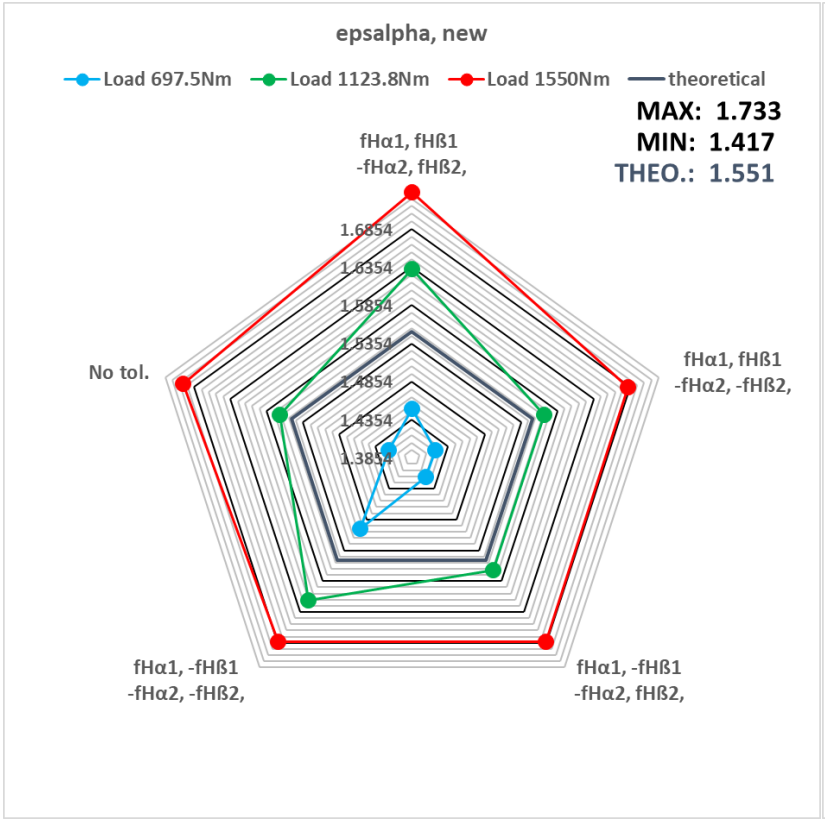


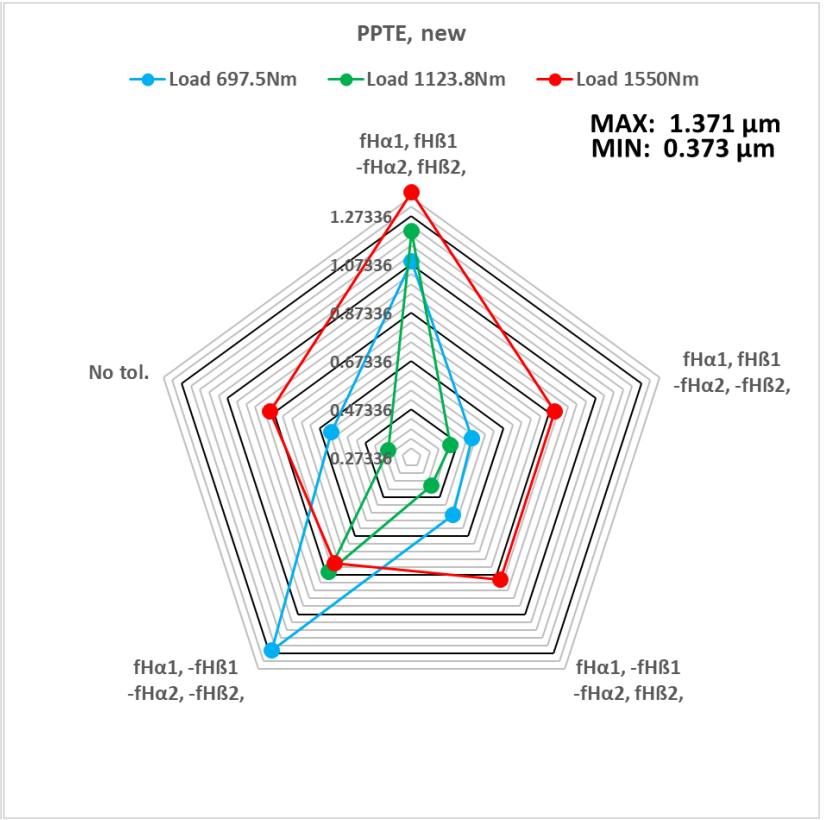




Influence of manufacturing errors

- Check of the effect of manufacturing errors on the gear performance
- Profile deviation $f_{H\alpha}$
- Helix angle deviation $f_{H\beta}$
- Using modification sizing to get different combinations





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Conclusions

- Profile modifications can (and should) be applied on plastic gears, despite having much lower quality compared to steel gears
- Wear and transmission error can be reduced by applying profile modifications or asymmetric gear design
- Modifications can be fully optimized only for 1 operating condition
- Important to check the effect of manufacturing errors
- **Profile modifications can‘t improve a bad macrogeometry design (m_n, α_n, β, x, *ref. profile*, ...)!**

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Thank you for your attention!

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Sharing Knowledge

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