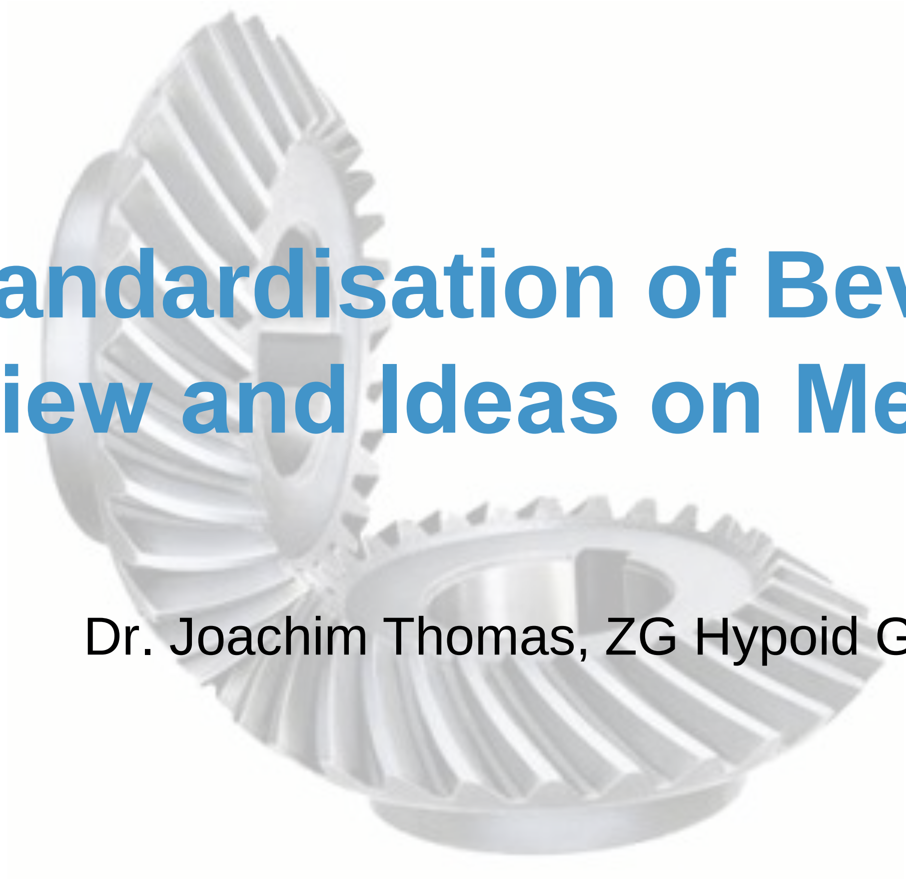

ISO Standardisation of Bevel Gears: Overview and Ideas on Method „A“

Dr. Joachim Thomas, ZG Hypoid GmbH

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1. ISO Standardisation of Bevel Gear
2. Calculation Methods B…C
3. Example Calculation
4. Conclusions

1. ISO Standardisation of Bevel Gears

ISO/TC60/SC2: Gear Capacity Calc.

ISO	International Standard Organisation	
TC 60	Technical Committee:	Gears Sekretariat: ANSI Chairperson: Thomas Maiuri
SC 1	Sub Committee:	Nomenclature & Worm Gearing Sekretariat: BSI Chairperson : Dr. Paul Bradley
SC 2	Sub Committee:	Gear Capacity Calculation Sekretariat: DIN Chairperson : Dr. Ralf Möllendorf

1. ISO Standardisation of Bevel Gears

ISO/TC60/SC2/WG13: Bevel Gears

WG 13

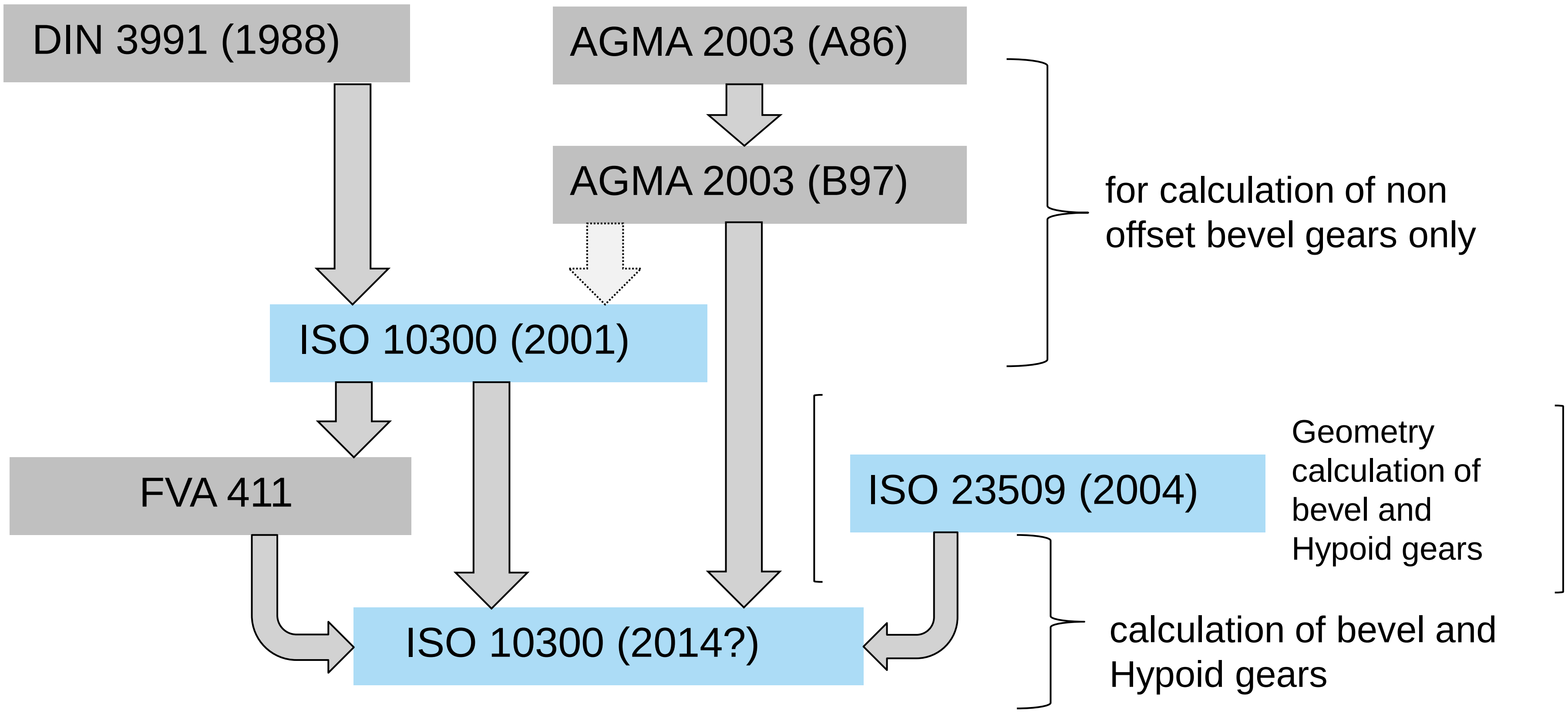
Working Group: Bevel Gears
Chairperson: Dr. Joachim Thomas

Delegates:

USA:	Claus Weyand, Amir Aboutaleb (AGMA)
UK:	N.N.
Japan:	Ryohei Takeda
Finland:	Jesse Rontu
Switzerland:	Jürg Langhart
Germany:	Dr. Ralf Hess, Rudolf Houben, Josef Pellkofer, N.N. (DIN / VDMA)

1. ISO Standardisation of Bevel Gears

Load Capacity Calc. of Bevel Gears



DIN 3991 (1988)

AGMA 2003 (A86)

AGMA 2003 (B97)

for calculation of non offset bevel gears only

ISO 10300 (2001)

FVA 411

ISO 23509 (2004)

Geometry calculation of bevel and Hypoid gears

ISO 10300 (2014?)

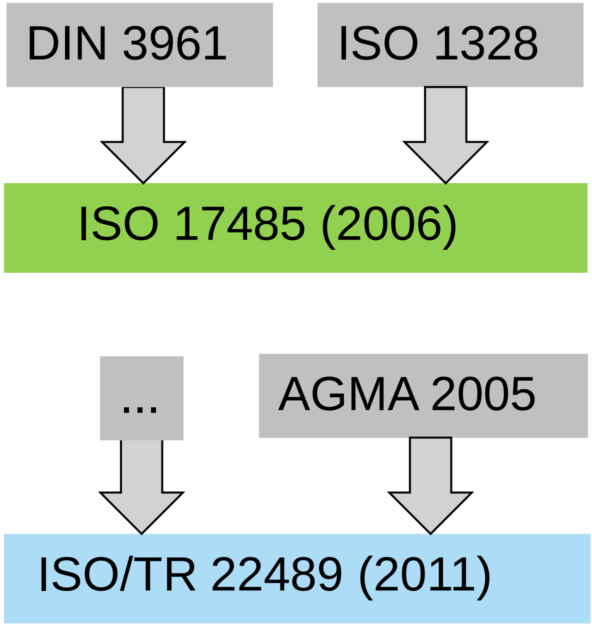
calculation of bevel and Hypoid gears

🟦 ISO TC60/SC2/WG13

1. ISO Standardisation of Bevel Gears

Load Capacity Calc. of Bevel Gears

Additional standards resp. recommendations:



Tolerances for bevel and Hypoid gears

DIN 3961

ISO 1328

ISO 17485 (2006)

Technical Report: Design recommendations for bevel gears

...

AGMA 2005

ISO/TR 22489 (2011)

🟩 ISO TC60/SC1/WG2 (Ad hoc: Bevel Gears)

🟦 ISO TC60/SC2/WG13

1. ISO Standardisation of Bevel Gears

Load Capacity Calc. of Bevel Gears

Fatigue	🟦 ISO 10300-1 (2014)	Introduction and general influence factors
	🟦 ISO 10300-2 (2014)	Calculation of surface durability (pitting)
	🟦 ISO 10300-3 (2014)	Calculation of tooth root strength
	⬛ ISO/TS 10300-4	Flank fracture
Tribology	⬜ ISO/TS 10300-20	Scuffing
	⬛ ISO/TS 10300-22	Micropitting
Examples	🟦 ISO/TR 10300-30	Examples to part 1…3
	⬜ ISO/TR 10300-32	Scuffing examples

🟦 valid ⬜ in progress ⬛ planed

1. ISO Standardisation of Bevel Gears

Methods within Standard

Method A	the most precise and high-grade calculation method, or proved load capacity on real parts, per example by measurements (of stresses).
Method B	the best (simplified) calculation method
Method C	a more simplified calculation method
Method D…	…

- ISO 10300 contains methods B and for some factors method C.

- It always is a target, to advance the methods to come nearer to method A as good as possible.
- It always is allowed to calculate even some individual factors according to a higher method, if available. Of course there always is the difficulty, if such a higher method is accepted by customers and business partners.

- Question: How near is Method B1 of ISO 10300 to Method A?

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2. Calculation Methods B…C

Safety Factors

$$S_{H\,1,2} = \frac{\sigma_{HP\,1,2}}{\sigma_{H\,1,2}} \geq S_{H\,,\min}$$

S_H : Safety factor for contact stress

σ_{HP} : Allowable contact stress

σ_H : Contact stress

$S_{H,\,\min}$: Minimal safety factor of contact stress

$$S_{F\,1,2} = \frac{\sigma_{FP\,1,2}}{\sigma_{F\,1,2}} \geq S_{F\,,\min}$$

S_F : Safety factor of tooth root stress

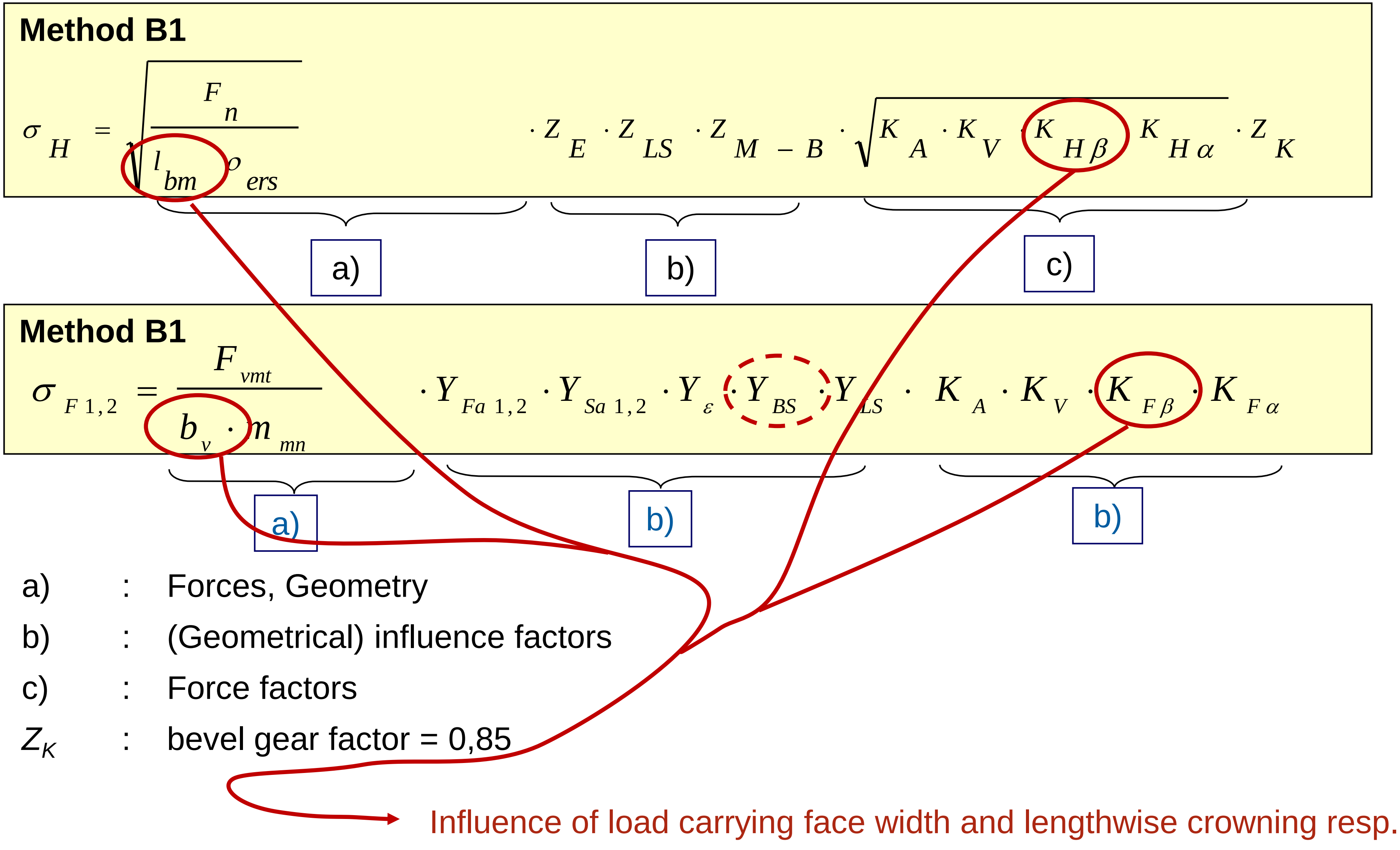
σ_{FP} : Allowable tooth root stress

σ_F : Tooth root stress

$S_{F,\,\min}$: minimal safety factor of tooth root stress

2. Calculation Methods B…C

Stresses



Method B1

$$\sigma_H = \underbrace{\sqrt{\frac{F_n}{l_{bm} \cdot \rho_{ers}}}}_{\boxed{\text{a)}}} \cdot \underbrace{Z_E \cdot Z_{LS} \cdot Z_{M-B}}_{\boxed{\text{b)}}} \cdot \underbrace{\sqrt{K_A \cdot K_V \cdot K_{H\beta} \cdot K_{H\alpha}} \cdot Z_K}_{\boxed{\text{c)}}}$$

Method B1

$$\sigma_{F\,1,2} = \underbrace{\frac{F_{vmt}}{b_v \cdot m_{mn}}}_{\boxed{\text{a)}}} \cdot \underbrace{Y_{Fa\,1,2} \cdot Y_{Sa\,1,2} \cdot Y_\varepsilon \cdot Y_{BS} \cdot Y_{LS}}_{\boxed{\text{b)}}} \cdot \underbrace{K_A \cdot K_V \cdot K_{F\beta} \cdot K_{F\alpha}}_{\boxed{\text{b)}}}$$

a) : Forces, Geometry

b) : (Geometrical) influence factors

c) : Force factors

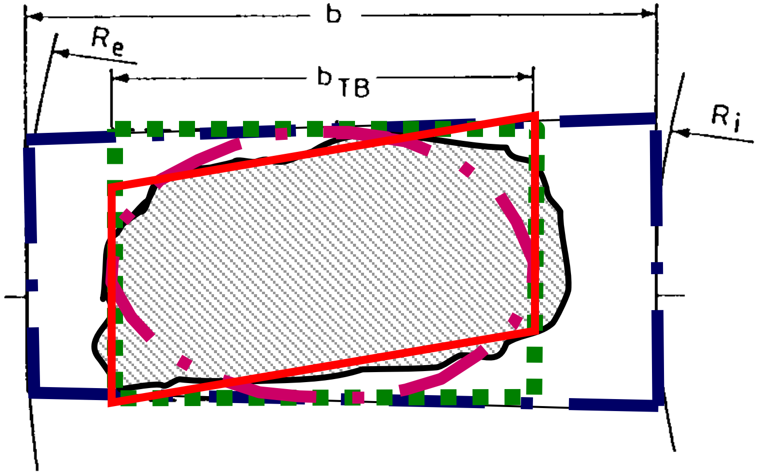
Z_K : bevel gear factor = 0,85

Influence of load carrying face width and lengthwise crowning resp.

2. Calculation Methods B…C

Zone of Action

Zone of action (schematic)



0) max. zone of action (without crowning)
1) Example of a real zone of action
2) square zone of action of DIN 3991
3) elliptical zone of action AGMA & ISO 10300 (01)
4) rhomboid zone of action acc. FVA 411

ISO 10300 (2014):

Method B1 acc. 4); width of contact pattern b_{TB} depending on „effective“ face width

- If real width of contact pattern is not known, typically 0.85 b can be taken.
- This is not a specification within the standard, just a recommendation.

- In reality with of contact pattern is depending on lengthwise crowning and is different for every different load case.

2. Calculation Methods B…C

Force Factors

$$K_A \cdot K_V \cdot K_{H\beta} \cdot K_{H\alpha}$$

for surface durability (pitting)

$$K_A \cdot K_V \cdot K_{F\beta} \cdot K_{F\alpha}$$

for tooth root strength

K_A : Application Factor

K_V : Dynamic Factor

$K_{H\beta}$, $K_{F\beta}$: Face Load Factors

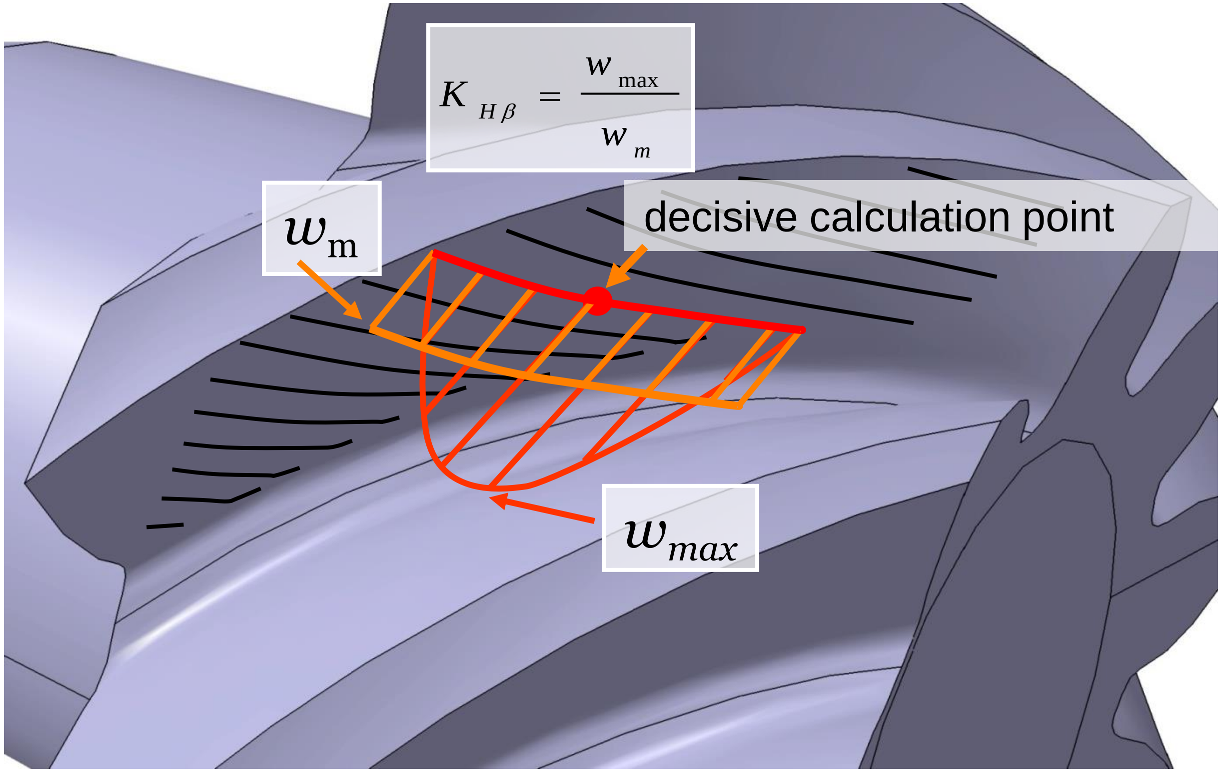
$K_{H\alpha}$, $K_{F\alpha}$: Transverse Load Factors

2. Calculation Methods B…C

Face Load Factor $K_{H\beta}$

The **Face Load Factor $K_{H\beta}$** considers uneven load distribution on the flank.

Definition:



$$K_{H\beta} = \frac{w_{\max}}{w_m}$$

w_{max}: maximum line load

w_m: mean line load, related to length of contact line

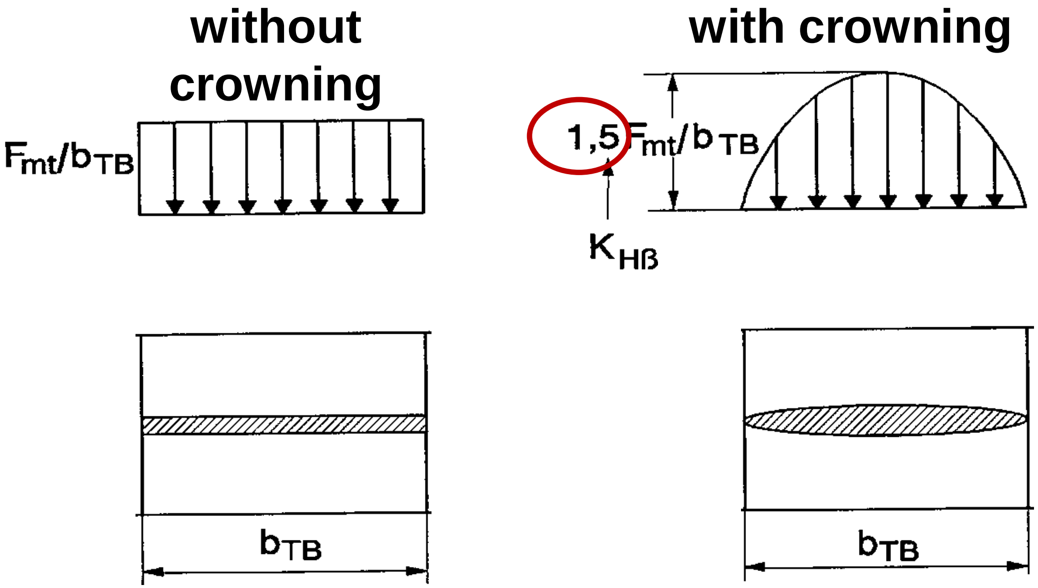
2. Calculation Methods B…C

Face Load Factor $K_{H\beta}$

Within ISO 10300 only a Method C is available for face load factors, but there is a hint, that a Method B could be an examination by Loaded Tooth Contact Analysis (LTCA).

Method C: $K_{\text{Hß-C}} = 1{,}5\, K_{\text{Hß-be}}$

- ***crowning***:



- ***shaft deviations*** caused by mounting conditions (arrangement of bearings):

2. Calculation Methods B…C

Mounting Factor $K_{H\beta-be}$

The **Mounting Factor $K_{Hb\text{-}be}$** considers displacement of gear and pinion under load caused by the arrangement of bearings

Verification of contact pattern	**Mounting conditions of pinion and gear**		
Contact pattern is checked:	both straddle mounted	one cantilever - one straddle mounted	both cantilever mounted
For each gear set in its carrier under full load	1.00	1.00	1.00
For each gear set under light test load	1.05	1.10	1.25
For a sample gear set and estimated for full load	1.20	1.32	1.50
Note: Based on optimum tooth contact pattern under maximum operating load as evidenced by results of a deflection test on the gears in their respective mountings.			

Often taken value for calculation acc. ISO 10300:

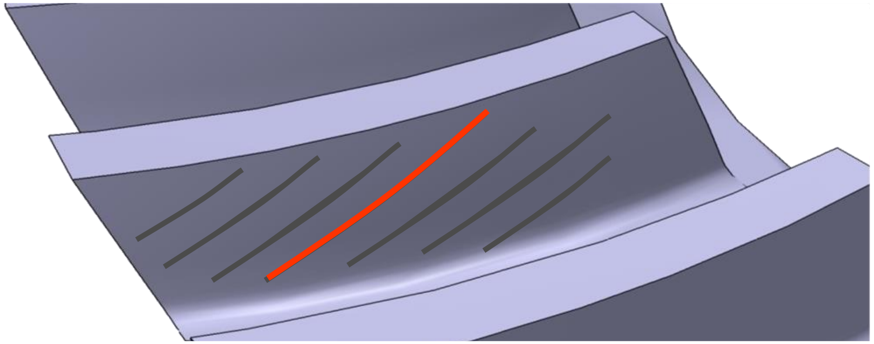
$$K_{Hß\text{-}C} = 1{,}5 \cdot 1{,}1 = 1{,}65$$

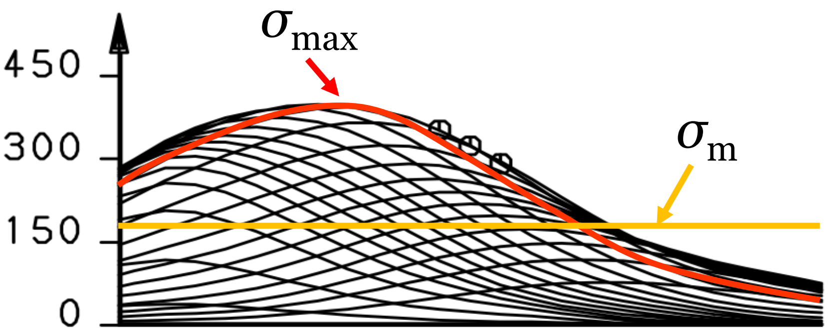
2. Calculation Methods B…C

Face Load Factor $K_{F\beta}$

The **Face Load Factor $K_{F\beta}$** considers uneven stress distribution on the tooth root.

Definition:





$$K_{F\beta} \cdot Y_{BS} = \frac{\sigma_{F\max}}{\sigma_{Fm}}$$

σ_{Fmax}: maximum tooth root stress

σ_{Fm}: mean tooth root stress

2. Calculation Methods B…C

Face Load Factor $K_{F\beta}$

Within ISO 10300 only a Method C is available for face load factors, but there is a hint, that a Method B could be an examination by Loaded Tooth Contact Analysis (LTCA).

Method C: $K_{Fß\text{-}C} = K_{Hß\text{-}C} / K_{F0}$

with K_{F0}: Lengthwise curvature factor

“The lengthwise curvature factor K_{F0} considers the contact pattern shift under different loads which is smallest, if the lengthwise tooth curvature at the mean point corresponds to that of an involute curve. This effect is well known and depends on the cutter radius r_{c0} and the spiral angle β_{m2}.” (Source: ISO 10300-1 (2014)).

$1{,}00 \leq K_{F0} \leq 1{,}15$: That means, that maximum effect of small tool radius is 15%.

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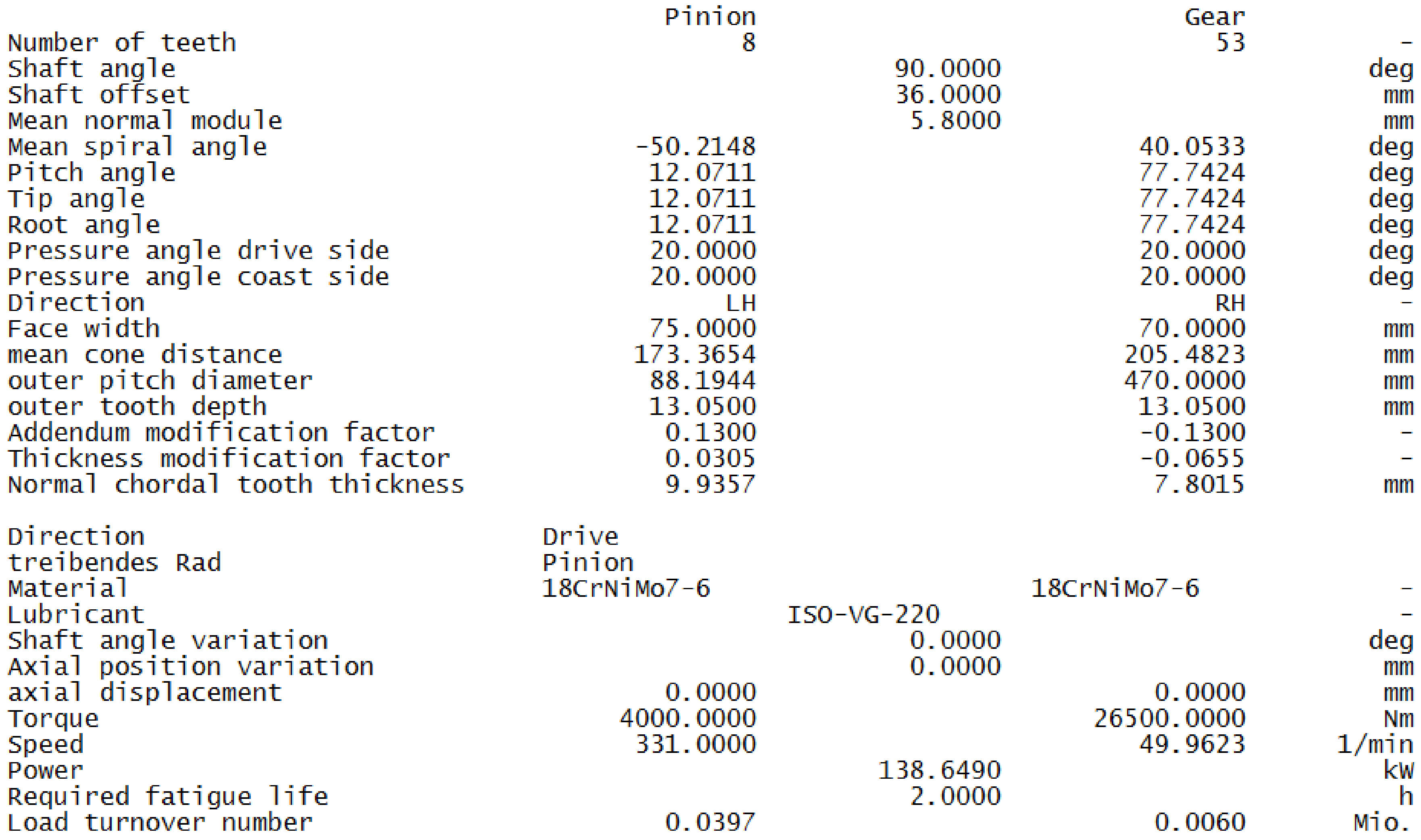
3. Example Calculation

Gear and Load Data



```
                                            Pinion                            Gear
Number of teeth                                  8                              53          -
Shaft angle                                              90.0000                          deg
Shaft offset                                             36.0000                           mm
Mean normal module                                        5.8000                           mm
Mean spiral angle                         -50.2148                         40.0533        deg
Pitch angle                                12.0711                         77.7424        deg
Tip angle                                  12.0711                         77.7424        deg
Root angle                                 12.0711                         77.7424        deg
Pressure angle drive side                  20.0000                         20.0000        deg
Pressure angle coast side                  20.0000                         20.0000        deg
Direction                                       LH                              RH          -
Face width                                 75.0000                         70.0000         mm
mean cone distance                        173.3654                        205.4823         mm
outer pitch diameter                       88.1944                        470.0000         mm
outer tooth depth                          13.0500                         13.0500         mm
Addendum modification factor                0.1300                         -0.1300          -
Thickness modification factor               0.0305                         -0.0655          -
Normal chordal tooth thickness              9.9357                          7.8015         mm

Direction                          Drive
treibendes Rad                     Pinion
Material                           18CrNiMo7-6                     18CrNiMo7-6              -
Lubricant                                          ISO-VG-220                               -
Shaft angle variation                                     0.0000                          deg
Axial position variation                                  0.0000                           mm
axial displacement                          0.0000                          0.0000         mm
Torque                                   4000.0000                      26500.0000         Nm
Speed                                     331.0000                         49.9623      1/min
Power                                                   138.6490                           kW
Required fatigue life                                     2.0000                            h
Load turnover number                        0.0397                          0.0060       Mio.
```

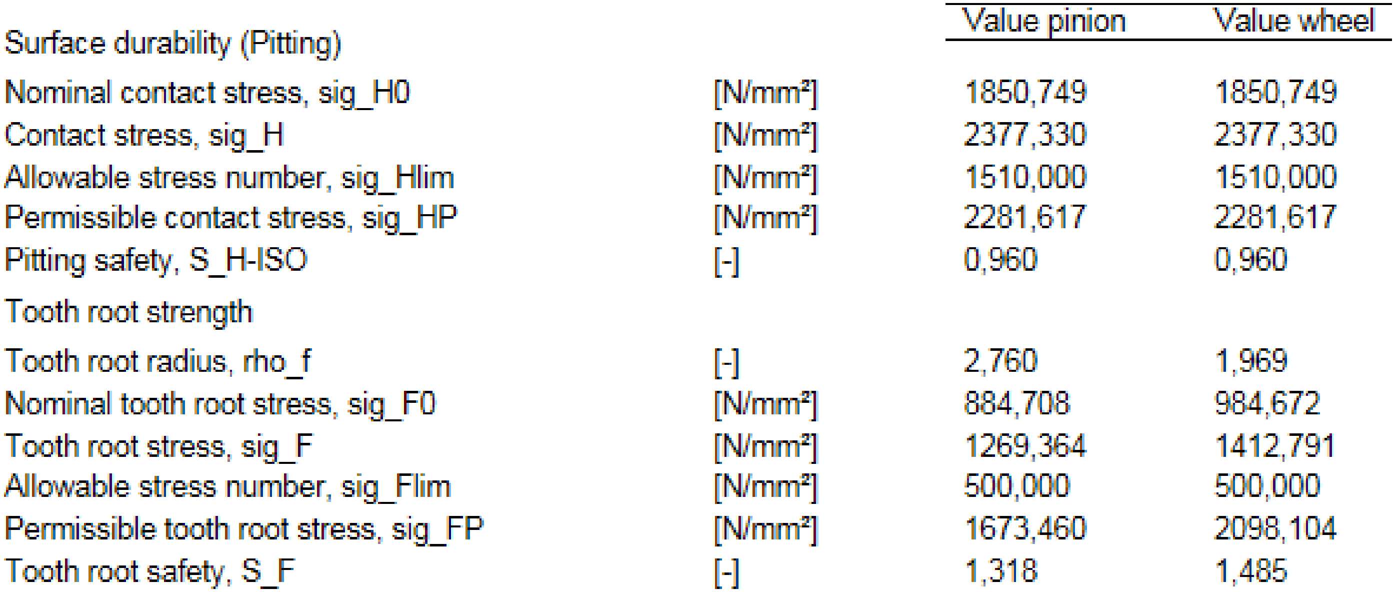
3. Example Calculation

ISO10300 Method B(C)

Input for first calculation acc. to ISO 10300 (Method B1):

Rel. contact width: $b_{\mathrm{eff}} = 0,85\ b$
Mounting factor: $K_{\mathrm{H\beta\text{-}be}} = 1,1$
Method C => $K_{\mathrm{H\beta\text{-}C}} = 1,65$
Method C => $K_{\mathrm{F\beta\text{-}C}} = 1,435$ with $K_{\mathrm{F0}} = 1,15$

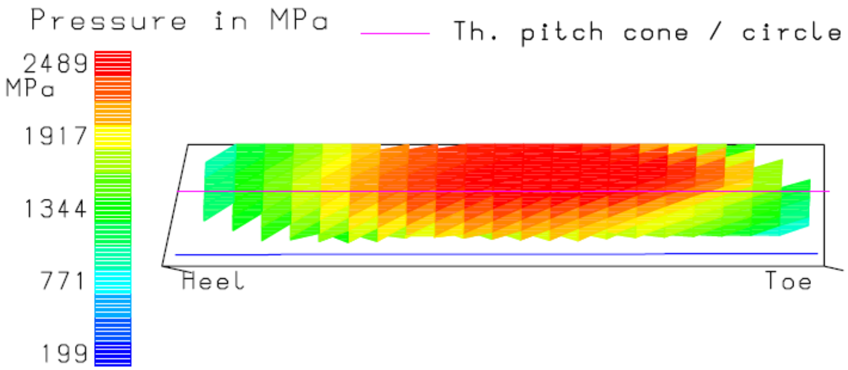
Results:



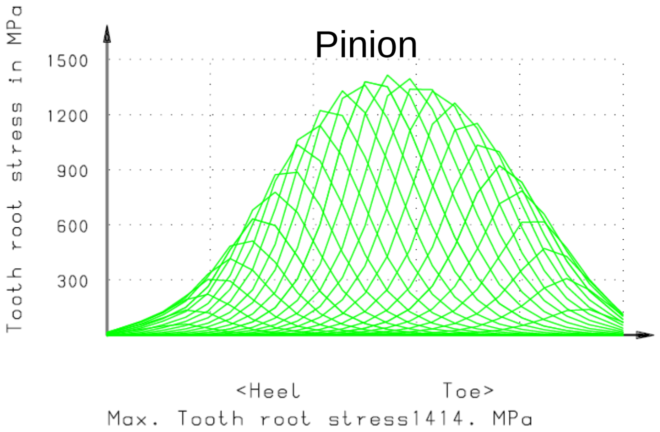
		Value pinion	Value wheel
Surface durability (Pitting)			
Nominal contact stress, sig_H0	[N/mm²]	1850,749	1850,749
Contact stress, sig_H	[N/mm²]	2377,330	2377,330
Allowable stress number, sig_Hlim	[N/mm²]	1510,000	1510,000
Permissible contact stress, sig_HP	[N/mm²]	2281,617	2281,617
Pitting safety, S_H-ISO	[-]	0,960	0,960
Tooth root strength			
Tooth root radius, rho_f	[-]	2,760	1,969
Nominal tooth root stress, sig_F0	[N/mm²]	884,708	984,672
Tooth root stress, sig_F	[N/mm²]	1269,364	1412,791
Allowable stress number, sig_Flim	[N/mm²]	500,000	500,000
Permissible tooth root stress, sig_FP	[N/mm²]	1673,460	2098,104
Tooth root safety, S_F	[-]	1,318	1,485

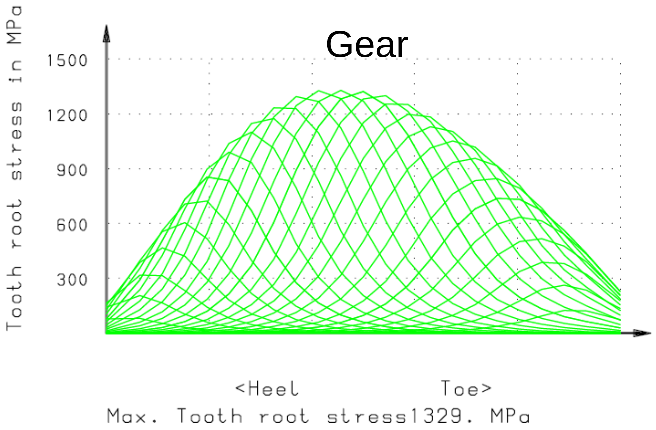
3. Example Calculation

Becal*) LTCA – comp. to ISO (Method B/C)



ISO (Meth. B/C): $\sigma_{H\_ISO} / Z_K = 2796{,}86\ \text{MPa}$





ISO (Meth. B/C): $\sigma_{F1\_ISO} = 1296{,}36\ \text{MPa}$ $\sigma_{F2\_ISO} = 1412{,}79\ \text{MPa}$

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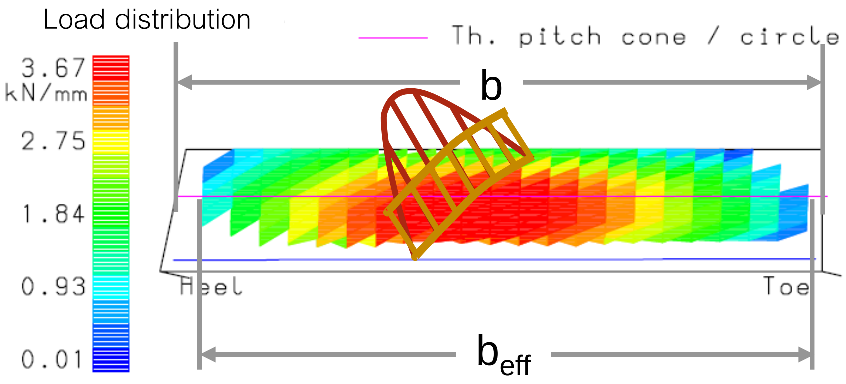
*) Becal is a software tool by FVA e.V. (Forschungsvereinigung Antriebstechnik – Research Association for Drive Technology)

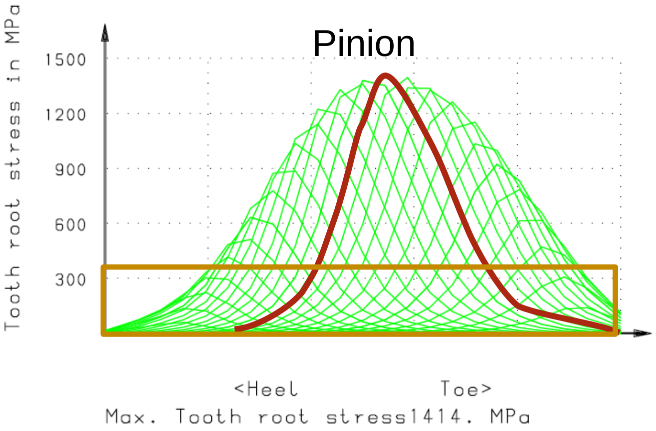
3. Example Calculation

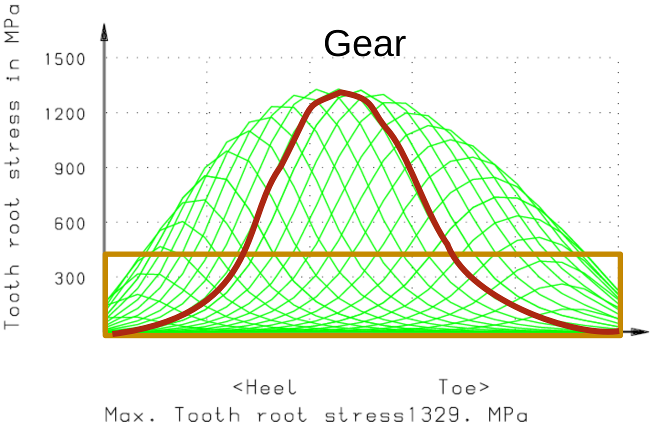
Face Load Factors Method B



$$b_{eff} / b = 0{,}90$$

$$K_{Hß} = w_{max} / w_m = 1{,}49$$





$$K_{Fß1} \cdot Y_{BS} = \sigma_{F1max} / \sigma_{F1m} = 3{,}44$$

$$K_{Fß2} \cdot Y_{BS} = \sigma_{F2max} / \sigma_{F2m} = 2{,}99$$

3. Example Calculation

ISO10300 Methode B(B)

Input for second calculation acc. ISO 10300:

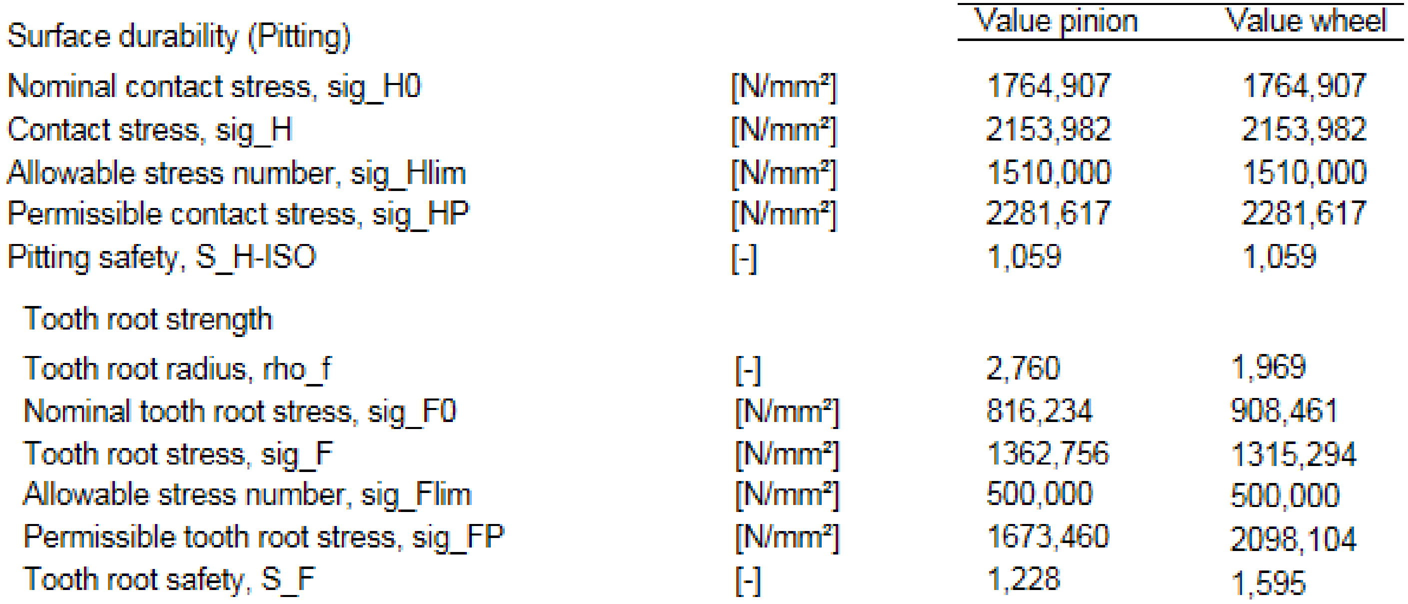
Rel. contact width: $b_{\mathrm{eff}} = 0{,}90\ b$

Face Load factors (Method B): $K_{\mathrm{Hß\text{-}B}} = 1{,}49$

$K_{\mathrm{Fß1\text{-}B}} = 1{,}67 \quad K_{\mathrm{Fß2\text{-}B}} = 1{,}45$

with $Y_{\mathrm{BS}} = 2{,}06$

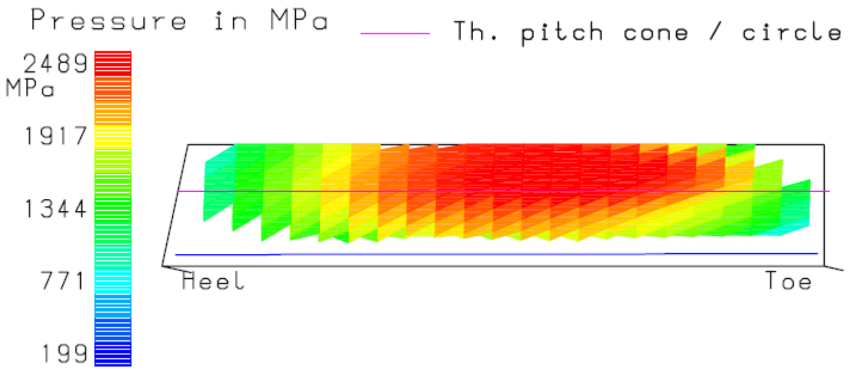
Results:



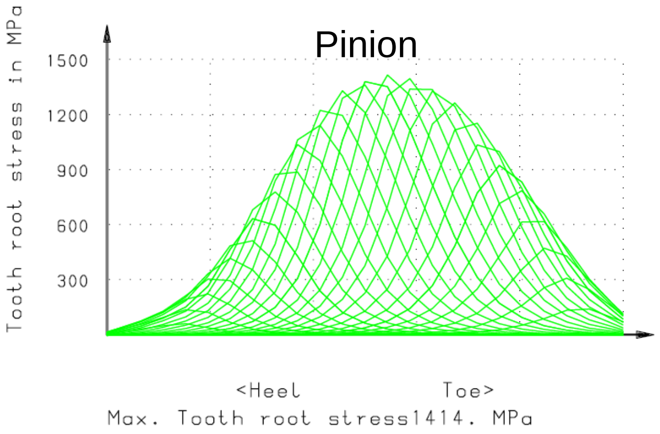
		Value pinion	Value wheel
Surface durability (Pitting)			
Nominal contact stress, sig_H0	[N/mm²]	1764,907	1764,907
Contact stress, sig_H	[N/mm²]	2153,982	2153,982
Allowable stress number, sig_Hlim	[N/mm²]	1510,000	1510,000
Permissible contact stress, sig_HP	[N/mm²]	2281,617	2281,617
Pitting safety, S_H-ISO	[-]	1,059	1,059
Tooth root strength			
Tooth root radius, rho_f	[-]	2,760	1,969
Nominal tooth root stress, sig_F0	[N/mm²]	816,234	908,461
Tooth root stress, sig_F	[N/mm²]	1362,756	1315,294
Allowable stress number, sig_Flim	[N/mm²]	500,000	500,000
Permissible tooth root stress, sig_FP	[N/mm²]	1673,460	2098,104
Tooth root safety, S_F	[-]	1,228	1,595

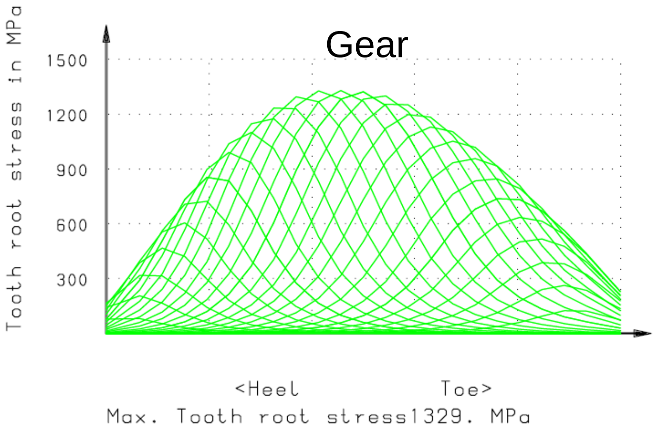
3. Example Calculation

Becal*) LTCA – comp. to ISO (Method B/B)



ISO (Meth. B/B): σ_{H_ISO} / Z_K = 2534,09 MPa





ISO (Meth. B/B): σ_{F1_ISO} = 1362,76 MPa σ_{F2_ISO} = 1315,29 MPa

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4. Conclusions

- **Within the series of standards ISO10300 for the load carrying capacity calculation of bevel gears actually are covered standards for the tooth flank (pitting) and tooth root capacity. There are available specifications for scuffing calculation as well as technical reports for sample calculations. Additional parts will be added continuously.**
- **The actual standards include quite rough influences of lengthwise crowning only (Method C). This lead to obvious differences in comparison to results according to superior calculation methods, like loaded tooth contact analysis (LTCA).**
- **As soon as results according to LTCA (Method B) are introduced into ISO10300, the differences in final results are (negligible?) low and a proof of load carrying capacity according ISO10300 is possible.**
- **If LTCA calculation software packages have been proved by measurements on real bevel gears, these methods actually are most near to reality (Method A) according to actual state of knowledge.**

Thank you for your attention!