ISO 6336:2019

Changes and consequences

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ISO 6336-1:2019

Calculation of load capacity of spur and helical gears — Part 1: Basic principles, introduction and general influence factors

ABSTRACT

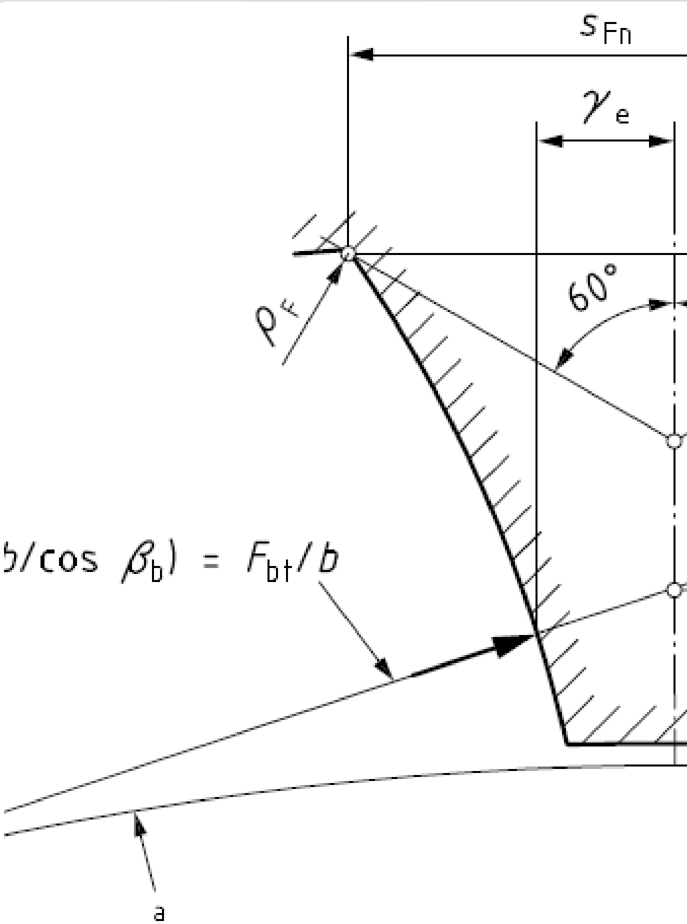
PREVIEW

This document presents the basic principles of, an introduction to, and the general influence factors for the calculation of the load capacity of spur and helical gears. Together with the other documents in the ISO 6336 series, it provides a method by which different gear designs can be compared. It is not intended to assure the performance of assembled drive gear systems. It is not intended for use by the general engineering public. Instead, it is intended for use by the experienced gear designer who is capable of selecting reasonable values for the factors in these formulae based on the knowledge of similar designs and the awareness of the effects of the items discussed.

The formulae in the ISO 6336 series are intended to establish a uniformly acceptable method for calculating the load capacity of cylindrical gears with straight or helical involute

Presentation, sections

1. Current situation
2. Implementation in KISSsoft
3. Overview of changes
4. Tooth form factor Y_F with new factor $\boldsymbol{f}_{\varepsilon}$
5. Tooth form factor Y_F when shaper cutter is used
6. Helix angle factor Y_{β}
7. Relative notch sensitivity factor $Y_{\delta relT}$ for static stress
8. Application examples, wind turbine gearboxes
9. Application example, EV transmission



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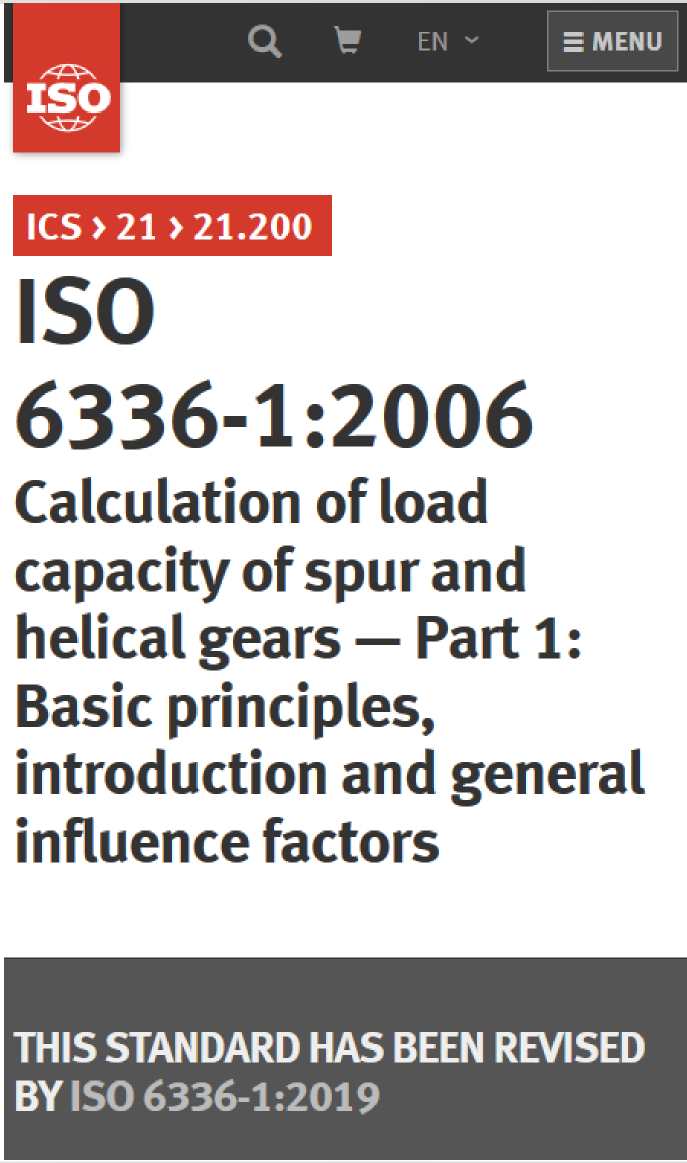
1. Current situation

ISO 6336:2019 is the only valid revision, other revisions are withdrawn

Previous versions of ISO 6336 are no longer valid. Refer to www.iso.org.

Contractual documents or certification guidelines that refer to ISO 6336 technically refer to the current revision (2019). Documents (calculation reports, contracts, specifications, certification guidelines, …) therefore need either to be specific (e.g. identifying the revision to be used) or updated.

It remains to be seen how the changes in the latest revision affect gear design procedures and customer requirements. It is recommended to gain experience with the 2019 revision of ISO 6336 by using both calculation methods (along revision 2006 and revision 2019) in parallel and to compare and assess the results.



ISO, ISO/TS, ISO/TR 6336 overview

ISO 6336 now consists of 5 parts, part 1, 2, 3, 5, 6

Note that part 4 is an ISO/TS

Parts 20, 21, 22 are also ISO/TS

Parts 30, 31 are ISO/TR

Calculation of load capacity of spur and helical gears	**International Standard**	**Technical Specification**	**Technical Report**
Part 1: Basic principles, introduction and general influence factors	X		
Part 2: Calculation of surface durability (pitting)	X		
Part 3: Calculation of tooth bending strength	X		
Part 4: Calculation of tooth flank fracture load capacity		X	
Part 5: Strength and quality of materials	X		
Part 6: Calculation of service life under variable load	X		
Part 20: Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) — Flash temperature method (replaces: ISO/TR 13989-1)		X	
Part 21: Calculation of scuffing load capacity (also applicable to bevel and hypoid gears) — Integral temperature method (replaces: ISO/TR 13989-2)		X	
Part 22: Calculation of micropitting load capacity (replaces: ISO/TR 15144-1)		X	
Part 30: Calculation examples for the application of ISO 6336 parts 1,2,3,5			X
Part 31: Calculation examples of micropitting load capacity (replaces: ISO/TR 15144-2)			X

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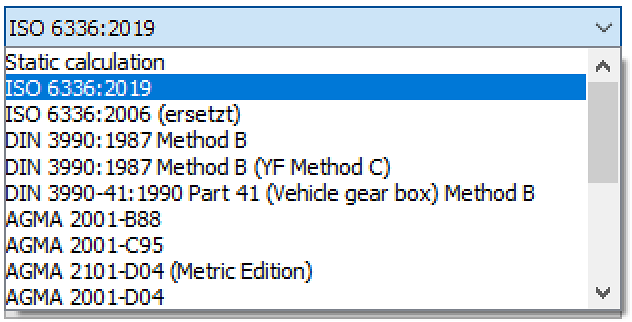
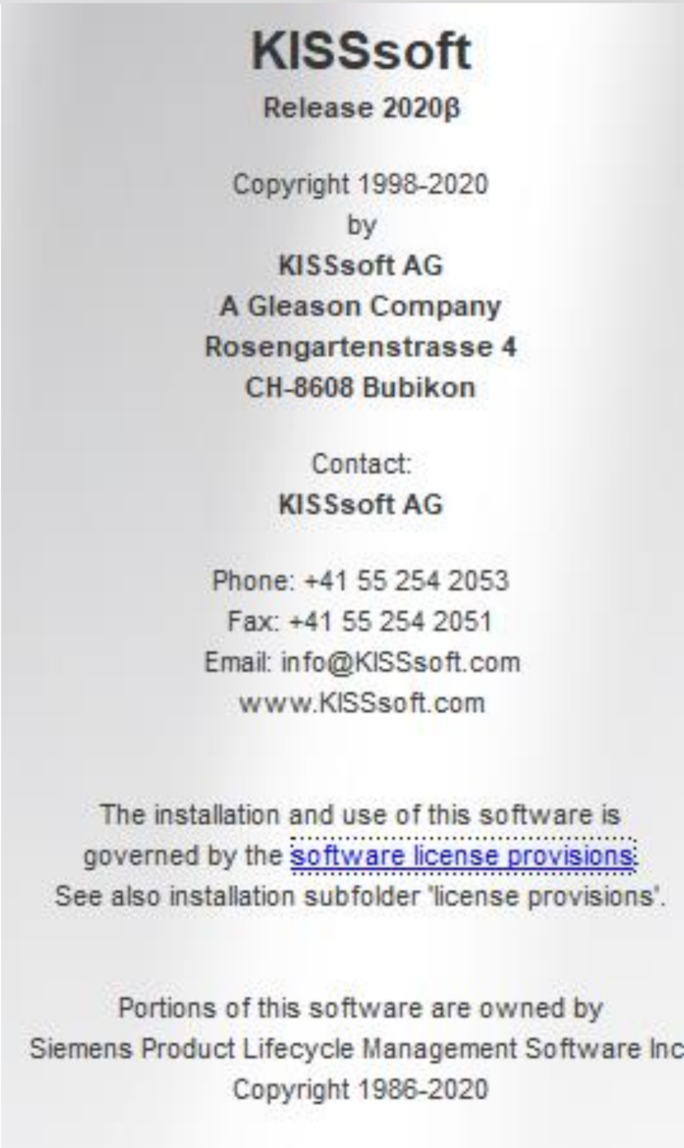
Software release 2020

Gear rating along ISO 6336:2019 for root and flank safety factors is implemented in KISSsoft for release 2020.



Also, scuffing rating, tooth flank fracture calcualtion and micropitting rating along the respective ISO 6336 or ISO/TS 6336 methods is included in KISSsoft.

All calculations documented here were performed with KISSsoft, Release 2020β



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The new revision ISO 6336:2019 replaces the previous revision ISO 6336:2006.
Changes are mainly affecting the root safety factor SF for external and internal gears.

Tooth form factor Y_F (see sections 4 and 5 below)

Influence of tooth form, cross sectional property of tooth. New factor f_ε considers the influence of load distribution between the teeth in mesh. For internal gears only **the shaper cutter data** is used. → Affects the calculated root stresses.

Helix angle factor Y_β (see section 6 below)

Considers reduced stress due to oblique contact line, as function of helix angle at reference circle β and overlap ratio ε_β. → Affects the calculated root stresses.

Relative notch sensitivity factor $Y_{\delta relT}$ for static stress (see section 7 below)

Influence of the notch sensitivity relative to test gear. → Affects the calculated static stress number for bending.

Calculation of YF for different tooth thicknesses

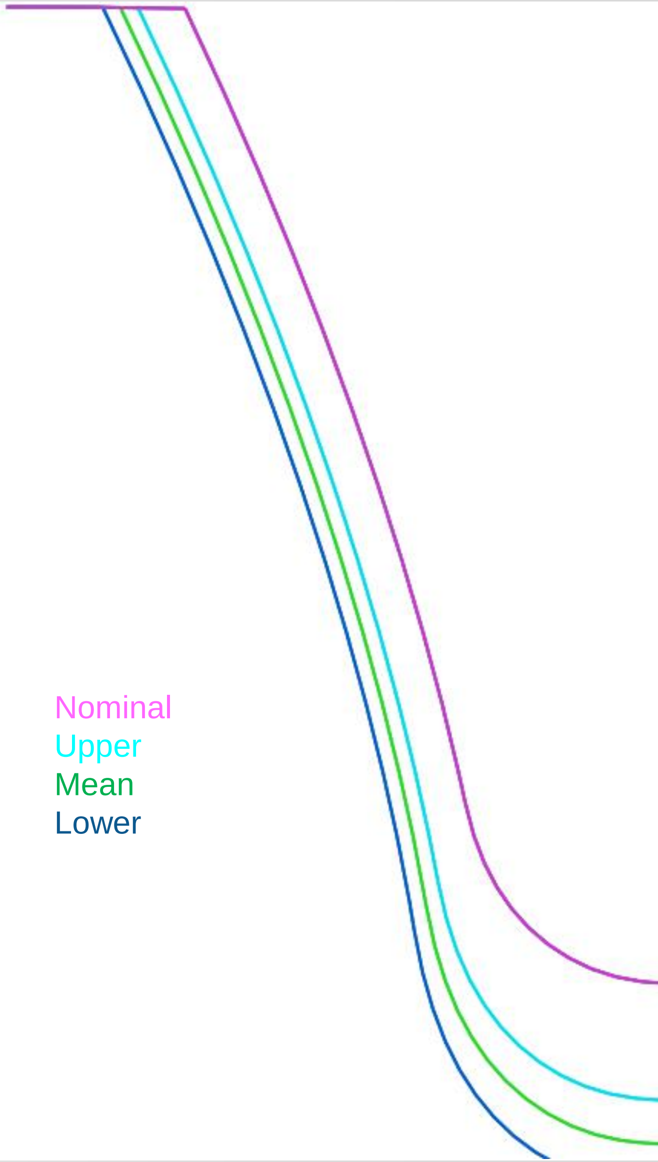
ISO 6336: 2006

YF is calculated from the nominal tooth form with the **theoretical profile shift coefficient x**.

If the tooth thickness deviation near the root results in a thickness reduction of more than 0.05*mn, this shall be taken into account, by taking the generated profile, x_E, relative to rack shift amount mn instead of the nominal profile.

ISO 6336: 2019

The tooth form factor is sensitive to the tooth thickness. When the manufactured geometry is measured, it should be used. If not, then, based on the tooth thickness tolerance, the **smallest generating profile shift, $x_{E\ min}$**, should be used to determine YF.



Introduction of factor f_ε

ISO 6336: 2006

No such factor.

ISO 6336: 2019

The factor f_ε considers the influence of load distribution between the teeth in the mesh. It provides more accurate results for gears with contact ratios $\varepsilon_{\alpha n} \geq 2{,}0$. Contact ratios of $\varepsilon_{\alpha n} \geq 2{,}0$ are calculated for gears with high helix angles, high contact ratios, ε_α, or both.

For spur gears with contact ratios $\varepsilon_{\alpha n} \leq 2{,}0$ the factor f_ε is equal to one according Formula (10). For helical gears with overlap ratio $\varepsilon_\beta \geq 1$ the factor is calculated according to Formula (14). Formulae (12) and (13) provide a smooth function for f_ε between Formulae (10) and (14).

If $\varepsilon_\beta = 0$ and $\varepsilon_{\alpha n} < 2$ then

$$f_\varepsilon = 1$$

If $\varepsilon_\beta = 0$ and $\varepsilon_{\alpha n} \geq 2$ then

$$f_\varepsilon = 0{,}7$$

If $0 < \varepsilon_\beta < 1$ and $\varepsilon_{\alpha n} < 2$ then

$$f_\varepsilon = \left(1 - \varepsilon_\beta + \frac{\varepsilon_\beta}{\varepsilon_{\alpha n}}\right)^{0{,}5}$$

If $0 < \varepsilon_\beta < 1$ and $\varepsilon_{\alpha n} \geq 2$ then

$$f_\varepsilon = \left(\frac{1 - \varepsilon_\beta}{2} + \frac{\varepsilon_\beta}{\varepsilon_{\alpha n}}\right)^{0{,}5}$$

If $\varepsilon_\beta \geq 1$ then

$$f_\varepsilon = \varepsilon_{\alpha n}^{-0{,}5}$$

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4. Tooth form factor Y_F

ISO 6336:2006

The following equation uses the symbols illustrated in Figures 3 and 4:

$$Y_F = \frac{\frac{6\, h_{Fe}}{m_n}\cos\alpha_{Fen}}{\left(\frac{s_{Fn}}{m_n}\right)^2 \cos\alpha_n} \qquad (9)$$

In order to evaluate precise values, s_{Fn} and α_{Fen}, of h_{Fe} it is first necessary to derive a value of θ which is reasonably accurate, usually after five iterations of Equation (14). Determination of Y_F by graphical means is not recommended.

6.2.1 Tooth root normal chord, s_{Fn}, radius of root fillet, ρ_F, bending moment arm, h_{Fe} [4)]

First, determine the auxiliary values for Equation (9):

$$E = \frac{\pi}{4} m_n - h_{fP} \tan\alpha_n + \frac{s_{pr}}{\cos\alpha_n} - (1 - \sin\alpha_n)\frac{\rho_{fP}}{\cos\alpha_n} \qquad (10)$$

ISO 6336:2019

$$Y_F = \frac{\frac{6 \cdot h_{Fe}}{m_n} \cdot \cos\alpha_{Fen}}{\left(\frac{s_{Fn}}{m_n}\right)^2 \cdot \cos\alpha_n} \cdot f_\varepsilon \qquad (9)$$

In order to evaluate precise values, s_{Fn} and α_{Fen}, of h_{Fe} it is first necessary to derive a value of θ which is reasonably accurate, usually after five iterations of Formula (29). Determination of Y_F by graphical means is not recommended.

The factor f_ε considers the influence of load distribution between the teeth in the mesh. It provides more accurate results for gears with contact ratios $\varepsilon_{\alpha n} \geq 2{,}0$. Contact ratios of $\varepsilon_{\alpha n} \geq 2{,}0$ are calculated for gears with high helix angles, high contact ratios, ε_α, or both.

For spur gears with contact ratios $\varepsilon_{\alpha n} \leq 2{,}0$ the factor f_ε is equal to one according Formula (10). For helical gears with overlap ratio $\varepsilon_\beta \geq 1$ the factor is calculated according to Formula (14). Formulae (12) and (13) provide a smooth function for f_ε between Formulae (10) and (14).

If $\varepsilon_\beta = 0$ and $\varepsilon_{\alpha n} < 2$ then

$$f_\varepsilon = 1 \qquad (10)$$

If $\varepsilon_\beta = 0$ and $\varepsilon_{\alpha n} \geq 2$ then

$$f_\varepsilon = 0{,}7 \qquad (11)$$

If $0 < \varepsilon_\beta < 1$ and $\varepsilon_{\alpha n} < 2$ then

$$f_\varepsilon = \left(1 - \varepsilon_\beta + \frac{\varepsilon_\beta}{\varepsilon_{\alpha n}}\right)^{0{,}5} \qquad (12)$$

$$\varepsilon_{\alpha n} = \frac{\varepsilon_\alpha}{(\cos\beta_b)^2}$$

If $0 < \varepsilon_\beta < 1$ and $\varepsilon_{\alpha n} \geq 2$ then

$$f_\varepsilon = \left(\frac{1 - \varepsilon_\beta}{2} + \frac{\varepsilon_\beta}{\varepsilon_{\alpha n}}\right)^{0{,}5} \qquad (13)$$

If $\varepsilon_\beta \geq 1$ then

$$f_\varepsilon = \varepsilon_{\alpha n}^{-0{,}5} \qquad (14)$$

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4. Tooth form factor Y_F, influence thereof, example

Example 1

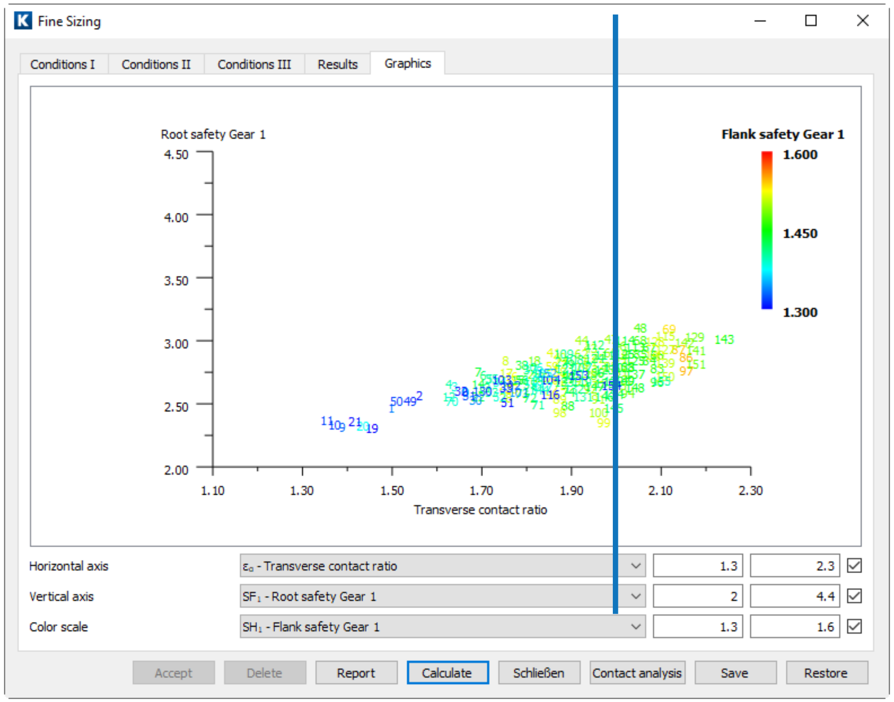
$h^*_{aP} = [1.0\,; 1.1, \ldots, 1.8]$ $\quad h^*_{fP} = 1.25$ $\quad \rho^*_{fP} = 0.25$

$\beta = 0°$

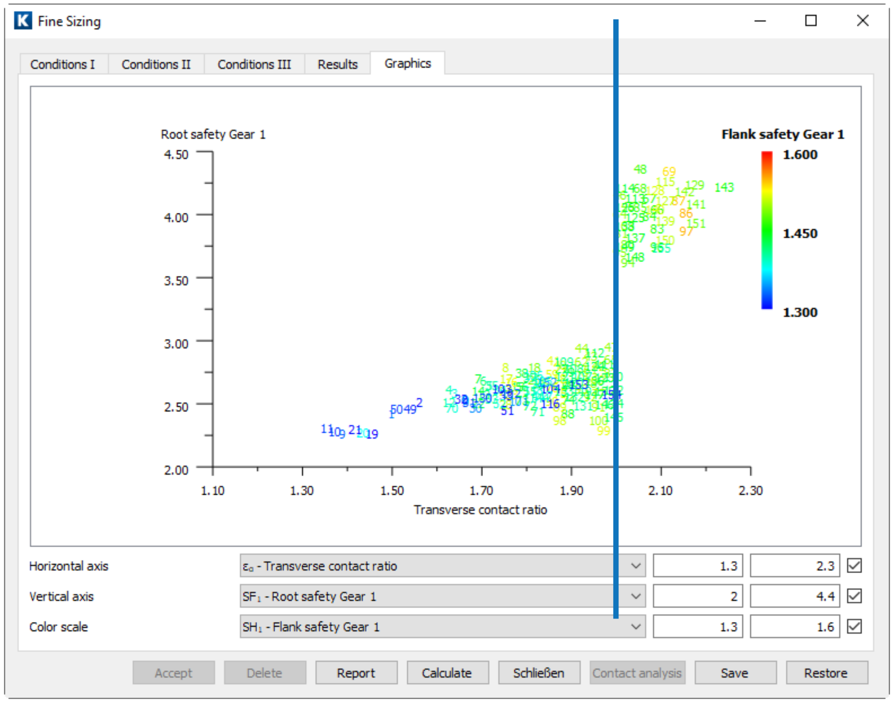
$a = 303\ mm$

$m_n = 6\ mm$

ISO 6336: 2006



ISO 6336: 2019



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Example 2

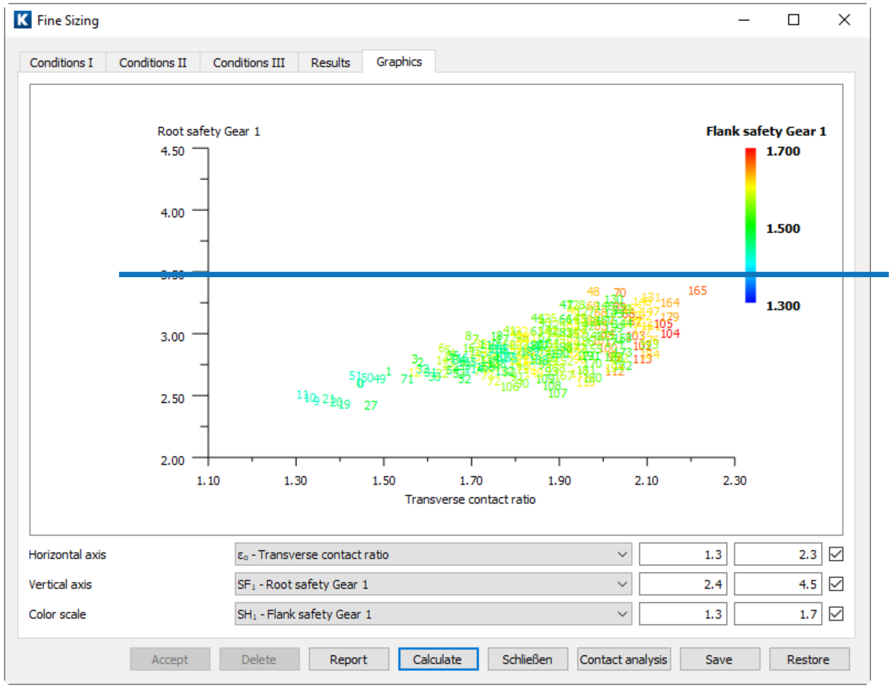
$h^*_{aP} = [1.0\,; 1.1, \ldots, 1.8]$ $\quad h^*_{fP} = 1.25 \quad \rho^*_{fP} = 0.25$, addendum is varied

$\beta = 15° \quad (\varepsilon_\beta = 0.75)$

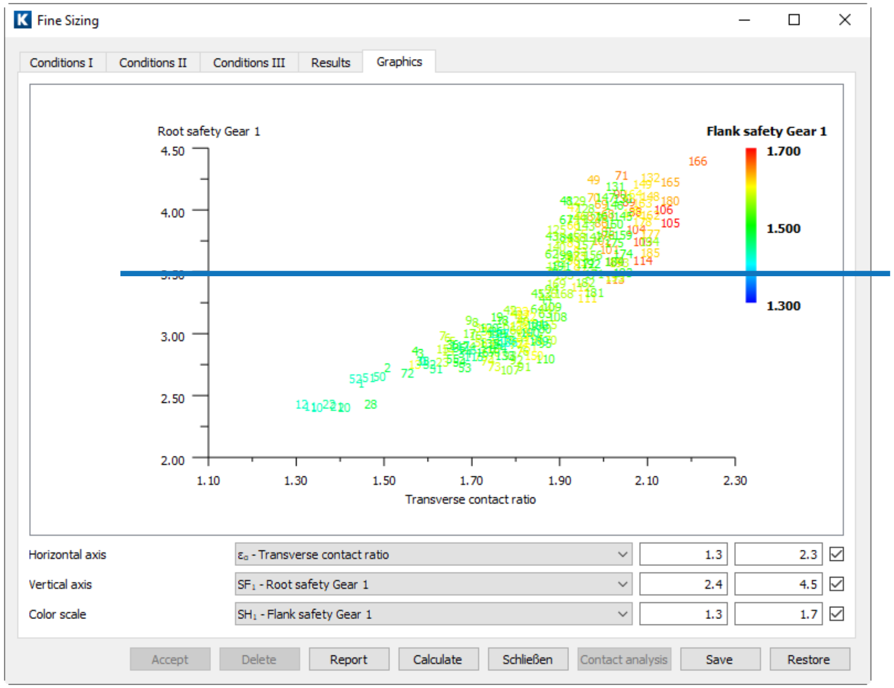
$a = 303\ mm$

$m_n = 5.8\ mm$

ISO 6336: 2006



ISO 6336: 2019



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4. Tooth form factor Y_F, influence thereof, example

Example 3

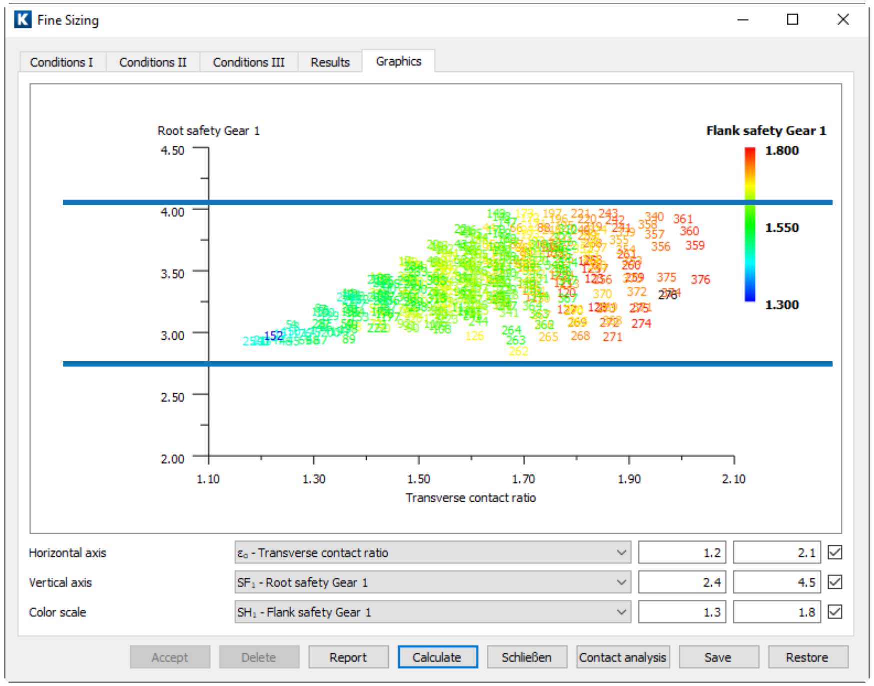
$h^*_{aP} = [1.0\,; 1.1, \ldots, 1.8] \quad h^*_{fP} = 1.25 \quad \rho^*_{fP} = 0.25$, addendum is varied

$\beta = 35° \;\; (\varepsilon_\beta = 1.6)$

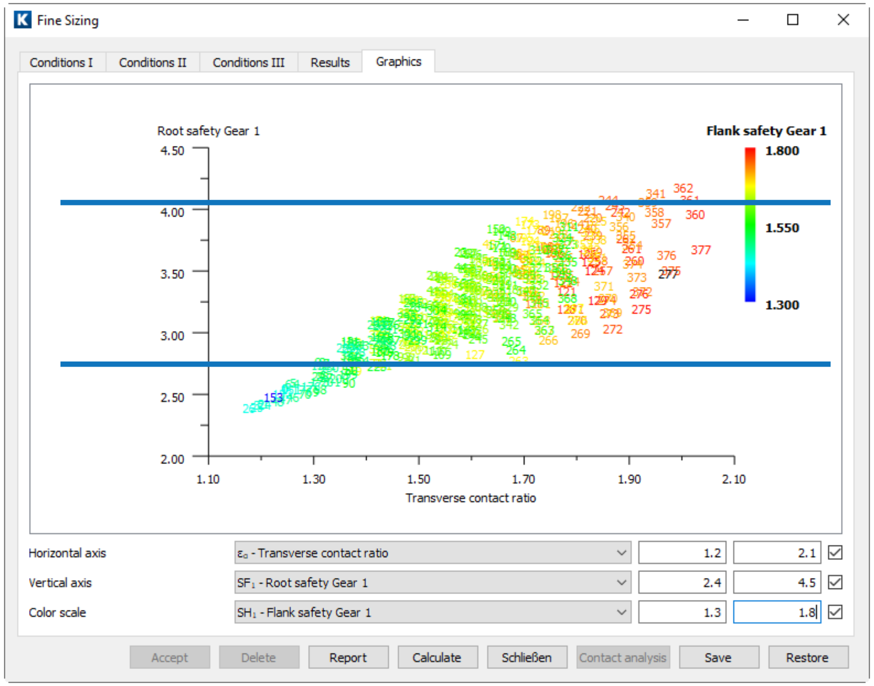
$a = 303\ mm$

$m_n = 4.9\ mm$

ISO 6336: 2006



ISO 6336: 2019



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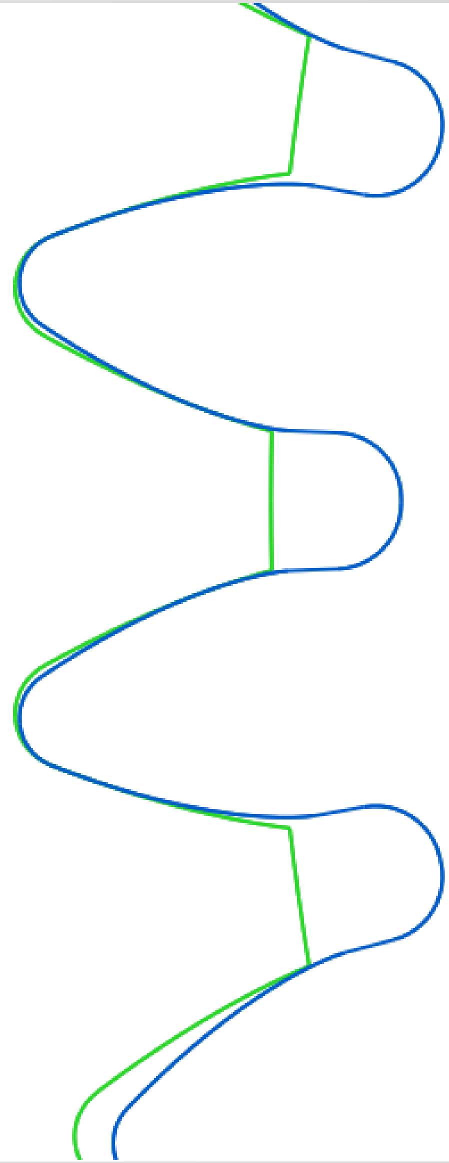
Calculation of YF for internal gears



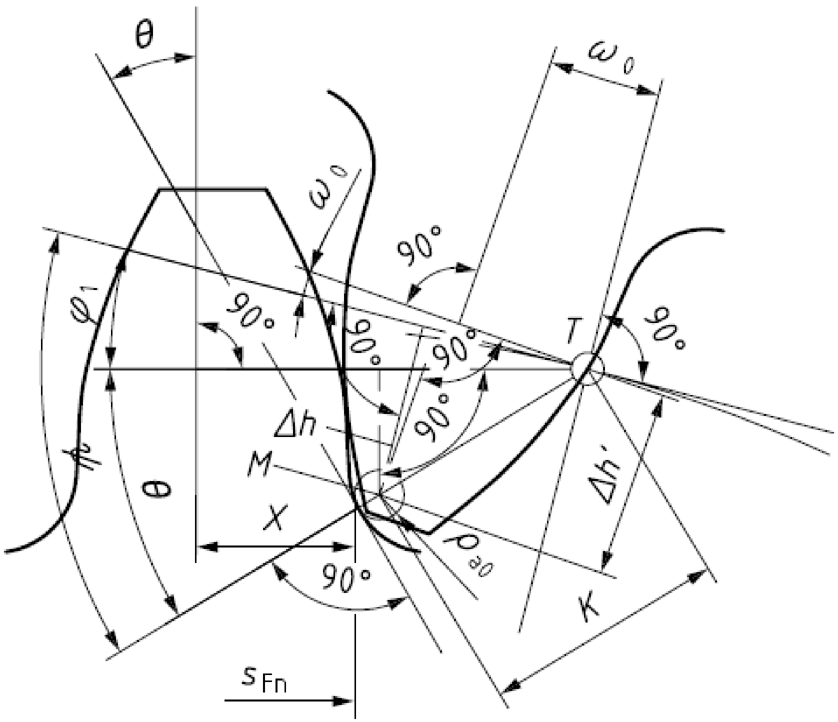
ISO 6336: 2006

For internal gears, a **virtual basic rack profile** is used which differs from the basic rack profile in the root radius ρfP.

ISO 6336: 2019

For internal gears only the **shaper cutter** data is used.

For internal gears only the shaper cutter data is used.



a) Shaper cutter

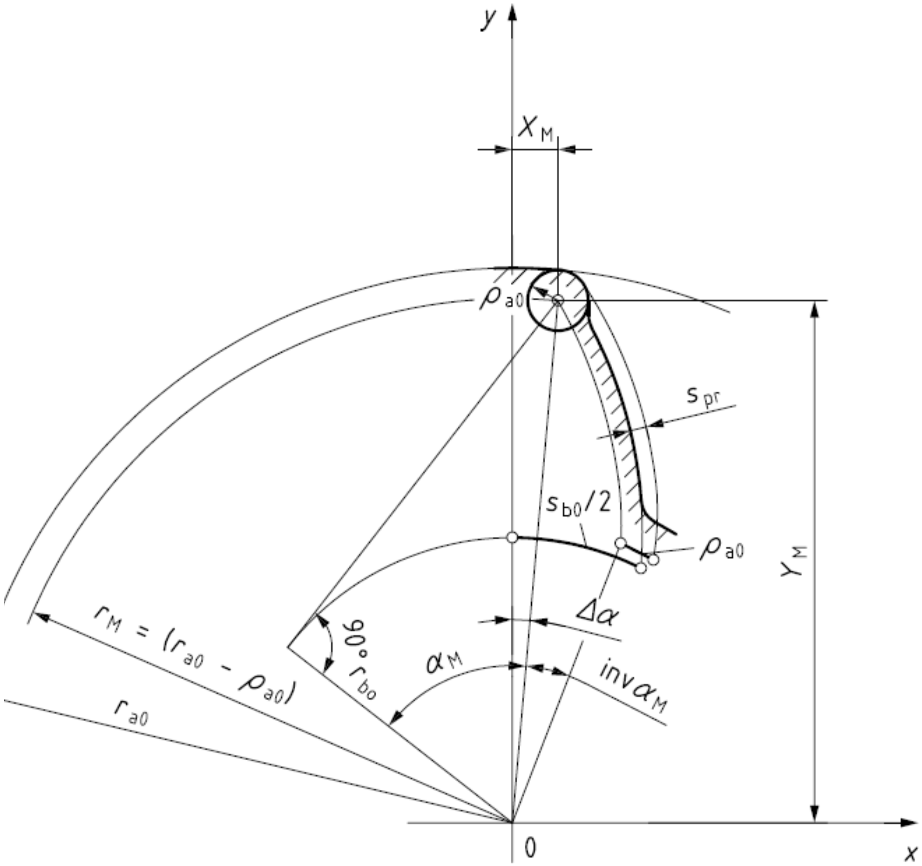


Figure 6 — Quantities at the shaper cutter

5. Tooth form factor Y_F when shaper cutter is used

Main problem is the error in the root fillet calculation in ISO 6336 (2006)

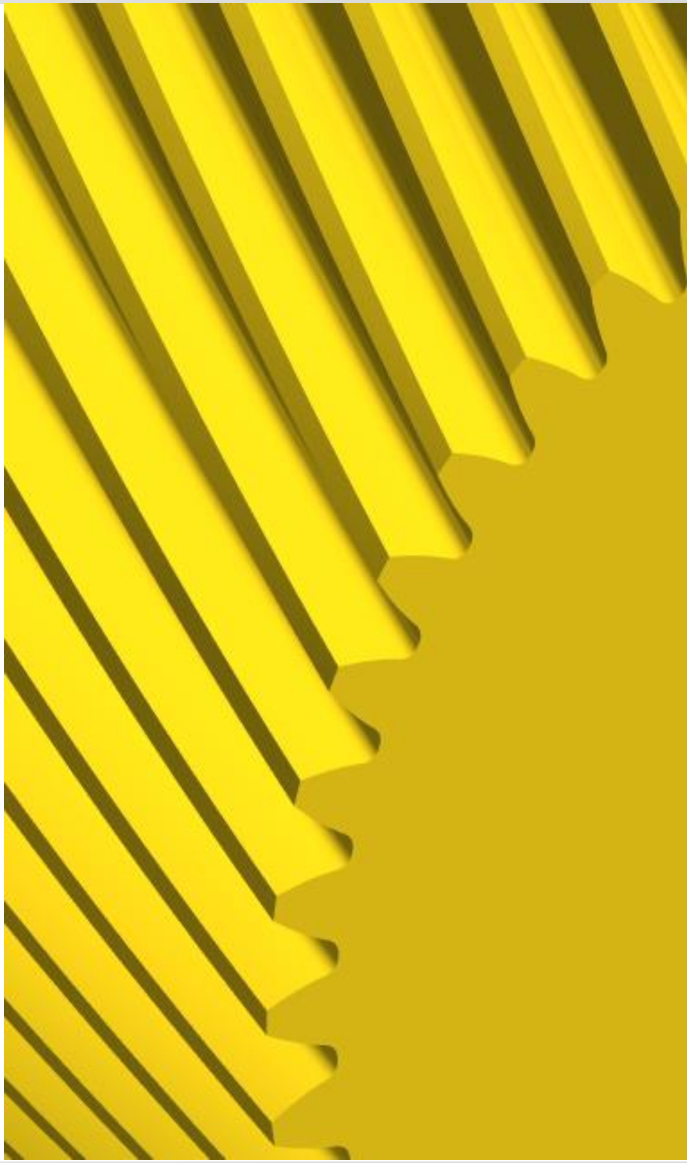
The following table illustrates the resulting root fillet for

- ISO 6336 (2006 & corrigendum 2007) root fillet calculation
- ISO 6336 (2007-04)
- Effective root fillet based on manufacturing simulation
- VDI 2737

gear x*	pinion cutter x0	ρ_{fP}	ρ_{fPv}	ρ_F 2006 / 2007-02	ρ_F 2007-04	ρ_F measured	ρ_F VDI 2736	ρ_F ISO 6336 2019	Deviation % (2007/2019)
-0.75	0.1	0.2	0.32	0.201	0.426	0.233	0.233	**0.233**	45%
-0.75	0.0	0.2	0.296	0.175	0.403	0.220	0.220	**0.220**	45%
0.00	0.1	0.2	0.332	0.298	0.364	0.284	0.286	**0.286**	21%
0.00	0.0	0.2	0.310	0.274	0.343	0.265	0.264	**0.264**	23%

ISO 6336 (2019) uses the same formulae as in VDI 2736.

6. Changes in helix angle factor Y_β



Use of the helix angle factor

See ISO 6336-3:2019 which states

“The tooth root stress of a virtual spur gear, calculated as a preliminary value, is converted by means of the helix factor, Y_β, to that of the corresponding helical gear. By this means, the oblique orientation of the lines of the mesh contact is taken into account (less tooth root stress).”

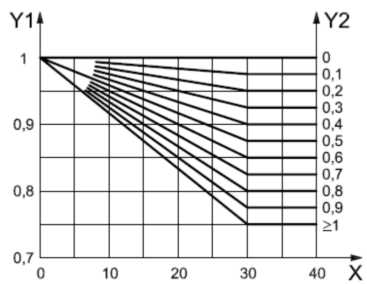
The factor is a function of the helix angle β and the overlap contact ratio ε_β. Note that β is limited to 30° and ε_β is limited to 1.00 for the calculation of this factor.

6. Changes in helix angle factor Y_β

ISO 6336: 2006

8.1 Graphical value

Y_β may be read from Figure 6 as a function of the helix angle, β, and the overlap ratio, ε_β.



Key

X reference helix angle, β, degrees

Y1 helix factor, Y_β

Y2 overlap ratio, ε_β

Helix factors $Y_\beta > 25°$ shall be confirmed by experience.

Figure 6 — Helix factor, Y_β

8.2 Determination by calculation

The factor Y_β can be calculated using Equation (40), which is consistent with the curves illustrated in Figure 6.

$$Y_\beta = 1 - \varepsilon_\beta \frac{\beta}{120°} \qquad (40)$$

where β is the reference helix angle, in degrees.

The value 1,0 is substituted for ε_β when $\varepsilon_\beta > 1{,}0$, and 30° is substituted for β when $\beta > 30°$.

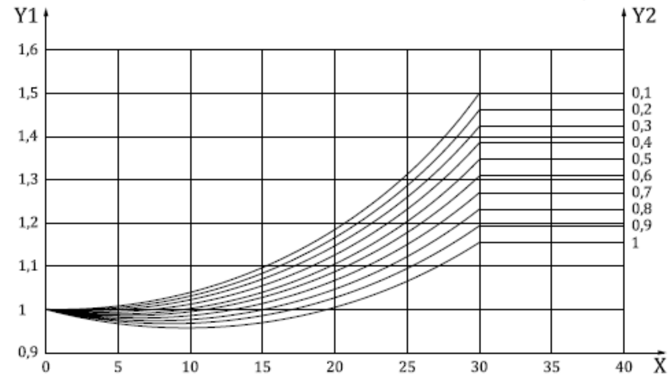
ISO 6336: 2019

8.1 General

The tooth root stress of a virtual spur gear, calculated as a preliminary value, is converted by means of the helix factor, Y_β, to that of the corresponding helical gear. By this means, the oblique orientation of the lines of the mesh contact is taken into account (less tooth root stress).

8.2 Graphical value

Y_β may be read from Figure 8 as a function of the helix angle, β and the overlap ratio, ε_β.



Key

X reference helix angle, β, degrees

Y1 helix factor, Y_β

Y2 overlap ratio, ε_β

Figure 8 — Helix factor, Y_β

Helix factors Y_β for $\beta > 25°$ shall be confirmed by experience.

8.3 Determination by calculation

The factor Y_β can be calculated using Formula (66) which is consistent with the curves illustrated in Figure 8.

$$Y_\beta = \left(1 - \varepsilon_\beta \cdot \frac{\beta}{120°}\right) \frac{1}{\cos^3 \beta} \qquad (66)$$

where β is the reference helix angle, in degrees and

$$\varepsilon_\beta > 0 \qquad (67)$$

The value 1,0 is substituted for ε_β when $\varepsilon_\beta > 1{,}0$, and 30° is substituted for β when $\beta > 30°$.

Influence of helix angle factor Y_β

Example 4

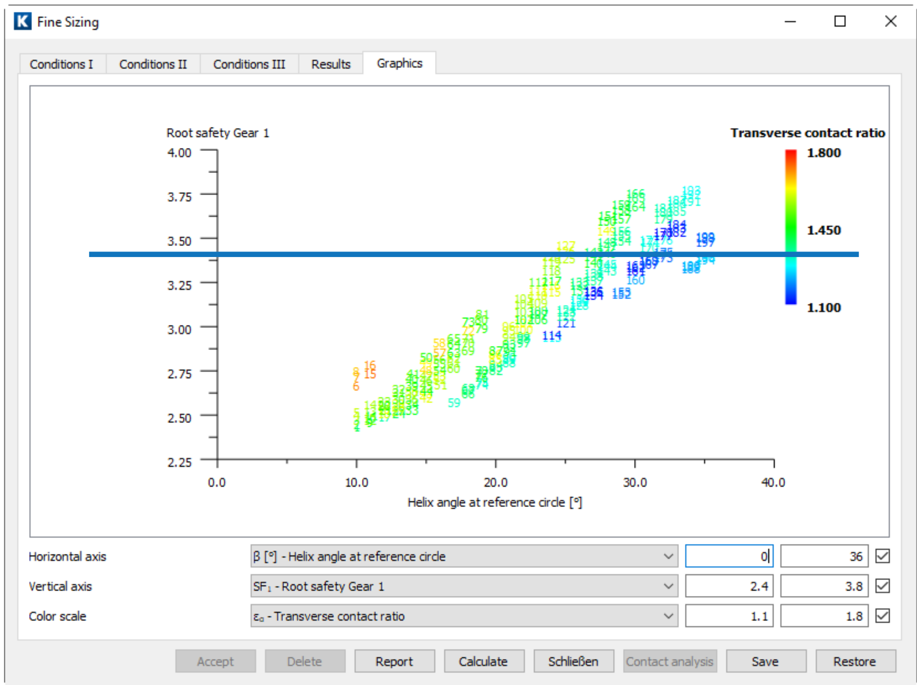
$h^*_{aP} = 1.0 \quad h^*_{fP} = 1.25 \quad \rho^*_{fP} = 1.25$

$\beta = [10°, 11°, \ldots, 35°]$, helix angle is varied

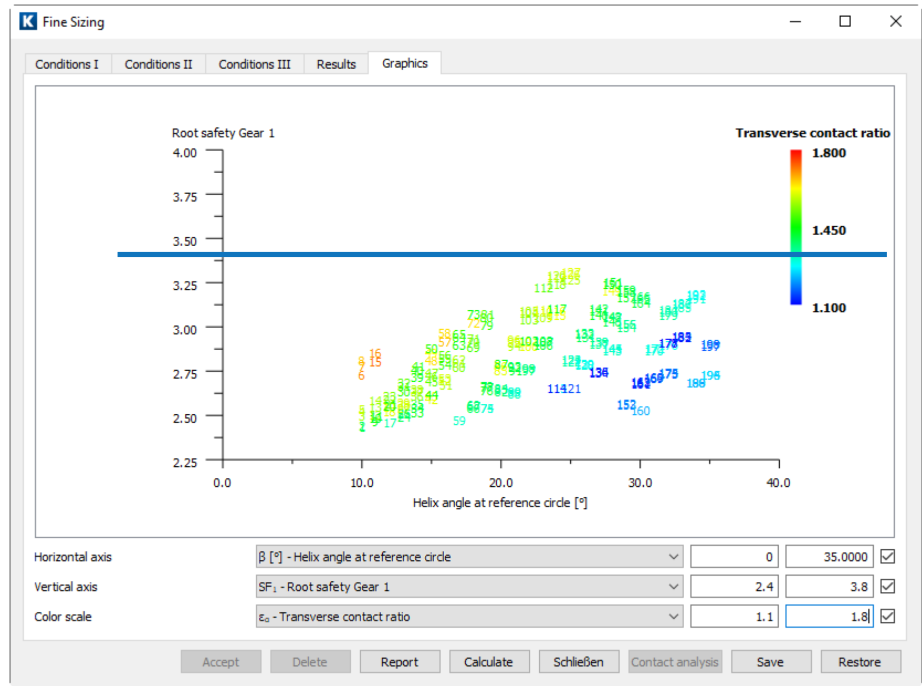
$a = 303\ mm$

$m_n = 6\ mm$

ISO 6336: 2006



ISO 6336: 2019



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Example 5

$h^*_{aP} = [1.0\,;1.1, \ldots, 1.8]$ $h^*_{fP} = 1.25$ $\rho^*_{fP} = 1.25$, addendum is varied

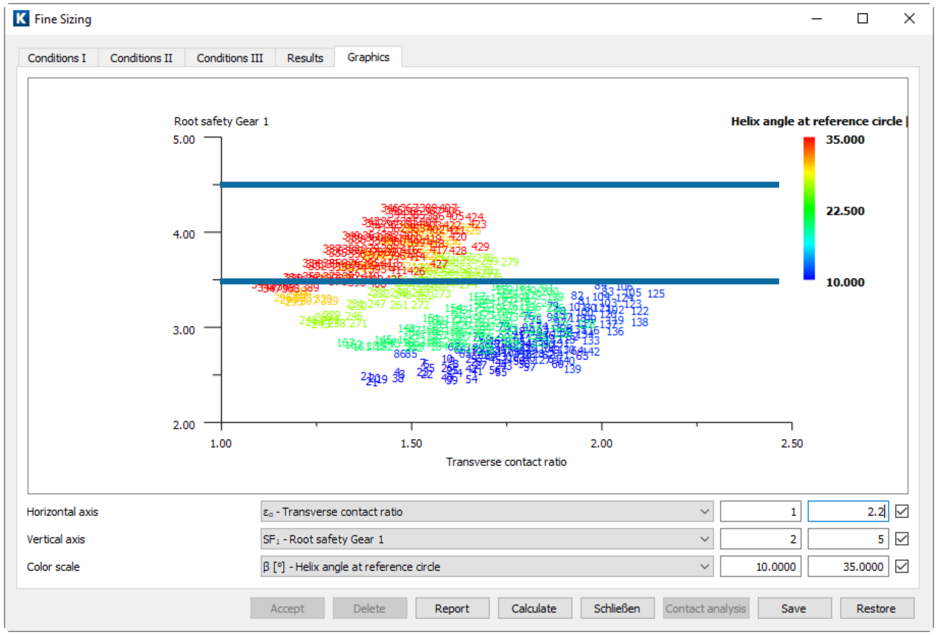
$\beta = [10°, 15°, \ldots, 35°]$, helix angle is varied

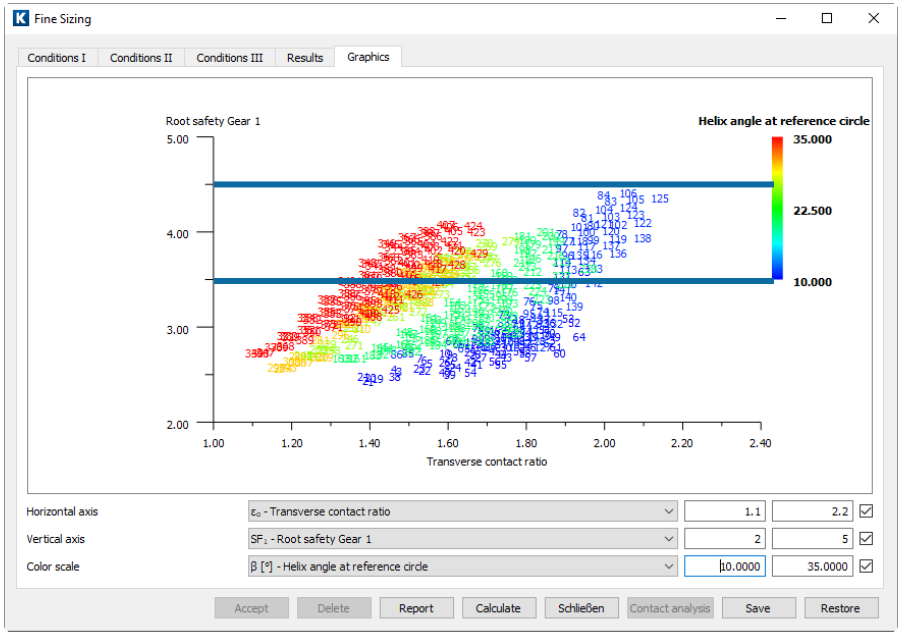
$a = 303\ mm$

$m_n = 6\ mm$

ISO 6336: 2006

ISO 6336: 2019





7. Relative notch sensitivity factor $Y_{\delta relT}$

ISO 6336: 2006

13.3.2.1.1 $Y_{\delta \mathrm{rel\,T}}$ for static stress

$Y_{\delta \mathrm{rel\,T}}$ can be calculated using Equations (50) to (54). These are consistent with the curves in Figure 11 (see ISO 6336-1:2006, Table 2, for an explanation of the abbreviations used).

a) For St with well defined yield point:

$$Y_{\delta \mathrm{rel\,T}} = \frac{1 + 0{,}93\,(Y_S - 1)\sqrt[4]{\frac{200}{\sigma_S}}}{1 + 0{,}93\sqrt[4]{\frac{200}{\sigma_S}}} \quad (50)$$

b) For St with steadily increasing elongation curve and 0,2 % proof stress, V and GGG (perl., bai.):

$$Y_{\delta \mathrm{rel\,T}} = \frac{1 + 0{,}82\,(Y_S - 1)\sqrt[4]{\frac{300}{\sigma_{0,2}}}}{1 + 0{,}82\sqrt[4]{\frac{300}{\sigma_{0,2}}}} \quad (51)$$

These values are only valid if the local stresses do not reach the yield point.

c) For Eh and IF(root) with stress up to crack initiation:

$$Y_{\delta \mathrm{rel\,T}} = 0{,}44\,Y_S + 0{,}12 \quad (52)$$

d) For NT and NV with stress up to crack initiation:

$$Y_{\delta \mathrm{rel\,T}} = 0{,}20\,Y_S + 0{,}60 \quad (53)$$

e) For GG and GGG (ferr.) with stress up to fracture limit:

$$Y_{\delta \mathrm{rel\,T}} = 1{,}0 \quad (54)$$

ISO 6336: 2019

13.3.2.2 $Y_{\delta \mathrm{rel\,T}}$ for static stress

$Y_{\delta \mathrm{rel\,T}}$ can be calculated using Formulae (78) to (83). These are consistent with the curves in Figure 13.

a) For St with well-defined yield point:

$$Y_{\delta \mathrm{rel\,T}} = \frac{1 + 0{,}93 \cdot (Y_S - 1) \cdot \sqrt[4]{\frac{200}{\sigma_S}}}{1 + 0{,}93 \cdot \sqrt[4]{\frac{200}{\sigma_S}}} \quad (78)$$

b) For St with steadily increasing elongation curve and 0,2 % proof stress, V and GGG (perl., bai.):

$$Y_{\delta \mathrm{rel\,T}} = \frac{1 + 0{,}82 \cdot (Y_S - 1) \cdot \sqrt[4]{\frac{300}{\sigma_{0,2}}}}{1 + 0{,}82 \cdot \sqrt[4]{\frac{300}{\sigma_{0,2}}}} \quad (79)$$

These values are only valid if the local stresses do not reach the yield point.

c) For Eh and IF(root) with stress up to crack initiation:

$$Y_{\delta \mathrm{rel\,T}} = 0{,}44 \cdot Y_S + 0{,}12 \quad (80)$$

d) For NT and NV with stress up to crack initiation:

$$Y_{\delta \mathrm{rel\,T}} = 0{,}20 \cdot Y_S + 0{,}60 \quad (81)$$

e) For GTS with stress up to crack initiation:

$$Y_{\delta \mathrm{rel\,T}} = 0{,}075 \cdot Y_S + 0{,}85 \quad (82)$$

f) For GG and GGG (ferr.) with stress up to fracture limit:

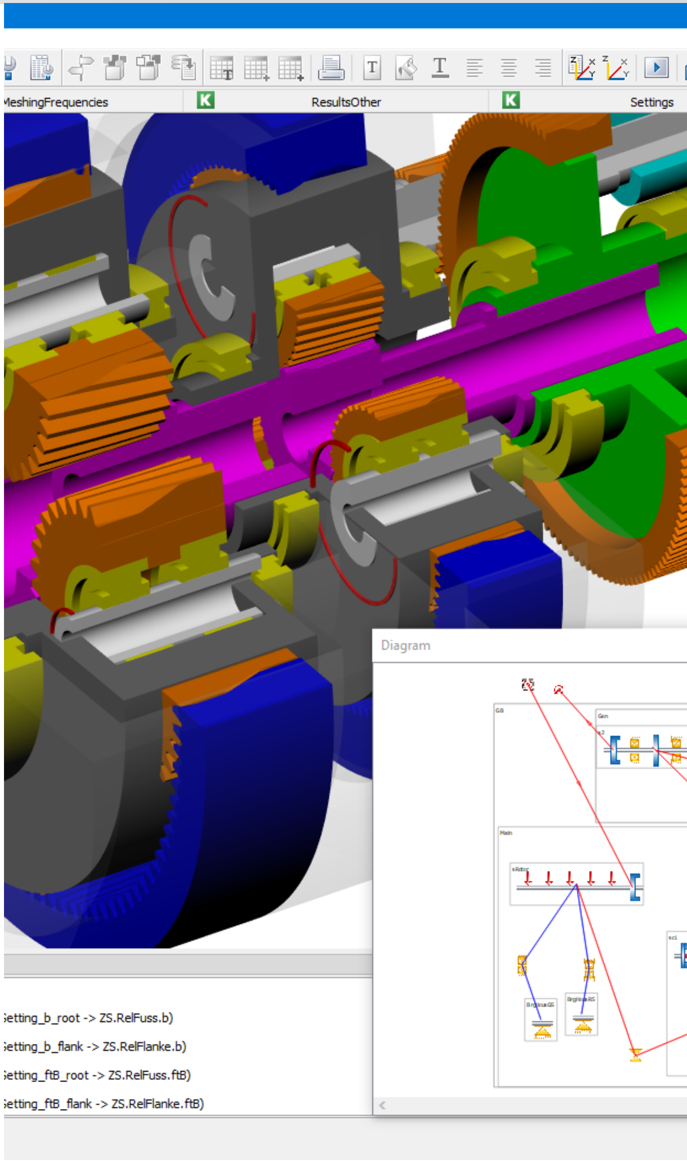
$$Y_{\delta \mathrm{rel\,T}} = 1{,}0 \quad (83)$$

Method

Four different wind turbine gearboxes were analyzed. For each stage, the cylindrical gear rating along ISO 6336:2006 and ISO 6336:2019 was performed. Resulting root and flank safety factors SF and SH are compared.

The choice of gearboxes was not systematic, and the results are therefore not to be taken as guidelines. The results illustrate that deviations can be significant. Deviations can be such that safety factors are greater or smaller when using ISO 6336:2019 compared to 2006 version.

It is recommended to use the ISO 6336:2019 method in parallel to the 2006 method to gain experience with the new standard version.



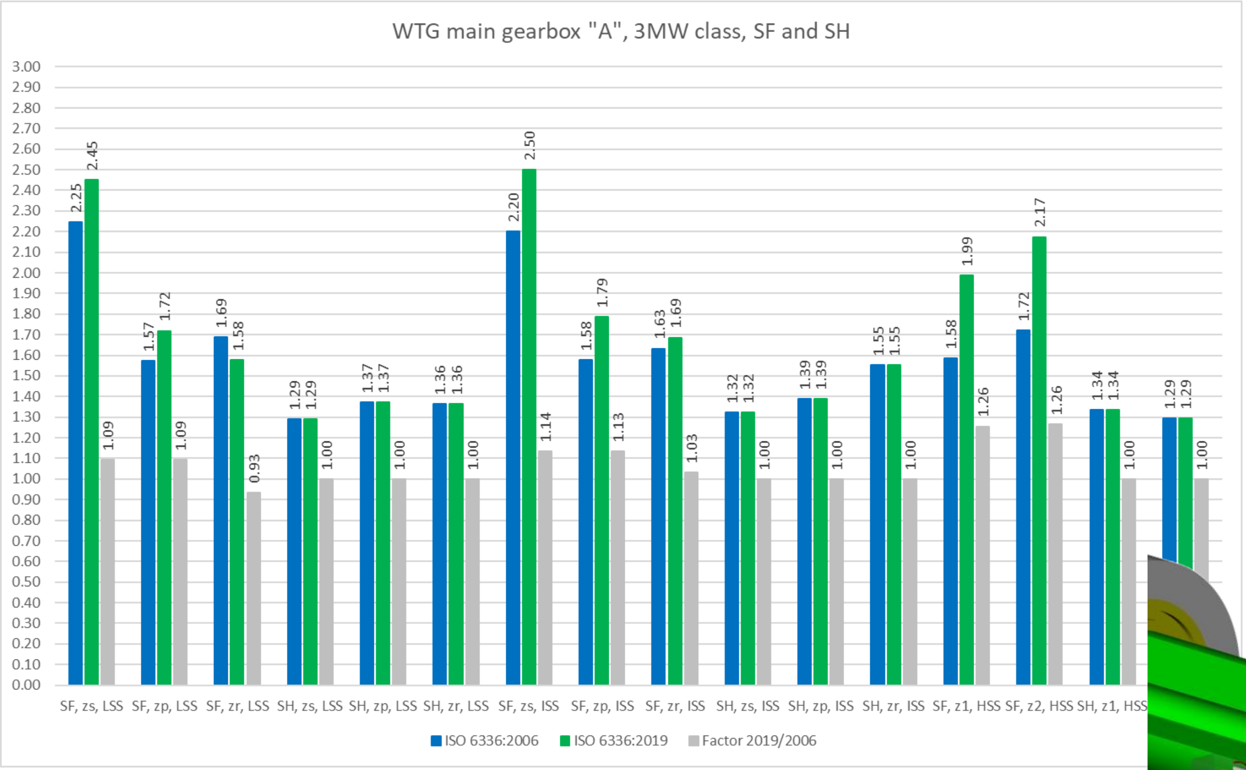
Four gearboxes A, B, C, D

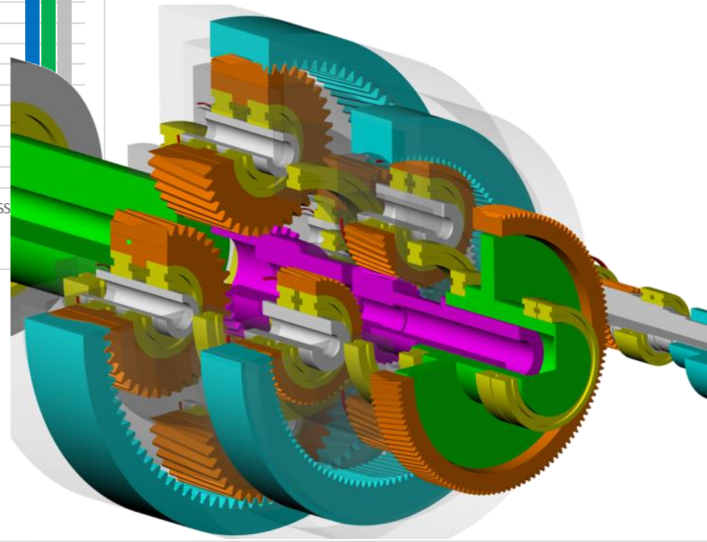
The following four gearboxes were rated along ISO 6336:2006 and ISO 6336:2019, for root and flank safety factor SF and SH

Designation	Arrangement	Power	Origin	Remarks
A	LSS=Planetary ISS=Planetary HSS=Helical	3.1 MW	European	Four planets in LSS, three planets in ISS Helical
B	LSS=Planetary ISS=Planetary HSS=none	3.0 MW	European	Four planets in LSS, three planets in ISS Helical
C	LSS=Planetary ISS=Planetary HSS=none	7.5 MW	European	Five planets in LSS, three planets in ISS Spur
D	LSS=Planetary ISS=Planetary HSS=Helical	3.3 MW	Chinese	Five planets in LSS, three planets in ISS Helical

Results, gearbox „A“

Root safety factor changes using ISO 6336:2019: +26%, -7%





LSS: low speed stage

ISS: intermediate speed stage

HSS: high speed stage

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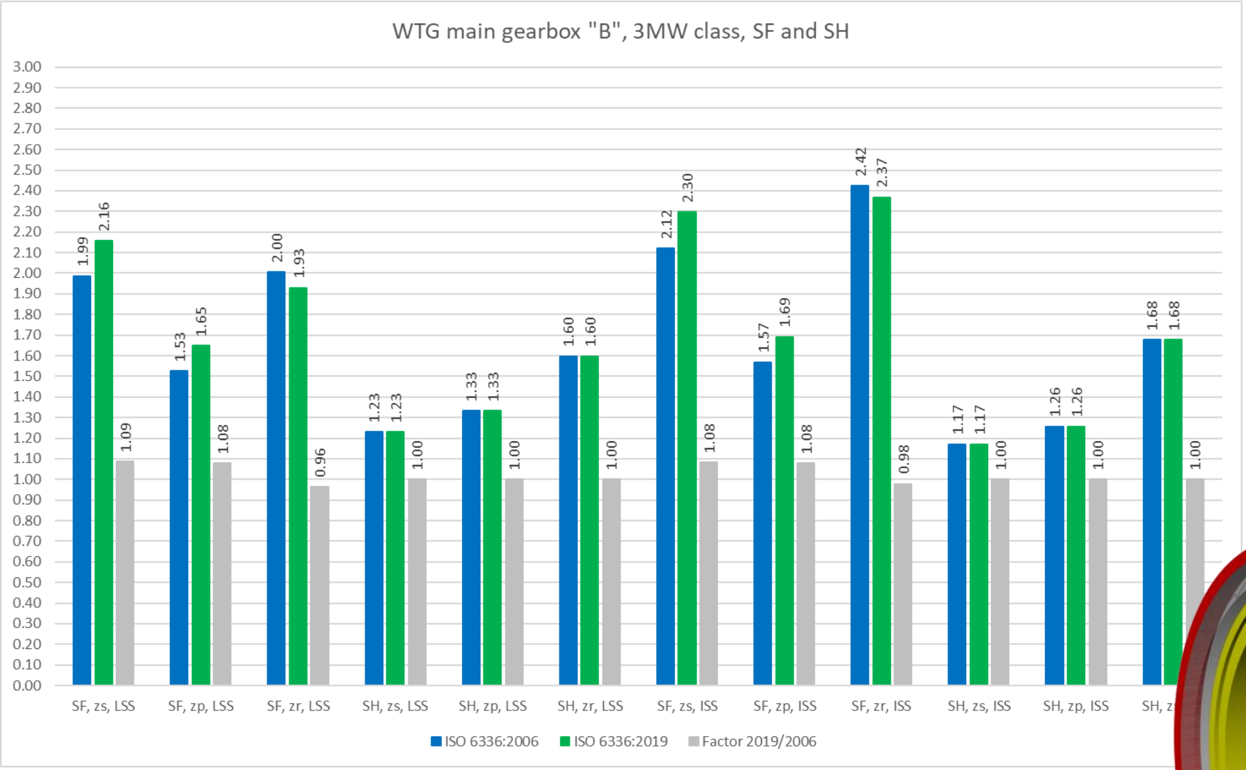
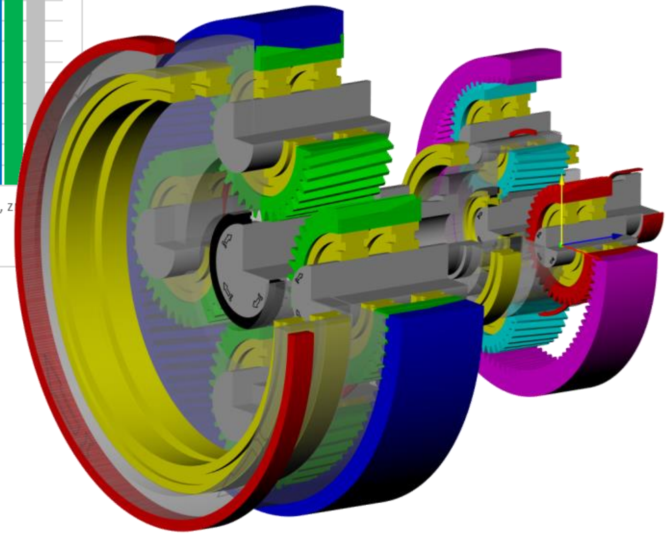
Results, gearbox „B“

Root safety factor changes using ISO 6336:2019: +9%, -4%





LSS: low speed stage

ISS: intermediate speed stage

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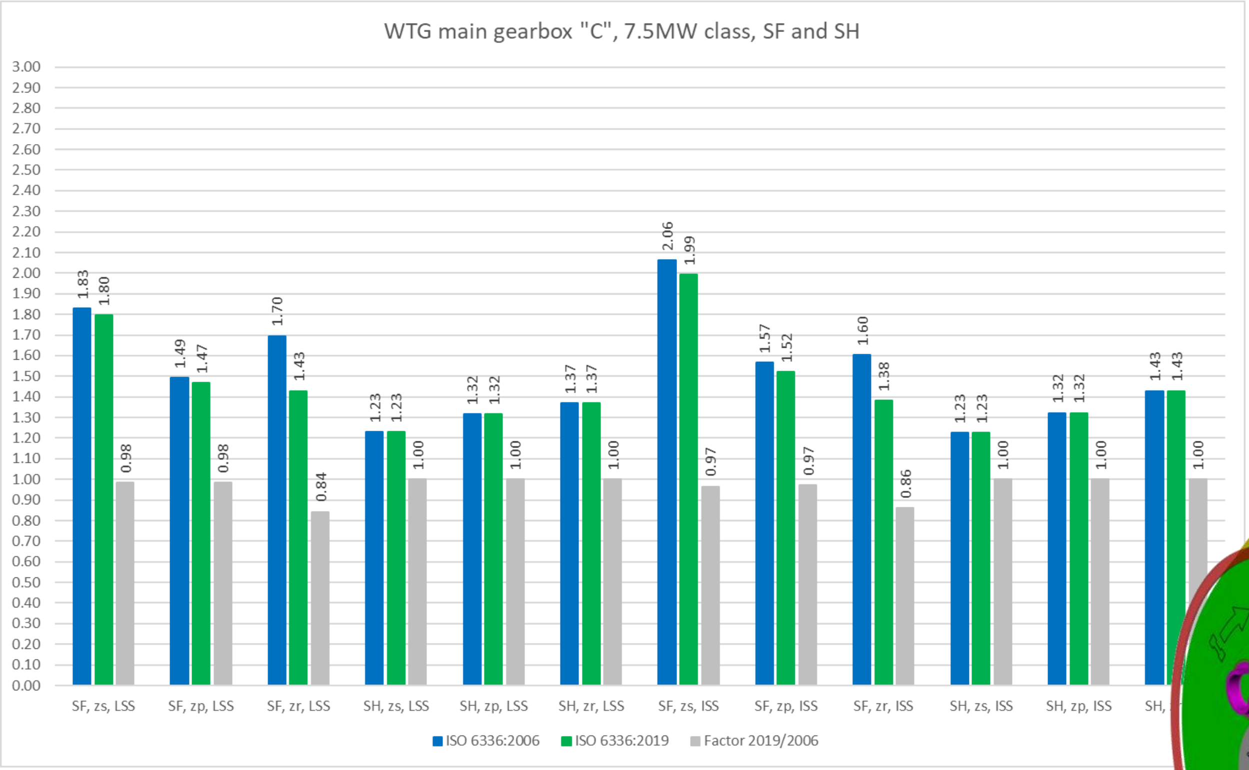
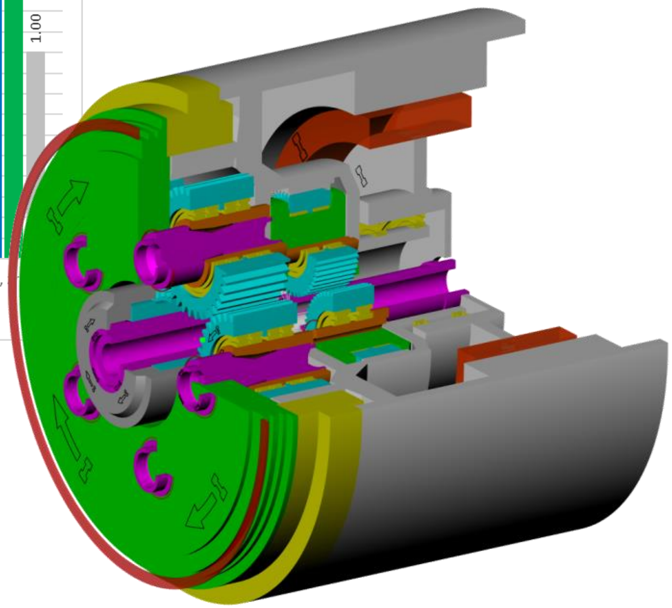
Root safety factor changes using ISO 6336:2019: +0%, -16%





LSS: low speed stage

ISS: intermediate speed stage

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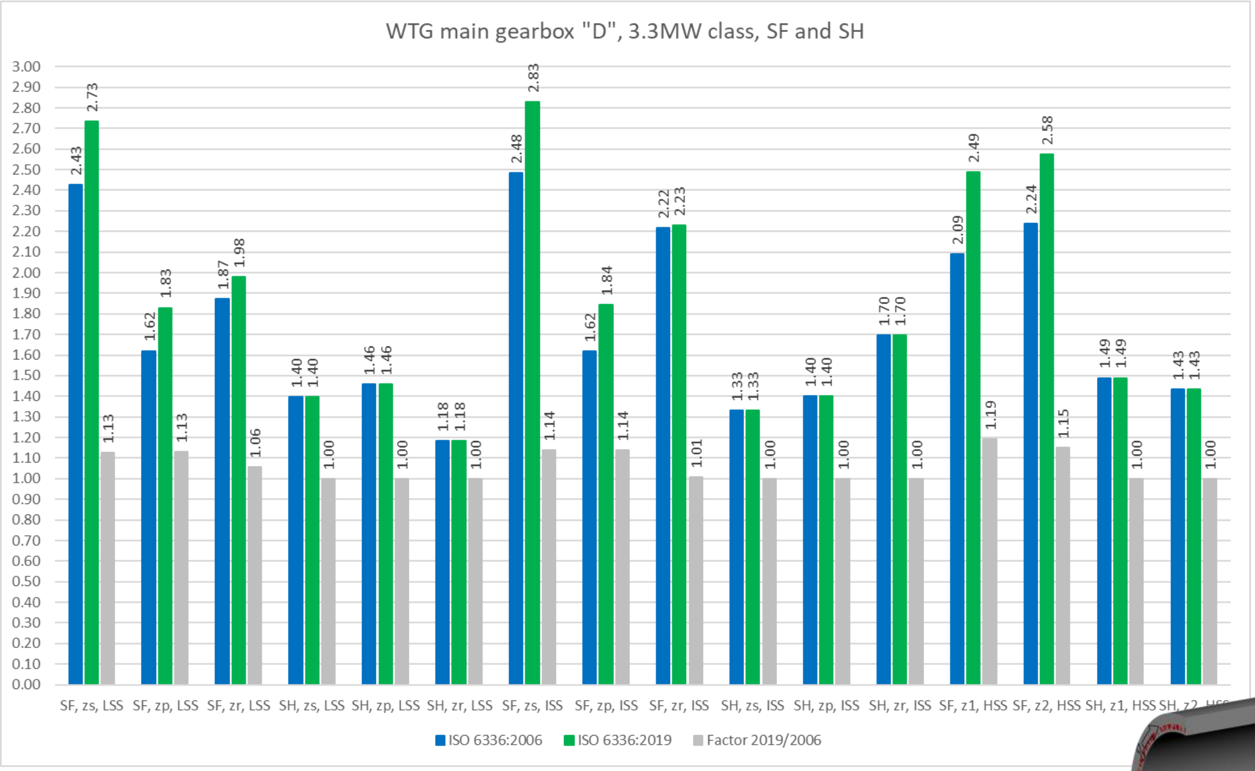
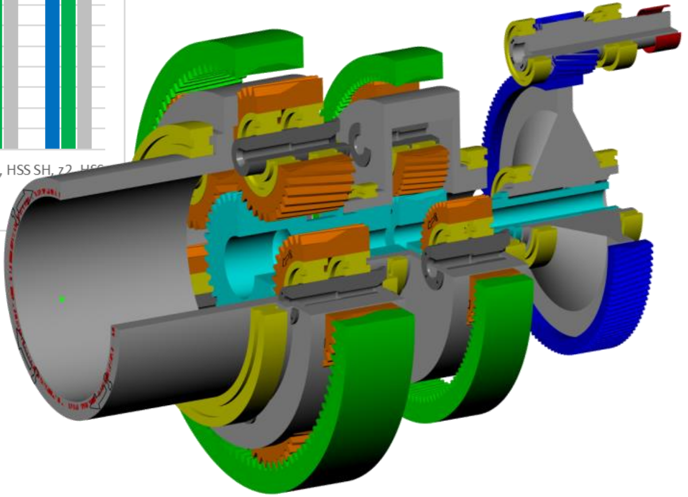
Root safety factor changes using ISO 6336:2019: +19%, -0%





LSS: low speed stage

ISS: intermediate speed stage

HSS: high speed stage

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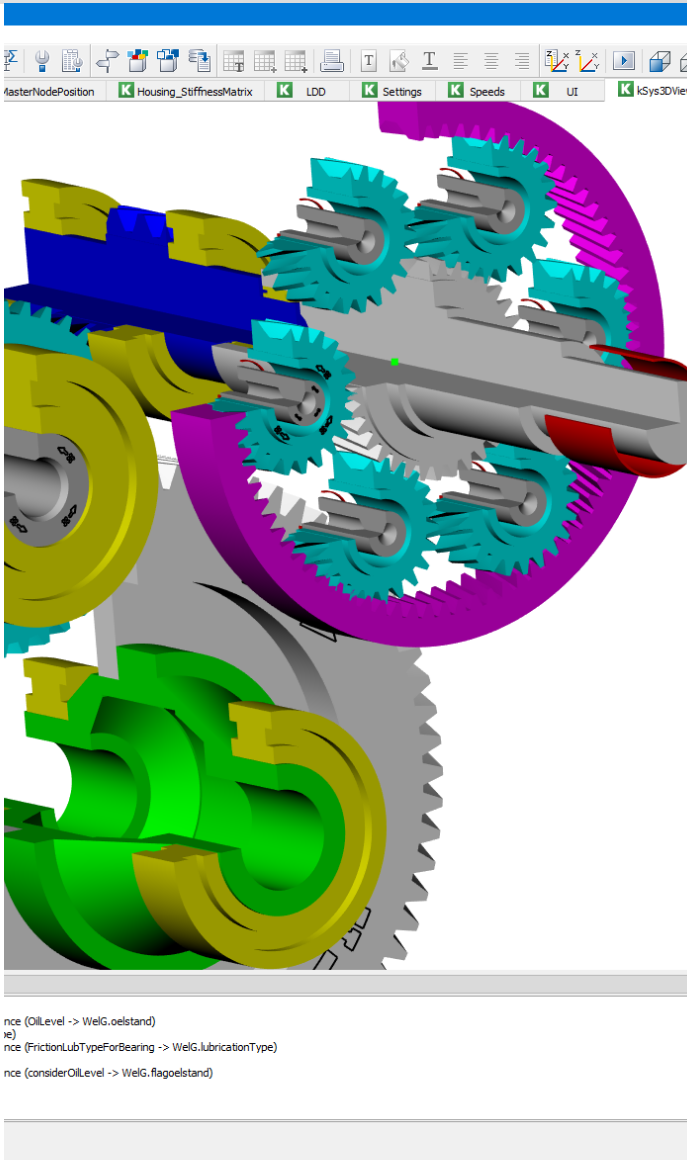
9. Application example, EV transmission

Method

The three stages of an EV transmission are rated along ISO 6336:2006 and ISO 6336:2019. Resulting root and flank safety factors SF and SH are compared.

It is recommended to use the ISO 6336:2019 method in parallel to the 2006 method to gain experience with the new standard version in the design of EV transmission since they typically use gears with high contact ratio.



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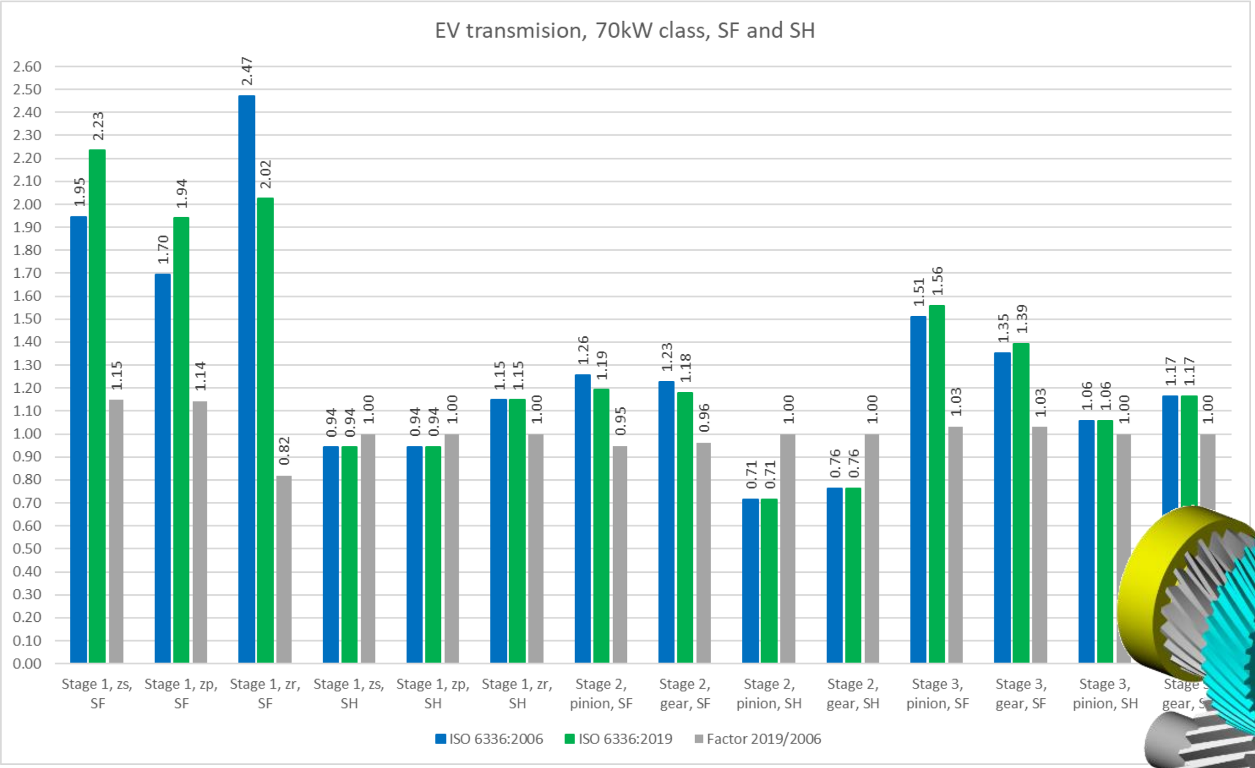
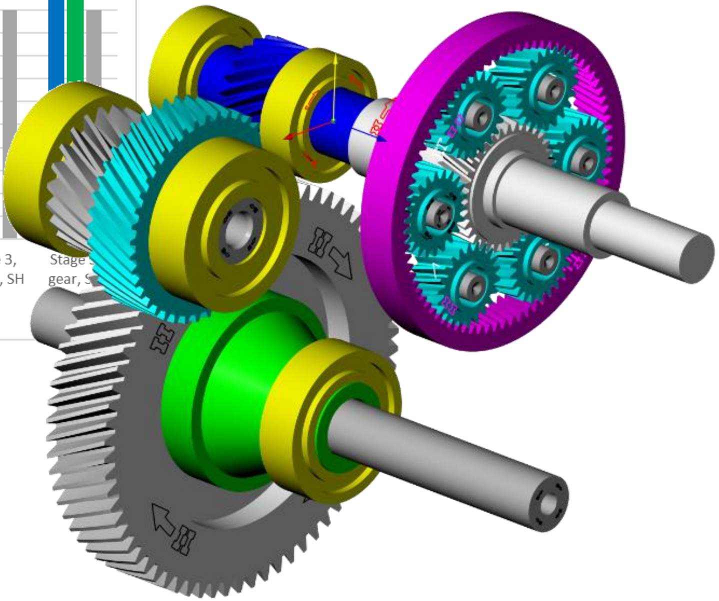
Root safety factor changes using ISO 6336:2019: +15%, -18%





Stage 1: planetary stage

Stage 2: intermediate stage

Stage 3: output stage

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Examples from ISO/TR 6336-30, compared

There are eight examples listed and solved:

Example 1: Single helical case carburized gear pair
Example 2: Single helical through-hardened gear pair
Example 3: Spur through-hardened gear pair
Example 4: Spur case carburized gear pair
Example 5: Spur gear pair with an induction hardened pinion and through-hardened cast gear
Example 6: Spur internal through-hardened gear pair
Example 7: Double helical through-hardened gear pair
Example 8: Single helical case carburized gear pair

ISO/TR 6336-30:2017(en) Calculation of loa
ISO 6336 parts 1,

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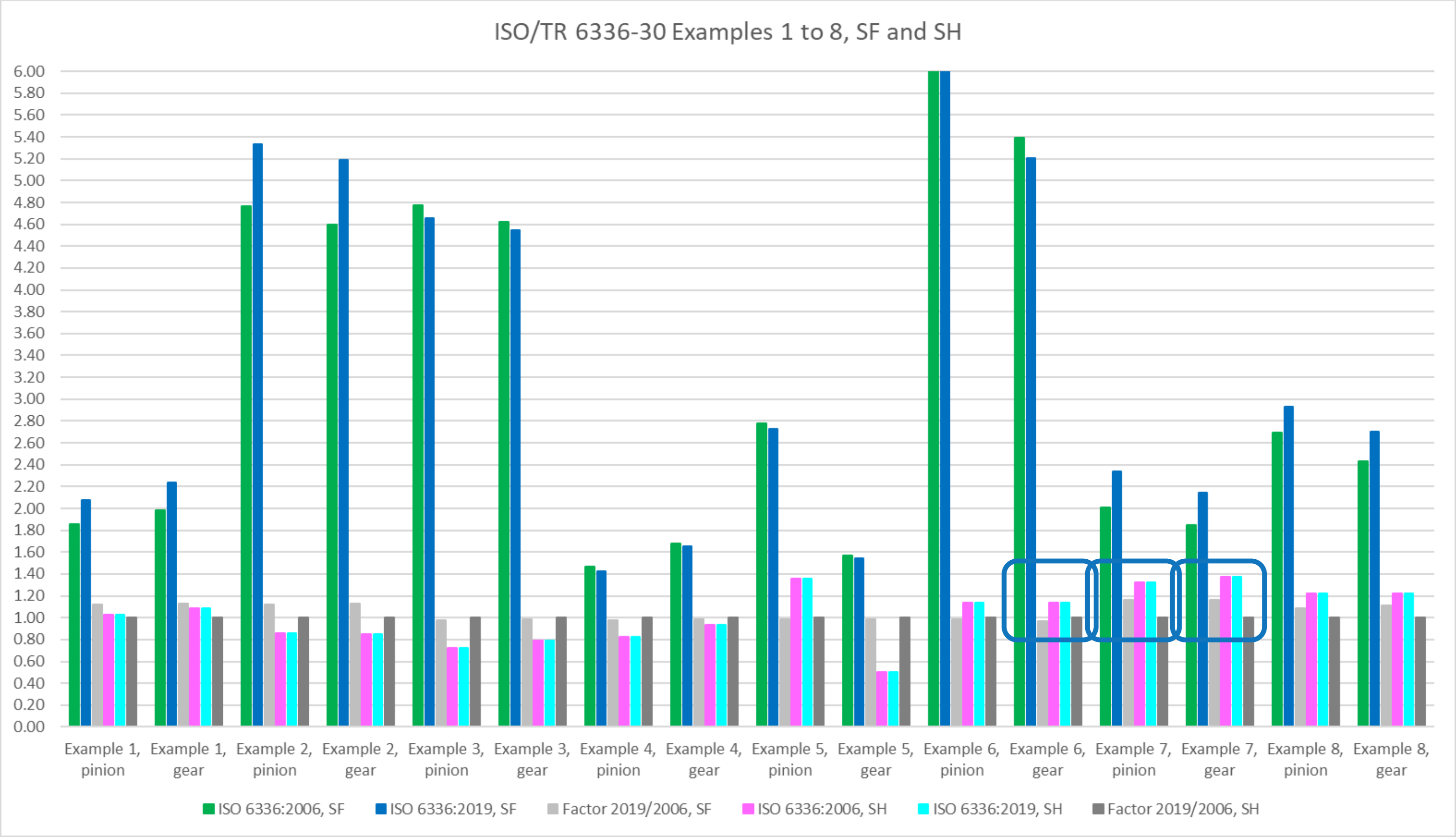
Examples from ISO/TR 6336-30, compared.

No changes in SH. SF changes by -3%, +16% (Example 6 and 7)



Thank you for your attention!

ICS › 21 › 21.200

ISO 6336-1:2019

Calculation of load capacity of spur and helical gears — Part 1: Basic principles, introduction and general influence factors

ABSTRACT

PREVIEW

This document presents the basic principles of, an introduction to, and the general influence factors for the calculation of the load capacity of spur and helical gears. Together with the other documents in the ISO 6336 series, it provides a method by which different gear designs can be compared. It is not intended to assure the performance of assembled drive gear systems. It is not intended for use by the general engineering public. Instead, it is intended for use by the experienced gear designer who is capable of selecting reasonable values for the factors in these formulae based on the knowledge of similar designs and the awareness of the effects of the items discussed.

The formulae in the ISO 6336 series are intended to establish a uniformly acceptable method for calculating the load capacity of cylindrical gears with straight or helical involute

Sharing Knowledge

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