Calculating Spur and Helical Gear Capacity with ISO 6336

Surface compressive (pitting) and tooth bending strength using ISO 6336-2; Calculation of surface durability (pitting) using ISO 6336-3; Calculation of tooth bending strength

Don McVittie

This is the third article in a series exploring the new ISO 6336 gear rating standard and its methods of calculation. The opinions expressed herein are those of the author as an individual. They do not represent the opinions of any organization of which he is a member.

Pitting strength

ISO 6336-2 shows how to calculate the maximum contact stress and the permissible contact stress. It is based on the same Hertzian surface compressive stress theory as AGMA 2001, so we should expect similar equations. The fundamental ISO contact stress equations are:

$$\sigma_H = Z_B\,\sigma_{HO}\sqrt{K_A K_V K_{H\beta} K_{H\alpha}} \le \sigma_{HP} \qquad \text{ISO6336-2...(1)}$$

$$\sigma_{HO} = Z_H Z_E Z_\varepsilon Z_\beta \sqrt{\frac{F_t}{d_1\,b}\,\frac{u+1}{u}} \qquad \text{ISO6336-2...(2)}$$

$$\sigma_{HP} = \frac{\sigma_{H\,lim} Z_{NT}}{S_{H\,min}} Z_L Z_V Z_R Z_W Z_X \qquad \text{ISO6336-2...(3)}$$

where:

σ_H is the calculated contact stress, similar to s_c in AGMA 2001.

σ_{HO} is the nominal contact stress.

σ_{HP} is the permissible contact stress.

$\sigma_{H\,lim}$ is the allowable contact stress number from ISO 6336-5, similar to s_{ac} in AGMA 2001.

The ISO 6336-2 equations look quite different at first, but they are similar to the AGMA equations. The terms Z_B, Z_H, Z_E, Z_ε, Z_β and $(u+1)/u$ serve the same purpose as the AGMA I factor. When combined, they are nearly identical to $\sqrt{I}$. The differences are:

• Z_B, which moves the calculated stress point from the pitch point to the lowest point of single tooth contact for spur gears, is not included in the nominal stress equation. Z_B is equal to 1.0 for helical gears.

• The value of Z_ε is a function of the transverse contact ratio ε_α. For spur gears it decreases the calculated stress from the AGMA value by 9% when ε_α is 1.5. There is no equivalent factor for spur gears in the AGMA standards. Z_ε is also used to interpolate between spur gears where ε_β is zero and true helical gears where ε_β is 1.0 or more.

• The value of Z_β is $\sqrt{\cos\beta}$. With Z_ε it approximates the value of F/l_{min} in the AGMA standards. The value tends to "run away" at high helix angles, so ISO

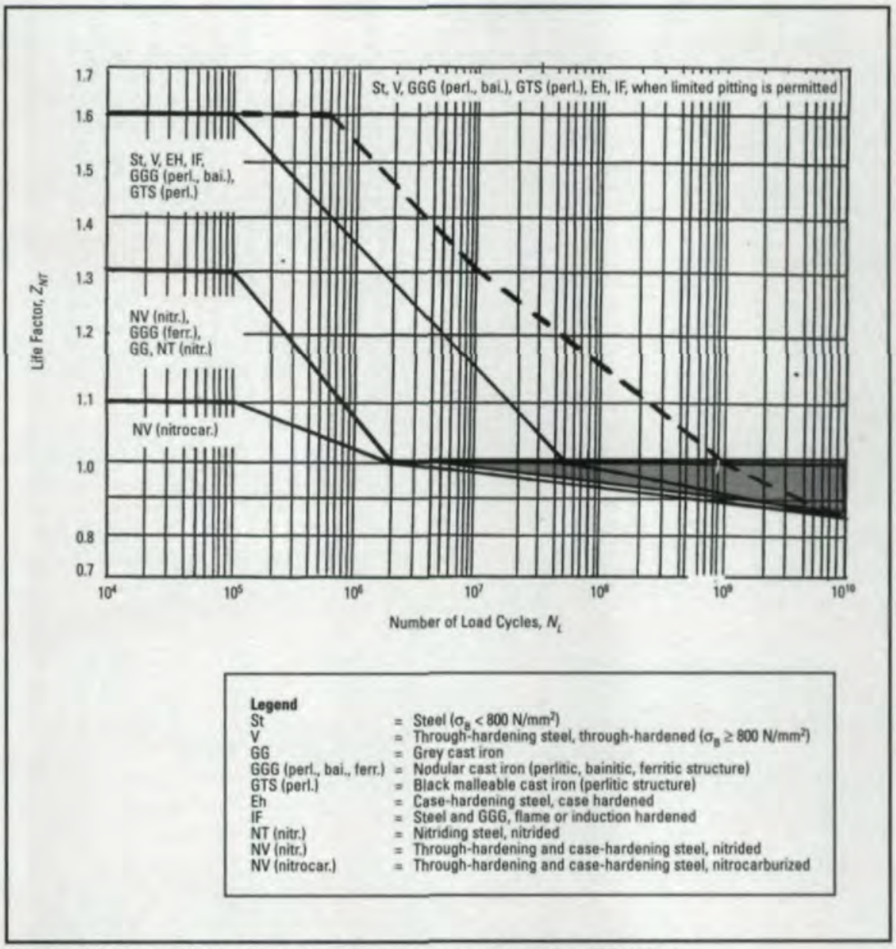


Fig. 1 — Life factor Z_{NT} for standard reference test gears, based on ISO 6336-2.

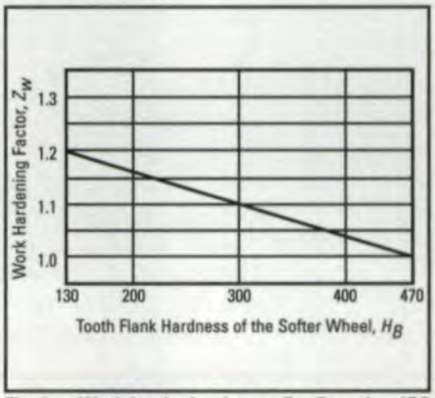


Fig. 2 — Work hardening factor, Z_W. Based on ISO 6336-2.

6336-1 suggests that users confirm their results by experience when operating helix angles exceed 30°. It is equal to 1.0 for spur gears.

The additional terms in the ISO equations are:

• K_A, K_v, etc. are the general influence factors from ISO 6336-1.

• $S_{H\ min}$ is the minimum safety factor input for contact stress.

• Z_{NT} is the life factor from Figure 1. Note that the life factors are similar to but different from AGMA practice, with a higher value if some pitting is permitted.

• Z_L, Z_v and Z_R are related influence factors accounting for the effects of lubricant viscosity, surface roughness and pitch line velocity on the permissible contact stress. Additional inputs for surface finish and lubricant viscosity are required. The combined effect of these three factors is usually less than 10% for industrial gears.

• Z_W is similar to the AGMA work hardening factor and accounts for the beneficial effect of running a harder pinion against a softer gear. Values are taken from Figure 2.

• Z_X is a size factor used to reduce the permissible stress for coarse pitch gears. It accounts for the greater possibility of encountering a material defect in the larger stressed volume of larger gears. The size factor is set to 1.0 for contact stress.

Root bending stresses

ISO 6336-3 shows how to calculate the root fillet tensile stress and the permissible bending stress. It is based on cantilever beam stress theory similar to AGMA 2001, with several significant differences:

• The point of critical stress is taken at the point on the root fillet which is tangent to an inscribed equilateral triangle, rather than the Lewis parabola. The location of this critical stress point agrees well with the other standards for "normal" gears, but diverges for gears with a small number of teeth and for gears with high operating pressure angles. ISO/TC60/SC2/WG6 has appointed an ad hoc group to study this area of the standard, but results are expected to take a few years. ISO 6336-1 suggests that users confirm their results by experience when operating pressure angles exceed 25° (Fig. 3).

• The stress concentration factors are based on strain gauge research performed on test gears at FZG[1], rather than on the photo elastic research of Dolan and Broghammer.

• The effect of the compressive component of tooth loading on the root tensile stress is ignored.

• There is no rim thickness factor similar to AGMA's K_B.

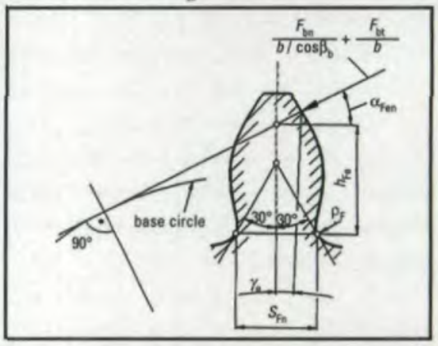
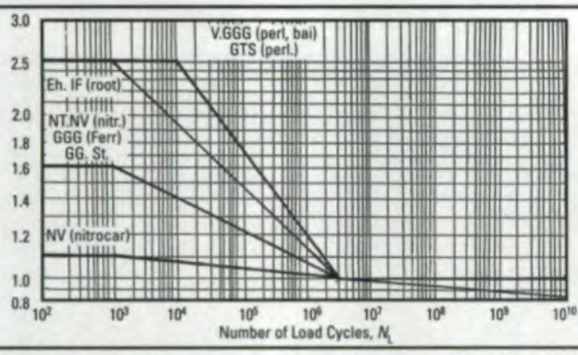


Fig. 3 — Determination of the normal chordal dimensions of the tooth root critical section for Method B. Based on ISO 6336-3.



Legend

St	= Steel (σ_B < 800 N/mm^2)
V	= Through-hardening steel, through-hardened ($\sigma_B \geq 800$ N/mm^2)
GG	= Grey cast iron
GGG (perl., bai., ferr.)	= Nodular cast iron (perlitic, bainitic, ferritic structure)
GTS (perl.)	= Black malleable cast iron (perlitic structure)
Eh	= Case-hardening steel, case hardened
IF	= Steel and GGG, flame or induction hardened
NT (nitr.)	= Nitriding steel, nitrided
NV (nitr.)	= Through-hardening and case-hardening steel, nitrided
NV (nitrocar.)	= Through-hardening and case-hardening steel, nitrocarburized

Fig. 4 — Life factor, Y_{NT}, for standard reference test gears. Based on ISO 6336-3.

The fundamental ISO root bending stress equations are:

$$\sigma_F = \sigma_{FO} K_A K_V K_{F\beta} K_{F\alpha} \leq \sigma_{FP} \qquad \text{ISO6336-3...(1)}$$

$$\sigma_{FO\text{-}B} = \frac{F_t}{b\ m_n} Y_F Y_S Y_\beta \qquad \text{ISO6336-3...(2)}$$

$$\sigma_{FP} = \frac{\sigma_{H\,lim} Y_{ST} Y_{NT}}{S_{F\,min}} Y_{\sigma\,rel\,T} Y_{P\,rel\,T} Y_X \qquad \text{ISO6336-3...(3)}$$

where:

σ_F is the calculated bending stress, similar to s_t in AGMA 2001.

$\sigma_{FO\text{-}B}$ is the nominal bending stress, The "$-B$" in the subscript indicates that method B is being used. An optional simplified method to find the geometry factors from graphs is called method C.

σ_{FP} is the permissible bending stress.

$\sigma_{F\,lim}$ is the allowable bending stress number from ISO 6336-5, similar to s_{at} in AGMA 2001. The terms Y_F, Y_S and Y_β serve the same purpose as the AGMA J factor. The values are not the same because of the differences in underlying assumptions described above.

The additional terms in the ISO equations are:

• $S_{F\,min}$ is the minimum safety factor input for bending stress.

• Y_{ST} is an experimental stress correction factor, set to 2.0.

• Y_{NT} is the life factor from Figure 4. Note that the life factors are similar to but different from AGMA practice.

• $Y_{\sigma\,rel\,T}$ and $Y_{R\,rel\,T}$ are material related influence factors which account for the effects of notch sensitivity and surface roughness on the permissible bending stress.

• Y_X is a size factor used to reduce the permissible stress for coarse pitch gears. It accounts for the greater possibility of encountering a material defect in the larger stressed volume of larger gears. The size factor is taken from Figure 5.

CORRECTION

Errors were introduced during editing to Fig. 3 of "Comparing Standards: The keys to understanding ISO 6336-1 gear rating" in the September/October 1998 issue. Below is the corrected illustration.

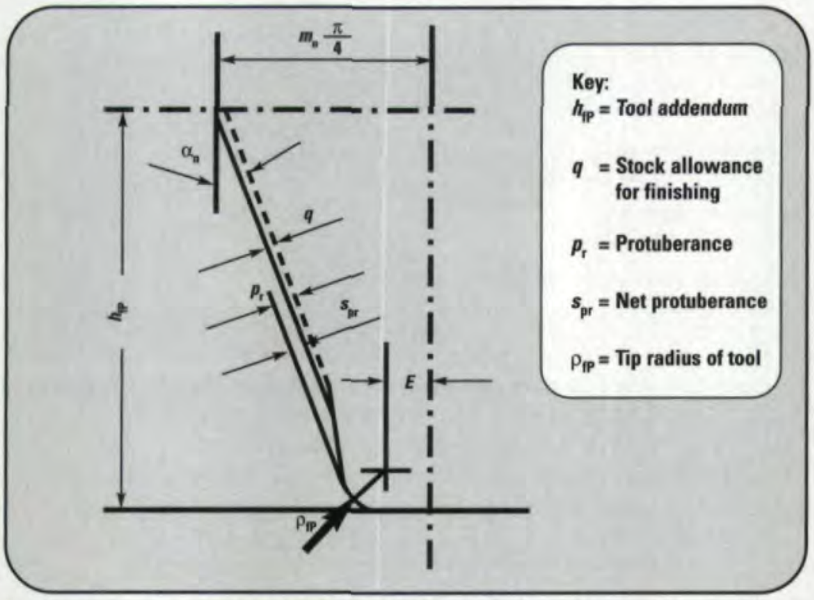
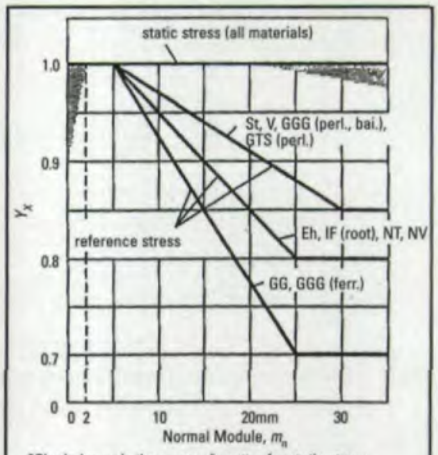


Fig. 3 — Dimensions and basic rack profile of the teeth (finished profile with undercut).



*Shaded area is the range of scatter for static stress.

Legend

St	= Steel ($\sigma_B < 800$ N/mm²)
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GG	= Grey cast iron
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Fig. 5 — Size factor, Y_X, for tooth bending strength. Based on ISO 6336-3.

The material properties to be used in these stress equations come from ISO 6336-5, *Strength and quality of materials*. The ISO material quality requirements and allowable stress levels are similar to AGMA's. The differences in material requirements will be pointed out in the last article of this series.

It is difficult to make a general comparison between the ISO and AGMA gear capacity calculation methods, since the details of the individual example can have a big effect on the results. We'll demonstrate this by comparing the calculated capacities of some actual gear sets by the ISO and AGMA methods in that article.

References:

1. Hirt, M. *Einfluβ der Zahnfuβausrundung und des Festigkeit von Geradstirnräern.* Doctorate dissertation, Technische Universität München, 1974. Also available in English translation from AGMA.

2. Brossmann, U. *Über den Einfluβ der Zahnfuβausrundung und des Schrägungswinkels auf Beanspruchung und Festigkeit schrägverzahnter Stirnräder.* Doctorate dissertation, Technische Universität München, 1979.

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