KISSsoft and Det Norske Veritas - It Figures!

Calculating the Safety of the Hardened Surface Layer

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The calculation method for cylindrical and bevel gears according to DNV [1] is a legal requirement for ocean-going ships. The method is largely identical to the method according to ISO 6336 [2], but includes some interesting additions, which are also applicable to general gear construction.

Det Norske Veritas (DNV) is a foundation, established in 1864, which creates standards, advises on risk classifications, and implements risk management systems. The foundation's purpose is to protect life, property and the environment. Among other things, it also verifies the sizing of the transmission systems used by ocean-going ships. Over the past few years, some KISSsoft users involved in ship-building have asked us whether the DNV 41.2 calculation method for calculating cylindrical and bevel gear transmissions could be integrated in KISSsoft.

Calculation method DNV 41.2 (Issue 2003) has been made public, and is freely available [1]. This method is largely based on the cylindrical gear strength calculation as specified in ISO 6336 [2] and the scuffing safety calculation according to ISO/TR 13989 [3], with some significant additions. The gear geometry corresponds to the ISO standards (ISO 21771 for cylindrical gears, and ISO 23509 for bevel gears).

Special S-N curves (Woehler lines) occurring in materials used in marine transmissions

For some material types (such as case hardening steel), the S-N curves (Woehler lines) specified in DNV 41.2 vary somewhat from the ISO standard. In the static range, the permitted flank pressure characteristic values are higher. This affects the range below $10^5$ load cycles, and can have an effect on the results of load spectra. In the range of endurance limit, the permitted strength may be reduced by 8%, depending on material quality. According to ISO 6336, this reduction is greater (15%). An option for performing strength calculation with measured S-N curves (Woehler lines) has been programmed in KISSsoft. This functionality is used to represent the special Woehler lines (S-N curves) according to DNV.

For the tooth root strength of case-hardened materials, the DNV regulation also requires the use of a case-hardening depth factor $Y_C$ (“case depth factor”), which considerably reduces the permitted strength in the tooth root if low case depth factor values are present. This is another useful addition to the calculation.

As a consequence, overall, a variety of differences to ISO 6336 result in the permitted material strength values – especially for case-hardened steels (Figure 1).
Calculating the Safety of the Hardened Surface Layer

For surface-hardened gears, the safety of the hardened layer against fatigue (endurance limit) and deformation (static strength) must also be proved. This is a simple calculation rule which is described using some equations that are derived from the shearing stress progression at depth when Hertzian pressure is present. Essentially, this calculation rule is used to check whether the hardening depth to be achieved by quench hardening is sufficient.

To do so, the gear unit designer is given a calculation rule with which they can verify the hardening depth they wish to specify. This is not governed by any specific rules in ISO 6336 (or DIN 3990): it is simply "expected" that the hardness and depth of the surface layer will be sized correctly. For this reason, the hardened surface layer calculation according to DNV is now performed in KISSsoft, if the ISO 6336 or DIN 3990 method is used. According to ISO or DIN there is no requirement to provide a proof of the surface layer safety, but it is a good indicator for the hardening depth that is to be specified.

Verifying the "hard surface layer", and examining the transitional zone between the surface layer and core structure, is currently an extremely hot topic. The ISO technical committee that manages the ISO 6336 standard, decided just this year to develop a method for calculating the tooth flank breaking value. Different investigations have been carried out in Germany in the last few years, for this purpose [5]. The complex calculation method for flank breaking is nothing to do with the simple rule according to DNV 41.2, but does
also concern the type and progression of the hardening depth. However, until an appropriate standard has been developed and made available, the current DNV method definitely has its practical uses.

In KISSsoft the recommended hardness curve (for safety 1.0) at depth can be represented, on the basis of the DNV rule (Figure 2).

![Figure 2. Representation of the recommended hardness curve and the shear stress, converted to a Vickers hardness value.](image)

- shear stress progression in the pitch point, calculated from the Hertzian pressure under continuous torque
- recommended hardness curve according to DNV for deformation (for safety 1.00)
- recommended hardness curve according to DNV for the endurance limit (for safety 1.00)
- crosses: entered hardness values (input data, see Figure 3)

To achieve a calculation that is as accurate as possible, it is recommended that you enter the hardening depth values for HV 550, HV 400 and HV 300, if known. In the case of case-hardened steels, it is only necessary to enter the hardening depth 550, or the hardening depth 400 for nitrided steels (Figure 3). The result of the calculation of the safety of the hard layer indicates whether the hardening depth is sufficient (safety verification fulfilled). If problems occur, the calculation results indicate whether the surface hardness is too low or the hardening depth is too shallow. The hardening depth can also be too deep: it should not be more than \( \frac{1}{4} \) of the tooth thickness at the tip, to avoid through hardening. The specified hardness on the surface is also verified.
Changes to DNV 41.2 between Issue 2003 and Issue 2012

In 2012 a new issue of the DNV rule was released. The only difference to the previous issue (2003) concerned the helix angle coefficient $Z_\beta$. Measurements performed at the FZG (Forschungsstelle für Zahnräder und Getriebebau - research establishment for gears and transmission production) in Munich, Germany showed that the tooth root stresses on helical gears are considerably higher than previously assumed. For this reason, the $Z_\beta$ coefficient was massively decreased in a correction to ISO 6336-2 [4]. This was added to the 2012 issue of the DNV 41.2 standard.

Outlook and summary

The DNV standard is a reference standard for marine applications and is very widely used in practice. Because of the extensive calculation methods against different risks of damage it contains, it is an interesting guideline, since certification according to DNV guarantees that the calculation has been verified and complied with according to different criteria. In KISSsoft, this calculation can be used in combination with the typical sizing tools, and can be applied to entire drive trains in a simple and efficient way, with KISSsys.