Correlation between Component Fatigue Performance and Results from Plane Bending Fatigue Tests on Notched Samples

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Abstract

A comparative study is made on root bending fatigue performance of spur gears and plane bending fatigue performance of notched test bars. R = 0 root bending fatigue tests are made on small spur gears with critical root radius 1.0 mm. The results are compared to plane bending fatigue tests of 0.9 mm radius notched specimens. Results are presented for tests on 4%Ni/2%Cu/1.5%Mo prealloyed PM steel with addition of about 0.6% graphite. Predicted values from the test bars coincide well with the results obtained from the gear root fatigue tests.

Keywords : P/M, fatigue, plane bending, gear tooth, notch, load ratio

1. Introduction

Extensive data on fatigue performance of PM steels are available today. However, most data are obtained for un-notched test bars at load ratio R = -1. Stress calculation of high loaded PM parts reveals highest stresses in the notches and the load ratio is normally closer to R = 0 than R = -1. The fatigue performance at pulsating load is typically 75% of the values obtained at alternate load. However, these values are obtained for un-notched test bars. Resent tests show that the fatigue limit ratio between pulsating and alternating loaded PM steels with heterogeneous microstructures is about 60-65% for 0.25mm and 0.9 mm notched test bars. A straightforward design calculation without considering this difference would reveal under-dimensioned components.

The comparison between tests on components and on test bars implies comparison between calculated stresses. Ideally, FEM calculations should be used to calculate the root bending stresses in the spur gear. The stresses are, however, here calculated from the ISO 6336 [1] standard that gives a slightly conservative result (the calculated stress level is slightly higher compared to FEM).

2. Experiments

The geometry of the HB-spur gear (thickness b = 10mm) and loading is presented in detail in Fig. 1.

The cyclic constant amplitude tests of the spur gears are made in a load-control servo-hydraulic test rig with a frequency of 25 Hz. The run-out limit for the tests is 3 million cycles.

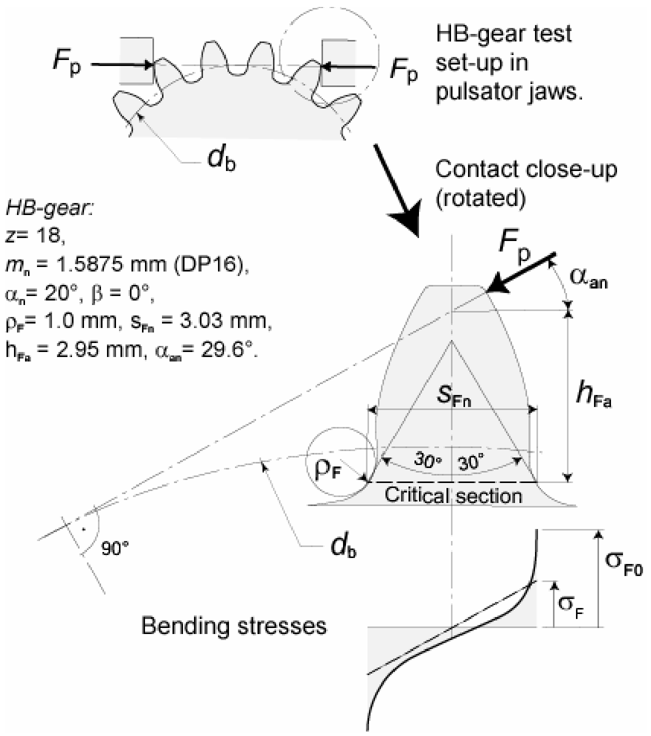

Fig. 1. Loading, dimension and stress distribution in HB spur gear.

The root bending nominal stress in the critical section is calculated according to ISO 6336 method C for tip contact:

$$\sigma_F = \frac{F_p \cdot \cos\alpha_{an} \cdot h_{fa}}{W_{ba}} \quad \textbf{Eq. 1}$$

where W_{ba} is the bending modulus $W_{ba} = \frac{b \cdot s_{Fn}^2}{6}$.

Compressive stresses are also obtained in the critical plane. The combined effect of compressive stresses and stress concentration is revealed from the ISO 6336 stress concentration factor Y_{Sa}, see also the principal stress distribution in Fig. 1:

$$\sigma_{Fa} = \sigma_F \cdot Y_{Sa} \qquad \textbf{Eq. 2}$$

The stress concentration factor for gear root bending is obtained from the ISO 6336 to $Y_{Sa} = 1.50$.

The un-notched and notched test bar geometries are presented in Fig. 2 [2]

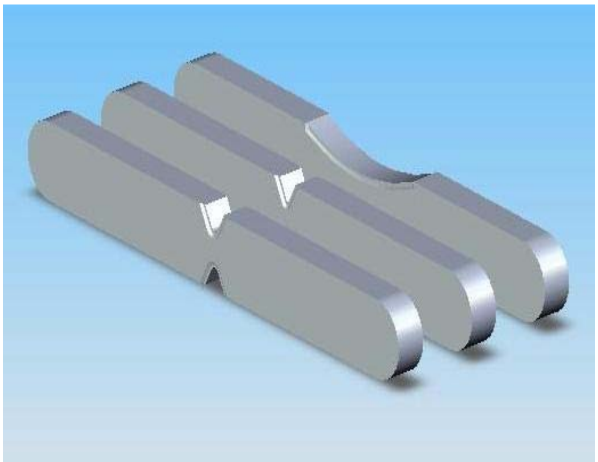

Fig. 2. 0.9mm, 0.2mm and un-notched test bars with chamfered corners.

The theoretical stress concentration factors is K_t=1.79 for the 0.9mm test bar.

Test on spur gears and un-notched and notched test bars have been performed on 4%Ni/2%Cu/1.5%Mo diffusion-alloyed PM steel (DistaloyHP-1) with addition of 0.6% graphite. Sintering is made at 1120^{o}C for 30 min. in 90%/10% N_2/H_2 with approximate cooling rate 0.8^{o}C/sec. The spur gear investigation includes full S-N curve tests on five stress levels with three run-outs at 3 million cycles.

3. Results

The gear root bending tests revealed run-outs at maximum force F_p = 2.0 kN. The calculated maximum tensile stress obtained from Eq. 1 – Eq. 2 is σ_{Fa} = 501 MPa.

The nominal stress fatigue limit of 0.9mm notched test bars is 140 MPa at load ratio R=0. The maximum theoretical tensile stress in the notch root is $\sigma_{tb} = K_t \cdot 2 \cdot \sigma_{ampl} = 1.79 \cdot 2 \cdot 140$ = 502 MPa.

4. Summary

A comparative study is made on on the fatigue performance of HB spur gears and plane bending fatigue performance of notched test bars in 4%Ni/2%Cu/1.5%Mo diffusion-alloyed PM steel with addition of 0.6% graphite. The notch radius of the spur gear is 1.0 mm and 0.9mm for the test bars. All tests are performed at pulsating load, i.e. load ratio R=0 that is the relevant load case for spur gears loaded in one direction only. The theoretical maximum stress at the fatigue limit is close to 500 MPa for both the spur gear and the test bars. It is, however, most likely that the apparent close results not reveals a high precision in the test method and stress analysis as the spur gear analysis is known to be conservative and also considering the relatively small number of tested gears.

The results stress the importance to base the calculations on performance data obtained at the same loading conditions and notch radius as the real component.

4. References

[1] ISO 6336, Calculation of load capacity of spur and helical gears, 1996.

[2] A. Bergmark, J. Andersson and S. Bengtsson *Chromium pre-alloyed PM Steel for high structural performance***.** Euro PM2005 proceedings Vol.1, pp 157-162 EPMA 2005