USING THE ANALYTICAL STRENGHT ASSESSMENT OF THE FKM GUIDELINE FOR BRONZE MATERIALS

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1. Introduction

The challenge was to calculate the tooth root strength of worm wheels [1]. This is important for a better prediction of cracks (**Fig. 1**). To use local stresses is a suitable way in comparison with rated stresses, especially in the case of complex shaped components.

Fig. 4: tooth with cracks at the tooth root notch

The local stresses can be identified due to FEA calculations [2]. To evaluate the local stresses, the FKM guideline [3] is an appropriate tool. Currently, the FKM guideline is only valid for steel and aluminium materials. Within a research project the usability of the FKM guideline for bronze materials could be shown. As shown in **Fig. 2**, a lot of experiments on specimens up to complete worm gears and finite element analyses were realized.

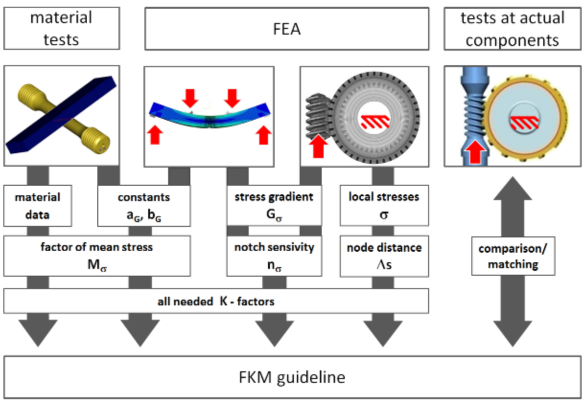

Fig. 5: adaption and validation of the FKM guideline

2. Calculation process

The calculation process followed the FKM guideline and is based on the determination of a degree of utilization. It was ascertained by comparison the bearable stress σ_{AK} with the present stress. The bearable stress is evaluated on the basis of tensile strength, geometrical and material parameters. The parameters of the calculation process are shown in **Fig. 3**.

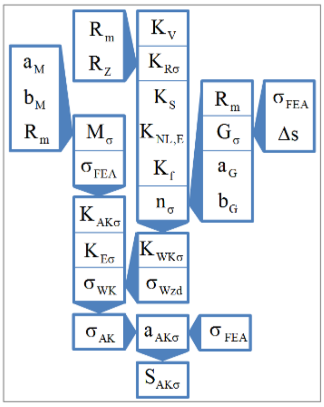

Fig. 6: schedule of the calculation

The central problem was to determine the factors which depend on material: the constants a_G an b_G to calculate the notch sensitivity n_σ and the constants a_M an b_M to identify the factor for mean stress M_σ. Another important step was to ascertain the contributory factors, which were needed for the calculation (Fig. 3, [3]).

3. Determining bronze parameters

To determine the notch sensitivity n_σ (3.01) for $0.1<G_\sigma<1$, the two factors a_G and b_G for bronze material and the stress gradient G_σ were needed. G_σ was predictable with parameters from the FEA.

$$n_\sigma = 1 + \sqrt{G_\sigma \cdot mm} \cdot 10^{-\left(a_G + \frac{R_m}{b_G \cdot MPa}\right)} \quad (3.01)$$

In order to calculate a_G and b_G, the notch factor K_f was identified for a special notch geometry by four point bending tests [5] on notched test specimens (**Fig. 4**). The form factor K_t was determined with the help of the FKM Guideline according to [3].

These two factors permit the calculation of n_σ out of tests according to equation (3.02).

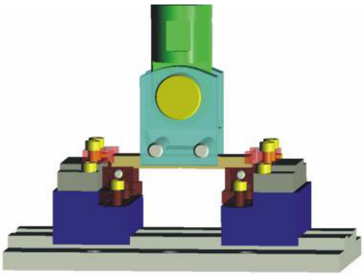

Fig. 7: test setup with specimen for four-point-bending tests

$$K_f = \frac{K_t}{n_\sigma} \tag{3.02}$$

With the n_σ, a determination of a_G and b_G was possible. These two parameters (**Table 1**) are valid for the material CuSn12Ni.

Table 1: parameters a_G an b_G

a_G	0.05
b_G	1050

The consideration of the mean stress factor M_σ depends on material and describes the dependency of the amplitude of fatigue strength of the component and the mean stress. To determine M_σ (3.03), the material constants a_M and b_M were needed.

$$M_\sigma = a_M \cdot 0.001 \cdot \frac{R_m}{MPa} + b_M \tag{3.03}$$

These two constants were reversely specified with the help of the mean stress factor $K_{AK\sigma}$ (3.04). It´s possible to evaluate this factor out of the pulsating bending strength σ_{AK} (out of own bending tests) and alternating bending strength σ_{WK} [4], whereas for the bronze material CuSn12Ni, σ_{AK}=280 MPa and σ_{WK}=140 MPa. The factor to take account of residual stresses $K_{E\sigma}$ was according to the FKM Guideline set to 1.

$$K_{AK\sigma} = \frac{\sigma_{AK}}{\sigma_{WK} \cdot K_{E\sigma}} \tag{3.04}$$

$$K_{AK\sigma} = \frac{\frac{1+M_\sigma/3}{1+M_\sigma}}{1+\frac{M_\sigma}{3}\cdot\frac{\sigma_m}{\sigma_a}} \tag{3.05}$$

$$\sigma_a = \frac{1}{2}\cdot(\sigma_{max} - \sigma_{min}) \tag{3.06}$$

With the value of $K_{AK\sigma}$ and the equation (3.05), M_σ was developed in an iterative process. The mean stress σ_m and stress amplitude σ_a were taken from the four-point-bending-tests, whereas σ_a was determined with equation (3.06).

With the known M_σ the parameters a_M and b_M, for bronze materials (**Table 2**) are identified with the equation (3.03).

Table 2: a_M and b_M for bronze materials

a_M	0.268
b_M	-0.05

For the reason of the unknown tension-compression fatigue stress, σ_{Wzd} (3.07) was specified out of the tensile strength R_m and the tension-compression fatigue stress factor $f_{W\sigma}$, which is recommended agreeing with the guideline using a value of 0.3.

$$\sigma_{Wzd} = f_{W\sigma} \cdot R_m \tag{3.07}$$

All other required factors, especially the K-factors were determined according to the guideline. Especially the factor $K_{NL,E}$, who serve the non-linear elastic of the stress-strain behaviour and depends on material was determined for the considered bronze material by comparing with component tests.

$$K_{NL,E}(CuSn12Ni) = 1.7$$

4. Validation of results

The comparison of the simulated worm gears had revealed a good correlation as well as the matching with the fatigue tests with real worm gears.

Based on these results the FKM guideline is possibly applicable for bronze materials. To ensure the results, further additional tests will be advantageous.

References

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[5] DIN EN 843-1: Hochleistungskeramik, Bestimmung der Biegefestigkeit, 2006