Influence of the Residual Stress State on Sub-Surface Initiated Fatigue Failures in Gears

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ABSTRACT

Power transmitting gears typically are heat treated, most often case hardened, to improve the fatigue strength and therefore to ensure higher fatigue life. The heat treatment causes higher hardness in the surface area and in addition compressive residual stresses in the case hardened layer. The near surface compressive residual stresses are compensated by tensile stresses in higher depths of the gear volume.

Pitting and tooth root breakage are the most common failure modes of gears, which are well researched and are addressed also in ISO 6336 [1]. The assessment of these failures provides the basis for the dimensioning of gears in the design phase. However, subsurface initiated failures, like tooth flank fracture (TFF), can also appear at loads below the allowable level of loading for pitting and tooth root bending. TFF is a fatigue damage with crack initiation in the region of the transition between compressive and tensile residual stresses and usually leads to a total loss of drive.

The existing theoretical calculation models for fatigue strength of gears with regard to TFF consider residual stresses differently. The base of the investigated calculation models is a local comparison of the occurring stresses and the strength value in the gear volume. The outcome of the calculation model from Oster [6] is highly influenced by the residual stress state. However, the material-physically model by Hertter [3] is more tolerant to slightly varying residual stresses. Further approaches such as Weber [7] and Konowalcyk [4] are based on the ideas of Oster and Hertter.

The verification of the models is complicated due to the lack of residual stress measurements in larger depths under the gear flank surface. For example, residual stress measurement by x-ray diffraction is only possible up to depths of approximately one millimeter. Therefore tensile residual stresses in the inner tooth volume are considered zero in the common residual stresses calculation of Lang [5] and not considered in the current calculation approach of ISO/DTS 6336-4 [2].

The paper describes the most important existing calculation approaches for the fatigue strength of gears with different consideration of residual stress states and compares them to a variety of experimental results. Hereby the failure mode TFF is the keynote. Furthermore, it presents a proposition on how to consider also tensile residual stresses in the different calculation approaches.

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