Experimental and computational evaluation of rolling bearing steel durability

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Abstract. Rolling element bearings are widely-used machine components and their failure can result in damage to the whole machine. A bearing failure can be caused by many factors. In most cases it is damage on the raceway surface as a result of rolling contact fatigue (RCF). This article describes the fatigue analysis consists of determining service-life of a roller bearing using a stress-strain analysis with finite element method and subsequent numeric calculation using software fe-safe with application of multiaxial fatigue criterion. These theoretical results are compared to the experiments carried out on AXMAT test-rig with more accurate defect detection using acoustic emission method. Numerical service-life calculation can be applied as tool for fatigue life prediction of full scale bearing with sufficient correlation with experimental results.

1 Introduction

Nowadays it is known several approaches for prediction of service life of machine parts. One of approaches on the highest level is computational modelling using multiaxial fatigue criteria (MFC). There are a lot of different MFC which are divided to several categories. Usually they differ to criteria used for low-cycle fatigue (strain-based criteria, energy-based criteria) and high-cycle fatigue (stress-based criteria). Machine parts like roller bearings, gears or train wheels are exposed to limit state which is called roller contact fatigue (RCF). If there are repeating contacts of objects, RCF is reached. The crack initiates in a subsurface layer and propagates to the surface. After that a small piece of material is rubbed and this defect is called pitting. In the article [1] is mentioned a possibility of using Brown-Miller MFC for RCF description. This is the strain-based criterion with the assumption of initiation in the critical plane (plane of maximal shear strain range). This criterion is primarily designed for low-cycle fatigue. Software fe-safe allows calculation of service-life from stress-strain analysis using finite element method applying Brown-Miller criterion. Article [2] proposes other criteria for description RCF. Stress-based Dang Van criterion is one of them. Second appropriate criterion is Liu-Mahadevan [3] which is based on critical plane of maximal shear stress range and it is used for high-cycle fatigue. Simultaneously it includes its mean stress correction. In article [4] is mentioned good match of life results according to Liu-Mahadevan with the experiment of bearing steel.

This paper compares approaches for possible prediction of service-life at multiaxial stress state and its contribution is possible verification with experimental approach. The experiment is based on tests series executed on testing machine AXMAT. It is the system of roller bearing ring, rolling elements and a sample. This system is axial loaded and causes the highest values of stress in the sample. RCF is reached primarily on the surface of the sample.

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2 Experimental procedure

2.1 Experimental test-rig

The experimental RCF apparatus employed in this study is a flat washer-type RCF test-rig with AE (acoustic emission) and vibration monitoring systems. This special test-rig, as shown in Figure 1, is designed for life tests of thrust bearings (smaller size) and an evaluation of the rolling contact fatigue resistance of the material. It consists of a mechanical loading lever, an electrical motor, a specimen holder, a catch driver, a supporting frame and the monitoring system. The speed of the electrical motor can be adjusted by a frequency converter to the required level. This allows standard RCF tests to be performed, including tests at low speed. [5]

The upper ring of the test bearing is clamped in the holder and the lower ring is fastened in the catch driver. In the case of testing material specimens, the specimen is fastened in the holder in place of the upper bearing ring. The holder is stationary and the catch driver is driven by a shaft attached to an electrical motor. For a standard RCF test, the speed is set at 1380 min^{-1}. The holder is equipped with a polyamide safety element to offload in case of specimen overheating. The Hertzian pressure for rolling contact tests can be set using the combination of weights in the range from 2000 to 6000 MPa. [5]

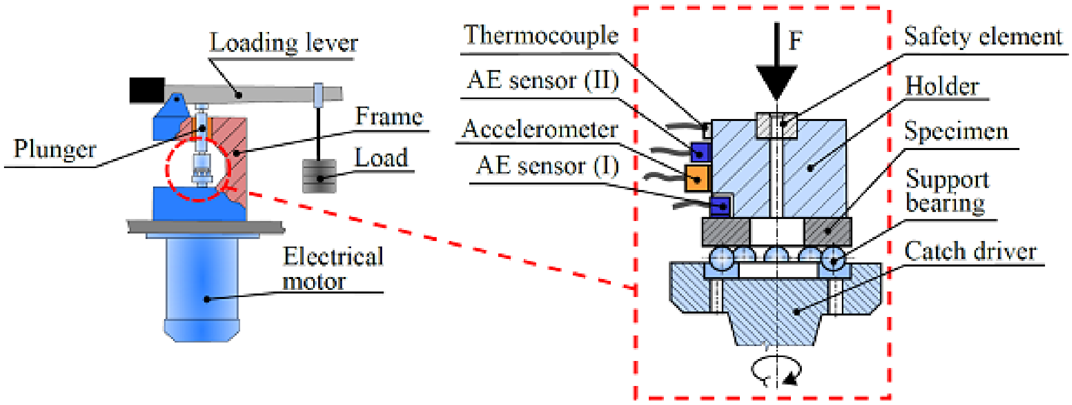

Figure 1. Experimental test-rig layout [5].

2.2 Specimens

The disc shape specimens with the dimensions 28×10×5 mm (outer diameter, inner diameter, thickness) were made from the steel 100Cr6 ISO 683-17. The specimens were heat-treated and ground at roughness Ra 0.1. The supporting bearings ZKL 51102A P6 had 21 balls with 3.175 mm in diameter and were lubricated by lithium complex soap based grease MOGUL LV 2-3.

Table 1. Chemical composition of the 100Cr6 steel.

Element	C	Si	Mn	P	S	Cr	Mo	Al	Cu
Wt. %	0.97	0.24	0.35	0.014	0.004	1.51	0.017	0.029	0.03

3 Results

3.1 Rolling contact fatigue tests

Test was carried out on 20 samples of steel 100Cr6 and durability results were processed by the two-parameter Weibull distribution and determined 10% quantile durability L_{10}, see table 2.

The life of a sample is the time from test start to pitting initiation. The vibration level and AE (acoustic emission) parameters are used for determination of the sample life. These parameters (vibration level, temperature, RMS AE and AE mean frequency) monitored during the test of one material sample are shown in figure 2.The process of experimental evaluation of steel durability using the acoustic emission method is described in more detail in articles [5] and [6].

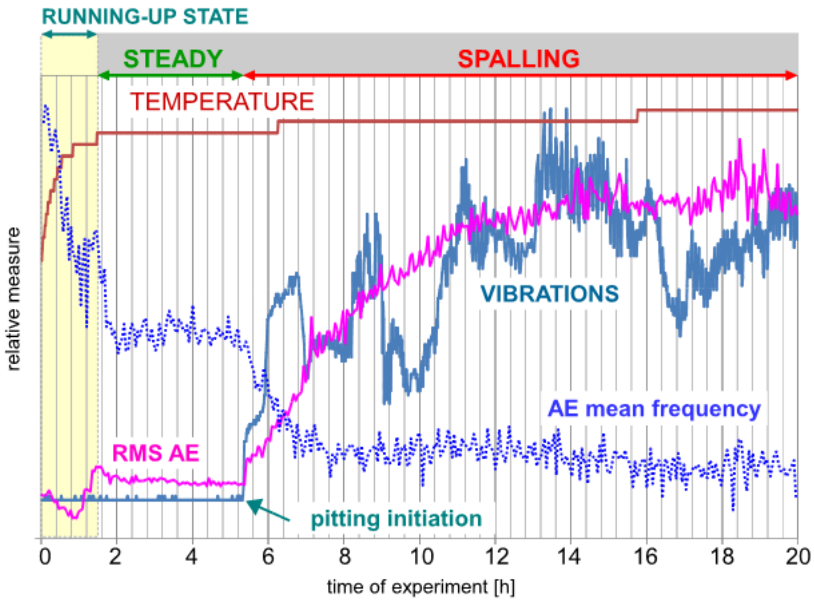

Figure 2. Observation of test: AE, vibration, temperature [6].

3.2 Comparison of theoretical and experimental results

The results based on numerical modelling of multiaxial fatigue criteria and tests are compared in table 2.Given the results presented in [7] was chosen for this criterion “SCALE” in fe-safe software to 0.93. With this setting the lifetime best matches the standard ISO 281.Higher value of experimentally obtained sample lifetimeis caused by the ability to detect only more developed defects. Numerical solution determines the time to fatigue crack initiation, not a pitting formation.

Table 2. Comparison of sample lifetime.

Method	Brown-Miller + Morrow	Experimental (L_{10})
Sample lifetime (min)	261	335

4 Conclusion

The lifetime of steel samples based on numerical modelling and experimental results was compared. A rolling contact fatigue test using the acoustic emission method was undertaken on a flat washer test-rig and the temperature, vibration level and AE parameters were processed by the two-parameter Weibull distribution. The calculation of service-life from stress-strain analysis using finite element method applying Brown-Miller criterion in software Fe-safe were done. The results shows that for more accurate calculation will be appropriate use other criteria suitable for high-cycle fatigue than Brown-Miller.

It can be concluded that calculation of service-life from stress-strain analysis using finite element method applying proper multiaxial fatigue criteria can be used for bearing or material sample lifetime prediction.

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