AN EVALUATION OF ROLLING CONTACT FATIGUE OF METALLIC MATERIALS USING ACOUSTIC EMISSION METHOD

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A major cause of a surface damage of the contact loading machine components (bearings, gears, cams etc.) is the rolling contact fatigue. Various methods of condition monitoring are used to detect damage of these components or specimens in the industry or during testing in laboratories. In the past decades, the acoustic emission technique has been developed into useful condition monitoring method. This paper is focused on the testing of rolling contact fatigue of the metallic materials using acoustic emission method. The methodology of testing, experimental test-rig and preliminary results, are presented in this paper. It can be concluded, that acoustic emission technique can be applied for more accurate rolling contact fatigue evaluation of material.

Keywords: *acoustic emission, rolling contact fatigue, defect, bearing, pitting*

1. Introduction

The tests of full-scale bearings and other machine components are expensive and time-consuming, because many test specimens are required to correct evaluation. For this reason, the geometrically simpler test specimens and various configurations of the test-rigs are used. The basic concepts of test-rigs include a four-ball machine, a ball on a washer, a ball on a rod, a disc on the rod and a twin-disc test-rig. Each of these test-rigs is designed for specific contact conditions and simulates rolling, rolling/sliding, point or line contact. The conditions of rolling contact in the ball on washer test-rig (plastic deformation etc.) are very similar to real conditions in the thrust roller bearings. This allows to compare the results of material tests with real thrust roller bearing tests. A vibration monitoring method, which is based on vibration acceleration measurement and its analysis in the time or frequency domain, is commonly used for spalling detection on the material specimen [1, 2]. In the last three decades, acoustic emission (AE) method has been developed into useful tool for defect detection in rotary machinery [3–5, 7]. This method of non-destructive testing is more sensitive to detection of the onset of the subsurface cracks and pitting formation on material surface in the first stage of rolling contact fatigue (RCF). The work of Yoshioka [3] focused the study on detection of subsurface cracks based on acoustic emission monitoring. A bearing type specimen with a flat ring and only three rolling elements was used for these experiments. Elforjani [4] described the method for detection and evaluation of the natural defects in a slow rotating thrust bearings using acoustic emission method. The experiments were performed on the ball on washer test-rig and the upper ring of thrust ball bearing

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was replaced with flat race taken from thrust roller bearing. This experiment configuration accords with the standard material specimen test configuration. The acoustic emission signal is influenced mainly by the presence of solid contaminant in the lubricant, test conditions (load, speed, temperature) and material of specimen. Miettinen et al. [5] studied changes in AE signal which was measured during the tests of grease lubricated deep groove ball bearings. The measured AE levels increased non-linearly with particle concentration. After the test with contaminated grease, the cleaning and re-greasing of tested bearings resulted in a reduction in the AE levels.

Publications which are currently known to authors only describe the AE monitoring of an artificial or natural damage of bearings and material specimens made from bearings steels 100Cr6 or 100CrMnSi6-4. This paper shows the preliminary results of a doctoral project which deals with RCF testing using acoustic emission method. The experiments were carried out on washer type test-rig with various rotation speeds and loading. For the project were selected several materials, commonly used for contact loaded components. The parameters of rolling contact fatigue evaluation experiments are summarized in figure 1. In this paper are presented the results of tests of case-hardened steel 16MnCr5.

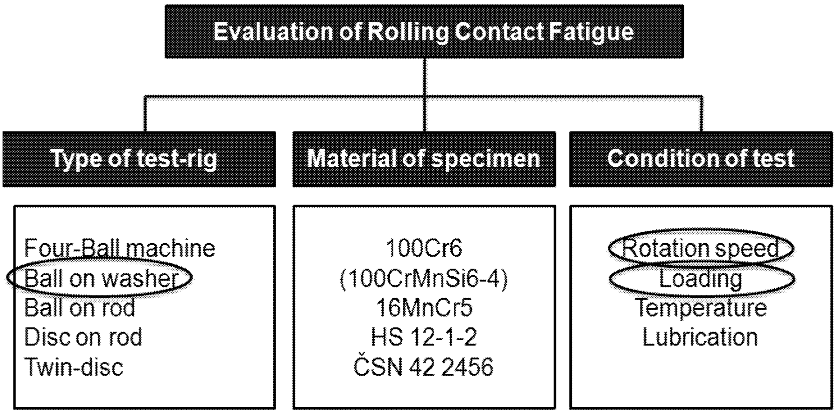

Fig.1: Evaluation of rolling contact fatigue parameters

2. Experimental procedure

The experimental RCF apparatus employed in this study is a flat washer type RCF test-rig with acoustic emission and vibration monitoring systems (AXMAT). This special test-rig, as shown in figure 2, is designed for life tests of thrust bearings and an evaluation of rolling contact fatigue resistance of material. It consists of a mechanical loading lever, an electrical motor, a specimen holder, a catch driver, a supporting frame, and monitoring system. The speed of the electrical motor can be adjusted by frequency converter to the required level. This allows performing standard RCF tests, including tests at low speed [7].

The test-rig is equipped with an AE monitoring assembly XEDO-IPL-AESWITCH made by DAKEL company. It consists of two AE piezoelectric transducers (DAKEL type MIDI) with frequency range 80–750 kHz and operating temperature −20 to 150 °C. The total gain of AE signal was set at 36 dB. The accelerometer with frequency response 2–10000 Hz (Wilcoxon ES-08100B), attached to the specimen holder, was used to measure the vibration levels. The arrangement of sensors is shown in figure 2.

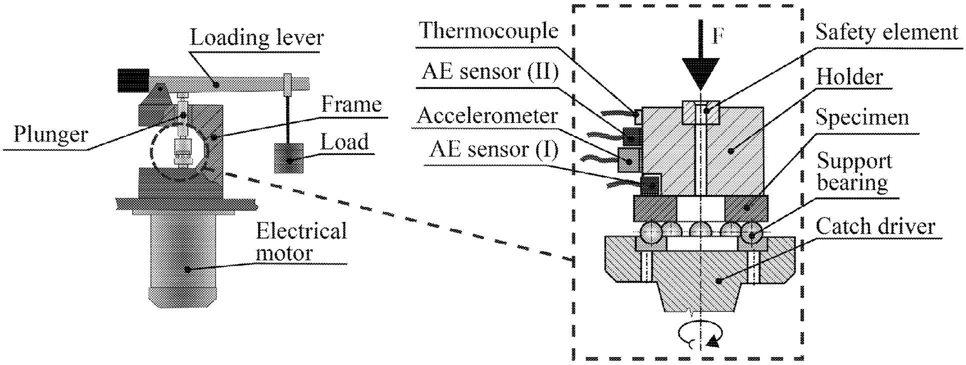

Fig.2: Experimental test-rig layout

The specimens for presented experiment were made from case-hardening steel 16MnCr5 with the dimensions 28×10×5 mm (outer diameter, inner diameter, thickness). They were loaded by a force of 4000 N that corresponds to maximum Hertzian contact pressure 5937 MPa. The rotation speed was constant during tests at 1380 min^{-1}. The supporting bearing had 21 balls with 3.175 mm in diameter and was lubricated by lithium complex soap based grease RENOLIT EP2. The specimens were carburised at 910 °C, cooled to 770 °C, quenched into oil and then tempered at 180 °C during 1 hour. After heat treatment was a surface ground at roughness Ra 0.25 . The specimen is shown in figure 5.

3. Results

The AE parameters in time and frequency domain are analyzed in this paper. The count rate levels and RMS (Root Mean Square) of acoustic emission signal are shown in figure 3. The first ten minutes the AE count rate (three levels) and RMS rapidly increased. This phenomenon is caused by creation of a rolling element track on the surface of the specimen due to plastic deformation.

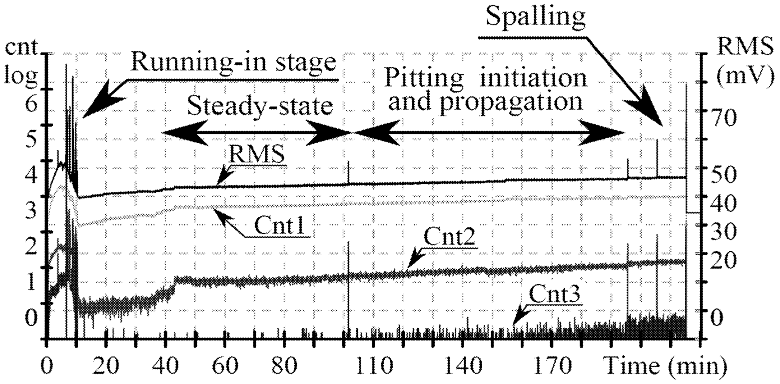

Fig.3: AE observation – AE count rate (3 levels – Cnt1, Cnt2 and Cnt3) and RMS

The growth of AE intensity before third minute is probably caused by the removing asperity in created track. After running-in stage the AE parameters were constant. It was observed that after 100 minutes, count rate levels began to increase steadily. It is caused by the initiation and propagation of pitting in the track on the material specimen. This phenomenon was observed also in previous works [4, 8, 9]. An experiment was terminated when the vibration exceeded the set threshold. It was approximately at the onset of spalling propagation and the final spalling is shown in figure 5.

The useful information of AE source can be traced by analysing the frequency domain of AE signals [8]. Figure 4 shows the FFT spectrogram for the frequency range 0–600 kHz. In the figure is clearly shown around the tenth minute increased intensity at all frequencies. This corresponds with running-in stage, which is also evident shown in figure 3. The gradual frequency shift from 500 to 750 kHz (highlighted section) corresponds to the running-in stage and smoothing of the raceway (up to 43rd minute). At 43rd minute is observed a step change in frequency from 520 to 515 kHz (highlighted section), this is probably the end of smoothing process.

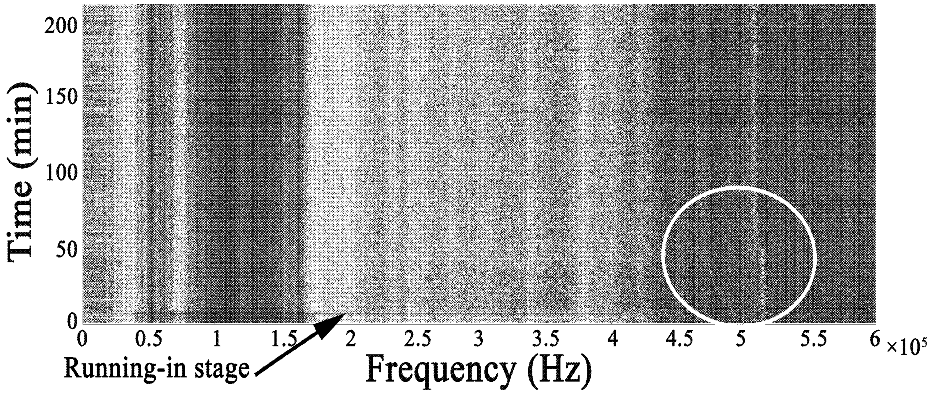

Fig.4: FFT spectrogram of AE signal

The frequency changes in area of a pitting initiation and spalling propagation are insignificant. The subsurface cracking and pitting formation cannot be distinguished in FFT spectrogram from other sources. It is hoped further analysis of several tests, potentially involving cyclostationary and time-frequency methods, can detect the onset of pitting process and distinguish among the different sources of AE in frequency domain.

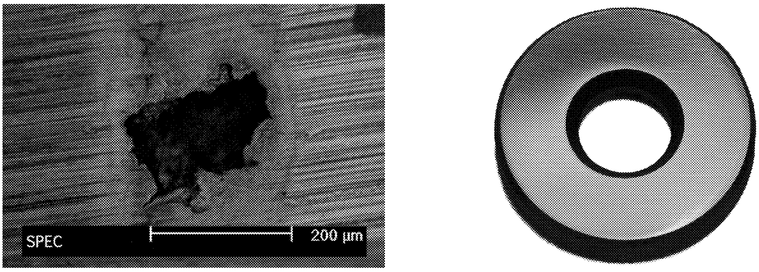

Fig.5: Final damage (left) and specimen before testing (right)

Figure 6 shows the observation from another AE measurement obtained by authors and presented in [9]. This experiment was performed under the same test conditions and the AE parameters respond similarly to the pitting onset and its propagation as in presented experiment.

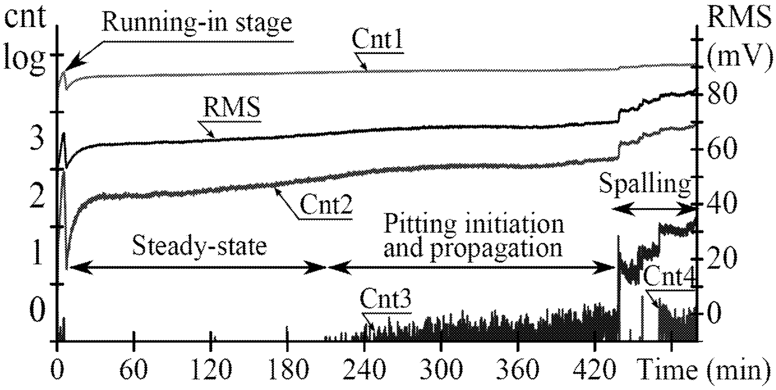

Fig.6: AE observation: AE count rate (four levels – Cnt1, Cnt2, Cnt3 and Cnt4) and RMS [9]

4. Conclusion

A rolling contact fatigue test of case-hardening steel 16MnCr5 using the acoustic emission method was undertaken on a flat washer test-rig. The acoustic emission parameters such as RMS, count rate were compared with frequency analysis of the obtained acoustic emission signal. It can be concluded that the acoustic emission method in time domain detected the onset and propagation of pitting in the raceway of the material specimen. The frequency analysis of acoustic emission signal could not clearly identify the onset of pitting formation. The acoustic emission monitoring is able to describe the processes, such as lubrication conditions, lubricant additive effect etc., which occurs during the test to detection of pitting. The vibration monitoring detects only greater defects in the form of spalling that can emit a detectable amount of energy. In further work the cyclostationary and time-frequency techniques can be helpful to distinguish the sources of acoustic emission signal. Finally, it can be concluded that the performed analyses and previous tests suggest the possibility to use acoustic emission as a tool for testing material and its homogeneity.

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