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CONDITION MONITORING OF THRUST BALL BEARINGS USING CONTINUOUS AE

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Abstract

In the last years AE become an important part of structural health or condition monitoring systems. AE analysers for that purpose should provide a long-time continuous signal records using relatively high sampling frequency. Recorded huge data must be analysed to disclose any faults in monitored processes or structures like e.g. leakages in pressure vessels or defects in rotating machines and gearboxes, etc. Fast and reliable AE signal processing and analysing methods, different from that used in burst AE, are required. In this paper we present such analysis of continuous AE recorded during endurance tests on flat washer parts reliably simulating critical rolling contact fatigue of the full-scale bearings. Two channels of continuous AE signal were partially recorded within whole specimen lifetime tests and compared with other experimental parameters as vibration rate or temperature. As an alternative to classical spectrogram analysis, we proposed to use histograms of time intervals between threshold amplitudes crossings in various frequency bands represented by the wavelet decomposition. Results obtained on long-time records are discussed, illustrating advantages of proposed AE signal processing, which can be done in real time to observe the processes before the onset of the final damage on the surface of the specimen more precisely than vibrodiagnostics. Continuous AE monitoring together with low frequency vibration analysis can be integral part of the rotating machinery condition monitoring system.

Keywords: Continuous acoustic emission, rolling contact fatigue, thrust ball bearing, histogram of counting periods, wavelet analysis

1. Introduction

The life of the bearing is defined by the ability to perform its function. In the case of rolling bearings, a failure is considered to occur when the bearings are unable to perform rotation, or the rotation takes place with unacceptable vibrations or noise. Vibration and wear debris monitoring are widely used methods for condition monitoring of bearings or whole machines. In the past decades, the acoustic emission method has grown in importance in condition monitoring applications. [1]
The acoustic emission (AE) method is used in many areas of non-destructive testing, such as leak detection, structure monitoring, condition monitoring, fatigue testing, etc. Acoustic emission as a phenomenon can be defined as transient elastic waves resulting from local internal microdisplacements in a material. Application of the AE method in the condition monitoring of rolling bearings has been a subject of interest for many authors. [1]

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 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. [1]
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. The presented test was conducted under load 5000 MPa. [1]

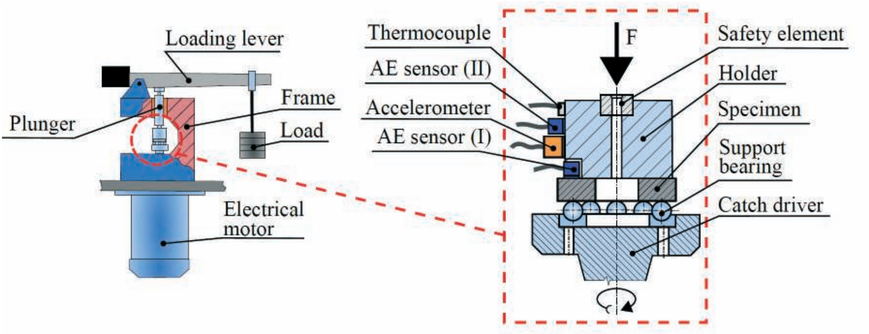

Figure 1. Experimental test-rig layout [1]

2. Processing of AE signals

2.1 Parameterization methods

One of the oldest and most common parameterization methods in the AE analysis is the threshold counting (TC) of AE signal crossings of predetermined voltage levels. The number of threshold counts *Nc* or count rate, *dNc/dt*, simply characterizes both the continuous and burst AE signals in time domain. TC substantially reduces information about AE signal, and saves good knowledge on the global AE activity. TC methods are very effective as simple devices and/or digital signal processing (DSP) procedures can be used for AE detection and quantitative evaluation. As a standard approach we can assume the dual TC (low and high amplitude threshold level), as it allows to distinguish solitary high amplitude signal bursts in quasi-continuous AE. However, in practice, it is not easy to set the proper values of counting thresholds in advance, especially in case of unpredictably changing signal amplitudes. For optimal covering of possible signal amplitudes let us set the levels as a basic number *c* to the power of *(-k)* multiplied by the maximum possible value of signal amplitude. Multilevel threshold counting can be also used for a new way of analysis of periodicities within various signal amplitude modulations. Let us define the "histogram of count periods" (HCP) as the histogram of the time intervals length T_i between each signal passings through the particular counting level in direction from zero. [2]
The crucial question is which counting level is the most predicative. A possible solution of this problem may be to choose a particular level inducing the highest diversity of count periods. As a measure of "diversity", entropy of count periods is considered. Entropy *S* is computed by the standard Shannon's definition:

$$S = -\sum_i p_i \log_2 p_i \quad , \tag{1}$$

where numbers p_i are the relative frequencies of count periods in analysed signal section. The sum goes through all existing periods, i.e., the zero histogram values are not considered.

2.2 Processing of experimental data

As an analogy to spectrogram, it is possible to compute HCPs for blocks of signal with constant time length. The result is so-called "countogram". This approach should provide gain-independence of signal processing, i.e., varying amplification of signal does not change the results of its analysis and solves the problem of proper setting of counting levels.

So as to have a possibility to capture modulation changes of various frequencies, it is necessary to analyse original signal in separate spectral bands. As a fast algorithm of decomposition, the wavelet transform was used [3]. Such successive analysis enables thresholding in specific complementary frequency bands. As the wavelet decomposition components are complementary within the meaning of contained frequencies, the countograms corresponding to each wavelet level can be summarized into one "combined countogram" that can be regarded as a map of signal periodicities and, in consequence, as a unique pattern or "ultrasound print" of AE source. Next figure shows combined countogram of whole experiment.[4]

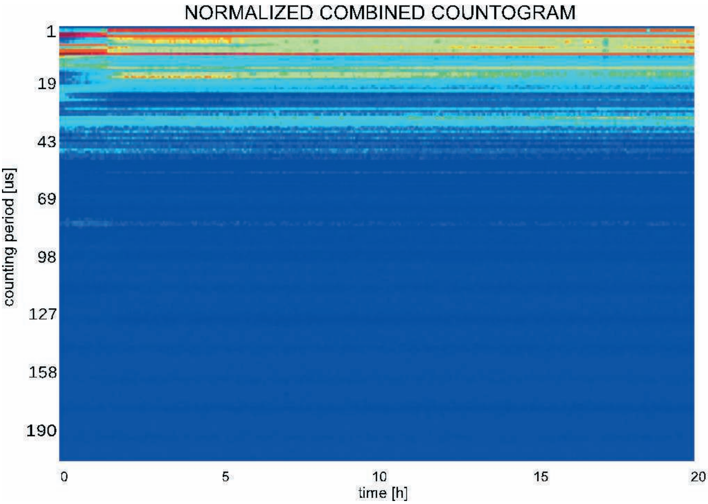

Figure 2. Normalized combined countogram

Although the computation of countograms is a method that should be further verified, it is already demonstrable that it brings completely new information, namely by a simple and illustrative form. However, the question is whether the developed method is suitable for classification of immediate health of mechanical device as a bearing. The analysis of the changes in countogram can be too much difficult or badly understandable for common serviceman. By this fact, one simple parameter was proposed. As we can see from the fig. 3, good candidate is the "mean frequency" parameter, defined as:

$$\tilde{\mu}_f = \frac{\sum_{i=1}^{N} i \cdot f(i)}{N \sum_{i=1}^{N} f(i)} \tag{2}$$

where f(i) is Power Spectral Density (PSD) estimate function and N is the half of the number of samples used for PSD computation.

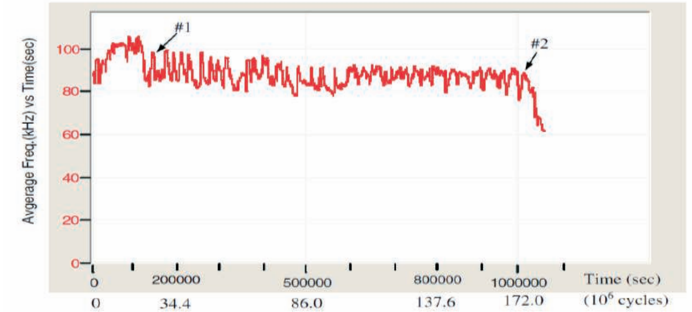

Figure 3. Mean frequency – RCF test [3]

3. Test results

The AE parameters were obtained at a sampling rate of 2 MHz. The waveform samples of 10 s duration were obtained by an IPL analyser periodically every 10 min. Data acquisition system is detailed described in [1]. The first 150 000 samples of each signal sample was processed. The results of whole experiment – vibration level, temperature, RMS AE and AE mean frequency are shown in Figure. 4. During the first 90 min of the test, the changes in parameters were detected. The temperature began to increase steadily, the AE mean frequency continuously decreased and RMS AE oscillated. This corresponds to the running-up state of the test and no response in vibration measurement was observed.

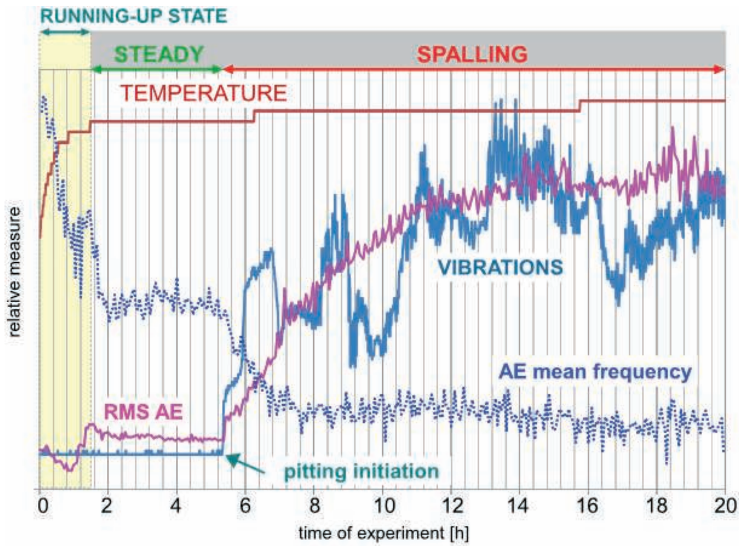

Figure 4. Observation of test: AE, vibration, temperature

In the first 20 min of running-up stage the plastic deformation created a track on surface of specimen and RMS AE sharply increased. After this, the smoothing process of the track surface began to increase the temperature and this changed the viscosity of the grease – an increase in AE activity was detected. After running-up stage, all parameters were constant.

After the 5th hour of the test, RMS AE and vibration began to grow rapidly. In contrast, the AE mean frequency began to decline. This is caused by the initiation and propagation of pitting in the track on the material specimen. The standard RCF test ended at 6 hour of test, when the one spalling was developed. After this point there were several pittings created in the track. The multipiting / spalling caused the breakdown of lubrication, as a result of this the temperature increased and vibration oscillated due to the unstable conditions in the contact. The AE parameters corresponded to the stage of damage – RMS AE was increasing steadily and the AE mean frequency was decreased to constant level. [5]

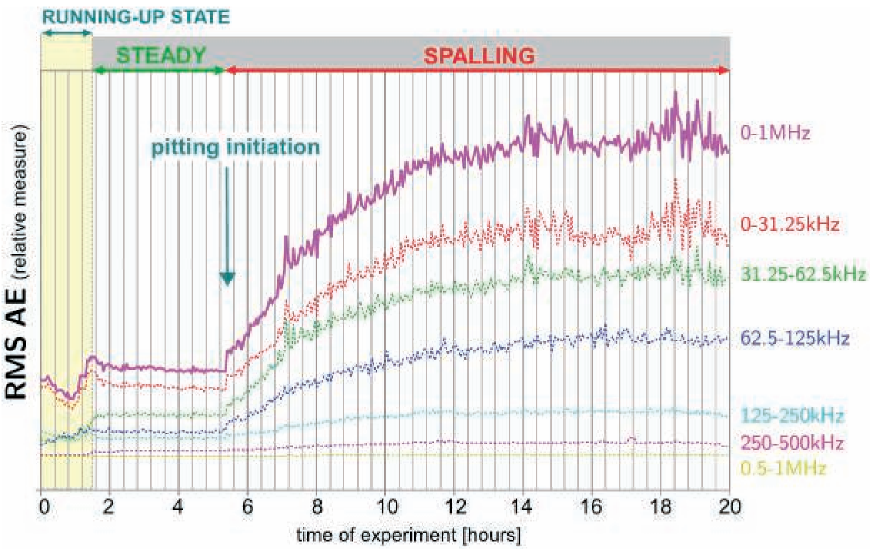

Figure 5. RMS AE – frequency distribution

The photograph of the specimen surface after whole experiment (20 hours) is shown in Figure 6. There can be very well recognized four spallings area as a final damage.

Figure 6. Surface damage after test on material specimen

7. Summary

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 analyzed. The AE mean frequency and RMS AE were more suitable for real time monitoring of the bearing health than countograms. The changes of the mean frequency very well separated the stages of rolling contact fatigue process and RMS responded to damage development. The AE signal processing can be done in real time to observe the processes before the onset of the final damage on the surface of the specimen more precisely than vibrodiagnostics. It can be concluded that continuous AE monitoring together with low frequency vibration analysis can be integral part of the rotating machinery condition monitoring system.

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