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ROLLER BEARING DIAGNOSING BASED ON ACOUSTIC EMISSION DISTRIBUTION IN TIME

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The parameters of signals of acoustic emission (count, activity, signal voltage root-mean-square value, amplitude histogram, statistical moment of distribution, peak factor, crest factor, kurtosis, pulse duration, pulse leading and trailing edge time, signal spectrum) generated in bearings and other tribosystems are analyzed. It is grounded, that an unevenness of distribution of impulses of acoustic emission in time is the diagnostic sign of roller bearing defect.

Introduction. A significant potential of reducing crop loss and operational costs in crop farming is operating agricultural machinery and trucks according to their technical conditions. This requires objective information about the condition of friction pairs and their wear intensity. Since wear involves dynamic restructuring of parts' surface layers (movement of dislocations, and emergence and development of micro cracks), acoustic emission testing proves to be a promising method.

Overview of recent research and publications. To test friction pairs (and in particular, roller bearings) acoustic emission (AE) parameters are used in compliance with standard ISO 12716:2001: count, activity, RMS signal voltage [1–5]. The amplitude histogram, statistical moment of distribution, peak factor, crest factor, kurtosis, pulse duration, pulse leading and trailing edge time, signal spectral analysis is used [1–3]. Authors of article [4] proposes to calculate information entropy of AE. Publication [5] proposes performing wavelet transforms for pre-treatment of AE signals. To identify roller bearing defects, publication [6] suggests using the Kolmogorov-Smirnov test to compare signal amplitude distributions against standard Gauss and Rayleigh, and exponential distributions. Let us analyse the relevance of these test sign for acoustic emission of a roller bearing.

We shall pay attention to the following features of the signal mentioned. First, this is the influence of different factors on the amplitude of the transducer output signal.

Such factors are as follows: attenuation of elastic waves in the material of a part and in the parts interface; sensitivity variation and significant irregularity of transducers' amplitude-frequency response; and transducer sensitivity dependence on test object surface flatness and smoothness. Second, these are comparatively short-term AE surges during contact of parts in fatigue failure zones.

Let us set forth the key requirements to acoustic emission testing parameters for roller bearings:

– invariance to signal amplitude scaling;

– sensitivity to signal sampling sequence in time.

Since the number of processed signal samples can be in the range of tens of thousands, it would be desirable to compute one or several generalised technical condition parameters, which would be convenient to transfer to the expert system. Hence, repeated compression of measurement information is required.

Table 1 shows the results of analysing the compliance of parameters used [1-6] to the stated requirements. Measuring pulse duration and leading and trailing edge time is impeded by multiple reflections of pulses off the surfaces of parts. Spectral analysis and wavelet transforms are computationally intensive and output huge amounts of information requiring post-processing. All this makes using the mentioned parameters an involved task. Part of the problem awaiting a solution is substantiating the AE parameters of the condition of friction pairs, which are invariant to signal amplitude scaling and sensitive to the signal sampling sequence in time.

Task statement. The objective of this research effort is substantiating the roller bearing technical condition parameters, which depends only on the acoustic emission distribution in time and is invariant to signal amplitude scaling.

Table 1 – Properties of acoustic emission parameters of friction pair defects

Acoustic emission parameters	Invariance to signal amplitude scaling	Sensitivity to signal sampling sequence
Count, activity, RMS	No	No
Peak factor, crest factor, amplitude histogram, information entropy	Yes	No
Pulse duration, pulse leading and trailing edge time	Yes	Yes
Spectrum, wavelet factors	No	Yes

Exposition of basic material. In absence of defects in the contacting surfaces of parts and under steady bearing running conditions, random fluctuations of AE are common. A pulse stream exceeding the threshold level shall be considered the simplest stream. Hence, according to the properties of the simplest stream, the instances of arrival of AE pulses will be random quantities uniformly distributed over the test interval [0, *T*]:

$$F(t) = t / T, \quad (1)$$

where: F – hypothetical integral function of uniform distribution of time points when AE pulses arrive; t – time, s; T – test interval duration, s.

If bearing parts contact in defect fatigue failure zones, this will increase acoustic emission power in appropriate time intervals. Hence, the empirical integral function of the distribution of time of detecting acoustic emission signals from a defect bearing shall differ from the hypothetical integral function of uniform distribution (1) the more the bigger the defects in the contacting surfaces.

The correspondence of actual distribution of the time of arrival of acoustic emission signals to hypothetical distribution (1) can be validated using the Kolmogorov goodness-of-fit test and the Cramer-Mises-Smirnov test.

Let us consider the Cramer-Mises-Smirnov test. The relevant statistic is:

$$W_n^2 = \sum_{i=1}^{n}\left(F(t_n) - \frac{2i-1}{2n} \right)^2 + \frac{1}{12n} , \quad (2)$$

where: W_n^2 – statistic; n – number of signal samples in the test interval.

The more the actual distribution of AE signals differs from the hypothetical uniform one, which is an sign of bearing defect, the bigger statistic W_n^2 values will be. This makes it possible to determine the sign of a bearing's technical condition by transforming (2) with account of (1):

$$d_{CMS} = \sum_{i=1}^{n}\left(\frac{t_i}{T} - \frac{2i-1}{2n} \right)^2 + \frac{1}{12n}, \quad (3)$$

where: d_{CMS} – the roller bearing technical condition sign according to the Cramer-Mises-Smirnov test.

The correspondence of distribution of time points of arrival of AE pulses to hypothetical distribution (1) can be validated using the Kolmogorov goodness-of-fit test to determine statistics. To prevent missing a defect, the measurement time interval should exceed the period of rotation of the bearing's rotatable ring. This shall correspond to several periods of signals from possible bearing defects.

Experiments. Experiments were conducted using a computerised test bench for investigating the acoustic emission sign of roller bearing defects [7], Fig. 1. The bearing outer ring 202 was immovably fixed, where: as the inner one rotated with a speed of 1,460 1/minute through the cone. The bearing axial load was 258 N.

A new bearing and a bearing with zones of ring fatigue failure (after accelerated endurance tests were conducted) were tested. The acoustic emission measurement interval was 0.1 s, corresponding to 2.4 revolutions. The instances when signals crossed the threshold level were monitored every 25 μs, the peak detector excluding the possibility of undetected crossings.

The threshold level was adjusted for the signal to exceed it for about 400 of the 4,000 measurement time intervals (i.e. corresponding to a quantile of about 90 %).

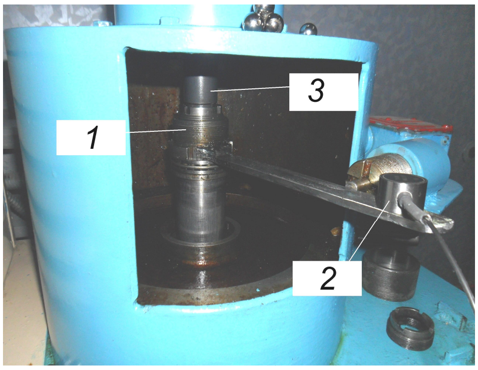

Fig. 1 – Test bench for investigating acoustic emission in roller bearings: 1 – casing of removable bearing assembly; 2 – acoustic emission transducer GT300; 3 – cone.

The bearing technical condition sign computed using formula (3) was 0.010 for a new bearing and 0.189 for a bearing with ring fatigue failure. Fig. 2 shows the integral functions of pulse distribution vs. time.

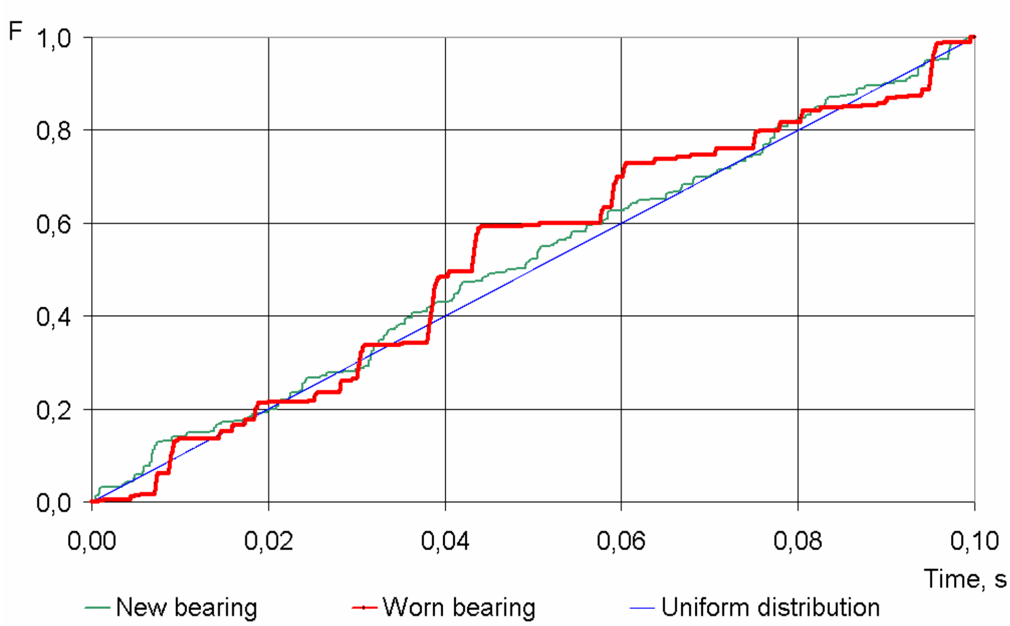

Figure 2. Integral functions of hypothetical uniform and empirical laws of distribution of acoustic emission signals vs. time

Conclusions. The proposed roller bearing technical condition sign is invariant to acoustic emission signal amplitude scaling. Besides, this parameters makes it possible to detect short-time acoustic emission surges during contact of fatigue failure zones in bearing parts.

A promising line of further research can be identification of parameters belonging to changes in the bearing technical conditions state with a view to forecasting a bearing’s residual life span.

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Аннотация

ДИАГНОСТИРОВАНИЕ ПОДШИПНИКА КАЧЕНИЯ ПО РАСПРЕДЕЛЕНИЮ АКУСТИЧЕСКОЙ ЭМИССИИ ВО ВРЕМЕНИ

Шевченко С.А.

Проанализированы параметры сигналов акустической эмиссии (счет, активность, среднеквадратическое значение напряжения, пик-фактор, коэффициент амплитуды, эксцесс, длительность импульса, длительность фронта и спада импульса, спектр сигнала), генерируемой в подшипниках и других трибосистемах. Обосновано, что неравномерность распределения импульсов акустической эмиссии во времени является диагностическим признаком дефекта подшипника качения.

Анотація

ДІАГНОСТУВАННЯ ПІДШИПНИКІВ КОЧЕННЯ ПО РОЗПОДІЛЕННЮ АКУСТИЧНОЇ ЕМІСІЇ У ЧАСІ

Шевченко С.А.

Проаналізовано параметри сигналів акустичної емісії (рахунок, активність, середньоквадратичне значення напруги, пік-фактор, коефіцієнт амплітуди, ексцес, тривалість імпульсу, тривалість фронту і спаду імпульсу, спектр сигналу), що генерується в підшипниках і інших трибосистемах. Обґрунтовано, що нерівномірність розподілу імпульсів акустичної емісії у часі є діагностичною ознакою дефекту підшипника кочення.

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