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EVALUATION OF STATE OF ROLLING BEARINGS MOUNTED IN VEHICLES WITH USE OF VIBRATION SIGNALS

OKREŚLANIE STANU ŁOŻYSK TOCZNYCH MONTOWANYCH W POJAZDACH SAMOCHODOWYCH Z WYKORZYSTANIEM SYGNAŁÓW DRGANIOWYCH

The article is a continuation of the research carried out in order to determine the possibility of diagnosing bearings of cars' wheels. The previous paper showed the results of metallographic research and the research carried out using vibroacoustic methods, with the use of vibration signals and frequency analysis. In this paper the results of further research will be presented, which used the acceleration signals again. To determine the state of the bearings this time simple amplitude measures were used.
Keywords: vibroacoustics, diagnostics, bearings

Artykuł jest kontynuacją badań prowadzonych w celu określenia możliwości diagnozowania łożysk kół jezdnych pojazdów samochodowych. Poprzedni artykuł przedstawiał wyniki badań metalograficznych i wibroakustycznych - z użyciem sygnałów drganiowych i analiz częstotliwościowych. W tym artykule zostały zaprezentowane wyniki dalszych badań, w których użyto ponownie sygnałów przyspieszeń drgań. Do określenia stanu technicznego łożysk zostały wykorzystane proste pomiary amplitudowe.

1. Introduction

Diagnosis of rolling bearings in automotive vehicles, as already shown in the publications of authors, despite the availability of increasingly advanced measuring and diagnostic instruments is often still performed using various subjective methods. This situation can often result from the high cost of modern instruments, as well as the lack of ready-to-use diagnostic procedures enabling the use of these instruments in terms of the diagnosis and servicing of vehicles stations.

Currently used methods of diagnosing bearings on their grounds exploit of the experience of the person who carried out the diagnosis. It follows their subjective nature, and unreliability. The effectiveness of diagnosis to a large extent depends on both the correct use of the instrument, as well as the skillful interpretation the obtained results.

For this reason, it is reasonable to conduct studies that will contribute to the development of objective methods of diagnosis with simple guidelines for diagnosis of bearing wheels in motor vehicles by vehicle inspection stations.

With the conclusions of previous research and review of literature, authors as a source of information on the state of the bearing arrangement adopted vibration signals [4, 5, 7, 8, 9]. It is generally agreed that they contain far more useful information from the acoustic signals, because thanks to the development of measurement methods, especially the possibility of contactless measurement with the use of laser vibrometers, in a very large extent are devoid of the impact of different disturbances.

Non-contact methods enable running vibration measurements of elements that are very hard-to-reach without the impact of different transmittances that could mask the interesting symptoms of a registered and analyzed process.

Application of contact vibration measurements, despite the absence of a number of undeniable advantages of contactless methods, also allows to get very good results. The undoubted advantage in this case, will definitely be a lower price of measuring test-bench instrumentation, which is of great importance for the subsequent application capabilities of diagnosis method.

Regardless of how the measurement is done, an extremely important aspect on the road to the creation of an objective test procedure is to develop algorithms for the processing of registered signals. Very useful for this purpose is diagnostic experience of the research team, which must be reflected in the form of the algorithm. Such an approach will make it possible to make a diagnosis using the finished instrument, even by a person without specialist knowledge. To create a database of diagnostic symptoms for specific bearing solutions should in turn allow increasing the certainty of diagnosis.

To ensure a high level of the correctness of diagnosis is an essential factor to justify the appropriateness of use of complex diagnostic procedures and replace them with now frequently

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used simplified methods, whose description is shown in a previous publications of authors.

In article will be presented the results of research carried out in order to assess the suitability of the simple amplitude measures in the diagnosis of the condition of wheels' bearings in vehicles. Using of simple measures, instead more advanced methods of analysis of vibration signals is intended to simplify of the diagnosis process.

2. The research subjects

The research objects was again bearings were mounted in wheels of three different vehicles. At first, vibration measurements of nodes bearing were taken. During the tests authors used the vibration acceleration signals recorded on the bearing with the use of vibration acceleration transducers.

Sampling frequency of recorded signals was 128 kHz.

During the test, was synchronously recorded:

- bearing vibration acceleration signals,
- reference signals obtained from ABS' wheel speed sensor.

Registered signals then have undergone analysis in computing environment Matlab. Sample time process of the registered vibration acceleration is shown in the figure. 1.

First research object was the bearing of wheel of Fiat Panda, marked as (SKF) VKBA 1401. The bearing is shown on figure 2.

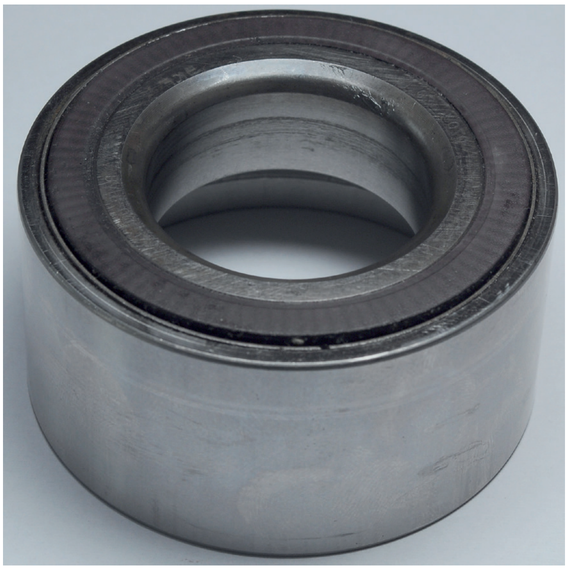

Fig. 2. Bearing VKBA 1401 from wheel of Fiat Panda

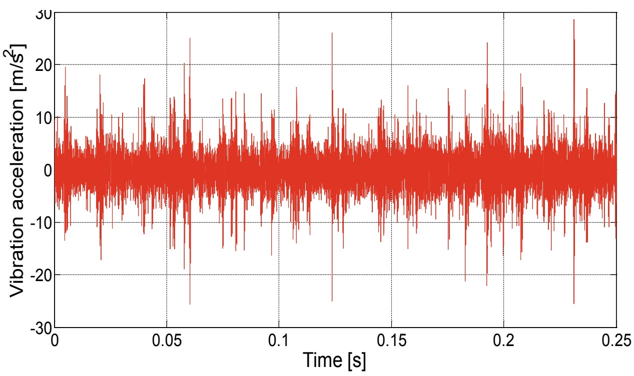

Fig. 1. Sample acceleration time process of vibration in the bearing arrangement - bearing worn out from wheel of Toyota Avensis

Second research object was the bearing of wheel from Renault Kangoo. It is presented on figure 3. The bearing was produced by SKF too, and is marked as VKBA 3692.

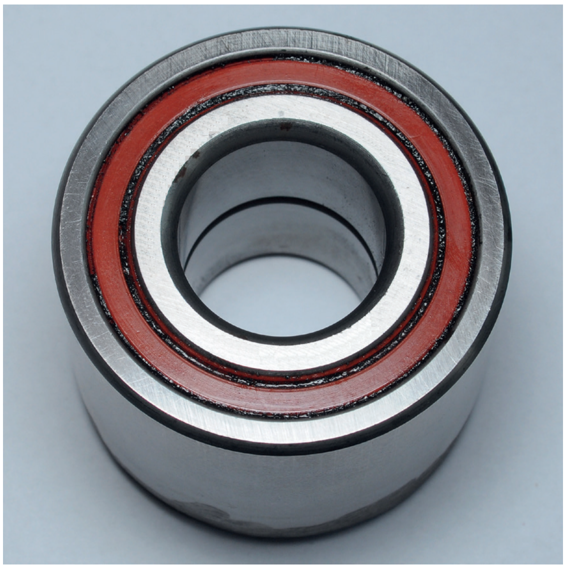

Fig. 3. Bearing VKBA 3692 from wheel of Renault Kangoo

Third bearing was mounted in wheel of Toyota Avensis. It is marked as SKF VKBA 6831. It is shown on figure 4.

Fig. 4. Bearing VKBA 6831 from wheel of Toyota Avensis

Bearing vibration acceleration was measured with the use of accelerometers PCB for vibration measurement up to 10 kHz. The signals was recorded with the use of eight-channel measuring card VibDAQ.

Measurements were taken at the rotational speed of the wheel, corresponding to the speed of around 150 km/h. It was conducted by using wheel balancer used for dynamic balancing of wheels. It is shown in Figure 5.

Fig. 5. Wheel balancer used to speed up wheels

Before the start of the study, in each case wheels were balanced according to standard procedure, enabling the service to skip the imbalanced impact on the results of the measurement.

Both bearing was after research dismounted from tested vehicles and then metallographic examinations were made. That's let to eliminate the presence of the material defects, which could be the reason for detected damages [10, 14, 16-18].

Metallographic test results, presented in the previous article, excluded the presence of material defects.

3. Diagnostic measures

Changes in the observed signal in time shall take a lot of temporary values. In the analysis of the signal, it is not necessary to observe every change in the instantaneous value, it is necessary to define the values of the signals indicating the most characteristic points, and having the greatest importance in the entire course of the signal [1-3, 15].

In this article the effectiveness of diagnosis of bearing using the well-known simple diagnostic measures has been verified. As will be shown, the value of such measures is determined from simple formula, which makes them very easy to use in diagnostic devices.

Some of the measures used in the study are listed below and described in formulas 1-15. The selection of the measures was based on the basis of literature sources and the practical experience of Authors [6, 7, 8, 11-13].

- Mean value:

$$\bar{x} = \lim_{T\to\infty}\frac{1}{T}\int_0^T x(t)\,dt. \quad (1)$$

where: T – time averaging [s]

- Mean square value:

$$\Psi^2 = \lim_{T\to\infty}\frac{1}{T}\int_0^T x^2(t)\,dt. \quad (2)$$

- RMS value:

$$x_{RMS} = \sqrt{\Psi^2}. \quad (3)$$

- Standard deviation:

$$\sigma = \sqrt{v}. \quad (4)$$

- The variance (the second-order central moment):

$$v = \lim_{T\to\infty}\frac{1}{T}\int_0^T [x(t)-\bar{x}]^2 dt. \quad (5)$$

- Absolute peak value:

$$x_{PEAK} = \max_{0<t\leq T}|x(t)|. \quad (6)$$

- Positive peak value:

$$x_{PEAK_+} = \max_{0<t\leq T} x(t). \quad (7)$$

- Negative peak value:

$$x_{PEAK_-} = \min_{0<t\leq T} x(t). \quad (8)$$

- Peak to peak value:

$$x_{p-p} = |x_{PEAK_+} - x_{PEAK_-}| \quad (9)$$

- Kurtosis (the fourth-order central moment):

$$Q = \lim_{T\to\infty}\frac{1}{T}\int_0^T [x(t)-\bar{x}]^4 dt. \quad (10)$$

- Kurtosis coefficient (based on the fourth-order central moment):

$$x_Q = \frac{\frac{1}{T}\int_0^T (x(t)-\bar{x})^4}{x_{RMS}^4} \quad (11)$$

- The skewness (the third-order central moment):

$$Sk = \lim_{T\to\infty}\frac{1}{T}\int_0^T [x(t)-\bar{x}]^3 dt. \quad (12)$$

- Coefficient of skewness (based on the third-order central moment):

$$x_{sk} = \frac{\frac{1}{T}\int_0^T (x(t)-\bar{x})^3}{x_{RMS}^{3}} \tag{13}$$

- Rescaling amplitude:

$$x_p = \left[\frac{1}{T}\int_0^T |x(t)|^{\frac{1}{2}} dt\right]^2 . \tag{14}$$

- Crest factor

$$C = \frac{x_{PEAK}}{x_{RMS}}.c \tag{15}$$

- Impulsivity factor:

$$I = \frac{x_{PEAK}}{\frac{1}{T}\int_0^T |x(t)| dt}. \tag{16}$$

- Waveform factor:

$$K = \frac{x_{RMS}}{\frac{1}{T}\int_0^T |x(t)| dt}. \tag{17}$$

- Clearance factor:

$$L = \frac{x_{AVE}}{x_p}. \tag{18}$$

4. Diagnosis of bearings with use of simple diagnostic measures

The undertaken analyses have made it possible to determine the effectiveness of each presented measure. Were analyzed two states of bearing: a new bearing and bearing worn out. The results obtained for the tested bearings were presented in figures as the quotient calculated from measures values obtained from time course of the vibration acceleration obtained for the worn bearing and for the new bearing.

On Figures 6 and 7 are presented results obtained for bearing of wheel from Toyota Avensis.

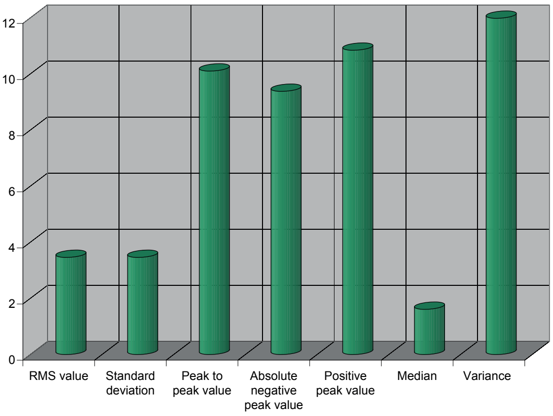

Fig. 6. Values of measures obtained for the tested bearing from wheel of Toyota Avensis

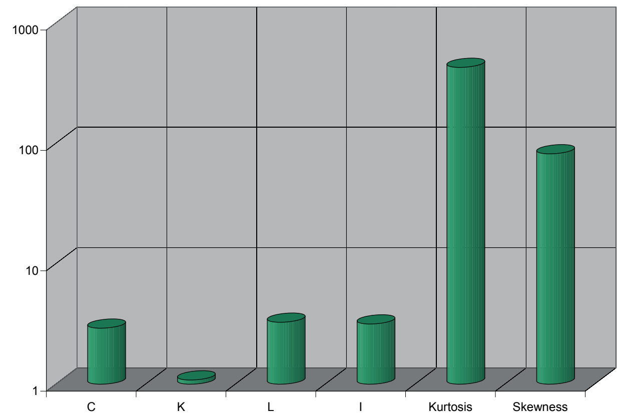

Fig. 7. Values of measures obtained for the tested bearing from wheel of Toyota Avensis - continuation

Analyzing the presented results, it can be concluded that from all the measures under consideration, the wear of rolling bearings is best visible growth of kurtosis. The value is more than 400 times higher for bearing worn out than for new bearing. Good results were also obtained inter alia with use skewness, variance, and peak to peak value. Increase their values was more than 10 times

On Figures 8 and 9 are presented results obtained for bearing of wheel from Fiat Panda.

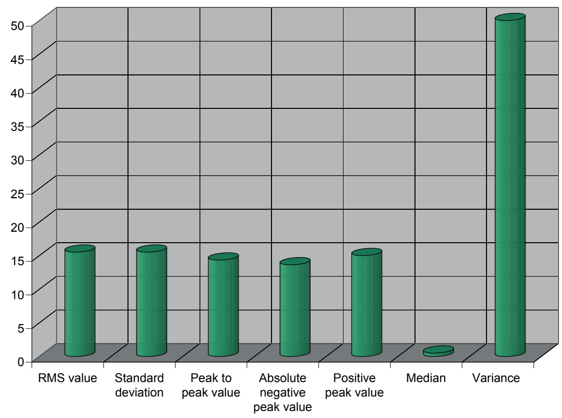

Fig. 8. Values of measures obtained for the tested bearing from wheel of Fiat Panda

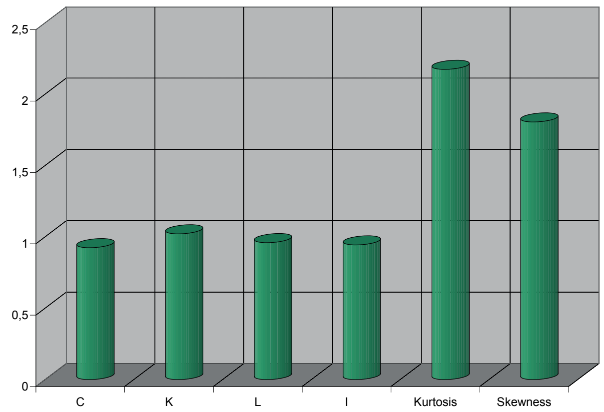

Fig. 9. Values of measures obtained for the tested bearing from wheel of Fiat Panda - continuation

Analyzing the presented results for bearing from Fiat Panda, it can be concluded that from all the measures under consideration, the wear of rolling bearings is best visible growth of variance. The value is about than 240 times higher for bearing worn out than for new bearing. Good results were also obtained with use measure: RMS value, standard deviation, peak to peak value, negative and positive peak values. Changes of other values are diagnostically ambiguous.

The worst results were obtained for median, and factors: crest, waveform, clearance and impulsity.

Significant differences in the evaluation of the suitability of measures for both showed bearings may result from various forms of their wear.

The analysis of vibration signals recorded during research of bearing mounted in Renault Kangoo confirmed the usefulness of kurtosis and variance.

5. Summary

Due to the driving safety diagnostics wheel bearings of vehicles should refer to objective and reliable methods. The test results show that even the use of simple diagnostic measures are appointed on the basis of vibration signals can in many situations to evaluate condition of the bearings. The results show the dependence of the measure on the type of wear. Use of a larger number of measures makes possible to observe significant changes in the vibration signal, that's indicate wear or damage.

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