DIAGNOSTICS OF ROLLING BEARING BY VIBRATION ANALYSIS

Grzegorz WOJNAR, Bogusław ŁAZARZ, Zbigniew STANIK

The Silesian University of Technology, Faculty of Transport
8 Krasińskiego Street, 40-019 Katowice
tel: (032) 603 41 93, e-mail: Grzegorz.Wojnar@polsl.pl

Summary

The bearings of wheels of carriageable vehicles with regard on disastrous state of roads in east Europe undergo accelerated waste what often it leads in consequence to damages different elements and threatens the safety of drive. Frequency analysis of vibroacoustical signals for diagnostics of bearing failure and wear are shown. Special focus is laid on typical faults (outer race, wear of surface). Axial vibrations have been recorded on bearing pivot at a different speed of carriageable wheels. Proposed methods are very sensitive to the development of bearings failure and wear.

Keywords: beraing, diagnostics, vibration car.

DIAGNOZOWANIE ŁOŻYSK TOCZNYCH METODĄ ANALIZY DRGAŃ

Streszczenie

W pracy przedstawiono metodę wykrywania zużycia oraz lokalnego uszkodzenia bieżni zewnętrznej łożysk nie napędzanych kół jezdnych pojazdu samochodowego. Analizom poddawano uzyskane na podstawie eksperymentów czynnych sygnały przyspieszeń drgań wzdłużnych czopa łożyskowego. Zaproponowana w pracy metoda okazała się być bardzo wrażliwa na zużycie oraz lokalne uszkodzenie bieżni zewnętrznej łożysk.

Słowa kluczowe: łożyska, diagnostyka, drgania, samochód, koła jezdne.

1. INTRODUCTION

During motor vehicle operation, its components are subject to wear. In terms of safety, major parts of a motor vehicle are bearing units in road wheels. Although the methods of recording and converting the vibration signals have developed dynamically, especially in recent years [2, 3, 4, 6, 7, 8, 10], today, car inspection stations to detections of wheel bearings damages use only untrustworthy organoleptic methods (fig. 1).

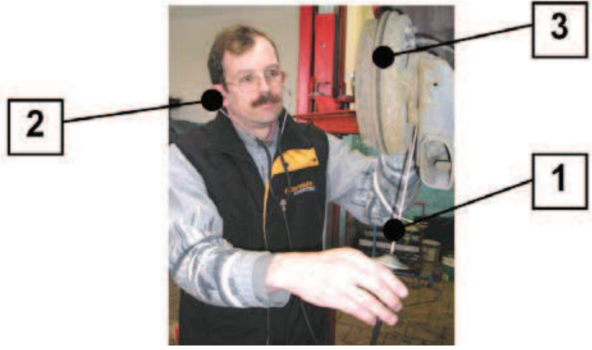

Fig. 1. Diagnostics method using by car inspection stations: 1-stethoscope, 2 - headphones, 3 - diagnosed bearing

Therefore, an attempt was made under this study at applying the method of vibration signals analysis of motor vehicle suspension components, for the purpose of detection of their faults , which breakdown (fig. 2) it can threaten the safety of road traffic.

Fig. 2. Crack of the external race of double-breasted ball bearing

2. THE SELECTION OF A PROCESS AS A SOURCE OF INFORMATION ABOUT THE DYNAMIC CONDITION

Information about the dynamic condition of a particular component can be found in various processes which occur inside the machine or in its surroundings, the processes including vibration, changes in acoustic pressure, driving torque and other. It is clear that each of the processes carries additional information, redundant from the point of view of the diagnostics' purpose. As a result, it is essential to properly reconstruct the information model of a particular process, based on which a decision can be taken to assume this particular process as the diagnostic signal. The course of the information model reconstruction for a machine with mechanical defects is presented in paper [1] . The model shown in Fig. 1 can be also assumed when analysing bearing units of motor vehicle wheels. The vibration signal coming from the mechanical defect to be investigated can be only disturbed by the movement of close kinematic pairs and by signals from other defects in the area (Fig. 1), whereas the acoustic signal can be additionally interfered by acoustic effects: some resulting from other faults in the machine and some connected with the properties of the environment where measurement takes place. If the situation when measurement is being taken is as in Figure 1, the vibration signal will include less information unnecessary from the point of view of the diagnosis purpose.

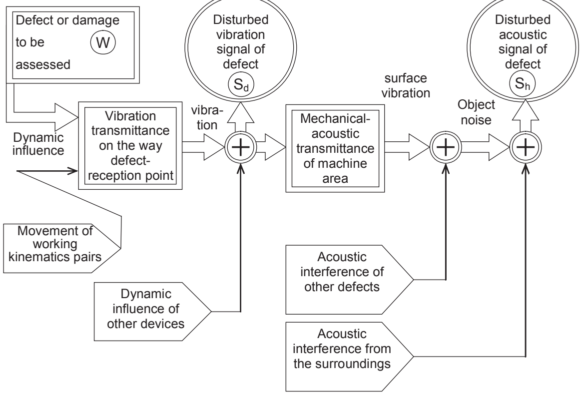

Fig. 1. Diagram showing the formation of vibration and acoustic signals connected with mechanical defectiveness of the machine [1]

Therefore, if the assessed condition of a machine is designated as w, and the vibration and acoustic signals by s_d and s_h, respectively, the following inequality will be highly probable:

$$\frac{\partial s_d}{\partial w} > \frac{\partial s_h}{\partial w} \qquad (1)$$

which means that sensitivity of the vibration signal to changes will be higher than the sensitivity of the acoustic signal [1].

As a consequence, for the detection of wear and local damage to the outer race of a rolling bearing, only acceleration signals were used of axial vibration of the bearing pivot (Fig. 2) which were measured with a piezoelectric acceleration transducer.

3. EXPERIMENTAL RESEARCH ANALYSIS OF THE RESULTS

The tests were carried out on cone rolling bearings of rear, non-driven wheels of a Seat Ibiza car – year of production 1993. Stand tests were carried out with the car lifted on a workshop lift. A car wheel balancer was used to velocity up one of the wheels (Fig. 2). This allowed acceleration of the wheel up to the rotation velocity which corresponded to the car's velocity of maximum ca.150 km/h.

Fig. 2. Method of speeding up the wheel for the purpose of vibration measurement: 1 – on the car wheel balancer, 2 – accelerometer, 3 – measuring apparatus

The acceleration values of axial vibration of the bearing pivot were measured. Also, synchronous reference signals corresponding to the wheel revolutions were recorded. The vibration signal and the signal from the system of averaging synchronization were sampled with the frequency of 25,600 Hz and recorded on a computer hard disk. The car wheel whose rolling bearings were diagnosed, was balanced on a standard balancer. The recorded vibration signal was analyzed within ten intervals (in Fig. 3 marked as bars) with a width corresponding to 25 revolutions of the wheel.

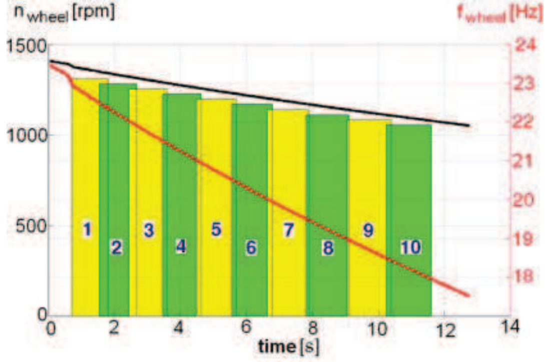

Fig. 3. Changes of rotation velocity and frequency of the wheel during its coasting – new bearings

This study shows only the results for the case where the initial rotation frequency (finitial) amounted to 22 Hz. In an active experiment, damage of the bearing gasket was simulated, in consequence of which was sand and other impurities got in the bearing unit. The bearings were damaged by adding sand and corundum powder to the lubricant. They caused accelerated wear of the race and rolling elements (Fig. 4), undetectable by organoleptic methods. There was no bearing slackness, either, and some traces of wear were observed only after its dismantling.

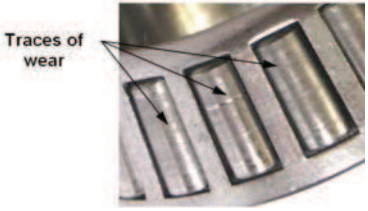

Fig. 4. Traces of wear of rolling elements

Fig. 5 shows changes of the frequency structure of a fragment of the vibration acceleration signal recorded when f initial = 22 Hz. In the spectrum of the vibration acceleration signal during the operation of new bearings, practically only the rotation frequency of the wheel (fwheel) and its harmonics (Fig. 5) were present.

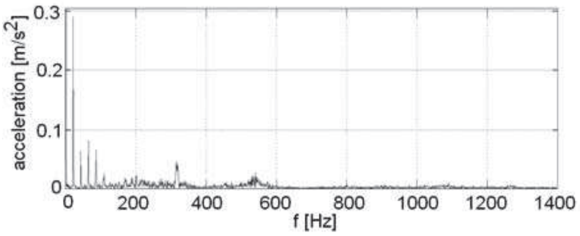

Fig. 5. Signal frequency analysis – new bearings

The addition of sand and corundum powder to the lubricant caused an increase of component values of amplitudes of signal component frequencies in a higher frequency range of over 400 Hz (Fig. 6a).

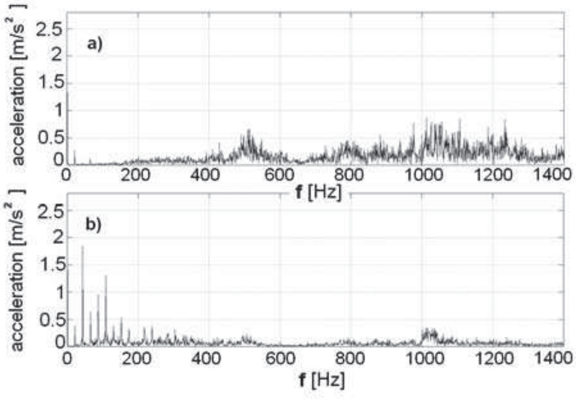

Fig. 6. Signal frequency analysis: a) worn bearings – sand and corundum were present in the lubricant, b) worn bearings – the lubricant was replaced with new one and one type of operational wear was simulated

The lubricant was then replaced with a new one so as to simulate the operation of worn rolling bearings without foreign matter, e.g. sand. In the spectrum of the vibration signal recorded, a considerable increase is visible (as compared to new bearings) of the wheel rotation frequency values (fwheel) and its harmonics (Fig. 6b). The amplitude values of successive harmonics of the wheel rotation frequency (fwheel) for new bearings are compared in Fig. 7 with the corresponding values for worn bearings after adding sand and in the case of using “pure" lubricant.

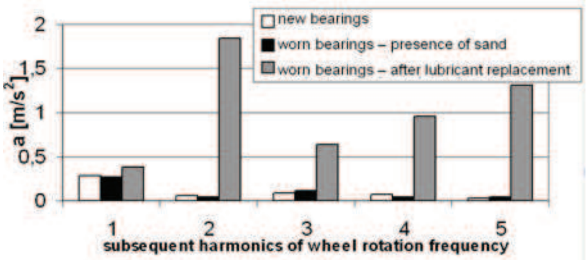

Fig. 7. Amplitudes of subsequent harmonics of the wheel rotation frequency (fwheel) for new and worn bearings in operation

During the operation of rolling bearings, the most common phenomenon is fatigue wear of the race working surfaces, as a result of which pitting occurs on them. In the next phase of the investigations, based on the fatigue damage of the bearing race (Fig. 8a), local damage was simulated of the outer race of the smaller of two bearings fitted on the bearing pivot of the investigated vehicle wheel (Fig. 8b)

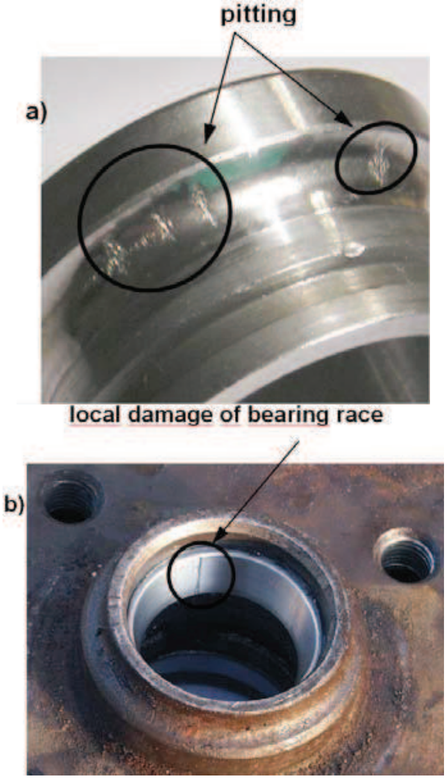

Fig. 8. Local damage of the rolling bearing race: a) operational, b) used in experimental research

The damage shown in Fig. 8b caused an increase in the frequency value (f_{bzM}) connected with the rolling of rolling elements over the damaged piece of the small bearing's outer race. In the case under consideration, the frequency (f_{bzM}) determined based on dependencies presented in [2, 3, 6, 9] was by ca. 5.619 times higher than the rotational frequency of the wheel (f_{wheel}). Fig. 9 shows the envelope spectrum for new bearings in operation. In the spectrum, a component of the wheel rotational frequency (f_{wheel}) and its harmonics predominate. Fig. 10 presents the envelope spectrum in the case of local damage to the outer race of the smaller of the rolling bearings. Components of frequency f_{bzM} connected with the rolling of rolling elements over the damaged piece of the race and its harmonics are clearly visible.

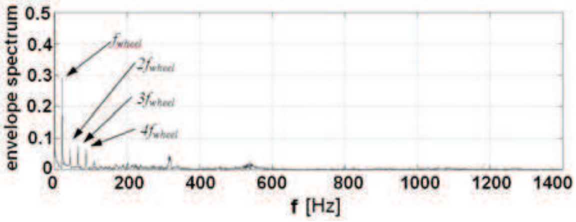

Fig. 9. Envelope spectrum – new bearings

Also, a linear dependence was noticed between the wheel rotational frequency (f_{wheel}) and the RMS value of the signal (Fig. 11). Next, the amplitudes of subsequent harmonics of the frequency(f_{bzM}) connected with the rolling of rolling elements over the damaged piece of the small bearing's outer race were referred to the RMS value of the signal (Fig. 12a). Furthermore, the amplitude values of the first six frequency harmonics (f_{bzM}) were added up, since this is were the energy related to the damage was cumulated and the so calculated sum was referred to the signal's RMS. The proposed measure calculated from relation (2) is little sensitive to any changes in the wheel rotational velocity (the maximum deviation from the mean value is ± 8%). It is sensitive, however, to local damage of the bearing race (Fig. 12b).

$$M_a = \frac{\sum_{i=1}^{6} \max A_o\left(i \cdot f_{bzM} \pm 5\% f_{bzM}\right)}{a_{RMS}}, \quad (2)$$

where:

a_{RMS} - RMS value of the vibration acceleration signal,

f_{bzM} - frequency connected with the rolling of a rolling element over the damaged piece of the small bearing's outer race,

$\max A_o\left(i \cdot f_{bzM} \pm 5\% f_{obzM}\right)$ - maximum amplitude of envelope spectrum determined in bands $i \cdot f_{bzM} \pm 5\% f_{bzM}$ for i=1÷6.

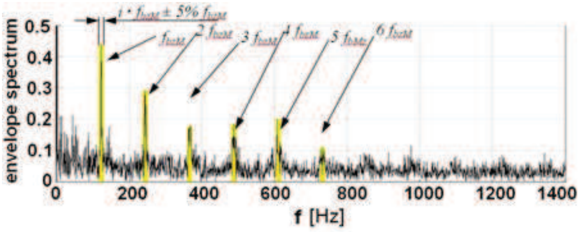

Fig. 10: Envelope spectrum – local damage of outer race of the smaller bearing, $f_{initial}$ = 22 Hz

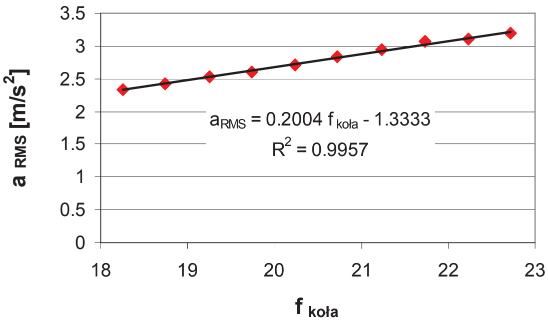

Fig. 11. Dependencies between the wheel rotational frequency (f_{wheel}) and the signal's root-mean-square value

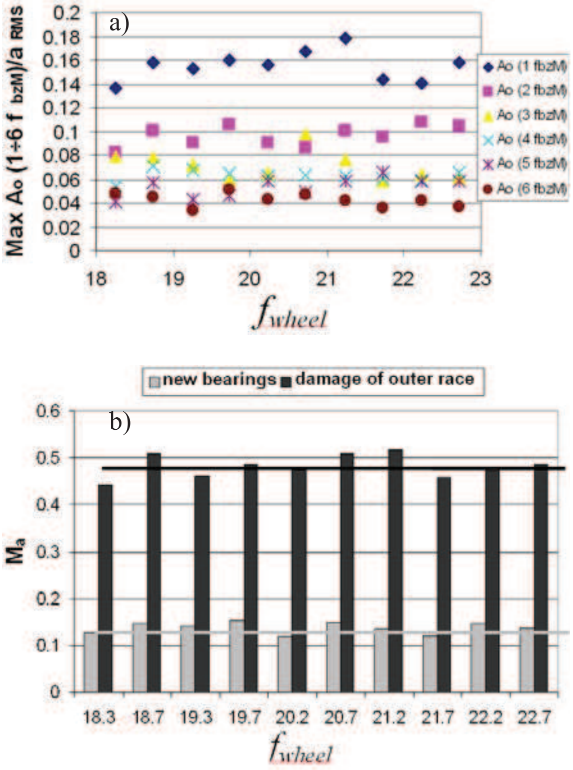

Fig. 12: Dependencies between: a) the amplitude of subsequent harmonics of frequency f_{bzM} and the wheel rotational frequency, b) the proposed measure and the wheel rotational frequency

4. CONCLUSIONS

Based on the investigations and analyses carried out, the following conclusions can be formulated:

- the wear of working surfaces of rolling elements in wheels' bearings and presence of sand in a bearing caused an increase in the component amplitudes of frequencies above 400 Hz,

- in the case of operational wear simulation (absence of foreign matters), the wear of working surfaces of rolling elements in wheels' bearings caused a significant increase in the amplitudes of subsequent harmonics of the wheel rotational frequency,
- local damage to the rolling bearing's outer race caused an increase in the component amplitude of frequency (f_{bzM}) connected with the rolling of rolling elements over the damaged piece of the bearing race.
- The proposed dimensionless measure of outer race damage is little sensitive to any changes in the wheel rotational velocity, however, it is sensitive to local damage of the bearing race.

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PhD. Eng. **Grzegorz WOJNAR** adjunct of The Silesian University of Technology. Scientific interest: modeling of dynamic processes, diagnostics of tooth gear, machine design and processing vibroacoustical signal.

DSc. Eng. **Bogusław ŁAZARZ** profesor of The Silesian University of Technology. Scientific interest: modeling of dynamic processes, diagnostics of tooth gear, machine design and processing vibroacoustical signal. Member of Machines Construction Committee.

PhD. Eng. **Zbigniew STANIK** adjunct of The Silesian University of Technology. Scientific interest: wear outer layer and cars design.