Automatic computer systems for roller bearings diagnostics

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Abstract

Within recent years the commercial success of the computer systems for the diagnostics of rolling element bearings by the analysis of vibration signal excited by friction forces is growing rapidly. Originally such systems were developed in Russia and afterwards due to their unique features, such as a possibility to provide detailed diagnostics and long term condition prediction of a bearing by a single vibration measurement combined with the simplicity in application that does not require special training in diagnostics from the operator, came into use in the West.

Nowadays, the experience in application of such system on transport, in particular on railways, was accumulated only in Russia where this system was tested during a year in a number of railway divisions. During these tests all the specific problems of the system application on railways were taken into account, especially the ones determined by the necessity to make vibration measurements on a moving object. The analysis of the obtained practical results and the problems observed together with the possible solutions are presented below.

Basics of the method

The suggested method of bearing diagnostics is based on the analysis of friction forces in a bearing. In a good rolling element bearing the friction force is stable in time and does not depend on the revolution angle of the cage and rollers. When such a defect as wear, flaws or spalls on the friction surfaces develops, a friction coefficient becomes not uniform. It causes amplitude modulation of the high and medium frequency vibration excited by the friction forces. The special methods of envelope spectrum analysis are used to determine and analyze the reason for the modulation of friction forces. To get a reliable diagnostics it is essential to use an appropriate band pass filter for extraction of pseudo random components from the vibration signal prior to demodulation. For example, consider an autospectrum of the wheel pair box bearing’s vibration on the locomotive (fig.1) and corresponding envelope spectra of random vibration. Envelope spectra were measured using a 1/3 octave band pass filter with a 6.3 kHz center frequency. The upper envelope spectrum with no harmonic components reveals the absence of vibration, and thus friction forces,
modulation. This is a good evidence that the bearing is in excellent condition and has no defects. The second envelope spectrum was measured on the other wheel pair and it has all symptoms for a severe spall of the outer race of the bearing.

\[ a) \]

\[ b) \]

\[ c) \]

*Figure 1: Autospectrum (a) and two envelope spectra measured on the box bearings of the locomotive. Envelope spectrum (b) was measured on a good bearing and (c) on a bearing with severe cavity or spall of outer race.*

All of the 12 possible types of defects even in the initial stage of development can be detected and identified in the rolling element bearing by the envelope spectrum analysis. The frequencies of the harmonic components in the envelope spectrum are responsible for the defect type and their amplitudes -- for the defect severity. One measurement of the envelope spectrum of high frequency vibration on the bearing shield is enough for the diagnostics of the
bearing. If there are no harmonic components in the envelope spectrum, the next measurement should be done in 20% of MTBF (mean time before failure), but not later than in 6 months. If one severe defect was found, as in the second envelope spectrum (figure 1c), the next measurement should be done in one month or the bearing should be replaced. If two severe defects were detected, the bearing should be immediately replaced.

As was described above, the analysis of pseudo random signals is used for diagnostics. The other side of the coin is the necessity of averaging during measurements. For a reliable diagnostic result the vibration should be measured during several dozens of bearing's revolutions. The envelope spectrum is processed automatically by the DREAM (Diagnostic Rolling Element Analysis Module) application software that identifies all defects and provides long term condition prediction for the bearing in a couple of seconds. One operator can control the condition of several thousands of bearings eliminating their unpredictable failures.

**Diagnostic complex configuration**

Diagnostic complex for rolling element bearings includes vibration transducer, spectrum analyzer with envelope detector and personal computer with the DREAM application software. Spectrum analyzer may be substituted with the analog to digital converter (ADC) board interfaced to the vibration transducer in the same computer and adequate software. Commonly the special industrial analyzers or data collectors are used in the portable systems. In this case they can be preprogrammed by the DREAM software for a great number of measurements included in the route map. In the stationary systems the number of the transducers can be from 4-10 up to several hundreds. The transducers are coupled to the ADC board directly or via multiplexor.

![Figure 2: A portable automatic system for roller bearings' diagnostics consists of a personal computer with the DREAM application software and spectrum analyzer or data collector.](image-url)
Such systems are widely used in a number of industries where there are no practical problems in vibration measurements on bearing shields. On the railway transport the vibration measurements on roller bearings are more complicated due to the train movement. At the same time a standard diagnostic system can be successfully used for the diagnostics of the locomotives’ equipment.

**Peculiarities of box bearing diagnostics**

The main experience in box bearings' diagnostics was gained during vibration measurements on the bearings of a single wheel pair mounted on a special stand. Such stands are used for trial runs of the wheel pairs before and after repair and balancing. Usually the wheel pair is rotated from an external drive at 200-1000 rpm. The gravitation force in this case provides the same direction of load on the bearing as in normal operation during train movement.

Bearing diagnostics in this case has no peculiarities compared to the bearing diagnostics in other branches of industry. The statistical results are identical to the ones observed on other machines. The probability of missing a severe defect in the bearing by the results of a single measurement does not exceed 1-2%. The probability of the correct identification of the defect type and severity in automatic mode is dependent on the defect danger and fully coincides with the earlier obtained data. One of the conclusions that was made by the results of bearing diagnostics, confirmed by the visual inspection, is that more than 50% of the wheel pairs that came to the shop for repair do not have severe wear of bearings or other defects that require bearing replacement.

There is also a great experience in box bearings diagnostics on locomotives. The locomotive was lifted using special jacks and the wheels were rotated by the main motors. The efficiency of diagnostics in this case is also very high, but it is possible to underestimate the severity of the outer race defect in the bearing. The reason for it is that the direction of load applied on the bearing in inverted in this case. (The load is applied on the bottom of the outer race by the weight of the wheel pair. In normal mode of operation the load is applied on the top of the race by the weight of the locomotive itself.) The outer race defects may be not loaded properly and their input in the overall friction forces and vibration may be decreased. As an example, consider figure 3 that presents two envelope spectra of the locomotive box bearing vibration. The upper spectrum was measured when the locomotive was lifted and the down spectrum was measured on a special stand. The first spectrum has typical symptoms of the medium wear of the bearing’s outer race and the second -- severe cavity or crack on the same race.

Investigations were carried out to determine whether it is possible to make diagnostics of roller bearings on a moving train. The vibration transducer was fixed on a wheel box and the cable went to the accessible place in the railway car or locomotive. The results in general were very positive, though sometimes
additional components in the envelope spectra were observed. These components should be taken into account in diagnostics.

a)  

\[0.5 \text{ G} \]
\[0.005 \text{ G} \]
\[0.0005 \text{ G} \]

b)  

\[0.5 \text{ G} \]
\[0.005 \text{ G} \]
\[0.0005 \text{ G} \]

Figure 3: Envelope spectra measured on the same box bearing with loads on the bearing applied in the opposite directions. Spectrum (a) was measured on the lifted locomotive. Spectrum (b) when the wheel pair was rotated on a special stand with the correct load applied on the bearings.

The reason for such line's appearance is the dynamic load applied on the bearing due to the deviations from circularity of the wheel or shock pulses from rail joints. These dynamic loads also result in modulation of friction forces. On figure 4 you can see examples of envelope spectra measured on railway cars' box bearings in motion. The first case demonstrates the possibilities in bearing flaws diagnostics, in particular the wear of rollers. The second one demonstrated the influence of deviations in wheel circularity. Here you can see a full set of rotation frequency harmonics in the envelope spectrum. The third spectrum demonstrates the influence of rail joins on the diagnostic signal. The spectrum was measured in winter when there are maximum gaps between rails. Here you can see the full set of harmonics of a frequency much lower than the rotation speed.

It is evident that a standard DREAM application software should be modified for this case, but there are no practical problems for doing this, besides it enables us to diagnose the circularity of the wheels and the quality of rail joins. It should be noted that one of the possible solutions can include vibration transducers with FM transmitters. These transducers can be fixed on box bearings for one span, providing all information for bearing diagnostics without significant financial investments for train equipment. Besides, very interesting
results were obtained not in vibration, but noise measurements emitted by bearings. Special directed microphones were used in this case. The measurements were done just from the cars of a moving train.

Figure 4: Envelope spectra measured on railway car box bearings in train motion. Spectrum (a) reveals the wear or rollers in the bearing, spectrum (b) indicates deviations of wheel circularity and the lines in spectrum (c) originated from the shocks from gaps in rail joins.
**Perspectives**

The described method of roller bearing diagnostics by the envelope spectrum analysis enables all types of bearing defects to be found several months before they can cause catastrophic failure of the bearing. We see three main application fields for this method and the existing automatic computer diagnostic system in the railway transport.

The first one, the most efficient, is to build special roller stands (figure 5). It should include rollers mounted in the rails with an external drive.

![Figure 5: The suggested stand for roller bearing diagnostics includes special rollers driven from external drive that would ensure wheel rotation of wheels for the period of measurements.](image)

The goal is to rotate wheel pairs of the locomotives or cars just in train. The stand should include 2-3 pairs of rollers that is enough to make measurements of all roller bearings in a wheel cartridge. It takes about 5 minutes for measurements and diagnostics of all bearings in a cartridge and then train advances one cartridge further. In this way the roller bearings should be diagnosed once every 3-6 months. This will decrease the probability of unpredicted bearing failures in several orders.

The next perspective is the use of stationary monitoring and diagnostic systems for roller bearings, in particular for locomotives. It should be noted that not only roller bearings, but also gearboxes, couplings and electromagnetic systems of electric motors can be diagnosed by the vibration of bearing shields.

The third direction is the wayside control of roller bearings by the use of directed microphones. There are some practical problems to be solved in the process of such a system development. The main one is how to decrease the measurement duration from the period of several dozens of wheel revolutions to
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about 5-10 preserving high reliability of diagnostics. Very good results were achieved by authors in the solution of this problem. The second problem is closely related to the additional modulation of the signal amplitude when the noise source moves relative to the directed microphone. This problem can be solved in the process of adaptation of the diagnostic algorithms in the existing computer system for wayside roller bearings condition diagnostics. Wayside bearing diagnostic system can be considered as the most perspective one as it enables one to plan maintenance schemes based on the actual condition of rolling stock.

Summary

1. Today there exists an automatic computer system that provides detailed diagnostics and long term condition prediction (up to 6 months) of roller bearings by a single vibration measurement.
2. This system is used on Russian railroads for diagnostics of roller bearings before and after repair of wheel pairs and for condition monitoring and diagnostics of rolling element bearings in other machines.
3. The system is being used for the diagnostics and maintenance planning of locomotives and condition diagnostics of their equipment.
4. It is possible to adapt this system for wayside control of the box roller bearings of the railway cars. One of the two possible ways to solve this problem may be suggested. The first one is to equip repair or maintenance shops with roller stand with diagnostic computer systems. The roller stands should ensure the rotation of wheel pairs from external drive. The second one is to use special equipment for roller bearing noise measurement from passing by trains.

References