

Roller bearing fault detection by applying wireless sensor of instantaneous accelerations of mechanisms moving elements

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Abstract – High-sensitivity tools and methods of receiving diagnostic information are needed to detect low-energy defects. In this paper, the author proposes experimental results of the application of instantaneous angular acceleration for roller bearing fault detection (outer race fault, inner race fault and one ball fault). The experimental results show that defects are clearly visible in frequency spectrum of the angular acceleration. Also, the results can be used to build the defect patterns. In addition, the results show that frequency spectrum components of angular acceleration are significantly amplified around natural frequencies of the mechanism. Moreover, the study showed that instantaneous angular acceleration can be applied for detection of incipient defects.

I. INTRODUCTION

Diagnostic information is the base of mechanism condition monitoring. Signals from accelerometers, which are mounted on bearings or on a housing of a mechanism, are the traditional sources of diagnostic information. However, special mathematical methods are needed to apply the diagnostic information from such accelerometers to detect defects which are low-energy or to detect incipient defects [1-3].

Alongside with the traditional method, researchers propose other methods. Thus, the authors in studies [4-6] used various encoders to measure the instantaneous angular speed and to measure the gear transmission error. Furthermore, the development of wireless-technologies (for example, wireless power transfer technologies such as Qi (WPC) [7]) and MEMS-technologies allows an increase in capability of sensor mounting on and inside of mechanisms (for example, on hard-to-reach places). To confirm this, in the study [8], the authors increased sensitivity of the sensor by mounting an accelerometer directly on rotating shaft. Also, in the study [9] the researchers mounted a two-axis accelerometer on the center of a hollow shaft. Moreover, the researchers in study [10] proposed the wireless sensor to measure angular and linear accelerations of mechanism shaft. The mathematical model of the sensor was described in [11].

The present study shows the application of the wireless sensor in practice to detect faults of rolling element bearing by measuring instantaneous angular acceleration.

II. TEST BENCH WITH WIRELESS SENSOR

The author developed a sample of the wireless sensor with three single-axis accelerometers. The accelerometers are oriented tangentially to axis of a sensor rotation. Also, the accelerometers are equidistant from the axis of a sensor rotation. Accordingly, the sensor sample allows measuring an angular acceleration around an axis of sensor rotation and linear accelerations which have an effect on the sensor at a normal plane to axis of the sensor rotation.



Fig. 1. Machinery fault simulator with wireless sensor.

The author used MEMS-accelerometers ADXL001-70 (Analog Device company). The accelerometers have $\pm 70g$ wideband range and 22 kHz resonant frequency structure. The signals of the accelerometers were sampled at 42 kHz by analog-to-digital converter AD7609 (Analog Device company).

The sensor sample was mounted next to the rolling bearing on the shaft end of a machinery fault simulator (Fig. 1). Also, the machinery fault simulator contained a defect-free induction motor and roller bearings.

The design of the machinery fault simulator allows changing the bearings on other ones with known defect. The author used three bearings each having one of the

following defects: outer race fault, inner race fault and one ball fault.

Fundamental excitation frequencies of roller bearing vibration are well-known. Also, the occurrence and increase of a defect leads to the occurrence of additional components in the frequency spectrum. Thus, the specific frequencies of the additional components indicate specific defects of a rolling bearing.

The frequency spectrum of the angular acceleration reacts to the defects in the same way as the frequency spectrum of the linear accelerations. However, the experimental results showed that the specific frequencies of the additional components are different from the well-known ones.

III. EXPERIMENT RESULTS

The author studied a change of accelerometer acceleration and of instantaneous angular acceleration due to the rolling bearing defects. The wireless sensor measured the accelerations of the shaft while the shaft was in steady rotation. The shaft speed was 12 Hz.

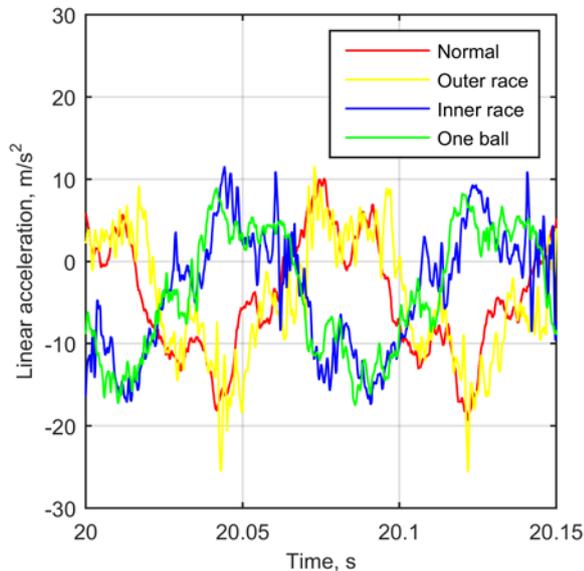


Fig. 2 The measured instantaneous acceleration from the accelerometer. Time domain.

Fig. 2 shows the acceleration of the sensor accelerometer in several situations when mechanism contains a good bearing and when mechanism contains a bearing with various defects. The rolling element bearings defects change the signal of the accelerometer. Furthermore, the various defects change the accelerometers signal in a different way. Besides, the accelerometer signal has a negative displacement. The displacement is caused by centrifugal force which impacts the inside components of the accelerometer. Moreover, the accelerometers measured also gravitas

acceleration because the shaft is oriented horizontally. Thus, a sensitivity plane of the sensor is oriented vertical. That fact explains a signal fluctuation with the frequency of the rotation shaft. In addition, a various initial angle of the shaft leads to an initial signal phase shift. The phase shift between the signals of the experiments is visible in Fig. 2.

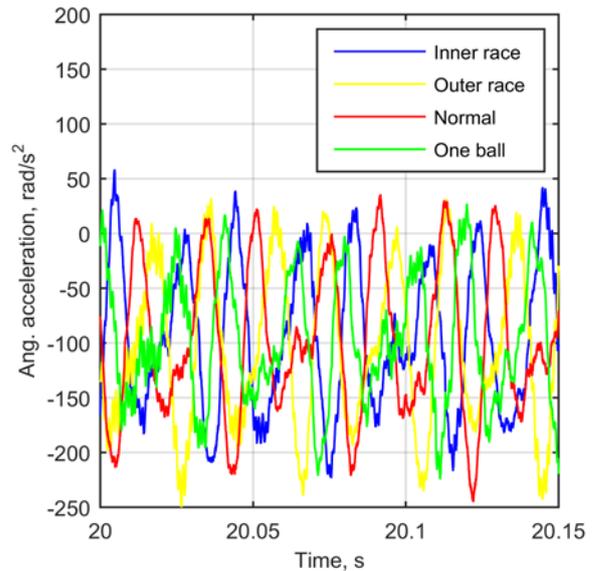


Fig. 3 The measured instantaneous angular acceleration. Time domain.

The instantaneous angular acceleration is calculated from the signals of three accelerometers by virtue of the ARM-based low-power micro-controller which the sensor contains. Moreover, the angular acceleration is calculated in real-time. Thus, the angular acceleration was calculated for each experiment. Fig. 3 shows the calculated instantaneous angular accelerations for each experiment.

The signal waveforms of the instantaneous angular accelerations differ from the signal waveforms of the acceleration of the accelerometers. Also, the instantaneous angular acceleration is free of gravitational acceleration. At the same time, the angular accelerations have also constant negative displacement; however, that problem has an insignificant effect on the defect detection procedure.

The author applied the fast Fourier transform (FFT) to value the frequency components of the angular accelerations. Fig. 4 shows frequency spectrum of the angular acceleration in several situations when the mechanism contains a good bearing and the mechanism contains a bearing with a defect.

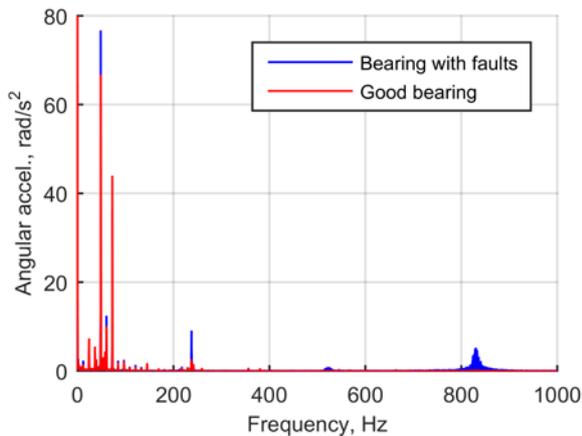


Fig. 4 The measured instantaneous angular acceleration. Frequency domain.

The frequency spectrums have mismatch in several frequency ranges. Also, several frequency components of the spectrum were amplified around the natural frequencies of the mechanism, for example, around 60 Hz, 220 Hz and 830 Hz. That effect occurred due to the fact that the sensor was mounted on the shaft of the mechanism, as a result, the sensor sensitivity increased around the natural frequencies of the mechanism. Thus, the measured accelerations by the sensor were amplified.

Figs 5 to 8 show some ranges of the frequency spectrum of the angular acceleration of the shaft for the bearing with various defects and the normal bearing. The frequency spectrums contain peaks which are multiple to the frequency of the shaft rotating. Also, the frequency spectrums have additional peaks and the components which are associated with the bearings.

Fig. 5 shows that the defects of the bearing lead to the significant amplitude change of the shaft rotating frequency. Also, spectrum components occur around 60 Hz which are caused by the defects of the bearing. The biggest components are caused by the inner race fault.

The amplitudes of the second and the third peaks of the rotation shaft harmonics of the fault bearings are less than the amplitudes of the normal bearing. In addition, the frequency spectrum of the normal bearing contains peaks around 53 Hz and 57.5 Hz, but the frequency spectrums of the fault bearings have no peaks. However, spectrum of the inner race fault bearing contains the peaks, but the amplitudes are smaller than the amplitudes of the normal bearing. In contrast, only spectrum of the normal bearing contains the peak of around 39 Hz. Presumably, the fact occurred due to the design features of the normal bearing.

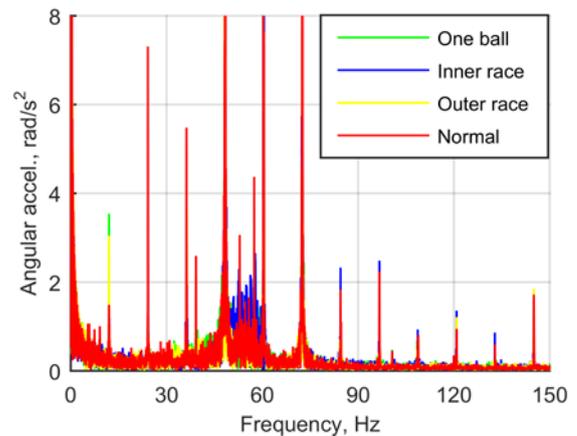


Fig. 5 The frequency spectrums of instantaneous angular acceleration from 0 to 150 Hz.

Fig. 6 shows several peaks. Most of the peaks are multiple to the frequency of the shaft rotating. However, the biggest peak is multiple to the frequencies of the bearing. Moreover, various defects contribute variously to the amplitude of the biggest peak. In contrast, the defects of the bearing lead to the decrease in the amplitudes of multiple frequencies of the shaft rotating.

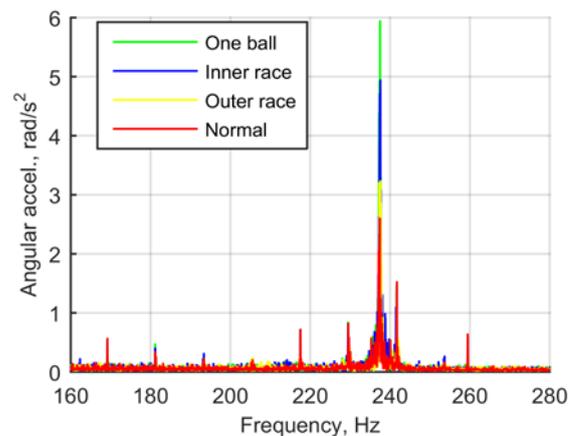


Fig. 6 The frequency spectrums of instantaneous angular acceleration from 160 to 280 Hz.

Fig. 7 shows that the defects of the bearing lead to the amplitude change of the existing peaks. In addition, the amplitude of the peak of around 545.3 Hz has increased significantly. Moreover, the defects lead to the appearance of additional components which are commensurable with the existing peaks.

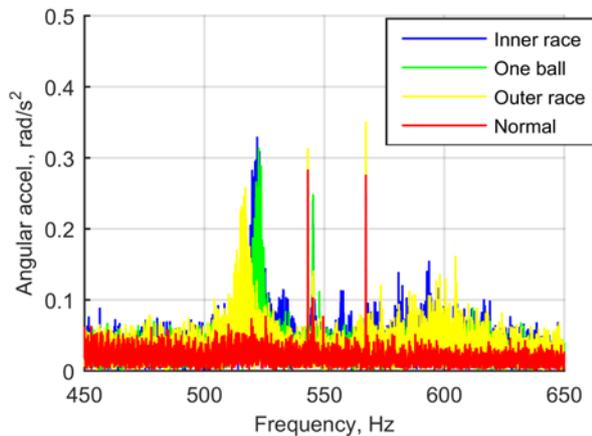


Fig. 7 The frequency spectrums of instantaneous angular acceleration from 450 to 650 Hz.

Fig. 8 shows several peaks which are multiple to the frequency of the shaft rotating and components which are caused by the defects of the bearings. What is more, the amplitudes of the components are much larger than the peaks amplitudes.

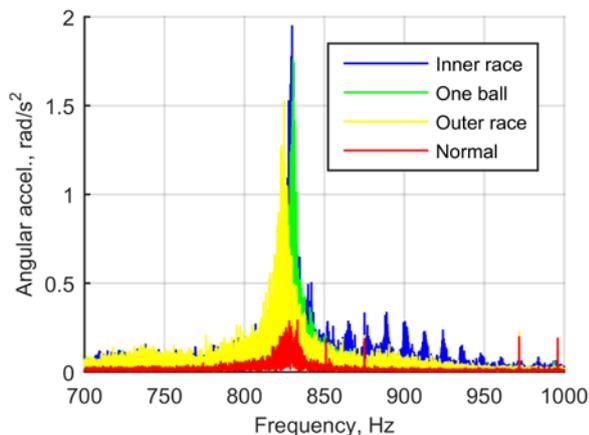


Fig. 8 The frequency spectrums of instantaneous angular acceleration from 700 to 1000 Hz.

Thus, each defect of the bearing has its own signature and frequencies. Therefore, researchers can build the pattern of defects which allows detecting defects from mixed signals of shaft angular acceleration of a mechanism.

IV. CONCLUSIONS

This study has demonstrated that the measurement of instantaneous angular acceleration by the wireless sensor allows detecting and unambiguously identifying defects of roller bearings such as outer race fault, inner race fault and one ball fault. Moreover, due to the sensor sensitivity increasing around natural frequencies of a mechanism the frequency spectrum of instantaneous angular acceleration

contains the amplified spectral components which are low-energy but high-informative about incipient defects.

The instantaneous angular acceleration is a highly effective source to obtain reliable diagnostic information about technical condition (including incipient defects) of rolling bearings.

The future studies will analyze the measured signals from the wireless sensor to identify several mixed defects such as bearing fault and gear fault.

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