Health Diagnosis and Fault Detection of Roller Bearings via Ultrasonic Technique

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Abstract

Roller bearings have been among highly inspected industrial products in recent years. Both condition monitoring as well as periodic inspection has been utilized to determine the status of bearings. Vibration analysis and acoustic emission have both been widely investigated in their applicability for the testing of bearings. These approaches are useful in case of bearing investigation during its life service and could help the user in implementing predictive maintenance. On the other hand, visual inspection is commonly used for periodic inspection and maintenance. Although, this approach could help in failure analysis and qualitative inspection of roller bearings, however, there isn’t any generalized method which could monitor the damage through quantification of surface damage level. There are different approaches for surface parameters quantification.. In this paper bearing surface geometry is investigated through Ultrasonic Spectroscopy. Three types of spherical bearings with healthy, somewhat faulty, and absolutely faulty status are investigated. Practical aspects of this approach are discussed herein and comments about future works are outlined.

Key words: Roller bearing, Ultrasonic spectroscopy, Damage classification, Roughness

Introduction

In rail transportation industry similar to other industries decisions and procedures are conducted as direct results of economic considerations. In the meantime, a considerable activity of this industry is comprised of maintenance division and its practices. Consequently, due to ever expanding application of bearings in the railroad industry, high volume of budgeting allocated to this section is not out of expectations. Presently, numerous methods are used for the inspection of bearings, amongst which very highly applicable methods in train axels bearings, is the visual inspection(Kayalı, Ucun et al. 2009). Although this is a very common procedure, however because of being a qualitative method, it’s not entirely trouble-free either. One of these difficulties is lesser precision compared with other quantitative methods and in addition due to personal mistakes, discarding of healthy bearings from service takes place rather frequently.

There are other methods for inspecting defective bearings. One of which is vibration analysis that is based on measuring generated vibrations due to the actual rolling of bearings. Although vibration analysis has gained more attention in recent years it has some practical limitation(Al-Ghamd and Mba 2006). Similar to this method, there’s another procedure named sonic analysis offering higher precision and at the same time, costing more (Stepanova, Tenitilov et al. 2009).

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Ultrasonic non-destructive testing method is one of the most common procedures in inspection of mechanical devices in different industries particularly in the railroad industry. Also this method is used for diagnoses of defects on different surfaces in a host of applications. One of which is using it in analysis of surface defects (Rokhlin and Kim 2003). Moreover, in many applications there are attempts in determining surface roughness by utilizing ultrasonic method. In research conducted by Rose and Bilgen by using ultrasonic waves and analysis of noise level to signal in echoed waves from the surface, surface roughness has been measured (Bilgen and Rose 1993).

Using the Doppler effects in ultrasonic waves; is another method utilized for surface roughness determination (Forouzbakhsh, Gatabi et al. 2009). In another research, by using fuzzy logic roughness level of the surface determination for three levels of roughness has taken place (Iseri, Kobashi et al. 2005). Also on the basis of wave reflection model coupled with analysis of changes occurring in the reflection coefficient of the frequency space, level of roughness in the surface has been determined (Gunarathne and Christidis 2001). In this investigation, attempt has been made to present criteria for quantification of destruction in different types of bearings by making a connection between level of surface roughness and generated distortion on the surface of the bearing. In addition, a new method for inspection of defects in different types of bearings in railroad industry is presented by utilizing ultrasonic testing. In order to evaluate the presented method, complementary tests have been conducted on the bearings of the head axle of a wagon with different levels of defects.

**Materials and Procedure**

**Calculation of surface roughness**

Surface defects made on internal and external rings of the bearing generated under working conditions leads to change in the level of surface roughness. Reflection wave through abnormal surface could be estimated from the following relation:

\[ F(\omega) = G(\omega) \cdot X(\omega) \]  \hspace{1cm} (1)

In which \( G(\omega) \) is the reflection from normal surface, and \( X(\omega) \) is the abnormality function which evolves with \( G(\omega) \) in time domain. Three spherical roller bearings with different levels of health were investigated through ultrasonic spectroscopy. Ultrasonic probes with 4 MHz natural frequency were used. Reflection wave were gathered and analyzed through 100 MHz digital oscilloscope. Time domain data was exported to MATLAB software and Fourier transformation was performed.

On the basis of points discussed; in this research, level of surface roughness was used as a parameter for the determination of surface defect and its level.

In order to measure the surface effect of roughness in reflection its coefficient of ultrasonic wave has been considered. By using the following relation, it is possible to connect single frequency ultrasonic wave’s amplitude of a smooth surface to reflected wave from a rough surface (Gunarathne and Christidis 2001);

\[ |m_{\text{rough}}| = |m_{\text{smooth}}| \cdot \exp \left( -\frac{8\pi^2 S_i f_i^2}{c^2} \right) \]  \hspace{1cm} (2)

Here \( m_{\text{rough}} \) is the amplitude of the reflected wave from defective surface which is found by theoretical method and \( m_{\text{smooth}} \) is amplitude of reflected wave from a healthy surface and \( S_i \) is the coefficient of surface roughness. Using the above relation in measuring reflected wave from a smooth surface, as well as reflected wave
from a none-smooth surface can enable us to determine the surface roughness. This equation is presented for a single frequency and since ultrasonic wave contains different frequency levels at the vicinity of resonant frequency of the probe, it becomes necessary to determine $S_T$ such that diagram of reflected wave from a healthy surface would fit that of a defective surface diagram in the frequency space. For this purpose, value of $S_t$ is determined by optimization method.

![Figure 1-Bearing and Holder](image1.png) ![Figure 2-Apparatus of C-Scan used for the Procedure](image2.png)

**Measurement of Reflected Ultrasonic Waves**

Bearings used in this research were medium type roller bearing and were used in axel heads of passenger cars with MD36 bogies (Farahpour and Younesian 2009). In conducting necessary analysis, three types of bearing selected through qualitative methods by a maintenance expert were selected. These bearings had three levels of distortion (low, medium, high) Figures 1 & 2 depict how equipment were set up for this experiment. In order to transmit ultrasonic wave to the bearing’s ring, a holder was designed and made as shown in figure 1. Also for maintaining and moving of the probe inside bearing, a special C-Scan was made in the NDT laboratory of Iran University and technology.

In this investigation, in order to generate ultrasonic waves, a probe of 4 Mega Hertz was used. Since using of water could have destructive effect on the bearing, low viscosity engine oil was used in the experiment. Furthermore, for Analog to Digital (AD) measurements, AD signal cart with sampling frequency of 20 Mega Hertz were used (SDS200A, 2CH, 200 MHz, 5GC/s equiv). Finally, received signals were analyzed in MATLAB mathematical software. Also to prove the ability of this method, each experiment was repeated several times.

**Results and Discussions**

Initially, reflected ultrasonic waves from distorted surfaces of bearings as well as reflected waves from a healthy surface were measured in time domain. Subsequently, while choosing a suitable window and by using fast Fourier transformation, the desired information were converted into frequency. In accordance to convolution theory and equation (1) it is possible to introduce a new function which mimics the abnormality in frequency domain. Figure 4 is the abnormality function in the frequency domain. This function can be used as an inspiration for pattern recognition in bearing health classification process.
Figure 3: Time Domain Presentation of Surface Reflection for healthy surface (Solid line) and for distorted (Dashed line)

Figure 4: Abnormality Function in Frequency Domain for faulty surface (Dashed line), most faulty surface (Solid line), and healthy surface (Dashed dotted line)
With the application of equation (2) and least square optimization method reflected waves from a healthy surface in frequency domain were mapped to the measured signal from distorted surfaces. Attained results from conducted procedure on these groups of bearings led to specific values of $S_T$ which imply surface roughness of the ring in specified location and the level of damage to that zone. Results of this process are shown in Figure 5 and figure 6 for most faulty and faulty surfaces respectively.

In light of results gathered, other tests were also conducted on different types of bearings also handpicked by the same maintenance expert. All the measured bearings were grouped into four categories. This was done through quantitative separation of that expert. Group A was indicative of healthy bearings, group B meant still workable bearings, C was representative of recoverable bearings and group D presented bearings not recoverable and hence labeled out of order.

Figure 5: frequency domain presentation of reflection from healthy surface (Dashed Dotted line), reflection from most faulty surface (Solid line), and mapped signal (Dashed line)

Figure 6: frequency domain presentation of reflection from healthy surface (Dashed Dotted line), reflection from faulty surface (Solid line), and mapped signal (Dashed line)
Considering possibility of very high sensitivity of frequencies surroundings resonant frequency of the probe (probe frequency) in analyzing statistical results; attempt was made to study signal to noise ratio for these frequencies and in the end a more suitable range for calculations was determined. On this end, the obtained result from all experiments for the bearing with highest amount of distortion was studied. Figure 6 shows changes of reflective wave’s amplitude in different frequencies along with mean value. As it could be seen in this diagram, frequency range from 2 to 5 Megahertz is the most suitable range for conducting designated analysis; considering short distance between bars in the mentioned range. It could be induced that reliability is rather high in this frequency range.

**Figure 7: Statistical Analysis for Abnormality Function in Absolutely Faulty Surface Case**

**Conclusions**

Surface inspection of a roller bearing raceway was performed using ultrasonic spectroscopy. Function of abnormality due to relation in frequency domain was estimated. The applicability of the method and its reliability was measured in several experiments. Reliability of the method around probe’s natural frequency was quantitatively measured and presented (figure 7). This approach is a useful method for automatic and quantitative analysis of bearing surface defects. Although, there are some limitations which could be addressed in future works, nevertheless, the resolution of this method is a major topic of interest that is in need of attention in upcoming investigations.

In this paper; a new method along quantification of level of surface distortions in different kinds of bearings particularly those used in the railroad industry was presented. In the applied method it was pointed out that in light of effect of distortion in the reflective coefficient of ultrasonic wave from bearing’s ring surface in a given frequency range, amount of distortion inflicted upon the surface was determined.

In order to determine effectiveness of the purposed method, three types of bearings with variety of surface distortions that were separated and selected by a maintenance expert were studied. Obtained results were indicative of high ability of separation in the designated method for attaining desired criteria for the separation of all the sets of samples.

On the basis of proposed method, other bearings separated by the same maintenance expert were studied and a specific range for the given parameter was achieved. In the end, for finding suitable frequency range for processing, reflective frequencies having fewer fluctuations were determined. Obtained results from this
investigation can extensively be used in inspection and diagnostics of surface defects of different bearings. Also; possibility of using this method for determination of defect level is conceivable by using ultrasonic lenses, utilization of ultra-sonic laser procedures and also development of obtained criterion; all are reflective of perspective researches on this topic.

References


