EARLY FAULT DETECTION IN BEARING USING TIME DOMAIN TECHNIQUE: FAULTY BEARING SEEDED ON INNER RACEWAY AND BALL

Abdoulhdi A. Borhana1, Uma Shankar2, R. Kalaivani3, M.A. Khattak4, Yasir Hassan Ali5, Omar Suliman Zaroog6

1,2,3 Mechanical Engineering Department, College of Engineering, University TenagaNasional (UNITEN), Kajang, Malaysia

1 Department of Mechanical Engineering, Faculty of Engineering Science and Technology, Sebha University, Libya.

4 ARL Laboratory Services PTY Ltd. 13 61/55 Pine Rd, Yennora Sydney, NSW 216, Australia.

5 Northern Technical University, Technical College Mosul, Mosul, Iraq.

6 Department of Mechanical and Mechatronic Engineering, Faculty of Engineering, Sohar University, Sohar, Oman

1amhmad@uniten.edu.my, 4adil@arllabservices.com.au, 5yha2006@ntu.edu.iq

Corresponding Author: Abdoulhdi A. Borhana

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Abstract

One of the most important assets in an industry would be rotating machines. The reliability and availability are very crucial in order to support the accomplishment of an industry field. Major and even minor faults in rotating machines cause a decrease in both productivity and cost efficiency. Various methods have been studied by researcher and introduced in the industry for the detection of an early fault in rotating machines. Vibration signal analysis is one of a standout amongst other methods. This research paper focused on early fault detection in the bearing component at two different positions; inner raceway and ball. The faults were established at three different diameters of 0.007 inches, 0.021 inches, and 0.028 inches. By utilizing time domain technique, parameters such as mean, median, standard deviation, RMS, skewness, impulse factor and shape factor were determined. The vibration signal for both healthy and faulty bearing was deliberated by using the MATLAB software. All the data obtained were represented in graphs where the healthy and faulty bearing values were compared and analyzed.

Keywords: Ball bearing, early fault detection, time domain technique, inner raceways.
I. Introduction

Rotating machinery has become a vital mechanical equipment in industrial infrastructure including oil and gas, manufacturing and power plant industry. It is an important element yet consists of most critical components which help the performance of the entire system. Abrupt failure on rotating machinery will impose a massive impact on the industrial. As the failure begins, the energy consumption of the machine will increase and at the same time, the efficiency will decrease. Gradually, followed by a sudden breakdown will not only reduce the production rate but also causes additional operational cost for the restoration as well as wasting employers time while waiting. On a bigger picture, continuous use of faulty machine may cause physical injury to human operating the machine and worse as it may cause death.

Therefore, early fault detection and diagnosis can significantly minimize the effects caused by faulty machinery. It is proven to be highly cost-effective, reducing the production losses and enhance efficiency as well as the safety of both human being and environments [V]. Previously, plenty of method for fault detection has been developed and oftentimes, the analysis using a vibration signal is one of the prominent techniques used [VII]. The common signal feature extraction methods for rotating machinery include time domain technique, frequency domain technique, time-frequency analysis and envelope analysis [III], [IV].

In a rotating machine, the typical fault was caused by shaft, gear, and bearings [VIII]. A faulty bearing can produce multiple types of problems within the rotating machinery. There are several factors that cause the failure of bearing and these defects can be identified using vibration analysis. This paper are focusing on healthy and faulty bearings which are seeded on inner raceway and balls ranging from 0.007 inches to 0.028 inches by using time domain technique in the absence of information about the bearing such as the bearing category and operating specifications.

Time domain technique is the interpretation of different parameters with respect to time [VI]. This technique provides the amplitude of signals at an immediate time at which it is being sampled. Mathematical functions and physical signals are some of the statistical parameters corresponding to along with the time domain technique. The list and definition of the parameter are as follows:

I. Mean – it is defined as the summation of all values and divided by the total number of values.

II. Median – it is defined as the middle value of the vibration signal.

III. Standard Deviation – it is defined as the square root of variance and one of the most important statistical parameter.

IV. Variance – it is defined as the expectation of the squared deviation of a value from its mean.

V. Minimum – it indicates the lowest value of the vibration signals.
VI. Maximum – it indicates the highest value of the vibration signals.

VII. Root Mean Square (RMS) – it is one of the most relevant statistical parameter that indicates the content of energy in the vibration signal.

VIII. Skewness – it is described as the symmetry of signal around its mean value obtained and obtained from the third statistical moment of the vibration signal.

IX. Kurtosis – it is derived from the fourth order central moment of amplitude probability distribution.

X. Crest Factor – it is defined as the ratio of the peak value of a waveform to its RMS value and it is also called the peak-to-RMS ratio.

XI. Impulse factor – it is described as the ratio of the peak value to mean value of time signal and it is an indicator of bearing faults.

XII. Shapes factor – it is described as the ratio of the RMS to mean value and represents changes under unbalance and misalignment.

II. Methodology

6205-2S JEM SKF, deep groove ball bearing was used for this research project. The vibration signal data for this research paper was obtained from the Case Western Reserve University Bearing Data Center website [I]. The fault seeded in the bearings is within the diameter range of 0.007 inches to 0.028 inches and introduced at the inner raceway and ball.

The experiments were conducted using two horsepower motor, dynamometer, torque transducer and control electronics. The vibration was collected using accelerometers. The accelerometers were attached to the housing with magnetic bases at the 12 o’clock position. The vibration signals were collected using channel DAT recorder and processed in MATLAB environment. Data were obtained at 12,000 sample per second and 48,000 sample per second for drive end bearing faults respectively. Figure 1 below shows the experimental setup.
III. Result and Discussion

Based on the calculated time domain parameter, graph was plotted to compare fault and healthy bearing.

**Statistical Analysis on Healthy and Faulty Bearing Seeded at Inner Raceway**

The best reflects the parameter on the inner raceway fault in a bearing were standard deviation, RMS, impulse factor and shape factor.

**Table 1: Standard deviation value of healthy and faulty bearing at different speeds [1]**

| RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|------|---------|------|------|------|------|
| 1797 | 0.0727  | 0.2912 | 0.1948 | 0.5252 | 0.8384 |
| 1772 | 0.0652  | 0.2928 | 0.1655 | 0.4418 | 0.8375 |
| 1750 | 0.0631  | 0.2995 | 0.1630 | 0.4889 | 0.8413 |
| 1730 | 0.0647  | 0.3136 | 0.1808 | 0.4487 | 0.8231 |

**Fig. 2:** Standard deviation value versus speed

It can be clearly seen in Figure 2 that the least value for standard deviation are healthy bearing and the values are constant throughout the speed. Low standard deviation shows that most of the values are close to the average value. For all fault bearings, the standard deviation values are constant throughout the speed. However, the standard deviation increase with increasing fault diameter. The highest standard deviation value was observed at fault diameter of 0.028.
Table 2: RMS value of healthy and faulty bearing at different speeds [I]

| RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|------|---------|-------|-------|-------|-------|
| 1797 | 0.0738  | 0.2915| 0.1978| 0.5254| 0.8384|
| 1772 | 0.0664  | 0.2929| 0.1655| 0.4418| 0.8376|
| 1750 | 0.0643  | 0.2995| 0.1631| 0.4889| 0.8413|
| 1730 | 0.0659  | 0.3136| 0.1808| 0.4487| 0.8231|

Fig. 3: RMS value versus speed

The graph trend in Figure 3 is identical to Figure 2. Similarly, the healthy bearing shows the smallest RMS value, followed by faulty bearing of 0.014, 0.007 and 0.021. The highest RMS value is shown by faulty bearing of 0.028. RMS represents the content of energy in the vibration signal. It has been widely used to detect progressive failures [II]. It is a detection tool that indicates the condition of the components which are better at lower value [IX].

Table 3: Impulse factor value of healthy and faulty bearing at different speeds [I]

| Impulse Factor | RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|----------------|------|---------|-------|-------|-------|-------|
|                | 1797 | 24.784  | 129.357| 56.174| 267.781| 621.364|
|                | 1772 | 25.271  | 272.508| 564.266| 1211.600| 480.159|
|                | 1750 | 29.300  | 360.204| 503.814| 1056.800| 541.346|
|                | 1730 | 22.772  | 354.242| 705.998| 1270.300| 537.453|
From the observation in Figure 4, the healthy bearing has the lowest and steady impulse factor value compared to faulty bearing with an increase in speed. The faulty bearing of 0.021 has the highest impulse factor and it has a similar trend line with a faulty bearing of 0.014. Impulse factor is a dimensionless parameter which is used as the benchmark of bearing faults.

Table 4: Shape factor value of healthy and faulty bearing at different speeds [I]

| Shape Factor | RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|--------------|------|---------|-------|-------|-------|-------|
|              | 1797 | 5.873   | 21.685| 5.745 | 37.139| 108.868|
|              | 1772 | 5.281   | 50.490| 46.004| 145.233| 102.314|
|              | 1750 | 5.246   | 65.798| 44.308| 142.588| 100.299|
|              | 1730 | 5.288   | 66.464| 60.009| 157.689| 101.769|

Fig. 5: Shape factor value versus speed

Shapes factor represent more towards the changes under unbalance and misalignment of the bearing. Based on Figure 5, healthy bearing has the lowest value.
in comparison to the faulty bearing. Corresponding to Figure 1.4, the faulty bearing of 0.014 and 0.021 have likewise trend line and faulty bearing of 0.021 have the highest value of shape factor.

**Statistical Analysis on Healthy and Faulty Bearing Seeded at Ball**

The best reflects the parameter on the ball (rolling element) fault in a bearing were mean, median standard deviation, RMS and skewness.

**Table 5:** Mean value of healthy and faulty bearing at different speeds [1]

| RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|------|---------|-------|-------|-------|-------|
| 1797 | 0.0126  | 0.0126| 0.0047| 0.0214| 0.0050|
| 1772 | 0.0126  | 0.0039| 0.0045| 0.0043| 0.0092|
| 1750 | 0.0123  | 0.0046| 0.0046| 0.0046| 0.0002|
| 1730 | 0.0125  | 0.0042| 0.0045| 0.0045| 0.0190|

**Fig. 6:** Mean value versus speed

Figure 6 shows that the healthy bearing maintains at a constant mean value within the range of 0.0123 to 0.0126 throughout the speed and identically, the faulty bearing of 0.014 also maintains at nearly constant mean value throughout the speed range. The faulty bearing of 0.028 shows the most fluctuation, followed by the faulty bearing of 0.007 and 0.021 as the speed increases.
Table 6: Median value of healthy and faulty bearing at different speeds [I]

| RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|------|---------|-------|-------|-------|-------|
| 1797 | 0.0125  | 0.0128| 0.0045| 0.0210| -0.0081|
| 1772 | 0.015   | 0.0037| 0.0041| 0.0044| -0.0049|
| 1750 | 0.0146  | 0.0039| 0.0044| 0.0050| -0.0106|
| 1730 | 0.0144  | 0.0037| 0.0065| 0.0039| 0.0090|

Fig. 8: Standard deviation value versus speed

Referring to Figure 8, healthy bearing has the smallest standard deviation value which is constant throughout different speeds. The faulty bearing of 0.007, 0.014 and 0.021 shows slight different value compared to the healthy bearing as well as possess nearly constant value throughout the speed range. The faulty bearing of 0.028 signifies the highest standard deviation value. Standard deviation describes the shape of the amplitude distribution of vibration data collected from a bearing [X].

Table 8: RMS value of healthy and faulty bearing at different speeds [I]

| RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|------|---------|-------|-------|-------|-------|
| 1797 | 0.0738  | 0.1392| 0.1527| 0.1356| 2.0771|
| 1772 | 0.0664  | 0.1391| 0.1409| 0.1291| 2.0299|
| 1750 | 0.0643  | 0.1473| 0.1435| 0.1073| 2.1457|
| 1730 | 0.0659  | 0.1536| 0.1337| 0.1180| 2.1450|
The graph trend in Figure 9 is identical to Figure 6. Similarly, healthy bearing has the smallest RMS value, followed by faulty bearing of 0.007, 0.021 and 0.014. The highest RMS value is shown by faulty bearing of 0.028. RMS represents the content of energy in the vibration signal. It has been widely used to detect progressive failures [II]. Lower value of RMS indicates a better condition of components [IX].

Table 9: Skewness value of healthy and faulty bearing at different speeds [I]

| RPM  | Healthy | 0.007 | 0.014 | 0.021 | 0.028 |
|------|---------|-------|-------|-------|-------|
| 1797 | -0.0354 | -0.0089 | 0.2251 | 0.0327 | 0.0560 |
| 1772 | -0.173 | 0.0075 | 0.0157 | -0.0608 | 0.0478 |
| 1750 | -0.1671 | 0.0271 | 0.1433 | -0.0039 | 0.0428 |
| 1730 | -0.1275 | 0.0204 | 0.1638 | 0.0251 | 0.0425 |

Skewness is the measure of asymmetry in statistical distribution where the curve is developed in a distorted manner. The graph plotted can be skewed to either side. Skewness value can also be both positive and negative. As shown in Figure 10,
faulty bearing of 0.007 and 0.021 gave both positive and negative values of skewness. The healthy bearing has a negative skew due to the long tail in the negative direction.

IV. Conclusion

This paper has reviewed the faulty bearing seeded on the inner raceway and ball. The parameters obtained for inner raceway are standard deviation, RMS, impulse factor and shape factor. On the other hand, the parameters obtained for the ball are mean, median standard deviation, RMS and skewness. All the parameters were compared with a healthy bearing. In comparison, all the parameters for faulty bearing have greater value while healthy bearing has lower values for all the parameters. On the other hand, the comparison to faulty bearing seeded on the ball, the healthy bearing has almost all constant value throughout the speed range expect for skewness data.

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