Experimental study on fault detection in roller bearing used in rolling mill industry

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Abstract. Rolling element bearings are extremely important components of rotating machines, and bearing defects can cause machines to fail. As a result, early detection of such defects, as well as the severity of damage while the bearing is in operation, may help to prevent machine malfunction and breakdown. Vibration is produced by defective bearings when no. of passes are increases to reduce down the thickness of raw materials and these vibration signals can be used to diagnose the problem. This article provides a summary of recent developments in bearing defect studies, as well as sources of vibration and vibration measurement methods in the time, frequency, and time frequency domains. An experimental setup has been established in this paper to determine roller bearing faults. The fault evaluation progress is extracted using the signal processing method. The results are presented as time series and FFT plots. Misalignment fault, Indentation event, Smoothened dent, Defects, and Damage growth state are the five wear fault assessment events examined. The test lasts 480 hours and takes place at temperatures ranging from 68 to 78 degrees Celsius. After 480 hours of testing, it was discovered that the roller bearing is damaged due to a high wear rate, with amplitude of acceleration in the frequency domain of 32.51 m/s\textsuperscript{2} at fifth event. The amplitude of acceleration in the frequency domain is also found to be greater than the critical value of 30 m/s\textsuperscript{2}. As a result, the state of the roller bearing after 480 hours is the damage growth state.

Keywords: bearing defects; misalignment fault; Indentation event; Smoothened dent; roller bearing

1. Introduction
The bearing is an important component of all rotating machines, as it serves to stabilize the machine and allow the shaft to rotate in relation to a fixed structure. Rolling element bearings are used in more than 90% of machines, and their failure will cause the machine to malfunction. Therefore, they are the most essential components in industrial applications. As a result, bearing reliability and robustness are critical for machine efficiency\cite{1}. Bearings are subjected to heavy and dynamic loads produced by machines and transmitted via rolling element-bearing components during operation. As a result, bearing condition is critical in high-volume production systems with a large number of rotating machines contributing to the system. Any bearing defect must be detected rapidly to prevent increased downtime, manufacturing time, and catastrophic machinery failure. As a result, detecting these flaws is critical for bearing condition control and quality inspection. Acoustic measurements, temperature control, wear debris analysis and vibration measurements are some of the techniques used to diagnose these defects in bearings. Vibration tracking is a commonly used and cost-effective method of...
identifying, finding, and separating defects in rolling element bearings[2]. Bearings create noise and vibration because of varying compliance or the presence of a defect. Even when these bearings are geometrically fine, they produce vibration when filled radially. The most critical parameter for bearing working life is the roller bearings used in rotating systems. As a result, prior to the design and manufacture of the bearing, a fault analysis is required[3]. Since a long time, scientists and engineers have been working both experimentally and theoretically to determine the various forms of bearing faults. When there are faults in them, the vibration level rises dramatically[4], [5]. Vibration and acoustic measurement have been used to diagnose bearing defects using a variety of techniques, including vibration measurement in the time domain, frequency domain, time-frequency domain, shock pulse system, and acoustic emission technique. Several articles on vibration signal analysis techniques have been performed, as well as various reviews focused on defect and fault diagnosis techniques[6], [7].

Our study provides a first-of-its-kind experimental review of roller bearing wear evaluation using time series signals and FFT plots. It is important to measure the bearing's working life before designing and manufacturing it, so that rotary machineries experience minimal wear and repair costs. During action, a fluid film lubrication between the roller and the inside of the outer race of the bearing should be maintained for low wear in rotary machineries. The wear rate is calculated for five events: Misalignment fault, Indentation event, Smoothened dent, Defects and Damage growth state at different times using time series signals and FFT plots, and wear rate is calculated for five events: Misalignment fault, Indentation event, Smoothened dent, Defects and Damage growth state at different times using time series signals and FFT plots. The amplitude of a time series signal of acceleration is calculated at different points in this evaluation.

2. Defects in Bearings
The mechanism of bearing vibration has been clarified by several researchers. Even a safe bearing produces vibration, but the presence of defects greatly raises vibration levels. Premature bearing failures can be caused by a variety of causes, the most common of which are fatigue, wear, plastic deformation, corrosion, brinelling, inadequate lubrication, defective installation, and incorrect design. Identification of these defects, as well as the vibration they cause, is critical for bearing condition monitoring. Bearing defects can be divided into two categories: dispersed defects and localized defects [8].

2.1. Distributed Defects
Surface roughness, waviness, misaligned races, and off-size rolling components are examples of distributed defects. Manufacturing mistakes, abrasive wear, and incorrect installation are the most common causes of distributed defects[9]. The contact force between rolling elements and raceways differs in distributed defects, resulting in vibration. The vibration response caused by a distributed defect is primarily used in bearing quality inspection and condition monitoring.

2.2. Localized Defects
Pits, cracks, and spalls that form on the rolling surfaces fall into this category of defects. Spalling is the most common mode of failure among these. Fatigue cracks originate underneath the surface and extend to the surface until the material fails and leaves localized defects[10]. According to Bentley's article, localized defects cause damage to the inner ring, outer ring, and rolling elements in 90% of all bearing faults [11].

3. Considerations from a theoretical standpoint
A complex of friction appearance ways produces the resistant torque that occurs in roller bearings. The rolling friction phenomenon is complicated by a variety of variables that arise at the same time.
Friction caused by contact deformations, rolling friction on contact surfaces, friction created by lubricants, slipping of bearing elements, and friction from seals are the most common sources of bearing friction. Friction torque can be calculated with reasonable precision using relationships derived from experimental findings in standard calculations. The gross friction torque \( M_{gc} \) is calculated using equation (1).

\[
M_{gc} = M_f + M_l
\]  

\( (1) \)

Where, \( M_f \) is the bearing load produces a resistant torque and \( M_l \) is the lubricant-induced resistant torque created by bearing elements in contact with the lubricant.

For bearings that work at a moderate speed and load, equation (1) is used. When using roller bearings for high-speed applications, the friction torque generated by the spin and gyroscopic motions should be considered. The bearing load produces a resistant torque \( M_f \), which is calculated using the equation (2).

\[
M_f = f_1.F.d_m
\]  

\( (2) \)

Where, \( F \) is the bearing radial load, in [N]; \( d_m \) is the mean bearing diameter, in [m]; Ball bearings factor \( f_1 \) is established with the following relation.

\[
f_1 = 0.0009 \left( \frac{F}{C_0} \right)^{0.55}
\]  

\( (3) \)

Where, \( F_r \) is the radial force acting on roller bearings, in [N]; \( C_0 \) is the dynamic load capacity, in [N]. To calculate the resistant torque \( M_l \) provided by the fluid friction of bearing elements in contact with the lubricant, use the formula given below.

\[
M_l = f_0.(v.N)^{2/3}.d_m.10^3 \quad \text{for } (v.N) \geq 20 \times 10^{-3}
\]  

\( (4) \)

\[
M_l = 16.f_0.(d_m)^3 \quad \text{for } (v.N) < 20 \times 10^{-3}
\]  

\( (5) \)

Where, \( v \) is the kinematic viscosity of the lubricants which would be taken \((25 \sim 33) \times 10^{-6}\), in \([m^2/s]\); \( N \) is the rotational speed of operated bearing, in [rpm] and the bearing factor \( f_0 \) should be taken \(1.5 \sim 2\).

### 4. Setup and procedure for the experiment
Experiments were carried out on a test rig in which the roller bearing (Bearing No. 202512) was filled with 100 N using the arrangement depicted in Figure 1. The roller bearing specifications are described in Table 1. Via a drive system consisting of a single phase induction motor of 1 HP, the shaft is rotated by a V-Belt and single stage cone pulley arrangement. The shaft's speed is maintained at 900 RPM using the arrangement shown in Figure 1. With the aid of a vibration metre and sensing element, the signals of acceleration and corresponding frequency are registered. Table 2 onward shows an example of a reading. Time series data and FFT plots are produced using those signals, which are then used to evaluate roller bearings.

| Sr. No. | Parameter                  | Value     |
|---------|----------------------------|-----------|
| 1       | Bearing Number             | 202512    |
| 2       | Category                   | Roller Bearing |
| 3       | Inner Race Diameter (mm)   | 20.04     |
| 4       | Outer Race Diameter (mm)   | 26.06     |
| 5       | Width (mm)                 | 11.96     |
| 6       | Speed (rpm)                | 900       |

Table 1. Specification of Test Bearing
Figure 1. Block Diagram of Experimental Setup

Figure 2. Practical Experimental Setup
Figure 3. Practical Bearing photos outside the machine (Left) and inside attached to a machine (right)

5. Results and Discussion
Figure 3 shows the photographs of bearing outside and inside of the machine. For the wear test, a roller bearing (202512) is used. The fault induced signal is detected using frequency domain methods. The test bearing is run for 480 hours in the experimental test. After 430 hours of testing, a misalignment fault occurred due to lubrication film that is not properly lubricated being formed between the roller and the inside of the outer race. After that, a high temperature was generated during the test run, which was registered as 68 °C. After 450 hours of work of operating the test bearing, an indentation event occurred due to unbalanced rolling contact between the roller and the inside of the outer race, resulting in a high temperature of 70 °C during the test cycle. After 460 hours of work of running the test bearing, a smoothened dent appeared due to an unbalanced spinning speed of the roller, and a high temperature was created during the test run, which was registered as 73 °C. After 470 hours of work of test bearing operation, a defect appears due to wear between the roller and the inside of the outer race, and then a high temperature is created during the test run, which is registered as 75 °C. Damage growth state occurred at the end of 480 hours of test bearing run due to high wear rate generated between roller and inside of outer race, followed by high temperature caused during the test run of 78 °C. The tests are carried out five times to investigate the five wear assessment events of misalignment fault, indentation, smoothened dent, defects and damage growth condition. When the amplitude of acceleration in the frequency domain exceeds 30 m/s², the roller bearing is found to be affected. As a result, in the frequency domain, the critical value for harm is 30 m/s².

5.1. Misalignment fault
The frequency range is 200 Hz to 1000 Hz. The data in Table 2 are used to produce the time series signal of acceleration. In Figure 4, the amplitude of the time series signal of acceleration ranges from -121.6 to 121.6 m/s². As shown in Figure 5, the amplitude of the FFT of acceleration reaches a maximum of 15.80 m/s² at 880 Hz and a minimum of 8.10 m/s² at 402 Hz. The amplitude of acceleration in the frequency domain is found to be far below the critical value. As a consequence, the roller bearing has a misalignment fault.
| Reading No. | Acceleration (in m/sec²) | Frequency in Hz |
|------------|--------------------------|-----------------|
| 1          | 8.1                      | 402             |
| 2          | 8.8                      | 430             |
| 3          | 12.7                     | 710             |
| 4          | 10.5                     | 462             |
| 5          | 11.6                     | 620             |
| 6          | 12.7                     | 687             |
| 7          | 15.7                     | 855             |
| 8          | 14.5                     | 820             |
| 9          | 10.7                     | 468             |
| 10         | 11.3                     | 670             |
| 11         | 9.7                      | 435             |
| 12         | 9.8                      | 443             |
| 13         | 10.1                     | 450             |
| 14         | 11.3                     | 614             |
| 15         | 12.8                     | 700             |
| 16         | 13.5                     | 765             |
| 17         | 14.3                     | 770             |
| 18         | 15.8                     | 880             |
| 19         | 11.8                     | 680             |
| 20         | 10.2                     | 455             |

**Table 2.** Acceleration and Frequency using roller bearing

**Figure 4.** Time series Signal

**Figure 5.** Fast Fourier Transform (FFT)
5.2 Indentation event
The frequency range is 0 Hz to 1000 Hz. The data in Table 3 are used to produce the time series signal of acceleration. In Fig. 6, the amplitude of the time series signal of acceleration ranges from -225.9 to 225.9 m/s². As shown in Fig. 7, the amplitude of the FFT of acceleration reaches a maximum of 20.7 m/s² at 944 Hz and a minimum of 11.4 m/s² at 480 Hz. The amplitude of acceleration in the frequency domain is found to be far below the critical value. As a result, this is a roller bearing indentation case.

| Reading No. | Acceleration (in m/sec²) | Frequency in Hz |
|-------------|--------------------------|-----------------|
| 1           | 12.7                     | 492             |
| 2           | 11.4                     | 480             |
| 3           | 14.5                     | 610             |
| 4           | 12.8                     | 522             |
| 5           | 13.6                     | 530             |
| 6           | 15.6                     | 640             |
| 7           | 14.8                     | 624             |
| 8           | 16.2                     | 725             |
| 9           | 17.3                     | 790             |
| 10          | 17.7                     | 793             |
| 11          | 18.4                     | 815             |
| 12          | 15.8                     | 704             |
| 13          | 16.2                     | 710             |
| 14          | 16.7                     | 734             |
| 15          | 19.2                     | 885             |
| 16          | 19.7                     | 902             |
| 17          | 17.6                     | 790             |
| 18          | 18.7                     | 840             |
| 19          | 20.7                     | 944             |
| 20          | 19.2                     | 860             |

**Table 3.** Acceleration and Frequency using roller bearing

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**Figure 6.** Time series Signal  
**Figure 7.** Fast Fourier Transform (FFT)
5.3 Smoothened dent

The frequency range is 0 Hz to 1000 Hz. The data in Table 4 is used to produce the time series signal of acceleration. In Fig 8, the amplitude of the time series signal of acceleration ranges from -292.5 to 292.5 m/s². As shown in Fig.9, the amplitude of the FFT of acceleration reaches a maximum of 28.70 m/s² at 943 Hz and a minimum of 14.70 m/s² at 477 Hz. The amplitude of acceleration in the frequency domain is found to be less than the critical value. As a consequence, the roller bearing's dent has been smoothed out.

| Reading No. | Acceleration (in m/sec²) | Frequency in Hz |
|-------------|--------------------------|-----------------|
| 1           | 15.3                     | 482             |
| 2           | 16.2                     | 498             |
| 3           | 18.4                     | 621             |
| 4           | 14.7                     | 477             |
| 5           | 17.8                     | 517             |
| 6           | 22.5                     | 724             |
| 7           | 21.5                     | 688             |
| 8           | 24.4                     | 762             |
| 9           | 25.8                     | 812             |
| 10          | 24.2                     | 753             |
| 11          | 26.7                     | 821             |
| 12          | 28.7                     | 943             |
| 13          | 17.8                     | 520             |
| 14          | 27.2                     | 910             |
| 15          | 26.9                     | 902             |
| 16          | 20.9                     | 649             |
| 17          | 21.8                     | 713             |
| 18          | 22.7                     | 732             |
| 19          | 20.6                     | 643             |
| 20          | 24.2                     | 720             |

**Figure 8.** Time series Signal

**Figure 9.** Fast Fourier Transform (FFT)
5.4 Defects
The frequency range used is 0 to 1000 Hz. The data in Table 6 are used to produce the time series signal of acceleration. In Fig.10, the amplitude of the time series signal of acceleration varies from -363.1 to 363.1 m/s². As shown in Fig.11, the amplitude of FFT of acceleration has a maximum of 32.51 m/s² at 86.91 Hz and a minimum of 15.26 m/s² at 352.5 Hz. The amplitude of acceleration in the frequency domain is found to be greater than the critical value. As a result, the roller bearing is in a weakened growth state.

| Reading No. | Acceleration (in m/sec²) | Frequency in Hz |
|-------------|--------------------------|-----------------|
| 1           | 16.6                     | 612             |
| 2           | 17.7                     | 628             |
| 3           | 14.3                     | 588             |
| 4           | 21.2                     | 704             |
| 5           | 20.3                     | 688             |
| 6           | 22.2                     | 712             |
| 7           | 24.7                     | 755             |
| 8           | 25.1                     | 806             |
| 9           | 27.8                     | 850             |
| 10          | 26.8                     | 832             |
| 11          | 26.3                     | 816             |
| 12          | 27.6                     | 842             |
| 13          | 28.6                     | 956             |
| 14          | 28.2                     | 941             |
| 15          | 18.9                     | 657             |
| 16          | 19.8                     | 671             |
| 17          | 20.7                     | 693             |
| 18          | 29.5                     | 971             |
| 19          | 29.2                     | 968             |
| 20          | 28.1                     | 872             |

Table 5. Acceleration and Frequency using roller bearing

Figure 10. Time series Signal

Figure 11. Fast Fourier Transform (FFT)
5.5 Damage growth state

Frequency range is taken from 0 to 1000 Hz. The time series signal of acceleration is generated using data given in Table 6. The amplitude of time series signal of acceleration is observed from -363.1 to 363.1 m/s² in Fig.12. The amplitude of FFT of acceleration is observed maximum of 34.6 m/s² at 998 Hz and minimum 22.5 m/s² at 613 Hz as shown in Fig.13. It is found that the amplitude of acceleration in frequency domain is more than the critical value. Therefore, this is damage growth state of the roller bearing.

| Reading No. | Acceleration (in m/sec²) | Frequency in Hz |
|-------------|--------------------------|-----------------|
| 1           | 24.5                     | 654             |
| 2           | 25.7                     | 671             |
| 3           | 27.5                     | 723             |
| 4           | 28.8                     | 797             |
| 5           | 22.5                     | 613             |
| 6           | 30.5                     | 845             |
| 7           | 34.6                     | 998             |
| 8           | 31.4                     | 872             |
| 9           | 32.8                     | 957             |
| 10          | 33.7                     | 984             |
| 11          | 27.9                     | 744             |
| 12          | 32.4                     | 912             |
| 13          | 33.2                     | 978             |
| 14          | 34.1                     | 989             |
| 15          | 30.2                     | 813             |
| 16          | 27.3                     | 711             |
| 17          | 23.5                     | 648             |
| 18          | 28.7                     | 768             |
| 19          | 31.8                     | 898             |
| 20          | 23.2                     | 642             |

Figure 12. Time series Signal

Figure 13. Fast Fourier Transform (FFT)
6. Conclusion
The research describes an experimental model for roller bearing wear evaluation. With the assistance of signal processing techniques, the wear assessment was observed. The wear assessment of roller bearing is evaluated using five events at different times. After 430 hours of work of testing, a misalignment fault occurred in the first case. In the second event, an indentation event occurred after 450 hours of test bearing activity. Smoothedent occurred after 460 hours of work of test bearing operation in the third case. After 470 hours of work of test bearing defects appears in the fourth event. Damage growth state occurred at the end of the 480-hour test bearing run in the fifth event. The temperatures measured during all five events were 68°C, 70°C, 73°C, 75°C and 78°C, respectively, with the fifth event having the highest temperature. The magnitude of acceleration in the frequency domain is also observed to be greater than the critical value at the fifth event as compared to the other four events. In this regard, the research demonstrates the maximum wear rate in roller bearings at the fifth event of wear assessment.

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