

Design and Development of Experimental Test Rig for Fault Diagnosis of Ball Bearing Using Fuzzy Logic Concept

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ABSTRACT

Rolling element bearings are frequently employed in industry. Many machine-related issues are linked to bearing failures. To minimize downtime and preserve product quality in a highly automated production, an online detection system is required. Condition-based monitoring for deep groove ball bearings is becoming more common. All rotating machinery uses these bearings extensively to accommodate both static and dynamic loads. Techniques for condition-based monitoring can be utilized to diagnose bearing defects to prevent this failure. So, it is important to study these faults present in the machines. The techniques for fault detection will be described in this paper. We are discussing Fast Fourier Transform (FFT) technique. In FFT, we obtain frequency-relationship graphs, and based on peak frequencies, we predict faults. A detailed analysis using the FFT Methodology is done to find out the possible faults, and finally validate with MATLAB software. For the aim of bearing diagnostics, the system performs vibration analysis. More advanced diagnostic systems use fuzzy logic and classification methods to identify the state of the machinery. These techniques enable the creation of more automatic and trustworthy diagnostic systems.

Keywords— Rolling Element Bearing, Condition-Based Monitoring, Deep Groove Ball Bearing, FFT, MATLAB, Fuzzy Logic

I. INTRODUCTION

In industries, equipment state monitoring and fault diagnosis are major concerns. Early machine diagnosis can prevent millions of dollars in emergency repair expenses. Rolling element bearings are one of the most crucial elements of rotating machinery because they are the parts that wear out the most frequently and account for a significant amount of system failures.

Bearings can generally be divided into two categories: sliding bearings and rolling bearings. Journal bearings and linear bearings are examples of sliding bearings. Rolling bearings, which include both ball and roller bearings, are a typical component of machines. In

machinery for a variety of uses, including bicycles, roller skates, electric motors, aircraft gas turbines, rolling mills, dental drills, gyroscopes, and power transfers, rolling element bearings allow rotating motion of shafts. The fault diagnosis techniques used for bearings are as follows:

1. Vibration Analysis: Every machine produces vibrations when it is operating. It is based on the processing of vibration signals, and the aims of the monitoring of these systems are: (i) Reducing the number of systems stops; (ii) enhancing the reliability of the production equipment; (iii) Increasing the system availability and (iv) Better managing the stock.

2. Wear Debris Analysis: To evaluate the state of the machine parts, component wear particle tests are conducted in the lubricant. It costs less than other methods. This provides only a limited amount of diagnostic information. One of the most important methods to determine wear particle counts and measure the fuels under test is wear debris analysis.

3. Acoustic Emission: Acoustic emission refers to the phenomenon of elastic wave production in materials under stress. Plastic deformation cracks cause acoustic emissions. The expansion of subsurface cracks can be found using acoustic emission. It requires appropriate signal processing

In the field of process control, fuzzy logic has become widely recognized as an effective method for balancing objectivity and flexibility. Additionally, fuzzy logic is proving to be an effective tool for knowledge modelling, especially when used in condition monitoring and diagnostics applications.

II. LITERATURE REVIEW

Surojit Poddar and Madan Lal Chandravanshi [1] in this research, bearing vibration is experimentally examined, and FFT spectra are employed as an intelligent diagnostic tool for finding bearing issues such as inner race flaws, outside race flaws, and ball flaws. This study focuses on vibration measurement techniques and the application of Fast Fourier Transformation (FFT) to obtain

vibration amplitude versus frequency spectra for bearing fault diagnosis. These approaches are used to evaluate bearing fault frequencies and identify various bearing failures. Each vibration occurs at a specific frequency. The vibration frequencies must be known in order to diagnose the issue.

R.A. Kanai and S.P. Chavan, et al. [2] this study suggests a novel condition-based monitoring (CBM) system that uses model-based estimation (MBE) and artificial neural networks (ANN). The ANN technique enables us to investigate the effects of various vibrational parameters through experiments. The results show that vibrations are greatly influenced by a variety of parameters, including defect size, speed, load, imbalance, and clearance. Using experimentally generated data from MBE and ANN rotor-bearing models, the damage diagnosis is determined with a respectable degree of accuracy. As a result of the investigations, it is now possible to continuously monitor the bearing's function and identify faults and vibrational features. The examination of vibration parameters generated from experimental, MBE, and ANN data, and the consequences of flaws.

S.P. Mogal and S.N. Palhe [3] single and multiple double-row ball bearing difficulties are taken into consideration in the study that is presented here. The purpose of the experiment is to identify single and multiple inner races, outer races, cage, and ball difficulties in bearings using envelope analysis. Envelope spectrum analysis is the most effective technique for locating ball-bearing problems like fractures and spalls. The envelope spectrum is a great tool for locating bearing frequencies.

Brahim Harhoud and Messaoud Ramdani [4] the author of this research introduces a time-varying parametric spectrum estimate technique for the evaluation of nonstationary vibration signals. This technique is used to create an automatic diagnosis system for the recognition and categorization of ball bearing issues. The categorization task is carried out via a neural fuzzy inference system that is adaptable. The ability to recognize four distinct pre-existing problems in ball bearings operating at diverse shaft speeds and loads was developed. The system was tested using experimental data from the drive end ball bearing of an induction motor run by a mechanical mechanism.

III. DEFECTS GENERATION IN BEARING

A bearing is a mechanical component that places two machine parts in relation to one another and allows minimum frictional relative motion between them.

Insufficient Lubrication: The majority of bearing failures are brought on by insufficient lubrication. If improper lubricant is used, not enough lubricant is applied, or if the bearing has been subjected to high temperatures that have caused the lubricant to breakdown, lubrication failure may result.

Corrosion and Contamination: It can lead to a number of problems with bearing assemblies. Examples of contaminants include dirt, sand, water, and chemical substances. For instance, they might deteriorate the lubrication or corrode or erode the bearing surfaces, both of which might cause an early failure.

Spalling, another name for fatigue, is the term used to describe the fracturing of bearing surfaces and subsequent breaking off of material components. Fatigue will ultimately end in failure as it develops.

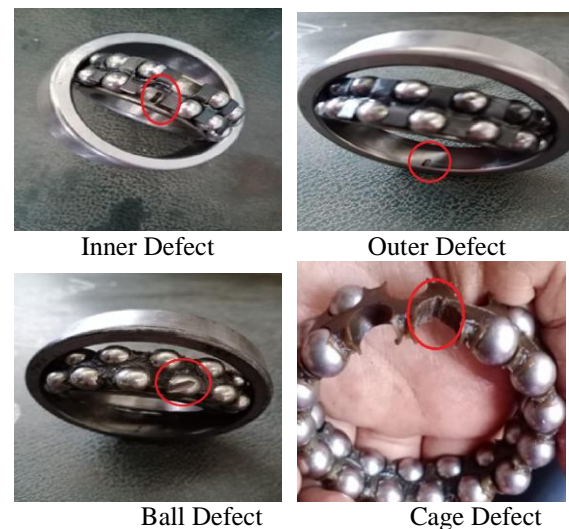


Figure 1: Bearing Defects

IV. DATA ACQUISITION SYSTEM

A data acquisition system (DAS) is the technique for collecting signals that measure actual objects and converting them into a digital representation that can be stored in a computer. Hardware and software are combined to create a data acquisition system. It is consisting of four essential components. These are as follows:

1. Sensors

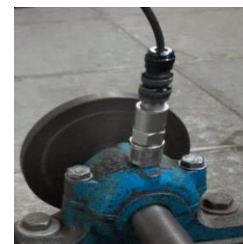


Figure 2: Accelerometer

Sensor Specification

Sensitivity of the sensor-100 mv/g

2. Signal Conditioning

Sensors are used to measure physical phenomena including temperature, vibration, and more. A transducer is another name for a sensor. An electrical signal is produced by a sensor from a physical input.

3. Analog to Digital Converter

Analogue output is used for most physical phenomena under signal conditions. By using an analog-to-digital converter system, it is converted to digital form.



Figure 3: DEWE 43 V

Table 1: Specification of DEWE 43V

No of channels	8
Inputs	Voltage
Power supply	9-36 V DC
IP rating	IP50
Sensor supply	+5V, +12V
Sampling Rate	Simultaneous 200 kS/sec
ADC type	24-bit sigma-delta with anti-aliasing filter
Input type	Differential

V. EXPERIMENTAL DETAILS

The experimental set up used for studying common machinery faults. Its study, flexible design makes bearing and loader installation and removal simple. A variable-speed motor is part of the arrangement, allowing it to operate at a variety of speeds depending on the needs and suitability of each experiment. To identify and classify various bearing failures, vibration measurement techniques and the use of Fast Fourier Transformation (FFT) to obtain vibration amplitude versus frequency spectra are used. FFT is used to convert time domain signal into frequency domain signal. Using DEWE software, the vibrational signal was collected and examined. Using a magnetic mount attachment, the accelerometer was installed on the housing of the defective bearing.

Four defective SKF and NSK EKTN9 1207 bearings were used for the experiment. The first having an

inner race fault, the second having an outer race fault, the third having a cage defect, and the fourth having a ball defect. For each bearing problem situation, experimental testing was run at shaft speeds of 1000RPM. On DEWE software, the signals were collected and analyzed. To identify specific bearing faults, the peak frequency of the associated signals' FFT was plotted and compared with the calculated fault frequencies.



Figure 4: Experimental Setup

The vibration signals are detected using an accelerometer. The cable linked to the accelerometer and the DEWESOFT system is shown in Fig-3. An accelerometer's signal is processed by a signal conditioning unit before being obtained by a computer.

Theoretical Calculation

$$\text{Ball Pass Frequency Outer Race} = \frac{n}{2} \left(\frac{Ns}{60} \right) \left(1 - \frac{d}{D} \right) \cos \alpha$$

$$= 113.35 \text{ Hz}$$

$$\text{Ball Pass Frequency Inner Race} = \frac{n}{2} \left(\frac{Ns}{60} \right) \left(1 + \frac{d}{D} \right) \cos \alpha$$

$$= 153.20 \text{ Hz}$$

$$\text{Ball Spin Frequency} = \frac{n}{2} \left(\frac{Ns}{60} \right) \left(1 - \frac{d^2}{D^2} \right) \cos \alpha$$

$$= 121.41 \text{ Hz}$$

$$\text{Fundamental Train Frequency} = \frac{n}{2} \left(1 - \frac{d}{D} \right) \cos \alpha$$

$$= 6.23 \text{ Hz}$$

Where, n- Number of Balls

Ns- Shaft Speed

d- Ball Diameter

D- Pitch Diameter

α - Contact Angle

VI. RESULT & DISCUSSION

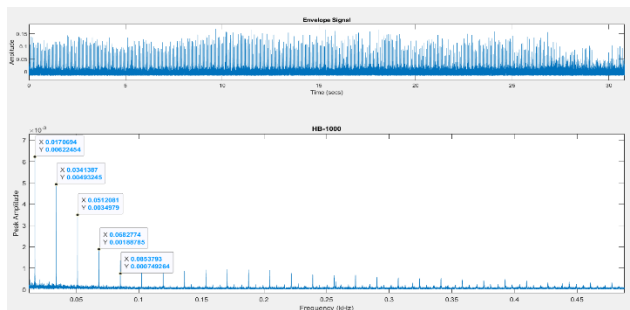


Figure 5: FFT of healthy bearing

Analysis- The shaft rotates at a 16.67 Hz frequency. The HB peaks at 1x at 17.06 Hz. The 2x harmonic of the fundamental frequency peaks at 34.13 Hz, and the 3x harmonic peaks at 51.20 Hz. In comparison, healthy bearings occur more frequently than defective ones.

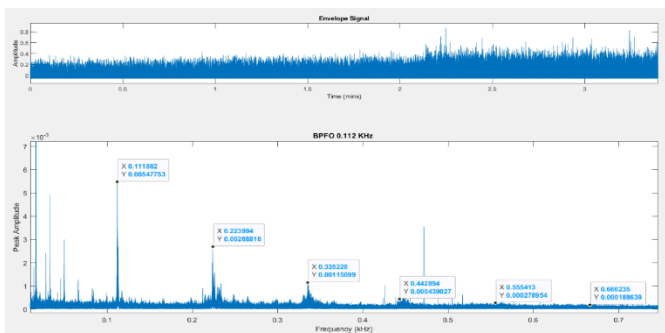


Figure 6: FFT Spectrum of Outer Defect

Analysis- The fundamental frequency, commonly known as the shaft rotational frequency, is 16.67 Hz. The BPFO peaks at 111.86 Hz. The 2X harmonic of the fundamental frequency peaks at 223.99 Hz, and the 3X harmonic peaks at 335.22 Hz.

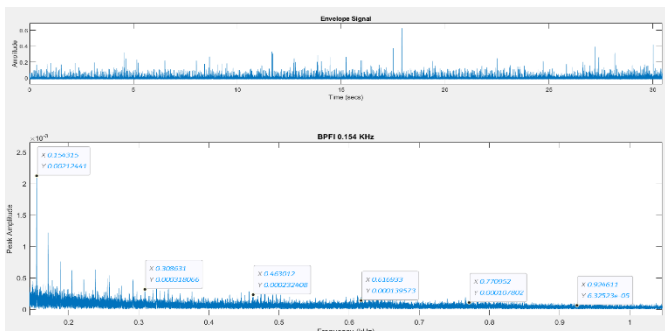


Figure 7: FFT Spectrum of Inner Defect

Analysis- The BPFI peaks at 154.33 Hz. The motor ran at a frequency set to 16.67 Hz. The 2X harmonic of the

fundamental frequency peaks at 308 Hz, and the 3X harmonic peaks at 463 Hz.

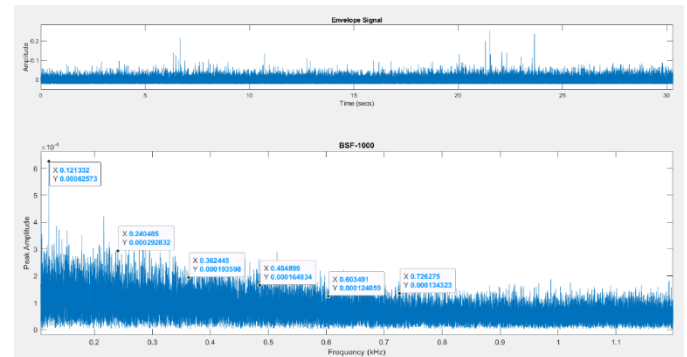


Figure 8: FFT Spectrum of Ball Defect

Analysis- The system's potential imbalance and looseness were shown by the fundamental frequency at 16.67 Hz and its harmonics, and the peak at 121 Hz corresponds to the ball spin, which indicates that the ball has a spall. This defect's theoretical outcome is 121.41 Hz.

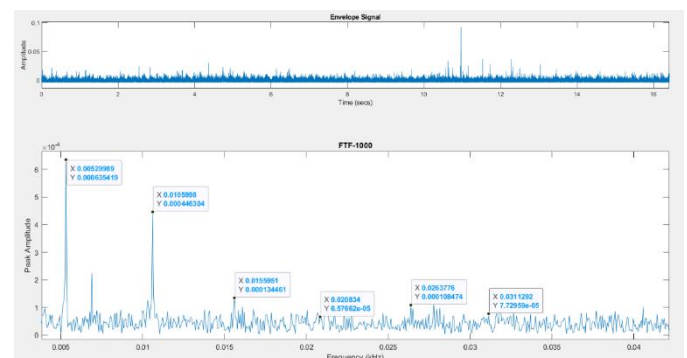


Figure 9: FFT Spectrum of Cage Defect

Analysis: The FTF peak frequency is 5.29 Hz. The motor was set up to run at 16.67 Hz. The cage fault's calculated result is 6.23 Hz

VII. FUZZY LOGIC RESULT

One of the recent developments in technology that enables a common language to express the desired system behavior is fuzzy logic. Vibration analysis is the process of using fuzzy logic to identify an unusual increase in a bearing's vibrations. A fuzzy logic system was developed based on the ball bearing's vibration characteristics. Since fuzzy logic can analyze and describe complex machine conditions using linguistic terms, it is widely used as the preferred method. Fuzzy logic is used in vibration analysis, which is the process of identifying an unusual rise in vibrations. Vibrations that suddenly increase could be a sign that a bearing is malfunctioning. A

fuzzy inference system (FIS) was developed based on the bearing's vibration characteristics.

Linguistic terms that indicate health conditions include red, yellow, and green. Red denotes a bearing that is defective or in poor condition, green denotes a bearing that is in acceptable condition, and yellow denotes a bearing that is in ideal condition. The membership function is triangular. The fuzzy membership function is a graphic representation of any value's level of membership in a specified fuzzy set. The graph's X-axis represents the discourse universe, and the Y-axis represents the range of participation in the interval [0, 1].

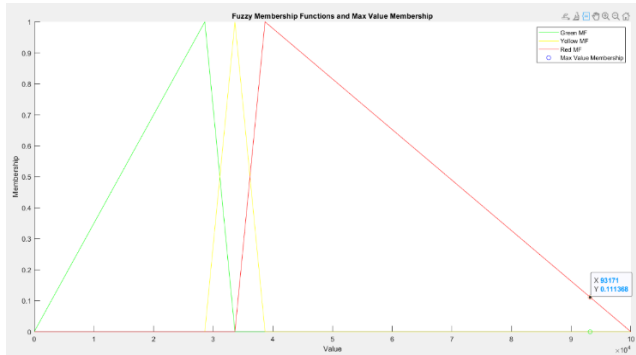


Figure 10: Fuzzy Output of Outer Defect

The output of the triangular membership is red at 1000 RPM. The fact that the membership's maximum value is 93171.031 indicates that it is defective. The bearing condition is around 93171.031, which is in the red zone and shows the bearing is defective.

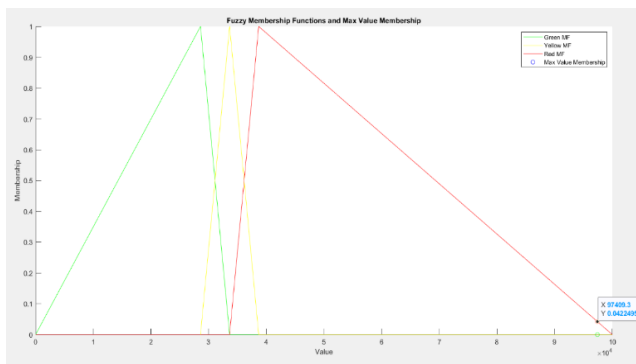


Figure 11: Fuzzy Output of Inner Defect

At 1000 RPM, the output of the triangle membership is red. Since the membership's highest value is 97409.258, it can be shown that it is flawed. The membership function shows clearly that it is not in an acceptable zone.

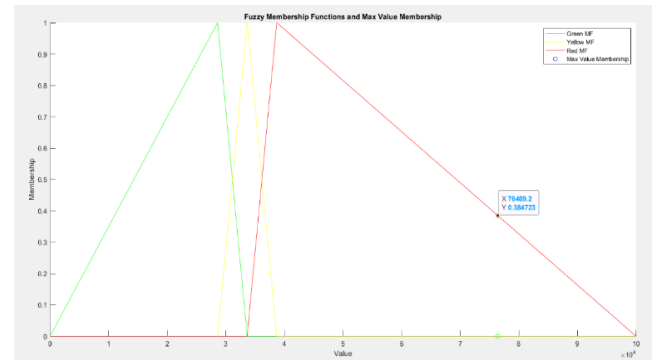


Figure 12: Fuzzy Output of Ball Defect

The maximum value of membership is 76409.195, indicating that it is faulty at 1000 RPM. The output is red in the triangular membership function (MF). It is shown by the membership function that it is not within an acceptable range.

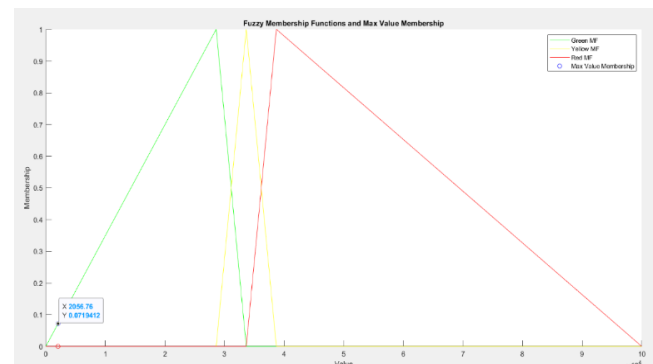


Figure 13: Fuzzy Output of Cage Defect

At 1000 RPM, the output of the triangular membership function, which is shown in green, is the result. Because the membership value can only go up to 2056.7554, it is seen that it is healthy bearing. The bearing condition is less at 2056.7554, which is an acceptable condition or healthy bearing.

VIII. CONCLUSION

1. There are different condition monitoring techniques used. In this research, vibration analysis techniques are used for bearing failure.
2. Higher peak frequencies are produced experimentally by bearing defects for the inner race, outer race, ball defect, and cage defect, and this is practically equivalent to theoretical calculations.
3. To monitor the vibrational state of the bearing and determine whether it is in a healthy or defective state, a fuzzy logic and a triangle membership function (MF) was built.

4. Using fuzzy logic, a system was created to monitor bearing status through vibration and determine whether it is in useful or bad condition. The output of the bearing condition is indicated in the form of green, yellow, and red. It is to determine whether the bearing is in a healthy or defective condition.

[10] *International Meeting of Advances in thermofluids.*
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