

# Life Prediction of Bearing by Using Vibration Analysis

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## ABSTRACT

The Machine Tool industry, sugar factory, petrochemical, power station aims for high precision and repeatability while it is in operation. The failure of any single machine rotary component in the process can results in loss of rupees per down time hours. Failure of bearing can disturb the entire process, losses in terms of production, manpower and equipment repair. Therefore maintenance of bearing is necessary. Maintenance of machine can be done either by preventive or breakdown technique. Condition based maintenance is preferred in industries now a days.

In this work, crack is created manually by using wire cutting method on bearings. Healthy and faulty bearings are installed one by one on the shaft. Time domain and Frequency domain graphs are obtained by using Fast Fourier transform (FFT) analyzer. By comparing Frequency domain graphs of healthy and faulty bearings, bearing fault is detected. Comparing fault frequencies with frequencies in Frequency domain graphs, exact bearing fault (i.e. inner race, outer race, and ball) is detected. Crack depth of bearing is obtained by using numerical relationship between crack depth and RMS and using that crack depth predicts the life of bearing.

The elimination of unexpected downtime, reduction of repair cost, increased service interval and extension of bearing life, all lead to reduce product cost.

**Keywords**— crack depth, FFT analyzer, Life prediction, RMS acceleration.

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## I. INTRODUCTION

Condition monitoring in process control industry has got now a day's very big relevance. The Machine Tool industry, sugar factory, petrochemical, power station aims for high precision and repeatability while it is in operation. The safety, reliability, efficiency and performance of rotating machinery are major concerns in industry. The task of condition monitoring and fault diagnosis of rotating machinery faults is significant but is often cumbersome and labour intensive. Diagnosing the faults before in hand can save the millions of rupees of industry and can save the time. Bearings have played a vital role in engineering. The main purpose of a bearing is to support a rotating shaft or play as intermediate between a rotating part and a stationary part. It has been found that Condition monitoring of bearings has enabled cost saving of over 50% as compared with the old

traditional methods. The most common method of monitoring the condition of bearing is by using vibration signal analysis. Measure the vibrations of machine recorded by velocity sensor or Accelerometer which is mounted on the casing of the machine [1]. The failure of bearing in the process can results in loss of rupees per down time hours. Maintenance of machine can be done either by preventive or breakdown technique. Condition based maintenance is preferred in industries now a day's [2].

A vibration signal produced by the process, allows monitoring and making conclusions about the operational state of the machine, in addition to that allows taking appropriate measures to extend the time of use, and to minimize costs resultant from the machine's down time which results in cost effectiveness [3].

To obtain the most possible real fatigue curve, the vibration level is shown according to different statistical

indicators such as the RMS (Root Mean Square), the crest value, the crest factor and the peak ratio, then to choose the best of them that is able to show the evolution of the bearing degradation [4]. A crack on a component introduces a local flexibility which is a function of the crack depth. Major characteristics of component, which undergo change due to presence of crack are the natural frequency, the amplitude response due to vibration, Mode shape [5].

Effective and efficient feature extraction techniques are critical for reliably diagnosing rotating machinery faults. Rotating machinery is widely used in today's industry some of which are complex, often with extremely demanding performance criteria. Machine failures can be catastrophic thus resulting in costly downtime. Without effective diagnosis, one is unable to make a reliable prediction of lead-time to failure [6].

Features regarding frequency information such as frequency domain features and time domain features are being widely investigated at present. Frequency domain vibration features can generally indicate machinery faults better than time domain vibration features because characteristic frequency components such as resonance frequency components or defect frequency components can be relatively easily detected and matched to faults. Frequency domain features are generally more consistent in the detection of damage than time domain parameters [7].

Localized fatigue damage of the bearing raceways and rolling elements will be easiest failure mode to detect because the characteristic bearing defect frequencies are well understood. Wear and geometric form errors of the raceways can also give rise to periodic vibrations. For the majority of other failure modes such as lubrication, starvation, corrosion, excessive looseness or faulty installation, definitive vibration characteristics are not well understood and the use of comprehensive trending and/or the application of advanced signal processing will be required [8]. The journal Bearing faults degrade machine performance, decrease life time service and cause unexpected failure which are dangerous for safety issues. Non-intrusive measurement e.g surface vibrations are appropriate monitoring methods for early stage journal bearing faults in low, medium and high frequency. The statistical parameter shows that RMS and peak value for faulty bearing is higher than normal bearing [9].

By comparing the signals of a machine running in normal and faulty conditions, detection of fault like journal-bearing defect is possible. Defective journal-bearing can alter the thickness of oil film. This will lead to changing normal movement of the shaft. So, failure journal-bearing increase vibration at rotational speed of the shaft. Common techniques used for journal-bearing fault detection include time and frequency domain analysis. The spectrum peaks in fault condition can be compared with spectrum peaks of normal journal-bearing to determine particular fault [10].

Time frequency domain techniques use both time and frequency domain information allowing for the investigation of transient features such as impacts. A number of time-frequency domain techniques have been proposed including Short Time Fourier Transform (STFT) and the Wavelet Transform (WT) [11]. Fatigue damage begins with the formation of minute cracks below the bearing surface. As loading continues, the cracks progress to the surface where cause material to break loose in the contact areas. The actual

failure can manifest itself as pitting, spalling or flaking of the bearing races or rolling elements. If the bearing continues in service, the damage will spread in the locality of the defect is due to stress concentration [12].

The life of bearing can be improved by carrying corrective actions & modifying its accessories like Plumber block to prevent bearing failure. The proposed work is planned in following phases Preparation of measuring instrument for data collection, Collection of data from various locations on surfaces in different directions. Data analysis is done on the basis of spectral plot, amplitude against frequencies. The results will be compared with initial condition & condition monitoring schedule is prepared for avoiding premature failure of equipment [13].

Bearing life analysis is based on the initiation or first evidence of fatigue crack. The term "basic rating life," as used in bearing catalogs, usually means the fatigue life exceeded by 90 percent of the bearings or the time before which 10 percent of the bearings fail. This basic rating life is referred to as " $L_{10}$  life" (sometimes called  $B_{10}$  life or 10-percent life). The 10-percent life is approximately one-seventh of the mean life, or MTBF (mean time between failures), for a normal life-dispersion curve [14].

In this work crack depth of bearing is measured using vibration technique like time domain, frequency domain analysis and using that crack depth predict the life of bearing.

## II. LITERATURE REVIEW

Natu [1] concluded that time domain analysis as well by using kurtosis or mean evaluation method but these methods doesn't give us the in depth analysis of signal which is necessary for fault diagnosis in bearing and therefore more advanced methods like wavelet analysis is necessary. Wavelet gives multi-resolution analysis in the sense that it gives the information of the faulty frequency along with the instant of time of fault occurrence in spectrum. He explains the procedure for detecting bearing faults using FFT and by using Wavelet analysis more specifically HAAR wavelet up to two levels of approximations and detail components. The analysis is carried out offline in MATLAB.

Djebili et.al [2] established a compromise between sensitivity and linearity. Consequently, the evolution of the peak ratio (peak value) indicator is more significant in term of sensitivity. Otherwise the evolution of the RMS indicator is more interesting in term of linearity. Therefore, the evolution of the bearing damage could be relatively expressed by the peak ratio (peak value) indicator or crest value indicator. Suryawanshi et.al [3] proposed that as crack initiates and propagates Critical speed and RMS Velocity changes accordingly and that can be monitored with condition monitoring technique. Therefore the change in Critical speed and RMS Velocity is effective way to identify the crack. In this paper, review of these two parameters carried out for effective identification of crack in a Rotor-shaft system. Finally they concluded that critical speed decreases with increase in crack depth. RMS velocity increases as crack depth increases.

Sawicki et.al [4] concluded that the vibration level increases with the depth of the crack. The orientation of unbalance eccentricity with respect to the crack centerline affects fundamental resonance and does have much less effect on sub-harmonics. Vaziri et.al [5] concluded that the

natural frequency changes substantially due to the presence of cracks. The changes are depending upon the location and size of cracks. The position of the cracks can be predicted from the deviation of the fundamental modes between the cracked and uncracked shaft. The frequency of the cracked shaft increases with increase in the crack depth for the all modes of vibration.

Yang et.al [6] proposed that frequency domain features are generally more consistent in the detection of damage than time domain parameters. Frequency techniques and time frequency techniques are being investigated by increasing the order of transformation parameters. Moreover, time frequency techniques are also being investigated to solve problems such as inter term components between neighboring frequency bands. Bhende et.al [8] concluded that Localized fatigue damage of the bearing raceways and rolling elements will be easiest failure mode to detect because the characteristic bearing defect frequencies are well understood. The results over time were processed by FFT analysis using the MATLAB functions for digital signal processing—Signal Processing Toolbox.

Raharjo et. al[9] proposed that surface vibration amplitude occurs in frequency range from 4250Hz to 8000Hz due to scratching. The amplitude is seen at frequency of 5500Hz. The RMS of surface vibration for scratching increases with shaft speeds but remains higher than that of healthy case which shows that vibration responses are well correlated to asperity contact characteristics. Moosavin et.al [10] proposed that Vibration technique in a machine condition monitoring provides useful reliable information, bringing significant cost benefits to industry. By comparing the signals of a machine running in normal and faulty conditions, detection of fault like journal-bearing defect is possible. This paper deals a new method of engine journal bearing fault diagnosis based on Power Spectral Density (PSD) of vibration signals.

Unal et.al [11] proposed that vibration analysis using FFT is computationally efficient method for bearing fault detection and diagnosis. In complex machines, the vibration generated by a component is easily affected by the vibration of other components or is corrupted by noise from other sources. Hence, the fault-related vibration must be recovered from among those sources for accurate diagnosis. In this paper, envelope analysis and FFT analysis used for feature extraction.

Khariche et.al [12] concluded that Vibration measurement in time domain and frequency domain are key points for feature extraction and fault diagnosis. Defective bearings are the source of vibrations in machines. Due to constructional features of bearing, they generate vibrations. As the condition of bearings changes during use, the nature of vibrations also changes and it has a definite characteristics depending upon the cause. This characteristic feature of bearing makes them suitable for vibration monitoring. Vibration in the time domain can be measured through parameters such as overall RMS level, crest factor, and kurtosis.

Kardile B.A [13] proposed that the life of bearing can be improved by carrying corrective actions on blower & modifying its accessories like Plumber block to prevent bearing failure. The proposed work is planned in following phases Preparation of measuring instrument for data collection, Collection of data from various locations on

blower surfaces in different directions. Data analysis is done on the basis of spectral plot, amplitude against frequencies. The results will be compared with initial condition & condition monitoring schedule is prepared for avoiding premature failure of equipment.

Peter et.al [14] found the bearing life using empirical relation. In studying the failure of brittle engineering materials, Weibull concluded that the strength of a material was a statistical variable, and assumed that the first initial crack led to the break of the entire structure under stress. Lundberg extended Weibull's weakest link theory to ductile bearing materials by arguing that a bearing's life consists of crack initiation life and crack propagation life, and that initiation life predominates the bearing's life. Based on extensive bearing tests, Lundberg and Palmgren proposed an empirical relationship.

From above review all authors concluded that detection and diagnosis of fault of bearing using vibration technique like time domain, frequency domain etc is possible, no one measure crack depth and predict the life of bearing. In this work crack depth of bearing is measured using vibration technique like time domain, frequency domain analysis and using that crack depth predict the life of bearing using empirical relation.

### III. THEORY

This chapter includes fault detection techniques, architecture of fault detection System, condition monitoring methods, vibration analysis and life prediction of bearing.

#### A. Fault Detection Techniques

There are several techniques that can be employed to predict the condition of bearing, these include: vibration monitoring, Current Signature Analysis, Tribology, Thermography, etc. Several studies showed that the most important technique in predictive maintenance is vibration analysis as it gives clear indications regarding the condition of the machine in question, in addition the level of vibrations and the frequency at which these vibrations occur can serve in determining the exact location of the defect and possibly severity of such defect. Following table shows the Comparison of various methods of fault detection.[8]

TABLE I : Comparison of Various Methods of Fault Detection [8]

Sr. No.	Method of analysis	Temp.	Press.	Oil Analysis	Vibration FFT
1	Ball brg. Damage	x		x	x
2	Journal brg. Damage	x	x	x	x
3	Gear damage			x	x
4	Mechanical looseness				x
5	Mechanical rubbing				x
6	Noise				x
7	Cracking				x

### B. Architecture Of Fault Detection System

First step of vibrations measurement of the bearing is to collect the signals. The sensing element for collecting the signals will be accelerometer. The accelerometer gives a voltage reading that corresponds to the level of vibration. The analog signals given by the accelerometer are then collected by the Data Acquisition Card and transform them into digital signals so that it can read by an analyzing interface. The analyzing interface (computer software) is used to perform and use the analysis methods.[8]

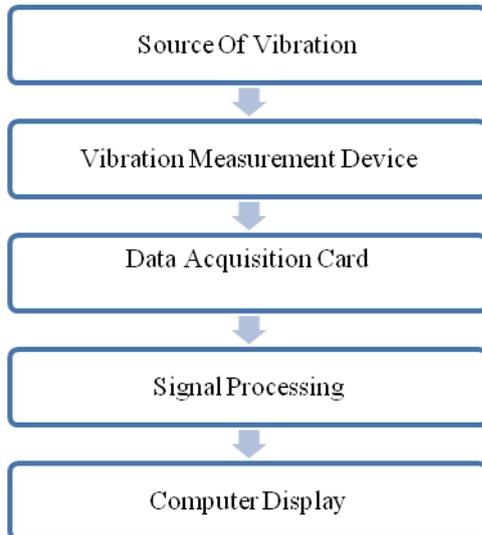


Fig.1 Component of Architecture [8]

### C. Vibration Analysis

Vibrations are always produced by machines even though they are in good conditions, this is due to periodic events in the machine's operation, such as rotating shafts, meshing gear teeth, rotating electric fields, bearing and so on. Condition monitoring using vibration measurement can be classified into time domain technique, frequency domain technique and time-frequency technique.

1) *Time Domain Technique*: Some of the time domain techniques can be used or applied for condition monitoring, such as root mean square (RMS), mean, peak value, Mean Square, crest factor

- Root mean square:

Root mean square (RMS), measures the overall level of a discrete signal.

$$RMS = \sqrt{\frac{1}{N} \sum_{n=1}^N x_n^2}$$

Where N is the number of discrete points and represents the signal from each sampled point. RMS is a powerful tool to estimate the average power in system vibrations. A substantial amount of research has employed RMS to successfully identify bearing defects using accelerometer.

- Mean:

The mean acceleration signal is the standard statistical mean value. Unlike RMS, the mean is reported only for rectified signals since for raw time signals, the mean remains close to zero. As the mean increases, the condition of the bearing appears to deteriorate

$$Mean = \frac{1}{N} \sum_{i=1}^N x_i$$

- Peak value:

Peak value is measured in the time domain or frequency domain. Peak value is the maximum acceleration in the signal amplitude.

$$P_v = [\max(f_n) - \min(f_n)]$$

- Crest factor:

Crest factor is the ratio of peak acceleration over RMS. This metric detects acceleration bursts even if signal RMS has not changed.

$$Crest\ factor = \frac{f}{Rf}$$

#### 2) Frequency Domain Technique

The frequency domain refers to the display or analysis of the vibration data based on the frequency. The time domain vibration signal is typically processed into the frequency domain by the application of Fourier, transform, usually in the form of fast Fourier transform [FFT] algorithm. The principal advantage of the method is that the repetitive nature of the vibration signals is clearly displaced as peaks in the frequency spectrum at the frequency where the repetition takes place.[8]

#### 3) Types of Vibration Analysis

The Condition monitoring systems are of two types: periodic and permanent. In a periodic monitoring system (also called an off-line condition monitoring system), machinery vibration is measured (or recorded and later analyzed) at selected time intervals in the field; then an analysis is made either in the field or in the laboratory. In a permanent monitoring system (also called an on-line condition monitoring system), machinery vibration is measured continuously at selected points of the machine and is constantly compared with acceptable levels of vibration. The permanent monitoring system can be costly, so it is usually used only in critical applications.

#### 4) Methodology

1. Searching of Test Rig.
2. Selection of bearing as per test rig.[standard]
3. Vibration measurement of normal and faulty bearing.
4. Signal Processing Techniques in Vibration Analysis
  - i) Time Domain Techniques
  - ii) Frequency Domain Technique
5. Comparison of the Spectrum(normal and faulty bearing)
6. Preparation of table for different crack depth and corresponding RMS.
7. Using curve fitting technique develops relationship between RMS and crack depth.
8. Validate the equation by taking random crack depth (0.35 mm).
9. By empirical relation find the life of bearing using crack depth.

## IV. NUMERICAL ANALYSIS

Regression analysis is a statistical process for estimating the relationships among variables. It attempts to establish the nature of relationship between the variables i.e used to study the functional relationship between the variable and thereby provides a mechanism for prediction or forecasting. This chapter includes various methods of curve fitting, Various Methods of Least Square Criteria and Least Square Criterion

### A. Introduction to Curve Fitting:

All engineering experiments land into collection of data which has discrete values. This section deals with techniques to fit curves to such data in order to obtain

intermediate estimates. The simplest method for fitting a curve to data is to plot the points and then sketch a line that visually conforms to the data. A technique is developed to derive a curve that minimizes the discrepancy between the data points and the curve. This technique is called as list-square regression. In many engineering and science applications, it is required to express the data, obtained from various observations and experiments in the form of a low. The low gives the mathematical relation between the two variables and is called as empirical low.

**B. Various Methods of Curve fitting**

If there are different values of x and the various corresponding values of y, then a mathematical relationship  $y=f(x)$  between these two variable can be obtained by

- 1) Graphical method
- 2) Method of group averages
- 3) Method of moments
- 4) Method of least squares

In this chapter we are going to study the method of least squares technique, as it has various applications in engineering and science field.

**C. Various Methods of Least Square Criteria:**

The least square technique is applied in such a way that it represents the curve of best fit. It represents the best possible values of the constants in the equation. To fit the given data, the data available is having the following mathematical relation.

- i. linear
- ii. Quadratic
- iii. Power
- iv. Exponential

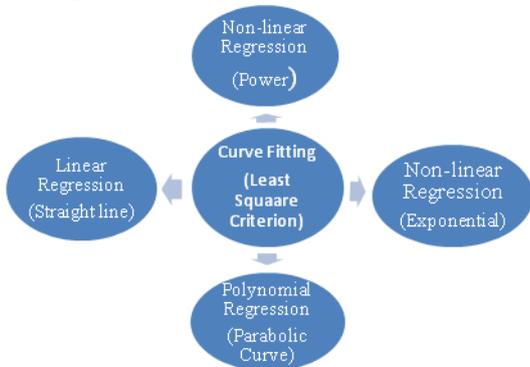


Fig 2 Methods of Least Square Criteria

**i. Straight Line Fit (Linear Regression):**

linear regression is an approach for modeling the relationship between a scalar dependent variable y and one or more explanatory variables (or independent variable) denoted x. In order to determine values of b and a in the equation of line we require value 'S' should be minimum, If the goal is prediction, or forecasting, or reduction, linear regression can be used to fit a predictive model to an observed data set of y and X values. After developing such a model, if an additional value of X is then given without its accompanying value of y, the fitted model can be used to make a prediction of the value of y.

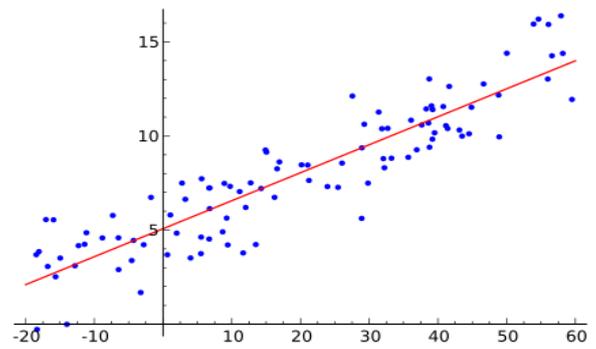


Fig 3 linear regression

To have error to be minimum

$$nb + \sum x_i = \sum y_i$$

$$\sum x_i + \sum x_i^2 = \sum x_i y_i$$

Solving the above equation simultaneously we get the values of b and a then we can write the relation between y and x as the line of equation  $y=b+ax$

**ii. Quadratic Equation (Polynomial Regression):**

In the previous method we have developed a technique to obtain straight line fit through the given set of data points. If the available data points are scattered then the straight line fit is not suitable.

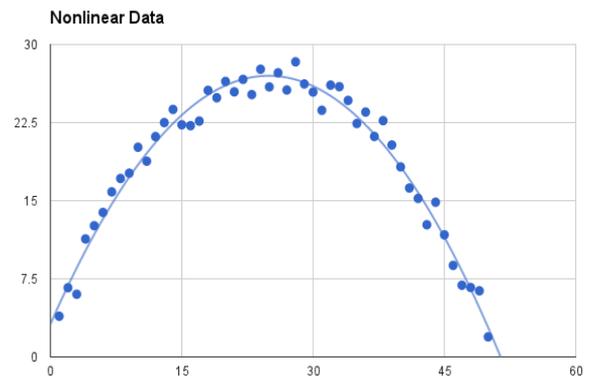


Fig 4 Polynomial Regression

Fig 4 shows a parabolic fit which is more suitable for the given set of data points. This method of fitting a parabola  $y= ax^2 + bx + c$  in short a polynomial through the given set of data points is called as polynomial regression. The least square procedure can be readily extended to fit data to a  $m^{th}$  degree polynomial as,

$$y=b+ax+a_2x^2+a_3x^3+\dots+a_mx^m+e$$

For this case sum of squares of the errors is,

$$S = \sum_{i=1}^n (y_i - b - ax_i - a_2x_i^2 + a_3x_i^3 - \dots - a_mx_i^m)^2$$

We have three unknowns a, b and c and hence we have three simultaneous equations

$$\sum y = a \sum x + b \sum 1 + c \sum x^2$$

$$\sum xy = a \sum x^2 + b \sum x + c \sum x^3$$

$$\sum x^2y = a \sum x^3 + b \sum x^2 + c \sum x^4$$

**V. EXPERIMENTATION**

**A. Experimental Set Up**

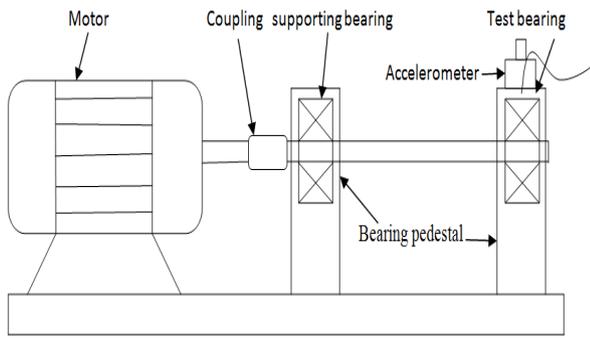


Fig 5 Experimental set up

Experimental bearing test rig worked for this study had an effective speed range of 250-1440 rpm via 1 phase AC servo motor having 1HP capacity. The ball bearings were used in test rig and manually defects to be planted onto inner and outer races with the help of programming wire cutting method. Bearing is a faulty component with a defect in the outer and inner race. The motor shaft was connected to the bearing shaft with a coupler.

It is a device which is used to regulate the speed of motor. With the help of this device we can vary the voltage given to prime mover and therefore we can regulate the speed of motor.

- Rolling bearing (Ball bearing):

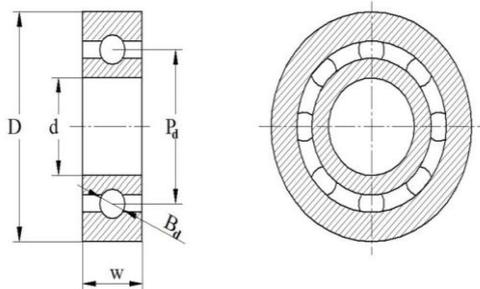


Fig 6 Details of Ball Bearing for vibration Analysis

The bearing type used in this study is a single row deep groove ball bearing with bearing model 6204 series. The details of the ball bearing used in vibration analysis are shown in Table 6.1

TABLE II Bearing Specification

Bearing Type	6204
Inner diameter (d), mm	20
Outer diameter (D), mm	47
Pitch diameter (Pd), mm	31.5
Number of Balls (n)	8
Ball diameter (db), mm	6
Width of the ring (W), mm	14
Contact angle	0

D. Fault frequencies:

The characteristic fault frequencies can be calculated by the following equations:

Ball Pass frequency outer race (BPFO)

$$BPFO = \frac{nf}{2} \left(1 - \frac{d}{D} \cos\beta\right)$$

Ball Pass frequency inner race (BPFI)

$$BPFI = \frac{nf}{2} \left(1 + \frac{d}{D} \cos\beta\right)$$

Ball Pass roller frequency (BPRF):

$$BPRF = \frac{Df}{d} \left(1 - \left(\frac{d}{D} \cos\beta\right)^2\right)$$

Where,

f is the shaft frequency

n is the number of balls

β is the contact angle between inner race and outer race

d is the ball diameter

D is bearing pitch diameter.

Calculated frequencies by formulae

- BPFO=53.96Hz.
- BPFI= 79.36 Hz.
- BPRF=84.32Hz.

E. Results

1) Inner race fault

Relationship between Crack depth and RMS

TABLE III Crack depth v/s RMS for inner race

Sr No	Crack Depth X	RMS Y
1	0	1.25
2	0.2	4.1
3	0.5	6.09
4	0.8	7.86
5	1	9.72

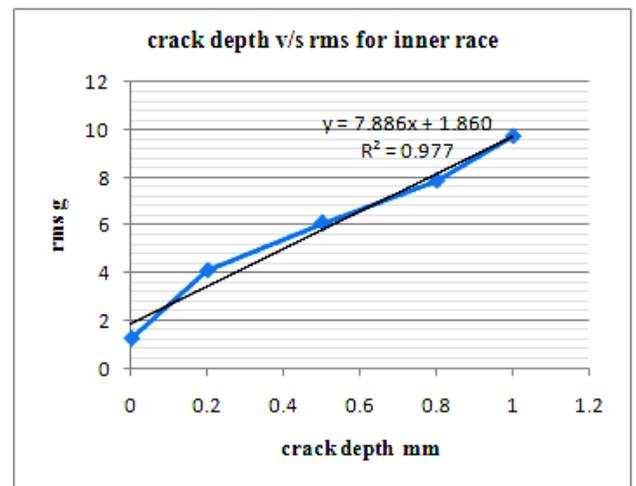


Fig 7 Crack depth v/s RMS for inner race

2) Outer race fault

Relationship between Crack depth and RMS

TABLE IV Crack depth v/s RMS for outer race

Sr No	Crack Depth X	RMS Y
1	0	1.25
2	0.2	3.56
3	0.5	4.75
4	0.8	5.49
5	1	6.2

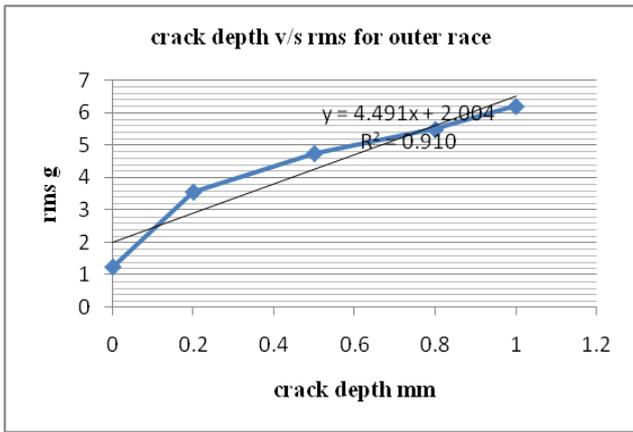


Fig 8 Crack depth v/s RMS for outer race

3) *Ball fault*

Relationship between Crack depth and RMS

TABLE V Crack depth v/s RMS for ball

Sr No	Crack Depth X	RMS Y
1	0	1.25
2	0.2	5.22
3	0.4	6.72
4	0.6	7.94

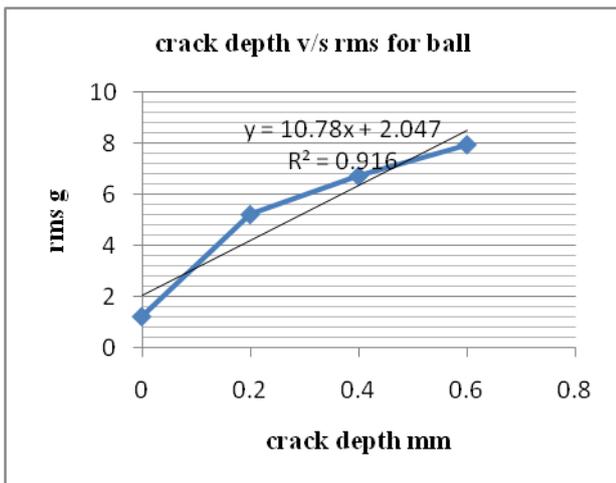


Fig.9 Crack depth v/s RMS for ball

We obtain the relationship from either Mathematical regression or curve fitting technique. But here we obtain relationship from Ms excel. Once we know the RMS value from FFT analyzer, then we easily investigate crack depth value from relationship.

TABLE VI Bearing failure distributions based upon weibull's theory [15]

Component	Weibull-based results
Inner race	70.1
Rolling element	14.8
Outer race	15.1

From above table maximum failure of bearings is only due to inner race.

**VI. ANALYTICAL AND EXPERIMENTAL VALIDATION**

In this chapter, we validate the Crack depth of bearing by experimentally and analytically. This chapter contains the validation procedure, test condition and the validation

results. Here 3 bearings are used and 0.35 mm crack is produced on inner race, outer race and ball respectively

TABLE VII Experimental Result v/s Analytical Result

Bearing Part	Analytical Result		Experimental Result	
	Crack depth mm	RMS For 0.35 mm	Crack Depth mm	RMS for 0.35 mm
Inner race	0.35	4.618	0.35	4.95
Outer race	0.35	3.5758	0.35	3.76
ball	0.35	5.82	0.35	6.12

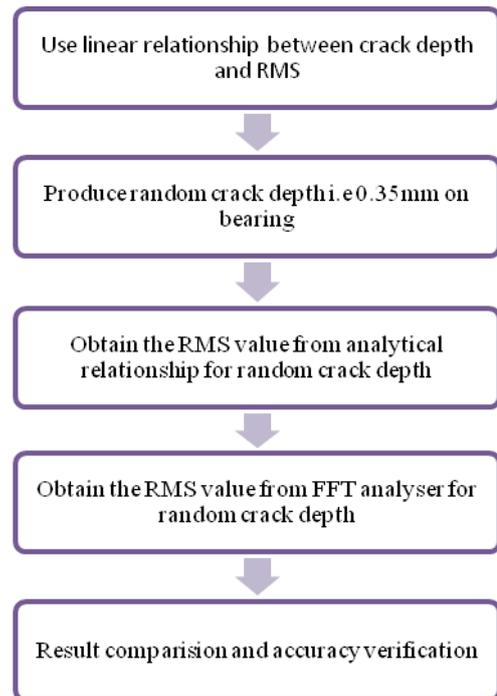


Fig 10 Analytical and Experimental Validation

From above TABLE VIII experimental results matches with analytical results. Once we know the RMS value of the crack, then we easily determine the crack depth.

1) *Bearing Life Prediction*

Weibull's theory to ductile bearing materials by arguing that a bearing's life consists of crack initiation life and crack propagation life, and that initiation life predominates the bearing's life. Based on extensive bearing tests, Palmgren proposed an empirical relationship: [14]

$$\ln \frac{1}{S} = \frac{\tau_0^c}{Z_0^h} N^e V$$

Where, S=probability of survival

$\tau_0$  =orthogonal shear stress corresponding to depth

N=life of bearing

V=stress volume

Z<sub>0</sub> =depth to critical shear stress

c=shear stress exponent

e=Weibull slope

h=exponent

Values of exponent can be found from following relation, e varies=1-2

$$\frac{h}{e} = 2.7$$

$$\frac{e}{c} = 9$$

Finally,

$$\ln \frac{1}{S} = \frac{\tau_0^c}{Z_0^h} N^e AZ$$

Where, A=cross section area of crack

Z=crack depth

Here, variable parameter is N and Z. All other parameter are constant

$$N^e = \text{constant}$$

e=1.5 is often recommended

Thus, crack depth and bearing life have inverse relation. Using that relation we easily predict the life of bearing for known crack depth.

From application

$$\text{Life of bearing } (N_1) = 100000 \text{ hrs } Z_1 = 0.01$$

$$Z_2 = 0.35$$

$$\text{Life remained } (N_2) = \left\{ \frac{N_1^e}{Z_2^h} Z_1 \right\} = 9345.90 \text{ hrs}$$

## VII. CONCLUSION

In present work ball bearings are selected and crack is created manually by using wire cutting method on bearings. These healthy and faulty bearings are installed one by one on the shaft. Time domain and Frequency domain graphs are obtained by using Fast Fourier transform (FFT) analyzer. From the investigation following conclusion can be drawn.

- i. By comparing Frequency domain graphs of healthy and faulty bearings, bearing fault is detected. Comparing fault frequencies with frequencies in Frequency domain graphs, exact bearing fault (i.e. inner race, outer race, and ball) is detected.
- ii. Crack depth of bearing is obtained by using numerical relationship between crack depth and RMS and using that crack depth predicts the life of bearing by empirical relationship.
- iii. Maximum bearing fails (70%) due to inner race fault.
- iv. The RMS of Surface vibration increases with crack depth.
- v. Vibration response is well correlated to crack depth.
- vi. The elimination of unexpected downtime, reduction of repair cost, increased service interval and extension of bearing life, all lead to reduce product cost.

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