Experimental Crack Depth Measurement And Life Prediction Of Bearing Using Vibration Analysis

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Abstract
Failure of bearing can disturb the entire process the staggering losses in terms of production, manpower and equipment repair. Therefore maintenances and repair of bearing are necessary**.** 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. Maintenance of machine can be done either by preventive or breakdown technique. Condition based maintenance is preferred in industries now a days.
Two journal bearings are selected, and crack is created manually on one bearing. These healthy and faulty bearings are installed one by one on the shaft, Time domain and Frequency domain graphs are obtained for different loads by using fast Fourier transform (FFT) analyzer. Comparing these graphs bearing fault is detected. Among the various techniques used for this purpose, vibration analysis technique is very popular now days. The data taken up by a vibration pick up from output end of a machine during dynamic condition can be analyzed in frequency domain. This technique is used to detect the cracks in the structure and machine components.
Keywords: *Vibration analyses of crack; FFT analyzer; RMS acceleration; crack depth; life prediction.*

1. INTRODUCTION

Condition monitoring in process control industry has got now a day's very big relevance. 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 Machine Tool industry, sugar factory, petrochemical, power station aims for high precision and repeatability while it is in operation. 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:
(1) The natural frequency.
(2) The amplitude response due to vibration
(3) Mode shape [5]

The journal Bearing faults degrade machine performance, decrease life time service and cause unexpected failure which are dangerous for safety issues[6].Non-intrusive measurement e.g surface vibration are appropriate monitoring methods for early stage journal bearing faults in low, medium and high frequency[8].The statistical parameter shows

that RMS and peak value for faulty bearing is higher than normal bearing.[9]
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. 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]Traditional bearing maintenance is periodic replacement, which possibly lead to 90 percent of bearing effective life waste[11]. The effective maintenance is to establish a condition monitoring program to check the satisfactory operation of bearings and carry out repair according to practical running condition and fault diagnosis[12]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_{IO}life" (sometimes called B_{IO}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.

2. Theory

2.1 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. [8]

2.2 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 inter face(computer software) is used to perform and use the analysis methods.[8]

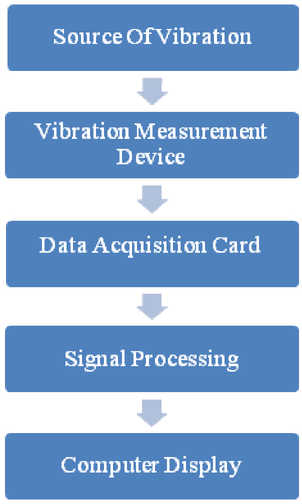

Figure: 1 Component of Architecture[8]

2.3 Condition monitoring methods[7]

Condition monitoring is the process which predicts the present and future conditions of the machinery when in operation. It gathers the information about internal effects of the operating machine. Main methods of condition monitoring are

2.3.1 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.

$$RMS=\sqrt{\frac{1}{N}\sum_{n=1}^{N} f_n^2} \quad (1)$$

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

$$Mean=\frac{1}{N}\sum_{i=1}^{N} f_n \quad (2)$$

- Peak value:

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

$$P_v=\frac{1}{2}[\max(f_n)-\min(f_n)] \quad (3)$$

- Crest factor:

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

$$Crest\ factor=\frac{P_v}{RMS} \quad (4)$$

(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]

2.3.2 Types of Vibration Analysis
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.[8]

2.4 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]

$$\ln\frac{1}{S}=\frac{\tau_0^c}{V}N^e Z_0^h \quad (5)$$

Where, S=probability of survival
τ_0=orthogonal shear stress corresponding to depth Z_0
N=life
V=stress volume
Z_0=depth of crack
c=shear stress exponent
e=Weibull slope
h=exponent

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

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

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

3.Case study
3.1 Experimental Setup:
As shown in Fig. 2, the Accelerometer is mounted on motor vertically it has two channels for recording signals. Since it has inbuilt electronics there is not necessity of any kind of signal conditioning circuit. The recorded signals are then further post processed in MATLAB for analysis purpose.

Figure 2 Experimental setup[1]

- Following are the motor specifications
  (1) KW/HP: 0.37/0.5
  (2) Speed : 2880 RPM at no load
  (3) Voltage: 230V
  (4) Frequency: 50Hz
  (5) Current: 2.6 A
- The bearing under Test is of type 6203Z, with following details.
  (1) ID(Inner Diameter):17mm
  (2) OD(outer diameter): 40mm
  (3) Ball diameter: 6mm
  (4) Cage diameter:30mm
  (5) Number of balls: 8.

3.2 Frequency Analysis

Frequency analysis is the most commonly used method for analyzing a vibration signal. The most basic type of frequency analysis is an FFT, or Fast Fourier Transform, which converts a signal from the time domain into the frequency domain. They can do the analysis by using haar wavelet as well. They have to carry out this analysis in MATLAB for approximations and details up two levels. Approximations are low frequency components and details are high frequency components.[1]

3.3 Results

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

Ball Pass frequency outer race (BPFO)

$$BPFO = \frac{nf}{2}\left(1 - \frac{d}{D}\cos\beta\right) \quad (6)$$

Ball Pass frequency inner race (BPFI)

$$BPFI = \frac{nf}{2}\left(1 + \frac{d}{D}\cos\beta\right) \quad (7)$$

Ball Pass roller frequency (BPRF):

$$BPRF = \frac{Df}{d}\left(1 - \left(\frac{d}{D}\cos\beta\right)^2\right) \quad (8)$$

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

1) BPFO=153.6Hz.
2) BPFI= 240 Hz.
3) BPRF=80Hz.

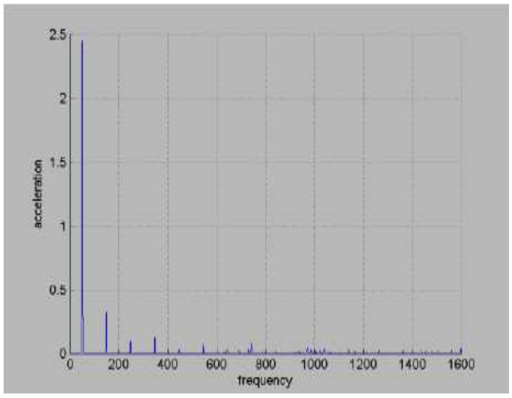

Figure 3 Healthy Bearing[1]

In above FFT the magnitude of 50Hz and 149Hz components. First harmonic at 50Hz indicate that there is unbalance in Power supply. As shown in Fig 3, it can be noted that at a 149Hz there is dominating component than in Fig 4 and if we compare our calculated result of frequency for outer race then it is at153.6Hz. Hence we can conclude that there is fault in outer race.

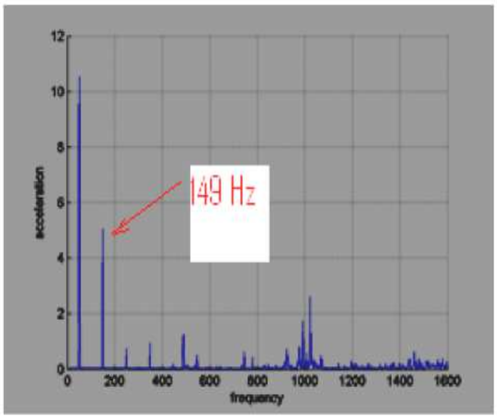

Figure 4 Outer race fault[1]

Fig. 4 and Fig. 5shows the time domain signal which is recorded by Accelerometer. We can make time domain analysis as well by using kurtosis or mean evaluation method but these methods does not 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.

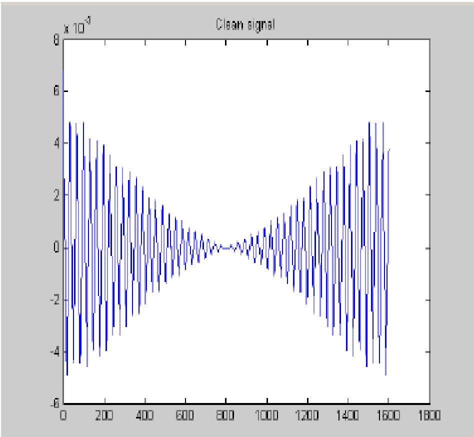

Figure 5 Time domain signal for healthy bearing[1]

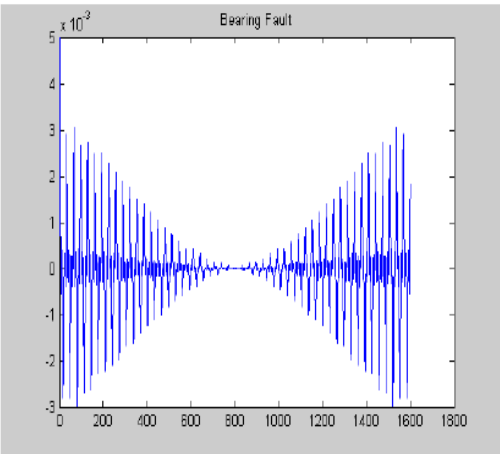

Figure 6 Time domain signal for faulty bearing[1]

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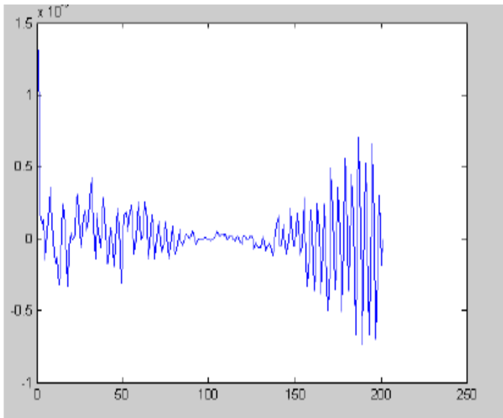

Figure 7 Second level detail component[1]

Figure 7 shows the second level detailing of Haar wavelet in which it is clear that fault frequency (i. e. High Resonant frequency) in between 150 to 200Hz which indicates that there is fault in outer race of bearing.[1]

4. Discussion

- 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[2]
- Speed decreases with increase in crack depth and RMS velocity increases as crack depth increases. [3]
- The crack reduces stiffness of the system, shifting the resonance to lower speeds. This effect is magnified by the depth of the crack. It can be noticed the presence of subcritical (1/3, 1/2) response peaks and large increase of fundamental vibration response when the crack exists.[4]
- The natural frequency changes substantially due to the presence of cracks. The changes depending upon the location and size of cracks.[5]
- The frequency increases with increase in the crack depth for the all modes of vibration.[5]
- Wear and geometric form errors of the raceways can also give rise to periodic vibrations[8]
- From above review ,detection of crack depth and prediction of bearing life is possible by using empirical relation.

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