Bearing Fault Analysis Using Frequency Analysis and Wavelet Analysis

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Abstract—**Bearing fault diagnosis is important in condition monitoring of any rotating machine. Early fault detection in machineries can save millions of dollars in emergency maintenance cost. Different techniques are used for fault analysis such as short time Fourier transforms (STFT), Wavelet analysis (WA), cepstrum analysis, Model based analysis, etc. This Paper 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.**

Index Terms—**Fault diagnosis, bearings, wavelet Analysis methods.**

I. 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 dollars of industry and can save the time as well. It has been found that Condition monitoring of rolling element bearings has enabled cost saving of over 50% as compared with the old traditional methods. The most common method of monitoring the condition of rolling element bearing is by using vibration signal analysis. Measure the vibrations of machine recorded by velocity sensor or Accelerometer continuously which is mounted on the casing of the machine.

More recently by taking thermal images of bearing also we can diagnose the bearing fault. But the problem in this method is that we cannot diagnose the exact location where the problem occurs. In rotating machines mainly faults occurs due to faulty bearings. IEEE analysis reveals the following fact as shown in Table: 1 below [1]

TABLE I: Analysis of Faults

Component	Failure
Bearing	40%
Stator	38%
Rotor	10%
Other	12%

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.

II. Bearing Failure Mechanism

Bearing has Inner Race, Outer race, Balls as rolling elements. Each bearing is associated with it some characteristic frequencies which are dependent on bearing geometry. Fig. 1 shows the basic elements of Bearing.

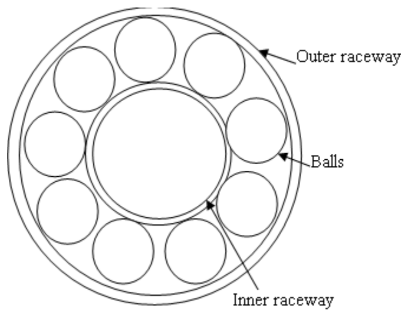

Fig. 1. Sectional view of bearing

Such as ball diameter, Pitch diameter, Inner race Diameter, Outer race diameter, rotational speed etc.

There are number of mechanisms [2] that can lead to bearing failure, including mechanical damages, cracks, wear and tear, lubricant deficiency and corrosion etc. Wear results in gradual deterioration of bearing components when lubrication is not proper the friction between metal to metal increases. Poor lubrication increases the bearing component temperature, which speeds up the deterioration process. Bearing that operates in an environment of high humidity may subjected to surface oxidation and produce subjected rust particles and pits. These particles can produce rapid wear.

III. Characteristic Fault Frequencies

As explained in the previous paragraph, for the ball bearings with angular contact with the cage, the outer ring is static and the inner ring rotates at the shaft speed [1] [2]. The characteristic fault frequencies can be calculated by the following equations:

Ball Pass frequency outer race (BPFO)

$$\text{BPFO} = \frac{n}{2} f\left(1 - \frac{d}{D}\cos\beta\right) \qquad (1)$$

Ball Pass frequency inner race (BPFI)

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$$\text{BPFI} = \frac{n}{2} f(1 + \frac{d}{D}\cos\beta) \qquad (2)$$

Ball Pass roller frequency (BPRF):

$$\text{BPRF} = \frac{D}{d} f(1 - (\frac{d}{D}\cos\beta)^2) \qquad (3)$$

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.

IV. Analysis Methods

Accelerometers are used as Vibration sensor for the bearing fault Analysis. As they have metallic housing and magnetic coupling for adherence. They have same spring mass damper like internal arrangement as shown in Fig. 2.

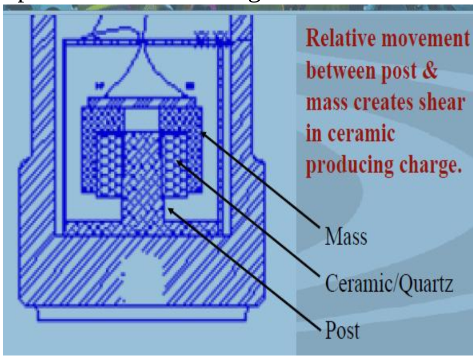

Fig. 2. Sectional view of Accelerometer

A. Exzperimental Setup:

As shown in Fig. 3, 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.

Fig. 3. Experimental setup

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.

B. 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 [3], [4], [5]. We can do the analysis by using haar wavelet as well. We 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

V. Results

Calculated frequencies by formulae given above
1) BPFO=153.6Hz.
2) BPFI= 240 Hz.
3) BPRF=80Hz.

Fig. 4 shows FFT of Healthy Bearing.

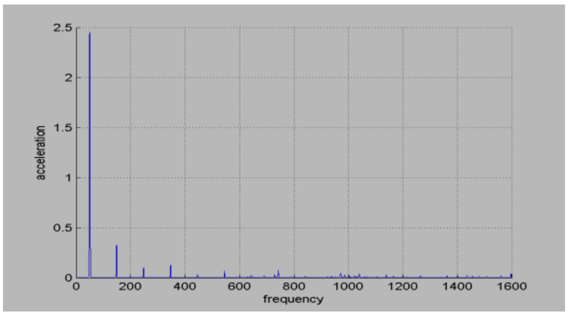

Fig. 4. Healthy Bearing

Table II shows the Acceleration value at each frequency in tabular form.

TABLE II: Frequency vs Acceleration for Healthy Bearing

FREQUENCY (Hz)	ACCELERATION (m/s^2)
50	1.75
149	0.23
248	0.07
347	0.08
548	0.04
743	0.05
971	0.03
1040	0.02

Note carefully 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 4, it can be noted that at a 149Hz there is dominating component than in Fig 5 and if we compare our calculated result of frequency for outer race then it is at 153.6Hz. Hence we can conclude that there is fault in outer race.

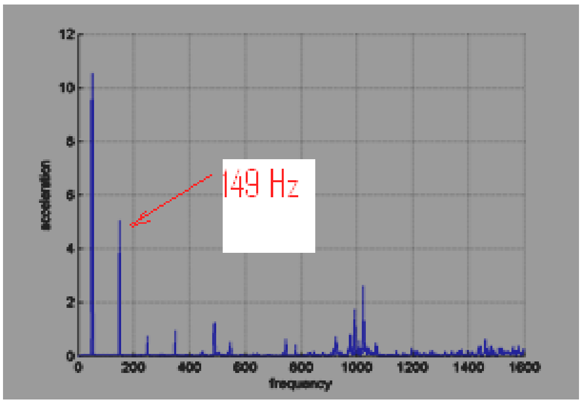

Fig. 5. Outer race fault

TABLE III: FREQUENCY VS ACCELERATION FOR FAULTY BEARING

FREQUENCY (Hz)	ACCELERATION (m/s^2)
50	7.4
149	3.5
248	0.53
348	0.66
489	0.89
976	0.57
992	1.2
1023	1.8

Fig. 6 and Fig. 7 shows 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 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.

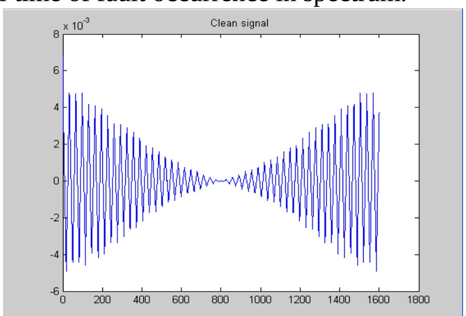

Fig. 6. Time domain graph of healthy bearing

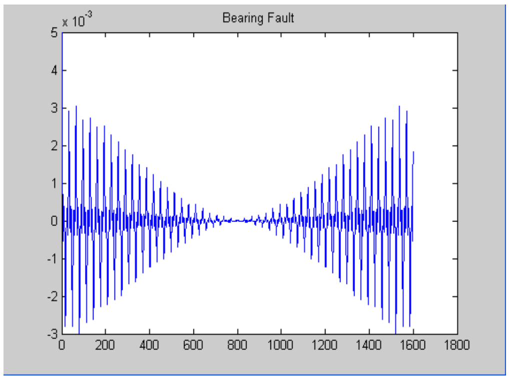

Fig. 7. Time domain signal for faulty bearing

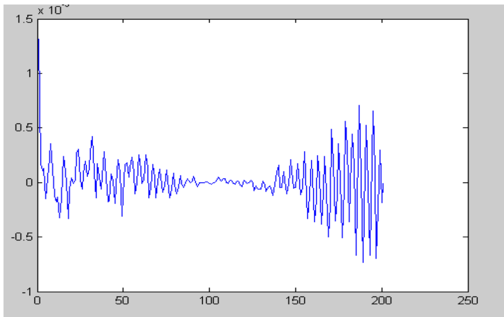

Fig. 8. Second level detail component

Fig. 8 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.

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