Vibration Monitoring System in Industrial Machinery Using Fast Fourier Transform

Rishikesh N

Assistant Professor, Bannari Amman Institute of Technology
Email: rishikesh[at]bitsathy.ac.in
Ph: 9884431408

Abstract: ***This Paper analyses the abnormal vibration patterns in industrial machinery to verify the machine has fault or not. Import the data into MATLAB in column vectors and perform the processes in Signal Processing Toolbox. Create a workspace for each vector, then plot the signals in time domain and to determine the exact fault location. Each of the elements will generate many fault frequencies in the frequency domain based on its characteristics which allowing quick and easy identification. The four possible bearing failing frequencies are: FTF (Fundamental Train Frequency), BPFO (Ball Pass Frequency Outer), BSF (Ball Spin Frequency), BPFI (Ball Pass Frequency Inner) and other overall machine condition faults are Misalignment, Unbalance and Looseness, frequency domain is required. It is used to show each fault location of the faulty machine. This system used to view all the amplitudes of the time waveform which are shown separately. Regarding to Fourier analysis, any vibration signals can be separated into several discrete frequencies or a spectrum of frequencies over a continuous range. Fast Fourier Transform is a system which is used to convert the signals in time domain into the Frequency domain signals. Compute a power spectrum and determine threshold to filter out noise. In this paper we use 1000 RPM, 50 Hz, 415V, 6-pole, 2HP, 1.5KW Induction Motor with 6205 ball bearing. Compare the measured signal with the signals obtained by calculations to determine the fault components.***

Keywords: Frequency domain analysis, Time domain analysis, Datasheet, Fast Fourier transform, MATLAB

1. Introduction

Induction motors are widely used in many industries based on its electrical needs for many years. Due to the working place quality of machines which causes noise and vibration and it is notable. When there is a fault in the given machinery then definitely there will be a noise in that machinery, if we match the natural frequencies of that machine (i. e. induction motor) and vibration match or close to the present motor's parameters (i. e. noise, vibration). In order to avoid such noise and vibration, it is necessary to estimate the amplitude of vibration signals. Assume that the motor vibration signals (i. e., Datasheet) are monitored and measured through accelerometer and signals are imported to MATLAB likewise data are created and have some peak amplitudes. The peak amplitudes are the fault frequencies. First, datasheet uploaded via MATLAB drive, then import the datasheet into MATLAB. Here, we use three vectors (X_vect1, Y_vect1, Z_vect1) because vibration signals are measured for rotatory machines will be in three dimensions. Import these data in column vectors to create a workspace and then continue the process.

2. Vibration Analysis and Motor Faults Detection Methods

In this project, 1000 RPM, 50 Hz, 415V, 6-pole, 2HP, 1.5KW Induction Motor with 6205 ball bearing.

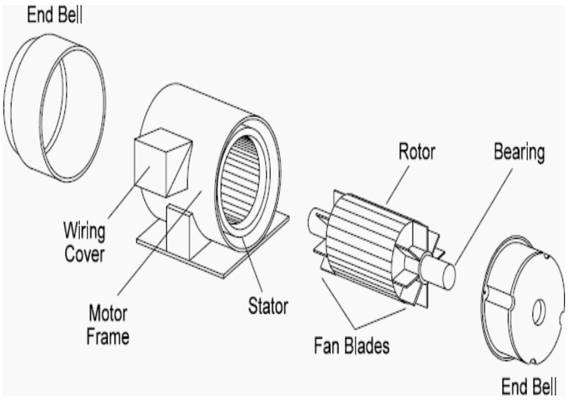

Figure 1

Frequencies of machinery and vibration levels has been defined by vibration analysis and then parameter values (vibration signals) are acquired to find the machine's health and its components.

Vibration analysing methods are classified into four different methods and each method will give specific description on the working conditions and features of the vibrating parts. In this project, 2 out-off 4 principles are used.

1) Time Domain Analysis:
The signal, monitored in the time-domain is also called as waveform. The time-domain analysis plotted between amplitude and time. While most of the machine faults are identified using this analysis and some faults like misalignment, looseness, unbalance are easily seen in this analysis.

2) Frequency-Domain Analysis:
The signal, monitored in this domain results in a waveform with frequency, amplitude values (frequency (Hz) vs amplitude (w/m2)), known as a spectrum, the spectrum

present in a frequency-domain is like the vibration signals (patterns) present in the time-domain. Most of the low frequency faults are detected in this analysis. Fast Fourier Transform is used, a vibration signals can convert from time-domain to frequency-domain.

2.1 Motor Faults Detection Methods

1) Bearing Faults:

Bearings have many components like balls, cage, outer race defect and inner race defect.

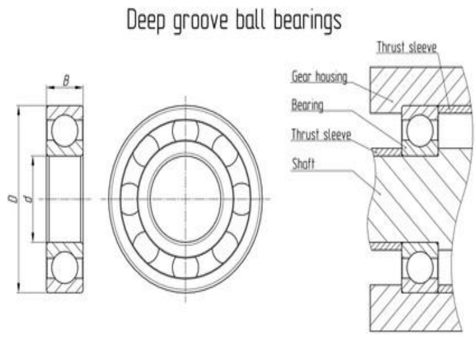

Figure 2

2) Outer Race Fault (BPFO):

An outer race is the bearing's exterior ring and it protects the bearing's internal parts. Rollers that present in a bearing that pass an outer race each time in a specific point, to make the shaft complete turn.

$$BPFO = RPM \{ (N_B/2)\ (I-(B_D/P_D) \cos\beta) \}$$

3) Inner Race Fault (BPFI):

Rollers that present in a bearing that pass an inner track each time in a specific point, to make the shaft complete turn.

$$BPFI = RPM \{ (N_B/2)\ (1+ (B_D/P_D) \cos\beta) \}$$

4) Ball Fault (BSF):

Rollers (balls) that present in a bearing that makes the shaft complete turn at specific point in each time.

$$BSF: RPM \{ (P_D/B_D)\ (1-((B_D/P_D) \cos\beta))^2 \}$$

5) Cage Fault (FTF):

Bearing cage that present in a bearing that makes the shaft complete turn at specific point in each time.

$$FTF: RPM \{ (1/2)\ (1-(B_D/P_D) \cos)\ \beta \}$$

2.2 Other Overall Machine Condition Faults:

1) Unbalance:

Unbalance the main cause of mechanical breakdown in rotating machinery. This fault is due to non-uniform distribution of rotating mass.

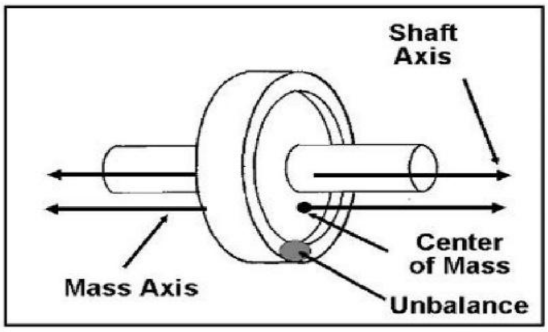

Figure 3

2) Fault Frequency at 1X RPM

a) LOOSENESS:

Looseness obtained in the vibration measurements provided that there is a source of excitation, so, that the small external excitation forces can result in high vibration amplitudes in the presence of looseness.

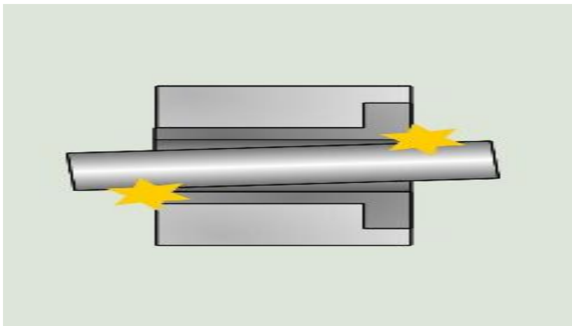

Figure 4

Fault Frequency at ½ RPM

b) MISALIGNMENT:

Misalignment is detected by high frequencies in machines which occurs in between two components that not parallel to each other which are aligned in horizontal planes and this fault results in high axial vibrations.

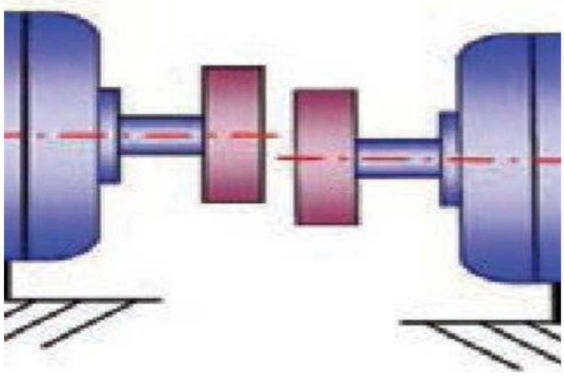

Figure 5

Fault Frequency at 2X RPM

3) Technical Terms Related to Formulae:

1) $P_D = D + d/2$
   - D=Outer diameter of the bearing
   - d=Inner diameter of the bearing
2) N_B= Number of Balls (10)

3) β = Contact Angle (25^0)
4) B_D=Width of the bearing

3. Calculated Results

First, we created the data as three vectors (X_vect, Y_vect, Z_vect) and import them as column vectors to get variables in workspace for future use. The sample data are mentioned below.

Table 1

X_vect	Y_vect	Z_vect
1	**0.5**	**-2**
2	**-0.9**	**1.5**
1000	**1500**	**2000**

Create the time vector (x-axis) by using sampling frequency of the given data, length of the signal (i. e., time_vect= (0: L-1) *T).

Add all the data (Vibration signals) in one vector [M_vect] (i. e., M-vect = (X_vect + Y_vect + Z_vect)).

In every faulty machine if there is a fault then there will be a noise. So, we add noise signals (i. e. vect=sin (M_vect) +0.5*rand (size (M_vect)) to the data to make them as a Non-Linear signal.

1) Time Domain Result:

Most challenging aspect in this vibration measurement is to acquire the vibration patterns (data) from the machine and the next part will work under the analysing of acquired data. In vibration analysis, understanding the types of waveforms are most important.

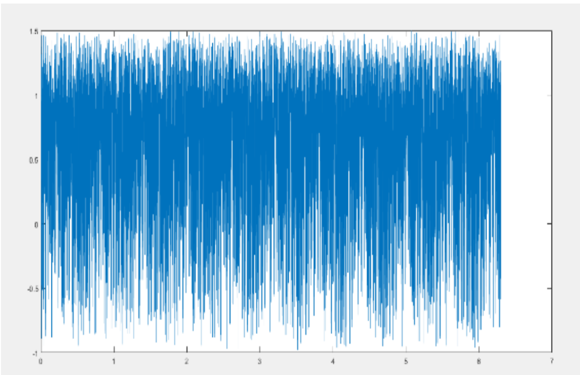

Figure 6

Basically, vibrations are generated in oscillating motion (equilibrium). Here rate of that oscillation is determined. In this analysis, the peak amplitudes are not identified because of the addition of noise in the given signal. Here, we plot the modified noisy signal with respect to time (i. e., Amplitude (w/m^2) vs time (ms)).

2) Noise Reduction Result:

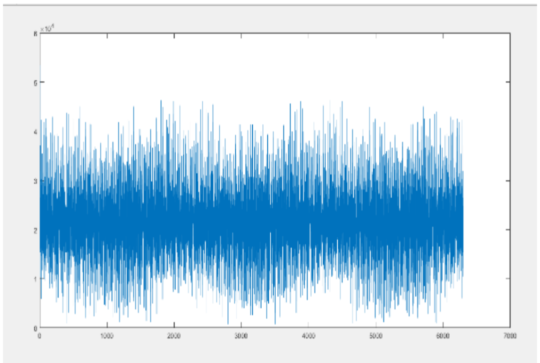

Figure 7

In this analysis, the major abnormal vibration patterns (signals) are controlled, this analysis is also called as spectrum subtraction method. This method helps to convert the Non-Linear signal into Linear signal. The FFT function acts as a low pass filter to reduce a noise in the given signal. The noise will be reduced partially and the spectra mentioned above is plotted between amplitude (w/m^2) against the frequency (Hz).

3) Deviation Reduction Result

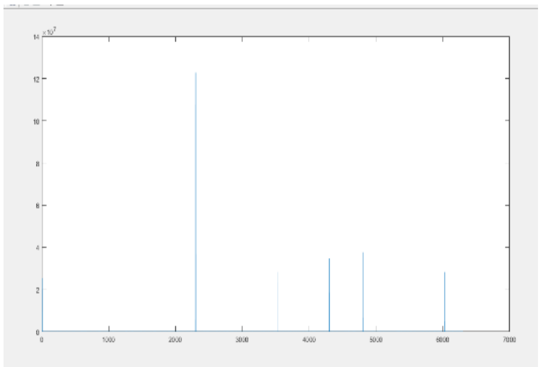

Figure 8

In this analysis, the Fourier Transform being used and the vibration amplitudes in output waveform as a function (i. e. separate fault locations) of frequency so the analyser can determine the causes for that abnormal vibration signals (peak amplitudes) and the peak amplitudes are obtained as a separate discrete waveform and using the FFT function again, the noise in the signal is completely reduced but the fault frequency is deviated. Here, we plot the amplitude (w/m^2) against the frequency (Hz).

4. Frequency Domain Result

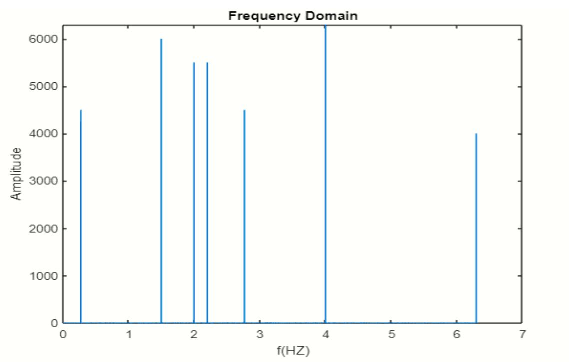

Figure 7

Paper ID: SR22523164451 DOI: 10.21275/SR22523164451

In this analysis, FFT function used again to get the desired output. The deviations for the fault frequencies were controlled and here we can see the exact fault locations which is in the output waveform. In the above spectra, we plot amplitude (w/m^2) vs frequency (Hz). The fault frequencies are determined and compare these frequencies with frequencies obtained by calculations and assume the faulty components.

5. Conclusion

This paper analyses the faulty components in the motor by analysing the fault frequencies determined by Fast Fourier Transform. The waveform in Time Domain analysis has the noise signals in it and the noises are filtered in frequency domain analysis by using the FFT function. Figure-7 shows the exact output of this paper. Finally, comparison between the frequencies generated in MATLAB with frequencies obtained by calculations are done to determine the faulty components.

References

[1] D. Mori and Takeo Ishikawa, Senior Member, IEEE **“Force and Vibration Analysis of Induction Motors”,** 5 MAY 2005.

[2] ABB, Ole Deviks vei 10, Oslo, Norway, waqas. ikram[at]no. abb. com **“Vibration-Based Wireless Machine Condition Monitoring System”.**

[3] Alaa Abdulhady Jaber, Robert Bicker, **“Design of a Wireless Sensor Node for Vibration Monitoring of Industrial Machinery”,** 2 APRIL 2016.

[4] Wang et al., **"Rolling element bearing fault detection using an improved combination of Hilbert and Wavelet transforms"** in, Journal of Mechanical Science and Technology, vol.23, pp.3292-3301, 2009.

[5] Xu Zhe, Zhang Di “**De-noising of spectral signal based on stationary wavelet transform”** International conference on electric information and control engineering (ICEICE) (2011), pp.3098-3101

[6] A. Bouida, O. Thami, R. Ibtiouen, A. Bealouchrani, M. Fadel, A. Rezzoung “**Fault diagnosis in industrial induction machines through discrete wavelet transform”** IEEE Trans Ind Electron, 58 (2011), pp.4385-4395

[7] E. C. C. Lau, H. W. Ngan “**Detection of Motor bearing outer raceway defect by wavelet packet transformed motor current signature analysis”** IEEE Trans Instrum Meas, 59 (2010), pp.2683-2690

[8] Vicente Climente-Alarcon, *et al.* “**Induction motor diagnosis by advanced notch FIR filters and the Wigner Ville distribution”** IEEE Trans Ind Electron, 61 (80) (2014), pp.4217-4227

[9] A. Belini, A. Yazidi, F. Fiipetti, C. Rossi, G. Capolino “**High frequency resolution techniques for rotor fault detection of induction machines** IEEE Trans Ind Electron, 55 (12) (2008), pp.4200-4209

[10] T. G. Habetler **“Effects of time varying loads on rotor fault detection in induction machines”**IEEE Trans Ind Appl, 31 (1995), pp.900-906

[11] E. T. Esfahani, Wang Shaocheng and V. Sundararajan, "**Bearing Fault Detection in Induction Motors**" in, Mechatronics, IEEE/ASME Transactions, vol.19, no.3, pp.818-826, June 2014.

[12] W. Wang and O. Jianu, "**A smart sensing unit for vibration measurement and monitoring**", *IEEE/ASME Trans. Mechatronics*, vol.15, no.1, pp.70-78, Feb.2010.

[13] Nandi, H. Toliyat and X. Li, "**Condition monitoring and fault diagnosis of electrical motors—A review**", *IEEE Trans. Energy Convers.*, vol.20, no.4, pp.719-729, Dec.2005.

[14] R. R. Schoen, T. G. Habetler, F. Kamran and R. G. Bartheld, **"Motor bearing damage detection using stator current monitoring",** *IEEE Trans. Ind. Appl.*, vol.31, no.6, pp.1274-1279, Nov. /Dec.1995.

[15] H. Henao, C. Demian and G. A. Capolino, "**A frequency-domain detection of stator winding faults in induction machines using an external flux sensor**", *IEEE Trans. Ind. Appl.*, vol.39, no.5, pp.1272-1279, Sep. /Oct.2003.

[16] S. Nandi and H. A. Toliyat, "**Novel frequency domain-based technique to detect incipient stator inter-turn faults in induction machines using stator induced voltage after switch-off**", *IEEE Trans. Ind. Appl.*, vol.38, no.1, pp.101-109, Jan. /Feb.2002.

[17] W. Wang and O. Jianu, "**A smart sensing unit for vibration measurement and monitoring**", *IEEE/ASME Trans. Mechatronics*, vol.15, no.1, pp.70-78, Feb.2010.

[18] R. Yan and R. Gao, "**Hilbert-huang transform-based vibration signal analysis for machine health monitoring**", *IEEE Trans. Instrum. Meas.*, vol.55, no.6, pp.2320-2329, Dec.2006.

[19] F. Salvadori, M. de Campos, P. S. Sausen, R. F. De Camargo, C. Gehrke, C. Rech, et al., "**Monitoring in industrial systems using wireless sensor network with dynamic power management**", *IEEE Trans. Instrum. Meas.*, vol.58, no.9, pp.3104-3111, Sep.2009.

[20] D. Dorrell, W. Thomson and S. Roach, "**Analysis of airgap flux current and vibration signals as a function of the combination of static and dynamic airgap eccentricity in 3 phase induction motors**", *IEEE Trans. Ind. Appl.*, vol.33, no.1, pp.24-34, Jan. /Feb.1997.

Lists of Figures

Lists of Tables