Review of Rotating Machinery Fault Diagnosis with Vibration Analysis

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ABSTRACT
A fully automatic system that can identify internal defects and forecast their remaining usable life is needed for smart factories worldwide. Utilizing the "predictive maintenance" method is one way to do this. It allows for intervention before failure occurs and considerably raises the efficiency of engineering components. Condition monitoring of rotating machinery can be done by vibration analyses utilizing various characteristic frequencies. Common defects like shaft misalignment, unbalanced, bend shafts, bearing defects and gear defects in rotating machinery must be identified before failure occurs. With the aid of frequency analysis, these errors can be anticipated. This paper covers a brief review of different fault diagnosis techniques, vibration analysis for fault detection and diagnosis, signal processing techniques, sensor position, dominant frequencies and the vibrational plane of different faults in rotating machinery.

***Keywords**: Predictive maintenance, rotating machinery, vibration analyses, internal defects, frequency analysis, condition monitoring*

INTRODUCTION

Condition monitoring, using vibration analysis can predict and diagnose structural or operational defects of rotating machinery. In rotating machinery, shaft misalignment and unbalance are common faults, and they must be diagnosed before failure occurs.

These faults can be predicted with the help of frequency analysis. Fault detection using vibration analysis involves analysing the vibration signature for the occurrence of a fault.

Any predominant fault occurring results in an increased vibration level, which has energy concentrated at certain frequency levels. By using this frequency response, it is easy to detect and diagnose faults.

A laboratory-scale device, Machine Fault Simulator (MFS), for conducting rotor dynamics studies was built. It assists in learning the vibration signature of the most common machinery failures in a controlled manner. The MFS is a benchtop system with a modular design. It allows for analyses of a range of gear and belt defects in rotating machinery. Vibration, noise, wear, and lubrication can all be diagnosed using simulators [1].

Gear is one of the key components in the transmission system of an automotive engine. To maintain the engine's performance, the gear system should be properly maintained. Fourier Transform (FT), and Continuous Wavelet Transform (CWT) techniques are used for fault diagnosis of gear damage detection. The IC

Engine's gearbox's vibrations were studied for both real and simulated fault gear. Wavelet analysis is effective in detecting non-stationary, non-periodic, and transient vibrational signal properties. Vibration analysis is a useful method for monitoring machine health [2].

The order analysis was used successfully in identifying the two common issues with rotating machinery: misalignment and cracking. The order analysis is based on the frequency domain vibration data derived from the FFT. After the data acquisition, an FFT was used to convert it from the time domain to the frequency domain. The machine used in the investigation had vibrations that were within acceptable limits as per ISO Standard 20816:2016. In the industrial setting, the majority of equipment has at least one shaft that frequently experiences problems with cracking or misalignment. When compared to a similar machine, this vibrational spectral trend of a misaligned and broken shaft can be used as a baseline to identify defects that will maximize productivity while minimizing downtime [3].

Pitting, scuffing, spalling, cracking, and wear are the main types of gear faults that are frequently encountered. Internal problems of gears cause a gearbox to malfunction. A gearbox’s fault analysis by using vibration analysis. The measurement of vibration with transducer ADXL3353-Axis. A national instrument data acquisition card was used. The data was examined for an 80-tooth gear meshing with a 32-tooth pinion at 600 rpm and no-load condition. A gear box’s fault analysis was done by Artificial neural network (ANN) (deep learning toolbox MATLAB), and frequency domain analysis with these two methods compare of the result. Vibrational defects analysed using both FFT and ANN. But ANN produced more accurate results than the FFT [4].

The most frequent problem with rotating machinery is a bend shaft. Depending on the degree and location of the bend, a bent shaft causes an excessive amount of vibration in a machine. Shaft bends can occur for a number of reasons, including creep, thermal distortion, or a significant imbalance force. A bend shaft can cause rotating equipment to fail unexpectedly, which could cause large financial losses. A machine's health is indicated by the vibration amplitude (displacement, velocity, and acceleration), which also tells us how serious a fault is. Higher amplitude at first order is shown by the bend shaft of the Spectra analysis. The bend shaft is confirmed by the phase difference between the axial directions at the Drive End (DE) bearing and Non Drive End (NDE) bearing. Both phase and amplitude are retrieved during order analysis. The fault type and location are often determined by the phase and amplitude [5].

The vibration analysis is a useful supplement to other NDT testing methods. Vibration analysis for application such as vertical sodium pump, centrifugal pump, sodium pump was done. Due to rotor rub and some mechanical looseness, the vibrational spectrum of vertical sodium pump showed harmonic peak. The pump was dismantled and it was found that hydrostatic bearing was damaged and journal was totally worm out. The spectra of centrifugal pump showed peak at 1X rpm because of bend and peak at 5X due to bearing fault. [6]
Vibration analysis is a technique for keeping track of the machine's health. In time space vibrational examination measurable qualities like RMS, mean, kurtosis and peak factor are contrasted and limit an incentive for shortcoming recognition in pivoting hardware. Time domain vibrational analysis do not detect early faults as compared to frequency

domain. In frequency domain more effectively define faults as compared to time domain [7].

Various condition monitoring techniques such as vibration monitoring, oil analysis, acoustics emission, particle analysis, corrosion monitoring and thermography. In rotating machinery all fault related with vibration so vibration analysis was used for condition monitoring. Vibrational signal processing with time domain, frequency domain and time frequency domain but in time frequency domain signal are comes with more effective than other two signal processing techniques [8].

Misalignment of shaft creates number of problems, including coupling failure, lubrication seal damage (leakage), and bearing failure. Shaft angular misalignment can be diagnosed with vibration and acoustic emission techniques. For collecting data of vibration and acoustic emission, proximity sensors were used. Acoustics emission is more effective to detect angular misalignment fault as compared to vibration analysis method [9].

Very less study based on, at a time analysis of all faults in rotating machine such as unbalanced shaft, bend shaft, angular & parallel misalignment, gear profile, and different bearing faults. This study is to investigate the study of different fault characteristics of rotating machinery.

FAULT DIAGNOSIS TECHNIQUES [10]

Various techniques for machinery fault diagnosis are:

Vibration Monitoring

The most reliable method for identifying mechanical defects in any rotating machinery. The mechanical parts of a machine vibrate when they respond to internal or external forces. Vibration signals are utilized as a tool to monitor mechanical condition of machine, because the majority of issues with rotating machinery results in excessive vibration.

Oil Analysis

This technique involves looking for specific small particles in the lubricating oil that can indicate the health of the bearings, gears etc.

Acoustic Emission

It is analysis of acoustic noise spectrum, a machine in good working condition has a stable noise spectrum. When a condition changes the spectrum also changes, which can be detected by use of acoustic condition monitoring. It is used finding and continuously monitoring cracks in different types of structures including pipelines.

Particle Analysis

In this technique, the material emitted by reciprocating machinery, such as hydraulic systems or gearboxes, is collected and examined. The material offers essential information on the components condition.

Thermography

Thermography used for detecting electrical and mechanical equipment fault. By using temperature measurement thermography is performed.

FAULT DETECTION AND DIAGNOSIS USING VIBRATION ANALYSIS [11]

The amount of vibration energy measured across all frequencies is known as vibration analysis. A machine's current state of health can be determined by measuring the "total" vibration of a machine or component. Value for total vibration higher than normal indicates presence of fault in the machine. Total vibration measure with scale factors consisting of peak, Peak to-Peak, average, and RMS. When working with sinusoidal waveforms, these scale factors have a direct relationship with one another. The relationship between average, RMS, peak, Peak-to-Peak, and average for sinusoidal waveforms are shown in Fig. 1.

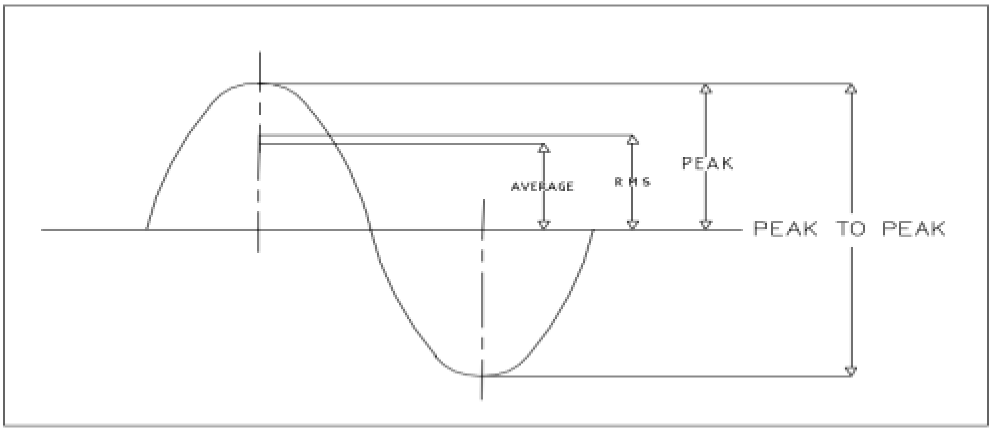

***Fig. 1:** Vibration sinusoidal waveforms.*

The Peak value indicates the waveform's height as measured from a zero reference. The amplitude measured from the topmost to the bottommost portion of the waveform is known as the peak-to-peak value. The average value represents the waveform's average amplitude value. A pure sine waveform has an average value of zero (it has equal positive and negative values). The majority of waveforms, though, are not wholly sinusoidal.

SIGNAL PROCESSING TECHNIQUES

Processing of signals is essential because there are several fault types. The right technique must be chosen based on the characteristics of the collected signal. Following are the signal processing techniques for rotating machinery fault detection.

Time Domain Analysis

Time domain analysis examines physical signals or time series of data in relation to one another. The change in a signal with respect to time is represented by a time-domain graph.

Frequency Domain Analysis

Analysing physical signals or data time series with respect to frequency is known as frequency domain analysis. It displays the number of signals over a range of frequencies with respect to amplitude.

Time-Frequency Domain Analysis

This includes methods that employ both the time and frequency domains simultaneously. Two-dimensional signals are studied.

SENSOR POSITION FOR VIBRATION MEASUREMENT

Special attention should be given to the sensor's placement on the machinery, its angle with the machinery, and the contact pressure used to hold the sensor against the machinery. A surface with without paint is required for mounting of vibration measurement sensor. Avoid positioning of sensor at unloaded bearing zones, structural gaps. It's essential to take consistent readings while measuring vibration using a hand-held sensor. The axial (A), horizontal (H), and radial (V) vertical direction should be used for vibration measurement sensor position. The sensor locations are shown in the Fig 2 below.

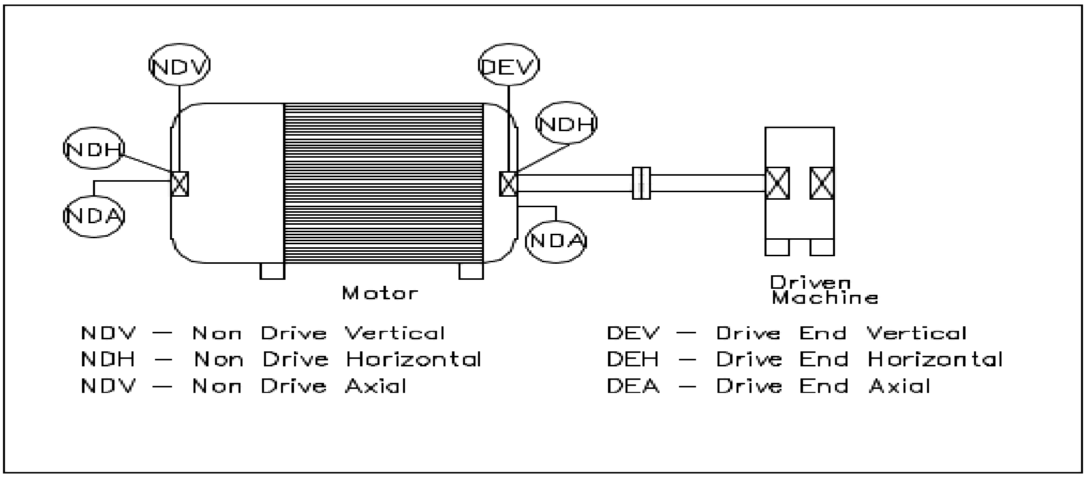

***Fig. 2:** Sensor Position for vibration measurement.*

FFT SPECTRUM ANALYSIS [12]

Applying Fast Fourier Transformation to the vibration signal is a technique more beneficial for vibration analysis. Fast Fourier Transform converts time domain signal into frequency domain. This means that the signal is divided into distinct amplitudes at different component frequencies. From the below Fig 3, the signal's higher amplitude peak is at 180 Hz frequency (1X), then again at 420 Hz frequency (2X) etc. The first harmonic component, represented by 1X, is equal to the rotor's rotational speed; the second harmonic component is represented by 2X.

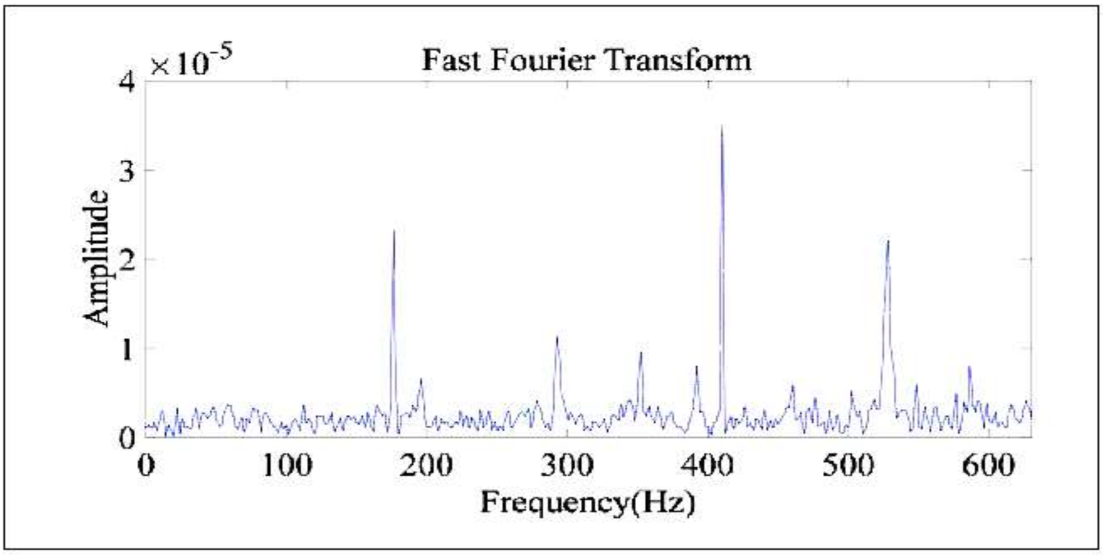

***Fig. 3:** FFT Spectrum Plot.*

FAULT IN ROTATING MACHINERY WITH DOMINANT FREQUENCIES AND VIBRATION PLANE

The various characteristic frequencies of rotating machinery faults are as follows:

Unbalance Shaft

For an unbalance shaft, the sinusoidal waveform of vibration produced by pure imbalance occurs once at each revolution. This shows as a higher-than-usual 1x amplitude on an FFT spectrum. Other faults frequently produce harmonics in addition to a high 1x amplitude. In a typical unbalance, the vibration amplitude in the radial direction is unusually high in comparison to the axial direction. Fig.4 shows unbalance shaft frequency response.

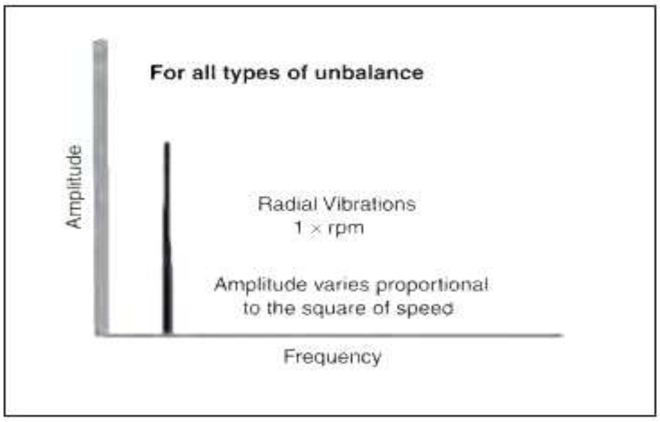

Fig. 4: *Unbalance shaft frequency response.*

Bend Shaft

A bend shaft results in spectra similar that of misalignment shaft. There could be a higher-than-usual 1x/2x amplitude. Axial vibrations are higher than the radial vibrations. If the bend is close to the shaft centre, then the amplitude of 1X is dominating. If the bend is close to the shaft end then the dominant amplitude is 2 X. Fig.5 shows bend shaft frequency response.

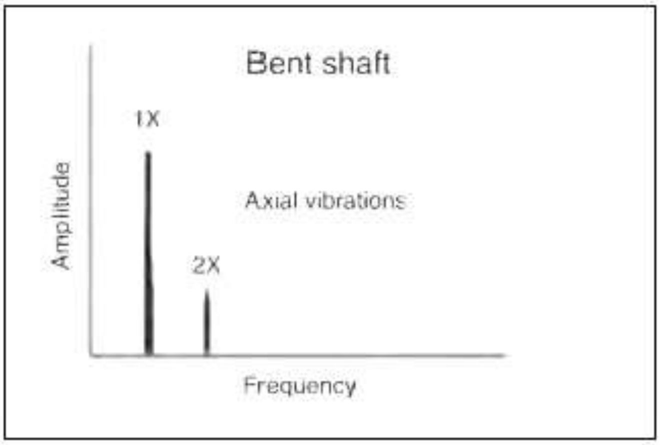

Fig. 5: *Bend shaft frequency response.*

Misalignment Shaft

A higher than usual 1x/2x amplitude may occur due to misalignment shaft. Axial vibration due to angular misalignment occurs at the running speed frequency (1x). Radial vibration due to parallel misalignment occurs a frequency that is twice that of running speed (2x). Both the radial and axial plane measurement, 1x and 2x frequencies are examined because the majority of misalignment consists of an angular and parallel component. A higher than normal 1x amplitude divided by 2x amplitude may occur in FFT spectrum of angular misalignment. Fig. 6 & Fig. 7 shows shaft frequency response for angular and parallel misalignment respectively.

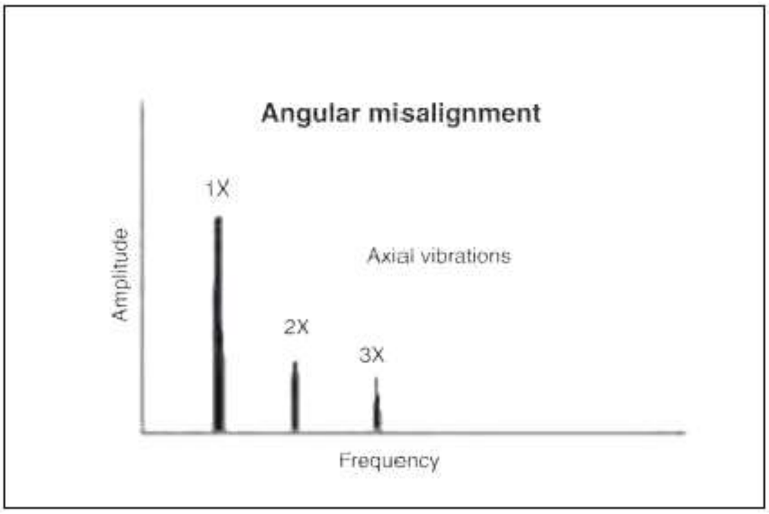

Fig. 6: *Angular misalignment shaft frequency response.*

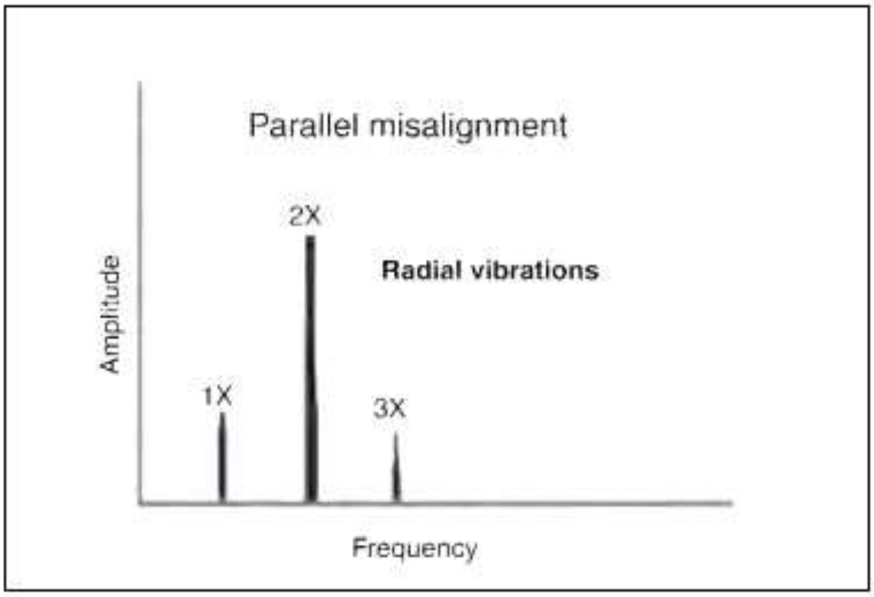

Fig. 7: *Parallel misalignment shaft frequency response.*

Gear Faults

Gear faults appear in a radial plane. Gear mesh frequency (GMF) means the number of teeth on the gear multiplied by the speed of the shaft to which the gear is attached. The multiple GMFs and their harmonics produce a spectrum of frequencies in gearboxes. If the gearbox is still in a good condition, all peaks have small amplitudes and no natural gear frequencies are excited. The tooth wear and backlash faults in gear excite natural frequencies along with the gear mesh frequencies and their sidebands. Fig. 8. shows normal gear and frequency response of gear with tooth wear.

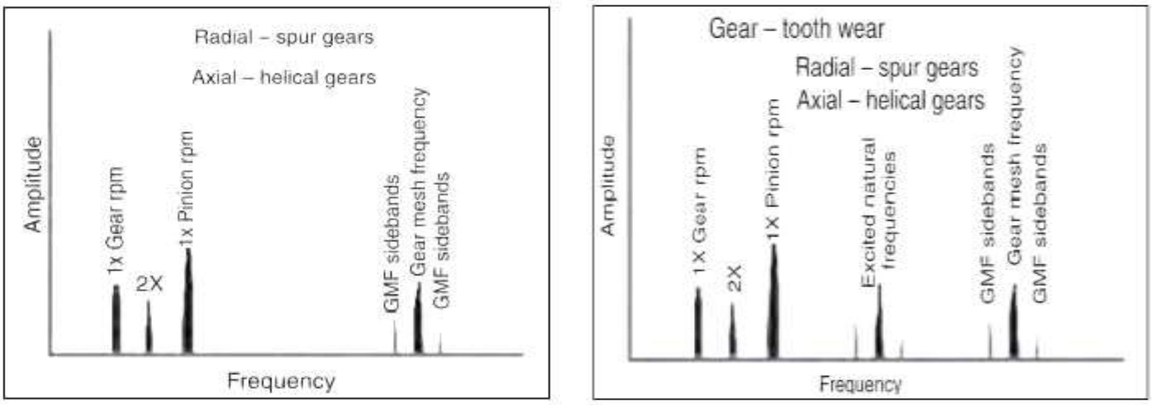

Fig. 8: *Normal gear and tooth wear of gear frequency response.*

Bearing Fault

The dominant frequency for bearing fault is 4X … 15X and the plane of vibration is radial.

CONCLUSION

In this review, study of different machinery fault diagnosis techniques is done and different rotating machinery faults are presented with the help of vibration analysis. Vibration analysis is a non-destructive technique for detecting faults in that is helpful for finding various fault frequencies in rotating machinery. Vibration data can be analysed by using various signal-processing techniques. Study of measurement sensor position and FFT spectrum analysis was also done. With the help of spectrum analysis, it is easy to point out location of the defect. This paper also gives the plane of vibration and dominant frequencies of various rotating machinery faults. In rotating machinery common faults such as unbalanced, bent, and misaligned shafts are easy to find by using vibration analysis.

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