Vibration Analysis of Electrical Rotating Machines using FFT

A method of predictive maintenance

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Abstract—**Present day requirements for enhanced reliability of rotating equipments are most critical than ever before, and demands continue to grow constantly. Detection of faults play important role in the quest for highly reliable operations. Reducing maintenance and production cost, improving uptime, product quality, advance safety and reducing risks are some of the essential drivers for deploying vibration analysis. These serve as goals of any plant or corporation. Vibration analysis for predictive maintenance is an important ingredient in all these goals. Vibration analysis can be used as part of root cause analysis efforts within any plant. The present work offers a course of action for analyzing the vibration signals of electrical rotating machines and diagnoses the health of machine for predictive maintenance requirements using Fast Fourier Transform (FFT). The Vibration analysis of electrical rotating machines lies on the fact that all rotating machines in good condition have fairly stable vibration pattern. Under any abnormal condition in working of machines, the vibration pattern gets changed. The amount of variation can be detected and the nature of abnormalities can be analyzed with LabVIEW to get an idea about the fault in the machine. Based on the type of defect and its slope of progression, predictive maintenance schedule can be proposed. This work also aims at overcoming the limitations of traditional vibration analysis techniques.**

Index Terms - Vibration Analysis; Predictive Maintenance; FFT

I. INTRODUCTION

Mechanical and operational conditions must be periodically monitored, and when unhealthy trends are detected, the troublesome parts in the machine should be scheduled for maintenance. [9] The continuous evaluation of plant and equipment throughout its serviceable life can be done by vibration monitoring. It is a process of monitoring a parameter in machinery, such that a significant change is indicative of a developing failure. It is a major component of maintenance. The use of vibration analysis can be made to avoid the consequences of failure, before the failure occurs. Machines with defects are more at risk of failure than defect free machines. [7]

Analysis of machine vibrations brings about several benefits including increased revenue, increased production reliability, less downtime, and lower repair costs. This analysis is closely related to protection. However, its main function is that it leads to early detection of faults unlike protection. This greatly helps to schedule activities conveniently reducing downtime and losses. [7]

Machinery maintenance in industry has evolved from breakdown maintenance to time based preventive and predictive maintenance. Vibration Analysis in particular has for some time been used as a predictive maintenance procedure and as a support for machinery maintenance decisions [7, 9]. As a general rule, machines do not break down or fail without some form of warning, which is indicated by an increased vibration level. By measuring and analyzing the vibration of a machine, it is possible to determine both the nature and severity of the defect, and hence predict the machine's failure. The over-all vibration signal from a machine is contributed from many components and structure to which it may be coupled. However, mechanical defects produce characteristic vibrations at different frequencies, which can be related to specific machine fault conditions. By analyzing the time and frequency spectrums, and using signal processing techniques, both the defect and natural frequencies of the various structural components can be identified [2].

In this paper, vibration analysis using FFT is studied. This is achieved by investigating different operating conditions of the rotating electrical machines. The rotating electrical machines are to be run under normal operating conditions as a reference test. A series of tests conducted where a number of different machine defects are intentionally introduced. Specifically, four tests conducted in total, during which vibration data is regularly collected. Mechanical problems produce much smaller amplitude vibration signals in a higher frequency signals are produced in the gear mesh frequency range, which is determined by the number of teeth. Numerical data produced by vibration analysis spectra provides effectiveness in predictive maintenance and diagnosis of machine faults.

II. EXPERIMENTAL WORK

An experimental assembly with controlled operating conditions is set-up to conduct a series of tests using spur gears. Mid Steel spur Gears are used in the test with a step down speed ratio 1.5:1. The input shaft has 36 teeth while the output shaft has 54 teeth. The gears are driven by a permanent magnet DC-motor with variable speed and 0.25 hp rating. The motor has full speed of 3000 RPM. A photograph of the experimental assembly is shown in fig. 1.

Fig.1. Experimental Test Set-up

Tests have been carried out at different speed conditions. An accelerometer is used to measure the acceleration, velocity and displacement as vibration amplitude. Since majority of general rotating machinery operates in the range of 10 and 1000 Hz, velocity is commonly used for vibration measurement and analysis. The sensors are connected to Data Acquisition (DAQ) device and interfaced with the computer. The sensor operates in accordance with the piezoelectric principle. Its frequency range is from 2 Hz to 10 kHz and its resonance frequency is 22 kHz.

The system vibrations are being measured at three different positions of the assembly, namely horizontal (x), vertical (y) and axial (z) positions.

III. VIBRATION ANALYSIS

Rotating electrical machines convert electrical energy, or vice versa, and they achieve this by magnetically coupling electrical circuits across an air-gap that permits rotational freedom of one of these circuits. Mechanical energy is transmitted into or out of the machine [5].

The rotating electrical machine consists of a driver and driven equipment. At times when the driven at speeds other than prime mover, a gear box is used [7].

When components of rotating electrical machines operate continuously at high speeds, wear and failure is imminent. The defects can be stated that whenever one or more parts are unbalanced, misaligned, loose, eccentric, damaged or reacting to some external force; they result into higher vibration levels. The vibrations caused by the defects occur at specific vibration frequencies. The vibration amplitudes at particular frequencies are indicative of severity of the defects. Vibration analysis aims to correlate the vibration response of the system with specific defects that occur in the machinery, its components, even in mechanical structures [6].

Vibration Measurements are taken on the set-up using Mechanalysis MIL 521 accelerometer (Mechanalysis is the manufacturer). It is a standard top exit accelerometer for measuring vibration on industrial rotating machines. This industrial grade piezoelectric sensor is primarily used with online installations and has built-in, signal conditioning electronics that convert the high–impedance voltage signal. Hence, it is very suitable option available with a machined QuickFit mount when associated pads are mounted on machinery measurement points. This offers a superior frequency range compared to magnetic mounts and achieves consistent data collection for fixed machine check. The signals from accelerometer are acquired with the help of a data acquisition device – NI9234, which is used as an interface between the computer and the set-up. The acquired signals are processed using the LabVIEW software.

The vibration analysis of the normal operation test and faulty conditions are summarized below.

A. Normal Test

As the gears have been in operation for a short period of time, they are relatively “wear-free”. The peaks apart from the dominant frequencies represent an electrical fault within the motor. This is most likely attributed to an uneven air gap between the rotor and stator, which generates a pulsating vibration [3]. The amplitude throughout all the tests remains fairly constant and hence does not present any great concern.

A sample of FFT spectrum for the setup at 900 RPM for normal working conditions, no intentional faults is shown in Fig.2, 3 & 4. The results for 900 RPM and its harmonics 1x for horizontal, vertical and axial position are tabulated in Table 1. The peaks in all the samples are at or around 540Hz.

The vibration amplitude increases for 1x with the increase of the shaft running speed which all is tolerable according to ISO 2372 in Fig.5 and Standard VDI 2025 in Fig.6.

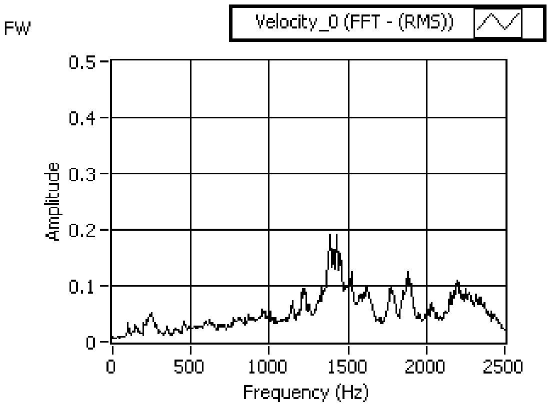


Fig 2. Horizontal FFT spectrum in normal operating condition at 900 RPM and no fault

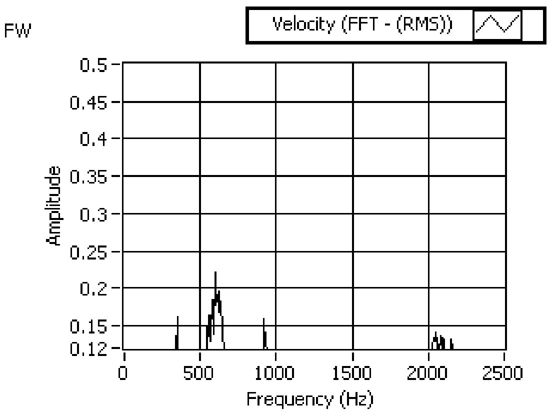


Fig 3. Vertical FFT spectrum in normal operating condition at 900 RPM

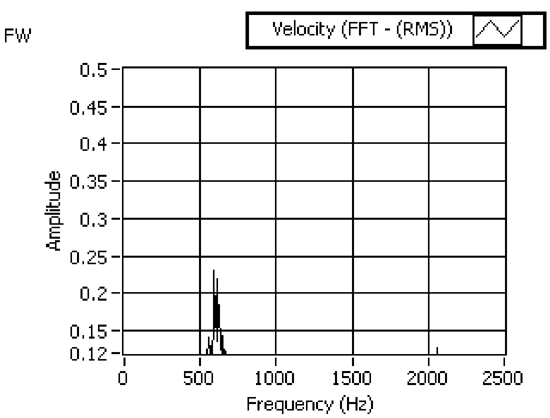
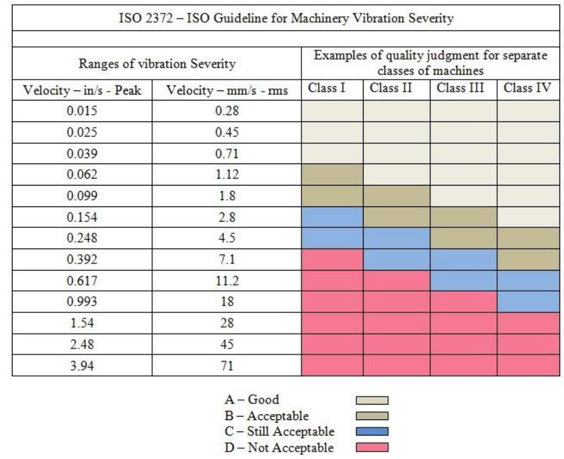


Fig 4. Axial FFT spectrum in normal operating condition at 900 RPM

Table I. Vibration Amplitude In mm/s in Normal Operating Condition

Speed	Sensor position								
	Horizontal			*Vertical*			*Axial*		
	1x	2x	3x	1x	2x	3x	1x	2x	3x
900 RPM	0.19	-	-	0.23	-	-	0.23	-	-



ISO 2372 – ISO Guideline for Machinery Vibration Severity					
Ranges of vibration Severity		Examples of quality judgment for separate classes of machines			
Velocity – in/s - Peak	Velocity – mm/s - rms	Class I	Class II	Class III	Class IV
0.015	0.28				
0.025	0.45				
0.039	0.71				
0.062	1.12				
0.099	1.8				
0.154	2.8				
0.248	4.5				
0.392	7.1				
0.617	11.2				
0.993	18				
1.54	28				
2.48	45				
3.94	71				

Fig 5. ISO 2372 vibration standard

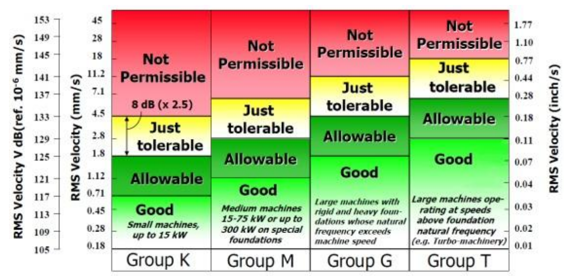


Fig 6. Standard VDI 2056

B. Unbalance of Rotating parts

Unbalance is introduced to the assembly by adding external mass on the gears at the gear mesh. The samples of FFT spectrum for the assembly after applying unbalance at 900 RPM, for an intentional fault are shown in Fig. 7, 8 and 9.

The results for 900 RPM and its harmonics 1x at horizontal, vertical and axial position are tabulated in Table II. The peaks are at or around 540Hz.

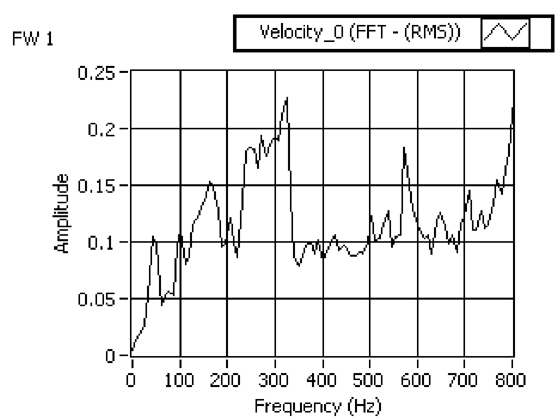


Fig 7. Horizontal FFT spectrum in Unbalance condition at 900 RPM

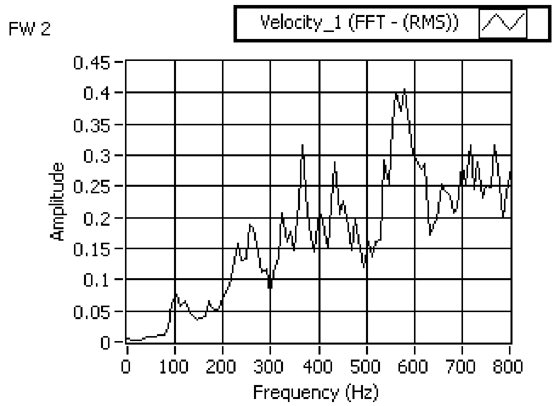


Fig 8. Vertical FFT spectrum in Unbalance condition at 900 RPM

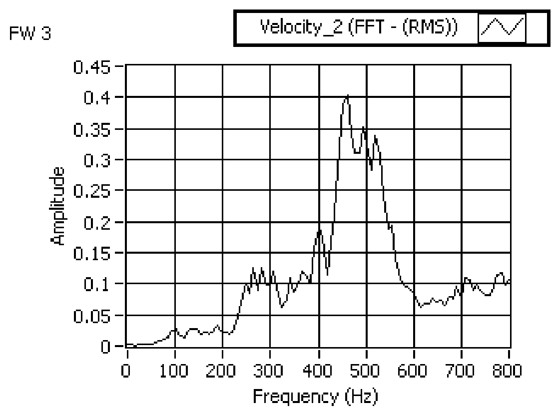


Fig 9. Axial FFT spectrum in Unbalance condition at 900 RPM

Table II. Vibration Amplitude In mm/s in Unbalance Condition

Speed	Sensor position								
	Horizontal			*Vertical*			*Axial*		
	1x	2x	3x	1x	2x	3x	1x	2x	3x
900 RPM	0.17	-	-	0.40	-	-	0.41	-	-

C. Looseness at machine to base plate interface

By loosing the fixing bolts of the test set-up at the base plate interface, looseness fault is introduced in the system. The measurements are recorded and tabulated in Table III. The effect of looseness fault appears as small elevation in vibration amplitude at 2x in vertical position for 900 RPM. The samples of FFT spectrum are as shown in Fig. 10, 11 and 12.

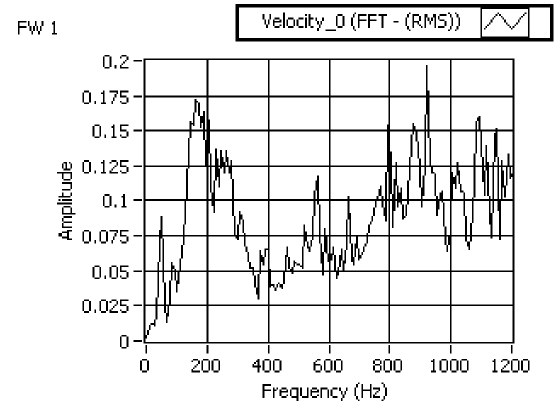


Fig 10. Horizontal FFT spectrum in Looseness condition at 900 RPM

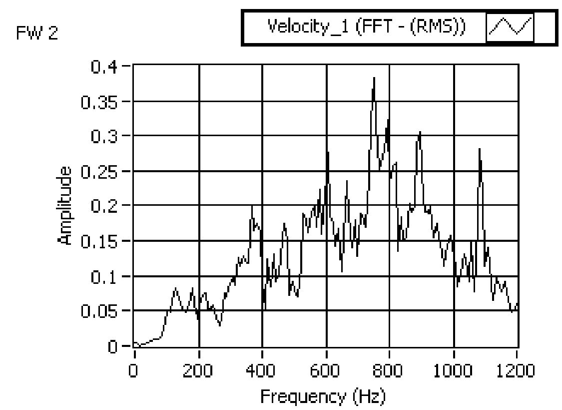


Fig 11. Vertical FFT spectrum in Looseness condition at 900 RPM

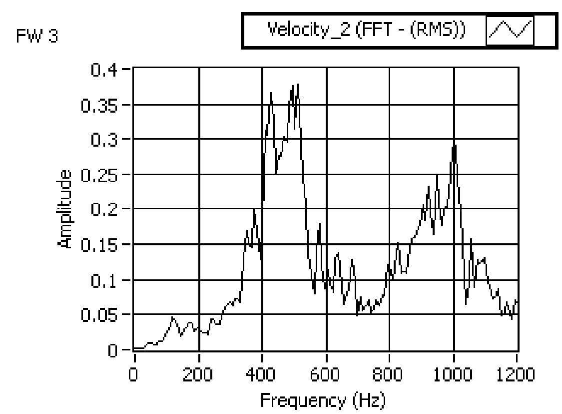


Fig 12. Axial FFT spectrum in Looseness condition at 900 RPM

Table III. Vibration Amplitude In mm/s in Looseness Condition

Speed	Sensor position								
	Horizontal			*Vertical*			*Axial*		
	1x	2x	3x	1x	2x	3x	1x	2x	3x
900 RPM	-	0.19	-	0	0.27	-	-	0.29	-

D. Gear Defects

Fig. 13, 14 and 15 show the FFT spectrum for gear defect fault for 1200 RPM. This fault is introduced by adding a gear with broken tooth in the test set-up. The measurements are recorded and tabulated in Table IV.

The results indicate that vibrations caused by bad gears are at high frequencies and are dependent of the number of gear teeth.

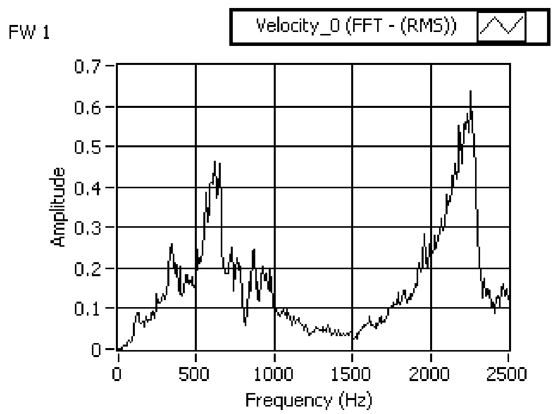


Fig 13. Horizontal FFT spectrum in Bad gear condition at 1200 RPM

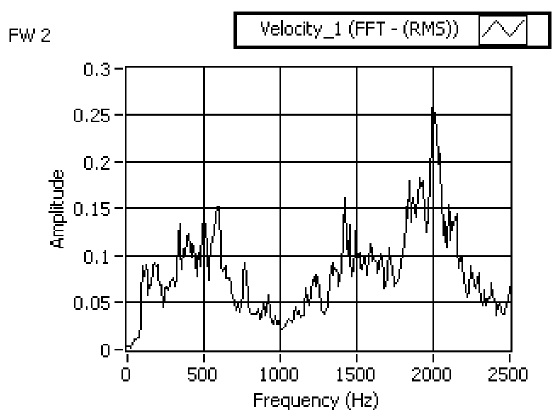


Fig 14. Vertical FFT spectrum in bad gear condition at 1200 RPM

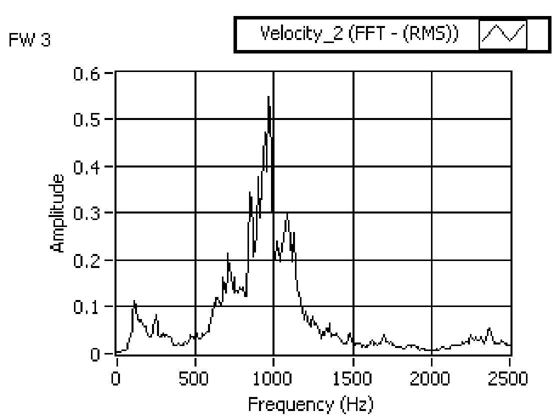


Fig 15. Axial FFT spectrum in bad gear condition at 1200 RPM

Table IV. Vibration Amplitude In mm/s in Bad Gear Condition

Speed	**Sensor position**								
	Horizontal			***Vertical***			***Axial***		
	1x	2x	3x	1x	2x	3x	1x	2x	3x
900RPM	0.43	0.07	0.65	0.15	0.17	0.26	0.21	0.08	0.08

E. Misalignment of Gear Couplings

Misalignment is introduced to the test set-up at the gear mesh. The samples of FFT spectrum for the set-up after introducing misalignment as intentional fault at 1200 RPM are shown in Fig. 16, 17 and 18.

The results and its harmonics at horizontal, vertical and axial position are tabulated in Table V. The peaks in all the samples are around 720Hz, 1440Hz and soon on. The peaks observed are usually at 1x, 2x or 3x RPM.

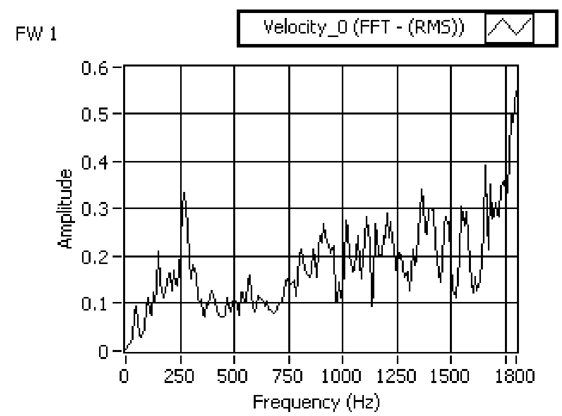


Fig 16. Horizontal FFT spectrum in misaligned condition at 1200 RPM

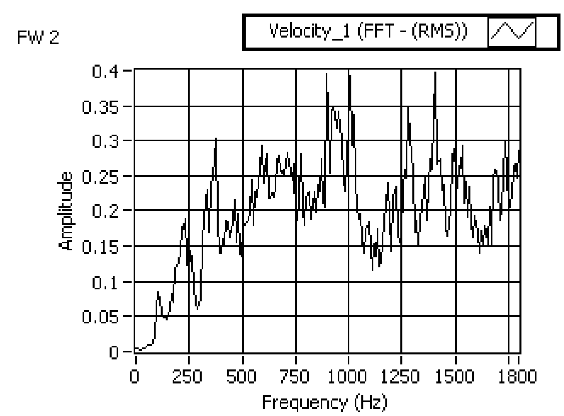


Fig 17. Vertical FFT spectrum in misaligned condition at 1200 RPM

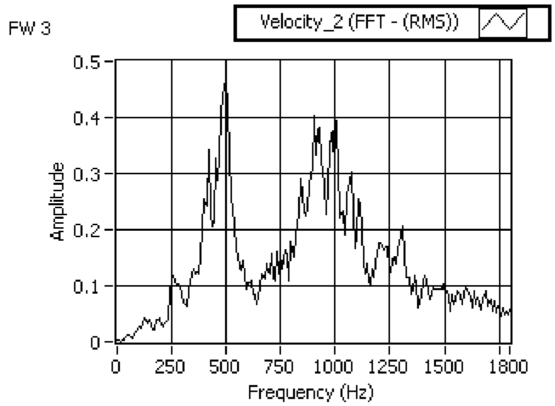


Fig 18. Axial FFT spectrum in misaligned condition at 1200 RPM

Table V. Vibration Amplitude In mm/s in Misaligned Condition

Speed	**Sensor position**								
	Horizontal			***Vertical***			***Axial***		
	1x	2x	3x	1x	2x	3x	1x	2x	3x
1200 RPM	0.15	0.34	-	0.27	0.40	-	0.18	0.12	-

IV. CONCLUSIONS

The vibration analysis technique is the mainstay of the predictive maintenance technique. Vibration analysis is most effective techniques for monitoring the health of machinery. Implementation of vibration analysis program can significantly reduce maintenance cost for a production plant and also improve plant reliability and safety.

The vibration analysis of intentional faults using FFT is determined experimentally, taking the amplitude of vibrations using an accelerometer and verified against the ISO and German VDI standards.

1. Amplitude of vibration in range 0.18mm/s to 0.71mm/s at 900 RPM in horizontal, vertical and axial position obtained at 540 Hz interprets Normal operating conditions.
2. Amplitude of vibration at 900 RPM is largest in axial position and more or less same in vertical and horizontal position with frequency 540 Hz interprets Unbalance fault condition.
3. Vibration at 900 RPM appears as small elevation in vibration amplitude at frequency 1080 Hz interprets Looseness fault condition.
4. Amplitude of vibration at 1200 RPM is comparatively in range for lower frequencies and very more at higher frequencies like 720 Hz and 1440 Hz interprets Bad Gear condition
5. Amplitude of vibration at 1200 RPM is observed at 720 Hz and 1440 Hz interprets Misalignment

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