iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VII **Month of publication:** July 2021

DOI: https://doi.org/10.22214/ijraset.2021.36933

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VII July 2021- Available at www.ijraset.com

Fault Diagnosis of Rotary Machine Using FFT (Fast Fourier Transformation) and Orbital Analyzer

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***Abstract:** In different industries we use different machines and most of the machines are rotary machines. The small fault in machine cause vibrations in machines. These vibrations may cause effect on machine or product produced by machine. So, it is important to study these faults present in the machines. In this paper we are going to discuss fault detection techniques. We are discussing two technique FFT (Fast Fourier Transformation) and Orbital Analysis. In FFT we are getting graphs with respect to frequencies and according to peak frequencies we predict fault while in Orbital Analysis we are getting different orbital shape graph and according to shape we predict fault in machine.*
***Keywords:** Fault Analysis, FFT, Orbital Analysis*

I. INTRODUCTION

In our day-to-day life we are using number of machines and most of these machines consist of rotating parts to perform their specific work. Since, these parts are rotating at high rpm so sever fault in it causes a vibration and these vibrations may cause large damage, damage caused by them may cause serious effect either in form of human injury or company cost. To avoid these types of vibrational effects the faults in rotating machine should be diagnosed before it occurs. There are number of techniques to diagnosis rotary parts. But we are going to use FFT (Fast Fourier Transformation) and orbital Analysis to diagnosis faults in rotating parts of machines. Fault analysis is applied to the rotating equipment, such as pumps, gas turbines, motors, compressors, and used to determine the electrical condition, mechanical condition, and operating condition of the equipment. The advantage of such type of fault analysis is that the problems can be identified before minor fault become critical, and analysis can be done using continuous monitoring. Vibration monitoring can detect defects like misalignment, unbalance, mechanical gap, broken gear teeth. An orbit of pedestal can be generated using horizontal and vertical seismic sensors. The orbit represents an current position of a shaft within bearing and relative amplitudes of the frequencies will determine orbital size and shape.

II. DETAILED STUDY OF FFT

To analyze vibration in signal form first we need to convert vibrational motion into electric form. The physical motion of machine in micro level is nothing but vibration produced by that machine. These vibrations cannot be found out by naked eyes. To analyze these micro vibrations, we use different sensors like proximity sensor, seismic sensor, accelerometer, etc. In this experiment I am using accelerometer to analyze vibration produced. Then these electrical signals produced by accelerometer are then passed to data collector or analyzer then analyzer analyses data and gives FFT graphs and other parameters. To detect any fault in machine using FFT analyzer we have the data in a frequency domain but the data collected from accelerometer is in time domain. So, we have to convert this data into frequency domain data. Fast Fourier transformation (FFT) technique is used to do this job.

A. Fourier Transformation

$$X\lfloor t\rfloor = \frac{1}{N}\sum_{n=0}^{N-1} x[n]\, e^{\; j2\pi(x\frac{n}{N})}$$

Were,

X[n] = Digitally collected time domain signal
N = Digitally required number of data point
n = Time index
t = Frequency index

The obtained time domain data is real time data. Form above equation we can easily say that the converted frequency domain data is in complex form.

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Fig 1: FFT flow Diagram

The working of Fast Fourier Transformation can be understood by following figure:

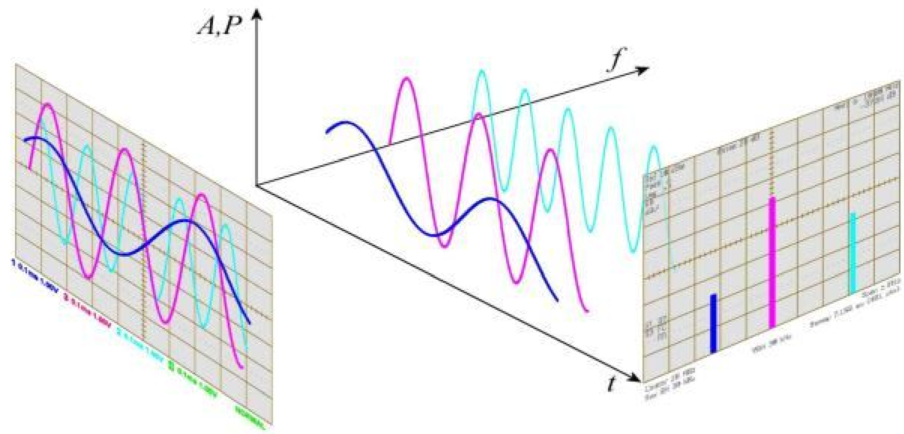

Fig 2: Fourier Transformation in 3D

In above figure you are observing 3 axes, the vertical is amplitude or power axis, it consists of values like displacement, velocity and acceleration. It contains two horizontal axes namely time domain axis and frequency domain axis. In time domain plane (left side graph) the signal readings are in the sine or cosine form. In frequency domain plane (right side graph) the signal readings are in the form of series of sine and cosine waves. The readings on frequency axis are in rpm or in Hz. And according to the frequency reading and fault frequency we can predict the proper fault in rotating system.

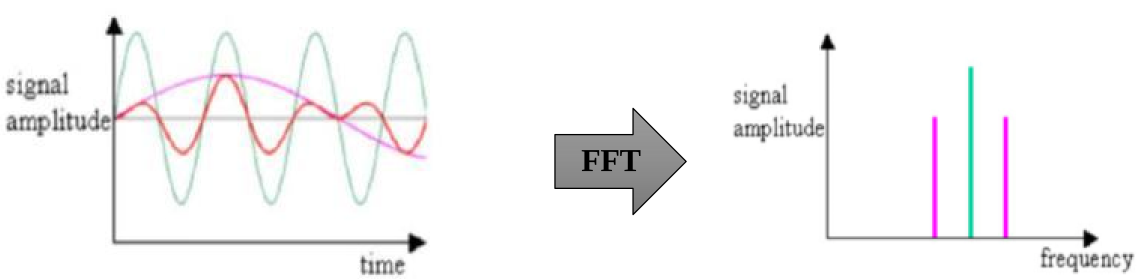

Fig 3: Time domain to frequency domain

III.DETAILED STUDY OF ORBITAL ANALYSIS

The study of orbit for vibration analysis is very important for smooth conduction of machine performance. For orbital analysis we have to use two accelerometer sensors and these are connected orthogonally to each other on machine frame, as shown in figure 4. Along with accelerometer the tachometer is used to calculate rpm at respective points. These two accelerometers give different time domain signals. In Orbital analysis these time domain signals are combined and one orbit is plotted. According to the shape, size, orientation, major axis, orientation of minor axis the fault in rotary machine is predicted. There is different orbital graph for different fault in machine. This is the very simple and easy method to calculate the fault in machine, because here are no any peak least and no to many observations. Simply by looking at orbital graph we can predict which fault is present in rotary machine.

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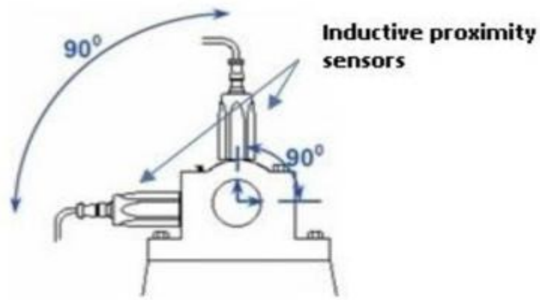

Fig 4: Arrangement of Accelerometers for Orbital Analysis

A. Orbit Generation

The entire document should be in Times New Roman or Times font. Type 3 fonts must not be used. Other font types may be used if needed for special purposes. The orbit is generated using two time domain graph, that graphs are converted to orbit by using orbital analysis. In following figure 5 the process of orbit generation is shown. The upper accelerometer will take time domain reading at 5 points marked as 1 to 5. Another accelerometer will take 5 readings at same points whichever taken by first accelerometer. Then in Orbital analysis these two readings from different accelerometer are combined and orbit for corresponding points were plotted as 1 to 5. The key phasar nothing but tachometer is used to calculate the speed (rpm) of rotating shaft. By using the combination of two accelerometer and Keyphasar we can plot the orbital graph as per the following procedure.

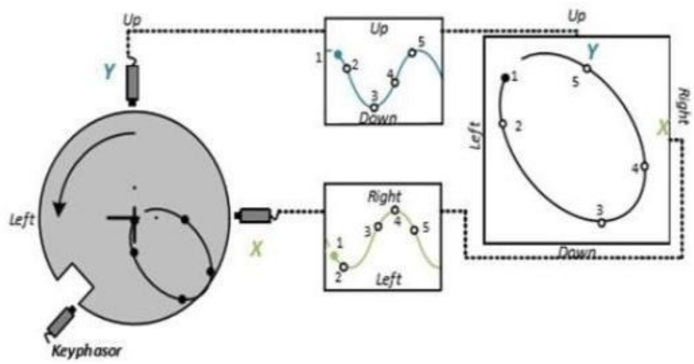

Fig 5: Orbit generation

For better understanding of orbit production, we go through following figure:

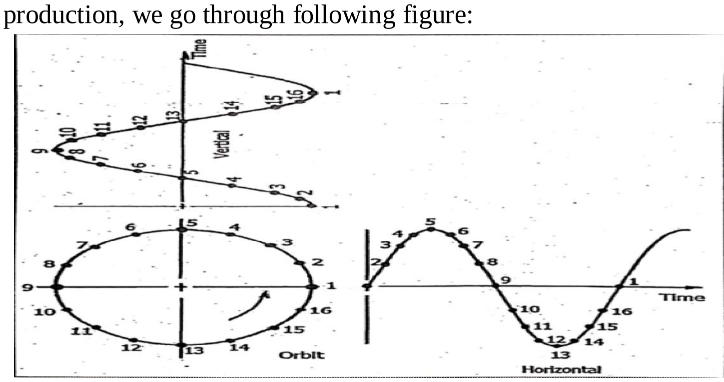

Fig 6: Graphical representation of Orbit generation

In above figure we can see two-time domain graph namely vertical and horizontal. These two-graph having 90-degree phase angle. The horizontal graph is started from origin of vertical axis but vertical graph is started from negative side of vertical axis so both are having 90-degree phase angle, because the two sensors are connected in orthogonal position. Time domain graph is having 1 to 16 points. By combining these 16 points of these two-time domain graph, orbital graph is plotted.

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IV. FAULT DETECTION TECHNIQUE

A. Fault detection using FFT

From FFT analyzer and orbital graph we are getting graphs of different shapes. But how to decide proper fault for proper shape. There are some standard shapes of graph which are used to detect correct fault. In FFT graphs there are number of peaks in graph, so it is difficult to predict graph. To solve this complexity, we are using standard graphs. One standard format of detection table is taken form SKF bearing manufacturer. Which is shown below:

Table 1: Spectrum Analysis Table from SKF manufacturer

Spectrum Analysis Table

	Primary Plane	Detection Units	Dominant Frequencies	Phase Relationship	Comments
Imbalance				• **NOTE: Phase references are accurate within ± 30 degrees.**	
Mass	Radial	Acceleration/ Velocity/ Displacement	1X	90 degree phase shift as sensor is moved from horizontal to vertical position. No radial phase shift across the machine or coupling.	
Overhung Mass	Axial and Radial	Acceleration/ Velocity/ Displacement	1X	Axial reading will be in phase.	Account for change in sensor orientation when making axial measurements.
Bent Shaft	Axial and Radial	Acceleration/ Velocity/ Displacement	1X	180 degree phase shift in the axial direction across the machine with no phase shift in the radial direction.	
Misalignment					
Angular	Axial	Acceleration/ Velocity/ Displacement	1X, 2X	A phase shift of 180 degrees in the axial direction will exist across the coupling.	With severe misalignment, the spectrum may contain multiple harmonics from 3X to 10X. If vibration amplitude in the horizontal plane is increased 2 or 3 times, then misalignment is again indicated. (Account for change in sensor orientation when making axial measurements.)
Parallel	Radial	Acceleration/ Velocity/ Displacement	1X, 2X	A phase shift of 180 degrees in the radial direction will exist across the coupling. Sensor will show 0° or 180 degrees phase shift as it is moved from horizontal to vertical position on the same bearing.	
Combination of Angular and Parallel	Axial and Radial	Acceleration/ Velocity/ Displacement	1X, 2X	A phase shift of 180 degrees in the radial and axial direction will exist across the coupling.	
Mechanical Looseness					
Structural	Radial	Acceleration/ Velocity/ Displacement	1X	Phase shifts of 180 degrees will exist between the machine's feet, baseplate, and/or foundation if the machine is rocking.	Usually caused when the machine's foundation degrades to such an extent that it is no longer stiff, causing the machine to "rock".
Soft Foot	Radial	Acceleration/ Velocity/ Displacement	1X, 2X, …	Phase will shift when the machine foot is tightened.	Result of the machine footing coming loose from the foundation.
Wear/ Fitting	Axial and Radial	Acceleration/ Velocity/ Displacement	1X, 2X, … 10X	Phase reading will be unstable from one reading to the next.	Vibration amplitudes may vary significantly as the sensor is placed at different locations around the bearing. (Account for change in sensor orientation when making axial measurements).

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Also, from following graph we can analyses fault:

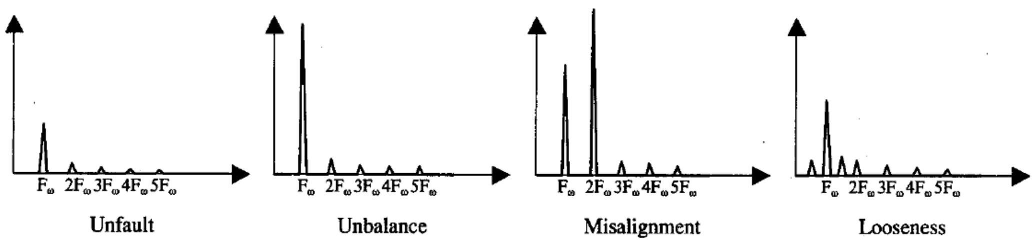


Fig 7: Fault Diagnosis picks

In above figure 7 the different fault detection techniques are shown for FFT fault detection. By knowing the peak at which rpm is greater we can predict the which fault is present in machine. As shown in above figure for non-faulty machine there is no any strong peak present. If the peak is present at first frequency (F) then fault present is unbalance fault. If there are two peaks at first frequency and at second frequency, but the peak at second frequency is greater than first frequency, then the fault present is Misalignment. If the first frequency is present at peak and third to ninth are presents then that fault is known as looseness.

B. Orbital Fault Detection

As orbit is a path traced by center of shaft within bearing. The following figure shows the circular orbit traced by center of shaft within bearing. The circular orbit represents good condition of machine i.e., non-faulty machine.

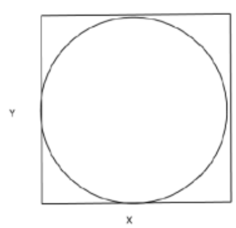


Fig 8: Orbit for good conditioned machine

For unbalance fault the orbit shape is elliptical shape. The following figure shows filtered orbit for unbalance fault in machine.

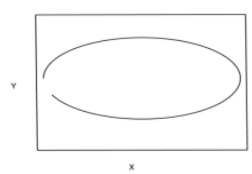
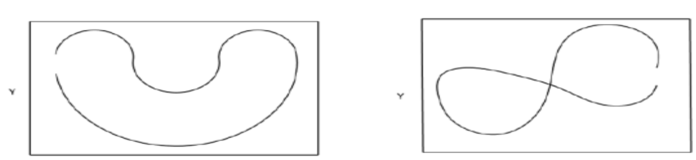


Fig 9: Orbit for unbalanced machine

There are two types of misalignments angular and parallel. For angular misalignment the shape of graph is of banana shape and for parallel misalignment the shape of graph is of '8' digit shape. These graphs are shown below:



(A) (B)

Fig 10: Orbit for misalignment fault

(A) Angular misalignment

(B) Parallel Misalignment

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V. EXPERIMENTAL SETUP

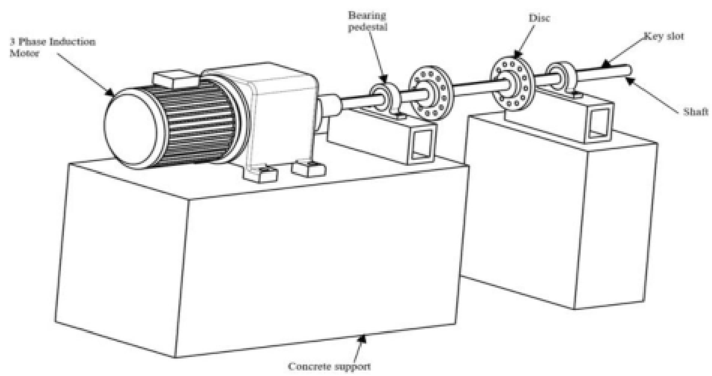

Fig 11: Experimental Setup

I have taken experimental setup as shown in above figure. It consists of:

1) 3 phase induction motor
2) Two bearing pedestal
3) Discs
4) Shaft
5) Mountings

If any fault is present in machine produces vibration in machine. These vibrations transferred to foundation. If we have to take readings of those vibrations by using sensors, sensors should be attached at place where vibrations are maximum. The vibration in machine is transferred to ground through bearing. So maximum vibration is present at bearings. Therefore, sensors must attach at bearing.

I used CEMB N600 for analyzing signals. This is dual channel FFT analyzer. It consists of photocell to read rpm/Hz reading. In this machine Two Seismic sensors are attached and used simultaneously can take screen shots of readings and those screenshots are then taken in laptop by using pendrive.

Fig 12: Practical set up

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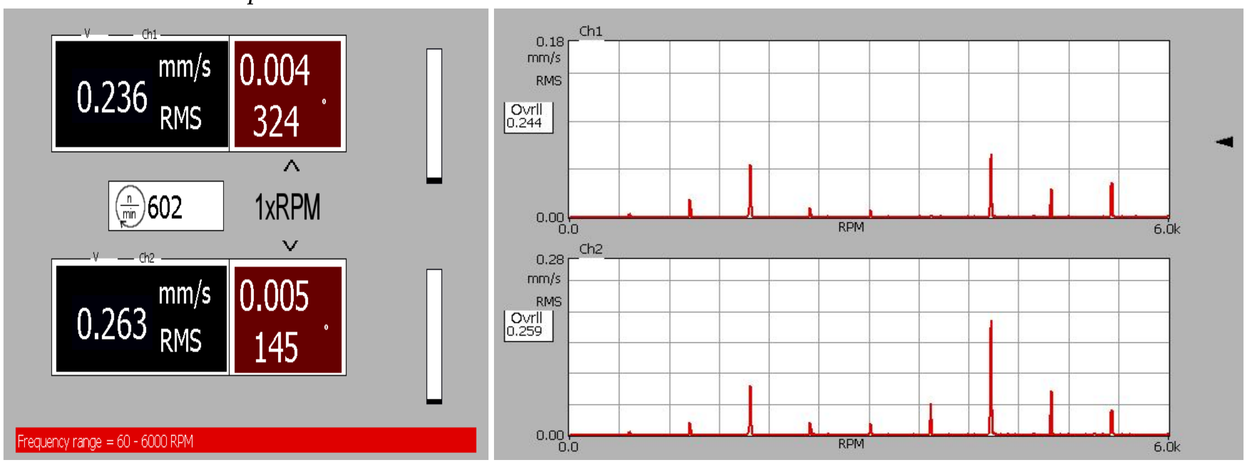
VI. RESULT AND CONCLUSION

I have taken readings at 600 rpm. I taken readings in Vertical, Horizontal and Axial direction. Here channel 1 is connected to Driving end and channel 2 is connected to Nondriving end.

A. Accelerometer at Horizontal position:



(A) (B)

Ch1 mm/s RMS	Freq [RPM]
0.310	1200
0.140	800
0.077	399
0.076	4799
0.067	2400
0.064	4400
0.038	2800
0.035	4000
0.024	2997
0.023	68

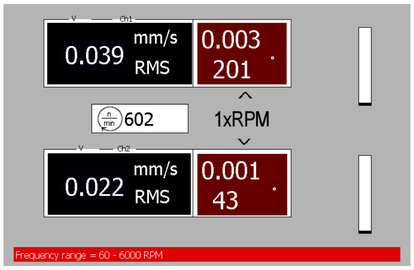
Ch2 mm/s RMS	Freq [RPM]
0.200	4225
0.087	1811
0.071	4828
0.050	3621
0.044	5432
0.021	2414
0.020	1207
0.020	3018
0.005	604
0.004	5000

(C) (D)

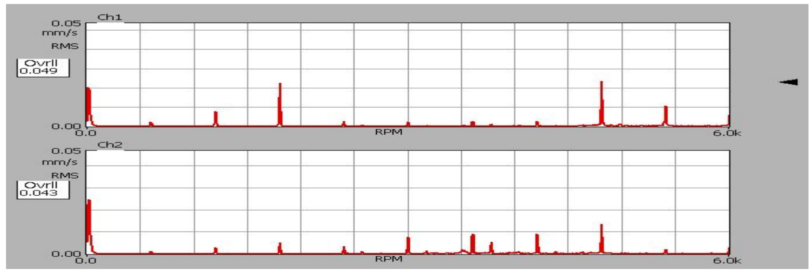
Fig 13: Readings at 600 rpm at Horizontal position
(A) Vibrometer readings
(B) FFT Graphs
(C) Peak list for channel 1
(D) Peak least for channel

1) From figure 7.4 phase difference (324-145) 179°
2) From peak list table 7.1, at driving end peaks are at 2X and at non driving end peaks are at 1X, 2X, 3X.
3) There are number of peaks after 3X frequency
4) From SKF manufacturer catalogue it is a fault of Angular and Parallel misalignment

B. Accelerometer at Vertical Position



(A)



(B)

Ch1 mm/s RMS	Freq [RPM]
0.023	4814
0.023	1806
0.020	17
0.011	5415
0.008	1204
0.003	3611
0.002	2407
0.002	601
0.002	4212
0.002	3008

(C)

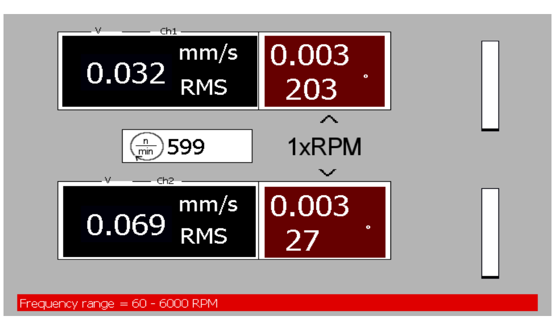
Ch2 mm/s RMS	Freq [RPM]
0.025	20
0.013	4814
0.010	3611
0.009	4212
0.008	3008
0.005	3784
0.005	1806
0.003	2407
0.003	1204
0.002	3516

(D)

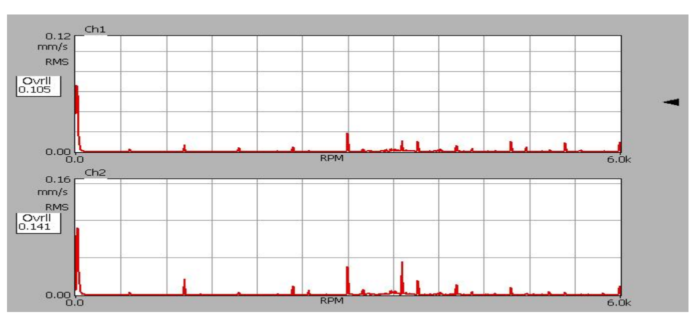
Fig 14: Readings at 600 rpm at vertical position
(A) Vibrometer readings
(B) FFT Graphs
(C) Peak list for channel 1
(D) Peak least for channel 2

1) From figure 7.6 phase difference (201-43) 158°
2) From peak list table 7.2, at driving end peaks are at 1X, 2X, 3X and at non driving end peaks are at 2X, 3X.
3) There are number of peaks after 3X frequency
4) From SKF manufacturer catalogue it is a fault of Angular and Parallel misalignment
5) In FFT graph, figure 7.7, first peak is below 60 rpm, that peak is not faulty peak but it is noise which is produced during signal processing.

C. Accelerometer at Axial Position



(A)



(B)

Ch1	mm/s RMS	Freq [RPM]
	0.067	13
	0.019	2998
	0.011	3598
	0.010	4797
	0.010	3770
	0.009	5396
	0.007	1199
	0.006	4197
	0.005	2398
	0.005	4969

(C)

Ch2	mm/s RMS	Freq [RPM]
	0.091	21
	0.044	3598
	0.038	2998
	0.021	1199
	0.019	3771
	0.014	4197
	0.012	2398
	0.010	4797
	0.008	3170
	0.006	2571

(D)

Fig 15: Readings at 600 rpm at Horizontal position
(A) Vibrometer readings
(B) FFT Graphs
(C) Peak list for channel 1
(D) Peak least for channel 2

1) From figure 7.8 phase difference (203-27) 176°
2) From peak list table 7.3, at driving end peaks are at 2X and at non driving end peaks are at 2X.
3) There are number of peaks after 2X frequency
4) From SKF manufacturer catalogue it is a fault of Angular and Parallel misalignment

In FFT graph, figure 7.9, first peak is below 60 rpm, that peak is not faulty peak but it is noise which is produced during signal processing.

VII. ACKNOWLEDGEMENT

The Authors acknowledge the support provided by the institute named as Walchand College of Engineering, Sangli.

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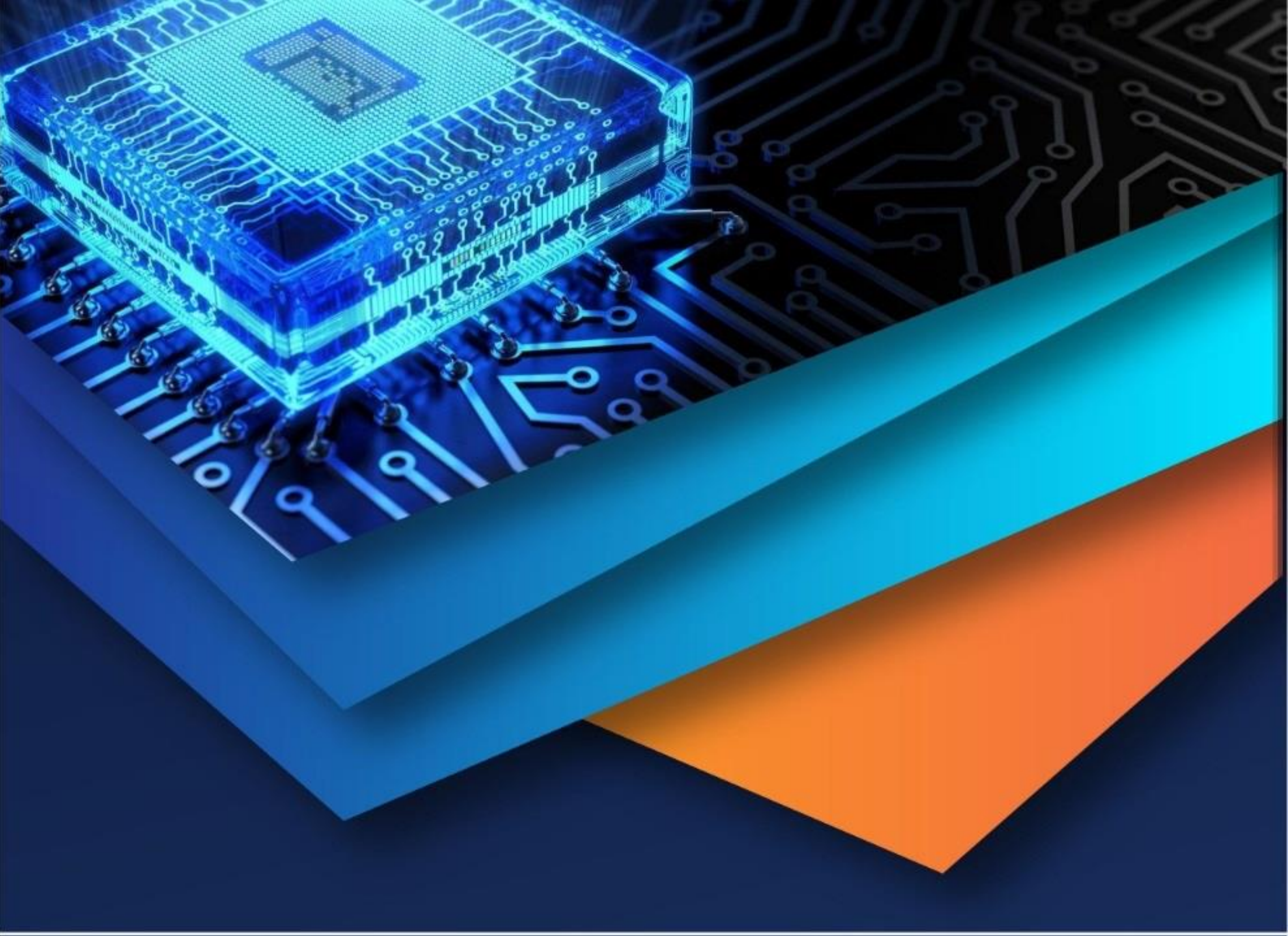

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