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Determination of Unbalance in Rotating Machine Using Vibration Signature Analysis

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ABSTRACT: *Vibrations are found almost everywhere in rotating machines. Rotating machinery vibrates due to unbalances, misalignments and imperfect bearings. Vibrational analysis of rotating machinery is able to identify a large number of system ills. Shaft bow, shaft unbalance and coupling misalignments make up the major portion of the observed vibrational frequency spectra of rotating machinery. These vibrational spectra can be used to determine the type of rotating system abnormality. Unbalance is the most cause of machine vibration, an unbalanced rotor always cause more vibration and generates excessive force in the bearing area and reduces the life of the machine. In this paper, experimental studies were performed on a rotor to predict the unbalance in rotor. The vibration velocities were measured at five different speeds using FFT (Fast Fourier Transform) at initial condition. Based on vibration readings spectrum analysis and phase analysis was carried out to determine the cause of high vibrations. By observing the spectrum unbalance was identified. Then Rotor was balanced and found that vibrations were reduced.. The experimental frequency spectra were obtained for both balanced and unbalanced condition under different unbalanced forces at different speed conditions. This paper aims at the implementation of condition based maintenance on rotating machine, by adopting Vibration spectrum analysis which is a predictive maintenance technology. It eliminates unnecessary opening of equipment with considerable savings in personnel resources.*

Keyword**:** *Vibration Signature Analysis, Vibration Spectrum Analysis, Unbalance, FFT*

Nomenclature:

MNDE: Motor Non Drive End;	H: Horizontal;	v: Velocity
MDE: Motor Drive End;	V: Vertical	
PBE: Pillow Block End;	A: Axial	

I. INTRODUCTION

Rotor unbalance is the most common reason in machine vibrations. Most of the rotating machinery problem can be solved by using the rotor balancing and misalignment. A very small amount of unbalance may cause severe problem in high speed rotating machines. Overhung rotors are used in many engineering applications like pump, fans, propellers and turbo machinery. The vibration signature of the overhung rotor is totally different from the center hung rotors. The vibration caused by unbalance may destroy critical parts of the machine, such as bearings, seals, gears and couplings. In practice, rotors can never be perfectly balanced because of manufacturing errors such as porosity in casting, non-uniform density of material, manufacturing tolerances and gain or loss of material during operation [1] As a result of mass unbalance, a centrifugal force is generated and must be reacted against by bearing and support structures. A number of analytical methods have been applied to unbalance response such as the transfer method [2]. Further, the unbalance part of the rotor rotates at the same speed as the rotor and therefore the force caused by the unbalance is synchronous [3]. However all the above investigations resulted in fu numerical solutions of the unbalance responses of coupled two-shaft rotor-bearing system. On the other hand, Rao [4] suggested analytical closed-form expressions for the major and minor axis radii of the unbalance response orbit for one-shaft rotor-bearing system. Rao *et al*. [5] and Shiau *et al*.[6]. Vibration signatures are widely used as a useful tool for studying progressive machine mechanical malfunctions, and also form the baseline signature for further comparative monitoring to detect mechanical faults [7].In this paper a general method is presented for obtaining the unbalance response orbit based on the experimental, where the shafts rotate at different speeds. Unbalance system of an overhung rotors are considered for unbalance study. Experiments were conducted for a single mass, at five different speeds and corresponding results are plotted. The rotor unbalance can be detected by spectral and phase analysis.

Description of the Experimental Setup: The Experimental apparatus is shown in photograph of Figure 2 and Figure 3. It consists of a 0.5 hp A.C. Induction motor 1440 rpm speed, a fixed type flange coupling and a single disk rotor. The rotor shaft is supported by single identical ball bearing (pillow block) and has a length of 1000 mm with a bearing span of 750 mm. The diameter of the rotor shaft is 16 mm. A disk of 220 mm in diameter and 6 mm in thickness is mounted on the rotor shaft at bearing end. The rotor shaft is driven by 0.5 hp A.C. motor. The speed of the motor is controlled by using VFD (Variable Frequency Drive) which is mainly used for A.C motors, to increase or decrease the speeds of the motor in the range of 500 to1440 rpm. The instrument used in experiment includes FFT which measures the vibration in terms of velocity at MNDE, MDE & PBE housing and gives the corresponding values.

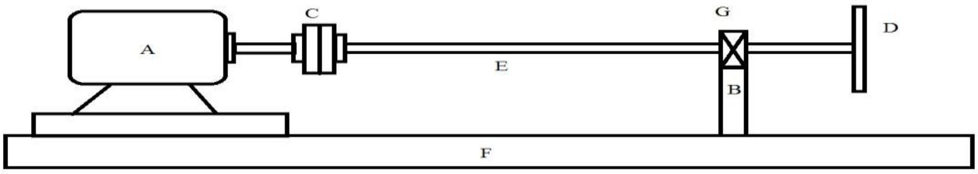


Fig. 1: Line diagram of experimental setup.

A-A.C Induction Motor, B-Bearing Support, C-Coupling, D-Disk, E-Rotor Shaft, F-Base, G-Pillow Block

Fig. 2: Photo graph of VFD

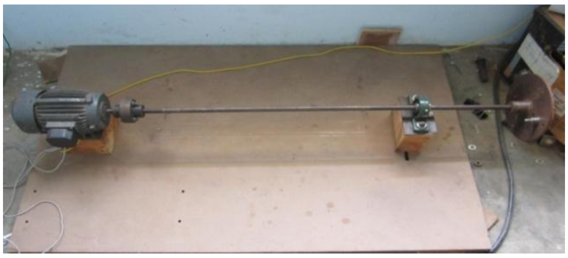


Fig. 3: Photo graph of experimental setup

Experimental Procedure: Experimental facility as shown in Figure: 2 and 3 is used for unbalance test. First the setup is run for few minutes to settle down all minor vibrations. Before creating the unbalanced, the shaft is checked for any misalignment and unbalance. After this an unbalance has been created by placing a mass of 96 gram in the overhung rotor at a radius of 98 mm. FFT is the vibration analyzer is used to acquire the vibration signals in terms of velocity. Vibration signals are measured at five different speeds 600, 800, 1000, 1250 and 1440 rpm with the unbalanced rotor system at drive end (DE) , non drive end (NDE) and Pillow block end (PBE) stored in the vibration analyzer. And same masses were added at exact opposite direction i.e in balanced state and vibration signals were taken. Following are the vibration readings observed.

Vibration readings at unbalanced condition:

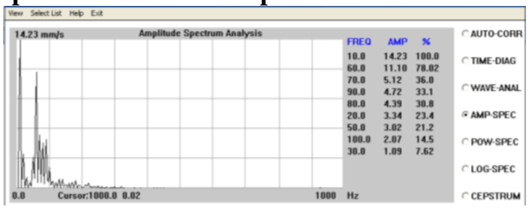
Table: 1

speed (rpm)	MNDE			MDE			PBE		
	H	V (mm/sec)	A	H	V (mm/sec)	A	H	V (mm/sec)	A
600	4.53	3.68	6.25	4.74	6.89	3.19	14.23	16.64	2.57
800	16.44	12.95	8.45	15.67	13.36	13.79	45.68	67.15	14.56
1000	76.01	80.53	58.49	22.37	22.91	59.98	83.72	158.5	50.78
1250	83.40	64.15	44.82	92.50	83.53	70.27	111.7	51.72	92.44
1440	43.17	31.15	104.93	72.09	57.90	126.1	383.8	89.06	77.61

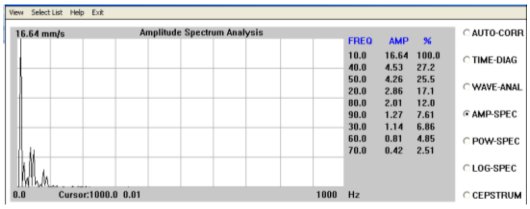
OBSERVATIONS:

Above readings show that high vibrations are present at PBE. At all speeds vibrations in radial direction are higher than axial direction. High radial vibrations are present due to unbalance, misalignment and bending of the shaft. To determine the cause of high vibrations spectrum analysis was carried. Following are the spectrums taken at different speeds using FFT Analyzer with Mcme2.0 software.

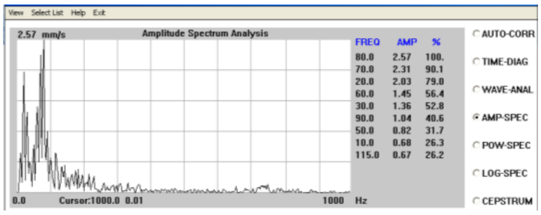
Unbalanced spectrum at different speeds:



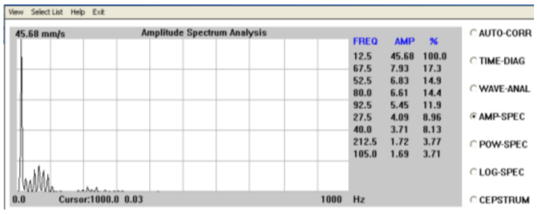
Spectrum in PBE HOZ direction at 600 rpm



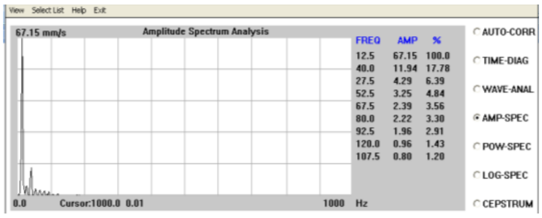
Spectrum in PBE VER direction at 600rpm



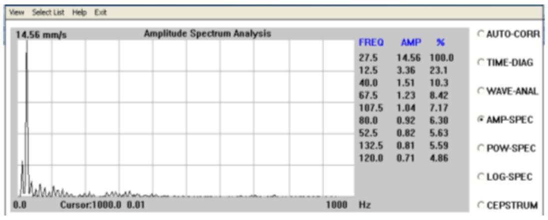
Spectrum in PBE AXL direction at 600rpm



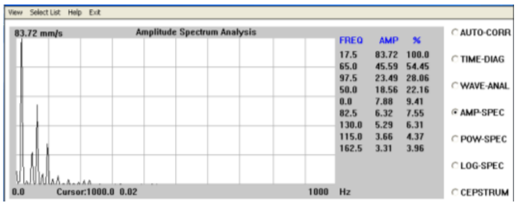
Spectrum in PBE HOZ direction at 800rpm



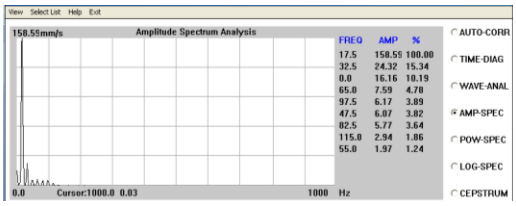
Spectrum in PBE VER direction at 800rpm



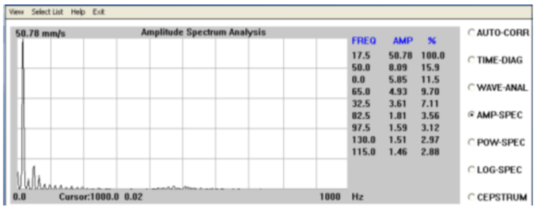
Spectrum in PBE AXL direction at 800rpm



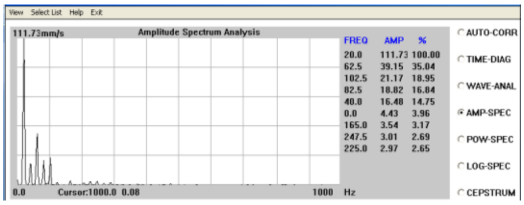
Spectrum in PBE HOZ direction at 1000rpm



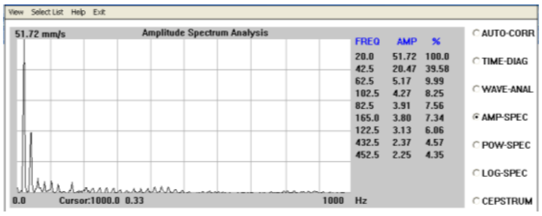
Spectrum in PBE VER direction at 1000rpm



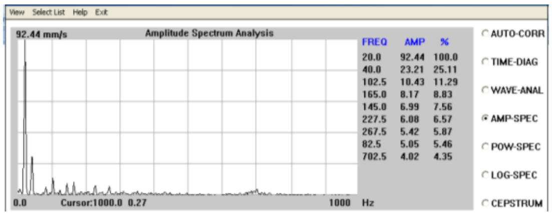
Spectrum in PBE AXL direction at 1000rpm



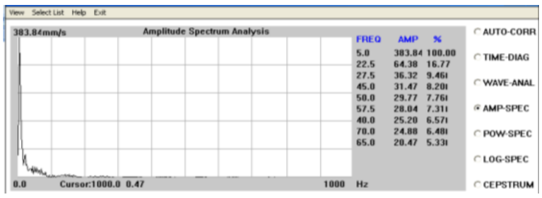
Spectrum in PBE HOZ direction at 1250rpm



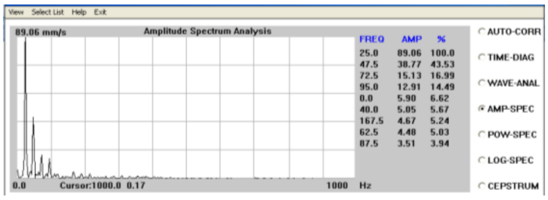
Spectrum in PBE VER direction at 1250rpm



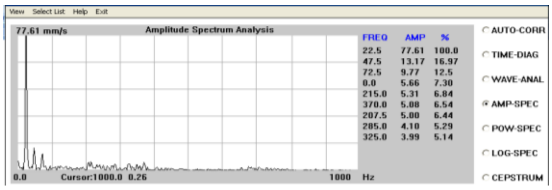
Spectrum in PBE AXL direction at 1250rpm



Spectrum in PBE HOZ direction at 1440rpm



Spectrum in PBE VER direction at 1440rpm



Spectrum in PBE AXL direction at 1440rpm

Table: 2
The following phase readings are also observed:

SPEED (rpm)	DISPLACMENT(µm) At 0^0	30^0	60^0	90^0	120^0	150^0	180^0	PHASEANGLE IN DEGREES
600	307	324	395	549	476	384	310	90^0
800	907	1028	1245	1980	1270	1372	1260	90^0
1000	1008	862	1604	2024	1345	1002	1119	60^0
1250	796	876	683	603	1311	1001	703	30^0
1440	735	1061	897	556	901	925	687	60^0

OBSERVATION FROM SPECTRUMS:

1. In all the spectrums of pillow block end 1X and its harmonics are present.
2. No bearing defective frequency peaks are present in the pillow block spectrums.
3. In the pillow block at 1000 rpm vertical spectrum "1X" is predominant and having its highest value is 158.5mm/sec.
4. In the pillow block at 1250 horizontal spectrum 1x is predominant and having the highest value is 111.7mm/sec.
5. High "1X" amplitudes in PBE horizontal and vertical spectrum indicates abnormal condition such as unbalance misalignment, looseness or resonance condition.
   To determine the exact cause of high vibrations phase readings are taken. phase readings are shown in table.

Observation from Phase Analysis

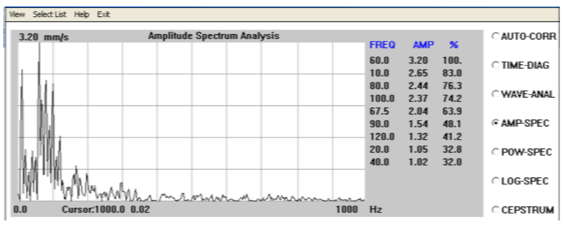
1. From the phase reading at the PBE it is observed that there is 90^0 phase difference between the PBE horizontal and vertical.
2. 90^0 phase difference between horizontal and vertical reveals that there presents an unbalance at PBE.
3. From the spectrum analysis and phase analysis it is conformed that there is a presence of mass unbalance in the PBE.

Rotor was removed and balanced weight is added diametrically opposite to unbalanced mass and vibration readings were taken after balancing. Vibration readings are shown in following table.

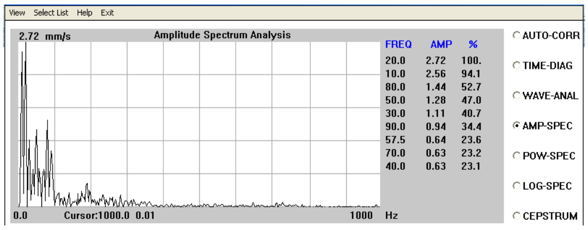
Table: 3
Vibration readings after balanced condition:

speed (rpm)	MNDE H	MNDE V (mm/sec)	MNDE A	MDE H	MDE V (mm/sec)	MDE A	PBE H	PBE V (mm/sec)	PBE A
600	1.45	0.98	1.69	1.59	2.48	2.70	3.20	2.72	1.55
800	7.92	3.24	5.90	7.26	7.00	7.08	15.16	20.77	4.38
1000	12.36	4.43	14.89	12.15	10.37	11.56	22.95	17.85	8.01
1250	6.04	4.31	18.97	9.83	18.76	21.85	9.72	12.22	7.66
1440	10.44	25.79	21.11	6.46	12.27	20.96	13.16	20.90	9.82

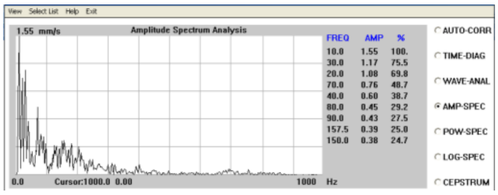
Balanced spectrum at different speeds:



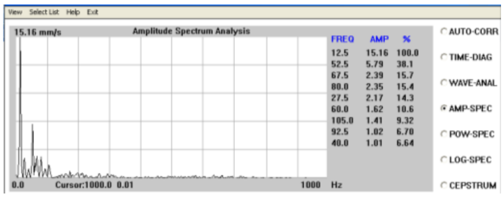
Spectrum in PBE HOZ direction at 600rpm



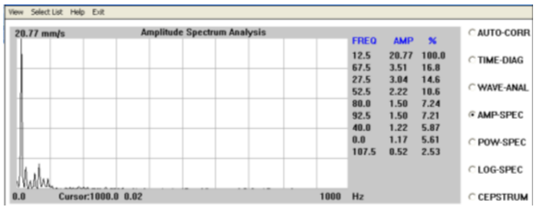
Spectrum in PBE VER direction at 600rpm



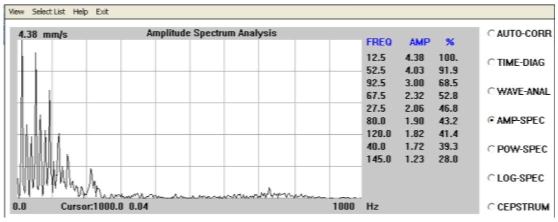
Spectrum in PBE AXL direction at 600rpm



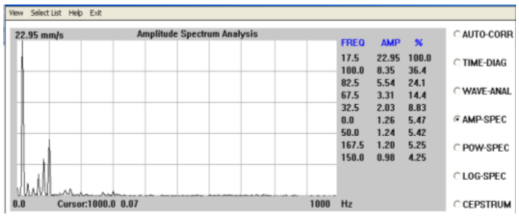
Spectrum in PBE HOZ direction at 800rpm

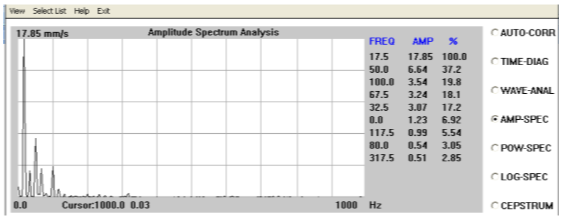


Spectrum in PBE VER direction at 800rpm



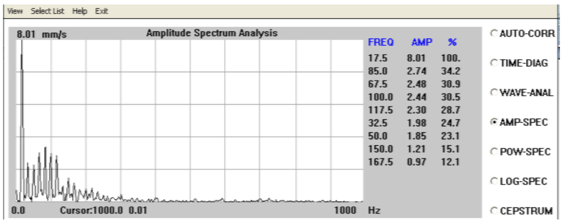
Spectrum in PBE AXL direction at 800rpm

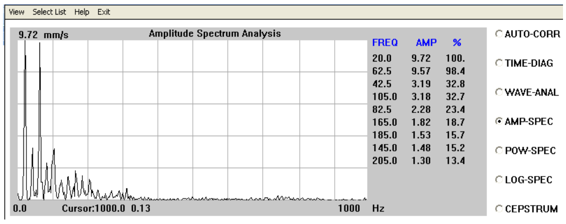




Spectrum in PBE HOZ direction at 10000rpm

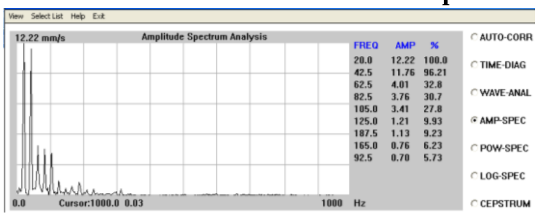
Spectrum in PBE VER direction at 1000rpm

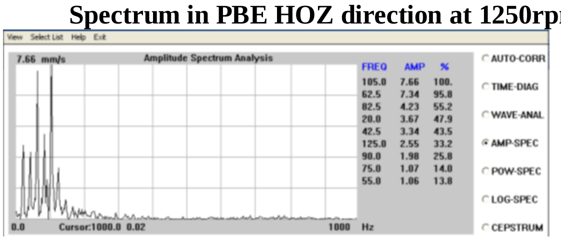




Spectrum in PBE AXL direction at 1000rpm

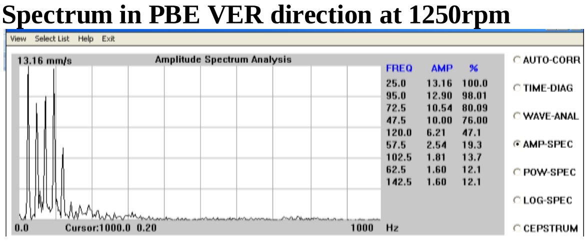
Spectrum in PBE HOZ direction at 1250rpm

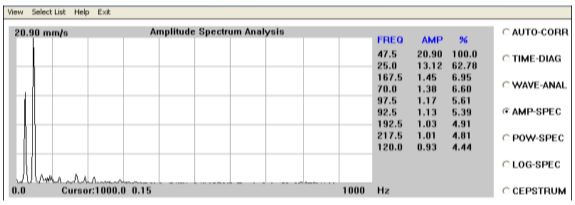




Spectrum in PBE VER direction at 1250rpm

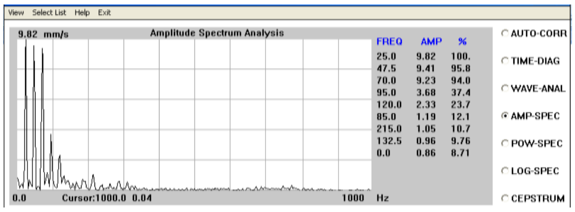
Spectrum in PBE AXL direction at 1250rpm





Spectrum in PBE HOZ direction at 1440rpm

Spectrum in PBE VER direction at 1440rpm



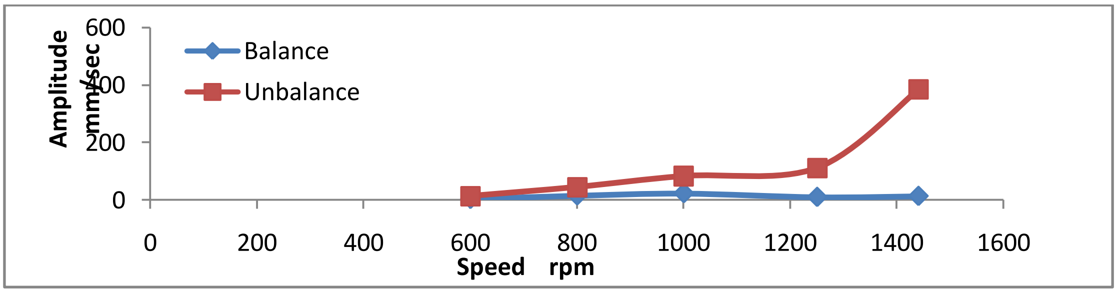
Spectrum in PBE AXL direction at 1440rpm

All vibration readings show that the readings were reduced to normal level.

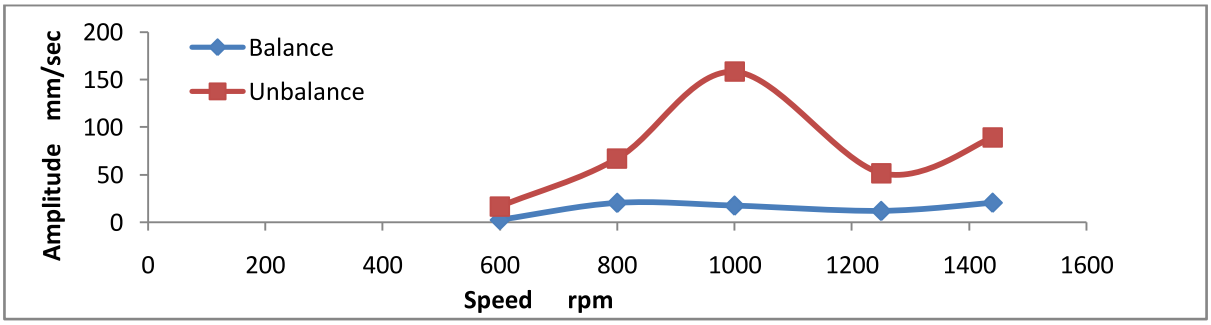
Table: 4
Comparisons of vibration amplitudes for unbalanced and balanced signals:

Speed (rpm)	Direction	MNDE Unbalance	MNDE Balance	MDE Unbalance	MDE Balance	PBE Unbalance	PBE Balance
		v (mm/sec)		v (mm/sec)		v (mm/sec)	
600	**H**	4.53	1.45	4.74	1.59	14.23	3.20
	V	3.68	0.98	6.89	2.48	16.64	2.72
	A	6.25	1.69	3.19	2.70	2.57	1.55
800	**H**	16.44	7.92	15.67	7.26	45.68	15.16
	V	12.95	3.24	13.36	7.00	67.15	20.77
	A	8.45	5.90	13.79	7.08	14.56	4.38
1000	**H**	76.01	12.36	22.37	12.15	83.72	22.95
	V	80.53	4.43	22.91	10.37	158.5	17.85
	A	58.49	14.89	59.98	11.56	50.78	8.01
1250	**H**	83.40	6.04	92.50	9.83	111.7	9.72
	V	64.15	4.31	83.53	18.76	51.72	12.22
	A	44.82	18.97	70.27	21.85	92.44	7.66
1440	**H**	43.17	10.44	72.09	6.46	383.8	13.16
	V	31.15	25.79	57.90	12.27	89.06	20.90
	A	104.93	21.11	126.1	20.96	77.61	9.82

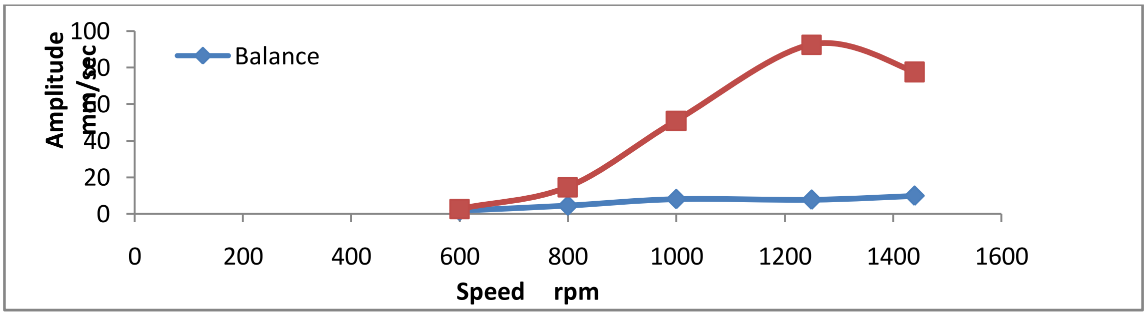
Graph shows for amplitude against speed, comparison with unbalance and balance at PBE:



Vibration amplitude at PBE HOZ against speed



Vibration amplitude at PBE VER against speed



Vibration amplitude at PBE AXL against speed

CONCLUSION

As the speed increases the amplitude at 1X is also increases for the same unbalance weight. This increase in amplitude value is because of the different unbalanced force.

Since the system frequency is nearer to 1000rpm due to the presence of resonance at this speed higher amplitudes were presented.

Phase analysis and spectrum analysis show that there presents an unbalance in the rotor.

Rotor is balanced and vibration readings are taken after balancing. It was shown that amplitude of vibration is reduced drastically.

This is an NDT method to detect the fault in rotating machine. Hence Vibration monitoring method reduces the maintenance cost when it is applied to industries and improves the profit

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