# 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 unbalance 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



**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.

speed	MNDE			MDE			PBE		
(rpm)	Η	V	Α	Η	V	Α	Н	V	Α
		(mm/sec)		(	mm/sec)		(	mm/sec)	
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

#### Vibration readings at unbalanced condition:

Table: 1

#### **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 s	spectrum a	t different speed	s:														
]	View Select List Help Exit							Vie	w SelectList Help Exit								
	14.23 mm/s	Amplitude Spectrum Analysis		FREQ	АМР	×	CAUTO-CORR		16.64 mm/s	Amplitude :	Spectrum Ana	llysis		FREQ	AMP	%	C AUTO-CORR
	L			10.0 60.0	14.23 11.10	100.0 78.02	⊂ TIME-DIAG							10.0 40.0	16.64 4.53	100.0 27.2	○ TIME-DIAG
				70.0	5.12 4.72	36.0 33.1	C WAVE-ANAL							50.0 20.0	4.26	25.5	C WAVE-ANAL
				80.0 20.0	4.39	30.8 23.4 21.2	C AMP-SPEC							90.0 20.0	1.27	7.61	@ AMP-SPEC
	. Jai			100.0 30.0	2.07	14.5	C POW-SPEC		h					60.0 70.0	0.81	4.85	C POW-SPEC
	All Anno a						C LOG-SPEC		M.h.								CLOG-SPEC
	0.0 Cursor:1000.0 0.	.02	1000	Hz			C CEPSTRUM	0	.0 Cursor:1000.0	0.01			1000	Hz			C CEPSTRUM

Spectrum in PBE HOZ direction at 600 rpm

Spectrum in PBE VER direction at 600rpm

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View SelectList Help Ex	ż					
2.57 mm/s	Amplitude Spectrum Analysis		FREQ	AMP	×	C AUTO-CORR
			80.0 70.0	2.57 2.31	100. 90.1	C TIME-DIAG
			20.0	2.03	79.0 56.4	C WAVE-ANAL
11			30.0 90.0	1.36 1.04	52.8 40.6	@ AMP-SPEC
JAN,			50.0 10.0 115.0	0.82 0.68 0.67	31.7 26.3 26.2	C POW-SPEC
IN WWW	Ann ha					C LOG-SPEC
0.0 Cursor 10	00.0.01	1000	Hz			COEPSTRUM

#### Spectrum in PBE AXL direction at 600rpm

View Select List Help Exit						
67.15 mm/s	Amplitude Spectrum Analysis		FREQ	AMP	*	CAUTO-CORR
			12.5 40.0	67.15 11.94	100.0 17.78	C TIME-DIAG
			27.5 52.5	4.29 3.25	6.39 4.84	O WAVE-ANAL
			67.5 80.0	2.39	3.56	AMP-SPEC
			92.5 120.0 107.5	1.96 0.96 0.80	2.91 1.43 1.20	C POW-SPEC
Maria						C LOG-SPEC
0.0 Cursor:1000.0 (	0.01	1000	Hz			C CEPSTRUM

Spectrum in PBE VER direction at 800rpm

View Select List Help E	đ				
83.72 mm/s	Amplitude Spectrum	Analysis	FREQ AM	e s	CAUTO-CORR
			17.5 83.	72 100.0	C TIME-DIAG
			97.5 23. 50.0 18.	49 28.06 56 22.16	C WAVE-ANAL
			0.0 7.8 82.5 6.3 130.0 5.2	8 9.41 2 7.55 9 6.31	@ AMP-SPEC
			115.0 3.6 162.5 3.3	6 4.37 1 3.96	C POW-SPEC
Vallation					C LOG-SPEC
0.0 Cursor:10	00.0 0.02	1000	Hz		C CEPSTRUM

Spectrum in PBE HOZ direction at 1000rpm

View Select List Help Exit						
50.78 mm/s	Amplitude Spectrum Analysi	5	FREQ	AMP	*	CAUTO-CORR
			17.5 50.0	50.78 8.09	100.0 15.9	⊂ TIME-DIAG
			0.0 65.0	5.85 4.93	11.5 9.70	C WAVE-ANAL
			32.5 82.5	3.61 1.81	7.11 3.56	@ AMP-SPEC
			97.5 130.0 115.0	1.59 1.51 1.46	3.12 2.97 2.88	C POW-SPEC
Vale						CLOG-SPEC
0.0 Cursor:100	0.0 0.02	1000	Hz			C CEPSTRUM

#### Spectrum in PBE AXL direction at 1000rpm

View Select List Help Exit					
51.72 mm/s	Amplitude Spectrum Analysis	F	REQ A	MP %	C AUTO-CORR
		2	0.0 51 2.5 20	.72 100.0 1.47 39.58	⊂ TIME-DIAG
		6. 1	2.5 5. 02.5 4.	17 9.99 27 8.25	C WAVE-ANAL
		8	2.5 3. 65.0 3.	91 7.56 80 7.34	@ AMP-SPEC
		4	22.5 3. 32.5 2. 52.5 2.	37 4.57 25 4.35	C POW-SPEC
					C LOG-SPEC
0.0 Cursor:1000.	0 0.33	1000 H	łz		C CEPSTRUM

#### Spectrum in PBE VER direction at 1250rpm



Spectrum in PBE HOZ direction at 1440rpm



Spectrum in PBE HOZ direction at 800rpm



Spectrum in PBE AXL direction at 800rpm



#### Spectrum in PBE VER direction at 1000rpm



#### Spectrum in PBE HOZ direction at 1250rpm

View Select List Help Exit						
92.44 mm/s	Amplitude Spectrum Analysis		FREQ	AMP	%	CAUTO-CORR
			20.0 40.0	92.44 23.21	100.0 25.11	C TIME-DIAG
			102.5 165.0	10.43 8.17	11.29 8.83	C WAVE-ANAL
			145.0	6.99 6.08	7.56	@ AMP-SPEC
			267.5 82.5 702.5	5.42 5.05 4.02	5.87 5.46 4.35	C POW-SPEC
Addison						C LOG-SPEC
0.0 Cursor:1000.0 0.	27	1000	Hz			C CEPSTRUM

#### Spectrum in PBE AXL direction at 1250rpm



#### Spectrum in PBE VER direction at 1440rpm

view select List Help Exit					
77.61 mm/s	Amplitude Spectrum Analys	iis	FREQ AMP	*	C AUTO-CORR
			22.5 77.61 47.5 13.17	100.0	C TIME-DIAG
			72.5 9.77 0.0 5.66	12.5 7.30	C WAVE-ANAL
			215.0 5.31 370.0 5.08	6.84 6.54	@ AMP-SPEC
			207.5 5.00 285.0 4.10 325.0 3.99	6.44 5.29 5.14	C POW-SPEC
All					C LOG-SPEC
0.0 Cursor:1000.	0 0.26	1000	Hz		C CEPSTRUM

Spectrum in PBE AXL direction at 1440rpm

SDEED		DUASEANCIE						
(rpm)	00	<b>30</b> <sup>0</sup>	60 <sup>0</sup>	At 90 <sup>0</sup>	120 <sup>0</sup>	150 <sup>0</sup>	<b>180<sup>0</sup></b>	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	$60^{0}$

# Table: 2The following phase readings are also observed:

#### **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.
- High "1X" amplitudes in PBE horizontal and vertical spectrum indicates abnormal condition such as unbalance misalignment, looseness or resonance condition.
   To determine the quest equep of high vibrations phase readings are taken, phase readings are shown in table.

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  $90^{\circ}$  phase difference between the PBE horizontal and vertical.
- 2.  $90^{\circ}$  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.

speed	MNDE				MDE			PBE			
(rpm)	Н	V	Α	H	V	Α	Н	V	Α		
	(mm/sec) (mm/sec)				(mm/sec)			(mm/sec)			
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		

 Table: 3

 Vibration readings after balanced condition:

#### **Balanced spectrum at different speeds:**

View SelectList Help Exit						/iew SelectList Help Exit			
3.20 mm/s	Amplitude Spectrum Analysis	FREO	AMP	*	CAUTO-CORR	2.72 mm/s Amplitude Spectrum Analysis	EQ AMF	» %	CAUTO-CORR
		60.0 10.0	3.20	100.	C TIME-DIAG	20	0 2.72 0 2.56	100. 94.1	C TIME-DIAG
l i lii		80.0 100.0	2.44	76.3 74.2	C WAVE-ANAL	80	0 1.44 0 1.28	52.7 47.0	C WAVE-ANAL
		67.5 90.0	2.04 1.54	63.9 48.1	@ AMP-SPEC	30	0 1.11 0 0.94	40.7 34.4	• AMP-SPEC
		120.0 20.0	1.32 1.05	41.2 32.8	C POW-SPEC		5 0.64 0 0.63	23.6 23.2	C POW-SPEC
開催る		40.0	1.02	32.0	C LOG-SPEC		0 0.63	23.1	C LOG-SPEC
0.0 Cursor:1000	MMrs mrs man manue 100	0 Hz			CCEPSTRUM	0.0 Cursor 1000.0.0.01 1000.0.0			OCEPSTBUM

Spectrum in PBE HOZ direction at 600rpm

Spectrum in PBE VER direction at 600rpm

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.55 mm/s	Amplitude Spectrum Analysis			~	C AUTO-COF
		FRE	U AMP	~	
		10.0	1.55	100.	C TIME-DIA
		30.0	1.17	75.5	
		20.0	1.08	69.8	C WAVE-AN
		70.0	0.76	48.7	U WAYL AN
		40.0	0.60	38.7	
		80.0	0.45	29.2	· AMP-SPE
		90.0	0.43	27.5	
		157.	.5 0.39	25.0	C POW-SPE
(I Mi		150.	.0 0.38	24.7	
INTERNA -					CLOG-SPE

Spectrum in PBE AXL direction at 600rpm

View SelectList Help Exi	R					
20.77 mm/s	Amplitude Spectrum Analys	is	FREQ	AMP	×	CAUTO-CORR
			12.5 67.5	20.77 3.51	100.0 16.8	C TIME-DIAG
			27.5 52.5	3.04 2.22	14.6 10.6	C WAVE-ANAL
			80.0 92.5	1.50 1.50	7.24 7.21	@ AMP-SPEC
			40.0	1.22 1.17 8.52	5.87 5.61 2.53	C POW-SPEC
Lul.				5.JL		C LOG-SPEC
0.0 Cursor:10	00.0 0.02	1000	Hz			CEPSTRUM

Spectrum in PBE VER direction at 800rpm



Spectrum in PBE HOZ direction at 800rpm



Spectrum in PBE AXL direction at 800rpm

View SelectList Help Exit			View SelectList Help Exit			
22.95 mm/s Amplitude Spectrum Analysis	REQ AMP %	CAUTO-CORR	17.85 mm/s Amplitude Spectrum Analysis	FREQ	MP %	CAUTO-CORR
17.	7.5 22.95 100.0 00.0 8.35 36.4	C TIME-DIAG		17.5 1 50.0 6	7.85 100.0 64 37.2	C TIME-DIAG
82. 67.	2.5 5.54 24.1 7.5 3.31 14.4	C WAVE-ANAL		100.0 3. 67.5 3.	54 19.8 24 18.1	C WAVE-ANAL
32.	2.5 2.03 8.83 0 1.26 5.47	AMP-SPEC		32.5 3. 0.0 1. 117.5 0	07 17.2 23 6.92	AMP-SPEC
50.	J.U 1.24 5.42 57.5 1.20 5.25 50.0 0.98 4.25	O POW-SPEC		80.0 0. 317.5 0.	54 3.05 51 2.85	C POW-SPEC
		CLOG-SPEC	JAA A.			CLOG-SPEC
0.0 Cursor:1000.0 0.07 1000 Hz	z	CEPSTRUM	0.0 Cursor:1000.0 0.03 1	00 Hz		CCEPSTRUM

MAMA

#### Spectrum in PBE HOZ direction at 10000rpm

#### Spectrum in PBE VER direction at 1000rpm



#### Spectrum in PBE AXL direction at 1000rpm

12.22 mm/s	Amplitude Spectrum Analysis	Amplitude Spectrum Analysis				C AUTO-CORR
			20.0	12.22	100.0	C TIME-DIAG
			62.5 82.5	4.01 3.76	32.8 30.7	C WAVE-ANAL
			105.0	3.41	27.8 9.93	
lin			165.0 92.5	0.76	6.23 5.73	C POW-SPEC
MALLAN						C LOG-SPEC
0.0 Cursor:100	00.0 0.03	1000	Hz			C CEPSTRUM

#### Spectrum in PBE VER direction at 1250rpm



Spectrum in PBE HOZ direction at 1440rpm



#### Spectrum in PBE HOZ direction at 1250rpm

CEPSTRUM

View SelectList Help Exit					
7.66 mm/s	Amplitude Spectrum Analy	is FR	EQ AMP	*	CAUTO-CORR
		105	5.0 7.66 5 7.34	100. 95.8	C TIME-DIAG
		82. 20.	5 4.23 0 3.67	55.2 47.9	C WAVE-ANAL
		42.	5 3.34 5.0 2.55	43.5 33.2	AMP-SPEC
		90. 75.	0 1.98	25.8 14.0	C POW-SPEC
WAR.			0 1.06	13.0	C LOG-SPEC
0.0 Cursor:100	Nrsushing dimensional	1000 Hz			C CEPSTRUM

#### Spectrum in PBE AXL direction at 1250rpm

View Select List Help Es	k					
20.90 mm/s	Amplitude Spectrum	Analysis	FREO		96	CAUTO-CORR
			47.5 25.0	20.90	100.0	C TIME-DIAG
			167.5 70.0	1.45 1.38	6.95 6.60	C WAVE-ANAL
			97.5 92.5	1.17 1.13	5.61 5.39	@ AMP-SPEC
			192.5 217.5 120.0	1.03 1.01 0.93	4.91 4.81 4.44	⊂ POW-SPEC
			12010			C LOG-SPEC
0.0 Cursor:10	00.0 0.15	1000	Hz			C CEPSTRUM

#### Spectrum in PBE VER direction at 1440rpm

View Select List Help Exit						
9.82 mm/s	Amplitude Spectrum Anal	ysis	FREQ	AMP	%	C AUTO-CORR
			25.0	9.82 9.41	100.	⊂ TIME-DIAG
			70.0	9.23	94.0	C WAVE-ANAL
			120.0	2.33	23.7	@ AMP-SPEC
			215.0	1.05	10.7	C DOW ODEC
			0.0	0.86	8.71	OPUW-SPEC
WWWWWWW	A.A.					C LOG-SPEC
0.0 Cursor:100	0.0 0.04	1000	Hz			○ CEPSTRUM

Spectrum in PBE AXL direction at 1440rpm

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

		MN	INDE		MI	DE	PB	E	
Speed	Direc	Unbalance	Balance		Unbalance	Balance	Unbalance	Balance	
(rpm)	tion	<b>v</b> (mm	/sec)		v (mn	n/sec)	<b>v</b> (mm	ı/sec)	
	Н	4.53	1.45		4.74	1.59	14.23	3.20	
600	$\mathbf{V}$	3.68	0.98		6.89	2.48	16.64	2.72	
	Α	6.25	1.69		3.19	2.70	2.57	1.55	
	Н	16.44	7.92		15.67	7.26	45.68	15.16	
800	$\mathbf{V}$	12.95	3.24		13.36	7.00	67.15	20.77	
	Α	8.45	5.90		13.79	7.08	14.56	4.38	
	Н	76.01	12.36		22.37	12.15	83.72	22.95	
1000	$\mathbf{V}$	80.53	4.43		22.91	10.37	158.5	17.85	
	Α	58.49	14.89		59.98	11.56	50.78	8.01	
	Н	83.40	6.04		92.50	9.83	111.7	9.72	
1250	V	64.15	4.31		83.53	18.76	51.72	12.22	
	Α	44.82	18.97		70.27	21.85	92.44	7.66	
	Н	43.17	10.44		72.09	6.46	383.8	13.16	
1440	V	31.15	25.79		57.90	12.27	89.06	20.90	
	Α	104.93	21.11		126.1	20.96	77.61	9.82	

 Table: 4

 Comparisons of vibration amplitudes for unbalanced and balanced signals:

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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