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Determination Of Misalignment Using Motor Current Signature Analysis In Rotating Machine

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ABSTRACT

Misalignment is one of the predominant failure of rotating machines driven by induction motors .there are several methods for identifying the misalignment vibration monitoring, acoustic noise measurements ,temperature monitoring etc. Motor current signature analysis is used recently in determine the faults in rotating machines. It is based on signal analysis of motor current obtained via regular current transformer used for motor protection purposes. This paper inspects the misaligned motor and machine shafts by using diagnostic medium such as current, frequency and instantaneous power signal. Misalignments in machines can cause decrease in efficiency and in the long-run it may cause catastrophic failure because of unnecessary vibration, stress on motor & bearings and short-circuiting in stator and rotor windings. The measurements have been taken from no load to full load for detecting the misaligned motor and machine shaft performed at full-load to detect the misaligned motors by considered the fault frequencies characteristics using current, flux and instantaneous power spectrums. Experimental study demonstrates that current increases with increase of load since that misalignment is also one type of load on motor that progression of current is high in misalignment position .Mat lab software is used for generating spectrum .By the analysis of current spectrum fault frequency components (f1±fr) from the flux spectrum are more helpful for the purpose of detecting misalignment in machines as compared to any other side band components of fault frequencies of current and instantaneous power signals.

Keywords: *Motor Current Signature Analysis, Vibration Spectrum Analysis, Mean-Square Spectrum, FFT*

Nomenclature:

H: Horizontal;	*D: Displacement*	*MDE: Motor Drive End;*	*V: Vertical;*
PBE: Pillow Block End;	*A: Axial*	*Vfd: variable frequency drive*	*v: Velocity*

I. INTRODUCTION

The basis of any condition monitoring depends on understanding the electric, magnetic and mechanical behaviour of a machine in both the healthy and faulty state [1]. An induction machine is highly symmetrical and the presence of any kind of fault modifies its symmetry and produces changes in the measured sensor signals, or more precisely, in the magnitude of certain fault frequencies [2].Misalignment phenomenon is one of main causes for economic losses in industry. That is due to the fact that it reduces the machine's life and causes a decrease in motor arrangement efficiency, and misaligned machinery is more prone to failure due to increased load on bearing, seals and coupling.[3] [4].In most of the cases, misalignment in motor exhibits the combination of both types of misalignment [5]. Offset Misalignment which is the amount by which the alignment of driver and driven shaft are out of parallel alignment and Angular Misalignment which is the amount by which the alignment of driver and driven shaft."A proper shaft alignment is inevitable because it reduces excessive axial and radial forces on the most vulnerable parts of a machine system such as the bearings, seals, and couplings [6]". Maintenance strategies are changing from periodic inspection strategies to condition-based predictive maintenance strategies due to changes in manufacturing world [7]. "Timely and accurate information about incipient faults in online machines will greatly enhance the development of optimal maintenance procedures.[8]" Some benefits of a functional predictive maintenance, an increase in the availability and safety of the plant and workers improvements in the quality of products, an improvement in the quality of the available information about machine failures, maintenance activities, and support services in the design and improvement of future machines a reduction in maintenance costs[9]. Induction motors are used extensively in every industry the electric motors and motor system experience a wide range of electrical and mechanical faults as described in [10], [11]. Particular in metal rolling process electric motors experience a wide range of mechanical problems Literature survey shows that mechanical faults are responsible for more than 95%of all failures [12].

Shaft misalignment has major implications for modern-day rotating equipment reliability. Although effective alignment techniques have been applied successfully on a wide range of equipment for some time, deterioration of the alignment state can frequently occur due to changes in equipment operating conditions, foundation settlement and piping strain [13]. This situation can lead to the imposition of excessive forces on the equipment rotating and static elements, most commonly resulting in bearing or coupling failure. In extreme circumstances contact between rotating and stationary components can be expected to occur the presence of shaft misalignment can greatly influence machinery vibration response [14]. However, it's detection through vibration diagnostics is not a straightforward matter due to the lack of a clear understanding of the physical mechanism relating shaft misalignment to vibration. Dewell and Mitchell [15] investigated the vibration spectrums produced by a misaligned flexible-disk coupling and showed that 2X and 4X frequency components could be used to detect the presence of misalignment. Jackson [16] described the emergence of a 2X vibration component resulting from the non-linear properties of oil-film bearings when preloaded due to misalignment forces. Simon [17] modelled misalignment in large turbo-machinery and computed the vibration response based on assumed values for the coupling reaction forces, the form of which was not disclosed. Xu and Marangoni [18, 19] studied, analytically and experimentally, the vibration response of a misaligned motor-driven system.

1.1 Types of misalignment

There are two types of misalignment: parallel and angular misalignment. With parallel misalignment, the center lines of both shafts are parallel but they are offset. With angular misalignment, the shafts are at an angle to each other. The parallel misalignment can be further divided up in horizontal and vertical misalignment. Horizontal misalignment is misalignment of the shafts in the horizontal plane and vertical misalignment is misalignment of the shafts in the vertical plane. Parallel horizontal misalignment is where the motor shaft is moved horizontally away from the pump shaft, but both shafts are still in the same horizontal plane and parallel. Parallel vertical misalignment is where the motor shaft is moved vertically away from the pump shaft, but both shafts are still in the same vertical plane and parallel. Similar, angular misalignment can be divided up in horizontal and vertical misalignment. Angular horizontal misalignment is where the motor shaft is under an angle with the pump shaft but both shafts are still in the same horizontal plane. Angular vertical misalignment is where the motor shaft is under an angle with the pump shaft but both shafts are still in the same vertical plane.

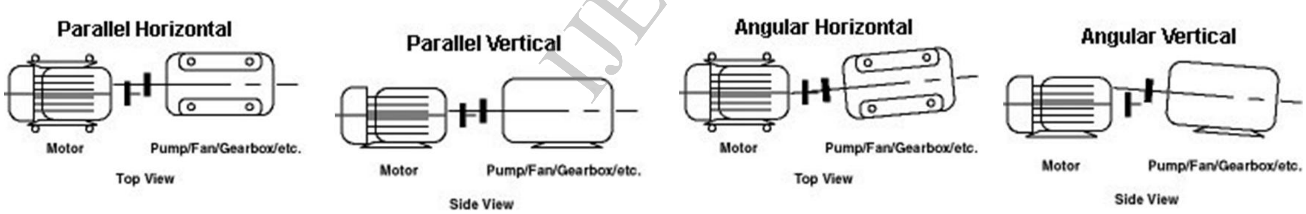

Fig. 1: Types of misalignment

1.2 Motor Current Signature Analysis

Motor Current Signature Analysis (MCSA) is a technique used to determine the operating condition of AC induction motors without interrupting production. MCSA techniques can be used in conjunction with vibration and thermal analysis to confirm key machinery diagnostic decisions. Motor current signature analysis is used recently in determine the faults in rotating machines. It is based on signal analysis of motor current obtained via regular current transformer used for motor protection purposes MCSA operates on the principle that induction motor circuits can, in essence, be viewed as a transducer.. An idealized current spectrum is shown in Fig. 5. The two slip frequency sidebands due to misalignment near the main harmonic can be clearly observed. Usually a decibel (dB) versus frequency spectrum is used in order to give a wide dynamic range and to detect the unique current signature patterns that are characteristic of different faults.

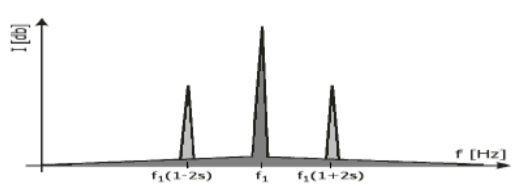

Fig.2: Idealized Current Spectrum

1.3 Theory of Motor current signal

A motor current signal is ideally a perfect sinusoidal wave at 50 Hz we can represent the current in terms of time as well frequency. Figure .3 shows the current vs. time while the second shows the current vs. frequency. The amplitude of the peak in frequency is equal to the RMS amplitude of the sine wave. As this is a theoretical situation with no harmonics, we see only one peak in the frequency spectrum. The conversion of the current from time to the frequency domain is achieved using an algorithm called the fast Fourier transform.

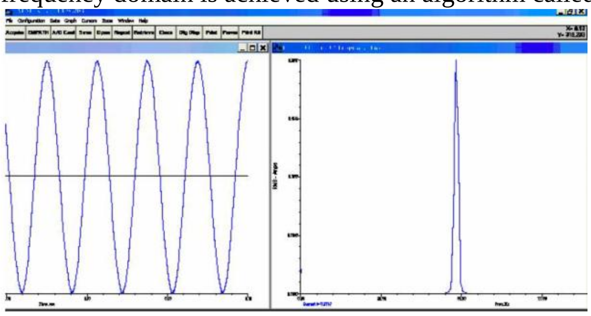

Fig. 3: A perfect 50 Hz signal in both time & frequency domains

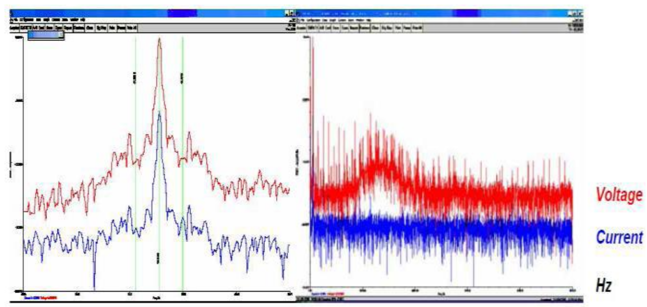

Fig. 4: Typical low and high frequency spectra of a good motor

During actual operation many harmonics will be present in the motor signal, thus an actual signal will show many peaks including line frequency and its harmonics is shown in figure.4. This is known as the motor's current signature. Analyzing these harmonics after amplification and signal conditioning will enable identification of the various motor faults. Certain harmonics come in on the supply & these are of little consequence. However, harmonics are also generated due to various electrical and mechanical faults. All faults cause change in internal flux distribution thus generating the harmonics.

II. DESCRIPTION OF THE EXPERIMENTAL SETUP

The Experimental setup is as shown in Figure 2 and 3. It consists of a 0.5 hp A.C. Induction motor, a fixed type flange coupling and load setup arrangement. 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 at the end of shaft length B-type pulley is arranged 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 MDE & PBE housing and gives the corresponding values.

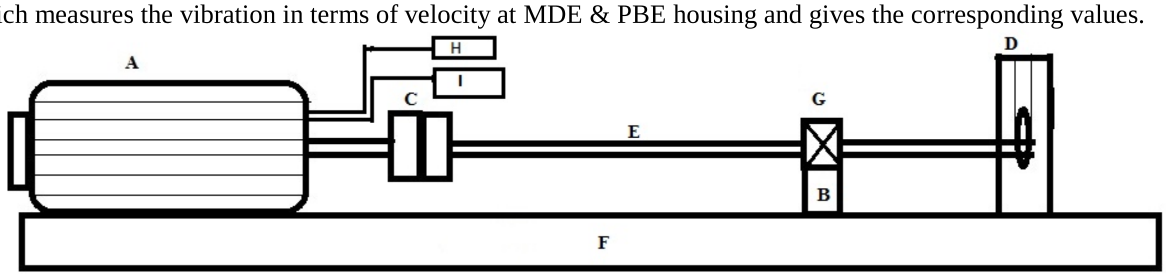

Fig. 5: Line diagram of experimental setup.

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

Fig. 6: VFD

Fig. 7: Experimental setup

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Specifications:

Rated Power : 0.375 kW.
Rated Speed : 1440rpm
Frequency : 50 Hz.
Voltage : 600 V.
Current : 2 A.

Shaft Length : 1000mm
Shaft Diameter : 16mm
Pulley Diameter : 99mm
Coupling Diameter: 75mm

Vfd drive capacity: 2.5kW

III. EXPERIMENTAL PROCEDURE

Experimental setup shown in Figure: 2 and 3 used for generate spectrum wave forms. First the setup is run for few minutes note down readings from ammeter, voltmeter, speed, load and load%, wave form is captured through cathode ray oscilloscope. Current, voltage, speed, % of load for different loads are taken in good condition and same are taken for misalignment of 1.5cm. In the same way reading were taken for vertical misalignment for different distances. FFT is the vibration analyzer is used to acquire the vibration signals in terms of velocity. Vibration signals are measured at full speed rotor system at drive end (DE), Pillow block end (PBE) stored in the vibration analyzer. Following are the readings observed

Without misalignment full speed

S.no	Load (kg)	Current (A)	Voltage (V)	Speed (RPM)	Load %
1	0	0.88	400	1441	9.3
2	2	0.90	400	1439	16.8
3	4	0.94	400	1438	22.6
4	6	1.00	400	1434	34.8
5	8	1.10	400	1434	38.2
6	10	1.36	400	1434	56.1

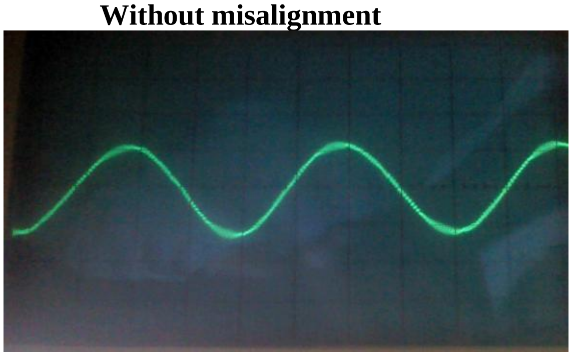
Horizontal angular misalignment of 2cm

S.no	Load (kg)	Current (A)	Voltage (V)	Speed (RPM)	Load %
1	0	0.88	400	1441	11
2	2	0.90	400	1438	26.2
3	4	0.94	400	1437	27.3
4	6	1.1	400	1434	45.2
5	8	1.24	400	1431	59.6
6	10	1.42	400	1429	72

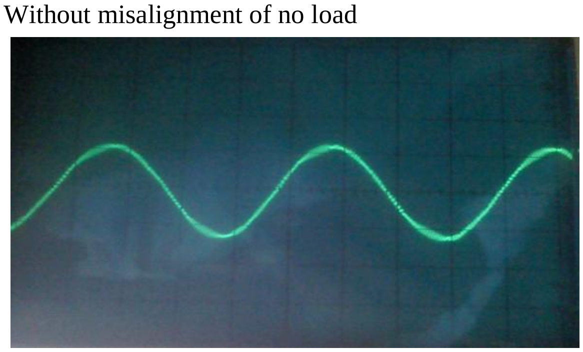
IV. OBSERVATIONS

4.1 CRO Waveforms

Without misalignment

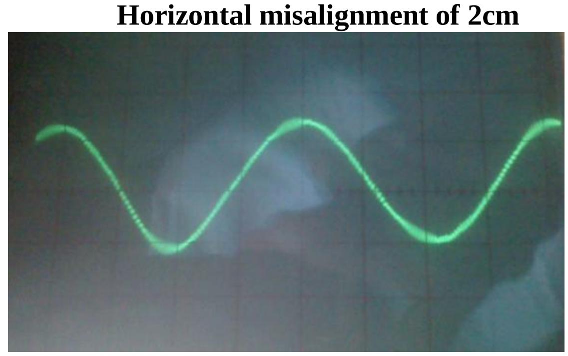


Without misalignment of no load

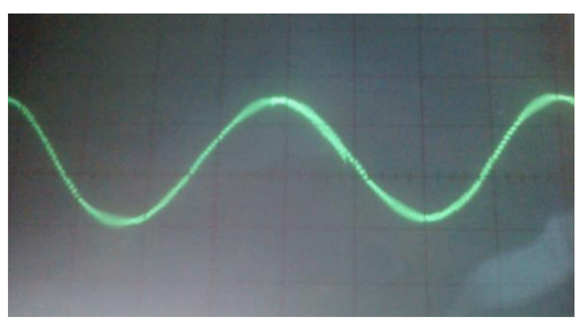


Without misalignment of 2kg load

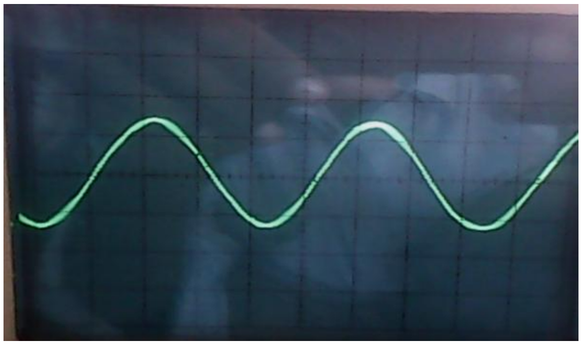
Horizontal misalignment of 2cm

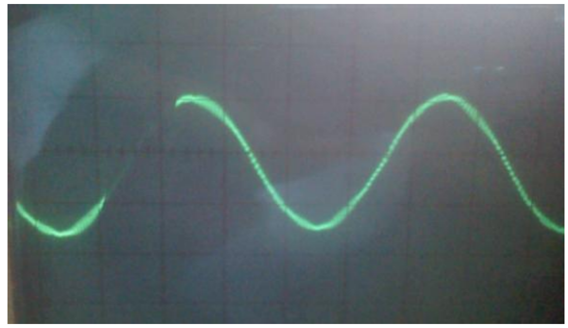


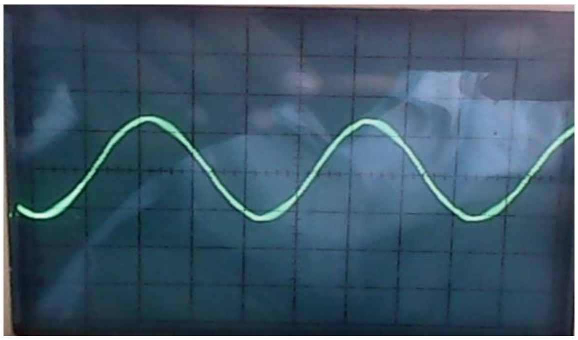
Horizontal misalignment of 2cm with no load

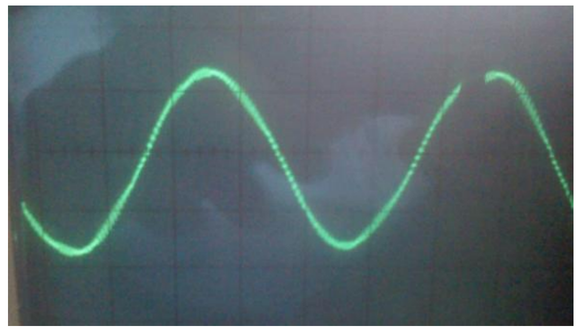


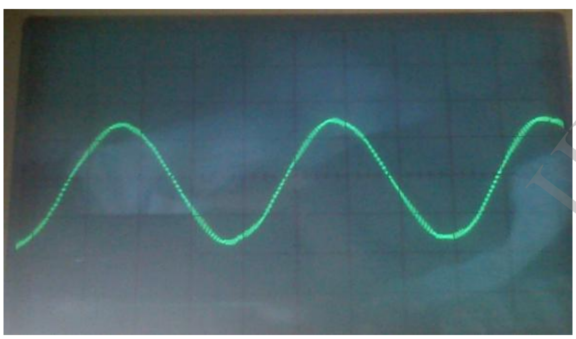
Horizontal misalignment of 2cm with 2kg load

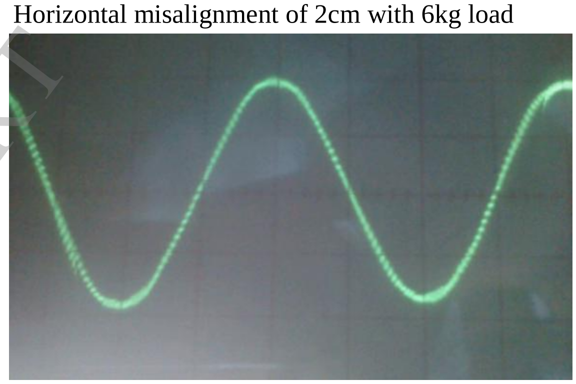

Without misalignment of 4kg load

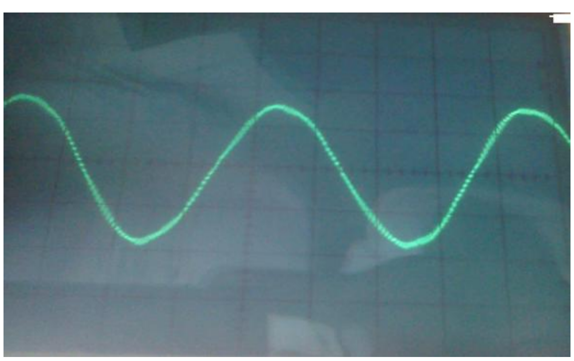

Horizontal misalignment of 2cm with 4kg load

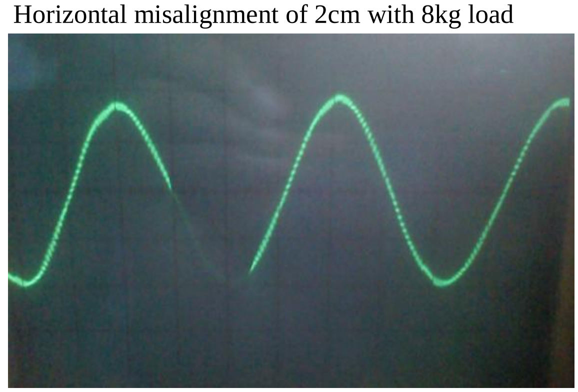

Without misalignment of 6kg load


Horizontal misalignment of 2cm with 6kg load


Without misalignment of 8kg load


Horizontal misalignment of 2cm with 8kg load


Without misalignment of 10kg load


Horizontal misalignment of 2cm with 10kg load

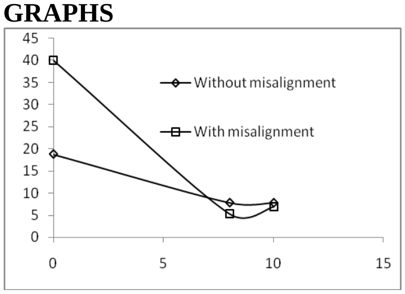
4.2 FFT READINGS

POSITION	LOAD (Kg)	HORIZANTAL (v mm/s)		VERTICAL (v mm/s)		AXIAL (v mm/s)	
MDE		WITHOUT MISALIGN MENT	WITH MISALIGN MENT	WITHOUT MISALIGN MENT	WITH MISALIGN MENT	WITHOUT MISALIGN MENT	WITH MISALIGN MENT
	0	18.8	40	5.6	6.67	12.8	17.6
	8	7.84	5.37	5.17	6.22	6.61	7.08
	10	7.82	6.89	4.08	6.84	6.39	10.4
PBE	0	28.7	22.7	20.2	21.6	16.8	22.7
	8	28.1	26	23.6	24.8	21.2	25.9
	10	21.6	29.4	37.5	29.4	26.7	33.6

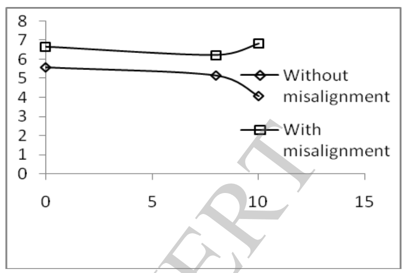
OBSERVATIONS

Increase of load with misalignment at motor end increase vibration in horizontal and vertical and axial directions**.** The vibrations at no load are high since the motor is running at full speed. The rate of increase of vibration in axial direction is high when compared to radial direction. High axial vibration may cause misalignment to confirm the problem of misalignment spectral analysis and phase analysis are done.

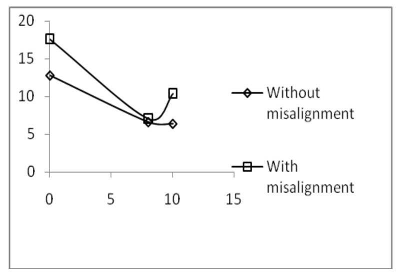
GRAPHS



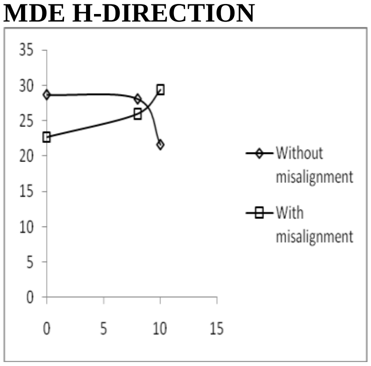
MDE H-DIRECTION



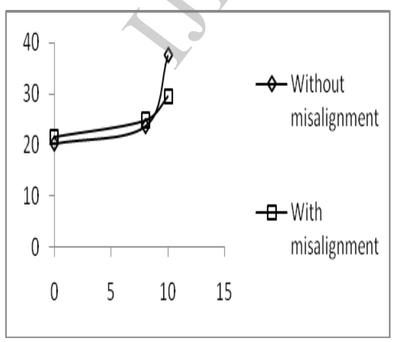
MDE V-DIRECTION



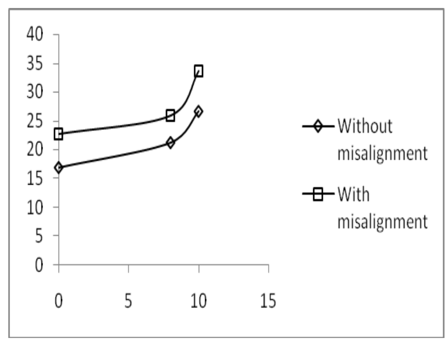
MDE A-DIRECTION



PBE H-DIRECTION



PBE V-DIRECTION



PBE A-DIRECTION

OBSERVATIONS

The graphs are plotted between load verses amplitude. The above graphs show that presence of misalignment not affects the horizontal vibration. For overhang rotor increases of load and presence of misalignment the vertical and axial direction.

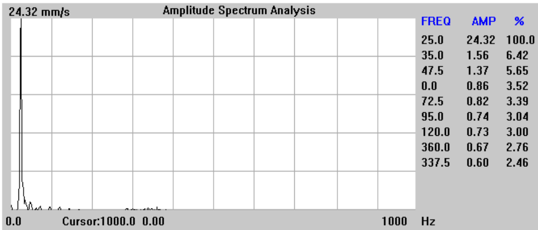
4.3 PHASE READINGS

S NO	ANGLE	MDE	PBE
1	0^0	136	194
2	90^0	188	252
3	180^0	121	188

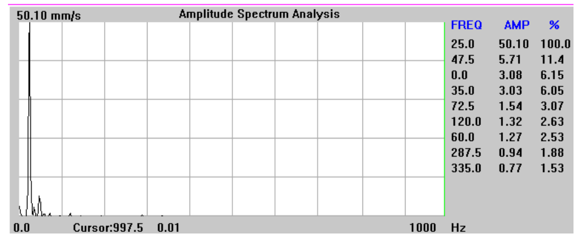
Phase readings observe that maximum value at MDE is $+90^0$as well as PBE at maximum value is -90^0 in case of PBE is placed in opposite direction of mde. We got phase angle as 180^0 we can confirm it is the problem of misalignment.

V. FFT OBSERVATIONS

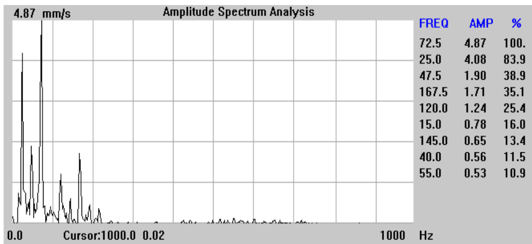
5.1 Spectrums from FFT



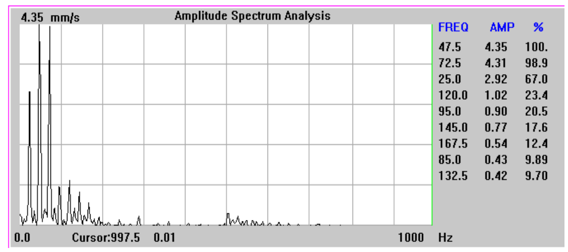
Without misalignment at mde-h-no load



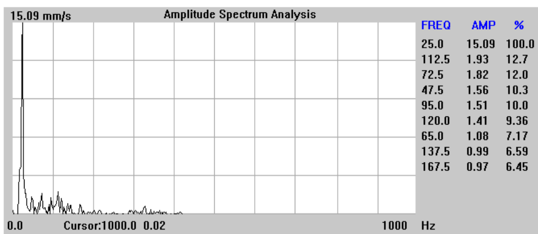
Horizontal misalignment of 2cm at mde-h-no load



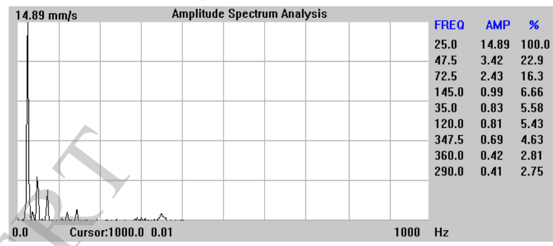
Without misalignment at mde-v-no load



Horizontal misalignment of 2cm at mde-v-no load



Without misalignment at mde-a-no load



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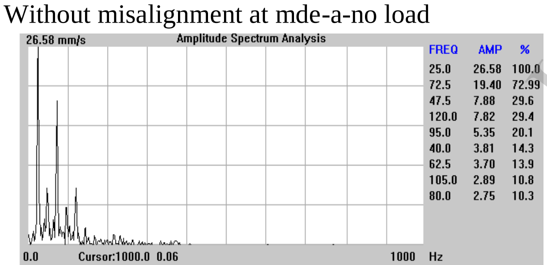
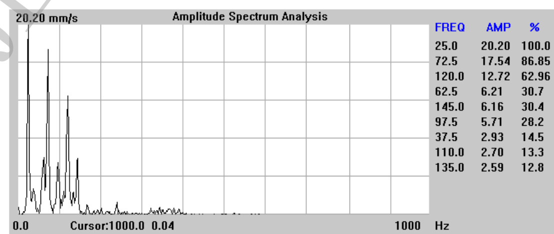
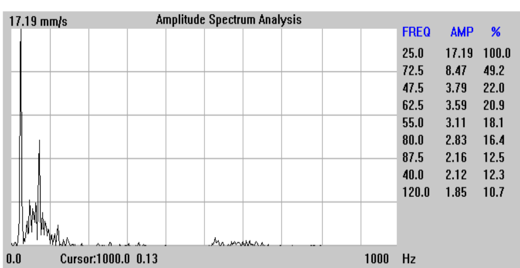


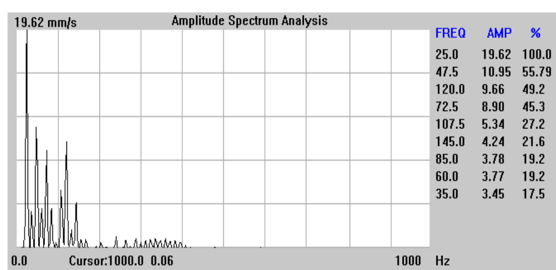
Without misalignment at pbe-h-no load



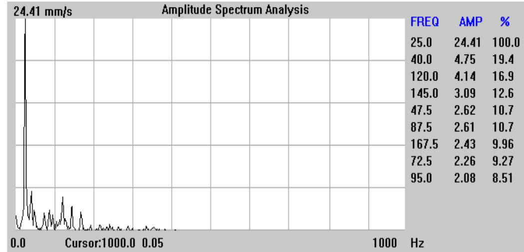
Horizontal misalignment of 2cm at pbe-h-no load



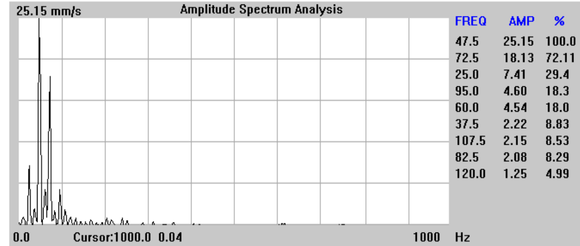
Without misalignment at pbe-v-no load



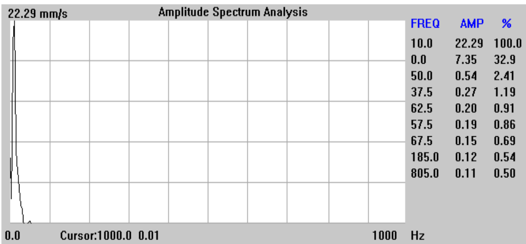
Horizontal misalignment of 2cm at pbe-v-no load



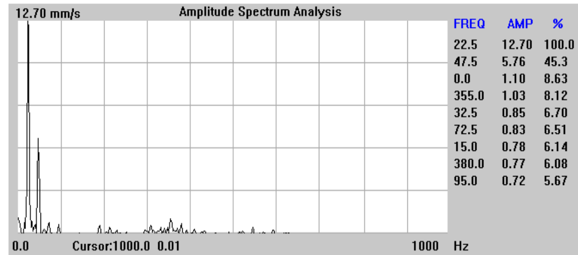
Without misalignment at pbe-a-no load



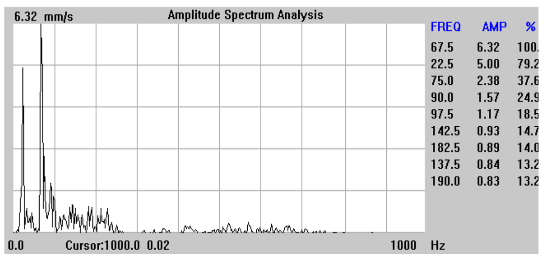
Horizontal misalignment of 2cm at pbe-a-no load



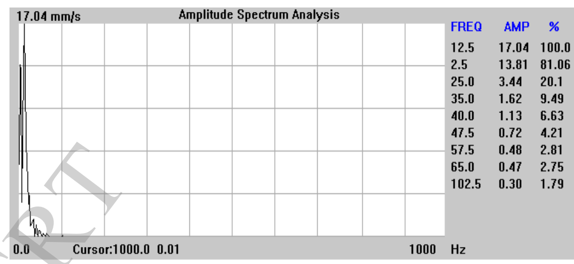
Without misalignment at mde-h-8kgload



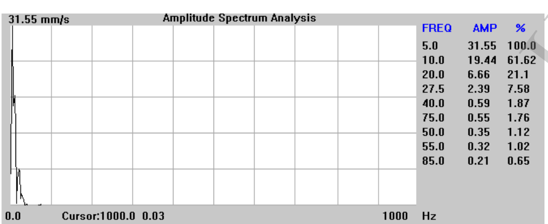
Horizontal misalignment of 2cm at mde-h-8kgload



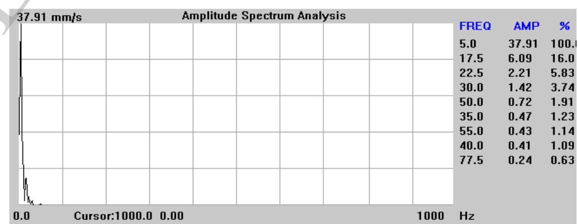
Without misalignment at mde-v-8kgload



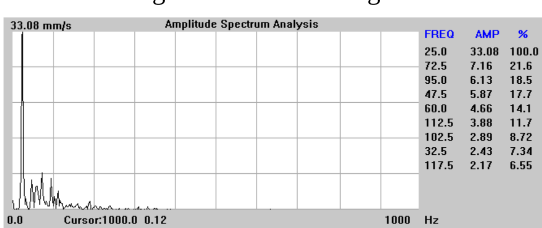
Horizontal misalignment of 2cm at mde-v-8kgload



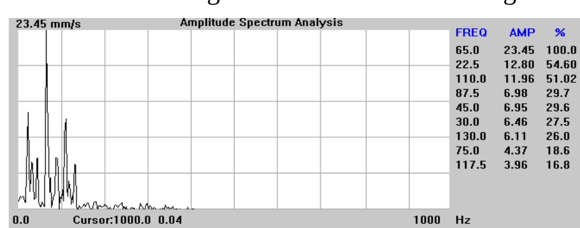
Without misalignment at mde-a-8kgload



Horizontal misalignment of 2cm at mde-a-8kgload



Without misalignment at pbe-h-8kgload



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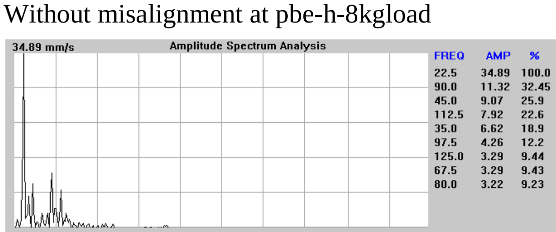
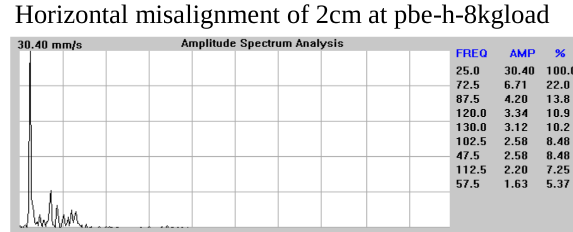


Without misalignment at pbe-v-8kgload



Horizontal misalignment of 2cm at pbe-v-8kgload

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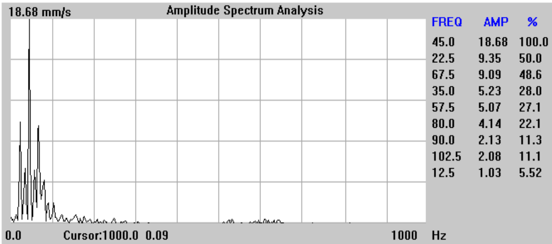
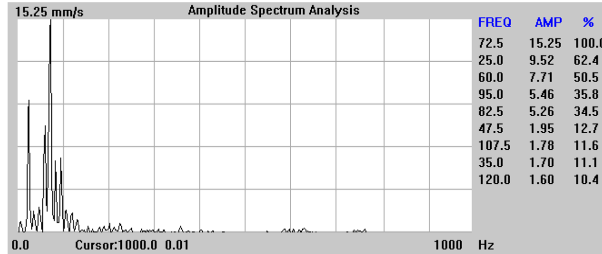
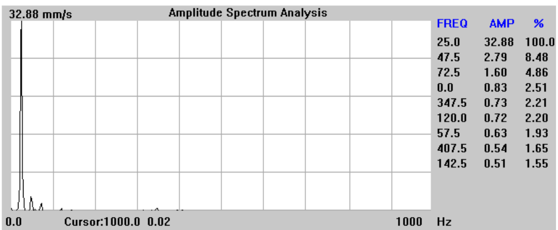


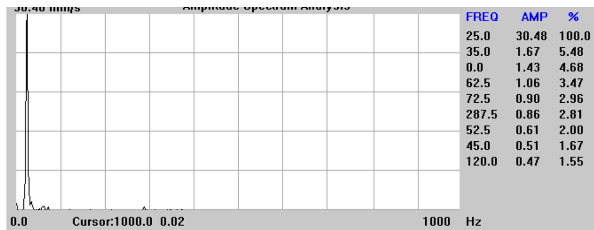
Without misalignment at pbe-a-8kgload



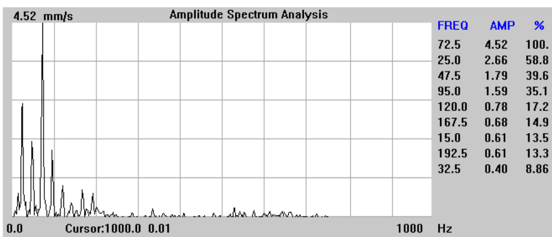
Horizontal misalignment of 2cm at pbe-a-8kgload



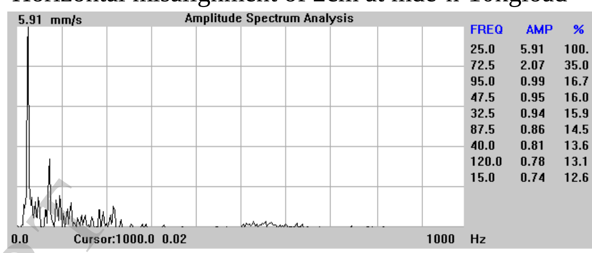
Without misalignment at mde-h-10kgload



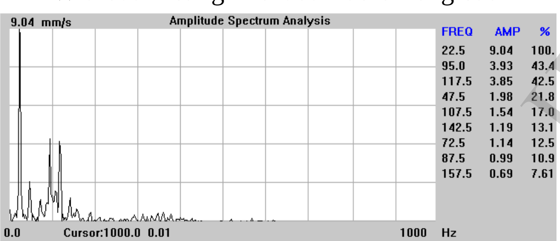
Horizontal misalignment of 2cm at mde-h-10kgload



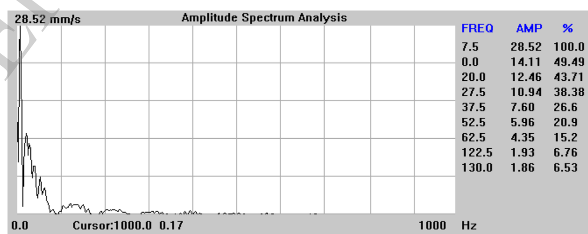
Without misalignment at mde-v-10kgload



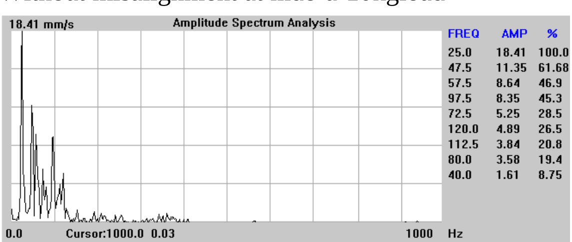
Horizontal misalignment of 2cm at mde-v-10kgload



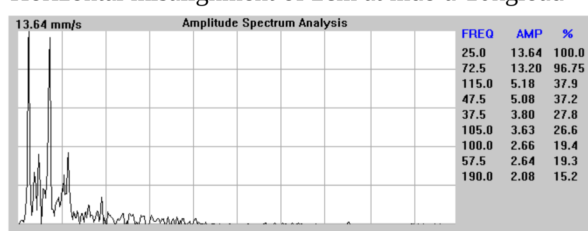
Without misalignment at mde-a-10kgload



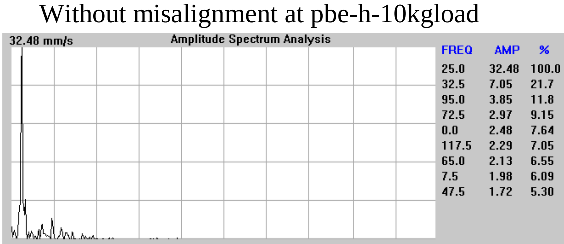
Horizontal misalignment of 2cm at mde-a-10kgload



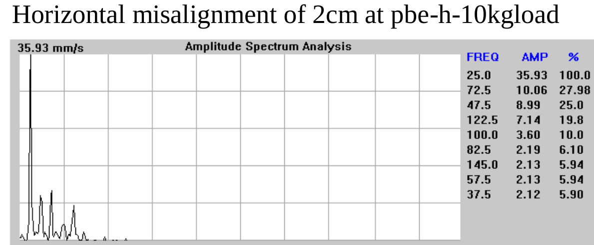
Without misalignment at pbe-h-10kgload



Horizontal misalignment of 2cm at pbe-h-10kgload



Without misalignment at pbe-v-10kgload



Horizontal misalignment of 2cm at pbe-v-10kgload

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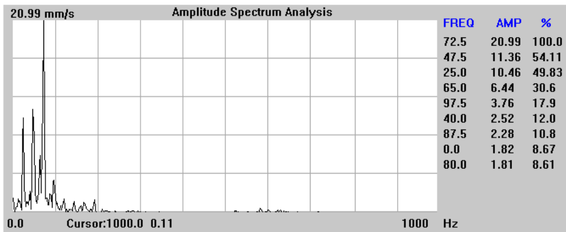
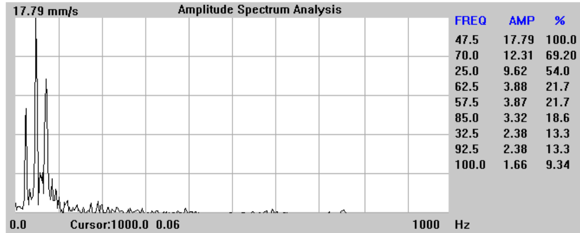


Without misalignment at pbe-a-10kgload



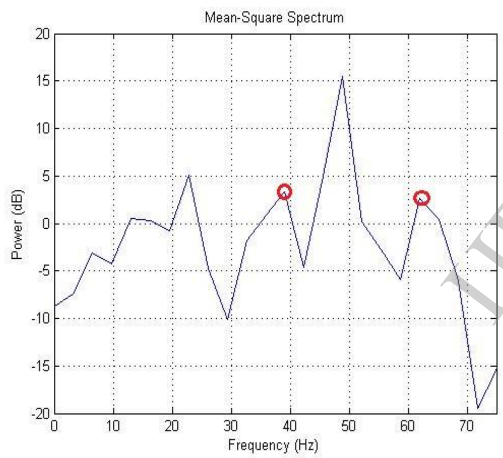
Horizontal misalignment of 2cm at pbe-a-10kgload

5.2 Observations from the spectrums

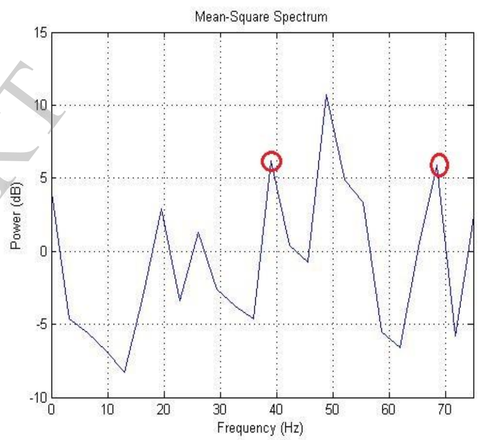
By observing the spectrum peak are present at 1X. 1X peaks in radial (or) axial directions causes unbalance (or) misalignment .To clarify the unbalance (or) misalignment phase readings are observed. If the phase angle is 90^0 it is the problem of unbalance. If the phase angle is 180^0 it is the problem of misalignment. Since we got the phase angle as 180^0 we can confirm it is the problem of misalignment.

5.3 Mat lab Spectrums

The current, frequency, % of load is taken from variable frequency drive and the values as input "Welch's Spectrum" in mat lab. Afterwards, computed power spectral density is converted into one-sided mean-squared spectrum for each frame using the spectrum function in mat lab.



Without misalignment



Horizontal angular misalignment of 2cm

5.4 Observations from mat lab spectrums

By observing the instantaneous power spectrum the amplitude of fault frequency is less when compared to the healthy motor. There is a maximum variation in the side band for faulty motor. It can be concluded from figures above that variation in the sideband components of fault frequency due to misalignment are clearly visible in the frequency spectrum of healthy and misaligned motor in the current when compared to the sideband components.

VI. CONCLUSIONS

Experimental work has been conducted on 0.5H.P motor with overhang rotor. In healthy condition and misalignment condition the vibration readings are high in misalignment condition and the amplitude of vibration increases with increase load. Peak amplitudes are observed at 1X in axial direction. Phase angle measured between motor and coupled shaft end is 180^0.The motor stator current is drawn in healthy and faulty conditions of setup and the current and frequency values are used to generate current spectrum using mat lab .the current spectrum indicates that reduction in peak amplitude and increase in side band Amplitudes for faulty motor. With is due to the presence of misalignment .motor current signature analysis is an emerging technology to detect the faults in machines. it has wide range of use due to it is portability less cost because special sensors not require like vibration monitoring and remote sensing capability. There is no need to physical contact with the faulty machines so that we can reduce the hazardless effects to the human hence it is safest method.

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