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Detection of Shaft Misalignment Using Machinery Fault Simulator (MFS)

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Abstract – *This paper aims to present a method of detecting deterioration on rotating machinery in the form of Machinery Fault Simulator (MFS) performed in the lab. The study enhances the knowledge of signal pattern of misalignment phenomenon as compared to baseline signal pattern obtained from normal condition of rotating shaft. The focus of this experiment was on misalignment problem. There are two types of misalignment which are parallel and angular misalignment. Input in frequency was selected for motor movement and the shaft start to rotate. The vibration signal from the shaft was acquired using in built tachometer in the MFS. In this experiment, data shows that the vibration occurs in different shape of the amplitude at different speed of the angular motion. In baseline test, the amplitude values are fluctuated at every accelerometer channels. Meanwhile, the amplitude on the angular test shows that the amplitude is higher at axial axes only compared to both axes. Meanwhile, for the second test, the angle of 15º was applied at inboard in the system caused to the misalignment of the shaft. In vibration analysis, the misalignment of the shaft was detected from the changes of the amplitude at three different axes.*

Keywords: Machinery Fault Simulator, Shaft Misalignment, Vibration Monitoring, Spectrum Graph, Vibration Analysis

1.0 INTRODUCTION

Nowadays, with the increasing output and aiming for high efficiency of plant operation, predictive maintenance has been very popular in industry. One of the major areas in predictive maintenance is condition based maintenance where it encompasses the concept of detecting irregularities, defects or abnormality by using specific advanced tool based on physical behavior of the system/machinery/parts under study. Rotating machineries and parts such as shafts, bearing, discs etc will induce problems that are so common which relate to vibration and this repetitive as well as periodic/cyclic pattern contribute to the birth of advanced tool of detecting problems in rotating parts using vibration monitoring technique. This paper attempt to simulate the industrial scenario that occurs in industry performed but in small scale at lab using a unit which simulates the similar behavior which is called Machinery Fault Simulator (MFS). Condition monitoring based technique consists of the measurement of the vibration, noise and temperature. All of these three indicators are very important to be monitor on the machine. Vibration indicator is first levels of the monitoring technique condition that must be applied on the machine before it turns to the emergency stop warning level until to the last stage which is breakdown system occur [1]. The examples of the indicators are accelerometer and tachometer. Accelerometers are transducers for measuring the dynamic acceleration of a physical device [2]. Meanwhile, a tachometer is also a transducer for measuring the rotational speed of a physical device. Both of the transducers will transmit the signal detected to the signal

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processing software by converting the signal from mechanical to electrical motion. There is many possible processing software that able to analyzed the signal such as LabVIEW, Vibra Quest and others software. Several researchers have studied the misalignment behavior of different parameter and condition using vibration based study. They even used advanced signal processing method in gaining fine signal in the form of amplitude to characterize the misalignment occurrence in rotating disc [2,3,4,5,6]. There was also study of vibration phenomena in rotating part using acoustic emission technique [7]. Very little research have been done on the behavior of vibration that due to misalignment via MFS experimental in the lab. This also brings to the situation where documented step by step procedure for conducting such experimental is not available in the literature. This paper is aimed to fill in the gap of exploring the MFS capability in performing misalignment behavior with parametric study on effect of different angle and speed.

2.0 EXPERIMENTAL OF MACHINE FAULT SIMLATOR (MFS)

Vibration can happen due to misalignment. Misalignment is the root cause of majority of machine breakdown. Shaft is misaligned when its rotational center lines are not collinear when the machine is operating under normal conditions. Rotating machinery will usually provide warning signs before failing including changes of vibration level and pattern. These faults can be detected from the vibration signal. By recognizing these signs, early attempt of rectification can be made to prevent the machine from total failure.The design of experiment uses machine fault simulator to detect misalignment [2]. However, based on literature review found that in order to detect misalignment is by using Operating Deflection Shapes (ODS)[4]. Specifying the motion of two or more points defines a shape. ODS can be obtained from many different types of frequency domain measurements [4]. There are also several researches suggested the use of amplitude domain measurement to characterize the vibration problem [2,3,5,].

2.1 Misalignment Phenomenon in MFS

There are two types of misalignment which are parallel and angular misalignment as in Figure 1 and Figure 2. Parallel misalignment is defined as the center lines of both shafts are parallel but they are offset, while the shafts are at an angle to each other for the angular misalignment. Both of the types of misalignment can be further divided up in horizontal and vertical misalignment as depicted in Figure 3.

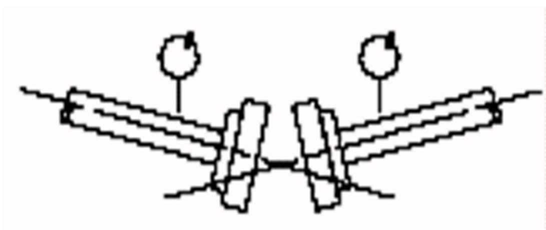

Figure 1: Angular misalignment [8]

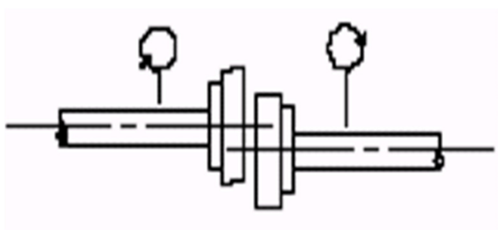

Figure 2: Parallel misalignment [8]

Horizontal misalignment is misalignment of the shafts in the horizontal plane and vertical misalignment is misalignment of the shafts in the vertical plane. However, the focus in this experiment is the angular misalignment. The Machine Fault Simulator (MFS) is used to set up and detect the misalignment behaviour. The angular misalignment is set at 15° angle and compared with the baseline alignment. The different rotating speed are set up at 20Hz and 30Hz

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independently. The vertical and horizontal of the angular misalignment are detected and analyzed by using Machinery Fault Simulator. Angular misalignment in horizontal and vertical condition is as shown in Figure 3.

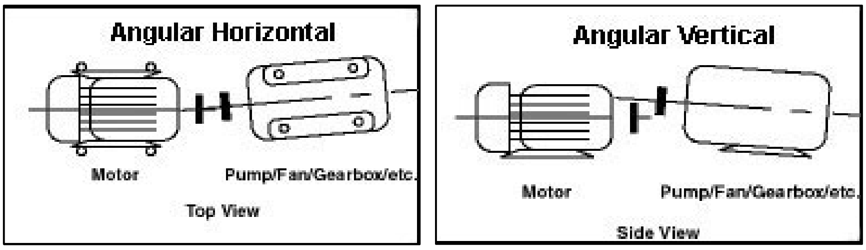

Figure 3: Horizontal and vertical angular misalignment [8]

2.2 Objectives of Study

Vibration fault simulation shows many types of faults due to machine such as mechanical looseness, bent shaft, bearing fault, gear fault, imbalance and misalignment. Objectives of the experiments are:

1) To study the phenomena of vibration response to faults using MFS
2) To analyze the angular misalignment behaviour in rotating syaft
3) To identify the relationship between the speed and misalignment of rotating shaft.
4) Documenting procedure of misalignment occurrence experimental using MFS

3.0 EXPERIMENTAL SETUP

The experiment is designed by using the Machinery Fault Simulator and Vibra Quest processing software.

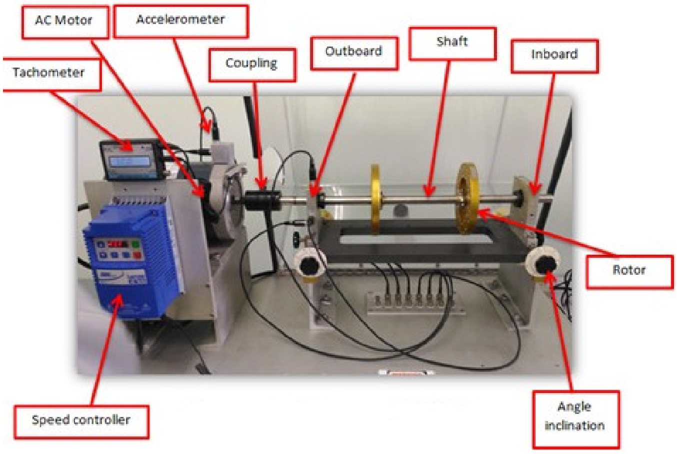

Figure 4: Machinery Fault Simulator (MFS)

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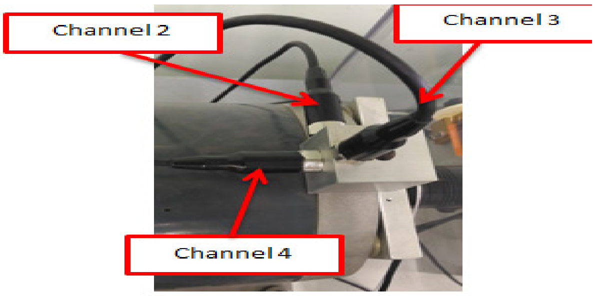

Figure 5: Accelerometer channel on motor

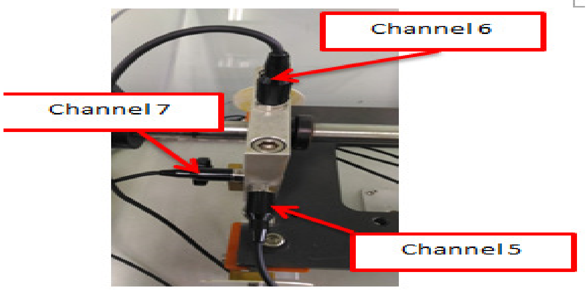

Figure 6: Accelerometer channel on shaft

The six channel of accelerometer sensors are used to detect any vibration occur in axial, horizontal and vertical direction at the shaft and motor as shown in Figure 4. Figure 5 and Figure 6 shows the location of accelerometer on motor and shaft.

Table 1 shows the channels which represents position for accelerometer and its detection model.

Table 1: The channel of accelerometer on MFS and its respective name

Channel	Detection Mode
Channel 2 (Ch2)	Horizontal direction on motor
Channel 3 (Ch3)	Vertical direction on motor
Channel 4 (Ch4)	Axial direction on motor
Channel 5 (Ch5)	Horizontal direction on inboard
Channel 6 (Ch6)	Vertical direction on inboard
Channel 7 (Ch7)	Axial direction on inboard

3.1 Sensor and instrumentation

The individual parts/tools of MFS used in this project are described as below:

1. *Machinery fault simulator (MFS):* Tool to study the signatures of machinery fault in which are commonly occurred. The simulator can be used to study balancing, alignment, resonance, bearing defects, crack shaft, fan and mechanical rub. It comprises of rotors, gearbox, reciprocating mechanism, motor and tachometer [3,4].
2. *Tachometer*: Transducer to measure speed in rpm and frequency in Hz of the shaft.
3. *AC Motor:* The conversion medium from electrical to mechanical energy as a source to run the MFS by spinning the shaft in clockwise or anti clockwise direction.
4. *Accelerometer:* The electromechanical device that will measure acceleration force, converts the mechanical behavior to the electrical energy [3]. It acts as transducers to detect vibration and measure the signal at every channel in motor and inboard shaft.
5. *Coupling:* Mechanical element that couples two different drive elements which enables motions to be transferred from one element to another.
6. *Inboard / outboard:* The board space for the misalignment of the shaft occurs due to the vibration.
7. *Shaft* : Support the rotor between two bearings

8. *Rotor:* Mechanical structures supported by bearings and influenced by internal phenomena that rotate around an axis.
9. *Vibra Quest Software:* Signal processing medium by generating the waveform signal visualization.
10. *Angle inclination:* Adjuster for the angle of inclination for the purpose of angular
11. misalignment.
12. *Speed controller:* Controls the speed and frequency of the machine. [3,6,8,9]

3.2 Procedure of Baseline Measurement

1. A straight shaft with two balance rotors in a center hung position is installed.
2. The shaft and the motor are coupled by a flexible helical beam coupling.
3. Channel 1 for Tachometer is connected to measure operational speed of the motor.
4. The accelerometers are connected at the six channels in horizontal, vertical and axial direction of the motor and shaft.
5. The data acquisition (DAQ) is set up the frequency limit, spectrum line and block.
6. The speed parameter is set at 20Hz in speed controller device and run button is pushed.
7. The analyses button in the DAQ Vibra Quest software is clicked when the frequency magnitude on the tachometer becomes stable.
8. The signal graph that set up to the spectrum, suppress and harmonic properties are recorded.
9. The stopped button is pressed in speed controller device to stop the operation.
10. Step 1 until 9 are repeated by 30Hz frequency of rotational speed.

3.3 Shaft Misalignment Measurement

1. The angle of inclination of the shaft is set 15º by adjusting the angle using jackscrew at inboard only. The outboard is maintained to the normal angle 0º.
2. The speed is set at 20Hz in speed controller device and run button is pushed.
3. The analyses button in the DAQ Vibra Quest software is clicked when the frequency magnitude on the tachometer is stable.
4. The signal graph that set up to the spectrum, suppress and harmonic properties are recorded.
5. The stopped button is pressed in speed controller device to stop the operation.
6. Step 3 until 6 are repeated with 30Hz frequency of rotational speed for angular misalignment behavior.
7. The rotor deck is returned to the aligned condition after data collections are completed.

3.4 Vibration Signal Analysis

The signal analyzed in this experiment is able to show the condition of the shaft whether in misalignment or not. The signals are analyzed as follow [3,7,10]:

1. Input in frequency is inserted for motor movement and the shaft start to rotate.
2. Tachometer is detected the signal speed of the rotating shaft and convert it into electrical behavior for signal processing.
3. The six channels of accelerometer are detected the vibration occur from the rotating shaft and the motor.

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4. The accelerometers are converted the signal come from mechanical energy to the electrical energy.
5. The entire signals in electrical movement are processed in Vibra Quest Software.
6. The data acquisition signals are visualized in the form of spectrum wave graph in vibration frequency domain and the amplitude are recorded.

4.0 EXPERIMENTAL RESULTS

Experimental results in terms of data of amplitudes which determined from each position containing accelerometer are tabulated in Table 2 and Table 3 for angle of inclination of 0 degree (baseline) and 15-degree misalignment respectively.

Table 2: Baseline Measurement for 0^0 of angle rotation

Frequency, Hz	Harmonic frequency, Hz	Amplitude, VRMS (10^{-5})					
		Ch2	Ch3	Ch4	Ch5	Ch6	Ch7
20	20	229.10	87.505	239.55	32.724	56.247	112.15
	40	138.60	31.866	17.679	12.071	6.8907	17.088
	60	48.598	89.385	272.44	8.8418	95.405	69.105
	80	138.74	23.108	40.426	109.50	22.859	153.74
30	50	2.5357	1.0048	4.0560	0.9115	1.2065	2.3128
	100	8.1124	14.062	12.854	31.130	14.484	62.224
	150	179.34	52.240	99.841	106.45	87.441	225.46

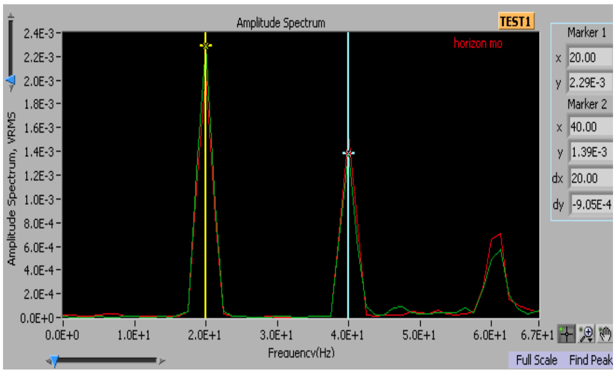

Figure 7: Amplitude spectrum at channel 2

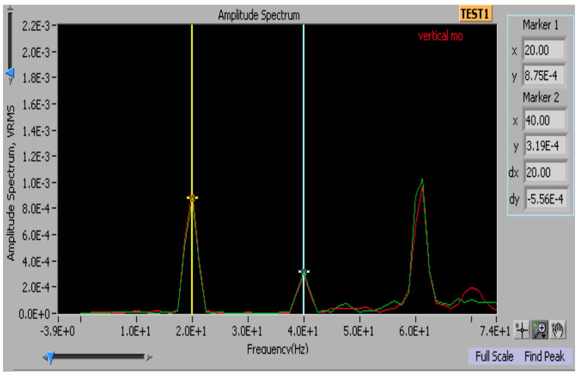

Figure 8: Amplitude spectrum at channel 3

Comparison of spectrum graph between baseline and misalignment measurement at each channel on 20Hz frequency are visualized and analyzed as in Figure 7, 8,9,10,11 and 12. It is seen that amplitude at channel 7 (inboard radial axis) is higher at first harmonic frequency of

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50Hz with 8.332x10^{-5} as compared to the channel 5 (inboard horizontal axis) with 1.3477 x10^{-5} and channel 6 (inboard vertical axis) with 4.7276 x10^{-5}.

Table 3: Misalignment Measurement for 15^0 of angle rotation

Frequency, Hz	**Harmonic frequency, Hz**	**Amplitude, VRMS (10^{-5})**					
		Ch-2	**Ch-3**	**Ch-4**	**Ch-5**	**Ch-6**	**Ch-7**
20	**50**	4.2849	3.2574	18.787	1.3477	4.7276	8.3322
	100	87.569	26.544	22.598	73.711	34.600	88.159
	150	12.743	6.2654	10.710	26.685	21.628	17.655
30	**50**	2.2338	1.1146	5.6736	0.3195	1.5401	1.6913
	100	13.558	17.606	17.449	41.569	11.477	63.278
	150	42.666	98.593	163.47	41.592	44.987	394.20

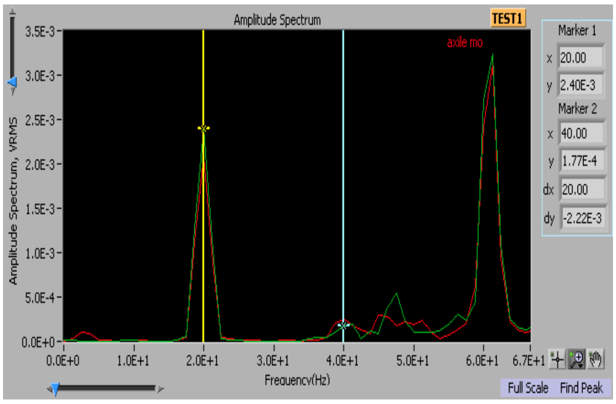

Figure 9: Amplitude spectrum at channel 4

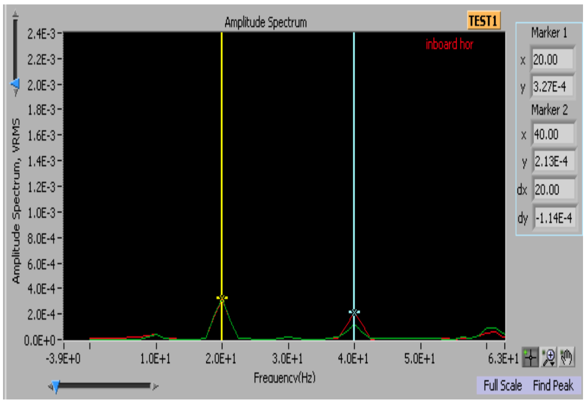

Figure 10: Amplitude spectrum at channel 5

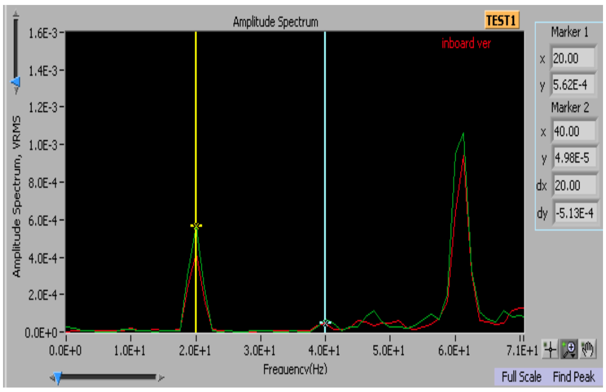

Figure 11: Amplitude spectrum at channel 6

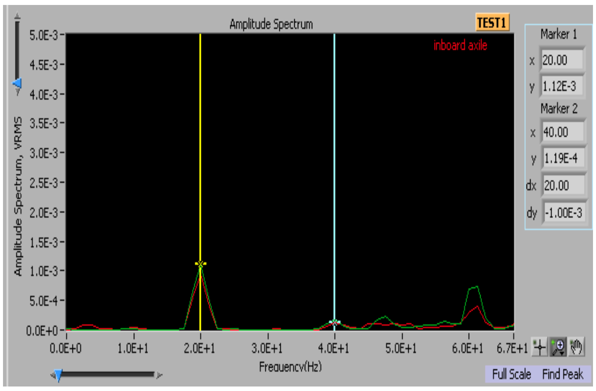

Figure 12: Amplitude spectrum at channel 7

It is observed that amplitude at channel 7 as in Figure 12 is higher at first harmonic frequency of 50Hz as compared to the channel 5 in Figure 10 (inboard horizontal axis) and channel 6 (inboard vertical axis). Comparison spectrum graph between baseline and misalignment

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measurement at each channel on 30Hz frequency are visualized and analyzed as in Figure 13,14,15,16,17 and 18.

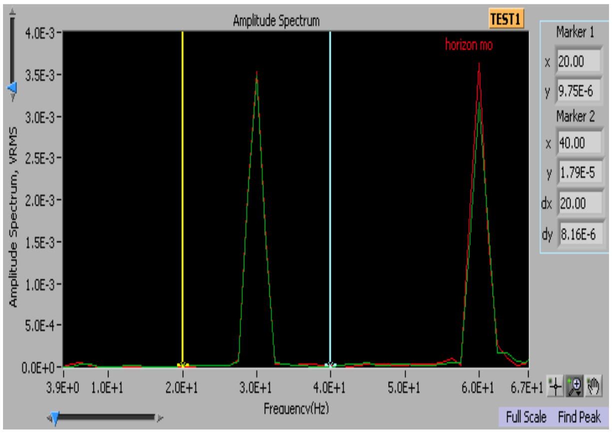

Figure 13: Amplitude spectrum at channel 2

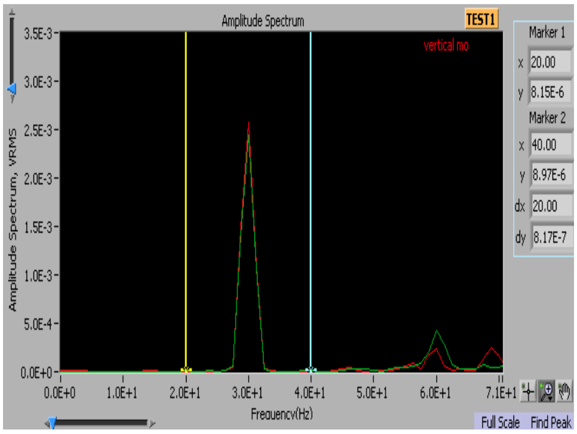

Figure 14: Amplitude spectrum at channel 3

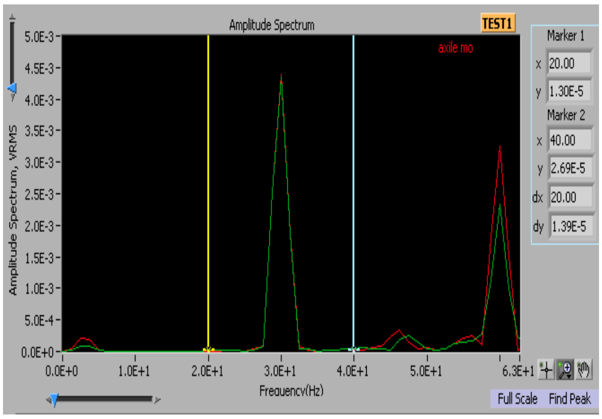

Figure 15: Amplitude spectrum at channel 4

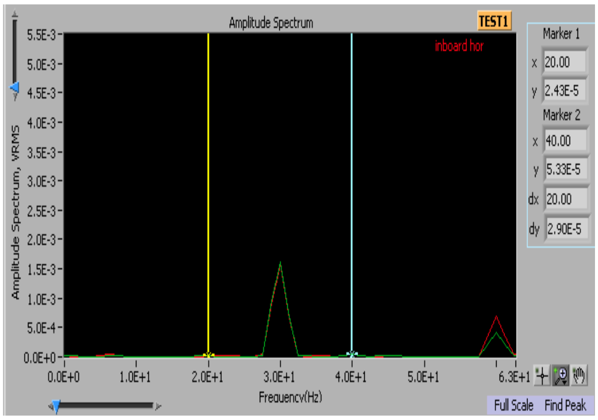

Figure 16: Amplitude spectrum at channel 5

It can be seen from channel 7 as in Figure 18, amplitude recorded slightly lower for 30kHz as compared with Figure 12 at lower frequency (20kHz) which recorded slightly higher in amplitude.

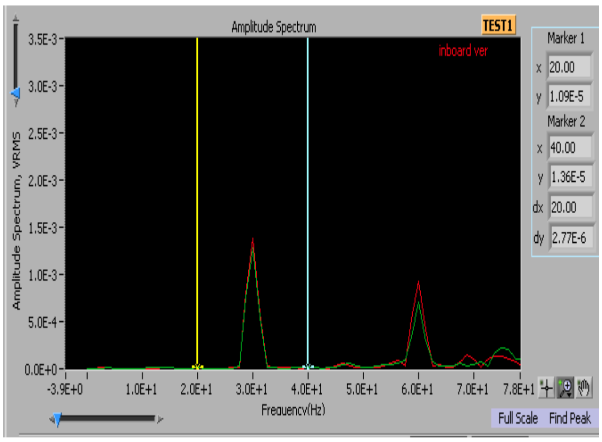

Figure 17: Amplitude spectrum at channel 6

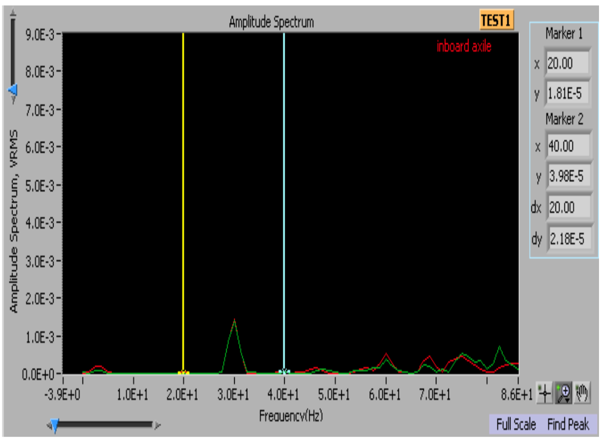

Figure 18: Amplitude spectrum at channel 7

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5.0 DISCUSSION

The misalignment occurs when driven and the driver of the system is not in their same axis. As example, the driver axes of the motor are not parallel to the axes of the driven shaft causes an angle between them. This is called as the angular misalignment. The vibration will occur when the shaft is not aligned [9].Therefore, in this experiment data shows that the vibration occurs in different pattern/trend of amplitude at different speed of the angular motion. In baseline test, the amplitude values are fluctuated at every accelerometer channels.

Meanwhile, the amplitude on the angular test shows that the amplitude is higher at axial axes when compared to both axes. This is because baseline test is normal condition for the system or machine where there is no angle required to rotate the shaft [11]. It is called aligned shaft condition. Meanwhile, for the second test, the angle of 15^{o} is applied at inboard in the system which causes the misalignment of the shaft. In vibration analysis, the misalignment of the shaft is detected from the changes of the amplitude at three different axes. Larger amplitude on radial axes compared with other two axes shows that the shaft is not in aligned condition [5]. Amplitude of radial axis decreases when the shaft is rotated at 30Hz frequency. It means, when the rotating shaft is higher, the misalignment impact of the shaft slowly reduces. Based on the radial axis at channel 7 in *Table 3* for both frequencies, it is obvious that amplitude reduces from $8.332x10^{-5}$ at 20Hz to 1.6913 $x10^{-5}$ at 30Hz. The probability to this condition is misalignment of the shaft will be replaced by the imbalance condition when the angular speed of the shaft keeps increasing. Based on the comparison graph, it shows that graph of 15^{o} angle inclination (red line) is obviously differs baseline graph (green line). It occurs at every channel especially results on the inboard shaft. This is because the shaft is in angular misalignment condition. The misalignment occur in the system of machine normally causes vibration. The vibration is monitored and analyzed to determine the problem. The misalignment occurs when the amplitude at the radial direction is higher than the horizontal and vertical direction. Besides it is observed that the angular misalignment depends on the angle of the shaft to be slip from their axis. Based on the results, it shows that the angular misalignment properties can be identified by comparison of the vibration amplitude of the spectrum graph between baseline and misalignment condition. The higher the speed of the angular motion, the amplitude vibration of the shaft in radial axis will gradually reduce. Therefore, the misalignment properties can be neglected because of the probability of imbalance properties will appear then.

The solution to the misalignment problem on shaft is the usage of the technology tools. Vibration analysis is a monitoring technique to tell that the system have misalignment issues on the shaft [6]. Meanwhile, the laser shaft alignment used as technology tool to overcome the problem. Laser shaft alignment come in variety shape and functionality depends on the industry. Twin laser shaft alignment are used in industry function as a process of aligning two or more shafts with each other to within a specified tolerance [8]. Misalignment of the shaft can be solved where laser detects the alignment of the shaft and angular misalignment between the shafts. [7]

6.0 CONCLUSION

This paper presents systematic procedure of simulating misalignment behavior in industrial from academic/research lab experimental using MFS. The step by step methodology of utilizing MFS for studying misalignment problem is documented well in this report for future reference and guidance for other researchers. In industry, the vibration monitoring technique

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and misalignment problem uses technology tools such as the vibration tester and laser alignment which is convenient to analyze and interpret. The experimental data and results in this MFS experiment are obtained using technological tools which include tachometer, accelerometer, speed controller etc have been very consistent in yielding the results. It can be used as research tool for parameteric study, different material of disc, influence of external loads etc as well as can be used in teaching and learning purpose for tangible and clear understanding of vibration phenomena that occurs in industrial machineries. Future works can include the study of different parameter for predictive maintenance tool, design optimization of shaft, sensor development, advanced signal processing etc.

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REFERENCES

[1] Xu, M., and R. D. Marangoni. "Vibration analysis of a motor-flexible coupling-rotor system subject to misalignment and unbalance, Part II: experimental validation." Journal of sound and vibration 176, no. 5 (1994): 681-691.

[2] Vance, John M. Rotordynamics of turbomachinery. John Wiley & Sons, 1988.

[3] Xu, M., and R. D. Marangoni. "Vibration analysis of a motor-flexible coupling-rotor system subject to misalignment and unbalance, part I: theoretical model and analysis." Journal of Sound and Vibration 176, no. 5 (1994): 663-679.

[4] Patel, Tejas H., and Ashish K. Darpe. "Experimental investigations on vibration response of misaligned rotors." Mechanical Systems and Signal Processing 23, no. 7 (2009): 2236-2252.

[5] Dewell, D. L., and L. D. Mitchell. "Detection of a misaligned disk coupling using spectrum analysis." Journal of vibration, acoustics, stress, and reliability in design 106, no. 1 (1984): 9-16.

[6] Barkov, A. V., N. A. Barkova, and A. Yu Azovtsev. "Condition Monitoring and Diagnostics of Rotating Machines Using Vibration." VAST, Inc., St. Petersburg, Russia (1997).

[7] Widodo, Achmad, Bo-Suk Yang, Eric Y. Kim, Andy CC Tan, and Joseph Mathew. "Fault diagnosis of low speed bearing based on acoustic emission signal and multi-class relevance vector machine." Nondestructive Testing and Evaluation 24, no. 4 (2009): 313-328.

[8] Piotrowski, John. Shaft alignment handbook. Crc Press, 2006.

[9] Ganeriwala, S., S. Patel, and H. Hartung. "The truth behind misalignment vibration spectra of rotating machinery." In Proceedings of International Modal Analysis Conference, pp. 2078-205. 1999.

[10] Bognatz, S. R. "Alignment of critical and non critical machines." Orbit 4 (1995): 23-25.

Journal of Advanced Research in Applied Sciences and Engineering Technology
ISSN (online): 2462-1943 | Vol. 4, No.1. Pages 47-57, 2016

[11] Bently, Donald E., and T. Charles. "Fundamentals of rotating machinery diagnostics." Mechanical Engineering-CIME 125, no. 12 (2003): 53-54.