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Vibration Analysis on Centrifugal Pump in UTHM Biodiesel Plant

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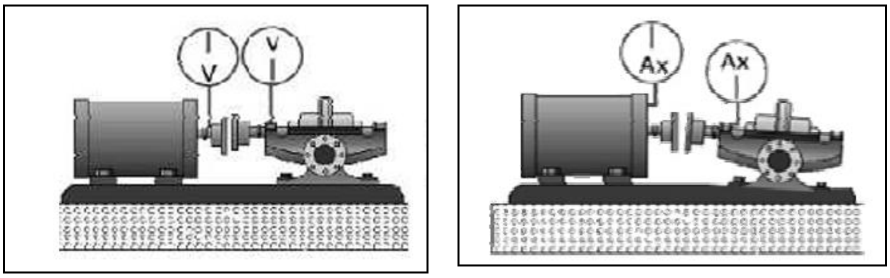
Abstract

Vibration is the most common problem in rotating machinery and equipment and these problems need to be investigated to determine the possible causes and recommended actions to minimize these vibration problems. This research investigates vibration issues in centrifugal pumps at UTHM Biodiesel Plant, focusing on vibration analysis based on ISO 10816 and ISO 2372 (severity chart) standards. The study analyzes vibration severity at four bearing locations (motor and pump) in three directions (horizontal, axial, vertical) on pumps P001, P202, and P219 using a vibration analyzer. The condition of the pump is assessed using the vibration velocity (mm/s), referring to the severity chart. Fault diagnosis, including misalignment, unbalance, and looseness, is conducted via Fast Fourier Transform (FFT) data, interpreting peak properties and harmonics using Vibrograph software. Results show that pumps P001 and P202 exceed safe vibration limits, indicating significant misalignment and looseness requiring immediate maintenance. The pump P219 is in good condition but needs alignment maintenance due to parallel misalignment. The study emphasizes early diagnostics of potential failures, enabling cost- and time-effective maintenance while ensuring operational safety and reliability.

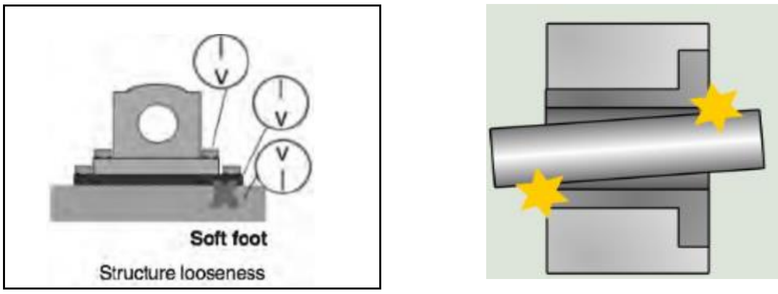
1. Introduction

A centrifugal pump is a rotating equipment that transfers liquid to different elevations by generating high rotational velocity (kinetic energy) of the liquid to the pressure energy [1]. The vibration problem of centrifugal pumps is bound to bring challenges to the safety and stability of operation such as misalignment or looseness. Misalignment occurs when the shaft centre line connecting the motor and pump at the coupling forms an offset or gap from each other. Shaft centre lines that are parallel but spaced apart either vertically, horizontally, or in both directions are known as parallel misalignment in Fig. 1(a). Shaft centre lines intersecting at an angle is the cause of angular misalignment Fig. 1(b). Looseness occurs when mechanical components are not secured properly, leading to instability of machines or structures. Looseness can be either structural looseness involving machines, foundation, support or soft foot (improper contact with the base or foundation) in Fig. 2(a) or rotating looseness occurs due to excessive movement in the rotating parts such as shaft, coupling, bearing or the impeller as shown in Fig. 2(b) [2].



(a) **(b)**

Fig. 1 *(a) Parallel Misalignment; (b) Angular Misalignment.*



(a) **(b)**

Fig. 2 *(a) Structural Looseness (soft foot); (b) Rotating looseness (improper shaft clearance)*

Vibration analysis is a widely adopted predictive maintenance method for rotating machinery which involves using monitoring tools to extract vibration data from machines and classifying or forecasting normal and abnormal operational conditions. Vibration data interpretation enables early diagnosis of faults in pump equipment that saves time and cost at the same time, preventing sudden failures [3]. Previous studies indicate that more than 82% of the fault diagnostic processes on rotating equipment are done using the vibration method [4].

The vibration data acquisition by velocity (mm/s) is the most effective approach in diagnosing the vibration problem since it has a direct relationship to the ISO 2372 vibration chart in Fig. 3. It provides a preliminary diagnosis on the health status of the rotating machinery from good to unacceptable limit [5]. This ISO 2372 classifies the vibration velocity limit based on the classes of machinery (motor power). The vibration data collection is based on the ISO 10816 guideline at the bearing location of the pump and motor in triaxial direction (vertical, horizontal, and axial) to provide depth vibration analysis on a specific fault within the equipment.

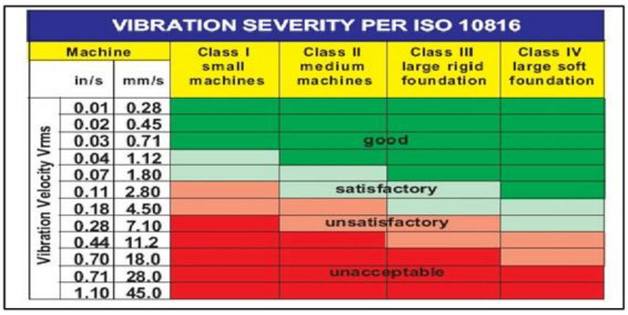


Fig. 3 *ISO 2372 Severity Chart*

Vibration data analysis by frequency domain is the most common approach in vibration spectrum. This is because compared to time domain, fault frequency has better resonance properties to identify the fault in rotating machinery [6]. This frequency domain analysis is assisted by the Fast Fourier Transform (FFT). The FFT spectrum can produce a variety of signal spectrum either by velocity, displacement or acceleration for the amplitude-frequency plot [7]. Research shows that FFT spectrum can be interpreted by evaluating vibration parameters such as peak properties of the graph 1x, 2x or 3x of the rotational speed on dominating axis [8]. These peak properties in FFT data ease the vibration monitoring and diagnosis to determine specific problems in rotating machinery such as misalignment, looseness or unbalance.

At present, the main limiting factor in this vibration analysis is the data collection and fault diagnosis method to determine the accurate causes of the vibration problem. Some studies still lack proper vibration data collection, in which vibration velocity is taken in one direction at the bearing point and not in a triaxial direction.[9] This provides insufficient quantification data to of the vibration severity to diagnose pump condition based on ISO 2372. The previous research indicates gaps for FFT analysis without explaining spectrum properties (peak variables) that generate the specific fault such as misalignment and looseness. [10][11]. However, previous studies show achievement in determining the common fault diagnosis in centrifugal pump such as misalignment at coupling, looseness, unbalance and hydrodynamic issues.

In this study, vibration analysis on a centrifugal pump in the UTHM Biodiesel Plant, according to ISO 10816, was conducted at the bearing locations of the pump and motor. The vibration data collected based on velocity (mm/s) in triaxial direction (horizontal, vertical and axial) of each bearing points. Each of the velocity results is compared to the vibration severity chart (ISO 2372) to determine the health status of the pump at bearing points. Meanwhile, FFT analysis involves explaining the spectrum properties via peak variables to diagnose specific faults and the possible root cause of the vibrational issue.

2. Methodology

This study involves vibration data acquisition and analysis of centrifugal pumps in UTHM Biodiesel Plant for condition monitoring to determine the condition of the pump and perform mechanical diagnosis as a part of predictive maintenance based on ISO 10816 and ISO 2372 [12].

In this current study, three centrifugal pumps were chosen for vibration analysis, which are pump P001, P202, and P219, as shown in Figure 4. These centrifugal pumps have similar specifications as according:

- Power: 11 kW
- Frequency: 50 Hz
- Rotational Speed: < 3000 RPM
- Voltage: 415 V

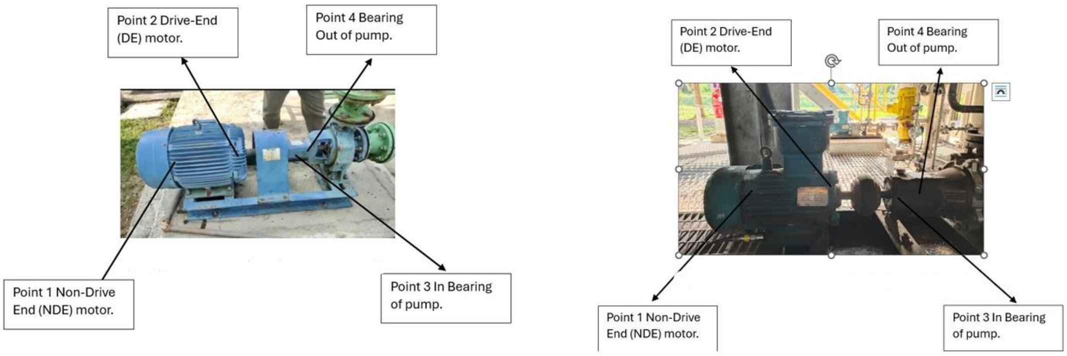
(a) (b) (c)

Fig. 4 *(a) Pump P001; (b) Pump P202; (c) Pump P219*

2.1 Vibration data acquisition

Vibration data acquisition is conducted on the stationary part of the centrifugal pump which is the bearing location as per the ISO 10816. The vibration measurement points of the centrifugal pump are located on the bearing housing of the pump. The bearing location at the motor is located at the Non-Drive End (NDE), Drive End (DE) and coupling of the pump and the motor. Thus 4 bearing locations on each respective centrifugal pump P001, P219 and P202. Each bearing point is measured in horizontal, vertical and axial directions. Hence, each pump has 12 measurement points, and the total measurement for three centrifugal pumps will be 36 points. Fig. 5 shows the bearing location of three centrifugal pumps based on the pump housing.

Vibration analyser (OneproD MVP 200 vibration analyzer) used in this research produces vibrational data in the frequency domain of the FFT spectrum to detect if there is any fault in rotating machines. It is a single analyser that is used to measure one vibration direction point at a time. The signal is first amplified and then digitalized in an A/D converter before passing through a processing device to obtain a frequency spectrum or be displayed as a time waveform. It measures the vibrational velocity of the pump either by velocity (mm/s), displacement (m) or acceleration (mm2/s). In this analysis, the vibration velocity is measured by the velocity (mm/s) of the pump. The vibration analyzer consists of a probe (accelerometer) that has a magnet for temporary mounting on the pump housing as shown in Fig. 6.



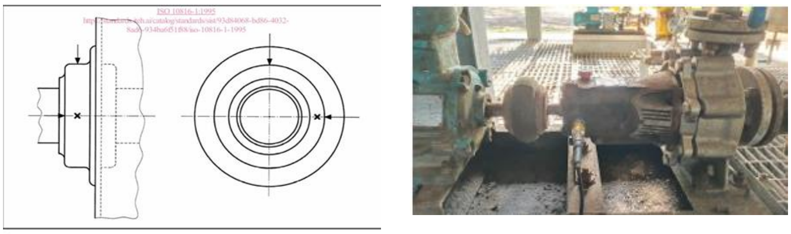
(a) **(b)**

Fig. 5 *(a) Bearing Location Pump P001; (b) Bearing Location Pump P202 & P219*

Fig. 6 *OneproD MVP 200 Vibrational Analyser and probe*

2.2 Data collection procedure

The procedure starts by marking the bearing location on the pump and motor housing for horizontal, vertical and axial direction. The markings are ensured to be accessible for probe placement without any interference during the measurement of the pump vibration data. The marking points between the horizontal and vertical direction are as close to 90 degrees to the shaft axis and meanwhile the axial direction is as close to 180 degrees as per ISO 10816 for triaxial direction measurement shown in Fig. 7(a). The probe is placed on the marking points starting from point 1 (NDE motor) to point 4 (bearing out) pumps with each point in triaxial direction as shown in Fig. 7(b). The data collection is taken every 2 weeks for 5 times for pump P202 and P219 (Week 2,4,6,8,10) and four times (Week 2,4,10,11) for pump P001. The average velocity is calculated by using formula in equation (1).



(a) **(b)**

Fig. 7 *(a) Probe placement guideline ISO 10816; (b) Probe location (horizontal) at point 3 for P219*

$$V_{avg} = \frac{V_{total,n}}{n} \tag{1}$$

$V_{avg} = Total\ Velocity\ for\ n\ weeks$
$V_{total,n} = Total\ Velocity\ for\ n\ weeks$
$n = number\ of\ weeks$

2.3 Vibration analysis method

The vibration data analysis is divided into two types, which are the vibrational velocity (mm/s) and FFT spectrum analysis, which provides a graphical spectrum (velocity vs frequency) for mechanical diagnosis of the pump, such as misalignment, unbalance, and looseness, for the health monitoring status.

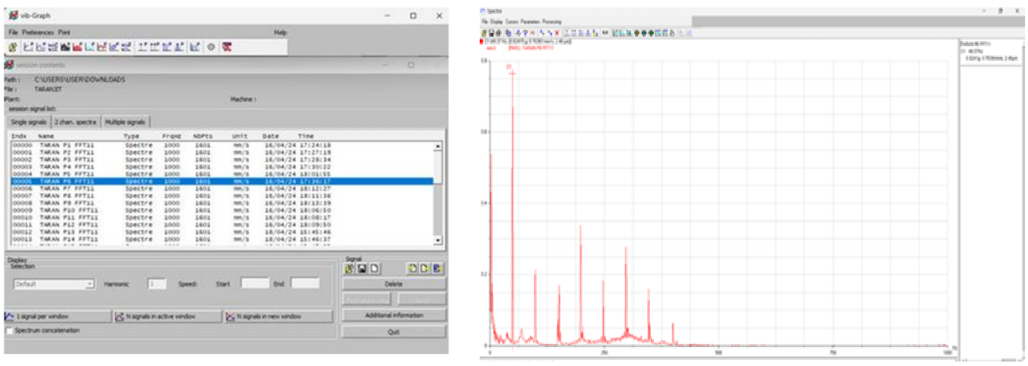
2.3.1 Status and health monitoring methods

The vibration analysis procedure is first by assessing the condition and pump severity based on the average vibration velocity of the three centrifugal pumps by referring to the ISO 2372 (severity chart under Class I machines since the power supplied is less than 15 kW). The severity chart shows the condition of the pumps at each bearing location by referring to the velocity (mm/s) to determine the health of the pump from good to unacceptable limit. The point on the pump that shows above unsatisfactory condition will be analysed in detail for the possible mechanical fault by the FFT analysis.

2.3.2 Fault diagnosis method

The FFT analysis is obtained by extracting the data from the vibration analyser device with aid in Vibrograph software. Vibrograph software, which is a conditioning monitoring software, displays the vibration spectrum of velocity vs frequency as shown in Fig. 8 (a). The fault diagnosis on the centrifugal pump to determine the specific vibration causes on the centrifugal pumps is done by analyzing the frequency domain, in which the waveform properties. In the meantime Fig. 8 (b) depicted the characteristic analyzed first peak such 1x and 2x vibration from the left side to right side of the data together with the axis of point measurement are studied to determine specific faults by using the Mobius Quick Reference Guide (Fault Diagnosis on Machine) [13] and SKF vibration guideline [14] to interpret waveform of the FFT and the interface of the software.

If the vibration data shows abnormality, it shows that there is a vibration problem with the centrifugal pump hence, preventive measurement is needed to be taken to fix the causes of vibration. For each fault diagnosis that is determined on the pump, a few recommendations are suggested to minimize the vibration problems on the centrifugal pumps.



(a) **(b)**

Fig. 8 *(a) Interface of Vibrograph Software; (b) FFT spectrum data*

3. Results and Discussion

3.1 Health Condition of Pump

Table 1 shows the health condition of pump P001 with the average velocity of data collection of four times. Point 2 (horizontal direction) has the highest vibration velocity of 5.57 mm/s near the coupling shaft (motor side), which shows an unacceptable limit based on the ISO 2372 vibration severity chart. Meanwhile, point 1 (horizontal) has a velocity of 4.97 mm/s and point 3 (axial) has a velocity of 3.91 mm/s in which both show an unsatisfactory condition. The overall vibration velocity indicates that the pump is deplorable and needs to be shut down immediately for maintenance. The vibration severity is much higher at the motor side bearing location compared to the pump bearing location.

Table 1 *Health condition of pump P001*

Vibration Points	Direction of measurement	Average velocity (mm/s)	Severity Limit (ISO 2372)
Point 1 (NDE Motor)	Horizontal	4.97	**Unsatisfactory**
	Vertical	2.49	Satisfactory
	Axial	1.38	Satisfactory
Point 2 (DE Motor)	Horizontal	5.57	**Unacceptable**
	Vertical	1.91	Satisfactory
	Axial	1.29	Satisfactory
Point 3 (Bearing In)	Horizontal	1.56	Satisfactory
	Vertical	1.59	Satisfactory
	Axial	3.91	**Unsatisfactory**
Point 4 (Bearing Out)	Horizontal	2.34	Satisfactory
	Vertical	1.38	Satisfactory
	Axial	1.18	Satisfactory

Table 2 *Health condition of pump P202*

Vibration Points	Direction of measurement	Average velocity (mm/s)	Severity Limit (ISO 2372)
Point 1 (NDE Motor)	Horizontal	1.56	Satisfactory
	Vertical	0.89	Good
	Axial	0.77	Good
Point 2 (DE Motor)	Horizontal	2.11	Satisfactory
	Vertical	3.95	**Unsatisfactory**
	Axial	1.25	Satisfactory
Point 3 (Bearing In)	Horizontal	3.03	**Unsatisfactory**
	Vertical	1.74	Satisfactory
	Axial	2.95	**Unsatisfactory**
Point 4 (Bearing Out)	Horizontal	1.52	Satisfactory
	Vertical	2.19	Satisfactory
	Axial	1.01	Good

Table 2 shows the health condition of pump P202 with average velocity data of five times. Point 2 (vertical) has the highest vibration velocity of 3.95 mm/s near the coupling shaft (motor side), which shows an unsatisfactory limit. Meanwhile, point 3 (horizontal) has a velocity of 3.03 mm/s and point 4 (axial) has a velocity of 2.95 mm/s in which both shows an unsatisfactory condition. The overall vibration velocity indicates that the pump is less severe than P001 but still need to be shut down immediately for the maintenance. The vibration severity is much higher at the pump side bearing location compared to the motor bearing location.

Table 3 *Health condition of pump P219*

Vibration Points	Direction of measurement	Average velocity (mm/s)	Severity Limit (ISO 2372)
Point 1 (NDE Motor)	Horizontal	1.45	Satisfactory
	Vertical	1.12	Good
	Axial	0.63	Good
Point 2 (DE Motor)	Horizontal	1.85	Satisfactory
	Vertical	2.91	**Unsatisfactory**
	Axial	1.05	Good
Point 3 (Bearing In)	Horizontal	1.30	Satisfactory
	Vertical	1.84	Satisfactory
	Axial	0.65	Good
Point 4 (Bearing Out)	Horizontal	2.19	Satisfactory
	Vertical	1.90	Satisfactory
	Axial	0.75	Good

Table 3 shows the health condition of pump P219 with average velocity data of five times. The point 2 (vertical) has the highest vibration velocity of 2.91 mm/s near the coupling shaft (motor side) that shows unsatisfactory. The overall pump condition is still in good condition and can operate as usual compared to other two pumps. This pump is not deplorable and require minor maintenance task on the suggested vibration limit. However, continuous monitoring is required to assess the pump condition during operation.

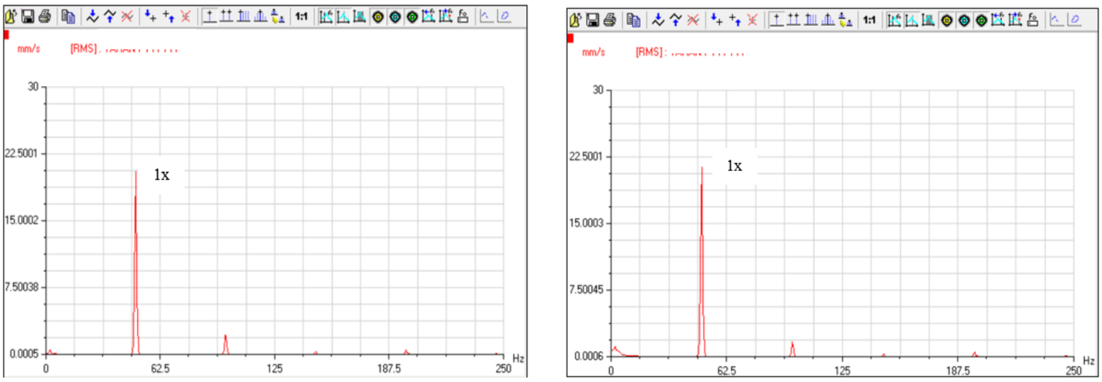
3.2 FFT spectrum analysis for fault diagnosis

The result of the Fast Fourier Transform (FFT) waveform is displayed based on velocity (mm/s) vs frequency (Hz) by the Vibrograph Software. The FFT graph provides a more detailed explanation of the behavior of the pump faults based on peak forms (1x, 2x, etc), such as misalignment, unbalance, and looseness. The FFT spectrum that is generated is compared to the Mobius Quick Reference Guide (Fault Diagnosis on Machine)

3.2.1 Fault diagnosis for pump P001

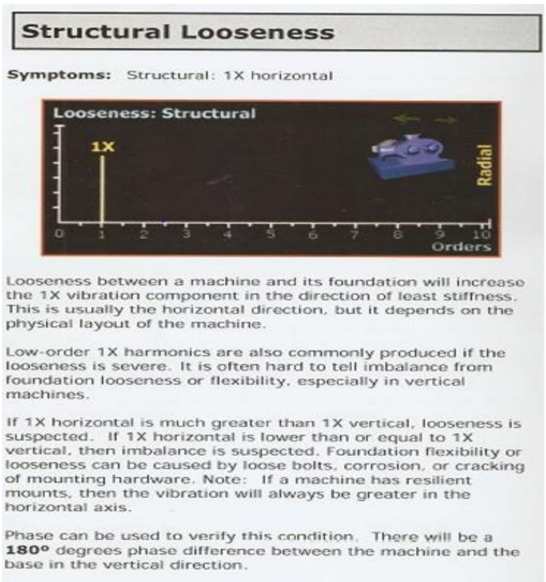
The vibration spectrum for points 1 and 2 horizontal directions in Fig. 9 indicates the pump shows vibration issues related to structural looseness which can be compared to Figure 10 FFT. The FFT spectrum guide shows the peak properties of the structural looseness issue, which generates a strong 1x vibration in the horizontal direction. The harmonic generation of the structural looseness can form 2x, 3x peak generation indicating the severity of the looseness with respect to the frequency at 1x.

In Fig. 9, the FFT spectrum is a structural looseness issue due to the properties of the spectrum whereby there is a strong 1x peak running speed in horizontal direction. This is because the 1x peak running speed in horizontal direction is higher than 1x running speed of pump in vertical direction that indicates it is structural looseness [15]. To support this statement, a comparison of the FFT spectrum is made in Fig. 11 in which the red line indicates point 1 spectrum in horizontal direction and blue line indicates the point 1 spectrum in vertical direction. It shows that the red line peak is higher than blue peak which further proves that it is structural looseness. This type of looseness is caused by structural looseness or weaknesses in the machine's feet, baseplate or foundation [16]. It can also be caused by deteriorating grouting, loose hold-down bolts at the base and distortion of the frame or base (known as 'soft foot') [17]. The recommendation action is by tightening loose bolts, checking wear on nuts and washer, proper mounting of base by adding shim plate to minimize distortion and strengthening foundation support.



(a) **(b)**

Fig. 9 *(a) Point 1(Horizontal spectrum); (b) Point 2 (Horizontal spectrum)*



Structural Looseness

Symptoms: Structural: 1X horizontal

Looseness between a machine and its foundation will increase the 1X vibration component in the direction of least stiffness. This is usually the horizontal direction, but it depends on the physical layout of the machine.

Low-order 1X harmonics are also commonly produced if the looseness is severe. It is often hard to tell imbalance from foundation looseness or flexibility, especially in vertical machines.

If 1X horizontal is much greater than 1X vertical, looseness is suspected. If 1X horizontal is lower than or equal to 1X vertical, then imbalance is suspected. Foundation flexibility or looseness can be caused by loose bolts, corrosion, or cracking of mounting hardware. Note: If a machine has resilient mounts, then the vibration will always be greater in the horizontal axis.

Phase can be used to verify this condition. There will be a **180°** degrees phase difference between the machine and the base in the vertical direction.

Fig. 10 *FFT spectrum guide structural looseness*

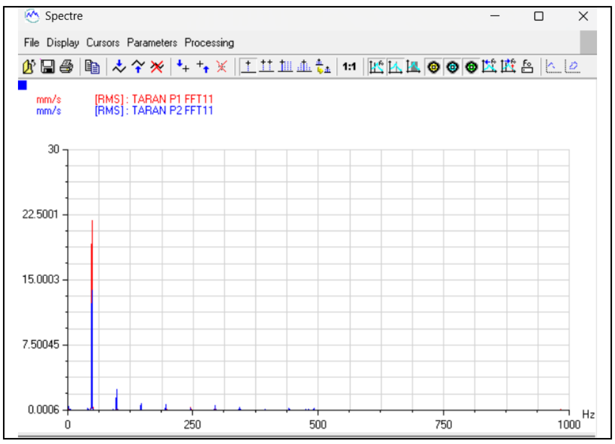


Fig. 11 *FFT Point 1 horizontal (red) and Point 1 vertical (blue)*

The vibration spectrum for point 3 in axial direction indicates the pump shows vibration issues related to misalignment. The spectrum properties in Fig. 12 can be compared to Fig. 13 for type of misalignment issue. The FFT spectrum guide in Fig. 13(a) indicates the peak properties of common misalignment issues (combination of angular and parallel misalignment) which it generates a harmonic spectrum generation in axial direction or radial direction with 2x peak generation is stronger than 1x peak then followed by decreasing peak from 4x to 6x. The Fig. 13(b) shows angular misalignment properties with 1x peak generation in axial direction near the coupling of motor and pump followed by decreasing peak 2x and 3x. Fig. 13(c) shows parallel misalignment issue with strong 2x peak generation compared to 1x peak generation followed by decreasing peak 3x after strong 2x peak frequency.

In Fig. 12, the FFT spectrum is a misalignment issue due to the properties of the spectrum whereby there is a strong harmonic generation from 1x to 6x peak running speed in axial direction near the motor coupling. The peaks properties show a combination of parallel and angular misalignment. The parallel misalignment shows can be seen at the first three peaks (1x, 2x and 3x). Parallel misalignment shows a predominant 2x peak relative to 1x followed by a decreasing 3x peak. The angular misalignment can be analysed from 4x to 6x peaks. Angular misalignment shows a predominant 4x peak then with decreasing peak of 5x and 6x. The possible causes of this combination misalignment are that shaft centre lines are parallel but spaced apart either vertically, horizontally, or in both directions. Coupled units are not in the same vertical and horizontal planes. This can also be inexperienced students handling the alignment process, such as dismantling the coupling and motor fastener. The recommendation action is by realignment of the coupling using dial indicators before and after for verification. Adding shim plates and adjusting motor height to minimize offset and gap value.

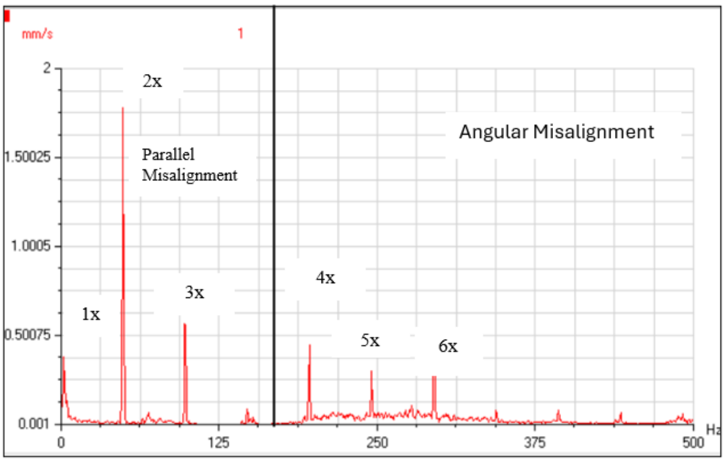
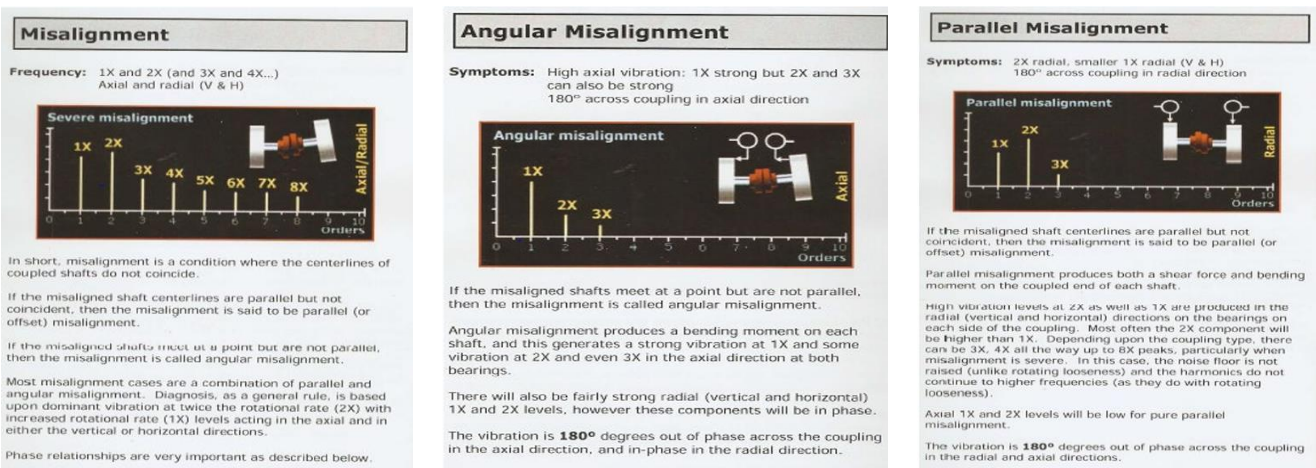


Fig. 12 *Point 3 (Axial spectrum)*



(a) **(b)** **(c)**

Fig. 13 *FFT spectrum guide for misalignment issues*

3.2.2 Fault diagnosis for pump P202

The vibration spectrum at point 2 in vertical direction in Fig. 14(a) indicates that the pump has misalignment. This is due to the properties of the spectrum whereby there is a strong harmonic generation from 1x to 4x peak running speed in vertical. The peaks properties show specific misalignment issue which is parallel misalignment which can be referred to Fig. 13(c) for the peak properties as explained earlier for the misalignment issue at pump P001. Parallel misalignment shows a predominant 2x peak relative to 1x followed by decreasing 3x and 4x peak. The possible causes are the couplings are parallel to each other, but the center line forms offset.

The vibration spectrum at point 3 axial direction indicates that the pump has angular misalignment. This is due to the properties of the spectrum whereby there is a strong harmonic generation from 1x to 4x peak running speed in axial direction as shown in Fig. 14 (b). These peak properties are similar to the FFT spectrum in Fig. 13(b). Angular misalignment shows a predominant 1x peak relative to 2x followed by decreasing 3x and 4x peak. The possible causes are the coupling are not parallel to each other but are angle to each other.

The other possible causes general causes of misalignment for both angular and parallel is also can be due to improper installation of alignment coupling during maintenance. This can also be inexperienced students handling the alignment process, such as dismantling the coupling and motor fastener. The recommendation action is by realignment of the coupling using dial indicators before and after for verification. Adding shim plates and adjusting motor height to minimize offset and gap value. Close coupling method by connecting pump and motor with minimal distance to minimize long shaft or coupling spacer.

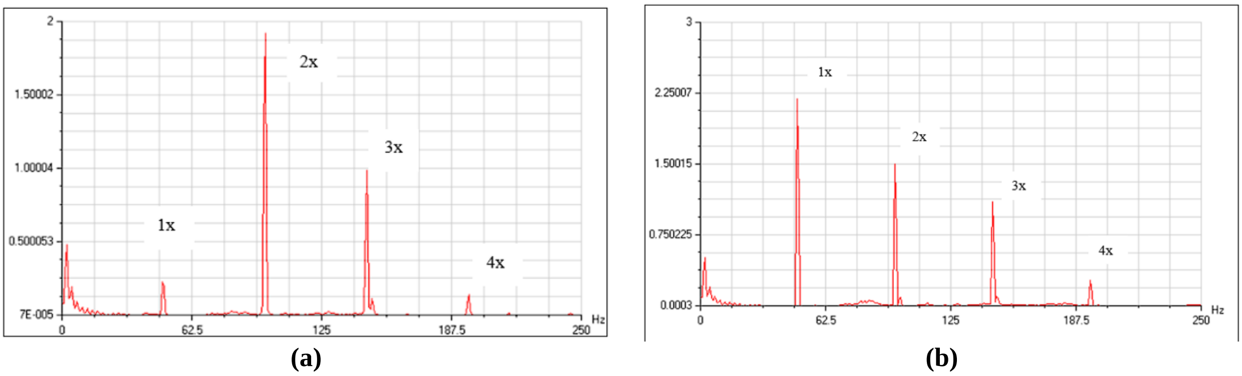


Fig. 14 *(a) Point 2(Vertical spectrum); (b) Point 3 (Axial spectrum)*

The vibration spectrum for point 3 in horizontal direction indicates the pump shows vibration issues related to looseness in Fig. 15 which is like the peak properties explained in Fig. 9 for pump P001. This is due to the properties of the spectrum whereby there is a strong 1x peak running speed at in horizontal direction as shown in Figure 11 without harmonic generation. The specific type of looseness is structural looseness in which the 1x peak running speed in horizontal direction is higher than 1x running speed of pump in vertical direction that indicate it is structural looseness which is similar to the looseness in pump P001. The cause of the structural looseness is similar as the looseness explained in pump P001. The recommendation action is by tightening loose bolts, checking wear on nuts and washer, proper mounting of base by adding shim plate to minimize distortion and strengthening foundation support.

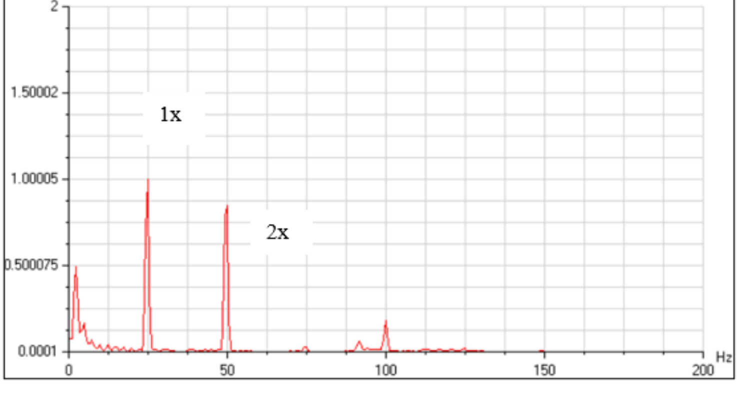


Fig. 15 *Point 3 (Horizontal spectrum)*

3.2.3 Fault diagnosis for pump P219

The vibration spectrum at point 2 in the vertical direction indicates that the pump has misalignment. This is due to the properties of the spectrum whereby there is a strong harmonic generation from 1x to 4x peak running speed in the axial direction as shown in Figure 16. The peaks properties show a specific misalignment issue which is parallel misalignment. Parallel misalignment shows a predominant 2x peak relative to 1x followed by decreasing 3x and 4x peaks. This similar to the peak properties as explained in pump P202 for the misalignment issue. The possible causes are parallel to each other, but the center line forms an offset.

The other possible causes are general causes of parallel misalignment due to improper installation of the alignment coupling during maintenance. This can also be inexperienced students handling the alignment process, such as dismantling the coupling and motor fastener. The recommendation action is by realignment of the coupling using dial indicators before and after for verification. Adding shim plates and adjusting motor height to minimize offset and gap value. Close coupling method by connecting the pump and motor with minimal distance to minimize the long shaft or coupling spacer.

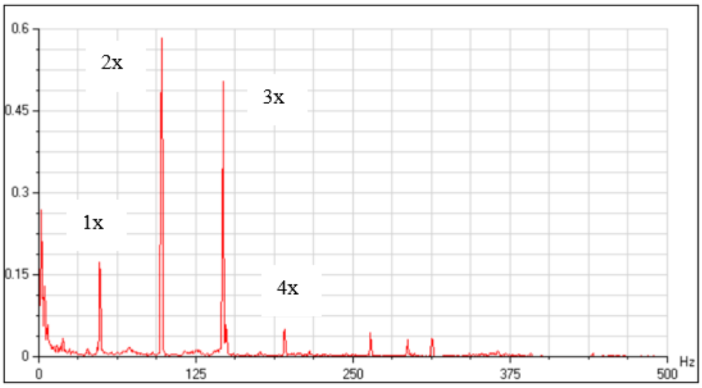


Fig. 16 *Point 2 (Vertical spectrum)*

4. Conclusion

The vibration analysis on the centrifugal pump in UTHM Biodiesel plant provides in depth discussion to determine the condition and specific fault of the pumps. The vibration velocity of the pump is taken on 4 bearing location by using the vibration analyzer in triaxial direction (horizontal, vertical and axial) in accordance to ISO 10816. The vibration velocity is to identify the pump health condition from good to unacceptable limit. The vibration limit is referred to the vibration severity chart (ISO 2372) in class I machinery (under 15 kW rated power). Both pump P001 and P202 show poor health status which are deplorable and must be stopped immediately for maintenance since vibration velocity exceeds 2.80 mm/s. The pump P219 is still in good condition since almost all the vibration velocities are in a safe vibration limit but with minor alignment issues.

The FFT spectrum analysis helps to provide in depth analysis on the specific fault or mechanical issue of the pump with by using the Vibrograph Software to provide frequency domain graph. The analysis of the peak properties assists in diagnosing problem related to the pump. The pump P001 and P219 shows major issues such as structural looseness, parallel misalignment and angular misalignment. Pump P001 has minor misalignment issue that require minor alignment maintenance to cope coupling fault. These vibration method by FFT helps to ease the predictive maintenance to minimize time and cost at the same time improving the longevity and reliability. Hence by this analysis, the objective has achieved in which to perform vibration analysis and determine severity of the pump condition by FFT analysis for specific fault.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Taranjit Singh data collection: Taranjit Singh; analysis and interpretation of results: Taranjit Singh; draft manuscript preparation: Taranjit Singh, Dr Nurhafizzah Binti Hassan. All authors reviewed the results and approved the final version of the manuscript.

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