Progress in Engineering Application and Technology Vol. 4 No. 1 (2023) 505-516

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Vibration Investigation on Rotational Pumps at UTHM Biodiesel Pilot Plants

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DOI: https://doi.org/10.30880/peat.2023.04.01.054
Received 14 January 2023; Accepted 11 February 2023; Available online 11 February 2023

Abstract: Vibration is an unavoidable reality in machinery and equipment. Therefore, it was essential in investigated the vibration phenomena occurring in the rotating equipment to maintain its performance. The research aimed to study the different specifications of the rotating pump's vibration in determining the fault occurrence prediction and correlation of temperature fluid to the pump's vibration. Based on the ISO-10816 standard, the pump safe limit was identified, and the pump operation was decided to continue to run, stop immediately, or undergo maintenance. In determining the type of maintenance, the pump's fault was investigated individually based on the characteristics shown in the Fast Fourier Transform (FFT) waveform. If the safe limit condition is exceeded, the maintenance is done according to the fault diagnostic test. The experiment shows that pump A must stop immediately, undergo alignment maintenance, and change the rubber bush since it generated a vibration velocity of more than 2.80 mm/s (safe limit standard for motor less than 5kW power). In contrast, pumps B, C, and D are acceptable because vibration velocity is lower than 2.80 mm/s. The effect of temperature fluid (25℃ to 70℃) was studied during the occurrence of vibration. The results indicated the vibration velocity increased by 38%, 22%, 64%, and 21% at four (4) measured points as the fluid temperature increased when flowing in the pump. The significant causes of these problems were the lower viscosity of the fluid and the decreasing pump's stiffness.

Keywords: Vibration Analysis, Fast Fourier Transform, ISO-10816 Standard

1. Introduction

A centrifugal pump in utility area that used for pumping liquid from cooling tower to the heat exchanger at the plant created huge amount of noise and the concrete base vibrates when the pump is running. Other pumps in the plant area also having similar vibrations when running. This phenomenon was an abnormal since it created uncomfortable situation whether the pump is in good condition [1].

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Vibration is a common phenomenon that occur in rotating machinery or devices when running. Devices vibrated in certain degree and became unusual or obvious when the components became older or had tendency to broke. Since the pump is one of the most important and energy consuming devices, slight problems or defects will cause huge consequences to the process system. Analysis on pump performance often being practiced in industries to ensure the problems can be determining earlier to decreases chances for the pump to fail or becoming major issues that causes the plant to shut down [2].

The vibration safe limit had been determined by international organisation in standardize the measurement in all countries. The main purpose is to ease and also changeable of expertise across field of science and engineering [3]. For this research, international standard ISO 10816- used to determine the safe limit of general motor and machinery up to more than 10MW. The importance of the standard is to ensure safety and health of the worker.

The temperature of the fluid in the pumps also one of the factors that can affect the vibration of the pumps. The high temperature of the fluid can lead to some negative impact to the pumps such as structural degradation and also the decreasing of pump performance [4]. The energy stored in the heated fluid causes the atoms in the fluid to be expand and posses' high energy. The energy from the fluid will be transferred it energy to the structural of the pump which fronting with the fluid.

2. Equipment and Setup

2.1 Equipment

The vibration measurement used OneproD MVP 200 vibration analyser from FKMP, UTHM. The instrument supports a triaxial accelerometer, which can record the vibration reading in vertical, horizontal and axial directions. This device interpreted the signal to Fast Fourier Transform (FFT) wave form for the analyse process. The FFT wave form was used in determining the fault diagnosis process.

2.2 Experimental setup

The process of the experiment was conducting vibration measurement on four (4) pumps which three (3) centrifugal pumps (Pumps A, B, and C) and a multistage centrifugal pump (Pump D) in ambient fluid temperature. The effect of fluid's temperature on vibration conducted on pump D. **Figure 1** shows the flowchart of this experiment.

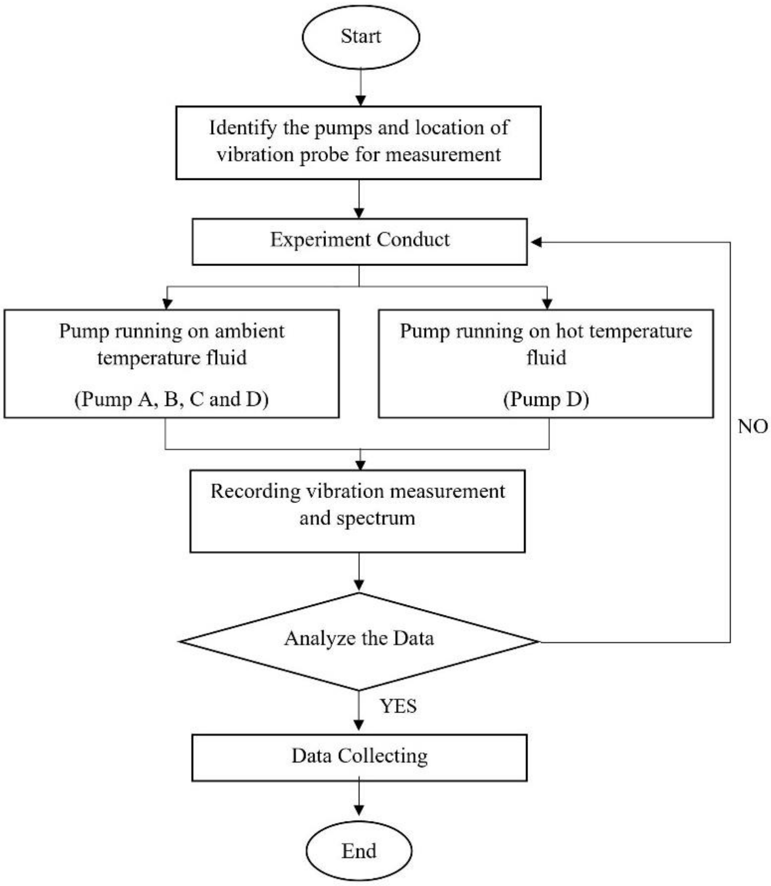

Figure 1 Experiment flowchart

The procedure of experiment and safety measurement followed according to ISO 10816-1 (Mechanical Vibration - Evaluation of machine Vibration by measurements on non-rotating Parts).

First of all, the location and position of the probe were determined and attached to the pump based on the closest point to the bearing. Four (4) points of probe location on the pump were determined based on Figure 2 as guidance. The probe recorded each location in three (3) directions of the probe, which are horizontal, axial and vertical directions as shown in Figure 3. The average of the velocity measurement was compared to the ISO-10816 in to predict the safe limit of the pump.

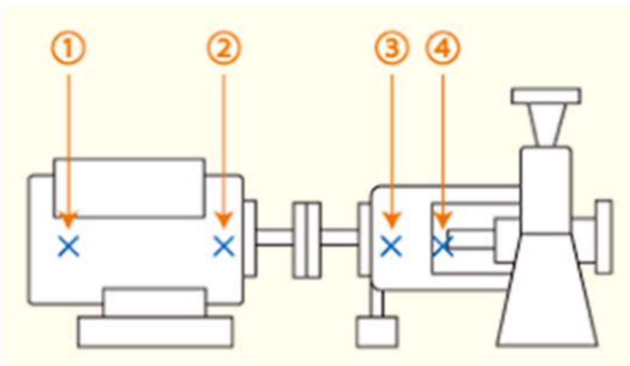

Figure 2 Points for vibration measurement on pump

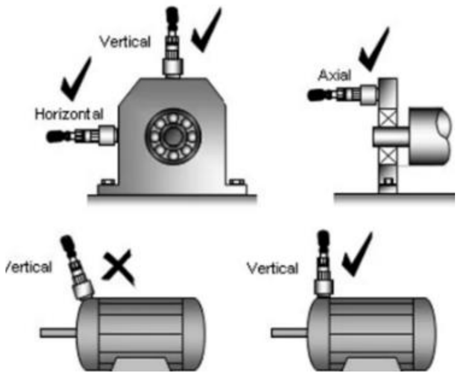

Figure 3 Correct orientation of probe

Then the recorded velocity data from the vibration analyser, transferred to the computer, and analysed by the virtual spectrum analyser tool in Vid-Soft software. In the software, it converted to an FFT waveform graph to ease the fault's detection. The FFT waveform was analysed to determine the characteristic of fault based on the peak and noise of the spectrum. The recommendation of the pump's health was generated from this experiment and recorded.

The effect of temperature on the vibration of pump was done by flowing different fluid temperatures to the pump D. The fluid, biodiesel fluid heated inside the vessel using steam. After reaching the set temperature, the valve channeled the liquid to the pump and vibration measurements was conducted. The vibration velocity was recorded at five (5) different temperatures, which were 25℃, 36℃, 47℃, 58℃ and 70℃. The vibration's velocity and FFT waveform was analysed to investigate the correlation of the fluid's temperature and vibration occurrence.

3. Results and Discussion

The results and discussion of the research covered the health monitoring of the pump, fault diagnosis of pump to predict fault using FFT waveform and effect of temperature on the vibration measurement and vibration characteristics by running different fluid temperatures through the pump.

3.1 Health status monitoring

There are twelve (12) points needed measured the vibration's measurement for each pump. Then, one point consists three (3) direction need to be averaged and compared with ISO-10816 to determine the condition of the pump.

Table 1, Table 2, Table 3, and

The result of average velocity measurement at points 1, 2, 3 and 4 were 0.967 mm/s, 1.019 mm/s, 0.682 mm/s and 0.677 mm/s, respectively. These velocities data were compared to ISO-10816. The safe limit was in good condition for all points 1, 2, 3 and 4, respectively. It shows the overall motor and pump were in decent condition, and the safe limit was in good condition. The pump can run as usual.

The maximum was measured on the motor side, which was 0.453 mm/s and 0.489 mm/s. Most of the motion came from the vertical and axial directions. The vibration was documented higher on the motor side than the pump, which recorded a lower value. The data can be referred to in Table 3. Since the vibration safe limit was still in the good limit, the pump's condition can be utilized. But the pump must continuously be monitored and ensure that any abnormalities occur being notified.

Table 4 showed the result for the vibration's velocity of pumps.

Table 1 Velocity measurement of V_{rms} for pump A

Points	Direction	Velocity (mm/s)	Average Velocity (mm/s)	Safe Limit Observation (ISO-10816)
1	Vertical Axial Horizontal	5.17 17.0 3.12	8.43	Unacceptable
2	Vertical Axial Horizontal	8.92 17.1 6.24	10.75	Unacceptable
3	Vertical Axial Horizontal	2.71 8.46 4.78	5.31	Unsatisfactory
4	Vertical Axial Horizontal	2.36 4.19 5.62	4.06	Unsatisfactory

The result of average velocity measurement at points 1, 2, 3 and 4 was 8.43 mm/s, 10.75 mm/s, 5.31 mm/s and 4.06 mm/s, respectively, based on Table 1. These velocities data were compared to ISO-10816. The safe limit was unacceptable, unacceptable, unsatisfactory and unsatisfactory for points 1, 2, 3 and 4, respectively. It showed the motor was in bad condition since it can cause harm to the pump if it keeps running. The pump needed to be shut down immediately and undergo maintenance.

The maximum was measured on the motor side, which was 8.43 mm/s and 10.75 mm/s. Most of the motion came from the axial direction, which was 17.0 mm/s and 17.1 mm/s, and it was the primary motion of the pump, and it was very abnormal for the pump to experience this type of motion.

The vibration was documented higher on the motor side rather than the pump, which recorded a lower value. Since the vibration can be transmitted through a solid, point 3, the nearest point to the motor, experienced a higher value and lowered down to point 4. It showed that most of the vibration source was from the motion of the motor.

Table 2 Velocity measurement of V_{rms} for pump B

Points	Direction	Velocity (mm/s)	Average Velocity (mm/s)	Safe Limit Observation (ISO-10816)
1	Vertical Axial Horizontal	0.0047 1.36 2.61	1.32	Satisfactory
2	Vertical Axial Horizontal	2.58 2.91 1.63	2.37	Satisfactory
3	Vertical Axial Horizontal	2.16 2.00 1.67	1.94	Satisfactory
4	Vertical Axial Horizontal	2.21 2.14 1.32	1.89	Satisfactory

The result of average velocity measurement at points 1, 2, 3 and 4 were 1.32 mm/s, 2.37 mm/s, 1.94 mm/s and 1.89 mm/s, respectively. These velocities data were compared to ISO-10816. The safe limit was satisfactory for all points 1, 2, 3 and 4, respectively. It shows the overall motor and pump were in fair condition, and the safe limit is in satisfactory condition. The pump can run as usual.

The maximum was measured on the pump side, which was 1.94 mm/s and 1.89 mm/s. Most of the motion came from the vertical and axial directions, higher than the horizontal. The vibration was documented higher on the pump side than the motor, which recorded a lower value. The data can be referred to in Table 2. Since the vibration safe limit was in satisfactory limit, the pump's condition can be utilized. But the pump must continuously be monitored and ensure that any abnormalities occur being notified.

Table 3 Velocity measurement of V_{rms} for pump C

Points	Direction	Velocity (mm/s)	Average Velocity (mm/s)	Safe Limit Observation (ISO-10816)
1	Vertical Axial Horizontal	0.446 0.706 0.208	0.453	Good
2	Vertical Axial Horizontal	0.443 0.537 0.489	0.489	Good
3	Vertical Axial Horizontal	0.458 0.418 0.231	0.369	Good
4	Vertical Axial Horizontal	0.420 0.304 0.300	0.341	Good

The result of average velocity measurement at points 1, 2, 3 and 4 were 0.967 mm/s, 1.019 mm/s, 0.682 mm/s and 0.677 mm/s, respectively. These velocities data were compared to ISO-10816. The safe limit was in good condition for all points 1, 2, 3 and 4, respectively. It shows the overall motor and pump were in decent condition, and the safe limit was in good condition. The pump can run as usual.

The maximum was measured on the motor side, which was 0.453 mm/s and 0.489 mm/s. Most of the motion came from the vertical and axial directions. The vibration was documented higher on the motor side than the pump, which recorded a lower value. The data can be referred to in Table 3. Since the vibration safe limit was still in the good limit, the pump's condition can be utilized. But the pump must continuously be monitored and ensure that any abnormalities occur being notified.

Table 4 Velocity measurement of V_{rms} for pump D

Points	Direction	Velocity (mm/s)	Average Velocity (mm/s)	Safe Limit Observation (ISO-10816)
1	Vertical Axial Horizontal	1.04 0.53 1.33	0.967	Good
2	Vertical Axial Horizontal	1.20 0.417 1.44	1.019	Good
3	Vertical Axial Horizontal	0.719 0.846 0.480	0.687	Good
4	Vertical Axial Horizontal	0.912 0.413 0.707	0.677	Good

The result of average velocity measurement at points 1, 2, 3 and 4 were 0.453 mm/s, 0.489 mm/s, 0.369 mm/s and 0.341 mm/s, respectively. These velocities data were compared to ISO-10816. The safe limit was in good condition for all points 1, 2, 3 and 4, respectively. It shows the overall motor and pump were in decent condition, and the safe limit is in good condition. The pump can run as usual.

The maximum was measured on the motor side, which was 0.453 mm/s and 0.489 mm/s. Most of the motion came from the axial direction. The vibration was documented higher on the motor side than the pump, which recorded a lower value. The data can be referred to in Table 4. Since the vibration safe limit was still in good limit, the condition of the pump remain can be utilized. But the pump must continuously be monitored and ensure that any abnormalities occur being notified.

Overall, the condition of pump A was deplorable, and the pump must be stopped instantly to ensure no hazard to the pump for immediate maintenance. This was due to the unsafe condition based on ISO-10816, which categorized the pump as unacceptable and unsatisfactory. While pumps B, C and D were in fair and good condition where the velocity measurement of the pump was satisfactory and promising. Even though the pump can be run, it needs to be continuously monitored and maintained to ensure the condition does not cause a threat to workers and the environment. This is because the pump in high-speed rotation can cause harm if any minor incident occurs.

3.2 Fault diagnosis

Fault diagnostic using the FFT waveform method is one of the most popular methods in determining the fault of rotating machinery by analysing the characteristic of the vibration spectrum. The result of the fault diagnostic was clarified based on the velocity vs speed graph. The waveform analysis explained more about the behavior of the pump's faults

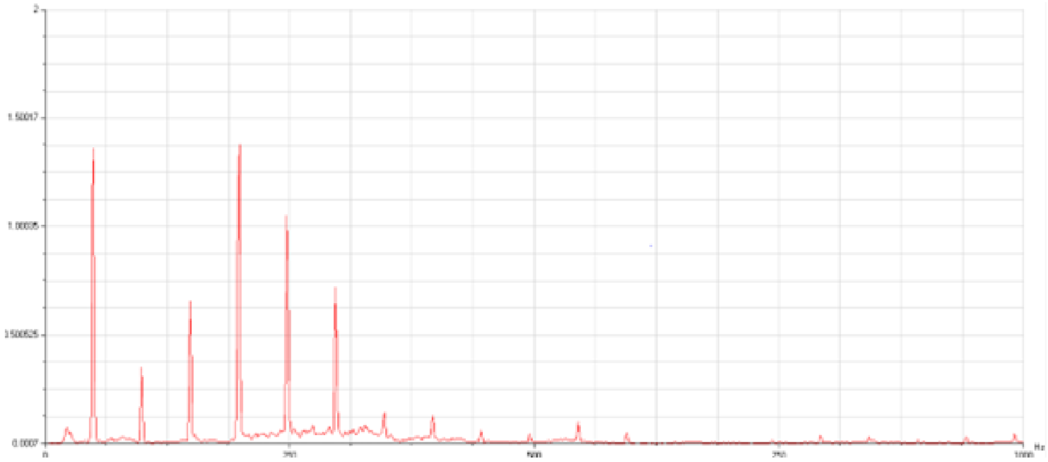

Figure 4 Horizontal vibration spectrum for pump A at Point 2

Based on Figure 4, pump A showed several peaks that can be analysed to misalignment, angular misalignment, parallel misalignment and coupling fault. First, the misalignment is a combination of angular and parallel misalignment. Misalignment of the pump recognized from the six (6) firm peaks. The angular misalignment showed by the reasonably strong peaks at the vertical and horizontal at almost the point collected. For parallel misalignment, the high peak at 2X and relatively strong peaks at 1X and 3X produced shear force and bending moment on the coupled end of the shaft. Since this type of pump had parallel flange faces, the coupling fault needs to be considered since the vibration measurement of the pump exceeded the safe limit. The criteria of the coupling faults were the same as misalignment and required to be inspected before the pump could be run in a safe condition and not create hazards. After the inspection, the coupling fault may occur from the rubber bush on the bolt that couples the flange of the shaft at the motor and pump. The rubber bush's condition was not poor and needed to be changed. This problem was suspected to be a source of fault that occurred on the coupling.

The recommendation for the pump is to cope with these problems by aligning pump A, adjusting the height of the motor by adding shims and adjusting the angle of the motor. The rubber bush on the coupling also must be changed for the better performance of the pump.

Figure 5 Vertical vibration spectrum for pump B at Point 4

Based on Figure 5, pump B showed three (3) peaks that were at 180º, which can be analysed as purely parallel misalignment. It is because the 1X and 2X were low in height at the peaks. The criteria of parallel misalignment in which the vertical and horizontal recordings showed the same conditions of peaks could be concluded as parallel misalignment. This problem may be caused by the shim plate being used soft and getting thinner after some time. Since the pump was in satisfactory condition according to ISO-10816, the pump may be used and need to be changed if necessary, and the state of the pump will worsen.

The recommendation for the pump to cope with this problem by adding shims on the motor of pump B to decrease the parallel misalignment

Figure 6 Vertical vibration spectrum for pump C at Point 2

Based on Figure 6, pump C showed multiple characteristics of fault, which suspected angular misalignment and eccentric rotor. This was due to the vibration graph showing symptoms from numerous peaks and noise. The angular misalignment can be seen on the peaks generated at 50, 100 and 150Hz. The criteria of angular misalignment, in which the vertical and horizontal recordings showed the same conditions as a referral. The problem caused by the angular misalignment may come from the manufacturer's imperfection or when the assembly process. The eccentric rotor showed from the generated peak at 90 °, called the high pass pole in FFT. The 2X line frequency was also developed at the 2X of the graph's peaks, which also confirmed the eccentric rotor defects. It may cause by the loose rotor bars in the motor. This reason was also supported by the vibration measurement, where the motor side experienced higher velocity than the pump side.

The recommendation for the pump to cope with these problems was to realignment the pump for angular misalignment and checked the rotor shaft at the motor for eccentric rotor faults.

Figure 7 Horizontal vibration spectrum for pump D at Point 2

Based on Figure 7, pump D showed several peaks and noise on the velocity times speed of vibration. This behavior was analysed, and suspected flow turbulence, cavitation and structural looseness. The flow turbulence was detected from the random and low-frequency spectrum right before 180º. This turbulence occurred due to observing the variation of fluid velocity that entered the pump from vessel 203. It causes the presence of the air inside the pump was also the causes of the flow turbulence recorded. Since the presence of air inside the pump, the cavitation on the pump also occurred based on the noise generated at the back of the graph. The noise showed hump looking graph at the 5X to 7X rotation, indicating cavitation. Bubbles develop within a fluid during cavitation when the pressure rapidly falls below the vapor pressure. Higher pressures cause the bubbles to collapse and created shockwaves that eventually cause damage to parts of the pump. The structural looseness was spotted from the criteria of the single strong peak, in which the horizontal measurement recorded a higher amount than the vertical direction. The looseness fault was in unsatisfactory level since the vertical peak value lower than horizontal peak value based on ISO 2372 It may cause the base of the plant platform that was holding the base of the pumps loosed and need to be tightened back. It may occur from the need for more maintenance and supervision from the facility.

The recommendation for the pump to cope with these problems was installing an anti-vortex fitting at the bottom of vessel 203 before entering pump D to decrease the flow turbulence in the pump and check the bolts and nuts at the foundation to eliminate the structural looseness

After the fault diagnostic analysis had been accomplished, almost all pumps generated various types of faults. These faults may come from human imperfection when assembling, components' wear and tear, and other factors. The result shows that three (3) pumps were analysed for misalignment, which was pumps A, B, and C. Misalignment was one of the common faults that occurred since very hard to reach the perfection phase of alignment. Although the number of suspected faults in the pump was high and the vibration velocity did not exceed the ISO-10816 standard, the pump condition was accepted and can continue to run.3.3 Effect of fluid's temperature to the vibration.

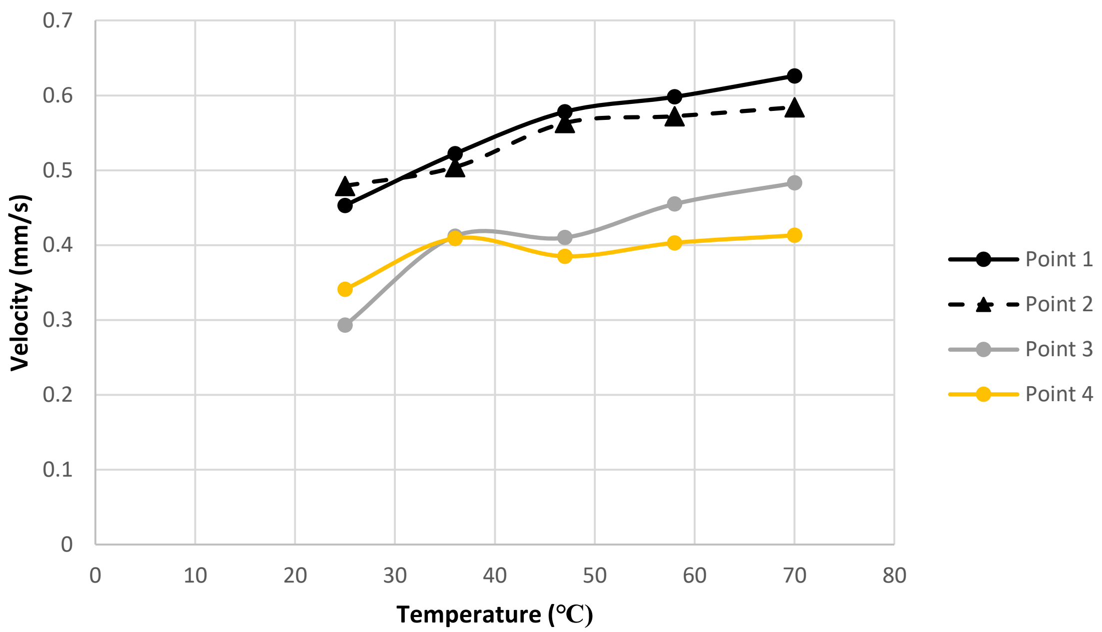

Figure 8 Velocity measurement of average V_{rms} for pump D in different temperature

Figure 8 shows the average velocity measurement during five (5) operating temperature tests at the 1435 rpm speed of 50 Hz. Based on the figure, the pattern of the vibration velocity increased at all points that had been measured. The motor side velocity measurement points 1 and 2 increased by 38%

and 22%, respectively. The pump side velocity measurement, points 3 and 4, increased by 64% and 21%, respectively. When temperature increases, the pump's structure will be affected by decreasing the pump's stiffness, which enhances faster vibration. The increased fluid temperature also influences the viscosity of the fluid. Since the fluid's viscosity decreases, less energy absorption may increase the vibration in the pump's structure. It is because the heated fluid stores more energy than the cooler fluid.

The vibration on point 3 and point 4, located at the pump side, showed an increased value due to the effect of temperature fluid. When the fluid temperature was 36℃, the velocity measurements for points 3 and 4 were almost the same, 0.412 mm/s and 0.409 mm/s, respectively. It was suspected the resonance occurred when the fluid was at this specific temperature. This resonance can be different for all pumps since the states of the wear and tear were not identical to all pumps. Since the first 180º shows flow turbulence, the resonance cannot be detected since the flow turbulence produces a more significant frequency than resonance., So the pump analysis using a few different parameters can be used to detect this problem. The other way was also by referring to the manufacturer's operating standard.

On the motor side, which points 1 and 2, the measured velocity was higher than the pump side. Based on the primary mechanical term, the motor will generate more energy than the pump side since the motor converts electrical energy to mechanical movement. The motor had more components and generated more vibration energy than a pump. It is a normal phenomenon where the driver device causes more vibration than the driven device.

The characteristic of the vibration spectrum graph showed less variation in pattern. The deviation from the vibration spectrum graph showed a similar characteristic: flow turbulence, cavitation and structural looseness, same as in ambient temperature. This characteristic of vibration does not change a lot as the temperature of the fluid increases. It was parallel with the research by Wang et al. in 2022 [6], where the fluid type does not affect the vibration characteristic experienced in the tested machine.

4. Conclusion

Overall, the vibration safe limit of the pumps B, C and D were in fair condition except for pump A, must stop running and undergo maintenance. Pump A, recorded 8.43 mm/s, 10.75 mm/s, 5.31 mm/s and 4.06 mm/s for point 1, 2, 3 and 4, respectively and exceeded 2.80 mm/s safe limit of machine less than 5kW power. Every pump showed a different type of fault occurring in the pumps, which for pump A were misalignment, angular misalignment, parallel misalignment, and coupling fault. Pump B suspected only parallel misalignment; pump C suspected. angular misalignment and eccentric rotor, and last is pump D suspected flow turbulence, cavitation, and structural looseness. Although pumps B, C, and D experienced faults, the pumps can continue running and did not need to undergo maintenance because the pumps were in fair condition based on safe limit standard. In contrast, pump A needed alignment maintenance and changes of the rubber bush to cope with generated faults. The effect of temperature on vibration has been accomplished from the test. The results indicated the vibration velocity increased by 38%, 22%, 64%, and 21% at four (4) measured points as the fluid temperature increased when flowing in the pump. As expected, when temperature increases, the pump's structure will be affected by decreasing the pump's stiffness and enhancing faster vibration. The increased fluid temperature also influences where it reduces the fluid's viscosity. Since less variation of vibration characteristics showed, the hypothesis that the type of fluid does not affect the vibration characteristic experienced in the tested machine was parallel with the previous research written by Wang et al. in 2022 [5].

Acknowledgement

The author would like to thank the Faculty of Engineering and Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia for its equipment, technical and expertise support.

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