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# Motor Current Signature Analysis and Vibration Test on Rotating Machines of Chiller System at Uthm G2 Building

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**Abstract**: Rotating machines especially induction motors are widely used as industrial drives due to the self-starting factor, reliability, and economical. The three-phase induction motors are commonly used for complex systems such as generators or motors in chiller systems. However, these motors require maintenance as they enter a certain amount of time. Thus, motor testing can be done to provide the latest condition of the motors while it still running. The data obtained from the testing were be interpreted to detect any faults that occurred on the motors. This project provided testing of induction motors for the chiller system. Two parameters that be measured are the physical vibration of the motor and the phase current. Two sensors were used to take the vibration and current reading which are accelerometer and current clamp, respectively. The results were analyzed by using vibration analysis and motor current signature analysis (MCSA). Motor faults such as misalignment, unbalance and stator winding had been detected based on the magnitudes and respective frequencies presented in the spectra. Thus, machine testing should be taken seriously as it can assist maintenance work to ensure machines are long-lasting.

**Keywords**: Rotating Machine, MCSA, Vibration Analysis

## 1. Introduction

Rotating machines are inventions to convert mechanical to electrical energy known as generators or electrical energy to mechanical energy widely called motors. The common type of motor used for chiller system was induction motor as it has self-starting torque hence no starting methods are employed and cheaper [1]. Considering the importance of rotating machines, condition monitoring should be applied to observe the machine's condition. As the rotating machines enter the wear-out phase as time goes by. It may encounter sudden failures or errors that can affect the process plant. The errors may be

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caused by components that face some damages. Failures can happen because of abnormal operating conditions, causing the production to shut down. This situation will cost the factory a huge amount of money to repair the system. Therefore, maintenance and preventive actions such as condition monitoring should be taken before any further damage occurs. Motor current signature analysis and vibration analysis were adapted to further analyze the data from the sensors using signal-based fault detection techniques. his project was carried out by testing the induction motors for the chiller system in UTHM G2 Building. The project also detected either the stator winding faults, broken rotor bar or air-gap eccentricities faults that might present on the tested machines by MCSA. Moreover, other mechanical faults such as rotor unbalance, misalignment, mechanical looseness, cavitation, turbulence and bent shaft had been detected by the vibration analysis technique. The conditions of the tested induction motors were summarized.

### 1.1 Common faults of rotating machines

The faults can be due to the machine itself or may be created by operating conditions. The inherent faults could be caused by the mechanical or electrical forces acting on the machine enclosure [2]. Late fault detection or further developed faults may lead to a failure and may cause damage to the motor. Among the common faults of the induction motor are the broken rotor bar, air-gap eccentricities, and stator winding's fault. In various surveys that focused on studying induction machine faults have categorized the most common fault of the motor. Based on the statistical report of the Motor Reliability Working Group of the IEEE-Industry Applications Society (IEE-IAS), which surveyed 1141 motors, and the Electrical Power Research Institute (EPRI), which surveyed 6312 motors, can be summarized in the results depicted in Figure 1 [3]-[]5].

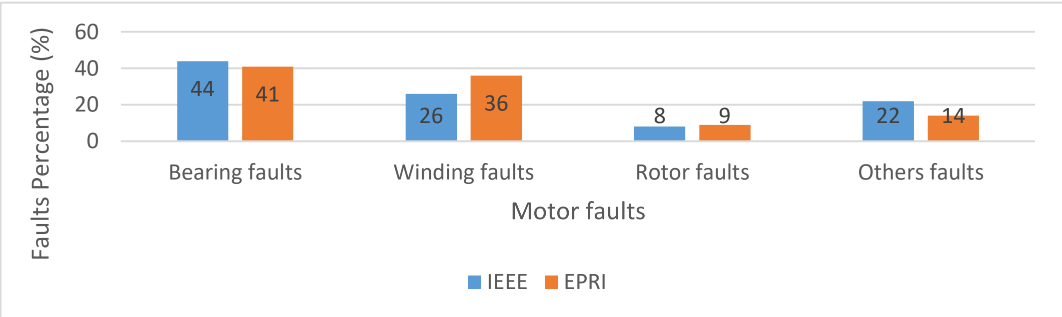



**Figure 1: The percentages of common faults in three-phase induction machines [3]-[5]**

Based on the surveys shown in Figure 1 above, bearing fault has the highest percentage of faults experienced by the motors recorded by both IEEE-IAS and EPRI which were 44% and 41 % respectively. Besides, EPRI recorded 36 % of winding faults while IEEE recorded 26 % faults made the winding faults with second highest percentage recorded from both surveys. On the other hand, rotor faults had the least percentage of faults which were 8% and 9% based on IEEE and EPRI, respectively.

### 1.2 Motor current signature analysis

Motor current signature analysis is a condition monitoring technique used to diagnose problems in induction motors [6]. Tests are performed without interrupting production with the motor running under the load at normal operating conditions [7],[8]. MCSA provides monitoring of the stator current of the motor [9]. Motor current is sensed by a current sensor, can be a clamp probe or current transformer with resistive shunt across its output, [10], and recorded in the time domain also in frequency domain. MCSA is done by detecting frequency sidebands calculated from a specific equation for certain faults. Among the faults that can be detected by MCSA are broken rotor bar and air-gap eccentricity, static and dynamic. Example in Figure 2 below illustrated how MCSA detects the broken rotor bar problem.

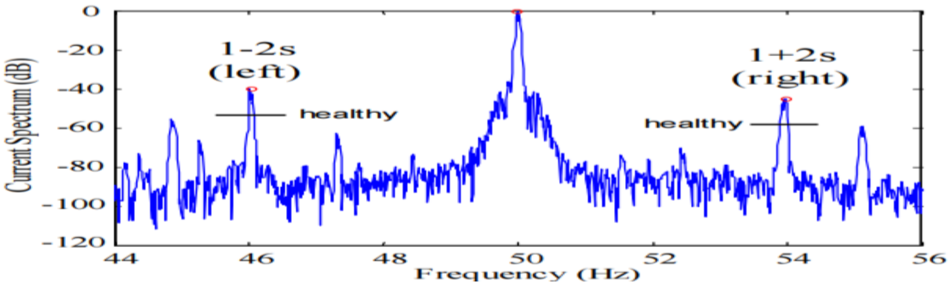



**Figure 2: Current signature at the 50Hz for a motor with one broken rotor bar showing the (1±2*s*) *f* sidebands [11]**

Next, stator winding fault can be determined by stator winding fault sideband frequency, $f_{stw}$ in the current spectrum. To determine this sideband frequency, the equation was given by Eq. 1 and 2 [12].

$$\mathrm{f_{stw}} = \mathrm{k.f_s} \pm \mathrm{n.f_r} \qquad \textit{Eq. 1}$$

Where $f_s$ is supply frequency, $f_r$ is rotational frequency, parameter n = 1, 2, 3…. And parameter k = 1, 3, 5….

Rotational frequency can be obtained by:

$$f_r = \frac{motor\ running\ speed\ in\ rpm}{60\ s} \qquad Eq.\ 2$$

Where $s$ is the slip and $p$ is the number of poles.

The upper sideband (usb) can be expressed by *Eq. 3* and the lower sideband (lsb) can be expressed by *Eq. 4*.

$$f_{stw\_usb} = k.f_s + n.f_r \qquad \textit{Eq. 3}$$

$$f_{stw\_lsb} = k.f_s - n.f_r \qquad \textit{Eq. 4}$$

Lastly, the sideband frequency for air-gap eccentricities fault can be determined by a simple calculation for static and dynamic eccentricities can be defined by Eq. 5 and 6 respectively [13].

$$f_{static} = RB.f_r \pm n.f_s \qquad \textit{Eq. 5}$$

Where *RB* is number of rotor bar, $f_r$ is rotational frequency, $f_s$ is supply frequency and integer n = 1, 2, 3…

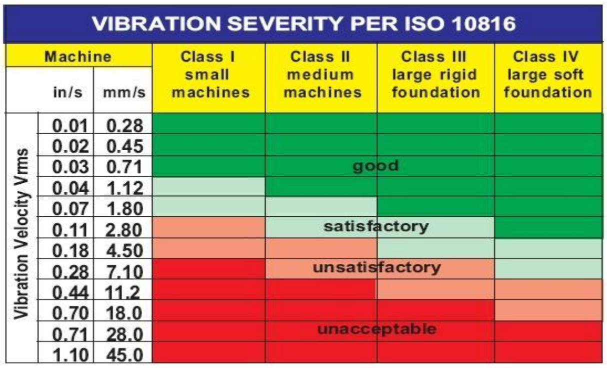
$$f_{dynamic} = f_{static} \pm f_r \qquad \textit{Eq. 6}$$

Static and dynamic eccentricities can be found in the high frequency of the current spectrum. Both sidebands must be presented in the spectrum to detect the faults.

### 1.3 Vibration analysis

Vibration analysis helps to determine the condition of the motor during operation either the motor operates efficiently or not. By using vibration analysis helps in expecting the motor downtime without disrupting the operation of the motor or altering it in any way. In the process of vibration analysis, start by monitoring motor vibration then motor condition analysis. Fault detection is when a measurement parameter taken exceeds a normal operating range. Fault diagnosis focuses on specific changes and symptoms to determine a cause, severity, and corrective action [14]. Many powerful signal processing techniques can be applied to vibration signals to extract even very weak fault indications from noise and other masking signals [15]. The types of vibration sources present in an induction motor are mechanical source – typical of all rotating machines may be due to rotor imbalance, shaft bow, and misalignment [16]. On the other hand, electromagnetic vibration source is specific to electrical machinery and for induction motors. Table 1 below shows the mechanical vibration severity of different machines type according to the International Organization for Standardization (ISO).

**Table 1: Vibration severity of rotating machine [17]**




Induction motors can be categorized into 4 classes, class me, II, III and IV. The description of each class differs as class I consists of small motors, normally connected to the complete machine to operate. The range of production of the motors are up to 15 kW. Class II involves medium-sized motors with production range from 15kW up until 75kW (20HP to 75HP) and rigidly mounted machines with up to 300 kW on special foundations. Enormous prime-movers or other large motors with rotating masses attached on rigid and heavy foundations which are rigid in the direction of vibration measurements are included in class III. Lastly, class IV associated with also huge prime-movers or large machines with rotating masses fixed on foundations which are comparatively soft in the direction of vibration measurements [16]. The condition of the motor can be known based on the overall vibration severity of the motor.

To figure out the reasons or the faults that might affect the vibration of the motor, analysis on the vibration spectrum can be done. The vibration spectrum analysis was carried out by considering the amplitude of vibration in velocity mm/s and the indicator frequencies as certain type of faults happen only at certain frequencies. Specification of the motor such as the speed frequency, number of rotor bar, number of motor blades and more are needed to obtain the indicator frequencies [16]. Table 2 showed the indicator frequencies for each type of faults.

**Table 2: Indicator frequencies based on faults [18]**

| Fault | Indicator frequency |
|---|---|
| Mass unbalance | 1x rotational frequency |
| Misalignment | 1x, 2x rotational frequency |
| Mechanical looseness | 1x, 2x, to 10x rotational frequency |
| Bent shaft | 1x rotational frequency |
| Cavitation | Low vibration at below 1x rotational frequency |
| Turbulence | Low vibration located 10x rotational frequency |

## 2. Equipment and Methods

In order to carry this monitoring project, measurement of physical vibration, and phase current of the 3-phase induction motor while the motor was running should be taken and analyzed. The vibration level of the machines was measured with the help of accelerometers and the data logger while the current readings were taken using an AC/DC Current clamps and oscilloscope. The raw data taken in the time domain were interpreted into the frequency domain using FFT. The data then saved and transferred to the PC for analysis process.

2.1 Equipment

The vibration analyzer set that was used consist of ASH-201A accelerometer with 01 dB Movipack OneproD system analyzer. The CC65 AC/DC Current Clamp and KEYSIGHT DSOX1202G Oscilloscope were used to measure current.

2.2 Methods

The flow of the project block diagram shown in Figure 3. Initial step was the measuring process. The current sensor must be clamped to the cable in the panel board. Measurement range was adjusted accordingly to the phase current of the motor. The accelerometer with temporary installed magnet was attached to the 3 directions of each end of the motor. The measured signal then being processed using the data acquisition process occur in the 01 dB Movipack for vibration signal and Keysight Oscilloscope for the current signal. FFT mode was selected to acquire frequency domain spectrum for current and vibration.


**Figure 3: Project block diagram**

The desired data then transferred to the PC to be diagnosed by MCSA and vibration analysis. The raw data collected from the oscilloscope were in excel files and stored in USB. These files then were the input data for further MCSA analysis using MATLAB software. The data from 01 dB Movipack were transferred to PC by using cable R232 cable and displayed by the Vib-Graph software. The vibration data were compared to Table 1 and the spectrum analysis were carried out manually by detecting the indicator frequencies specified for each type of fault through simple calculation as in Table 2.

## 3. Results and Discussion

The induction motors for chilled water pump chiller system 4 were analyzed based on the MCSA and vibration analysis. The results of both analyses were summarized to determine the latest condition of the motor.

3.1 Results

The actual tested motor, the motor specification was given in Figure 4 and Table 3, respectively. The current of chiller water pump motor was 25A based on the panel ammeter. The parameters such motor speed, horsepower and motor frequency were utilized in the analysis.

**Figure 4: Motor for chilled water pump 4**

**Table 3: Motor specification based on nameplate**

| Serial No. | 1394/04 | Connection | Delta |
|---|---|---|---|
| HP | 25 | Power | 18 kW |
| Frequency | 50 Hz | Voltage | 415 V |
| RPM | 1470 | Current | 32.9 A |

3.1.1 Motor Current Signature Analysis

The results of this analysis explained as below.

Based on Figure 5, the sidebands to indicate broken rotor bar (dotted line), stator winding fault (solid line), static eccentricities (dashed line) and dynamic eccentricities (dashed dotted line) are shown in the spectrum. The faults are said to be occurred when there was high magnitude of vibrations found at the frequency sidebands.

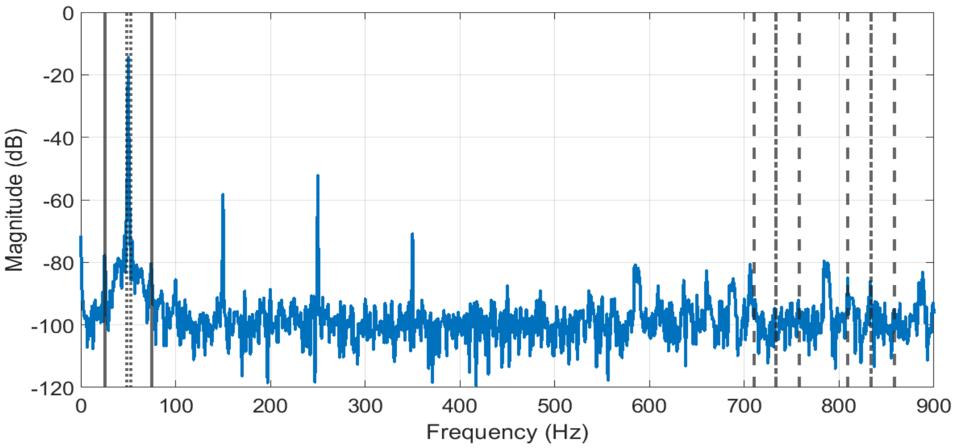



**Figure 5: Phase current spectrum in frequency domain**

This Figure 6 visualized a smaller range of the same current spectrum as in Figure 5. The broken rotor bar sidebands pair (dotted lines) with lower sideband frequency and upper sideband frequency of 48 Hz and 52 Hz, respectively. The stator winding fault sidebands pair (solid lines) also presented in the range with the value of lower and upper sideband, 25.5 Hz and 74.5 Hz, respectively. There was no high magnitude happened at the broken rotor bar sideband frequencies. Therefore, this motor may not experience this fault. Nevertheless, there were high magnitude presented at the pair of stators winding sideband with magnitude of 60 dB. Hence, this motor might encounter the stator winding fault.

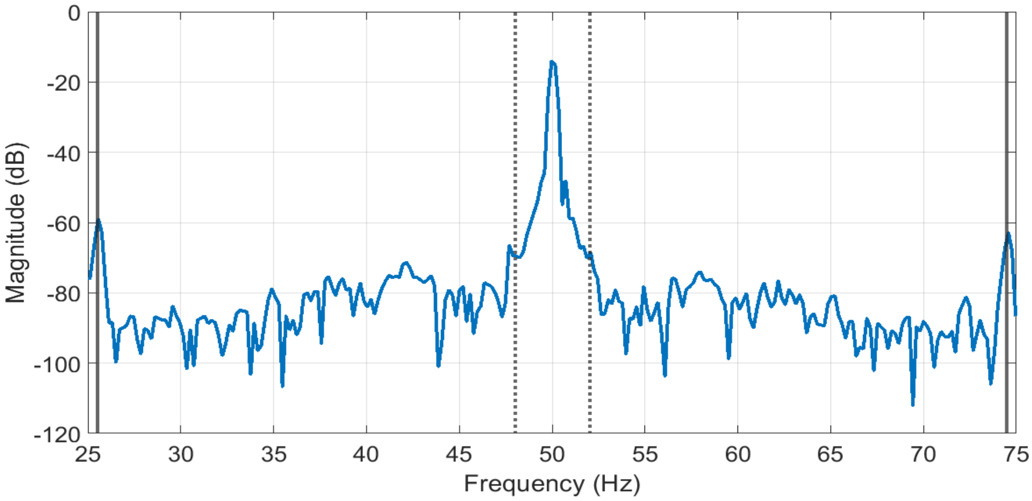



**Figure 6: The current spectrum with range 25 Hz to 75 Hz**

3.1.2 Vibration Analysis

Based on Table 3, this motor has power of 18kW with HP of 25. By referring to the ISO 10816, this motor can be included in Class II with production range from 15kW up until 75kW. Table 5 showed the condition of the motor based on the Vibration Severity per ISO10816.

**Table 5: Results of motor condition**

| End type | Direction | Velocity, mm/s | Condition (Class II) |
|---|---|---|---|
| Motor non drive end | Vertical | 9.43 | Unacceptable |
| | Horizontal | 5.03 | Unsatisfactory |
| | Axial | 11.8 | Unacceptable |
| Motor drive end | Vertical | 4.14 | Unsatisfactory |
| | Horizontal | 5.24 | Unsatisfactory |
| | Axial | 9.36 | Unacceptable |

Since the motor result mostly fall into unsatisfactory and unacceptable condition as shown above, further analysis on the vibration spectrum was done. Based on the motor specification, the rated speed of the motor was 1470 RPM. Therefore, the indicator frequencies of 1X up until 10X can be determined as in the Table 6. The values of indicator frequencies may be slightly differed as in the vibration spectra since the motor may not run at exactly as the rated speed obtained on the nameplate.

**Table 6: Indicator frequencies**

| Indicators | Frequency, Hz | Indicators | Frequency, Hz |
|---|---|---|---|
| 1X | $\frac{1470\,rpm}{60s} = 24.5$ | 6X | 147.0 |
| 2X | 49.0 | 7X | 171.5 |
| 3X | 73.5 | 8X | 196.0 |
| 4X | 98.0 | 9X | 220.5 |
| 5X | 122.5 | 10X | 245.0 |

Based on Figure 7, the highest peak existed at the range of 1X frequency with 7727 mm/s showed that the motor may experience mass unbalance since 1X frequency dominated the spectrum [18]-[21]. Other than that, this motor also suspected to face mechanical looseness caused by the structural looseness of the machine foundation. However, there were some vibrations happened such as at the frequency of 215 Hz cannot be interpreted due to lack of motor specification data.

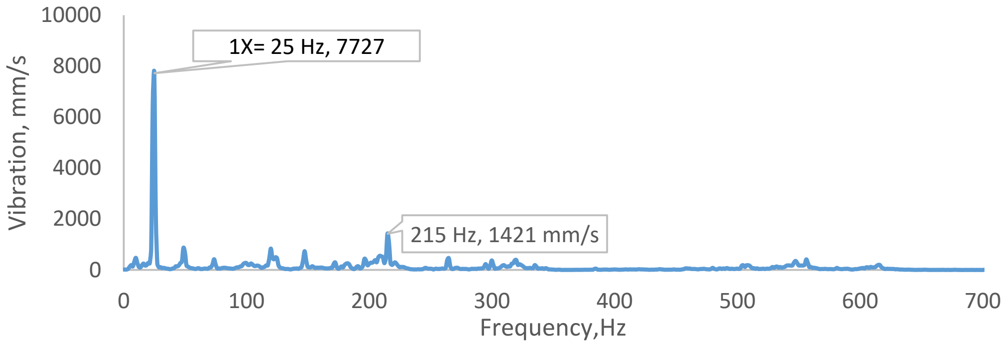



**Figure 7: Vertical vibration spectrum**

Based on Figure 8, a random low vibration occurred at the lower range of frequency before the 1X indicator might happened due to turbulence [20]. Besides, there was a random higher frequency broadband at 500 Hz as shown above occurred and may be due to cavitation [20]. There was visible high vibration at 1X frequency with 1627 mm/s which may indicated the same problem visualized by Figure 4.6 which are mass unbalance, and mechanical looseness. Lastly, the highest vibration shown presented at 7X frequency, 172.5 Hz with vibration of 2921 mm/s. This might be caused by the mechanical looseness problem [18]-[21].

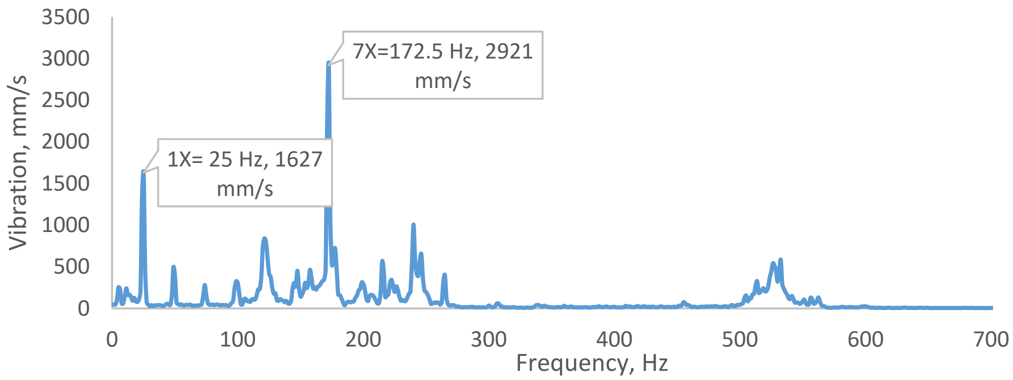



**Figure 8: Horizontal vibration spectrum**

Based on Figure 9, the highest vibration happened at the frequency range of 1X with 7816 mm/s. The vibration also raised at the frequency of 2X with 2764 mm/s indicated that the motor may experience bent shaft and angular misalignment [18]-[21]. The bent shaft occurred once the rotor loses its symmetry with respect to its rotating axis. Other than that, with the presence of 2901 mm/s vibration at 6X, this motor may also face looseness fault [18]-[21].

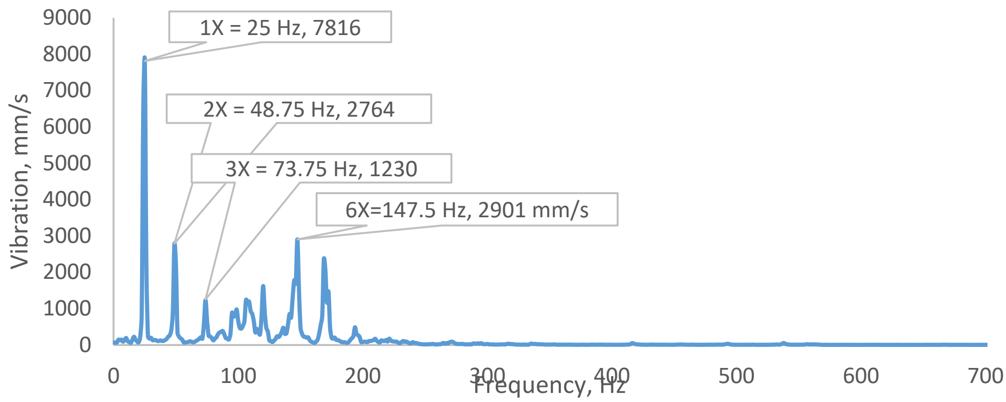



**Figure 9: Axial vibration spectrum**

3.1.3 Summary of the Motor Condition

Table 8 contains the review of the whole analysis with the possible faults that might be happened to the motor.

**Table 8: Summary on the motor condition**

| Analysis | Types of faults | Comment |
|---|---|---|
| MCSA | Stator winding fault | High magnitude with 60 dB presented at both sideband pair. |
| Vibration Analysis | • Bent shaft<br>• Angular misalignment<br>• Mass unbalance<br>• Mechanical looseness<br>• Cavitation<br>• Turbulence | The presence of high vibration at the indicators frequency range from 1X to 10X. Additional of low magnitude vibration at low range of frequency (below 1X) may cause by cavitation. Random low vibration at higher range frequency (above 10X) might cause by turbulence. |

## 4. Conclusion

Based on this project findings, MCSA and vibration analysis provide quite wide range on detection of faults that may encounter by the rotating machines. The overall condition of the motor had been known. Further maintenance work can be done based on the results. Recommendation for future work is to acquire the machines datasheet or manual to gather all the motor related parameters. This can help in widen the types of faults to be detected.

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