PUMP MONITORING USING MULTI-SENSOR AND ANALYSIS BY STATISTICAL TECHNIQUE

DAYANG NURHAFIZA BINTI AWANG KHALID
B092010301

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY IN MAINTENANCE WITH HONOURS

2024

Faculty of Mechanical Technology and Engineering

PUMP MONITORING USING MULTI-SENSOR AND ANALYSIS BY STATISTICAL TECHNIQUE

Dayang Nurhafiza Binti Awang Khalid

Bachelor of Mechanical Engineering Technology In Maintenance with Honours

2024

PUMP MONITORING USING MULTI-SENSOR AND ANALYSIS BY STATISTICAL TECHNIQUE

DAYANG NURHAFIZA BINTI AWANG KHALID

A thesis submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology In Maintenance with Honours

Faculty of Mechanical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **PUMP MONITORING USING MULTI-SENSOR AND ANALYSIS BY STATISTICAL TECHNIQUE**

SESI PENGAJIAN: **2023-2024 Semester 1**

Saya **DAYANG NURHAFIZA BINTI AWANG KHALID**

mengaku membenarkan tesis ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐	TERHAD	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)
☐	SULIT	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
☑	TIDAK TERHAD	

Disahkan oleh:

Alamat Tetap:
No 124, Kampung Bakong
Oya, 96410 Mukah Sarawak

Cop Rasmi:

Tarikh: 09 January 2024 Tarikh: 09 January 2024

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this Choose an item.entitled “Pump Monitoring using Multi-Sensor and Analysis by Statistical Technique” is the result of my own research except as cited in references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Dayang Nurhafiza Binti Awang Khalid

Date : 09 January 2024

APPROVAL

I hereby declare I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology in Maintenance with Honors

Signature :

Supervisor Name : Ts. Dr Nor Azazi Bin Ngatiman .

Date : 09 January 2024

DEDICATION

In the name of Allah S.W.T, the Most Gracious and Merciful,

I dedicated this project to my beloved parents,

Awang Khalid Bin Awang Rosli & Marlina Binti Idris,

Not to be forgotten, my supervisor,

Ts. Dr. Nor Azazi Bin Ngatiman,

For guiding and advise me through this final year project,

And to all those who stood beside me, consistently encourage and support me.

ABSTRACT

Centrifugal pumps are widely used in both industrial and municipal water systems due to their efficiency and versatility. These pumps work by converting mechanical energy into kinetic energy to move the fluids, typically water, from one place to another. However, during their operation, centrifugal pumps can experience several failures or issues that can affect their performance and efficiency. In recent years, the development of online pump monitoring strategies has emerged as a valuable approach to detect faults and anomalies in pump systems. This project aims to investigate online pump monitoring utilizing vibration signal analysis and a machine learning method with a 2-type different sensor of accelerometer and piezoelectric film sensor. By analyzing the vibration signal generated during pump operation, this technique enables real-time assessment of pump performance and health. A piezoelectric film sensor is affixed to the pump to monitor and record the vibration signal produced by its components. The gathered information from the vibration signal is then transmitted for advanced signal processing. This involves analyzing the frequency, amplitude, and other characteristics of the vibration signals to extract crucial features that indicate the actual condition of the pump. Machine learning algorithms are employed to analyze the extracted features and provide historical data and patterns that can be utilized to predict the health status of the pump. The research results demonstrate that different pump speeds, valve opening, and flow rates generate distinct vibration signal patterns. This knowledge enhances our understanding of pump behavior, enabling better defect detection and ultimately leading to improvements in pump performance.

ABSTRAK

Pam sentrifugal mempunyai pelbagai aplikasi yang luas dalam sistem air industri dan perbandaran. Namun, semasa operasinya, berbagai kegagalan seperti haus galas, kerosakan bilah, ketidakseimbangan pendesak, ketidakselarian poros, peronggaan, dan hentakan air sering kali berlaku. Dalam beberapa tahun terakhir, pembangunan strategi pemantauan pam dalam talian telah muncul sebagai pendekatan berharga untuk mengesan kerosakan dan anomali dalam sistem pam. Projek ini bertujuan untuk menyiasat pemantauan pam dalam talian menggunakan analisis isyarat getaran dan kaedah pembelajaran mesin dengan menggunakan 2 sensor yang berbeza iaitu 'accelerometer' dan filem piezoelektrik sensor. Dengan menganalisis isyarat getaran yang dihasilkan semasa operasi pam, teknik ini memungkinkan penilaian prestasi dan kesehatan pam secara real-time. Sebuah sensor filem piezoelektrik dipasang pada pam untuk memantau dan merekod isyarat getaran yang dihasilkan oleh komponen-komponennya. Maklumat yang dikumpulkan dari isyarat getaran tersebut kemudian dikirimkan untuk pemprosesan isyarat yang lebih lanjut. Ini melibatkan analisis frekuensi, amplitudo, dan karakteristik lain dari isyarat getaran untuk mengekstrak fitur penting yang menunjukkan kondisi sebenarnya pam. Algoritma pembelajaran mesin digunakan untuk menganalisis fitur-fitur yang diekstrak dan memberikan data dan pola historis yang dapat digunakan untuk meramalkan status kesehatan pam. Hasil penelitian menunjukkan bahwa kecepatan, bukaan injap dan laju aliran pam yang berbeda menghasilkan pola isyarat getaran yang berbeda. Pengetahuan ini meningkatkan pemahaman kita tentang perilaku pam, memungkinkan deteksi kegagalan yang lebih baik, dan pada akhirnya, membawa peningkatan dalam kinerja pam.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. Thank you also to the Malaysian Ministry of Higher Education (MOHE) for the financial assistance.

My most appreciation goes to my main supervisor, Ts. Dr. Nor Azazi Bin Ngatiman for all his support, advice and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. It is impossible for me to fulfill this project without his supervision and encouragement. I am grateful. I am grateful to all my lecturers for their continuous inspirations.

Last but not least, from the bottom of my heart I express gratitude to my beloved parents, Awang Khalid Bin Awang Rosli and Marlina Binti Idris, for their patients and all sacrifices in raising me and my siblings. I also would like to express my heartfelt gratitude to my siblings, my course mates and my friends who are always supporting and encouraging me through all the difficulties. Your prayers and love gave me a lot of strength in order to finish this report. I am truly grateful to them. Last but not least, I wanna thank me. I wanna thank me for believing in me, for doing all this hard work, for never quitting, always being a giver and trying give more than I receive and I wanna thank me for trying to do more right than wrong and just being me at all times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

f	-	Frequency
P	-	Period in seconds
P	-	Pressure
ρ	-	Density of liquid
V	-	Velocity
g	-	Gravitational acceleration constant
Z	-	Elevation at the centroid
H	-	Head
MHZ	-	Mega Hertz
ṁ	-	Mass flow rate
EGL	-	Energy grade line
$\dot{V}$/Q	-	Volume flow rate
η	-	Efficiency
ZFreq	-	Z Frequency
RMS	-	Root Mean Square
SVM	-	Support Vector Machine
kNN	-	k-Nearest Neighbour
RPM	-	Revolution per minute

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Online pump monitoring based on vibration signal analysis and machine learning has emerged as an effective approach for ensuring the efficient and dependable operation of industrial pumping systems. Pumps take an important role in a variety of industries, including oil and gas, water treatment, manufacturing, and power generation. Pump health and performance must be monitored in order to prevent failures, optimize maintenance, and minimize downtime.

Vibration signals are useful indicators of a pump's condition. They can reveal faults and irregularities such as imbalance, misalignment, wear, cavitation, and bearing problems. Changes in vibration patterns can be identified by continuously monitoring a pump's vibration signals, allowing for early identification of possible concerns.

Vibration signal analysis entails measuring, analyzing, and interpreting vibration signals to derive relevant information about the pump's status. To analyse the frequency content, amplitudes, and time-domain properties of the vibration signals, various signal processing techniques such as Fourier analysis, wavelet analysis, and envelope analysis are used. Specific fault signatures or abnormalities related with pump failures or performance degradation can be revealed by these analysis.

Machine learning techniques are used to improve vibration signal analysis and interpretation. Support vector machines, random forests, and neural networks, for example, can be trained using labeled datasets comprising vibration signals from various pump states, such as normal, malfunctioning, or in need of maintenance. The trained models can then classify real-time vibration signals and detect probable problems or irregularities in pump operation.

There are various advantages to incorporating vibration signal analysis and machine learning into online pump monitoring. It allows continuous monitoring of pumps, enabling for the early diagnosis of defects or decline in performance. Maintenance actions can be organized in advance by proactively identifying faults, minimizing downtime and lowering the chance of costly breakdowns.

The use of vibration signal analysis and machine learning in online pump monitoring has transformed the way industrial pumps are monitored and maintained. It allows for continuous, real-time monitoring of pump vibrations, improves fault detection accuracy, and encourages proactive maintenance practiced. Businesses can improve the dependability, efficiency, and lifespan of their pumping systems by harnessing these technologies, resulting in increased productivity and lower maintenance costs.

1.2 Problem Statement

Excessive vibration in centrifugal pumps can lead to catastrophic pump failure, increased operational costs, pump running noisily, pump not priming or priming only intermittently, and maintenance costs. While a few research studies have reported on the use of vibration analysis for centrifugal pump condition monitoring to detect cavitation and mechanical failures, there is a lack of knowledge on the precise vibration frequencies related with these faults. Increasing the pump flow rate or rotational speed also can lead to an increase in cavitation and will lead to failure pump.

It is vital to identify the vibration frequencies caused by centrifugal pump failures and to construct a vibration-based fault detection technique. The fault frequency can be utilized to discover defects or damage in the pump before the entire system breakdowns. Implementing such a plan will aid in mitigating the problems caused by centrifugal pump failures in industrial sectors.

The research aims to analyze the vibration levels of centrifugal water pump through machine monitoring and different types of analysis techniques thus enabling better decision making concerning the water pump use and lifespan. This research was done using online monitoring system and wireless using a accelerometer and piezoelectric film sensor which are more effective. Vibration analysis data was taken under the speed and flow rate of centrifugal pump. So, totally four readings of speed and three readings of opening valve were monitored which are 800rpm, 1000rpm, 1200rpm, and 1400rpm for speed while for reading of opening valve is 20%, 40 % and 100%.

1.3 Research Objective

The main aim of this research is to monitor the vibration of centrifugal pump. Specifically, the objectives are as follow:

a) To measure pump vibration using Accelerometer and Piezofilm sensor .

b) To analyze pump, speed and flow rate by using vibration signal analysis method with different opening valve.

c) To validate the analyzed data by using a machine learning method.

1.4 Scope of research

The scope of this research are as follows:

- Monitor the vibration through the speed and flow rate of centrifugal pump. Pump was set up by changing the reading speed, flow rate and opening valve.
- Measured the effectiveness of Accelerometer sensor and wired sensor of Piezoelectric film for vibration measurement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss the necessary theories and information regarding the scope of this project. Aside from that, the description of the information and methodologies employed in previous study is revised. This chapter describes the equipment and software associated with the project, Vibration Analysis on Centrifugal Pump. The literature review is the reading of others' works before embarking on inspection work to gather significant facts and information, as well as comparable initiatives completed by others. The sources include prior theses, journals, conference papers, books, and the internet. This chapter collected and discussed all linked topics. The pattern of energy that can be employed is readily visible and explained.

2.2 NI Signal Express 2015

NI Signal express is data-logging software that can swiftly acquire, analyze and provide data from hundreds of data collection devices and instruments without any requirements programming. It has a user-friendly design and a variety of capabilities for data collecting analysis and reporting. This version provides a several features and enhancements over past versions, such as increased interaction with NI hardware devices, broader analysis capabilities, and improved user interface. The objective was to provide engineers and scientists with a simple platform for performing measurements and analyzing data.

2.3 Centrifugal pump

Figure 2.1 Centrifugal pump

Centrifugal pumps are the most frequent type of pump used in the industrial sector. Because of their simple design, great efficiency, and ease of maintenance, they are widely utilized. These pumps come in various configurations. They belong to the category of rotor dynamic pumps, which operate by utilizing an impeller to increase fluid pressure. The pump transfers rotational kinetic energy into fluid flow hydrodynamic energy by turning the impeller, allowing it to move liquids across the system. The rotational energy required is generated by a motor. Pumping action occurs when fluid enters the impeller on or near the axis of rotation and is propelled radially outward into the volute casing. The pump's discharge vanes then allow the fluid to escape.

2.4 Centrifugal pump working principle.

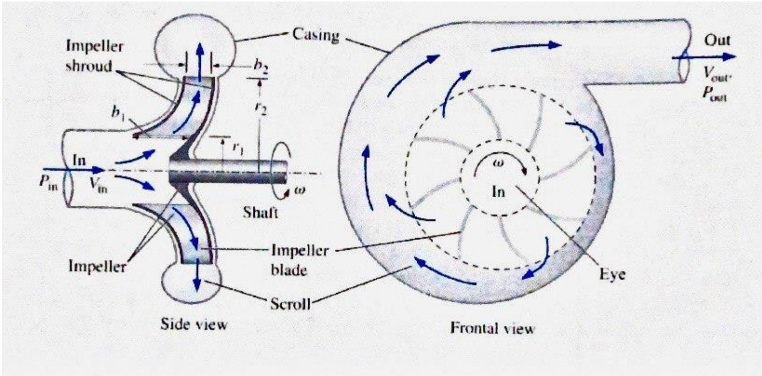


Figure 2.2 Side view and frontal view centrifugal pump

The impeller blades in a centrifugal pump are often surrounded with a shroud to promote rigidity, as shown in the schematic diagram for a centrifugal pump shown in Figure 2.2. Shaft, hub, and impeller blades provide the rotating assembly in a pump, and their accelerated radial motion is made possible by centrifugal forces generated by the rotation's circular motion. The fluid leaves the impeller at high velocity and pressure, and pushed into the volute, or scroll.

This scroll, as depicted in Figure 2.2, acts as a snail-shaped diffuser that decelerates the fast-moving fluid, further increasing its pressure, and the flow is directed from all blade passageways to a common outlet. As previously mentioned, under steady mean flow, incompressible fluid conditions, assuming equal inlet and outlet sizes, the average flow speed at the outlet remains the same as that at the inlet. Instead of speed, centrifugal pumps raise pressure from inlet to outlet.

In figure 2.2 represents a centrifugal pump from the side and front, depicting how the fluid enters axially at the pump's middle (known as the eye), is expended by the whirling impeller blades, dispersed by the expanding scroll, and finally expelled from the pump's side.

2.5 Vibration measurement

Vibration measurements are widely used in many domains, including mechanical engineering, condition monitoring and structural analysis. Time domain analysis and Fast Fourier Transform (FFT) in the frequency domain are two extensively used for approaches for analyzing vibration signals.

2.5.1 Analysis time-domain

According to (Dunton, 1999, the concept of analyzing time waveform data is not revolutionary. Oscilloscopes are often used to display time waveform data, and frequency components were calculated manually in the early days of vibration analysis. To connect time and frequency, use the following formula:

$$f = \frac{1}{P}$$

where:

f represents the frequency in hertz, and p represents the period in seconds.

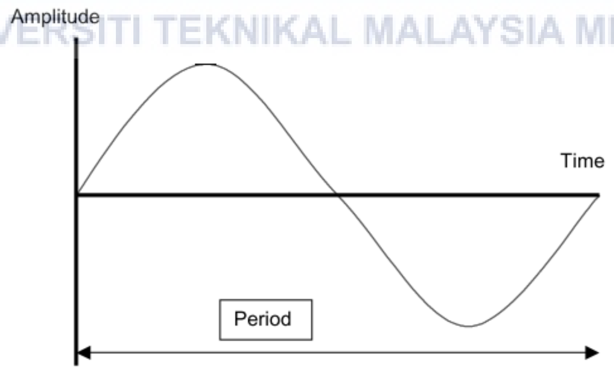


Figure 2.3 Frequency vs. time graph (Dunton)

Information on the overall condition of the gears, rubs, and sleeve bearings, can be found from the time-waveform, as well as to indicate appropriate amplitudes during machinery defects. By examining the time-domain graph, it is possible to identify machine faults or defects. Time-domain analysis involves investigating vibration information in relation to time, as stated by Kumar and Manjunath (2018). By analyzing the vibration or acoustic information captured by accelerometers, time-domain signals can be used to assess defects and faults. The standard deviation, root mean square, peak value, crest factor, Kurtosis, Skewness, clearance factor, impulse factor, shape factor, and upper and lower bound vibration values are examples of frequent statistical characteristics that are utilized. According to K M and T C (2016), doing a vibration analysis on rotating machinery can reveal a wide variety of system issues. Nonetheless, after the equalization of the energy reduction, and filtering of time-domain data, there is still noticeable variation in the vibration signatures produced by operational and malfunctioning machinery. Problems that can be found in machines in revolving parts include imbalance, rotor fracture, looseness, impeller defects, bearing defects, misalignment, high speed, rotor to stator friction, and flow whirl or whip. According to Vishwakarma et al. (2017), the Root Mean Square (RMS) and Crest factor are two important characteristics to consider while attempting to diagnose defects in rotating machinery. The RMS value of a vibration signal represents its power content and is particularly useful in detecting imbalances. However, while RMS is a fundamental method in time-domain analysis for fault detection in rotating machines, it may not be effective in detecting early-stage faults. Another important parameter is the crest factor, which is the ratio of the peak value to the RMS value of the input signal. The crest factor increases with the presence of peaks in time series signals.

2.5.2 Frequency Domain analysis

(Macfarlane, n.d.) used analysis frequency domain to quickly analyze the complex signal by decomposing them into their component parts and to simplify analysis by dividing the signal into smaller pieces. Analysis can be converted from time domain to frequency domain using the Fourier transform, while analysis can be converted from frequency domain to time domain using the inverse Fourier transform. Both of these transformations are employed often. The Discrete Fourier transform (DFT) is not as efficient as its faster counterpart, the Fast Fourier transform (FFT).

As explained by (Commtest.com, 2006), in Fast Fourier Transform (FFT) the vibrational frequencies and amplitude of the relevant part machine component are represented by a spectrum graph or other graphical representation. Vibrational frequencies of the component are revealed via the spectrum as well as the frequencies at which the amplitude of the vibration is greatest. By analyzing the frequencies and amplitudes at which a machine component vibrates, we can learn a great deal about the source of the vibration and the condition of the machine.

According (Shreve, 1995) explains that Fast Fourier Transform (FFT) is a new form of technology utilized for further signal processing. This is a method of separating the amplitude, phase, and frequency components of the time-varying signals. By correlating frequencies with machine attributes and examining amplitudes, problems or defects can be identified. The sweeping filter is frequently used in devices. Filters are utilized rather commonly in order to get rid of particular characteristics in the graph. For example, low pass filters are utilized in order to reduce the high frequency, while high pass filters are utilized to reduce the direct current (DC) and low-frequency noise.

2.6 Fault detection in centrifugal pump using vibration analysis.

2.6.1 Cavitation detection in centrifugal pump

When the liquid enters the center (eye) of a centrifugal pump, its pressure experiences a significant drop. This pressure drop becomes greater as the flow velocity through the pump increases. If the pressure drop is substantial enough or if the liquid's temperature is sufficiently high, the pressure can fall below the saturation pressure for the fluid being pumped, causing the liquid to vaporize and form steam bubbles. These vapor bubbles are carried along with the fluid by the pump impeller.

Because the flow velocity is increasing, the fluid pressure is increasing as well, which causes the vapour bubbles that are located on the outer sections of the impeller to suddenly burst. Cavitation is the name given to the phenomena that can present a significant challenge for centrifugal pumps. The majority of centrifugal pumps are not able to endure cavitation for extended periods of time, despite the fact that some pumps are built to withstand cavitation in limited volumes. Damage to the pump can be caused by cavitation in several different ways, including erosion of the impeller, vibrations, and other difficulties. According to the publications cited, vibration analysis is a technique for detecting cavitation in the centrifugal pumps. This technique is one of several.

In the study conducted by Al-Obaidi (2019b), vibration analysis was used to analyze how the speed of the pump's rotation affected the performance of the centrifugal pump as well as whether or not cavitation was detected. A range of pumping velocities and volumes rates were employed as parameters in the experiment. The results showed that cavitation occurrence and its size varied with both the flow rate as well as the speed at which the pump rotates. Increasing the pump flow rate or rotational speed led to an increase in cavitation, as evidenced by higher vibration amplitudes. The frequency range of the vibration is shown in the form of a waterfall graph in figure 2.4.

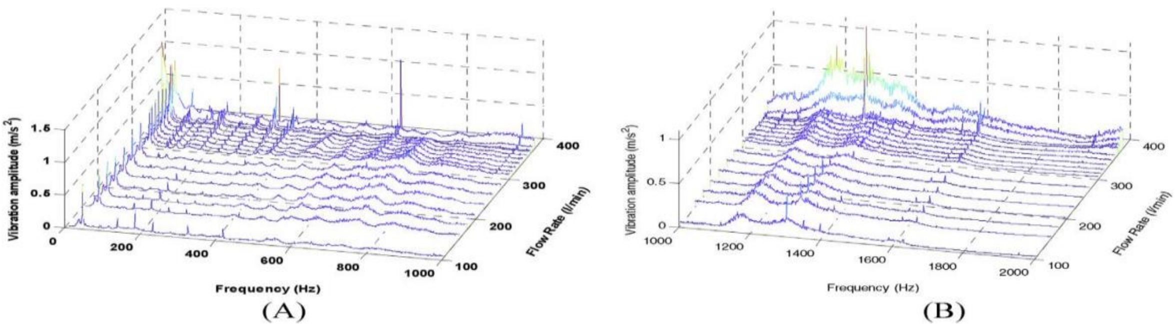


Figure 2.4 FFT spectrum at 2755rpm with different flow rates and vibration frequencies ranging from (a) 0 Hz to 1kHz and (b) 1kHz-2 kHz. Al-Obaidi (2019b).

In their research, Salem A. Al-Hashmi and Mohamed R. El-Hesnawi (2018) showed how cavitation can be detected through vibration signals. The vibrations from the pump were measured with an accelerometer. The speed of the pump was held constant at 2960 rpm while the flow rate varied. Using six distinct flow rates, vibration signals were recorded. It was determined that a flow rate of 340 l/min or higher was necessary for cavitation to occur. The time-domain and frequency-domain analyses were performed on the vibration signals. Using Fast Fourier Transform (FFT), the frequency domain amplitude spectrum was calculated. When the flow rate was more than 340 l/min, as shown in figure 2.5, the pump exhibited large vibration amplitudes even in the low-frequency range. To keep monitoring costs down, the authors looked for ways to detect cavitation in this low-frequency range.

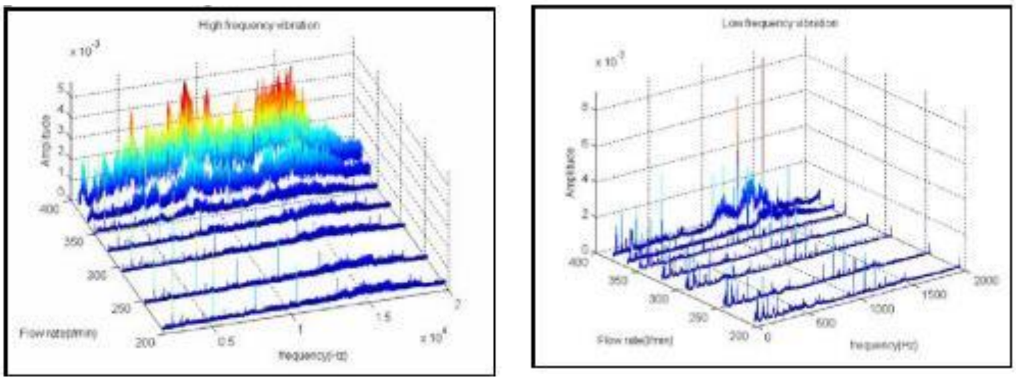


Figure 2.5 High-frequency and low-frequency waterfalls (Salem A. Al Hashmi, Mohamed R. El-Hesnawi*, 2018)

2.7 Pump

Pumps are the most significant asset in process industries, as they are utilized to transfer fluids and gases mechanically. The transported element is converted into a finished product that meets the target capacity. To achieve the goal, the performance of centrifugal pumps should be optimized. Pumps utilize 20% of global energy, according to statistics (Rakibuzzaman et al., 2015). The design of a pump and the operating circumstances of the system determine its energy efficiency.

Pumps are classified into two types which are dynamic pumps and positive displacement pumps. It is categorized according to the application, construction material, and fluid it handles. A positive displacement pump requires energy to mechanically move a fluid through a system by confining it to a set volume. This raises the pressure to the needed amount for the liquid to flow through the discharge line's ports. Because the PD (positive displacement) pump has a cyclic operating concept, it can be driven by components such as gears, pistons, vanes, rollers, diaphragms, or screws. A kinetic or rotodynamic pump is one that continually applies energy to a fluid via an impeller to raise its velocity.

2.8 Pump performance

A few factors should be taken into consideration while determining centrifugal pump performance. A pump's performance can be measured using three basic analytical models, which is volumetric flow rate, head and efficiency (η). pump performance is typically shown as a curve. This is known as the pump typical of curve. The pump typically describes the efficiency of pump's by graphing several elements like a pump head, pump efficiency, and power over a range of flowrate. Using a different volumetric flowrate, the pump head, efficiency and power will be investigated in this study and refine impeller performance. Figure 2.6 illustrates the pump characteristic curve.

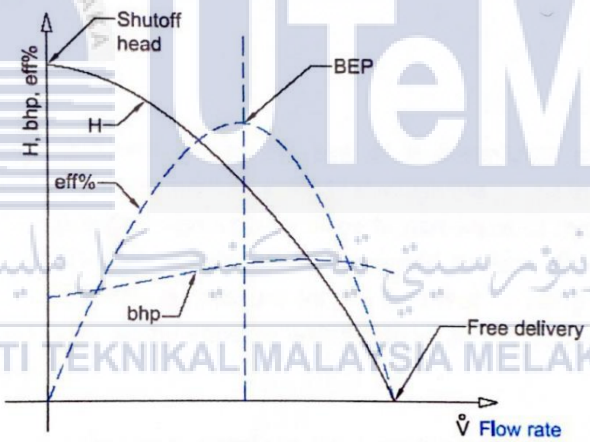


Figure 2.6 Pump performance curves

2.8.1 Volumetric flow rate

Several key parameters are utilized to evaluate the efficiency of a pump. One essential parameter is the mass flow rate (ṁ), which represents the amount of fluid passing through the pump. In situations involving incompressible flow, volume flow rate is often preferred over mass flow rate. Volume flow rate is referred to as capacity in the turbomachinery sector and is derived by calculating the mass flow rate and dividing it by the fluid's density.

$$\text{Volume flow rate (capacity)}: \dot{V} = \frac{\dot{m}}{p}$$

Where ṁ is mass flow rate, and p is density.

2.8.2 Head

The kinetic energy produced by the pump is described as a pump head. It is the height at which the pump can deliver a liquid at a certain volumetric flowrate. The pump's performance is determined by the head and flowrate. Instead of pressure, the centrifugal pump utilizes the head to measure its performance because pressure changes whereas fluid height does not depend on the liquid's specific gravity. Figure 2.7 depicts the pump head.

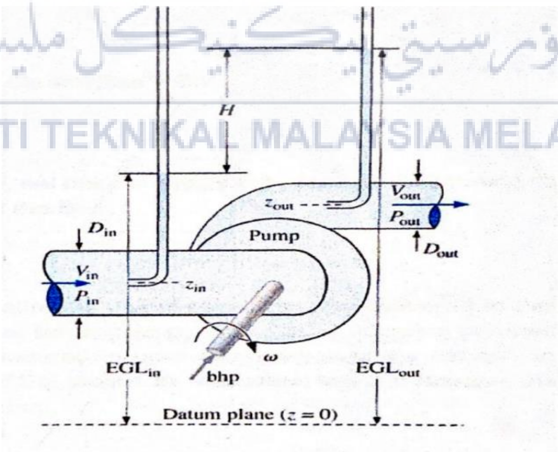


Figure 2.7 Pump head

The difference in Bernoulli head between the pump's input and output is known as the net head, H and it is also quantified. The net head is measured in length and generally represented as an equivalent column height of water, even it is for a dry pump.

$$\text{Net head: } H = \left(\frac{P}{pg} + \frac{V^2}{pg} + z\right)_{out} - \left(\frac{P}{pg} + \frac{V^2}{pg} + z\right)_{in}$$

Where:

P = Pressure (N/m²)

ρ = density of the liquid (kg/m³)

V = velocity (m/s)

g = gravitational acceleration constant (m/s²)

Z = elevation at the centroid (m)

When a liquid is being pushed, a Pitot probe in the flow can find the energy grade line (EGLin) at the intake, which is identical to the Bernoulli head, as shows in Figure 2.7. EGLout, the outlet energy grade line is obtained using the same technique shown in the picture. The height, diameter, and average speed of the discharge may vary from those of the inlet, depending on the design of the pump.the outlet energy grade line is obtained using the same technique shown in the picture. The height, diameter, and average speed of the discharge may vary from those of the inlet, depending on the design of the pump. Net head H equals the difference between EGLout and EGLin, regardless of the discrepancies.

Net head for a liquid pump: H = EGLout -EGLin

Consider the particular instance of incompressible flow through a pump with identical inlet and exit dimensions and no change in elevation. This equation requires the entire pumping system in order to calculate the pump value, however in this study, the analysis will only focus on the pump. As a result, the differential pressure between the intake and output was necessary to calculate the pump head from the simulation. To calculate the pump head from simulation, use the equation below.

$$H\ (m) = \frac{Poutlet - Pinlet}{Pg}$$

Where:

ρ = density of a liquid (kg/m³)

g = acceleration of the gravity (m/s²)

2.8.3 Efficiency

In the context of centrifugal pumps, efficiency can take several forms, such as the ratio of outlet power to intake power, the ratio of the pump's output water horsepower to shaft horsepower input for the pump, and so on. In this study, however, the pump efficiency is calculated by dividing the difference in pressure times flowrate by the impeller's angular velocity times the torque transferred by the shaft, as shown in the equation below.

$$\eta = \frac{(Poutlet - Pinlet)\ Q}{\omega T}$$

Where:

Pressure difference = P*outlet* - P*inlet* (Pa)

Q = volumetric flowrate (m³/s)

2.9 Centrifugal pump operating

The pump's operating point in a specific pipe system has been determined by the system's flow rate and head loss. One way to characterized a system is to plotted the volumetric flow rate versus the head loss. In order to find the operating point of a pump, its characteristic curve can be shown in the same coordinate system as the system's characteristic curve.

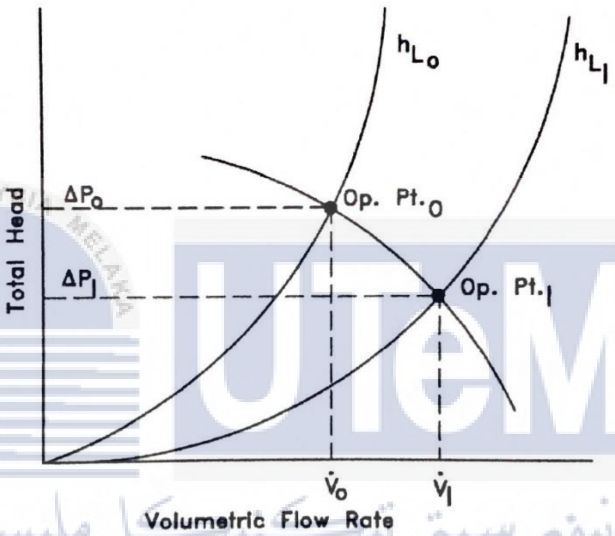


Figure 2.8 Operating point of centrifugal pump

The intersection of the pump curve with the system curve (hLo) represents the operating point of the centrifugal pump in the initial system, as illustrates in Figure 2.8. In this system, the flow rate is represented by Ủo, and the total system head loss is indicated by ΔPo. To maintain the desired flow rate (Ủ), the pump head should match ΔPo. In the system described by (Vo) and represented by the system curve (hL1), a valve has been opened to decrease the system resistance to flow. In this modified system, the pump can sustain a higher flow rate (Ủ) while operating at a reduced pump head, ΔP1.

2.9.1 System use of multiple centrifugal pump

A fundamental centrifugal pump consists of very few moving parts and is easily modifiable to work with a wide range of prime movers. Power sources such as alternating current (AC) and direct current (DC) electric motors, diesel engines, steam turbines, and air motors are all examples of prime movers. Centrifugal pumps are characterized by their diminutive size and low overall cost of construction. In addition, although operating at a low pressure, centrifugal pumps are capable of delivering a significant volumetric flow rate. Centrifugal pumps are frequently utilized in either a parallel or a series arrangement. This is typically done so that the system's volumetric flow rate can be increased, or so that high flow resistances can be compensated for.

2.9.1.1 Centrifugal pumps in parallel

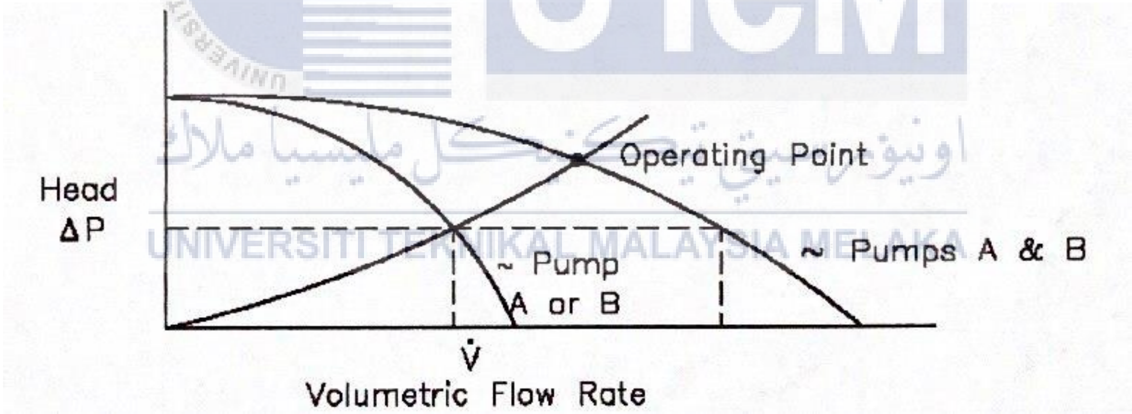


Figure 2.9 Operating point for two parallel centrifugal pumps

In a comparison between the system characteristic curve and the curve for pumps operating in parallel, the point of operation where the two curves intersect indicates an increased rate of volumetric flow compared to using a single pump, along with a greater system head loss. Figure 2.9 shows that the greater volumetric flow rates lead to higher fluid velocities results in a higher system head loss. However, because of increased system head, the actual volumetric flow rate attained by utilizing several parallel is less than twice that obtained by using a single pump.

2.9.1.2 Centrifugal pumps in series

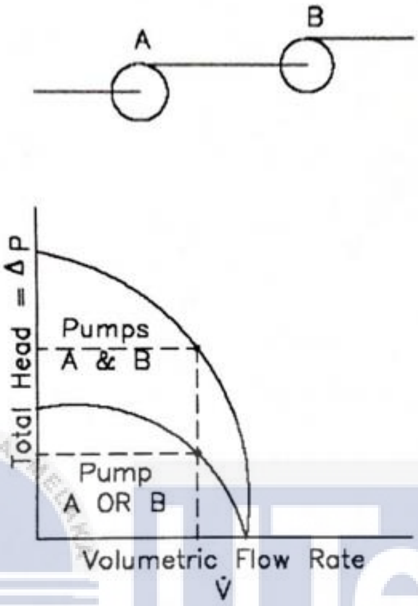


Figure 2.10 Pump characteristic curve for two identical centrifugal pumps used in series.

Frequently, centrifugal pumps are used in series to mitigate for a greater system head loss than can be compensated by a single pump. Figure 2.10 is a visual representation of this concept. When two centrifugal pumps of the same model are run at the same speed When two identical centrifugal pumps operate at the same speed and output volume, their contributions to the total pump head are equivalent. This means that both pump's output is summed to form the total head. Since the inlet of the second pump is connected to the outlet of the first pump, the volumetric flow rate remains the same throughout the system, from the first pump's intake to the second's discharge. This ensures a consistent flow rate through the pumps in the series arrangement. By combining the individual heads of multiple pumps operating in series, it becomes possible to overcome a larger system head loss. This arrangement allows for more efficient pumping and the ability to handle higher pressure or overcome resistance in the system. Overall, using a centrifugal pump in a series provides a means to compensate for larger head losses in a system by combining the individual heads of the multiple pumps, while maintaining a consistent volumetric flow rate.

As can be seen in figure 2.11, connecting two pumps in series does not actually result in an increase in the total amount of flow resistance inside the system. The two pumps contribute an acceptable amount of pump head to the new system, and in addition to that, they keep the volumetric flow rate at a somewhat higher level.

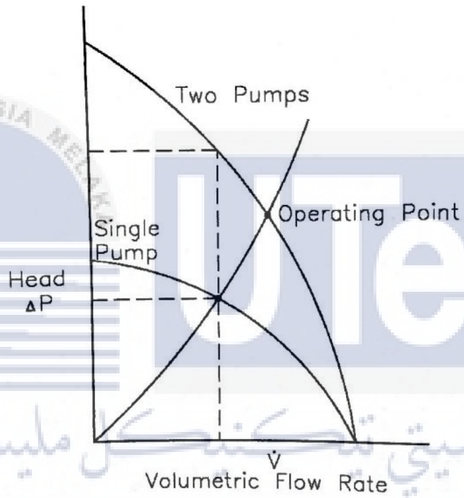


Figure 2.11 Point of operation for two centrifugal pumps connected in series.

2.10 Troubleshooting vibration in centrifugal pumps

Unbalance, rotor fracture, looseness, impeller flaws, bearing defects, misalignment, excessive speed, rotor to stator friction, and flow whirl are just a few of the system issues that can be detected by vibration analysis of rotating machinery. This is a sort of condition monitoring that is often used in spinning equipment such as centrifugal pumps. The vibration in a centrifugal pump can be classified into three groups, as presented in table 2.1.

Table 2.1 Symptom and causes of vibration.

Symptom leads to vibration	Causes of vibration
Pump leaking	• Casing bolts not properly tightened
	• Leakage in the mechanical seal
	• The seals are defective
Temperature of the pump increase	• Suction lift that is excessively high or positive suction head is set too low
	• Pump or pipework not completely filled
	• Pump is run against closed valve.
Output too low	• Back pressure too high
	• Wrong direction of rotation
	• Sealing gap too large because of wear

2.11 Previous research

This chapter is all about the research done to get more knowledge on the pump condition that the researchers previously employed. This is necessary to finish this bachelor's degree report thoroughly, as can be used as a guide and reference. So much crucial information was acquired, which aided in the completion of this project. To begin, condition monitoring, together with vibration analysis, is the primary focus of this project. The journals "A review on Pump Vibration Analysis Using Statistical Method" and "Pump Condition Monitoring" were utilized to research the condition monitoring system and machinery failures. The researchers' previous condition monitoring system was more suited to off-line monitoring, but these sources were nonetheless beneficial in comparing and identifying the benefits of online monitoring systems. Table 2.2 shows every research that has been studied.

Table 2.2 Summary of previous researches findings

No	Author	Title project	Case study	Advantage	Disadvantage
1.	Csanád Kalmár, Ferenc Hegedus (2019)	Condition monitoring of centrifugal pumps based on pressure measurement	Pressure signals are used to investigate the status of centrifugal pumps.	Pump continuous condition monitoring mechanism must be developed.	Some surface treatments void the guarantee, which is generally undesirable.
2.	Ahmed Ramadhan Al-Obaidi (2019)	Investigation of effect pump rotational speed on performance and detection of cavitation within a centrifugal pump using vibration analysis	Vibration techniques are used to detect and diagnose cavitation in a centrifugal pump	-	Reducing pump bearing life and seal failures.
3.	Xiaohui Luo, Jie Yang, Li Song (2022)	Analysis and research on vibration characteristics of nuclear centrifugal pumps at low flow rates	The purpose of this study is to look into the vibration characteristics of nuclear centrifugal pumps at low flow rates.	The root cause of nuclear centrifugal pumps hydraulic vibration was investigated using the vibration frequency characteristic that was discovered.	Low-flow centrifugal pumps can cause fluid separation, cavitation, and pressure pulsation. These phenomena can affect pump vibration performance negatively and unstably.
4.	TruettnerC. B., Barkdoll B.D.	Economic feasibility analysis of variable-speed pumps by simulating 15 multiple water distribution systems	To reduce pollution in the environment.	Variable-speed pumps (VSPs) can help to converse energy in water system	Variable-speed pumps (VSPs) does not always save energy

No	Author	Title project	Case study	Advantage	Disadvantage
5.	Ahmad Ramadhan Al-Obaidi (Jun 2020)	Detection of Cavitation Phenomenon within a Centrifugal Pump based on Vibration Analysis Technique in both Time and Frequency Domain	Time domain analysis (TDA) and frequency domain analysis (FDA) use statistical characteristics and the Fast Fourier Transform (FFT) to study the effects of various operating conditions, including cavitation flow rates.	-	-
6.	Salem A. Al-Hashmi , Mohamed R. El-Hesnawi	Processing Vibration Signals for Cavitation Detection	The use of structure vibration to detect and diagnose cavitation in a centrifugal pump.	Cavitation in centrifugal pumps can be detected by vibration in the construction.	-
7.	Xue R, Lin X, Zhang B (2022)	CFD and Energy Loss Model Analysis of High-Speed Centrifugal Pump with Low Specific Speed	To test the low specific speed pump with a sealed structure.	-	High speed centrifugal pumps are difficult to predict using the empirical correlation method because of the leakage generated by the bearing clearance and the motor channel.
8.	Zang J, Yang H, Liu H, Xu L, Lv Y (2021)	Pressure fluctuation characteristics of high-speed centrifugal pump with enlarged flow design	To pressure fluctuations were found to vary on a regular basis and to be consistent with the blade frequency.	High speed centrifugal pump with an expanded design performed	-

No	Author	Title project	Case study	Advantage	Disadvantage
				well at high flow rates.	

CHAPTER 3

METHODOLOGY

3.1 Introduction

This thesis is focused on how the motor pump works and the effect on the pump when it is in different speed and flow rate and also with three different of opening valve. The vibration analysis was done on centrifugal by using different types of speed and flow rate of centrifugal motor pump.

Vibration signal analysis was carried out through the National Instrument Signal Express 2015 software to monitor and analyze the vibration signals of centrifugal motor pump during its operation.

Piezoelectric film sensor were used to measure the conditions of the motor pump under five different speed and flow rate which is 600rpm, 1200rpm, 1800rpm, 2400rpm, and 3000rpm for speed while for reading flowrate is from 30 L/min, 60 L/min, 90 L/min, 120 L/min and 15 L/min.

3.2 Flow chart of methodology

The flowchart is the easiest way to describe the steps involved. In this research, the flowchart will determine the steps taken for redesign and analyze the centrifugal pump. Figure 3.1 below shows the flow chart of the process of this project to be easily understood.

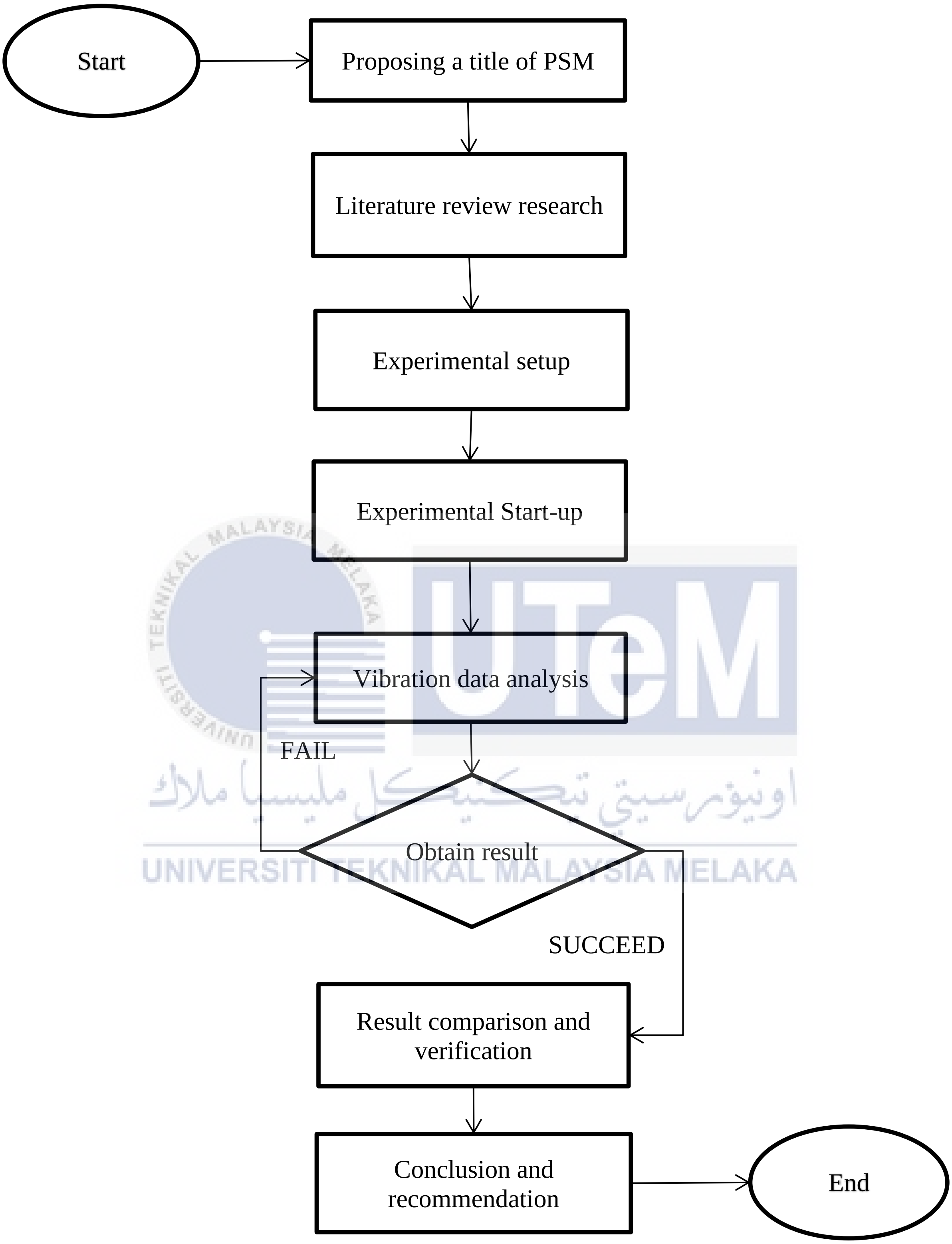


Figure 3.1 Project flow chart

3.3 Proposed Methodology

Firstly, the condition of centrifugal water pump was monitored. Each of the condition was tested with four different speeds and 3 different opening valves to detect the machine health conditioning. Each speed was set from 800 rpm to 1400 rpm. While opening valve is set from 20%, 40% and 100%. Figure 3.2 displays the flow chart of the motor pump condition during the process of taking data to be easily understood.

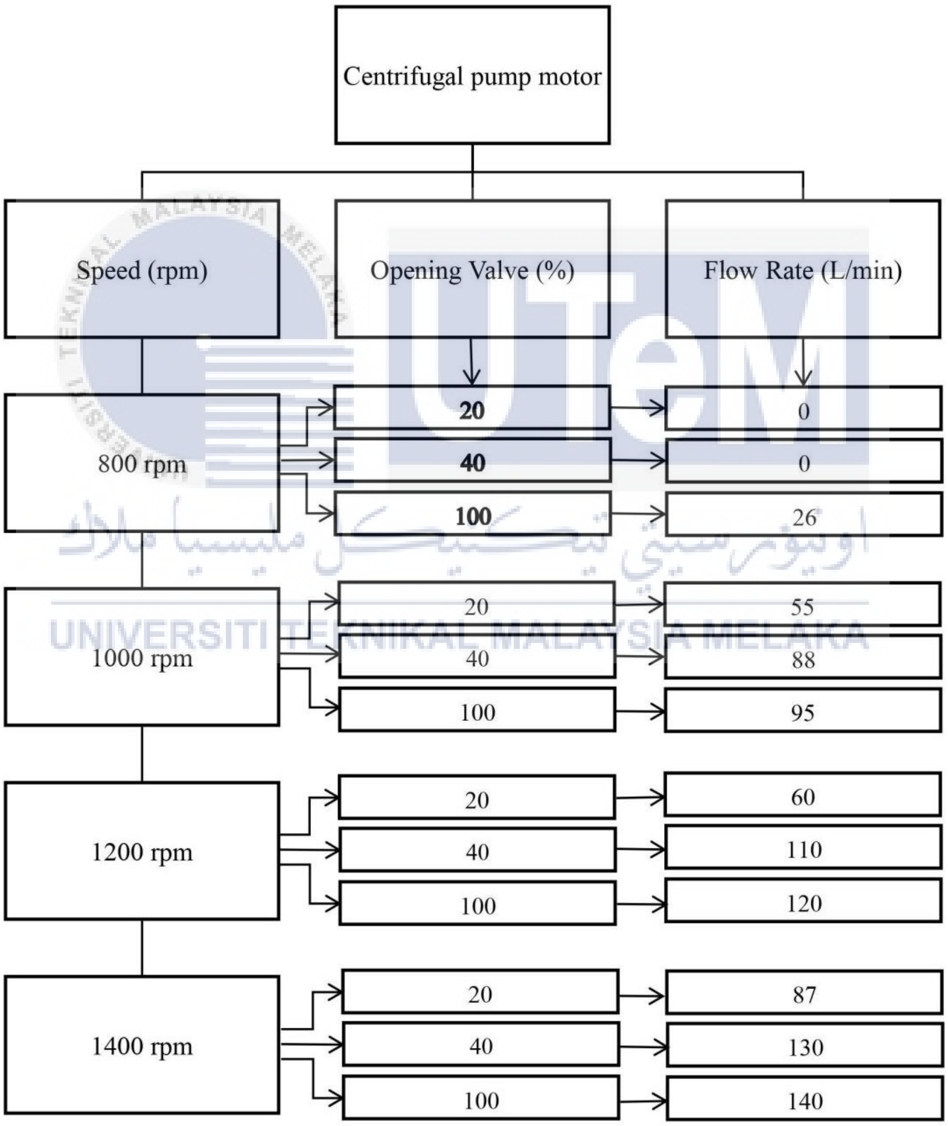


Figure 3.2 Flow chart of the motor pump condition during process of taking data.

3.3.1 Experimental Setup

This experiment setup consists of pump system, wired piezoelectric film, data acquisition, vibration analysis software, monitoring and analysis system and data validation. The pump used in the laboratory is selected for this monitoring purposes. Piezoelectric film wired are used to collect vibration data from the pump system. While NI-9234 is used to deliver 102dB of dynamic range and includes signal conditioning with Integrated Electronic Piezoelectric (IEPE). The obtain vibration signals is sent to the software specialized for vibration data, which is NI Signal Express to analyze the vibration data to perform time-domain and frequency domain analysis. For step monitoring and analysis system, which include algorithms is established to identify fault and abnormalities by triggering notifications if necessary. Furthermore, the vibration data with fault result is compared with benchmarking to ensure the accuracy.

The vibration analysis was conducted on the pump under varying conditions, encompassing five different speeds and flow rates. The pump was tested at speeds of 800 rpm, 1000 rpm, 1200 rpm, and 14000 rpm along with flow rates varying from 0 L/min to 140 L/min and opening valve from 20%, 40% and 100%. For efficient data transfer, the cable was initially connected from the NI-9234 to the laptop. Subsequently, the wires of the Piezoelectric Film were attached to channel 1. Once the connections were established, vibration readings were recorded. The configuration of the wires and cable connected to the laptop can be observed in Figure 3.3.

To detect the motor pump's vibration, a piezoelectric film was affixed to it. The resulting vibration data was analyzed using both time domain and frequency domain techniques within the NI Signal Express 2015 software. Additionally, a tape was applied to the motor pump, and by pressing the tachometer sensor against the tape, a laser was emitted, and the motor pump's speed was displayed on the laser tachometer screen. The distance between the tape and tachometer sensor was set at 1 meter.

Figure 3.3 Wires and cable connected to the laptop for transferred vibration data

3.3.1.1 Parameters

The parameters that were used in this project were the pump speed and flow rate by adjusting the electric control valve. The pumps were set to five different speed and valve opening. The data was collected three times for each of the conditions, and average value was calculated.

3.3.1.2 Equipment

This part shows that there were many equipment and software's were used in order to achieve the desired output of the project. The equipment that will be used in this project is Piezoelectric film, laser tachometer sensor, Module for inputting sound and vibration into the NI-9234 C Series, connecting wires and cable and software NI Signal Express 2015.

3.3.1.2.1 Piezoelectric film sensor

Piezoelectric films are used in a variety of sensor applications. Piezoelectric film switches are commonly used to compute the frequency, amplitude, and direction of an event, and they are extremely effective in detecting and recognizing things. These sensors are available in a wide range of thicknesses and measurement sizes. The DT film element generates more than 10 millivolt per micro-strain, which is approximately 60dB (decibels) more than the voltage output that is produced by a foil strain gauge. The DT type of sensors are the most basic type of piezofilm sensors and they are typically utilized as dynamic strain gauges and contact microphones for vibration or impact detection. The sensor is easily attached to a surface using double-sided tape or glue.

Furthermore, piezoelectric polymer film offers a significant advantage over ceramic piezoelectric materials. Piezoelectric polymer sheets have high sensitivity and low density. When extruded into thin film, piezoelectric polymers can be connected to structure without harming its mechanical motion.

Figure 3.4 Piezoelectric film sensor

3.3.1.2.2 Check-line PT-5000 Laser Tachometer

A laser tachometer is a non-contact device that measures rotational speed by directing a laser at a rotating object. The detection varies depending on the model, although it is normally within 78 inches or 2 meters. A contactless laser tachometer emits a laser light beam. This beam is directed at the rotating object’s reflecting strip (tape). on the reflective tape, the laser spot should be visible. When the light beam contacts this tape, the light from the tachometer is mirrored back to the detector. When the reflected signal is received, the device will counts on how many times it is received. As the result, the reading will be in rpm (revolution per minute). In Figure 3.5 shows that the tachometer sensor that we used to detect the reading of the motor speed.

Figure 3.5   Check-Line PLT-5000 Pocket Laser tachometer sensor

Display	5 digit 0.47" (12mm) height LCD
Rotation velocity	Non-contact / Contact 6.0-99,000 RPM
RPMs total	1-99,999
Detection of surface speed	Length 0.4% and ± 1 digit
Update time	One second
Detection	Laser Diode

Auto Power Off	5 minutes
Temperature of operation	32-110°F (0-45°C)
Dimensions	4.55" L x 2.52" W x1.24"H (115.5 mm x 64 mm x 3.15 mm)
Length with contact adaptor	149mm

Table 3.1 Specifications of Check-Line laser Tachometer

(Retrieved from : https://www.reliabilitydirectstore.com/product-p/ele-plt-5000.htm)

3.3.1.2.3 C Series sound and vibration input module NI-9234

The NI9234 is capable of monitoring signals from a wide variety of sensors, including integrated electronic piezoelectric (IEPE) and non -IEPE options such accelerometers, tachometers, and proximity probes. The NI-9234 can also work with advanced TEDS sensors. The NI-9234 has an extensive dynamic range, AC/DC coupling that can be toggled in software, and IEPE signal conditioning. Input channels do simultaneous measurements of signals. Anti-aliasing filters are built into each individual channel and scale up or down depending on the sample rate being used. This module, when combined with NI software, offers processing for condition monitoring activities including frequency analysis and order tracking. Figure 3.5 is a picture of an NI-9234.

Figure 3.6 NI-9234 C Series sound and vibration input module

Number of channels	4 analog input channels
ADC resolution	24 bits
Type of ADC	Delta-sigma (with analog prefiltering)
Frequency	13.1072 MHZ
Accuracy	±50 ppm maximum
Sampling mode	Simultaneous
Type of TEDS supported	IEEE 1451.4 TEDS Class 1

Table 3.2 Specification of C Series sound and vibration input module NI-9234

(Retrieved from: https://www.ni.com/docs/en-US/bundle/ni-9234-specs/page/specs.html)

3.3.1.2.4 Connecting Wires and Cable

The wires of Piezoelectric film are connected to the NI-9234 and then attached to the pumps. Connecting cables are utilized to establish a connection between the C series sound and vibration input module NI-9234 and a laptop, enabling the rapid transfer of data.

3.3.1.2.5 Software NI Signal Express 2015

NI Signal Express 2015 is especially effective in sound and vibration analysis applications, where it can analyze and monitor machine health, diagnose defects, and generate vibration analysis graphs. The software enables swift and efficient acquisition, analysis, and interpretation of data for diverse engineering and scientific purposes. Figure 3.6 shows the software of NI Signal Express.

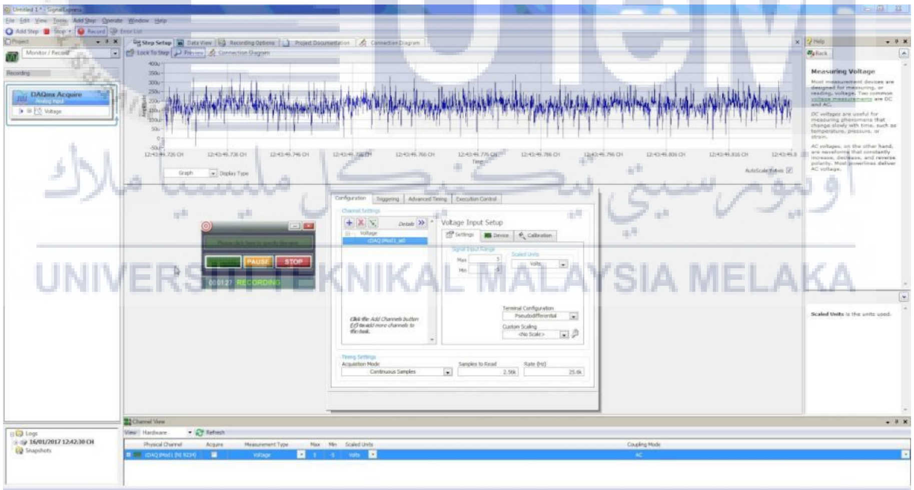


Figure 3.7 Software of NI Signal Express 2015

3.3.1.2.5 MATLAB R2023b

Matlab Matlab R2023b is a Matlab software suite version that is a strong tool for technical computing, simulation, and algorithm creation. In the context of vibrations in a centrifugal pump, Matlab may perform a variety of functions, including analysing vibration data obtained from sensors on the centrifugal pump. It can process, visualize, and interpret data to discover trends, frequencies, and potential vibration concerns. Matlab includes powerful signal processing tools that may be used to filter out noise, extract frequency components, do spectrum analysis, and much more. This is especially valuable in understanding the frequency components that contribute to pump vibration. Matlab can assist in detecting flaws or irregularities in a centrifugal pump by analysing vibration patterns.

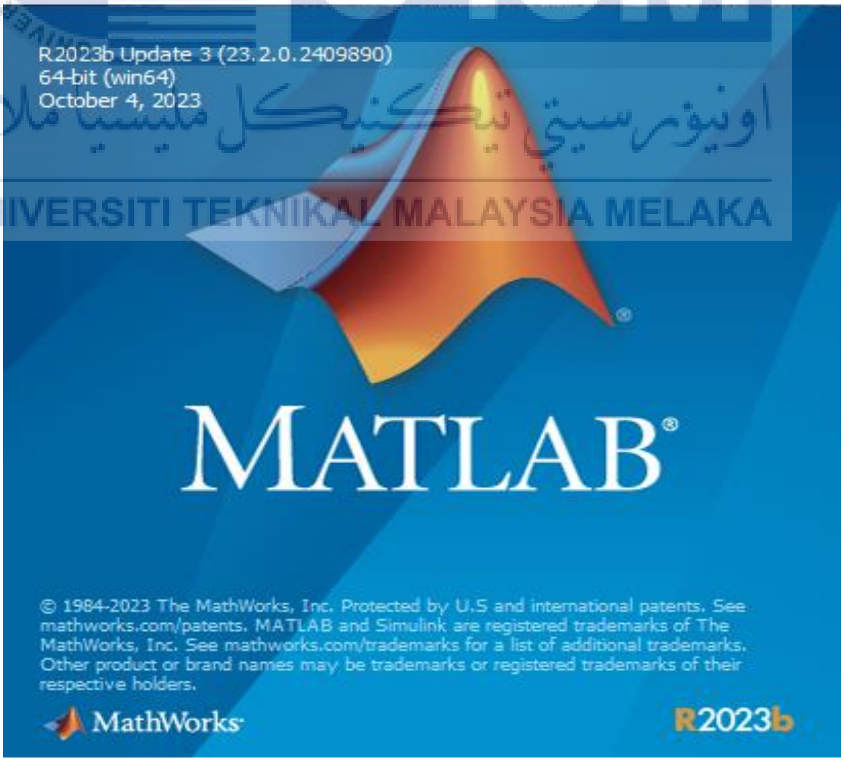


Figure 3.7 Matlab R2023

3.4 Summary

This chapter introduced the methodology that focuses on employing appropriate methods of analysis and regulatory planning with utmost efficiently. The recommended framework is supported by a series of steps aimed at ensuring the achievement of desired project outcomes. Additionally, this methodology discusses the essential required to collect the relevant data which is important to the purpose of implementing this PSM. The chapter is analysed in order to achieve an effective method to obtaining the exact result. This chapter present the proposed methodology of monitoring the vibration analysis of centrifugal pump using a Piezoelectric Film sensor. The software, NI Signal proves invaluable in generating vibration analysis graphs, detecting and diagnosing faults, and monitoring machine health. The pump was set up under different conditions during the process of monitoring. Subsequently, the acquired data is transferred to Microsoft Excel for ease of study, comparison and conclusive analysis.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will be covered the experiment’s anticipated results. The results will discuss the finding of all of pump speed and all flow rate to check whether the technique proposed can be applied significantly in that specific application. As mentioned before in Chapter 3, this experiment was carried out using the NI Signal Express 2015 to collect the data. Totally it was four different condition speed of the centrifugal pump were monitored accelerometer and piezofilm sensor to analyze the type of domain graphs produced by the vibration of the centrifugal pump machine. The centrifugal pump was setup in four different type of speed which is 800rpm, 1000rpm, 1200rpm and 1400rpm. The experiment was carried out at three different opening valve where is form 20% , 40%, and 100%.

4.2 Calibration Results

The vibration analysis cannot be undone until the accelerometer and piezofilm sensor interfaces in NI Signal Express have been calibrated. Each interface's calibration data is unique. As a result, it's also vital to ensure that the software accurately detects the interface being used before taking data.

4.2.1 Experimental Data Collection

The vibration data has been collected in term of speed, valve opening, ZFreq and RMS where the opening valve pump was setup from small to high. Table 4.1 shows the data that have been collected using a Ni Signal Express analysis. From the data, we can observe that vibration levels increase with the speed of valve. This is because the pump is rotating faster generating more centrifugal force. As the RPM rises, vibration levels elevate due to the pump's accelerated rotation, creating heightened centrifugal force. Similarly, when the valve opens wider, allowing more fluid flow, it imposes greater strain on the bearings and various components, consequently escalating vibration levels. Moreover, variations in RPM and valve opening cause shifts in the highest vibration peak's frequency, attributed to distinct fault types that trigger diverse vibration frequencies within the system. At 800 RPM and small valve opening, the highest vibration peak occurs at 20 Hz. This could be a sign of misalignment between the pump shaft and the bearing housing. At 1400 RPM and small valve opening, the highest vibration peak occurs at 2805 Hz. This could be a sign either its bearing fault or cavitation.

RPM		**800**		**1000**		**1200**		**1400**	
	Valve Opening	ZFreq	RMS	ZFreq	RMS	ZFreq	RMS	ZFreq	RMS
Small	20	966.1598	12.4504	3884.0895	18.7826	2603.9124	19.7166	2805.1663	20.7954
Medium	40	862.3241	11.8951	2827.8385	17.0792	2107.3431	18.3665	2554.4627	20.3188
High	100	798.8657	11.5909	2669.0813	16.7834	1970.2939	18.1807	1295.1194	17.2222

Table 4.1 Data collected using accelerometer sensor

RPM		800		1000		1200		1400	
	Valve Opening	ZFreq	RMS	ZFreq	RMS	ZFreq	RMS	ZFreq	RMS
Small	20	1.6759	0.4728	5.8619	0.8358	3.3763	0.7628	4.6539	0.8712
Medium	40	1.2421	0.4976	2.793	0.6618	3.5727	0.7672	4.5003	0.9033
High	100	0.7669	0.4823	1.7744	0.552	3.6303	0.8616	3.8988	0.8549

Table 4.2 Data collected using Piezofilm sensor

4.2.2 Experimental Result

From 800 to 1400 RPM at 4 different speeds with 3 different valve opening which is 20 %, 40% and 100. The vibration data are collected with respect to time in both the healthy and faulty conditions. After the data collection, a frequency valve opening has been performed and a graph percentage of valve opening and has been plotted. The graph in figure 4.1 using the accelerometer sensor and figure 4.3 using the piezofilm sensor shows the relationship between the frequency of the valve opening (ZFreq) and the percentage of valve opening (%) on centrifugal pump at different speed. The graph shows that the ZFreq increases at all speed. However, the increased in ZFreq is more pronounced at higher speeds. This is due the pump is more efficient at moving fluid at higher engine speed. The pump in more efficient at moving fluid at higher pump speed. The pump rotation speed increases as the pump speed increase. The increased pump rotation speed results in a higher ZFreq. The pump has a valve that can be used to control the flow rate of the water.

While for piezo film sensor data in figure 4.2 and figure 4.4, the graph shows the relationship between RMS (Root Mean Square) of the valve opening and the percentage of valve opening on a centrifugal pump. The RMS of the valve opening is a measure of the average amplitude of the valve opening over time. The RMS of the valve opening increases as the percentage of valve opening increases. This is because a higher percentage of valve opening allows more fluid to low through the pump, which increases the vibration of the valve. The increased vibration of the valve results in a higher RMS of the valve opening. The graph also shows that the RMS of the valve opening increases at a faster rate as the percentage of valve opening increases. This is because the valve is more likely to resonate at higher percentages of valve opening. When a valve resonates, it vibrates at much greater amplitude than it would otherwise, and it can cause the RMS of the valve opening increase significantly.

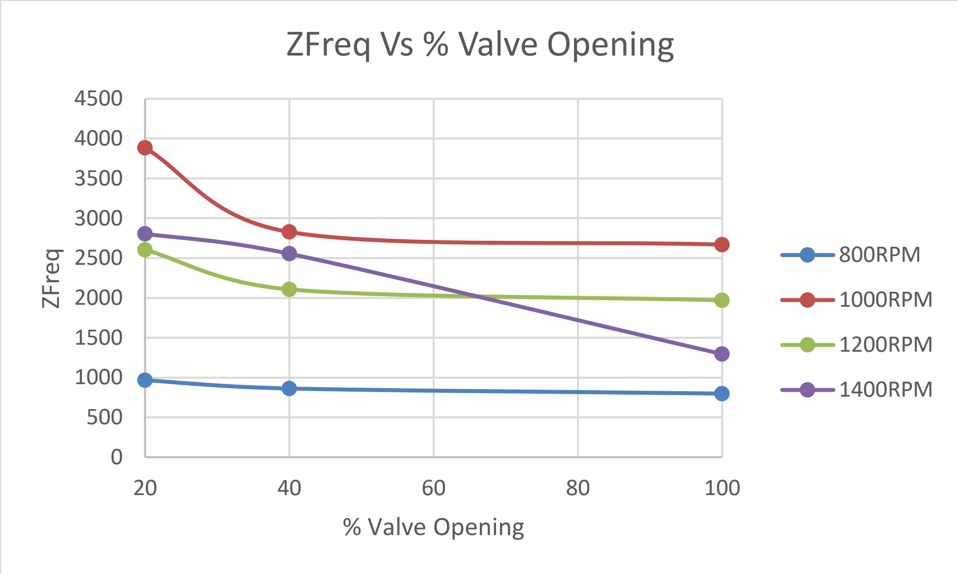


Figure 4.1 ZFreq Vs Valve Opening of Accelerometer sensor

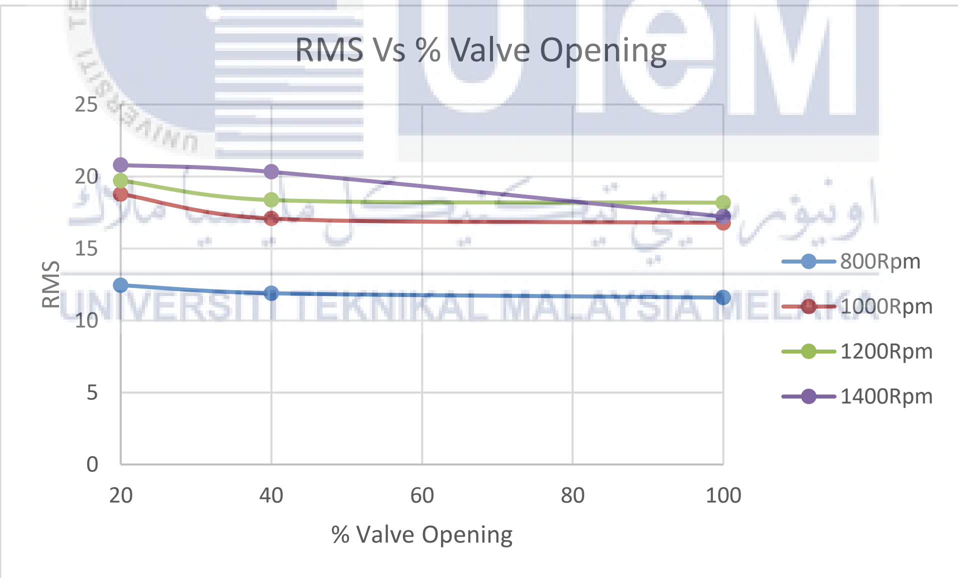


Figure 4.2 RMS Vs Valve Opening of Accelerometer sensor

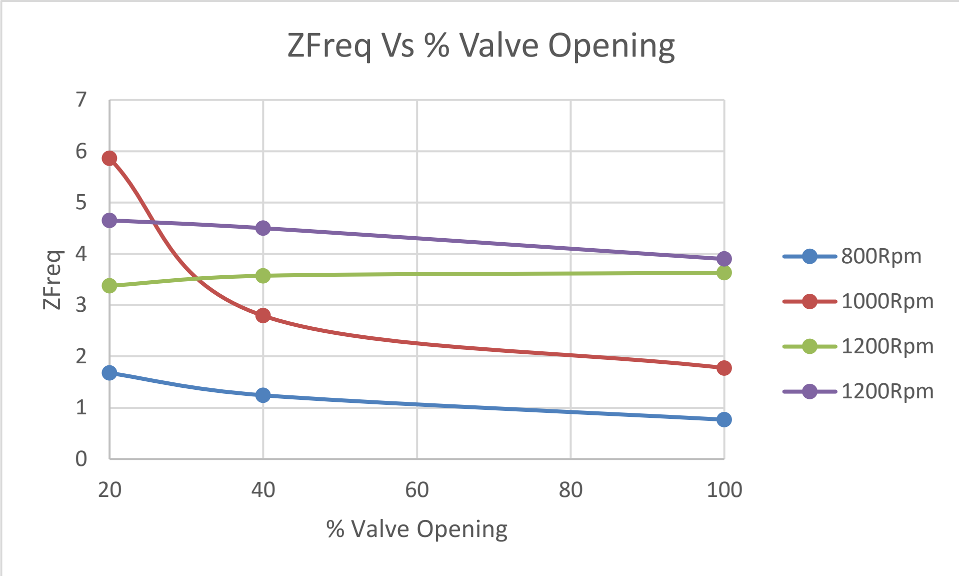


Figure 4.3 ZFreq Vs % Valve Opening of Piezofilm sensor

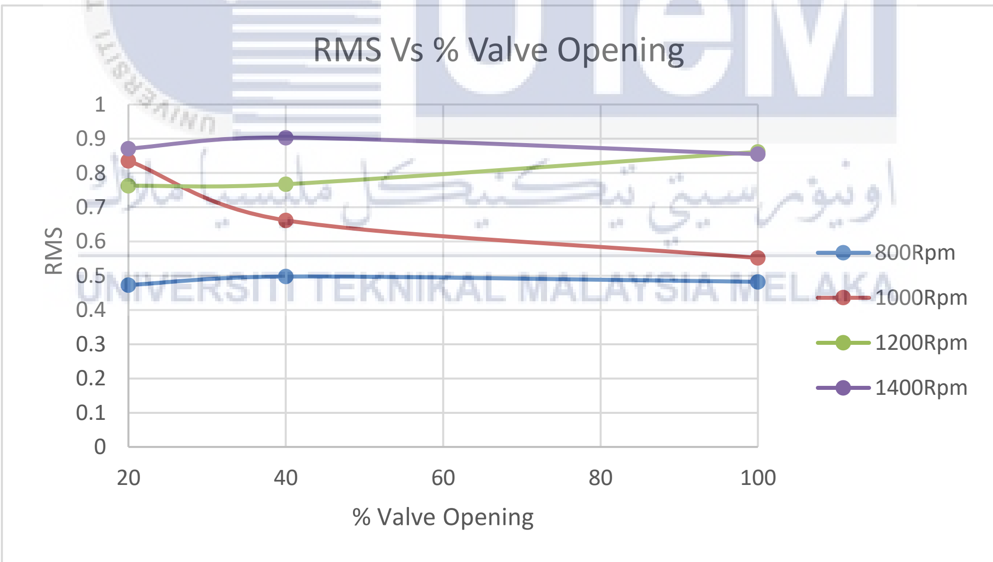


Figure 4.4 RMS Vs %Valve Opening of Piezofilm sensor

4.2.3 Prediction Tools

4.2.3.1 Support Vector Machine (SVM)

Support Vector Machine (SVM) is a machine learning prediction technique that is often used to forecast events such as stock market movements, weather patterns, and failure. This sort of supervised learning model is well-known for its application in pattern recognition and capacity to discover linear predictors in high-dimensional feature spaces. SVM is also an excellent AI technique for analysing and classifying engine vibration data and Z-freq coefficients, which makes it easier to spot these patterns. The training samples were chosen at random with equal ratios to examine the system's ability to classify normal and fault states in the measurement data.

4.2.3.2 k-Nearest Neighbor (kNN)

k-Nearest Neighbour (kNN) is a classification technique used in machine learning for defect diagnostics that requires training selected features and class labels for classification purposes. It remembers the training set and searches for the closest neighbour to predict the label of any new data. Under some conditions, selecting the nearest neighbour can be a remarkably quick process because it is predicated on the idea that the qualities are relevant to its classification. This kNN classification technique on engine signals is evaluated using different distance metrics, such as Euclidean, Manhattan, or cosine similarity. The metric used has a significant impact on categorization accuracy. Furthermore, determining the ideal value for 'k,' which represents the number of nearest neighbors evaluated, has a significant impact on the algorithm's performance. To obtain robust and accurate findings, our kNN evaluation on engine signals requires extensive validation and fine-tuning.

4.2.4 Prediction Results

Table 4.3 are the kNN and SVM conclusion matrix of the monitoring test with two different of the sensor. This information is about the accuracy of two machine learning, kNN and SVM, for classifying the condition of centrifugal pumps based on vibration data. As we can see, the accuracy for both sensor are slightly different. kNN has slightly higher accuracy than SVM for both sensor types, but the difference is small (around 2%). With accelerometer data, kNN has an accuracy of 100%, while SVM has an accuracy of 94.4%.

For the prediction speed of the engine, the kNN is slightly faster than SVM for both sensor types. This is means it can make predictions much quicker. SVM takes more time to build the classification model. KNN is better for getting the most accurate results. In important situations, even a small change in accuracy could be important. On the other hand, SVM is great if speed and efficiency are the most important things. It is a better choice because it can guess things quickly and needs less training. From the conclusion matrix, we can know which sensor is more accurate to calibrate the vibration of the centrifugal pump and can be considered successfully detected by the system.

Tools	SENSOR			
	ACCELEROMETER		PIEZOFILM	
kNN	Accuracy (%)	100	Accuracy (%)	66.7
	Prediction speed (obs/sec)	37	Prediction speed (obs/sec)	130
	Training time (sec)	231.08	Training time (sec)	295.74
	Total cost (Validation)	0	Total cost (Validation)	12
SVM	Accuracy (%)	94.4	Accuracy (%)	58.3
	Prediction speed (obs/sec)	17	Prediction speed (obs/sec)	17
	Training time (sec)	266.84	Training time (sec)	363.42
	Total cost (Validation)	2	Total cost (Validation)	15

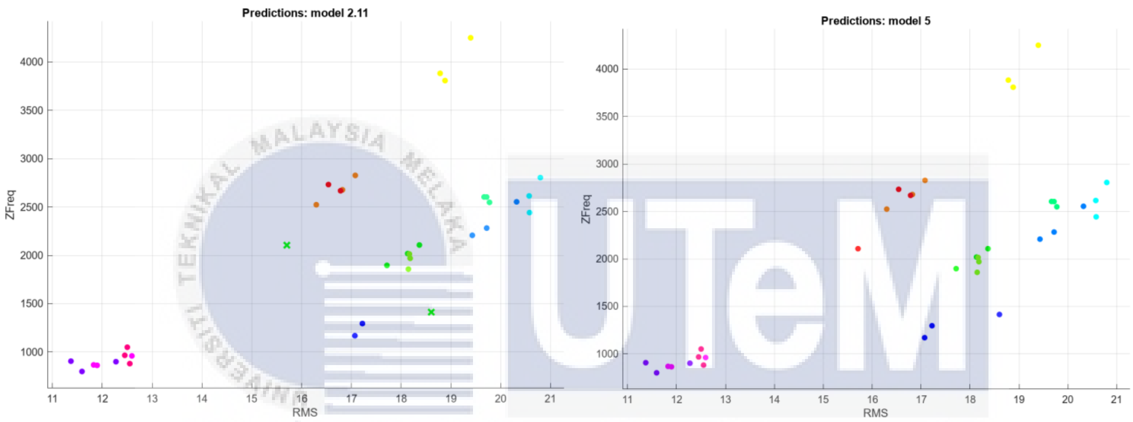
Table 4.3 Confusion Matrix

4.2.4.1 Scatter Plot

SVM and kNN exemplify several important trade-off in machine learning (ML). SVM is less computationally demanding than kNN and easier to interpret but can identify only a limited set of patterns. In figure 4.5 and figure 4.6 show a scatter plot with four distinct cluster of each data points, each in different colour as shown in Figure 4.7. On the other hand, kNN can find very complex patterns but its output is more challenging to interpret. In these cases, we'll illustrate SVM using a two class problem and begin with a case in which the classes are linearly separable, meaning that a straight line can be drawn that perfectly separates the classes with the margin being the perpendicular distance between the closest point to the line from each class.

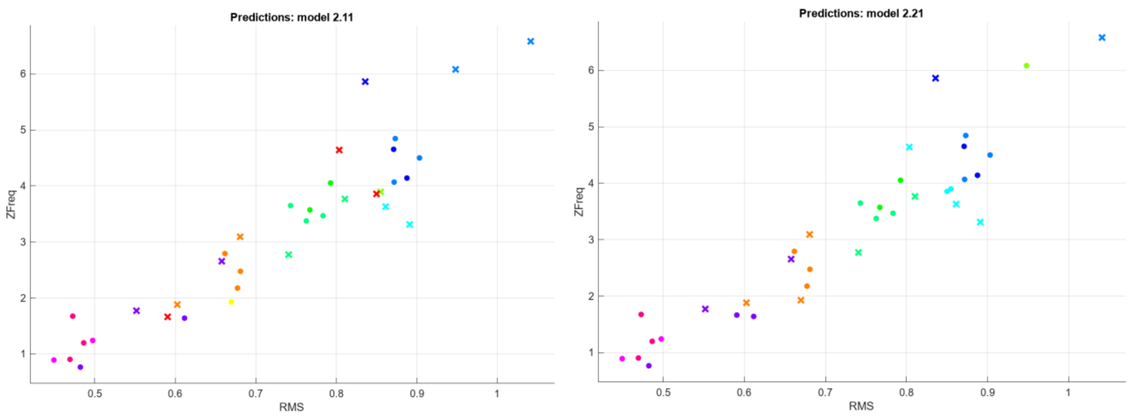
In SVM, the line that is used to separate the classes is referred to as hyperplane. In figure 4.5 (a) we can draw a hyperplane because of their separation of each data. The data points on either side of the hyperplane that are closest to the hyperplane are called Support Vectors which is used to plot the boundary line. The distance between the vectors and the hyperplane is called as margin. The hyperplane with maximum margin is called the optimal hyperplane. In figure 4.5 (a), the two 'X' of the green one is not in the right position means either scatter plot represent incorrect feature that can lead to misinterpreting the relationships captured by each algorithm or mislabeling of pump condition. SVM in Piezofilm sensor in figure 4.6 (a) shows that it can't draw a straight line because the data is not in the right position. If the predicted pump condition either in healthy or faulty condition is not correctly assigned to the data point, it can skew the accuracy and performances metrics for both SVM and kNN as shown in table 4.3.

In kNN, the algorithm is told how many nearest neighbors it has in terms of distance in the feature space. Based on their speed, the data points obviously form separate clusters. Measurements made at higher speeds in yellow, orange, red, green, turquoise, and blue appear further away from the origin, indicating higher vibration levels than those obtained at lower speeds in pink and blue. This is to be expected because centrifugal pumps vibrate more as their speed increases. There appears to be some divergence between the data points inside the RPM cluster based on the valve opening size. Larger valve apertures may cause increasing vibration levels due to increased flow turbulence or cavitation. The scatter plot illustrates how the vibration data of the centrifugal pump fluctuates under different operating situations.



(a) (b)

Figure 4.5 (a) Scatter Plot SVM for Accelerometer , b) Scatter Plot kNN for Accelerometer



(a) (b)

Figure 4.6 (a) Scatter plot SVM for Piezofilm, (b) Scatter Plot kNN for Piezofilm

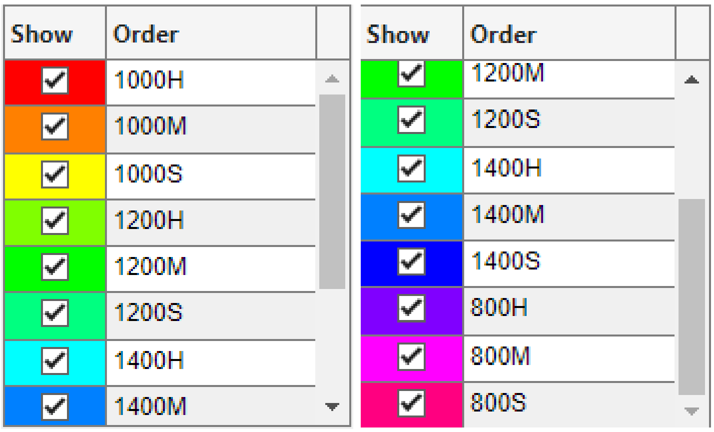
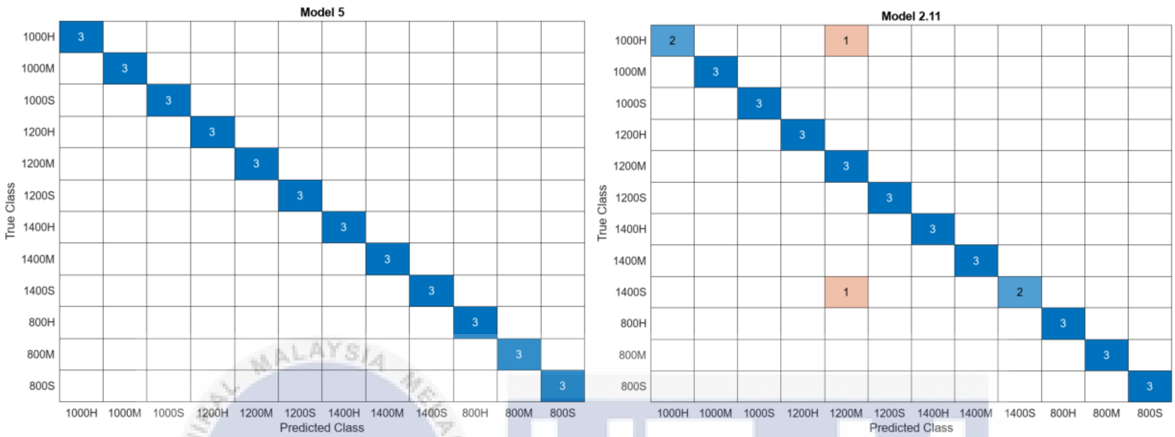


Figure 4.7 Label colour in Scatter Plot

4.2.4.2 Confusion Matrix

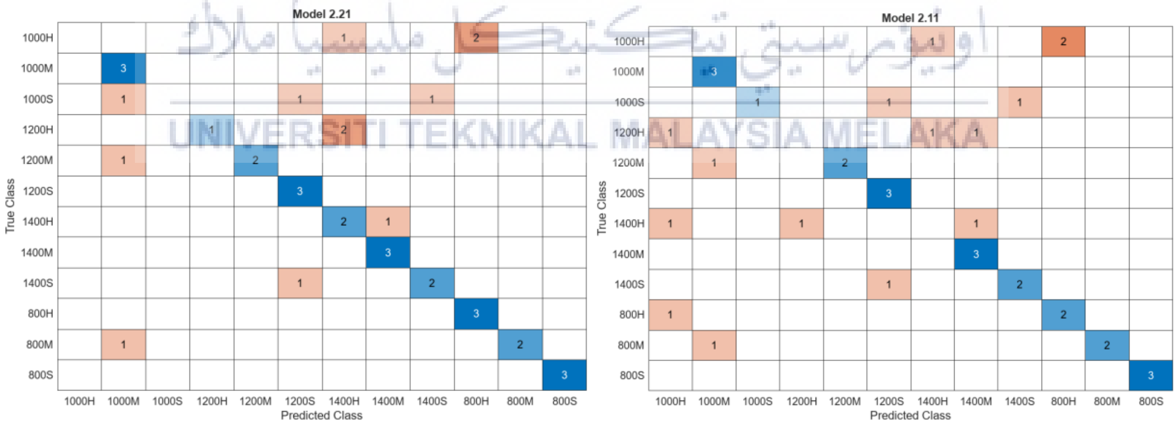
In machine learning and statistics, a confusion matrix is a table used to evaluate the effectiveness of a classification model. It summarizes the categorization findings by displaying the number of true positive, true negative, false positive, and false negative predictions. These numbers aid in evaluating a model's accuracy, precision, and recall, which are critical metrics for understanding how well the model categories data. Each row of the matrix represents an actual class, while each column represents a predicted class, allowing visualization of the model's performance in terms of properly or erroneously categorized examples.

The confusion matrix below shows that the accelerometer sensor is ideal for measuring vibration in centrifugal pump engines because the overall data in the confusion matrix of the accelerometer, as shown in Figure 4.8, is in the actual positions or classes and only two data points are not in the correct places in Figure 4.8 (b). So for the conclusion of kNN, it is more suited for the data measurement. The sensor in Figure 4.9 is a piezofilm sensor. We can observe from the confusion matrix that a significant part of the obtained data is not in the actual class. Centrifugal pump vibrations can have elaborate patterns that are impacted by different parameters such as speed and opening valve. Certain vibration patterns may be misclassified if the model fails to capture the intricacies. Different sensors may catch vibrations differently or have different noise characteristics, as seen in figure 4.9. In the data collection process, environmental noise or interference could generate anomalies or deceptive patterns, resulting in misclassifications. Misclassifications may occur if the variances are not accounted for in the model.



(a) (b)

Figure 4.8 (a) Confusion Matrix kNN of accelerometer sensor, (b) Confusion Matrix SVM of accelerometer sensor



(a) (b)

Figure 4.9 (a) Confusion Matrix kNN for Piezofilm sensor, (b) Confusion Matrix SVM for Piezofilm Sensor.

4.2.5 Comparison Analysis Vibration Signal Analysis

4.2.5.1 Accelerometer

Different vibration waveforms signals collected by accelerometer sensor that is mounted on the centrifugal pump casing. Both figure depicts the relation between the amplitude and time for the vibration waveform signals under various flow rates for different valve opening and pump rotational speed of 1200rpm. It can be seen from both figure there are different levels of vibration amplitudes according to the change in the flow rate. When the pump works under the 20% opening valve of flow rate, the levels of vibration amplitudes are almost the same. It is also worth noticing that at a 100% valve opening of flow rate, the levels of vibration amplitudes are lower than 20% when the pump operates under high flow rate.

Possible explanations for this phenomena include an increase in vibration amplitude caused by an incipient cavitation event occurring at a high flow rate, which will intensify as the flow rate is increased. The reason for this is that when cavitation occurs in the pump, it forms very small bubbles, which collapse, causing changes in the shape and amplitude of the vibration signals. Furthermore, it can be observed that cavitation is one of the primary reasons of flow instability within a pump. The comparison of figures 4.10 and 4.11 shows that vibration signals are sensitive to anticipating cavitation within a pump.

To analyse further, frequency domain analysis has been carried out in studying the effect of the different measurements of the flow rates on the vibration amplitude. For this purpose, the 2 percentage valve opening has been used in this section. Both of the figure allows comparing more than one vibration amplitude signal in frequency domain and hence it can be illustrated that from this figure how the vibration amplitude it changes within the centrifugal pump under various operation conditions. It can be seen that from both figures, there are small variances in the level of vibration amplitude within the centrifugal pump. The most higher peak of frequency domain is x-axis 59 and y-axis 10028.7. However, it can be clearly observed that there is a significant increase in the level of vibration amplitude that occurred, when the pump is operated under flow rate. The reason behind that is due to the high interaction between water and the blades of the impeller, as well as the interaction between the impeller and volute. Moreover, one important reason is due to the occurrence of cavitation within the pump.

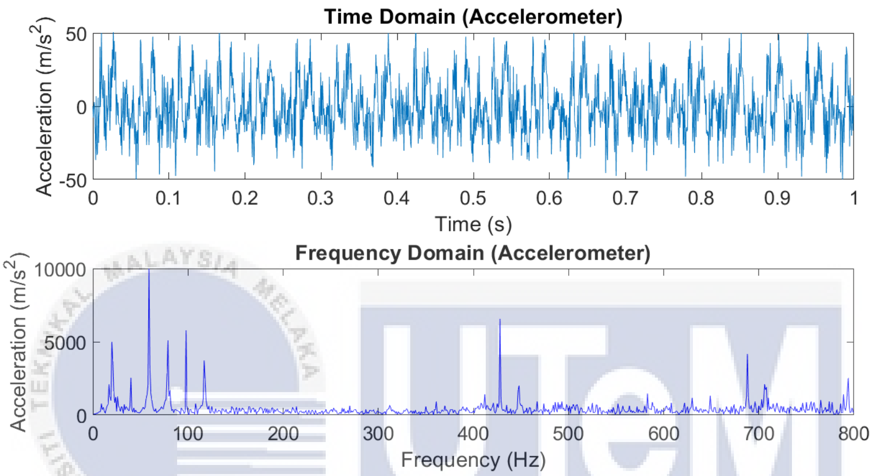


Figure 4.10 Time domain and Frequency domain of 20% Valve opening using accelerometer sensor

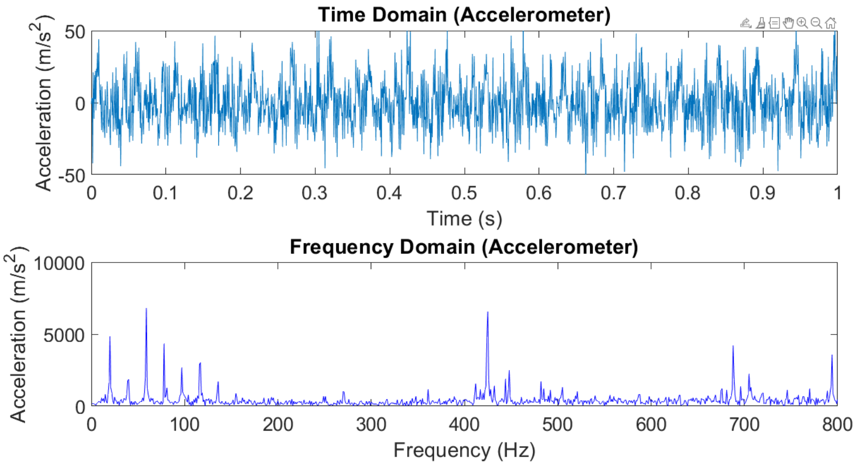


Figure 4.11 Time domain and Frequency domain of 100% Valve opening using accelerometer sensor

4.2.5.2 Piezofilm

While using the Piezofilm sensor, both of opening valve in time domain shows that there's only slightly peak. This is due to a low-sensitivity sensor may produce smaller peak values in the recorded data, indicating a diminished ability to collect and magnify these signals. Sensor sensitivity, which varies between piezofilm sensors, has a significant impact on its reactivity to force or vibration. Because of this variation, same force or vibration levels may produce different responses.

Furthermore, the sensor's placement and orientation are critical to its function. If the sensor is not placed close to the vibration source or is poorly angled, it may detect weaker signals, resulting in fewer peaks in the data. Incorrect sensor or data acquisition system calibration can further distort measurements, influencing observed peak levels. Furthermore, parameters such as flow velocity, pressure, and turbulence levels inside the system all have a substantial impact on the force conveyed to the sensor. Weaker or laminar flows may not produce sufficiently robust vibrations, limiting the sensor's capacity to register significant peaks in response to transmitted force.

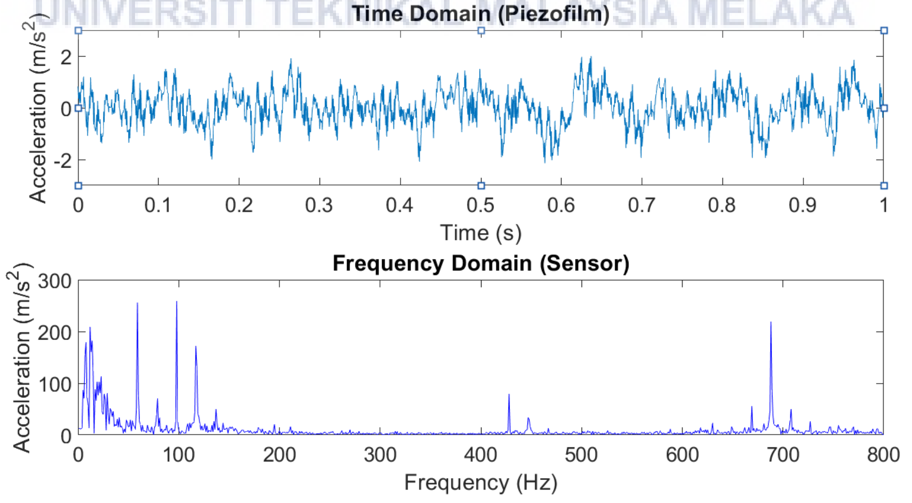


Figure 4.12 Time domain and Frequency domain of 20% Valve opening using piezofilm sensor

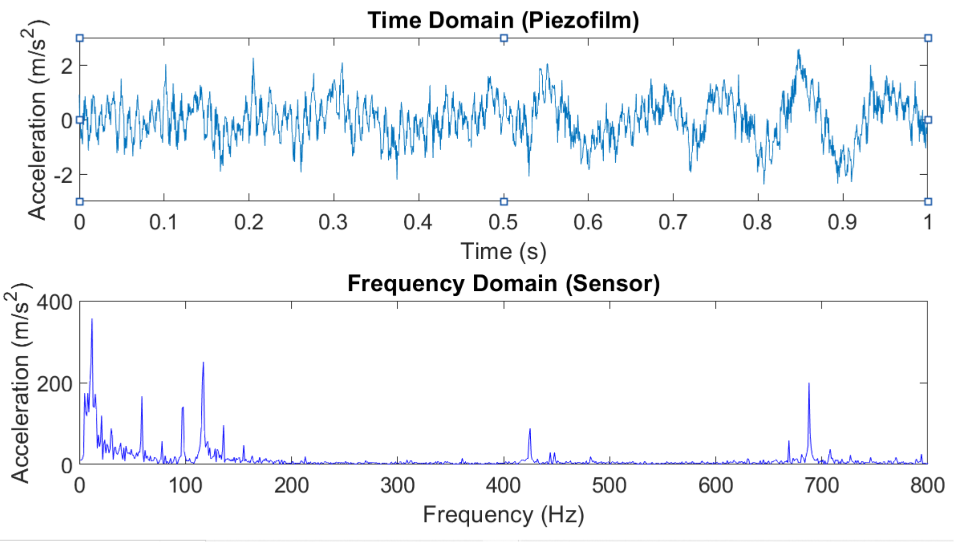


Figure 4.13 Time domain and Frequency domain of 100% Valve opening using piezofilm sensor

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study examines centrifugal pump behavior under varying speeds and valve openings, using accelerometer and piezofilm sensors. At higher speeds, the pump operates more efficiently, moving fluid better. Accelerometer data shows increased valve opening frequency with higher speeds, while piezofilm data indicates higher valve vibration amplitude with larger openings, especially at resonance levels. Understanding these relationships aids in optimizing pump performance and controlling water flow through valve adjustments.

Specifically, with accelerometer data, kNN achieves 100% accuracy while SVM reaches 94.4%. Additionally, kNN demonstrates faster prediction speeds than SVM for both sensors, making quicker predictions. While kNN excels in accuracy, SVM shines in speed and efficiency, requiring less training and faster guesswork. Overall, these findings underscore the significant impact of flow rates, valve openings, and cavitation on vibration patterns within the centrifugal pump, providing valuable insights into its operational behavior and potential instabilities.

5.2 Recommendations

There are few recommendations that can made for future work:

i. Choose sensors with higher sensitivity for accurate signal capture. Ensure precise calibration to minimize data distortion and ensure consistent readings.

ii. Optimize sensor positioning and angles close to the vibration source for enhanced signal detection. Proper placement is crucial for capturing robust data.

GANTT CHART PSM 1

PSM 1 PLANNING GANTT CHART																
2023																
MONTH	FEB		MARCH				APRIL				MAY				JUNE	
ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Proposed Project																
Find Supervisor																
Decide Project Title																
Identify objective, problem statement, and literature review																
Thesis for Instrumentations and Software																
Plan experimental setup																
Method of Component																
Project Costing																
Identify instrumentations and software	PSM 1 BRIEFING								MID SEMESTER BREAK							SEMESTER BREAK
Selection of Instrumentations and Software																
Final selection of suitable system																
Finalize the project experimental setup																
Project Deliverable (PSM1)																
Chapter 1,2 and 3 draft submission																
Chapter 1,2 and 3 final submission																
Submission Final Report																
Presentation																
Slide Presentation																

GANNT CHART PSM 2

PSM 2 PLANNING GANTT CHART																
2023																
BIL	TASK	PLAN/ ACTUAL	WEEK													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Briefing	Plan														
		Actual														
2	Experimental setup	Plan														
		Actual														
3	Data Collection	Plan														
		Actual														
4	Result Analysis	Plan														
		Actual														
5	Result Verification	Plan														
		Actual														
6	Conclusion and Recommendation	Plan									MID SEMESTER BREAK					
		Actual														
7	Weekly BDP Reporting (Logbook)	Plan														
		Actual														
8	Project Reporting	Plan														
		Actual														
9	4 Pages Summary	Plan														
		Actual														
10	Presentation & Poster	Plan														
		Actual														

REFERENCES

Zhang, J., Yang, H., Liu, H., Xu, L., & Lv, Y. (2021). *Pressure Fluctuation Characteristics Of High-Speed Centrifugal Pump With Enlarged Flow Design*. *Processes*, 9(12). https://doi.org/10.3390/pr9122261

Zhou, R., Chen, H., Dong, L., Liu, H., Chen, Z., Zhang, Y., & Cheng, Z. (2022). *Effect Of Vibration And Noise Measuring Points Distribution On The Sensitivity Of Pump Cavitation Diagnosis*. *Strojniski Vestnik/Journal Of Mechanical Engineering*, *68*(5), 325–338. https://doi.org/10.5545/sv-jme.2022.59

Altobi, M. A. S., Bevan, G., Wallace, P., Harrison, D., & Ramachandran, K. P. (2019). *Centrifugal Pump Condition Monitoring And Diagnosis Using Frequency Domain Analysis*. *In Applied Condition Monitoring* (Vol. 15, Pp. 122–131). Springer. https://doi.org/10.1007/978-3-030-11220-2_13

Xue, R., Lin, X., Zhang, B., Zhou, H., Lai, T., & Hou, Y. (2022). *CFD And Energy Loss Model Analysis Of High-Speed Centrifugal Pump With Low Specific Speed*. *Applied Sciences (Switzerland)*, *12*(15). https://doi.org/10.3390/app12157435

Luo, X., Yang, J., & Song, L. (2022). *Analysis And Research On Vibration Characteristics Of Nuclear Centrifugal Pumps At Low Flow Rates*. *Energy Reports*, *8*, 1273–1282. https://doi.org/10.1016/j.egyr.2022.01.210

Al-Obaidi, A. R. (2019). *Investigation Of Effect Of Pump Rotational Speed On Performance And Detection Of Cavitation Within A Centrifugal Pump Using Vibration Analysis*. *Heliyon*, *5*(6). https://doi.org/10.1016/j.heliyon.2019.e01910

Kalmár, C., & Hegedus, F. (2019). *Condition Monitoring Of Centrifugal Pumps Based On Pressure Measurements*. *Periodica Polytechnica Mechanical Engineering*, *63*(2), 80–90. https://doi.org/10.3311/PPme.12140

Irfan, M., Althobiani, F., Alwadie, A. S., Zaffar, M., Abbass, A., Glowacz, A., …Alkahtani, F. S. (2022). *Condition Monitoring Of Water Pump Bearings Using Ensemble Classifier*. *Advances In Mechanical Engineering*, *14*(3). https://doi.org/10.1177/16878132221089170

Hajnayeb, A. (2021). *Cavitation Analysis In Centrifugal Pumps Based On Vibration Bispectrum And Transfer Learning*. *Shock And Vibration*, *2021*. https://doi.org/10.1155/2021/6988949

Dutta, N., Kaliannan, P., & Shanmugam, P. (2023). *SVM Algorithm For Vibration Fault Diagnosis In Centrifugal Pump*. *Intelligent Automation And Soft Computing*, *35*(3), 2997–3020. https://doi.org/10.32604/iasc.2023.028704

Ebrahimi, E., & Javidan, M. M. (2017, June 30). *Vibration-Based Classification Of Centrifugal Pumps Using Support Vector Machine And Discrete Wavelet Transform*. Journal Of Vibroengineering. https://doi.org/10.21595/jve.2017.18120

Veena, K., Meena, K., Teekaraman, Y., Kuppusamy, R., & Radhakrishnan, A. (2022, January 17). *C SVM Classification and KNN Techniques for Cyber Crime Detection*. Wireless Communications and Mobile Computing. https://doi.org/10.1155/2022/3640017

K, G. M. (2021, December 15). *Machine Learning Basics: Support Vector Machine (SVM) Classification*. Medium. https://towardsdatascience.com/machine-learning-basics-support-vector-machine-svm-classification-205ecd28a09d