

STUDY OF VIBRATION ON MACHINERY FAULTS IN SHAFT USING STATISTICAL ANALYSIS METHOD



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Bachelor of Mechnical Engineering Technology (Maintenance Technology) with Honours

STUDY OF VIBRATION ON MACHINERY FAULTS IN SHAFT USING STATISTICAL ANALYSIS METHOD

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2023

DECLARATION

I declare that this thesis entitled "Study of Vibration on Machinery Faults in Shaft Using Statistical Analysis Method " is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



APPROVAL

I hereby declare that 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 (Maintenance Technology) with Honours.

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DEDICATION

To my beloved family, friends, and lecturers.



ABSTRACT

The shaft is the most important component in a machine to transmit the rotation motion to another machine or component. An inspection is vital to reduce the breakdown of the machine due to shaft damage. Thus, the vibration of the shaft was studied in this thesis. The experiment was performed by tested stainless steel and mild steel shaft under three different conditions (normal, minimum crack and maximum crack) at different speeds (800rpm, 1200rpm and 1600rpm). The vibration of a normal shaft and cracked shaft were measured using an accelerometer and processed through Data Acquisition (DAQ) box and software Smart Office (SO) analyser. Lastly, the time domain data was transformed into vibration spectrum and statistical data, which is skewness was graphically presented with the aid of MATLAB and Microsoft Excel. Three parameters used were the speed of rotation, conditions experienced by shafts, and material of the shafts. The analysis shows a significant difference in vibration amplitude between the normal shaft and abnormal shaft. This experiment also discovers the presence of misalignment and resonance when mild steel shaft was tested. The result obtained concludes the relationship where vibration amplitude increases as the speed of rotation increases. It also shows the vibration amplitude increases as the condition of shaft getting worst.

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ABSTRAK

Aci adalah komponen terpenting dalam mesin untuk menghantar gerakan putaran ke mesin atau komponen lain. Pemeriksaan adalah penting untuk mengurangkan kerosakan mesin akibat kerosakan aci. Oleh itu, getaran aci telah dikaji dalam tesis ini. Eksperimen dilakukan dengan menguji aci keluli tahan karat dan aci keluli lembut di bawah tiga keadaan berbeza (biasa, retak minimum dan retak maksimum) pada kelajuan berbeza (800rpm, 1200rpm dan 1600rpm). Getaran aci biasa dan aci retak diukur menggunakan akselerometer dan diproses melalui kotak Pemerolehan Data (DAQ) dan perisian penganalisis Pejabat Pintar (SO). Akhir sekali, data domain masa telah diubah menjadi spektrum getaran dan data statistik, iaitu kecondongan telah dipersembahkan secara grafik dengan bantuan MATLAB dan Microsoft Excel. Tiga parameter yang digunakan ialah kelajuan putaran, keadaan yang dialami oleh aci, dan bahan aci. Analisis menunjukkan perbezaan ketara dalam amplitud getaran antara aci biasa dan aci tidak normal. Eksperimen ini juga menemui kehadiran salah jajaran dan resonans apabila aci keluli lembut diuji. Keputusan yang diperolehi menyimpulkan hubungan di mana amplitud getaran meningkat apabila kelajuan putaran meningkat. Ia juga menunjukkan amplitud getaran meningkat apabila keadaan aci semakin teruk.

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LIST OF SYMBOLS AND ABBREVIATIONS

-	MATrix LABoratory
-	Vibration Spectrum Analysis
-	Revolutions per minutes
-	Root mean square
-	Micro-Electro-Mechanical Systems
-	Structural Health Monitoring
-	Fast Fourier Transform
-	Discrete Fourier Transform
- 14	Smart Office
A. C.	Acceleration from gravity
EK.	Mean
F I	Summation
Ser.	Number of samples
	Individual sample
ملاك	Standard deviation
_	Skewness
UNIVE	Percenti TEKNIKAL MALAYSIA MELAKA
-	Degree
-	Millimetre per second
-	Millimetre per second square
-	Kilowatt
-	Per minute
-	Metric thread designation
-	American Iron and Steel Institute
-	American Society for Testing and Materials
-	International Organization for Standardization
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CHAPTER 1

INTRODUCTION

1.1 Background

A shaft is the most important component in every machine. It is used to transmit power from one machine to another machine. It is among the components in highperformance rotating equipment used in process and utility facilities, such as turbines, pumps, compressors, and so on, that are subjected to some of the harshest operating conditions. A shaft in operation is sometimes susceptible to major faults that arise without much notice, even though it is normally quite sturdy and properly engineered. Some of the faults that are commonly found in the shaft are cracks, bent shaft, misalignment between two shafts, the unbalance of weights on the shaft, and others.

Some faults can be found using visual inspection while some are not. They will need a specific method or go through numerous checking and inspection to measure and investigate whether there is a fault. There are various types of diagnostic tools that can be used to diagnose failure based on machine conditions and requirements. For example, a machine that involves temperature problems needs to use thermography to inspect the fault by visualizing the temperature distribution. For wear particles and lubricant properties, tribology will take place. Common machinery faults such as misalignment, broken bearings or gears, cracks in shafts, and others can be measured using vibration.

Vibration is the primary diagnostic tool for most mechanical systems. This is because every machine vibrates when it is operating. In general, vibration is defined as the oscillatory motion of a physical system. It is encountered in many mechanical and structural applications, for example, vehicles, bridges, gears, bearings, buildings, and machines. The motion can be harmonic, periodic motion, or general motion in which the amplitude is relative to time (Shabana, 2019). Vibration not only can be inspected visually, but it can also measure using specific tools such as vibration sensors and vibrometers. It will then be displayed either in a vibration spectrum (time domain and frequency domain) or a level/ indicator bar.

Besides, there is also software available to process the vibration data collected into mathematical form. The popular software that was recently used is MATrix LABoratory (MATLAB). Many researchers used MATLAB for vibration measurement such as vibration in rotating shafts (Gopinath & Periyasamy, 2016). MATLAB was used to generate velocity root mean square, and analyse the time domain and frequency domain of various signals. Other than that, MATLAB can also use to simulate the model to get vibration data. In short, MATLAB is a multi-paradigm programming language and numeric computing that is widely used nowadays.

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Usually, engineers try to avoid vibrations because they always come with an unpleasant problem or failure. Most industrial machines are designed to work without vibration. In these kinds of machines, any vibration indicates failures or damage to the equipment. If maintenance is not conducted on time, the vibration can cause additional damage. However, vibration is essential in some cases. For example, when using a vibratory feeder, vibration will take an important role in removing the materials. In constructions, vibrators use to settle down concrete into forms and compact the fill materials while vibratory rollers assist with compacting the black-top utilized in the parkway clearing.

1.2 Problem Statement

The shaft is the main character in every rotating machine because it transmits the power to the component on it. When the shaft is under bad conditions such as cracking, bending, and unbalancing, the performance and efficiency of a machine will be severely affected. The production line and profit of a company will also be affected. To diagnose the faults and carry out maintenance on a machine, vibration analysis is the best choice compared to the others. This is because all machines produced vibrations and sometimes the problem that occurs inside the shaft is hard to detect using other inspection tools. Thus, this study will measure the vibration of machinery fault in a rotating shaft that might have happened in real life. It will then identify the difference between the normal and faulty shaft through vibration analysis.

1.3 Research Objective

The objectives of this research are as follows:

- a) To measure the shaft for normal and abnormal conditions with different
 parameters using a vibration analysing tool (vibration sensor).
- b) To analyse the data collected using MATLAB and Vibration Spectrum Analysis (VSA).

1.4 Scope of Research

The focus of this research is the rotating shaft. The scope of the study is to apply the range speed of 500 rpm to 1500 rpm on the shaft in different conditions. The conditions were the normal shaft, shaft under the minimum crack, and shaft under the maximum crack. Besides, the experiment was conducted on different shaft materials which are stainless steel and also mild steel. The data was collected using the accelerometer. Then, data generated

into the vibration spectrum, which is in the frequency domain, and it will also be analysed using MATLAB. The analysed data will further explain how normal and faulty shafts are detected and diagnosed through the graph and also the mathematical parameter. A comparison between the data of two different shaft materials was also conducted.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter attempts to review the relevant literature and research related to vibration and machinery faults in shafts. The chapter will divide into 3 parts, where the first part introduces the basics of vibration followed by the second part which discusses the method that generally use to analyse and interpret vibration. The third part will discuss the shaft and its machinery faults. This chapter will review the literature generally and some specific literature related to this research case study will also be reviewed.

2.2 Vibration

Vibration is the oscillatory motion of a mechanical system. All bodies with mass and elasticity will generate vibration (Thomson, 1996). Hence, most machines and engineering structures vibrate, and it depends on the mass, force applied, stiffness of spring, and damping system in the bodies. These are the 4 main components that resulted in vibration. The role of mass in the system is the motion of the rigid body which stores kinetic energy while force is act as external excitation of vibration, which will increase the frequency of vibration. Next, stiffness is the deflection of a flexible component which stores potential energy while damping is where the energy dissipated due to friction or resistance. Vibration is an effective diagnostic tool used to diagnose faults and evaluate the technical state of engineering structures. Based on the results of the study (diagnose roller bearings' faults) conducted by Minorov et al. (2014), they concluded that vibration-based diagnostics can benefit users/companies by reducing downtime and cost, and at the same time improve the reliability

of the machine. There was also research conducted by Siano & Panza (2018), which adopted vibration to detect the pump cavitation problem. Okah-Avae (1977) As studied by Ramli et al. (2020), vibration is used to measure the performance of the engine with different fuels. In research from Wang et al. (2021), they combined vibration signal analysis and multi-features extracted from vibration signals to diagnose diesel engine gearbox faults. Vibration seems to be widely and wisely used in detecting and monitoring the status of engineering structures.

2.3 Vibration Instrumentations

Vibration is a measurable magnitude with direction. Vibration is measured either in displacement, velocity, or acceleration. It can be measured by various devices such as a velocity transducer, accelerometer, seismometer, proximity sensor, laser vibrometer, and many more.

2.3.1 Measuring Units

The measuring parameters of vibration are displacement, velocity, or acceleration. There is only one difference between these 3 parameters, which is the phase difference (Brüel & Kjær, n.d.-a). Referring to Figure 2.1, the amplitude-time curve for velocity has a 90° phase lead and a 180° phase lead for acceleration when compared to displacement.



Figure 2.1 Amplitude-time curve for velocity, displacement, and acceleration

(Source: https://www.bksv.com/en/knowledge/blog/vibration/measuring-vibration)

The unit of velocity in measuring vibration is mm/s while acceleration and displacement are mm/s² and mm respectively.

2.3.2 Transducer

As mentioned before, there are three parameters in measuring vibration, and there are also three types of transducers that match the parameters, which are velocity transducer, displacement transducer, and acceleration transducer. The main function of a transducer is to detect and transform the vibration into a normalised signal which could be further processed, measured, and analysed (Fernandez, 2020). Same as their name, the transducers are sensitive to a specific parameter. The displacement transducer is sensitive to displacement and the same to velocity and acceleration transducers.



Figure 2.2 Velocity transducer

(Source: https://www.beraninstruments.com/Products/Vibration-Transducers-and-Cabling/Velocity-Transducers/BI-5301V-4mV-mm-s)

2.3.3 Accelerometer

An accelerometer is an electromechanical device that measures the acceleration forces in a device/equipment. It is one of the acceleration transducers that are widely used in the market. Accelerometers are not only used in the mechanical engineering field, but also in electronic devices such as smartphones and laptops. The accelerometer can be used to measure the vibration of equipment, and the motion sensors inside can even be used in the medical field such as artificial body parts (Goodrich, 2013). According to the study by Pedotti, Zago, and Fruett (2016), shaft unbalance can be detected using Micro-Electro-Mechanical Systems (MEMS) accelerometer. A MEMS based accelerometer is frequently used in aerospace due to its advanced technology where it can sense the vibration on a micro-scale (Vedantu, 2022). There are 3 main types of accelerometers which are MEMS accelerometer, piezoresistive accelerometer, and lastly piezoelectric accelerometer.

Table 2.1 Types of accelerometers

Types of accelerometers	Description/ Explanation
VEMS accelerometer	MEMS accelerometer is a small and low-cost sensor that is ideal for measuring low-frequency acceleration inputs (Varanis et.al, 2018). The unit of performance data is expressed in gravity-referenced acceleration (g). It is applied in a wide range of applications such as factory automation, Structural Health Monitoring (SHM), home appliances, and building automation.
Piezoresistive accelerometer	A piezoresistive accelerometer is an ideal sensor to measure short-duration (high frequency) shocks because it has a very wide range of bandwidth (Hanly, n.d). It is adopted in automobile safety testing such as crash testing, braking system testing, and safety airbags system testing.



Piezoelectric accelerometer

For vibration measurements, the piezoelectric accelerometer is almost routinely employed. It surpasses all other types of vibration transducers in terms of overall performance. It has a wide frequency and dynamic range, as well as strong linearity throughout those ranges. Its features are largely stable over time since it is relatively sturdy and reliable (Brüel & Kjær, n.d.-b).

2.3.3.1 Working Principle Of Accelerometer



Figure 2.3 Schematic diagram of accelerometer

(Source: http://mymechatronics.pbworks.com/w/page/63741355/Accelerometers)

An accelerometer's working principle is transforming the experienced mechanical motion into an electrical signal. It is like the spring-mass system. When there is vibration force applied to the mass, it begins to accelerate and compress the spring. Then, the spring will push the mass back using the same speed it sensed, meaning that the mass is displaced. The displacement of the spring measures the acceleration. That acceleration is then transformed into an amount of electric signal, which is used to measure changes in the component's position.

2.3.4 Seismic Probe

A seismic probe is used to precisely detect and measure mechanical vibrations propagating in the ground, as well as to pinpoint the location of seismic occurrences or vibration sources (Crenner, 1997). Seismic probe is based on acceleration, and it is more likely used for monitoring and protection instead of diagnosis.



Figure 2.4 Seismic probe

(Source: http://www.seismicgeophone.com/sale-11592613-accurate-seismic-sensorgeophone-vertical-direction-horizontal-direction.html)

2.3.5 Proximity Probe

A proximity probe is a displacement transducer where it is measured and sensitive to the displacement of vibration. The vibration sensor's location is an important consideration that needs to consider to get an accurate result. Being to be the nearest stationary part of the vibration source such as the shaft, bearing and many more is the most preferable position.



Figure 2.5 Proximity probe

(Source: https://www.pch-engineering.dk/415/proximity-probes)

2.4 Vibration Analysis

Vibration analysis is a technique used to read, understand, and interpret the vibration signal received using specific devices. Besides, it is also one of the most popular diagnostic and monitoring tools in the maintenance field. This analysis helps to monitor the health status of the machine and components, moreover, it also detects the abnormality of the machine. According to the study of Elnady (2013), the performance of a rotary shaft is measured using vibration sensors with a combination of other technologies. In research by Alkhalifa (2003) on the damage detection of the rotary machine, he used three methods to determine the defect in the rotor, which are vibration analysis, finite element analysis, and lastly experimental modal analysis. In this section, the time and frequency domain will be discussed. Next, Fast Fourier Transform (FFT) and also the main focus of this research, spectrum analysis, will be included in this literature review.

2.4.1 Time Domain Analysis

Time domain analysis is a time-based analysis of physical signals. In the case of discrete time or continuous time, the signal's value is also understood for all real numbers at multiple separate instances in the time domain (Cadence, 2022). Acceptable performance vibration limits can be determined using long-term operation and maintenance history or instruction manuals. If measured vibration exceeds the limit, it could mean that the machine's overall health is declining and that faults have formed. As mentioned by Gopinath and Periyasamy (2016), time domain analysis has its disadvantages where it required numerous samples to get a detailed waveform. However, the waveform only displays the overall effect of vibration which is not specific enough to diagnose certain machine problems. In short, time domain analysis is suitable for monitoring the condition of the machine's performance instead of finding out the components' failure in a machine.



Figure 2.6 Time domain analysis graph

(Source: https://www.twi-global.com/technical-knowledge/faqs/vibrationanalysis#:~:text=Time%20domain%20analysis%20is%20capable%20of%20evaluating%2 0the,spectrum%20analysis%20in%20addition%20to%20time%20domain%20analysis.)

2.4.2 Frequency Domain Analysis

The frequency domain analysis principle is based on the transformation of signals in the frequency domain. Frequency domain analysis helps to separate and identify certain frequency components that are useful for fault identification. When checking on the frequency domain graph, there shows an amplitude versus frequency, where the amplitude at a certain frequency is high and some are low (Kekan & Kumar, 2021). For example, the vibration of a shaft in the graph shows abnormal when compared to the normal graph. It is easier to spot the difference because of the frequency. Thus, from the pattern of the graph, one would expect there is damage in the shaft, either shaft had cracked, bent shaft, or misalignment. In this case, frequency domain analysis has advantages over time domain analysis.



(Source: https://www.proquest.com/docview/2623613067/556A30C7764937PQ/62?accountid=349 84)

2.4.3 Fast Fourier Transform (FFT)

An FFT is a useful signal-processing tool. It is an algorithm that takes a time domain signal and turns it into a frequency domain graph. FFT is often used for fault analysis, quality control, and condition monitoring of machines or systems. The FFT is an optimized implementation of the Discrete Fourier Transform (DFT). DFT deconstructs a signal of the frequency domain components in discrete values. As reviewed by Lin and Ye (2019) on the bearing vibration measurement using FFT and enhanced FFT, DFT is the most used analysis tool for measurement under stationary conditions. However, it takes time for a non-stationary measurement. Hence, FFT is used to increase the efficiency of measurement. According to Collins (2019), DFT costs time to compute even for small signals. Thus, FFT is recommended to take over DFT since it is faster in transforming the signals.



(Source: https://www.researchgate.net/figure/Fast-Fourier-Transformation-2-Fast-Fourier-Transformation-To-increase-the-performance_fig6_323281289)

2.4.4 Spectrum Analysis

Previously, spectrum analyzers and vector signal analyzers were different devices, but technological advancements have allowed both capabilities to be combined into a single instrument. Signal analysis and spectrum analysis are sometimes referred to as just spectrum analysis. Spectrum analysis is a method that evaluates and determines the overall values and specific frequencies corresponding to the machinery abnormalities. Frequency spectrum analysis has a wide range of applications. It is easy to measure a signal's frequency and noise with a frequency-domain view of the spectrum. The signal stability, power bandwidth, and a variety of other measures may all be calculated using only a spectrum analyzer after these numbers have been determined (Diez, 2012). The approach has traditionally been used in industries including radar, communications, and astronomy. As spectrum analyzers become more affordable, they are finding new uses in different fields. With its unique capacity to expose the composition of signals and give a library of diverse components that make up the signal, its popularity is only likely to expand over time (Rathore, 2017). According to Mohamed et al. (2011), they had demonstrated an experiment to examine the vibration of a long-cracked shaft (1450 mm length) with the help of spectra.



Figure 2.9 Example of the velocity spectrum

(Source: https://www.skf.com/binaries/pub12/Images/0901d1968024acef-CM5118-EN-Spectrum-Analysis_tcm_12-113997.pdf)

2.5 MATLAB

MATLAB stands for MATrix LABoratory, a popular platform that utilizes by millions of engineers and scientists to analyze data, design algorithms, and creates models. It is capable to visualise the data in a graphic form such as a line graph, or bar chart, and mathematical parameters such as skewness and mean. In research by McInerny and Dai (2003), they use MATLAB to process the vibration signal of bearing fault and presented it in a graphic view. Besides, from the article paper by Howard (1995), two examples of signal processing using MATLAB were discussed, which are rotor vibration and the shaft speed estimation of a diesel engine. The shaft rotation motion was measured using a tachometer and with the use of complex FFT within MATLAB. According to Feng and Pang (2022), they used MATLAB to investigate the vibration of a typical mechanical system, particularly the wheel dual-mass system, and its amplitude-frequency characteristics, with an emphasis on the impact of system parameters on the vibration's root mean square (RMS) value. MATLAB is adopted in many industries such as aerospace and defense, automotive, biotech and pharmaceutical industry, energy production, medical field, and also metals, material, and mining field. It is also applied in the control system, machine learning, predictive maintenance and signal processing, and other applications (MathWorks, n.d.).



(Source: http://mathworksmatlab.blogspot.com/2015/04/xty.html)

2.6 Statistical Analysis

Statistical analysis is one of the mathematical methods to investigate and determine the shape and parameter of central tendency. Generally, skewness, mean, and standard deviation are considered.

2.6.1 Mean

The mean, also known as the average of numerical data measures the centre of the group of data. The calculation of the mean is dividing the sum of total values in the data set by the total number of values.

Skewness is the most important parameter as it measures the shape of the distribution, either skewed to the right or left. This means that it measures the asymmetry of the distribution. When it is negative, the graph has a longer tail toward the left while when it is positive, the graph has a longer tail toward the right. The formula is displayed as (2.2).

$$s_k = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{(x_i - \bar{\mu})}{\sigma} \right)^3$$
(2.2)



Figure 2.11 Graph of skewness

(Source:http://www.ijamhrjournal.org/viewimage.asp?img=IntJAdvMedRes_2014_1_1_30 _134449_u5.jpg)

Refer to Figure 2.11, when the distribution is negatively skewed or skewed to the left, the mean will be at the left of the median. When the distribution is normal, the line is identical on both sides of its central point. The mean, median and mode will be at the same point in this graph. For the distribution that shows positive skewness, the mean will be at the right of the median.

2.6.3 Standard Deviation | TEKNIKAL MALAYSIA MELAKA

Standard deviation is the measure of the dispersion of the data set. It indicates how far the data spread from the mean. When the standard deviation obtained is low, the data are spread on a small range around the mean. If the standard deviation is high, it indicates that the data is widely and more unevenly spread. Usually, the standard deviation is useful for normal distribution but less functional for non-normal distribution.

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{\mu})^2}$$
(2.3)

2.7 Shaft

A shaft is the mechanical part that transmits motion and torque from one machine to another machine. Generally, it is made of round metal rods and each segment can have different diameters. There are many types of shafts such as machine shaft, propeller shaft, stepped shaft, crankshaft, camshaft and more. The material of shaft is selected based on the desired performance of shaft, the environment of machine/equipment, the cost of the material, machinability of material, the properties of the material, maintenance cost and other considerations. For example, a machine shaft made of medium carbon steel which contains 0.30% to 0.60% of carbon and 0.60% to 1.65% of manganese is suitable and mainly used for making shafts, gears, and forgings (Singh, 2016). However, if one is going to use the shaft under a high humidity environment, stainless steel and alloy steel are recommended as they have combined other elements such as nickel, chromium and molybdenum to increase their corrosion resistance as well as strength.



Figure 2.12 Various types of shaft



2.8 Machinery Faults

Machinery faults can be defined as the malfunction of any part in a machine that affects the performance and availability of the machine (Jayaswal et al., 2008). Three common machinery faults are found in a shaft, which are misalignment, bent, and cracked shaft. Every fault in the component will lead to another failure of the machine, even reduced profits for a company. For example, a shaft misalignment will produce an excessive vibration and noise, where the bearings on the shaft will also be affected (bearing damage). Besides, if the maintenance has not taken place, it can directly affect the lifespan of the equipment. Other than that, the safety of users will greatly be influenced by faults such as shaft cracks, where the crack may propagate and cause the shaft to break while running at high speed.



Types of machinery faults	Description
Bent	
	A shaft is considered bent when it is rotating unsymmetrically. The axis of the shaft is different from its axis of rotation. A bent shaft can be determined using visual inspection and if it is only a small bending angle, a vibration inspection is needed.
Crack	Shaft Material - Q&T 4340 Steel Inrough Cross-section Failed Shats Creck on the Shaft Creck Northe Shaft
UNIVERSITI T	One of the reasons that a crack might happen is due to high-stress concentration at one spot. Once there is a crack in the shaft, the crack will propagate when operating the shaft. At last, the shaft will be full of cracks and its performance will be affected.

2.8.1 Fault Diagnosis

From the faults discussed above, there is already a general spectrum analysis that shows how the faults are being diagnosed. The resource of the solution is from Mobius Institute.



Table 2.3 I	Faults a	and their	spectrum	analysis
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CHAPTER 3

METHODOLOGY

3.1 Introduction

Shaft defects are difficult to detect as they may be very small. Thus, this thesis will present the approach to detect defect conditions using vibration signal analysis. This chapter gives an outline of the methods that were followed in the study. It provides information on the flow of this study and experiment. The methods that will be used for data collection, analysis, and also experiment setup, that is, the parameters and procedures will also be included here. This study is expected to obtain the data of vibration using an accelerometer and analyse the graph to find out how the parameters would affect the results.

3.2 Research Design

This thesis presents a modified study of vibration on the shaft with different materials and cracks under various speeds. The core of the approach used in this thesis is on the pattern of vibration spectrum and statistical analysis. The selected methods are quantitative types that aim to collect and analyse data through graph. The performed approach is experimental, which utilizes shaft failure modelling and a statistical technique. Subsequently, Figure 3.1 shows the research design of this thesis.



Figure 3.1 Flow chart of research

3.3 Proposed Methodology

The research problem in this thesis requires the use of quantitative analysis which is based on the data collected from the experiment. The quantitative analysis used to present the results are frequency spectrum, MATLAB, and also Microsoft Excel. The vibration signal is collected using accelerometer and processed through Data Acquisition (DAQ) box and Smart Office (SO) Analyser. The result is displayed in the form of time domain graph and then the numerical data go through MATLAB to convert to frequency spectrum. The data will also go through MATLAB to express skewness. Microsoft Excel was used to plot graph of skewness.



Figure 3.2 Experiment setup for DAQ box and laptop



Figure 3.3 Setup of crack detection rotating shaft kit

In the experiment, the crack detection in rotating shaft kit was used, where the accelerometer, DAQ box and also the base unit of machinery diagnostic system (control and display unit) were pre-assembled. The accelerometer connected from the rotating shaft kit (Point A) to the DAQ box, while DAQ box was connected to a computer and the SO analyser software. After set up the equipment as shown in Figure 3.2 and 3.3, the shaft is allowed to rotate slowly to the desired speed by adjusting the speed control unit. After a few minutes, when the speed of shaft is already stable, the reading will be recorded. The same procedure is repeated with other speeds and conditions. After the data of stainless steel shaft was completely obtained, it will be replaced by mild steel shaft and the same process will be carried out again.

3.3.1.1 Parameters

There are 3 parameters used in the experiment, which are the conditions of the shaft, speed of rotating shaft, and material of the shaft. The parameters are listed in Table 3.1.



Table 3.1 Experiment parameters

3.3.1.2 Equipment

The equipment used in the experiment including shafts, crack detection in rotating shaft kit and also computer. The specifications and quantity of equipment are listed in Table 3.2.

Equipment	Specification	Quantity
Shaft	Material: Stainless steel and mild steel	2
	Diameter: 20 mm	
	Length: 300 mm	
and a		
St. MA		
TERUM		
Crack Detection In	Equipment number: PT500 11	1
Rotating Shaft Kit	Flange	1
	-Diameter: 90 mm	
با ملاك	-6 hexagon flange bolts M8x20	
1		
UNIVER	Asynchronous motor with frequency converter	
OTTIC	-Drive power output: 0.37kW	
	-Nominal speed: 2800 min ⁻²	
	Accelerometer	
	-1 channel	
Computer	Desktop with installed software	1

Table 3.2 List of equipment

3.4 Limitation of Proposed Methodology

Due to the limitation of material properties and resources, mild steel was chosen as another test specimen. From the research and literature review, carbon steel is the mostly used as the material of a shaft. However, it takes time to find the source and get medium carbon steel. Thus, an alternative material, which is mild steel was used to fabricate the shaft. By comparing both medium carbon steel and mild steel, the difference is that the content of carbon in mild steel is much lower than medium carbon steel. Hence, its resistant of corrosion is lower than medium carbon steel.

The second limitation is the control of experiment data consistency and accuracy. The crack simulation equipment is utilised in this thesis because of the crack parameters had been stated in the equipment manual. Every shaft will be simulated using the same parameter. However, there are researchers that demonstrated the real cracks on the shaft which is risky for data collection as ones are unable make sure that the crack do not propagate inside the shaft. The machinery fault such as a bent shaft is facing the same problem because it is unable to estimate and make sure every bent shaft has the same bending angle and applied bending force.

The third limitation is that there is no clear benchmark or testing standard for the crack (minimum and maximum crack). Variable tightening of flange bolts resulted a temporary gaping which is similar to the behaviour of a crack. The size of crack is assumed based on insecure screw. For minimum crack, only one flange bolt is insecure and other five flange bolts are secure. The fraction of this situation is one over six which convert into the percentage is around 16.67%. This means that when perform the minimum crack, there is around 16.67% of the shaft cracked. Thus, this is assumed as minimum crack. As for

maximum crack, the percentage of crack over the whole shaft is around 66.67%. Hence, it is assumed as maximum crack.

3.5 Summary

This chapter presents the proposed methodology in order to study the effect of different parameters on the shaft under normal and abnormal condition. The focus in this experiment is the vibration spectrum and also the statistical data. The pattern of the vibration spectrum and graph will be analysed in order to compare the results.



CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis on the vibration generated from shaft under various parameters. Time domain, frequency domain graph and graph of skewness were presented in this chapter. The concern in this chapter is the comparison of vibration between stainless steel shaft and mild steel shaft under normal and abnormal conditions.

4.2 Results of Time Domain Graph

The time domain graph proved that vibration exists when shafts rotated as it captured the vibration and generated signal waves. Hence, time domain graphs were collected only to provide data needed in order to generate frequency domain graphs and statistical data. All the time domain graphs were attached in APPENDIX A for review.

4.3 Results Analysis and Comparison of Vibration in Shafts at 800rpm



Table 4.1 Frequency spectrum of shafts under different conditions at 800rpm



The table above shows vibration amplitude of stainless steel shaft and mild steel shaft rotated under normal, minimum crack, and maximum crack condition at 800rpm. Overall, both shafts showed significant difference where peak value of shafts under maximum crack condition is higher than that in minimum crack condition. The peak value of shafts under normal condition is the lowest compared to the other two conditions. For stainless steel shaft, the highest peak value in normal condition was 210.161g, and slightly increased to 214.95g when it was under minimum crack condition. The peak value then went up to 247.656g when it was tested under maximum crack condition. As for mild steel shaft, it peaked at 213.214g under normal condition and rose to 216.642g when it rotated under minimum crack condition. While under maximum crack condition, it was approximately doubled the highest

peak value under normal condition, that is 431.44g. Comparing data obtained between stainless steel shaft and mild steel shaft, it shows a great difference when the shafts were under maximum crack condition at this speed. The difference between data of two shafts is about 183.784g, where mild steel shaft had higher amplitude than stainless steel shaft. This was possibly due to the collision of gap between flange and the mechanical properties of material such as the hardness, malleability and brittleness.

4.4 Results Analysis and Comparison of Vibration in Shafts at 1200rpm



Table 4.2 Frequency spectrum of shafts under different conditions at 1200rpm



The graphs from Table 4.2 presents data on vibration amplitude of shafts at 1200rpm under 3 conditions. Under normal condition, the highest vibration peak achieved by stainless steel shaft is 393,036g while for mild steel, the highest amplitude is 957,004g. When they were under minimum crack condition, their highest peak also gradually increased to 538,989g (stainless steel shaft) and 1005,89g. The last graph shows the vibration amplitude obtained when they rotated with a maximum crack condition. The highest vibration amplitude of stainless steel shaft is climbed to 578,803g while for mild steel shaft, it is peaked at 1167.26g. It seems that there is an extremely huge difference between the vibration amplitude of these two shafts. From the overall results of mild steel shaft, at the same frequency, that is 168,958Hz, it recorded an abnormal high peak. This might due to resonance occurred when the frequency applied is close or match to the natural frequency of system. Hence, it amplified the vibration which results in an increment of vibration amplitude.

4.4.1 Natural Frequency and Resonance

Natural frequency is the frequency of a system vibrating naturally without any external forces added (Forsthoffer, 2017). An object can have more than one natural

frequency and it depends on the structural properties such as length, mass, and etc. When the system is operated close to its natural frequency, even a small vibration can be amplified, causing a sudden high vibration amplitude. The area around the base of this high peak is amplified. This phenomenon is described as resonance. In short, resonance is defined as the excitation of natural frequency (Wang et al., 2021).



(Source: https://dsp.stackexchange.com/questions/36919/how-to-understand-multiplepeaks-in-fft-analysis)

4.5 Results Analysis and Comparison of Vibration in Shafts at 1600rpm



Table 4.3 Frequency spectrum of shafts under different conditions at 1600rpm

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The table above shows the graphs of vibration amplitude of shafts under different **UNIVERSITITEKNIKAL MALAYSIA MELAKA** condition at 1600rpm. From the result table above, the vibration amplitude of shafts increased as the condition of shaft getting worst, which is from normal to minimum and maximum cracked. As for normal condition, the shafts rotated and have a high peak. This might due to the high speed rotation, where vibration increases directly with speed. The highest peak value for stainless steel shaft is 569.912g while for mild steel is 561.003g. When they were tested with minimum crack, the highest peak value of stainless steel and mild steel shaft also went up, which is 720.131g and 615.633g respectively. Lastly, for maximum crack condition, vibration of stainless steel shaft peaked at 723.29g while mild steel shaft peaked at 678.675g. As a whole, the vibration amplitude of stainless steel shaft is

higher than mild steel shaft under the same speed and condition. However, the vibration pattern changes in graphs of mild steel shaft show other possible machinery fault that might occurred at the same time it was tested. The unexpected fault might be misalignment of shaft and flange, either angular or parallel misalignment.

4.6 Comparison of Shafts Material Under Different Conditions

Speed (rpm)	Vibration Amplitude (g)						
	Normal Condition		Minimum Crack Condition		Maximum Crack Condition		
	Stainless Steel	Mild Steel	Stainless Steel	Mild Steel	Stainless Steel	Mild Steel	
800	210.161	213.214	214.950	216.642	247.656	431.440	
1200	393.036	957.004	538.989	1005.89	578.803	1167.260	
1600	569.912	561.003	720.131	615.633	723.290	678.675	

Table 4.4 Highest vibration amplitude of each speed



Figure 4.2 Comparison of materials under normal condition



Figure 4.3 Comparison of materials under minimum crack condition



Figure 4.4 Comparison of materials under maximum crack condition

As shown in Figure 4.2 until 4.4, for both material of shaft, the highest vibration amplitude for every condition increases as speed increases. The range of vibration amplitude for normal condition varies from 3.053g to 563.968g. This is due to the resonance that amplified the vibration amplitude. Same goes to minimum and maximum condition, the range is from 1.692g to 466.901g and 44.615g to 588.457g respectively.

4.7 Statistical Analysis on Skewness

Statistical data, which is skewness, was obtained in the experiment using MATLAB. Skewness shows the shape or the deviation of the data distribution, either it skews to the left, right or symmetric.

Speed (rpm)	Skewness			
Speed (Ipili)	Normal	Minimum Crack	Maximum Crack	
800	-0.1037	-0.0810	-0.0562	
1200	-0.0550	0.0128	-0.0592	
1600	0.0340	0.0188	0.1012	

Table 4.5 Skewness for stainless steel shaft under different parameters

Table 4.6 Skewness for mild steel shaft under different parameters

Speed (rpm)	Skewness		
	Normal	Minimum Crack	Maximum Crack
800	0.0634	0.0375	0.0141
1200	0.1593	0.0142	0.1900
1600	0.0413	0.0028	0.1860
To a			



Figure 4.5 Skewness of data collected for both shafts

Based on the results, the shape of mathematical graph for stainless steel shaft at 800 rpm under every condition is negatively skewed, where the skewness are -0.1037, -0.0810, and -0.0562 respectively. For mild steel shaft at 800 rpm, the distribution is positively skewed, which the skewness at normal condition is 0.0634 while at minimum crack condition is 0.0375, and at maximum crack condition is 0.0141. At 1200 rpm, skewness of stainless steel shaft under normal condition (-0.0550) is nearer to a symmetric distribution (skewness equal to 0), which is less negatively skewed while under minimum crack condition, the skewness is 0.0128, that is positively skewed. Skewness when it is under maximum crack condition is -0.0592, which is more negatively skewed compared to that in 800rpm. For mild steel shaft at 1200rpm, it is more positively skewed under normal (0.1593) AALAYS/ and maximum crack (0.1900) condition. However, it is less positively skewed, but close to symmetric as its skewness is 0.0142. Lastly, distribution of graph for both shafts are mostly positively skewed and some are close to symmetric distribution. Stainless steel and mild steel shaft that experienced maximum crack recorded skewness of 0.1012 and 0.1860 respectively. They are positively skewed. For normal condition, skewness of both shafts is positively skewed and close to symmetric distribution, which is 0.0340 for stainless steel shaft and 0.0413 for mild steel shaft. For minimum crack condition, they are closer to symmetric distribution as the skewness recorded is 0.0188 (stainless steel shaft) and 0.0028 (mild steel shaft). Overall, the skewness show that the data still present a good shape of distribution as the range for both shafts is in between -0.2 to 0.2.

4.8 Summary

All and all, the vibration amplitude increases as the conditions getting worst. The vibration amplitude also went up when the speed of rotation increases. In this experiment, resonance occurred and affect the vibration amplitude. As the frequency applied is close and

match the natural frequency of system, vibration amplitude of the system at that moment are amplified. Besides, from the analysis of results, an unexpected machinery fault is revealed, which is misalignment. For materials, stainless steel and mild steel both recorded high vibration amplitude. However, based on the experiment results, stainless steel gives higher vibration amplitude compared to mild steel. This may be because the shaft is used as equipment for laboratory session for quite some times in UTeM and hence, the performance is affected.



CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The shaft is the common and important part of a rotary machine. It transmits the power of the motor to another part of the machine. Since it is always in use, preventive maintenance has to be carried out to ensure the performance of the shaft and make sure it is good and functional (Basri et al., 2017). Vibration analysis is the most popular non-destructive testing that use to inspect machinery faults in machines. It diagnoses the faults through the vibration frequency spectrum, where it indicates the abnormality of components according to the position of the sensor located (Wang, 2007). In this study, the vibration of machinery faults in shafts is studied using statistical analysis method. The purpose of this study is to measure the shaft for normal and abnormal conditions with different parameters using a vibration analysing tool. Besides, this study also aims to analyse the data collected using MATLAB and vibration analysis.

From the results obtained, it was found that different materials give different vibration amplitude under the same condition, which is same cracked condition and same speed. This is because of the mechanical properties such as hardness, strength and others. These will also become consideration of material selection of shaft. In this case, stainless steel gave a higher vibration amplitude compared to mild steel as the shaft is frequently used before this study conducted. Therefore, it indicates that this shaft might have small defects, but still acceptable to be utilised.

In addition, resonance and misalignment was found in this study, where the frequency spectrum showed different pattern of vibration. Resonance occur in machine is dangerous as it can damage and shorten the lifespan of component. Therefore, some solution such as adding loads, reduce or increase speed of rotation can be considered to solve this problem. On the other hand, vibration also presented in statistical data, that is skewness, which determine the shape of graph distribution. In this study, the shape of graph distribution for both shafts is good. Overall, the objectives of this study are achieved.

5.2 Recommendations

Below are the recommendations to improve accuracy of data, enhance analysis and evaluation of the study :

- i) Utilise new and standard materials, where the properties of the material can be determined through various tests before conducting the experiment. For example, utilising the stainless steel with grades of AISI 304.
- ii) Include a study to find the natural frequency of the system.
- iii) Include study of the resonance reduction solutions and their effectiveness.
- iv) Including benchmarks/standards of the testing method such as ASTM, ISO and etc, if any.
- v) Comparing results to reference results, which are results of simulation using software with the same material and properties.

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APPENDICES



APPENDIX A Time domain graph of stainless steel shaft and mild steel shaft



