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

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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.

Signature	:	
Name	:	*Chan Sok Er*
Date	:	9 January 2023

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.

Signature	:	Irman
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Date	:	9 January 2023

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.

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

MATLAB	-	MATrix LABoratory
VSA	-	Vibration Spectrum Analysis
rpm	-	Revolutions per minutes
RMS	-	Root mean square
MEMS	-	Micro-Electro-Mechanical Systems
SHM	-	Structural Health Monitoring
FFT	-	Fast Fourier Transform
DFT	-	Discrete Fourier Transform
SO	-	Smart Office
g	-	Acceleration from gravity
$\bar{\mu}$	-	Mean
Σ	-	Summation
N	-	Number of samples
x_i	-	Individual sample
σ	-	Standard deviation
s_k	-	Skewness
%	-	Percent
°	-	Degree
mm/s	-	Millimetre per second
mm/s^2	-	Millimetre per second square
kW	-	Kilowatt
min^{-1}	-	Per minute
M	-	Metric thread designation
AISI	-	American Iron and Steel Institute
ASTM	-	American Society for Testing and Materials
ISO	-	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 high-performance 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.

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.

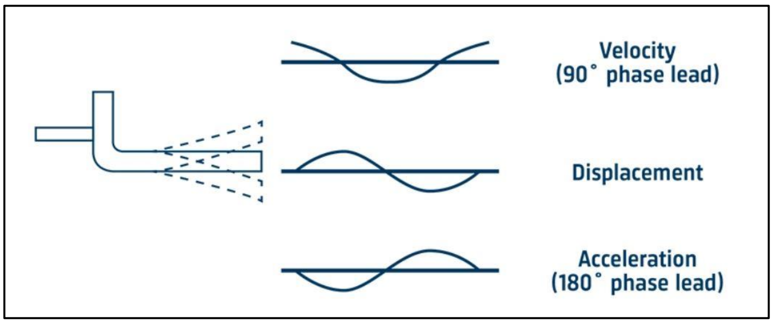


Figure 2.1 Amplitude-time curve for velocity, displacement, and acceleration

(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/s^2 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.

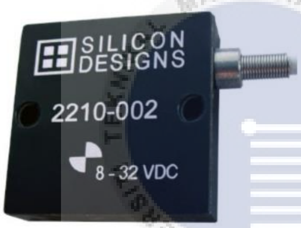
Figure 2.2 Velocity transducer

(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
 MEMS 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

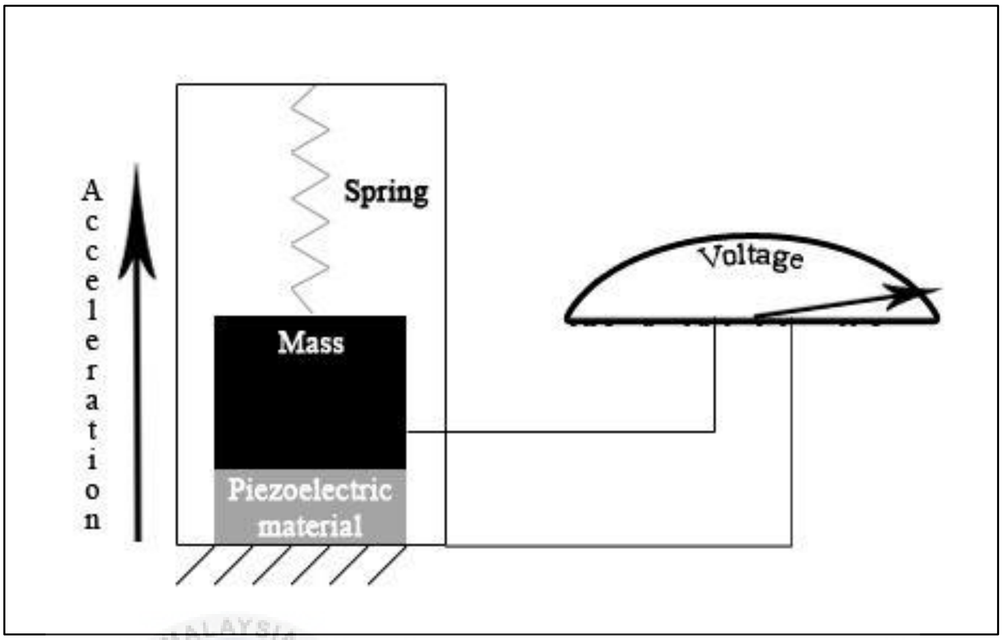


Figure 2.3 Schematic diagram of accelerometer

(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.