

VIBRATION ANALYSIS OF CORDLESS IMPACT WRENCH MECHANICAL SYSTEM USING STATISTICAL ANALYSIS



BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS

2022



Faculty of Mechanical and Manufacturing Engineering Technology



Haiqal Dzarif Bin Ramli

Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

VIBRATION ANALYSIS OF CORDLESS IMPACT WRENCH MECHANICAL SYSTEM USING STATISTICAL ANALYSIS METHOD

HAIQAL DZARIF BIN RAMLI



Faculty of Mechanical and Manufacturing Engineering Technology

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled "VIBRATION ANALYSIS OF CORDLESS IMPACT WRENCH MECHANICAL SYSTEM 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.



DEDICATION

This thesis is dedicated to my beloved family for thier patience, absolutely everything with love and for their continuous support and encouragement, while I have been away from home



ABSTRACT

Condition monitoring through vibration analysis can detect and identify the faulty from rotating machine. Thus, improve the safety, productivity and reduces maintenance costs while increases reliability. The literature study shows there many previous studies on condition monitoring through vibration analysis of bearing, gear and shaft. Vibration signal analysis (VSA) is one of the mostly used method of condition monitoring because through VSA, the type of defect and the severity of defect can be detected at early stage which can help to reduce massive breakdown risk. In this study, the vibration signal analysis of cordless impact wrench will be studied and analyzed.

The cordless impact wrench itself has a natural frequency vibration but it faulty condition, the excess vibration caused will give user a bad experience in term of comfortability and quality of work. Therefore, a study about it can help to understand the vibration signal characteristic. For this study, the vibration signal will be recorded using accelerometer transducer and data acquisition (DAQ) device. Then, the data will be filtered and processed by MATLAB and Microsoft Excel to extract the required vibration signal from time domain spectrum. Thus, statistical data such as root mean square (RMS) presented in the form of graph can be compared based on the normal and abnormal condition. Vibration spectrum of frequency domain from normal and abnormal condition can be analyzed to study and compare the pattern of the spectrum if there is any faulty in the cordless impact wrench.

ABSTRAK

Pemantauan keadaan melalui analisis getaran dapat mengesan dan mengenal pasti kerosakan dari mesin berputar. Oleh itu, tingkatkan keselamatan, produktiviti dan kurangkan kos penyelenggaraan sambil meningkatkan kebolehpercayaan. Kajian literatur menunjukkan terdapat banyak kajian sebelumnya mengenai pemantauan keadaan melalui analisis getaran galas, gear dan poros. Analisis isyarat getaran (VSA) adalah salah satu kaedah pemantauan keadaan yang paling banyak digunakan kerana melalui VSA, jenis kecacatan dan keparahan kecacatan dapat dikesan pada peringkat awal yang dapat membantu mengurangkan risiko kerosakan besar-besaran. Dalam kajian ini, analisis isyarat getaran sepana hentam nirwayar akan dikaji dan dianalisis.

Perengkuh tanpa wayar itu sendiri mempunyai getaran frekuensi semula jadi tetapi keadaannya rosak, getaran berlebihan yang disebabkan akan memberi pengguna pengalaman buruk dari segi keselesaan dan kualiti kerja. Oleh itu, kajian mengenainya dapat membantu memahami ciri isyarat getaran. Untuk kajian ini, isyarat getaran akan direkodkan menggunakan transduser akselerometer dan peranti akuisisi data (DAQ). Kemudian, data akan disaring dan diproses oleh MATLAB dan Microsoft Excel untuk mengekstrak isyarat getaran yang diperlukan dari spektrum domain masa. Oleh itu, data statistik seperti punca min kuasa dua (RMS) yang ditunjukkan dalam bentuk grafik dapat dibandingkan berdasarkan keadaan normal dan tidak normal. Spektrum getaran domain frekuensi dari keadaan normal dan tidak normal dapat dianalisis untuk mengkaji dan membandingkan corak spektrum jika terdapat kerosakan pada sepana hentam nirwayar.

ACKNOWLEDGEMENTS

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

First, 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 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 utmost appreciation goes to my main supervisor, Ts. Dr. Mohd Irman Bin Ramli, Faculty of Mechanical and Manufacturing Engineering Technology of UTeM, for all his support, advice, and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. Also, to lab assistant, Tc. Mohd Khairul Bin Hassan, Universiti Teknikal Malaysia Melaka (UTeM) who constantly supported my journey.

Last but not least, from the bottom of my heart a gratitude to my beloved parents, En Ramli Bin Moain and Puan Warsina Binti Karta, for their encouragements and who have been the pillar of strength in all my endeavors. My eternal love also to all my siblings, Nurul Ellina, Syazleen Ellina, Fatin Amira and Sara Nur Irdani for their patience and understanding. I would also like to thank all of them for their endless support, love, and prayers. Finally, thank you to all the individual(s) who had provided me the assistance, support, and inspiration to embark on my study.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF SYMBOLS AND ABBREVIATIONS	ix
LIST OF APPENDICES	X
CHAPTER 1 INTRODUCTION 1.1 Background 1.2 Problem Statement 1.3 Research Objective TI TEKNIKAL MALAYSIA MELAKA 1.4 Scope of Research	1 1 3 3 4
CHAPTER 2 LITERATURE REVIEW	5
2.1 Introduction	5
2.2 Cordless impact wrench	5
2.2.1 Internal parts of the cordless impact wrench	0 7
2.2.3 Brushless motor	9
2.2.4 Planetary gearbox	9
2.2.5 Possible faulty in cordless impact wrench	10
2.3 Condition monitoring	10
2.4 Vibration analysis	11
2.5 Signal processing	11
2.5.1 Time domain analysis	12
2.5.2 Frequency domain analysis	13
2.6 Advance Statistical Analysis	20
2.6.1 I-kaz Method	22
2.7 Data Acquisition	22

	2.7.1 Proximity Transducer	22
	2.7.2 Velocity Transducer	23
	2.7.3 Accelerometer	24
2.8	AI Based Signal Filtering	26
	2.8.1 MATLAB	26
	2.8.2 Microsoft Excel	28
CHA	PTER 3 METHODOLOGY	29
3.1	Introduction	29
3.2	Proposed Methodology	29
	3.2.1 Experimental Setup	30
	3.2.2 Parameters	32
	3.2.3 Test specimen	32
	3.2.4 Equipment	32
3.3	Signal Measurement	33
3.4	Signal Processing and Filtering	33
3.5	Limitation of Proposed Methodology	34
3.6	Summary	34
	DECUTED AND DECUCCION	25
	Introduction	25
4.1	Posults and Analysis of Laboratory Experiment Data	25
4.2	A 2.1 Result and Vibration Spectrum Analysis	33
	4.2.2 Result and Statistical Analysis	37 40
43	Summary	-0
7.5	Summary	11
CHA	PTER 5 CONCLUSION AND RECOMMENDATIONS	42
СНА	PTER 5	47
5 1	Conclusion Conclusion	42
5.1	Recommendations	43
5.3	Project Potential	43
DEF		
REFE	LKENCES	44
APPE	ENDICES	50

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Cordless Impact Wrench specification.	6
Table 2.2	Bearing specification.	8
Table 2.3	The advantages and disadvantages of time domain method.	15
Table 2.4	Advantages and Disadvantages of frequency domain method.	17
Table 2.5	The advantages and disadvantages of time-frequency domain	21
Table 3.1 Table 3.2	methods. Experimental parameters. List of component. اونون سيټي تيکنيکل مليسيا ملاك	32 33
	UNIVERSITI TEKNIKAL MALAYSIA MELAKA	

LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 2.1	Cordless Impact Wrench.	6
Figure 2.2	Internal parts of cordless impact wrench.	7
Figure 2.3	Bearing Parts.	8
Figure 2.4	Bearing 6902Z.	8
Figure 2.5	Brushless motor.	9
Figure 2.6	Planetary Gearbox.	9
Figure 2.7	Typical Time Domain Waveform.	13
Figure 2.8	Skewness distribution pattern.	14
Figure 2.9	Typical Frequency Domain Waveform.	16
Figure 2.10	FFT transform time domain to frequency domain.	18
Figure 2.11	Proxomity transducer.	23
Figure 2.12	Velocity transducer. NIKAL MALAYSIA MELAKA	24
Figure 2.13	Schematic cross-sectional view of a piezoelectric	24
	accelerometer.	
Figure 2.14	Piezoelectric accelerometer.	25
Figure 2.15	MATLAB logo.	28
Figure 2.16	Microsoft Excel logo.	28
Figure 3.1	Experiment set up.	30
Figure 3.2	Flowchart of experiment.	31
Figure 3.3	Test specimen.	32

Figure 4.1	Abrasive wear on bearing rolling element.	36
Figure 4.2	Vibration spectrum of 90 Nm.	37
Figure 4.3	Vibration spectrum of 100 Nm.	38
Figure 4.4	Vibration spectrum of 110 Nm.	39
Figure 4.5	Root mean square against Torque (Nm) graph.	40



LIST OF SYMBOLS AND ABBREVIATIONS

RMS	-	Root Mean Square
DAQ	-	Data Acquisition
MATLAB	-	Matrix Laboratory
Nm	-	Newton-meter
m/s^2	-	Meter per second square
g	-	Amplitude gravitational unit
Hz	-	Hertz
MEMS	-	Micro-electromechanical systems
VSA	- 10	Vibration signal analysis
FFT	and the second s	Fast Fourier Transform
mm	EK.	Milimeter
Ft-lb	T THOUSE	Foot-pound
	ملاك	اونيۈم سيتي تيڪنيڪل مليسيا و
	UNIVE	ERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF APPENDICES

TITLE

APPENDIX

PAGE

А	Time domain spectrum.	50
В	Gantt Chart.	52
С	ASTM A325: Standard Specification for Structural Bolts,	53
	Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength.	
D	Laboratory experiment pictures. UTERSITI TEKNIKAL MALAYSIA MELAKA	54
	UNIVERSITI TERNIKAL MALATSIA MELAKA	

CHAPTER 1

INTRODUCTION

1.1 Background

A significant number of modern industries rely on various rotating machine such as motor pump, compressor, generator, etc. All rotating equipment generates vibration and have its own unique vibration signal. Vibration is referred as mechanical system's oscillatory (Leonard Meirovitch, 2001). It can happen naturally or by exerting force on things around us. Vibration not only happen on machine that has moving parts, but it can happen on building, plants, human, even air and water particle vibrates. Excess vibration will cause difficulty in a variety of disciplines, including mechanical, civil, and electrical engineering. Therefore, condition monotoring is required to prevent them from happening. The most popular monitoring techniques are vibration analysis, lubricant analysis, infrared thermography, electrical monitoring, and sound (acoustic) emissions (Rao et al., 1996). Condition monitoring on rotating machines is important so that naintenance can be planned well in advance of the machinery failing (Nandi et al., 2005). Vibration signal analysis is one of the most accurate method to analyse the state of equipment beside its reliability (Rao et al., 1996). From vibration analysis, the structure damage detection and identification can be obtained.

In cordless impact wrench, vibration is a normal behaviour where there is no faulty. When there is a damage occur in cordless impact wrench, it make users feel uncomfortable due to excessive vibration. Motor, bearing and planetary gear set inside cordless impact wrench is the main component thus play a big role in determining the work quality. The excessive vibration is usually caused by an uneven or poorly condition of components. Alternatively, the vibration could indicate that the bearings are worn out or deterioration. Therefore, it is necessary to study the vibration signal from the faulty component so that prevention step can be taken. There are several method and tools of analysing the vibration signal and spectrum of cordless impact wrench. It is important to have a precise and detailed data to understand the characteristic of the vibration. The vibration of a machine is calculated by attaching an accelerometer and measuring the increasing accelerations caused by the vibration. The accelerometer is a sensor that monitors a physical tool's dynamic acceleration which affect the change in voltage (H.N Norton et al., 1989) and (S. Xianzhiong et al., 2005). Accelerometers are full-touch transducers that are frequently installed on high-frequency components, such as rolling-element bearings, motor housing, etc. The accelerometer data depicts the system's vibration response in time domain. Vibration data in the time domain can provide the maximum amplitude and period of a vibration. However, it is impossible to precisely identify the nature of machine's defects using only time domain data. As a result, the vibration data is evaluated in the frequency domain using signal processing methods. The Fast Fourier Transform (FFT) is the most widely used signal processing approach. The FFT method was proposed by Patel et al. (2018) as an analysis tool for monitoring a rotating machine, and important problems like misalignment and bearing can be tracked in this way FFT spectra contain information that can be used to identify the source and cause of an issue. Then, FFT spectrum from the accelerometer sensor that appear in the data acquisition tool will be filtered by the computer aided data processing system known as MATrix LABoratory (MATLAB). MATLAB is a programming software that was created with the goal of making scientific calculations as simple as possible. To process the data of vibration signal, the MATLAB software and Microsoft Excel is used.

1.2 Problem Statement

Cordless impact wrench nowadays is becoming modern and simple on its electrical and mechanical system. Motor, bearing, planetary gear are the main component in modern cordless impact wrench. When motor can not perform at it best performance, it might affect the quality of work. Beside motor, the breakdown of the bearing will give the user uncomfortable grip due to the excessive vibration caused by inner ring or outer ring damage, rolling element defect, and severe damage. In order to analyse the fault, vibration signal analysis method is used. For this study, a statistical analysis and spectrum analysis method will be used to obtain the best presentable and precise data regarding to the analysis fault on the cordless impact wrench bearing.

1.3 Research Objective

The main aim of this study is to analyse the characteristic of the cordless impact wrench's vibration signal with and without faulty on the system . Specifically, the objectives are as follows:

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

- a) To study paramater to be measured on cordless impact wrench when tested at 90 Nm, 100 Nm and 110 Nm of torque.
- b) To investigate the normal and abnormal data using vibration spectrum and statistical analysis method from MATLAB and Microsoft Excel.

1.4 Scope of Research

This project will be focused on cordless impact wrench bearing faulty diagnostic. This project involves three phase which are laboratory experimental activities, signal data analysis and result validation. Accelerometer will be used as vibration signal sensor detection. The signal are process by DAQ (Data Aquisition) by using accelerometer as the transducer. Then, MATLAB and Microsoft Excel are assigned to filter, process and analyze the vibration spectrum and produce the graph of statistical method chosen. The data will be represented by using FFT and Vibration Signal Analysis (VSA).

Using the proposed signal processing methods, the impacts of various failures and the frequency spectrum on the system's vibration response are explored. Ways to reduce machine vibrations will be suggested. To categorise the system's defect, various statistical methodologies are used. The statistical methodology and the spectrum analysis are used to reach the final conclusion.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of previous research and study on knowledge that related to this study. It introduces the framework for the case study that comprises the obejctives of the study stated in Chapter 1 in this thesis. It is important to set the context of the literature review by providing an explanation of its specific purpose for this particular case study. The main purpose of the literature review work was to survey previous studies on knowledge sharing and layout the framework where equipment details discussed first, then condition monitoring, vibration analysis, signal processing, advanced statistical analysis followed by data aquisition (tranducers) and fault recogniton technique based on artificial intelligence (AI).

2.2 Cordless impact wrench

Maintenance and construction sector nowadays use a lot of modern tools to help engineer, technician, and maintenance crew to solve a work in a short time and to do heavy work easily. One of it is cordless impact wrench or also called as torque gun. It is designed to transmit high torque output with minimal effort. A sudden high force supplied by its brushless motor contain high intensity of twisting motion to a fastener (nut) through shaft in a very short time. This motion can be set into forward and reverse motion (loosening or tightening) and this tool can be used to assemble and disassemble works. For this study, a cordless impact wrench will be tested to study it vibration characteristic with normal and abnormal condition.



Figure 2.1: Cordless Impact Wrench.

Features	Specification / Type	
Brand	KEELAT	
Model	KID004	
Type Mohumila Sol	Cordless	
Motor	Brushless Grand V Jan	
Battery model	21V (40000 mAh)	
Maximum torque	420 Nm	
Maximum speed	4200 RPM	
Impact rate	0~6200 per minute	
Wrench head size	1/2-inch	

Table 2.1: Cordless Impact Wrench specification.

2.2.1 Internal parts of the cordless impact wrench

In order to understand deeper about the cordless impact wrench, the internal part of it needs to be recognized to enhance our understanding of the mechanical system and electrical system in this tool.



2.2.2 Bearing

There are several types of bearing such as ball bearing, roller bearing, and cylinder bearing. Bearing main function is to reduce the friction between moving parts and to hold rotating parts such as shafts, wheels, gears, and rotors so that they can rotate smoothly. There are several main parts of bearing such as inner ring, outer ring, cage and rolling element. Figure 2.3 shows the main parts in bearing.



Figure 2.3: Bearing parts.

Source: https://koyo.jtekt.co.jp/en/2019/08/column01-03.html

Bearing is a core component of frictionless transmission for every rotating machine. Therefore, bearing condition monitoring become more crucial as it play a particularly important role. Bearing can give benefits as it maintained regularly. In other way, bearing can give massive downtime if it is not maintained well. Figure 2.4 below shows the ball bearing inside the cordless impact wrench. It is located inside the hammer system placed in between the planetary gear set and the brushless motor.







Bearing with model number 6902Z is used in this cordless impact wrench with dimension as follow.

Bearing model	Dimension (mm)	
6902Z	15 x 28 x 7	

2.2.3 Brushless motor

2.2.4

Motor used in this device due to it energy efficientcy which as stated on it name, there is no brush in contact againts anything meaning that there is no friction generated in this motor. Since there is no friction generated, there will be no energy lost and the battery capacity can last longer up to 50% than burshed impact wrench with burshed motor. Besides that, brushless motor is more responsive, generate more torque and speed, and last longer because it easy to maintain.



One of the benefits of using planetary gear set in impact wrench is to reduce the speed of the brushless motor with intention to increase the torque. Planetary gearbox is a popular choice because it compact size and its high capability to multiply the torque transmission.



Figure 2.6: Planetary Gearbox

2.2.5 Possible faulty in cordless impact wrench

There are several possible damage or wear that could happen in the impact wrench such as motor faulty and bearing damage. Motor faulty can cause a massive downtime as it is the heart of the impact wrench thus led to unplanned downtime. Contaminated motor can cause to electrical overload and overheating conditions. Other than that, bearing is also a vital component of impact wrench making it important to undergo regular maintenance through condition monitoring. The main bearing faulty such as damage rolling element (ball bearing), cracked body, inner and outer ring damage is commonly happened in every rotating machine. The reason of these bearing faulty is the bearing gets contaminated easily which by year, can cause misalignment and spark the premature failure. Second reason is bearing might be lubricated incorrectly and led to high rise of temperatures and evaporation process will occur at the same time causing it to create high friction. This is clearly contrary to it main function.

2.3 Condition monitoring

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

In industrial applications, equipment condition monitoring can help to improve machine health. When the state of the machine is always monitored, unexpected process halts due to machine breakdowns can be avoided, resulting in a significant gain in production efficiency. Furthermore, maintenance can be planned well in advance of the machinery failing (Nandi et al., 2005). There are numerous methods for condition monitoring. The most broadly used monitoring methods include sound (acoustic) emissions, vibration analysis, lubricant analysis, infrared thermography, and electrical monitoring (Rao et al., 1996). When two or more of the above methods are used, the most effective condition monitoring methodology is achieved.

2.4 Vibration analysis

All machines vibrate, whether they are in wholesome circumstance or whilst a fault is present withinside the device. These vibrations are associated with a periodic incidence withinside the device. Vibration evaluation has a few benefits as compared to different tracking techniques. First, it demonstrates the going on failure immediately. Second, the principal sign processing techniques may be implemented to the vibration signals (Randall et al., 2011). The remaining and most important benefit is that the mechanical methods withinside the rotating device produce energy at different frequencies. Therefore, the frequency spectrum of vibration records can show unique statistics on circumstance of various components of the device (Rao et al., 1996). A vibration analysis system includes the subsequent components which are a vibration signal transducer (accelerometer, displacement, or velocity probes), a dynamic signal analyzer, analysis software, and a computer for data analysis and storage (Scheffer et al., 2004). In brief, vibration analysis may be used to enhance the machine's reliability, through presenting detailed data on machines health condition. Vibration analysis was used to evaluate gear and bearing fault frequencies (Randal et.al., 2004). Investigating the vibration reaction of misaligned rotor of various machines, the use of sign processing techniques (Patel et al., 2009) and (Hariharan et al., 2011) demonstrates that vibration analysis has accomplished first rate precision in figuring out the most common machine faults.

2.5 Signal processing

This subtopic explains on what type of signal processing that is widely used in vibration signal analysis. There are three type of domain which is time domain, frequency

domain, and time-frequency domain. All those domains will be discussed to have an idea what are those domains about and its characteristics.

2.5.1 Time domain analysis

Time domain analysis (TDA) is one among the simplest and widely used VSA strategies. Time domain is that the graph between vibration amplitude and time. Vibration amplitude of vibration of developed in machinery is measured in phrases of displacement, speed, acceleration. Displacement is measured peak to peak and typically in microns or mils. Velocity is measured in peak, or root mean square (RMS) and usually in mm/sec or inch/sec. Acceleration is expressed peak and commonly measured in mm/s^2 or g's (Mechefske et al., 2005). Amplitude of vibration shows the severity of the fault in machine and frequency of vibration indicates the actual reason of vibration. For example, a time waveform of a bearing having fault can be seen as there is a rise in amplitude level of faulty bearing than that of good bearing shows the presence of defect in the bearing. The vibration levels of machines are compared with the good condition machines to detect the faults in them. Time domain makes use of actual data. Time domains contain greater data but provide limited data about condition of machines. The advantage of time domain is that little or no records are misplaced prior to inspection (Mechefske et al., 2005). On the other side, a drawback is that there is frequently too much data for accurate and simple equipment defect analysis (Patil et al., 2008). TDA of vibration signal is another time subdivided into the subsequent classes: Time-Waveform Analysis, Time Waveform Indices, Time Synchronous Averaging, Negative Averaging, Orbit analysis, and Probability Density Moments (Jayaswal et al., 2008). Figure 2.7 shows the typical time domain waveform.



Figure 2.7: Typical Time Domain Waveform (Howard et al., 1994).

With the use of several statistical indices, such as Peak, RMS, Crest factor, Skewness, Kurtosis, Clearance factor, Impulse factor, and Shape factor, flaws are identified in time waveform analysis. The indexes Peak, RMS, Crest factor, and Kurtosis are the most often used ones.

The peak is the maximum amplitude (displacement, velocity, or acceleration) of the vibration signal. The peak value increases with increasing defect size (Tandon et al., 1994). RMS measures the overall level of the vibration signal. That is, it measures the energy of the signal. This section describes the effective value (magnitude) of the signal. RMS increases with the increase in the defect size (Tandon et al., 1994). A sine wave's RMS value is 0.707 times its peak value. When spotting unbalance in spinning machinery, RMS value is useful. RMS value is the most fundamental and widely used way to identify defects in rotating machinery in the time domain, however it is unable to identify flaws when the issue is in its initial stages. Crest factor of vibration signal is the ratio of Peak Value of signal to the RMS of signal. This is an indicator of the spikiness or impulsive nature of the signal (Howard et al., 1994). The crest factor for a sine wave is 1.414.

Skewness is the third moment of distribution of the information. It is a measure of a signal's asymmetrical spread around its mean value. Skewness is zero when the signal is

radially symmetrical. Meaning that when skewness differing from zero indicates that something is wrong. Figure 2.8 shows skewness distribution pattern.



Figure 2.8: Skewness distribution pattern (Feunou et al., 2016).

Kurtosis is that the fourth moment of distribution of the signal data. It assesses the peak of a time series' probability density function (PDF). A kurtosis value near 3 implies a Gaussian-like peak. PDFs with comparatively sharp peaks have kurtosis larger than 3. PDFs with relatively flat peaks have kurtosis but three. For the undamaged bearing, the value of kurtosis is 3 (Martin et al., 1995). The pattern of the signal affects both the crest factor and the kurtosis. The crest factor decreases the outcome of a single, highly crest amplitude event when it is the only component considered. The calculation of the mean of the instantaneous amplitudes of the signal raised to the power of four offers a substantial weight to high amplitudes of the kurtosis (Mahamad et al., 2010). The kurtosis consequently seems to be a better indicator than crest factor, for the reason that the dispersion of the outcomes coming from successive measures is weaker. Skewness is the worst parameter amongst RMS, Kurtosis and Skewness (Tandon et al., 1992).

There are some previous studies about detection of fault by time domain analysis of rotating machinery like bearing, gears, and pumps. Study by Tandon et al. (1992) demonstrated that measurements of cross-correlation and vibration probability density are

15 both useful for identifying flaws in rolling element bearings. Comparison done by Tandon et al. (1994) about the vibration parameters including RMS, peak, crest factor for the condition monitoring of rolling element bearing found that the parameters increase as the defect size increases. However, the outer race defect is not detectable by crest factor. Statistical moments used by Martin et al. (1995) is skewness and kurtosis for bearing failure detection shows that the skewness and kurtosis are independent on load and speed, and kurtosis of healthy is three (3) and the value rising with the defect size. Study ran by Klinchaeam et al. (2014) exhibit spur gear fault detection using VSA based on time domain to analyses the vibration signals of healthy and faulty spur gear (faults like scuffing defect, crack defect and broken tooth). The statistical parameters of time domain signals were used to compare and evaluate the severity of faults.

Time domain	Advantages	Disadvantages		
method	M. L. K.			
Peak =	Straightforward technique	Noise high sensitivity		
RMS	Simple and straightforward approach	RMS vibration changes are		
U	that is directly tied to the energy content	only sensitive to high-		
	of the vibration profile	amplitude components		
Kurtois	Shock-sensitive, may be absorbed with	A costly kurtosis detector can		
	a form factor independent of signal	be inaccurate.		
	amplitude			
Crest factor	High availability and affordable	It is only reliable in the		
	instrument	presence of sufficient		
		impulsiveness		

Table 2.3: The advantages and disadvantages of time domain method

2.5.2 Frequency domain analysis

Spectral analysis also called as frequency domain analysis is one of the most used methods in analyzing the frequency contents of vibration spectrum (signal) of rotating machine. Once the vibration data collected through data acquisition tools, signal processing broke down the data into a synthesis of distinct sine waves which each of them represent a vertical frequency-domain line. The line's height and position are visible as the amplitude and frequency. The amplitude plotted against frequency in frequency analysis and as compared to the time domain, the resonant frequency component is easier to detect. This make frequency domain method is the favorite method of detecting fault in rotating machine (M. Vishwakarma et al., 2017). Frequency domain analysis can reveal certain aspects of the signal that are not observable in the time domain. On the other hand, frequency analysis is ineffective for signals whose frequencies change over time. Table 2.4 below shows the advantages and disadvantages of each frequency domain method.



https://knowledge.ni.com/KnowledgeArticleDetails?id=kA03q00000YGJ7CAO&l=en-US

Frequency domain method	Advantages	Disadvantages
FFT	Simple to use, quick method	Cannot evaluate transitory characteristics in time efficiently.
Cepstrum analysis	Simple to use, good for side band analysis	May only be applied to well separated harmonics, and the oscillations of the spectrum curve are averaged out owing to filtering
Envelope analysis	Excellent applicability in bearing systems; operates well even when subjected to minor random fluctuations.	Can result in a major diagnostic mistake, making it unsuitable for use in the gear system.
Spectrum analysis	Useful for identifying signals that vary tremendously in a short period of time, with better spectral estimate performance than the FFT.	Because of its complexities, it need the expertise of professionals.

Table 2.4: Advantages and Disadvantages of frequency domain method

2.5.2.1 Fast Fourier Transform (FFT)

The Fourier transform (FT) transfers a signal from the time domain to the frequency domain, resulting in the spectrum $F(\omega)$. Given that FT

اونيوم سيخ ٽيڪ ڪر ملسيا ملاك

$$F(\omega) = Ff(t) = \int_{\infty}^{\infty} f(t)e^{-i\omega t} dt.$$
 (1)
UNIVERSITI TEKNIKA MALAYSIA MELAKA

Where, ω is the frequency, and t is the time.

FT can be converted back to domain frequency from frequency domain by inverse the function of FT to become inverse Fourier transform (IFT) as showed in equation below.

$$f(t) = F^{-1}(F(\omega)) = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{i\omega t} d\omega.$$
(2)

FFT is a popular and effective method for obtaining the FT of discretized time signals. The FFT plot of fault-free industrial machinery has only one peak, which represents the working machine's inherent frequency. When the plot contains peaks other than the natural frequency peak, a machine issue can be identified. However, Goyal and Pabla (2017) suggested that a small amount of time information is lost during domain transfer. Additionally, FFT is unable to explore transient features quickly and can predict the defect but not its severity. (S. Kumar et al., 2018). However, for the diagnosing procedure, it is the quickest approach to isolate the signal's frequencies. When troubleshooting a low-speed machine, a combination of time domain signal analysis and FFT is usually used to generate more accurate results. The FFT method was proposed by Patel et al. (2018) as an analysis tool for monitoring a rotating machine, and important problems like misalignment and bearing can be tracked in this way. Ameid et al. (2017) use FFT method to diagnose induction motor fault and come out with the simulation results from MATLAB/Simulink agree with the experimental results. Figure 2.10 shows the FFT transformation.



Figure 2.10: FFT transform time domain to frequency domain

Source:

https://knowledge.ni.com/KnowledgeArticleDetails?id=kA03q000000YGJ7CAO&l=en-US

2.5.2.2 Cepstrum analysis

Cepstrum analysis is the power spectrum of the power spectrum's logarithm (Y. Liu et al., 2020), was established in the 1960s. The four types of cepstrum are real cepstrum, complex cepstrum, power spectrum, and phase spectrum, though power cepstrum is the most extensively utilized cepstrum in machine diagnostics and monitoring. Cepstrum analysis can identify any periodic structure in the spectrum, including harmonics, sidebands, and echoes (N. Aiswarya et al., 2018). This permits faults that produce low-level harmonically related frequencies, such as bearing and localized tooth faults, to be recognized. Cepstrum analysis is helpful in gearbox diagnosis, according to Goyal and Pabla (2016). Sako et al. (2016) used the cepstrum analysis approach to discover the rubbing phenomenon of the sliding bearing in the machine. The proposed method was proven to be capable of detecting minor rubbing, which is difficult to perform using traditional abnormality diagnosis methods.

2.5.2.3 Envelope analysis

Mechanical Technology Inc. (R.B. Randall, 1987) pioneered envelope analysis, commonly known as amplitude demodulation or demodulated resonance analysis. The low frequency signal is separated from the background noise using this technique (Vishwakarma et al., 2017). The signal envelope is extracted by a bandpass filtering and demodulation stage in envelope analysis, and its spectrum may contain the needed diagnostic information (D. Abboud et al., 2017). It is frequently employed in the diagnosis of rolling element bearings and low-speed machines, and it has the advantage of detecting bearing problems early (I. Howard, 1994) and (D. Abboud et al., 2017). The difficulty with this method is deciding which frequency range to envelope. To work smoothly, envelope analysis requires a sharp filter and exact frequency range selection for filtering (I. Howard, 1994). The noise components in bearing failure make envelope analysis difficult to pinpoint the defect. Leite et al. (2014) used envelope analysis to detect bearing faults in induction motors, and the proposed method may efficiently detect faults without any model information.

2.5.2.4 Spectrum analysis

Spectrum analysis is linked to FFT in the sense that FFT is frequently employed in spectrum analysis to transform signals from the time domain to the frequency domain (J. Trout, 2020). Spectrum comparisons should be done on a logarithmic amplitude scale (dB), as changes in the logarithmic axis can reveal the vibration's status. This approach (P.J. Loughlin et al., 1997) can detect a malfunction that can dramatically affect the vibration signature in a short amount of time. However, tiny oscillations in the machine's spinning speed must be dealt with (I. Howard, 1994). Spectrum analysis, unlike Cepstrum analysis, provides no information on the time localization of frequency components (S.S. Aralikatti et al., 2019) It is a complicated analysis that, despite the abundance of literature, requires expert skills to fully leverage spectrum analysis' diagnostic powers. When compared to the FFT method, Salami et al. (2001) discovered that smoothed and high-resolution spectral estimations of the vibration signals can be obtained by using the spectrum analysis method for machine condition monitoring. This spectrum can be used to track the status of devices..

2.5.3 Time-Frequency domain analysis

The time-frequency domain methodology involved both time and frequency domains. This means that in this technique, the signal frequency element and its time-variant characteristics can be computed concurrently. Feng et al. (2013) state that time domain and frequency domain methods rely on the stationary assumption, which makes it impossible to identify local features in both time and frequency domains at the same time. Consequently, such techniques are ineffective for nonstationary signal analysis. Wavelet transform (WT), Hilbert–Huang transform (HHT), Wigner–Ville distribution (WVD), short-time Fourier transform (STFT), and Power Spectral Density (PSD) are the time-frequency domain analysis methodologies. Table 2.5 shows the pros and cons of each time-frequency domain approach.

Time- frequency domain method	Advantages	Disadvantages
WT	Provide better time localization at high frequencies than STFT,	Convolution of a prior basis functions with the original signal is
	are more versatile than STFT, and have a wider range of	a problem and choosing the mother wavelet type is challenging
	wavelet functions.	wavelet type is chanteliging.
WVD	It has a good time and frequency	Interference-prone, and slower than
Kin	resolution and does not require	STFT.
	the use of a window feature.	
HHT	Has a high temporal and	Misinterpretation because of IMFs
0	frequency resolution and prior	created in the low-frequency area.
	basic function is not required.	
STFT	Simple approach that is	Constant frequency resolution for
12	suggested for novices in time-	the whole signal, challenging to
	frequency analysis due to its	discover a quick and effective
	minimal computing complexity.	STFT method
PSD UN	FFT can directly compute it, and	The window size influences
	it uses relatively minimal CPU	frequency resolution.
	resources.	

Table 2.5: The advantages and disadvantages of time-frequency domain methods.

2.6 Advance Statistical Analysis

Advanced statistical analysis is another modern way of statistical analysis compared to RMS, skewness, kurtosis, crest factor and peak. I-kaz is one of the methods commonly used in analysis statistical data not only for vibration analysis but for other analysis.

2.6.1 I-kaz Method

The I-kazTM technique was invented using the concept of data scattering around the data centroid with inferential statistics to classify the display. In order to model the data patterns, the I-kazTM procedure has been developed, which compensates for randomness and draws inferences from a broader population. These conclusions would be used to predict and forecast future observations.

The I-kazTM approach works by breaking down a dynamic signal into three frequency ranges: a low-frequency (LF) range of 0-0.25 f_{max} , a high-frequency (HF) range of 0.25 f_{max} –0.5 f_{max} , and a very high-frequency (VF) range of 0.5 f_{max} .

2.7 Data Acquisition

This subtopic will be discussed on the transducers that available in vibration analysis sector.

2.7.1 Proximity Transducer

A proximity sensor, often known as an eddy current or displacement sensor, detects both relative vibration and shaft position. The displacement unit might be in millimetres, centimetres, or millimetres. It is most commonly used to measure low-frequency vibrations under 10 Hz, but it can also measure vibrations up to 300 Hz (D. Goyal et al., 2016). They do not, however, perform well when measuring a shaft bending away from the probe (M.P. Boyce, 2011). Unbalance and misalignment are among the issues that the displacement probe can identify. The amplitude is frequently lost in the noise level at vibration frequencies exceeding 1 kHz (M.P. Boyce, 2011). It boasts a wide dynamic range within a narrow frequency range, good sensitivity, and a simple postprocessing circuit that requires little maintenance. In contrast, it is difficult to install, prone to shocks, and certain classic displacement sensors are not calibrated for unknown metal compositions (D. Goyal et al., 2015). Sarhan et al. (2004) used a proximity sensor to measure the machining center's cutting forces under various cutting situations. Figure 2.11 is s proximity tranducer.



Figure 2.11: Proxomity transducer

Source: https://www.ato.com/proximity-sensor-capacitive-m12-pnp

2.7.2 Velocity Transducer

A velocity transducer measures the voltage generated by an object's relative movement in m/s or cm/s units. It works on the principle of electromagnetic induction and can function without the use of any external devices (S. Pabla et al., 2016). The movement of the magnet in the coil produces a voltage proportionate to the velocity of the vibration as the surface where the sensor is mounted vibrates (A. Fernandez, 2020). This voltage signal is used to input a meter or analyzer (C. Sanders, 2020), which reflects the vibration caused. As the functioning frequency range is limited from 10 Hz to 2 kHz (Elango et al., 2018) velocity sensors are not suggested for diagnosing high-speed machines. Briefly, velocity transducers are less expensive than other sensors, and their ease of installation makes them ideal for monitoring the vibration of spinning machinery. It is, however, large and heavy, and most velocity transducers have reliability issues when operating temperatures above 121°C (D. Goyal et al., 2015) and (M.P. Boyce et al., 2011). Rossi (2012) used a velocity transducer to quantify compressor frame vibration, which typically occurs at frequencies below 10 Hz. Figure 2.12 displays a velocity transducer.



Figure 2.12: Velocity transducer

Source: https://buy.wilcoxon.com/893v.html

2.7.3 Accelerometer

An accelerometer is a device that uses the SI unit of $g (m/s^2)$ to measure the vibration or acceleration of a structure. Due of its dependability, simplicity, and robustness, the accelerometer is a commonly used sensor. Accelerometer works when the piezoelectric material in the accelerometer is subjected to a force, it produces a charge that is proportional to the force exerted. Since force is proportional to acceleration, any change in this factor will result in an increase in the charge created, which will then be magnified (C. Sanders, 2020).



Figure 2.13: Schematic cross-sectional view of a piezoelectric accelerometer.

Source: <u>https://www.etssolution-asia.com/blog/accelerometer</u>

Triaxial accelerometers detect movement in all three dimensions, whereas uniaxial accelerometers only detect movement in one plane. Triaxial accelerometers have a larger memory capacity than uniaxial accelerometers, but they are much more expensive (K.W. Cheung et al., 2014). Accelerometer sensors can be divided into piezoelectric and Micro-electromechanical systems (MEMS).

2.7.3.1 Piezoelectric Accelerometer

The piezoelectric effect of quartz or ceramic crystals, which are normally preloaded, is used to provide an electrical output proportional to the applied acceleration in a piezoelectric accelerometer. The charge created is affected by the acceleration (H.N Norton et al., 1989) and (S. Xianzhiong et al., 2005). The advantages of a piezoelectric accelerometer are improved frequency and dynamic range, minimal weight, and high sensitivity. It is, nevertheless, susceptible to disturbance from the outside (D. Goyal et al., 2015). Since it is AC coupled, it also necessitates electronic integration to acquire velocity and displacement data (D. Goyal et al., 2015). Salami et al. (2001) employed a piezoelectric accelerometer in their study to show the usage of LabVIEW in monitoring and analysing vibration data.



Figure 2.14: Piezoelectric accelerometer

Source: <u>https://catalogue.meggittsensing.com/wp-</u>

content/uploads/2022/11/CE620-piezoelectric-accelerometer-product-image-100x100.png

2.7.3.2 Micro-electromechanical systems (MEMS) Accelerometer

MEMS accelerometers are typically made up of a movable proof mass with plates attached to the frame by a mechanical suspension system (S.B. Chaudhury et al., 2014). Due to its own inertia, the proof mass tends to resist motion when subjected to acceleration, stretching or compressing the spring. As a result, force is created that corresponds to the applied acceleration. The DC coupled MEMS accelerometer is ideal for monitoring lowfrequency vibration and acceleration. It has a minimal processing power need and offers higher sensitivity (S.B. Chaudhury et al., 2014). Up to many tens of kHz, modern MEMS accelerometers give good data quality.

The disadvantage is that it has a low signal-to-noise ratio. For vibration monitoring, Chaudhury et al. (2014) used the MEMS accelerometer in various rotating machinery. The sensitivity of MEMS accelerometers is found to be more stable than piezoelectric accelerometers, suggesting that this low-cost MEMS accelerometer could be a good replacement to the high-cost piezoelectric accelerometer.

2.8 AI Based Signal Filtering

2.8.1 MATLAB

Matrix Laboratory (MATLAB), one of the most popular software tools for numerical computing and visualisation, has been used by many experts (Etter, Delores M and Kuncicky, 2011). Then, as shown in this article, the main data element is a matrix, thus in this situation, the programme that manipulates array-based data is completely correct and quick to create and execute in MATLAB. Then, MATLAB, a main feature of a high-performance language for technical computing, is used to generate a vibration output. Since then, MATLAB has been the focus of much research on how it blends compute,

visualisation, and programming environments (Houcque, 2005). MATLAB is a modern programming language of the environment that has advanced data structures, has built-in editing and debugging equipment, and aids in equipment-oriented programming by utilising MATLAB. Aside from that, one of the primary factors that contribute to MATLAB being a fantastic tool for teaching and research is its performance. Then, one of the most appealing aspects of MATLAB is its variety in terms of functions. So, using MATLAB, it has been possible to manage from a basic expression to a range of difficult mathematical operations on big collections of data. As a result, MATLAB contains a large number of predefined functions from which to choose.

As a result, there is now a scarcity of research to choose from in order to arrange and present records on the display screen correctly. This will allow for the investigation and interpretation of vibrations in mechanical structures or mechanical systems. Aside from that, excellent data must be obtained by analysing and visualising spectral content occuring in rotating gear or equipment used in industries. Despite this, the system of track and extract orders is the most important of their time-area waveforms that generate the outcome. Further investigation revealed that it is possible to estimate the common or average spectrum of a signal as a function of the order in the analysis. Once completed, do experimental modal analysis by estimating frequency-response functions, natural frequencies, damping ratios, and mode shapes that are commonly used in modal analysis. An significant element is that it eliminates all coherent noise using time synchronous averaging and evaluates the forms of wear using envelope spectra. Finally, it can properly and consistently provide the highest high-cycle rain flow counts for fatigue analysis.



Figure 2.15: MATLAB logo

Source: <u>https://www.keysight.com/my/en/product/N6171A/matlab-software.html</u>

2.8.2 Microsoft Excel

Microsoft Excel is one of the most used data analysis programmes in the world. However, Microsoft Excel is an excellent and easily accessible programme that may be used to analyse and analyse vibration data. Furthermore, to study the data, a few specialised mathematical techniques such as FFT may be required. The fast Fourier transform (FFT), which is a good efficiency of Fourier's work, is commonly employed to examine sound waves of data carried out. Then, we're going to perform it with MS-Excel, which is a readily available application software that is normally included on every personal laptop.



Figure 2.16: Microsoft Excel logo

Source: <u>https://www.techadvisor.com/how-to/software/microsoft-excel-free-</u>

<u>3689600/</u>

CHAPTER 3

METHODOLOGY

3.1 Introduction

Cordless impact wrench health status can be detected based on how the experiment is setup. The study of vibration on cordless impact wrench is aimed to obtain knowledge related to its performance and health status. There are few techniques and methods are identified to be used in this experiment. Combination of those techniques is to make sure the experiment can be run smoothly and to secure the data obtained in order to fulfil the objective of this study. This chapter give early picture of how the experiment will be conducted. Starting with the proposed methodology which in this subtopic will explain how to conduct the experiment. Then, proceed with the experiment setup and parameter discussed to increase the trust in result and improves the analysis process. After that, test specimen and equipment that will be used in the experiment will be explained and followed by the signal measurement, signal processing and filtering. Lastly, limitation alongside the methodology proposed. Chapter 3 also represents the flow of the experiment.

3.2 Proposed Methodology

The main idea of the experiment is by using the cordless impact wrench that has to loosen three nuts which are tightened with three different torque. The experiment will be run under two conditions, which are normal condition (no faulty) and abnormal condition with rolling element of ball bearing faulty. Method proposed is by attaching the piezoelectric accelerometer on the hammer housing on the cordless impact wrench. At the same time, the accelerometer is connected to the data acquisition device (DAQ). Then, the data is transferred from DAQ to laptop to be processed. MATLAB and Microsoft Excel software is used to filter the data and for signal analysis purpose.

3.2.1 Experimental Setup

Experiment setup for this experiment is described as Figure 3.1 below. The process flow of how the experiment conducted is also shown in Figure 3.2.



Figure 3.1: Experiment Setup.



Figure 3.2: Flow chart of experiment.

3.2.2 Parameters

In a single simulation, parameter usually kept constant and only altered when experiment model behavior changes are needed. In this experiment, the parameter is set up due to the ability of the cordless impact wrench to perform and to make sure the experiment can obtain the reliable result. The cordless impact wrench is to be run at maximum speed 4200 RPM with full battery capacity of 4.0 amp-hour. According to ASTM A325, maximum torque for plain M12 bolt is 158 Nm. Therefore, all of the three nut is tightened at 90 Nm, 100 Nm, and 110 Nm.

Table 3.1: Experimental parameters.

CONDITION	TORQUE (Nm)								
A.	1 st nut	2 nd nut	3 rd nut						
NORMAL	90	100	110						
ABNORMAL	90	100	110						

3.2.3 Test specimen

Test specimen used is a metal piece that is welded with 21 mm bolt. It will be clamped

at the edges of the table to lock it in one place. MALAYSIA MELAKA



Figure 3.3: Test specimen.

3.2.4 Equipment

Proposed methodology and experiment setup stated above requires equipment to run the experiment. Table 3.2 below shows the list of equipment with it model and type. These equipment are available in market and easy to purchase. There are several equipment that need to borrow from faculty laboratory lecturer and lab assistant such as DAQ device and accelerometer.

EQUIPMENT	MODEL / TYPE	QUANTITY
Cordless impact wrench	KEELAT KID004	1 set
Torque wrench	¹ / ₂ " driver click adjustable micrometer torque	1 set
_	wrench	
DAQ device	GUNT PT500.04 (two channel)	1
Accelerometer	ICP Vibration Sensor 6033C01	1
Laptop (data processor)	ASUS A-15	1

Table 3.2: List of component.

3.3 Signal Measurement

Measurement of signal is done by using piezoelectric accelerometer Piezoelectric accelerometer is the best tranducer that available for this experiment. Piezoelectric accelerometer is selected because it is easy to use and has character such like improved frequency and dynamic range, light weight, and highly sensitive to changes.

3.4 Signal Processing and Filtering UNIVERSITI TEKNIKAL MALAYSIA MELAKA

During the experiment, the vibration data will be recorded in DAQ software through accelerometer. Vibration data from DAQ software will be transformed into frequency domain (by FFT) using MATLAB. Spectrum of time domain is transformed into statistical data such as RMS. The time domain data will be calculated by Microsoft Excel to present the RMS in graph form to perform statistical analysis. Frequency domain is selected to analyze the vibration signal by spectrum analysis technique because it is the accurate method compared to time domain which only can be analyzed using the statistical data in term of value. Combination of these analysis method can secure the result and increase the trust on this experiment findings..

3.5 Limitation of Proposed Methodology

Limitation is a thing we can not avoid, but we have done the best to reduce it. In this experiment, there are few limitation that give us challenge to solve it. One of it, to hold the cordless impact wrench firmly for evey parameter and condition. When loosening the nut, the impact wrench might need constant and steady force to avoid from being stripped or slipped due to its own vibration. This situation might give the accelerometer false reading and unnecessary noise in vibration signal data reading. However, a universal holder is made to overcome this limitation. Other than that, the battery power will reduce after loosing a nut, then it is need to be charged again before running the second parameter. Luckily, there are another one spare battery to help reduce the time of the experiment. Last but not least, there are no standard for the experiment setup that is close to my study either from American Society for Testing and Materials (ASTM) or other testing society. However, for the data filtering, processing and analysis, several previous study was studied as the referrence and guide in completing my study.

3.6 Summary VERSITI TEKNIKAL MALAYSIA MELAKA

In brief, this chapter discussed about the proposed method to run the experiment relating with parameter, equipment, signal processing and filtering. The aim of the experiment is to study the vibration spectrum obtained from normal and abnormal condition of cordless impact wrench. Data obtained will be analysed to compare the characteristic from both condition and different parameter discussed in this chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained from the laboratory experiment of vibration signals observation on the cordless impact wrench. The performance of bearing was investigated via vibration spectrum using MATLAB and statistical analysis using the Microsoft Excel. Time domain and frequency domain analysis were discussed to identify the condition of the engine with a different condition of rolling element of ball bearing. The design and experimental procedure were discussed in the previous chapter.

4.2 Results and Analysis of Laboratory Experiment Data

The result of the laboratory experiment can be categorized in two sections. First, by using frequency domain processed in MATLAB and the second one is by using RMS value calculated from time domain in Microsoft Excel. Each section was run in two conditions where as in normal condition, there is no faulty on the bearing and the second one is in abnormal condition where the rolling element of bearing has abrasive wear on it. It is occurred when abrasive, hard and rough particle were present and slided on the softer surface, wedging a series of groove and removing material. The main root cause is identified on the surface of bearing rolling element. Hence, causing the grease inside it to dry and the presence of contaminant particle create an abrasive wear between rolling element and the cage.



Figure 4.1: Abrasive wear on bearing rolling element.

Laboratory experiment is conducted by lining up a few parameter. The fixed parameter are the speed of the cordless impact wrench whic is 4200 RPM and full battery capacity of 4.0 amp-hour. For manipulated parameter, the cordless impact wrench is required to loosen nut which is fastened at 90 Nm, 100 Nm and 110 Nm. Vibration signal (responsive parameter) from the cordless impact wrench is then recorded individually and then processed in MATLAB. It come out with two types of domain which are time domain and frequency domain of vibration spectrum. The result of the laboratory experiment for the time domain is recorded as time (s) against vibration acceleration (m/s²) while frequency domain is converted to amplitude (g) against frequency of vibration (Hz). For RMS calculation, it is done in Microsoft Excel.

4.2.1 **Result and Vibration Spectrum Analysis**

Frequency domain analysis is a widely used method in analyzing the frequency content of vibration spectrum. Certain aspects of the signal that are not detectable in the time domain can be revealed by frequency domain analysis. The amplitude recorded against frequency make the resonant frequency component is easier to detect as compared to the time domain. This make frequency domain method is the preferred method of detecting fault in rotating machine (M. Vishwakarma et al., 2017).

Torque: <u>90 Nm</u>



Figure 4.2: Vibration spectrum of 90 Nm.

Figure 4.2 shows the different in vibration spectrum between normal and abnormal condition of bearing rolling element that is being tested at 90 Nm. At normal condition, the highest amplitude value is 52.0112 g. However, when the bearing is in a severe condition, there are a few peaks appear and exceeded the maximum peak value of normal condition where the highest recorded value is 68.0723 g. In the range of 400 Hz - 1600 Hz, normal condition shows a steady vibration amplitude value under 10 g, while for abnormal condition, the uncertainty trend valued from 10 g up to 50 g. There are two humps detected in abnormal condition which are from 200 Hz - 900 Hz and from 900Hz – 1600Hz. The

existence of hump and sudden peak clearly shows that the bearing is in abrasive wear.

Torque: 100 Nm



Figure 4.3 shows the different in vibration spectrum between normal and abnormal condition of bearing rolling element that being tested at 100 Nm. The first peak of normal condition (72.9408 g) has higher amplitude than abnormal condition (33.4576 g), while the second peak of abnormal condition (32.5542 g) appears higher than normal condition (19.1555 g). This situation is due to inrush vibration that cause high sudden peak. However, second peak of abnormal condition represent defect frequency as well as the state of the bearing. The abnormal condition of bearing can be proved by observing and compare with the normal condition which are the pattern of the vibration frequency from 300 Hz up to 1600 Hz. It is clearly shows that the abnormal condition has frequency pattern more than 10 g of amplitude where the normal condition is below 10 g of amplitude.

Torque: <u>110 Nm</u>



Figure 4.4: Vibration spectrum of 110 Nm.

Figure 4.4 shows the different in vibration spectrum between normal and abnormal condition of bearing rolling element that being tested at 110 Nm. Normal condition shows the highest peak of vibration amplitude at 136.454 g. Abnormal condition shows there are 3 defect frequency which are 398.525 g, 351.564 g, and 207.487 g. Peak of 1x and 3x of abnormal condition is more than twice amplitude value of 1x peak at normal condition. Furthermore, at normal condition, the spectrum spread from 100 Hz – 1600 Hz is below than 50 g of amplitude. In abnormal condition, vibration generated cause the spectrum to spread from 50 g up to 150 g. The graph shows a significant different that indicate if there is a faulty on the rolling element of the tool's bearing.

4.2.2 Result and Statistical Analysis

Since RMS is the commonly used method to detect the faults in rotating machine, this section will analyze the RMS value of the vibration signal. RMS measures the overall performance of the vibration signal. Specifically, it measures the energy content of the vibration profile. The vibration peak value increases with defect size (Tandon et al., 1994). Which means, RMS increases with the increase in the defect size (Tandon et al., 1994).



Figure 4.5: Root mean square against Torque (Nm) graph.

Figure 4.5 presents the RMS comparison for both conditions. Trend line shown for both condition is rising with the torque. Since the vibration value is high as the torque increases, it proves that RMS increase with the vibration signal. However, for normal condition, RMS value is relatively below than 0.2 which means that, the cordless impact wrench is in good condition and no faulty detected in the bearing. On the other hand, when the cordless impact wrench is run with the abrasive wear on it bearing, the value of RMS is high starting from 0.1238 until 0.7268. At 100 Nm, the RMS value for both condition is slightly dropped due to the different size of defect detected by the accelerometer.

4.3 Summary

In general, Chapter 4 provide description of the experiment data and result obtained using vibration spectrum analysis method which is frequency domain analysis and root mean square (RMS) analysis as statistical analysis method. Frequency domain is the best choice in vibration spectrum analysis where it can detect the presence of bearing rolling element wear such as abrasive wear. RMS is used for statistical analysis because it is simple and direct method that is connected to the vibration profile's energy content.

In this laboratory experiment, the cordless impact wrench is tested in full capacity if battery with two condition of bearing which is normal condition and abnormal condition with the presence of abrasive wear on the rolling element. Both condition is required to loosen the nut that fastened with three different torque, 90 Nm, 100 Nm and 110 Nm. Data recorded from the experiment is then processed and analyzed. From frequency domain analysis, the pattern of normal condition is generally have a single primary peak that represent inrush vibration and followed by steady spectrum spread with a small value of amplitude as compared to the abnormal condition. Overall amplitude of normal condition is relatively lower than abnormal condition. Abrasive wear bearing causing the change in vibration spectrum pattern where there are 1-3 defect frequencies rising more than double the value of inrush vibration. Besides that, hump presence in the spectrum proves that there is a abrasive wear on the bearing rolling element. Next, RMS statistical analysis conclude that as the vibration amplitude content high energy, the RMS value increases. It is easier to detect which one is in severe condition by camparing the pattern of RMS value in Figure 4.5. Torque also influence the value of RMS as we can see the trend is increasing as the torque increases. At 100 Nm, both condition shows a slightly drop in value because of the different size of defect detected by the accelerometer.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research is conducted to study parameter to be measured on cordless impact wrench when tested at 90 Nm, 100 Nm, and 110 Nm of torque and to investigate the normal and abnormal data using vibration spectrum and statistical analysis method from MATLAB and Microsoft Excel. In practice, there are many ways to determine the bearing condition of rotating machinery. One of the best and widely used method is vibration analysis. Vibration sensor used in this study is accelerometer that measure the vibration acceleration of the cordless impact wrench. It is a robust device that make it commonly used vibration sensor.

This thesis presents a method for vibration analysis on bearing condition of cordless impact wrench. The main feature of the laboratory experiment is fixed, manipulated, and responding parameter. The full capacity of 4.0 amp-hour battery with the speed of 4200 RPM is the fixed parameter. However, for manipulated variable, the nut is fastened on the test specimen at 90 Nm, 100 Nm, and 110 Nm. Cordless impact wrench is required to loosen the nut at normal condition and abnormal condition of the bearing. The different in vibration signal (responding parameter) obtained from the test is then processed in MATLAB for frequency domain analysis and Microsoft Excel for statistical analysis (RMS) to have a good vibration analysis. The contribution of this study is on using frequency domain spectrum analysis as performance analysis method because the spectrum content more useful information in determining the state of the bearing. The spectrum analysis clearly indicates the presence of wear on the bearing. The other contribution is on using RMS statistical analysis to study the pattern of RMS value in normal and abnormal condition. Overall, the research presented in this thesis has succeeded to achieve both of the objective in making a contribution to understand the condition of bearing in cordless impact wrench with different torque using vibration spectrum and statistical analysis. The presented method utilizes reasonable type and amount of data input, using simple mathematical manipulations and requires less rigorous calculations, yet, capable to produce quick, credible, representative, and reasonably accurate results. Furthermore, the work carried out has involved the development of methodologies in vibration analysis of cordless impact wrench.

5.2 Recommendations

For future improvements, accuracy of the vibration analysis could be enhanced as follows:

- Wider range vibration sensor type, and more reliable test specimen with accurate torque measurement. Include study to find a better parameter.
- Development of standard operating procedure for vibration analysis of cordless impact wrench.

5.3 **Project Potential**

The study finding could be applied on cordless impact wrench vibration analysis. This help researchers to develop a more reliable testing and analysis method for further study. Additionally, a set of better parameters is developed to allow more effective and good vibration analysis.

REFERENCES

Leonard Meirovitch, 2001. *Fundamentals of Vibrations*. [e-book] Long Grove, Illinois: Waveland Press, Inc. Available through: Google Scholar. https://scholar.google.com/

Nandi, S., Toliyat, H. A., & Li, X., 2005. Condition monitoring and fault diagnosis of electrical motors, A review. *IEEE Transactions on Energy Conversion*, 20(4), pp. 719-729.

Rao, B. K. N., 1996. Handbook of condition monitoring. Elsevier.

Randall, R. B., 2011. Vibration-based condition monitoring: industrial, aerospace, and automotive applications. New York: John Wiley & Sons.

Scheffer, C., & Girdhar, P., 2004. *Practical machinery vibration analysis and predictive maintenance*. Elsevier.

Randall, R. B., 2004. State of the art in monitoring rotating machinery, part 1. Sound and vibration, 38(3), pp. 14-21.

Patel, T. H., & Darpe, A. K., 2009. Experimental investigations on vibration response of misaligned rotors. *Mechanical Systems and Signal Processing*, 23(7), pp. 2236-2252.

تىكنىكا ملىسيا ملاك

Hariharan, V., & Srinivasan, P. S. S., 2011. Vibration analysis of parallel misaligned shaft with ball bearing system. *Sonklanakarin Journal of Science and Technology*, 33(1), pp. 61.

Mechefske, C.K., 2005. 25 Machine Condition Monitoring and Fault Diagnostics. *In: Vibration and Shock Handbook*. (n.d)

Hasanzadeh Ghafari, S., 2007. *A Fault Diagnosis System for Rotary Machinery Supported by Rolling Element Bearings*, Available online: https://uwspace.uwaterloo.ca/handle/10012/3280.

Amarnath, M., Shrinidhi, R., Ramachandra, A., Kandagal, S.B., 2004. Prediction of Defects in Antifriction Bearings using Vibration Signal Analysis. J. Inst. Eng. India.

Patil, M.S., Mathew, J., RajendraKumar, P.K., 2008. *Bearing Signature Analysis as a Medium for Fault Detection*, A Review. J. Tribol., pp. 130.

Jayaswal, P., Wadhwani, A., Mulchandani, K., 2008. *Machine Fault Signature Analysis*. Int. J. Rotating Machine.

Howard, I., 1994. *A Review of Rolling Element Bearing Vibration "Detection, Diagnosis and Prognosis."* Defence Science and Technology Organization, Canberra, Australia.

Tandon, N., 1994. A comparison of some vibration parameters for the condition monitoring of rolling element bearings. *Measurement*. 12, pp. 285–289.

Feunou, B., Jahan-Parvar, M. R. and Tédongap, R., 2016. Which parametric model for conditional skewness? *European Journal of Finance*, 22(13), pp. 1237–1271.

Martin, H.R., Honarvar, F., 1995. *Application of statistical moments to bearing failure detection*. Appl. Acoust. 44, pp. 67–77.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA Mahamad, A.K.B., 2010. Diagnosis, Classification and Prognosis of Rotating Machine using Artificial Intelligence.

Tandon, N., 1992. Detection of Defects in Rolling Element Bearings by Vibration Probability Density and Cross-correlation Measurements. Int. J. Qual. Reliab. Manag. 9.

Dube, A.V., Dhamande, L.S., Kulkarni, P.G., 2013. Vibration Based ConditionAssessment of Rolling-element Bearings with Localized Defects. Int. J. Sci. Technol. Res.2, 7.

Jayaswal, P., Verma, S.N, 2011. Application of Vibration Signature Analysis Techniques for Rolling Element Bearing Fault Identification. *Aust. J. Mech. Eng.* 8, pp.21–36.

Samanta, B., Al-balushi, K.R., 2003. ANN based fault diagnostics of rolling element bearings using time-domain features. Mech. Syst. Signal Process. 17, pp. 317–328.

Sreejith, B., Verma, A.K., Srividya, A., 2008. Fault diagnosis of rolling element bearing using time-domain features and neural networks. In: 2008 IEEE Region 10 and the Third international Conference on Industrial and Information Systems. pp. 1–6.

Andrade, F.A., Esat, I., Badi, M., 2001. A new approach to time-domain vibration condition monitoring: Gear tooth fatigue crack detection and identification by the Kolmogorov-Smirnov test. J. Sound Vib. 240, pp. 909–919.

Klinchaeam, S., Ajavakom, N., Yongchareon, W., 2014. Fault detection of a spur gear using vibration signal with multivariable statistical parameters. *Sonklanakarin Journal of Science and Technology*. 36, pp. 563–568.

M. Vishwakarma, R. Purohit, V. Harshlata, and P. Rajput, 2017. Vibration analysis & condition monitoring for rotating machines: a review, *Materials Today: Proceedings*, vol. 4, no. 2, pp. 2659–2664.

D. Goyal and B. S. Pabla, 2015. Condition based maintenance of machine tools-A review, *CIRP Journal of Manufacturing Science and Technology*, vol. 10, pp. 24–35.

Kumar, M. Lokesha, K. Kumar, and K. Srinivas, 2018. Vibration based fault diagnosis techniques for rotating mechanical components: review paper, *in Proceedings of the International Conference on Advances in Manufacturing, Materials and Energy Engineering*, Karnataka, India, pp. 1–6.

H. K. Patel, D. Shah, and A. Raghuwanshi, 2019. Real time machine health monitoring and vibrational analysis using fft approach, *International Journal of Engineering and Advanced Technology*, vol. 8, no. 5, pp. 1833–1836.

T. Ameid, A. Menacer, H. Talhaoui, and I. Harzelli, 2017. Broken rotor bar fault diagnosis using fast fourier transform applied to field-oriented control induction machine: simulation and experimental study, *International Journal of Advanced Manufacturing Technology*, vol. 92, no. 1–4, pp. 917–928.

Y. Liu, Z. Jiang, H. Haizhou, and J. Xiang, 2020. Asymmetric penalty sparse model based cepstrum analysis for bearing fault detections, *Applied Acoustics*, vol. 165, p.p 107288.

N. Aiswarya, S. Suja Priyadharsini, and K. Moni, 2018. An Efficient Approach for The Diagnosis of Faults In Turbo Pump Of Liquid Rocket Engine By Employing FFT And Time-DomainbFeatures, *Australian Journal of Mechanical Engineering*, vol. 16, no. 3, pp. 163–172.

D. Goyal and B. S. Pabla, 2016. The vibration monitoring methods and signal processing techniques for structural health monitoring: a review, *Archives of Computational Methods in Engineering*, vol. 23, no. 4, pp. 585–594.

R. B. Randall, 1987. Frequency Analysis, Bruel and Kjaer, Copenhagen, Denmark.

D. Abboud, J. Antoni, S. Sieg-Zieba, and M. Eltabach, 2017. Envelope analysis of rotating machine vibrations in variable speed conditions: a comprehensive treatment, *Mechanical Systems and Signal Processing*, vol. 84, pp. 200–226.

 I. Howard, 1994. A Review of Rolling Element Bearing Vibration 'detection, Diagnosis and Prognosis, *The Defence Science and Technology Organization Canberra (Australia)*.
 DSTO-RR-0013, October. Victoria, DSTO Aeronautical and Maritime Research Laboratory., Tech. Rep., Melbourne, Victoria, Australia.

V. C. M. N. Leite, J. G. B. Da Silva, G. F. C. Veloso et al., 2014. Detection of Localized Bearing Faults in Induction Machines by Spectral Kurtosis and Envelope Analysis Of Stator Current," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 3, pp. 1855–1865.

J. Trout, 2020. *Vibration Analysis Explained*, Available online: https://www.reliableplant.com/vibration-analysis-31569

P. J. Loughlin and G. D. Bernard, 1997. Cohen-Posch (Positive) Time-Frequency Distributions and Their Application to Machine Vibration Analysis, *Mechanical Systems and Signal Processing*, vol. 11, no. 4, pp. 561–576.

S. S. Aralikatti, K. Ravikumar, and H. Kumar, 2019. Fault Diagnosis of Single Point Cutting Tool Using Spectrum, Cepstrum and Wavelet Analysis, in *Proceedings of the 1st International Conference on Manufacturing, Material Science and Engineering,* Telangana, India, pp. 1–9.

Z. Feng, M. Liang, and F. Chu, 2013. Recent advances in time-frequency analysis methods for machinery fault diagnosis, a review with application examples, *Mechanical Systems and Signal Processing*, vol. 38, no. 1, pp. 165–205.

M. P. Boyce, 2011. Gas Turbine Engineering Handbook, Elsevier, Oxford, England.

A. A. Sarhan, A. Matsubara, S. Ibaraki, and Y. Kakino, 2004. Monitoring of cutting force using spindle displacement sensor, in *Proceedings of the Japan – USA Symposium on Flexible Automation*, Denver, CO, USA, pp. 1–4.

J. Igba, K. Alemzadeh, C. Durugbo, and E. T. Eiriksson, 2016. Analysing rms and peak values of vibration signals for condition monitoring of wind turbine gearboxes, *Renewable Energy*, vol. 91, pp. 90–106.

A. Fernandez, 2020. *Seismic Velocity Transducers*, Available online: https://powermi.com/content/seismic-velocity-transducers.

S. Elango, J. G. Aravind, and S. Boopathi, 2018. Vibration Analysis of Bearing By Using Mechanical Stethoscope, *International Journal of Advanced Science and Research*, vol. 3, no. 1, pp. 1137–1149.

G. Rossi, 2012. Vibration Analysis for Reciprocating Compressors, *ORBIT Magazine*, vol. 32, no. 2, pp. 10–15.

C. Sanders, 2020. *A Guide to Vibration Analysis and Associated Techniques in Condition Monitoring*, Available online: https://www.scribd.com/document/320879762/Vibration-Analysis-Guideaccessed

K. W. Cheung, M. J. Starling, and P. D. McGreevy, 2014. A Comparison of Uniaxial and Triaxial Accelerometers for The Assessment Of Physical Activity In Dogs, *Journal of Veterinary Behaviour*, vol. 9, no. 2, pp. 66–71.

H. N. Norton, 1989. Handbook of Transducers, Prentice-Hall, Hoboken, NJ, USA.

S. Xianzhong, J. Zhuangde, L. Peng, G. Lin, and J. Xingdong, 2005. A novel pvdf based high-gn shock accelerometer, in *Proceedings of the 7th International Symposium on Measurement Technology and Intelligent Instruments*, Huddersfield, England, pp. 107–110.

M.-J. E. Salami, A. Gani, and T. Pervez, 2001. Machine condition monitoring and fault diagnosis using spectral analysis techniques, in *Proceedings of the 1st International Conference on Mechatronics*, Kuala Lumpur, Malaysia, pp. 690–700.

S. B. Chaudhury, M. Sengupta, and K. Mukherjee, 2014. Vibration monitoring of rotating machines using mems accelerometer, *International Journal of Scientific Engineering and Research*, vol. 2, no. 9, pp. 1–11.

Etter, Delores M and Kuncicky, D. C, 2011. Introduction to Matlab. n.d.

Houcque, D., 2005. *Introduction to MATLAB for Engineering Students*. Northwestern University, pp. 3–43. Available online:

http://web2.clarkson.edu/projects/fluidflow/kam/courses/2006/me326/downloads/matla b.pdf

APPENDICES

APPENDIX A

Time domain spectrum

Condition: Normal





110 Nm

APPENDIX B

Gantt Chart

FYP 1

NO.	TASK	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1.	BDP briefing															
2.	Thesis tittle verification															
3.	Meeting supervisor															
4.	Write thesis Chapter 1															
5.	Discuss thesis problem statement and objective															
6.	Study the purpose of the study															
7.	Literature review															
8.	Write thesis Chapter 2															
9.	Journal study related to vibration analysis															
10.	Journal study related to bearing faulty analysis	AALA	YSIA	ALC.												
11.	Experimental parameter study				or h											
12.	Study the experimental set up															
13.	Write thesis Chapter 3				Ξ											
14.	PSM 1 report submission	Nin.					_			_						

اونيوم سيتي تيڪنيڪل مليسيا ملاك FYP 2

NO.	TASK	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1.	BDP briefing UNIV	ER	SITI	TE	KNI	KAI	_ M.	ALA	YS	IA N	IEL/	AKA				
2.	Meeting SV															
3.	Data taking (experiment session)															
4.	Data analysis															
5.	Discuss with SV about data															
6.	Chapter 4 writing															
7.	Complete and finalize Chapter 4															
8.	4 pages summary writing and finalizing															
9.	Chapter 5 completing															
10.	Thesis submission															
11.	Prepare presentation poster															
12.	Thesis presentation															

APPENDIX C

ASTM A325: Standard Spe	ecification for	Structural	Bolts,	Steel,	Heat	Treated,	120/105	5 ksi
Minimum Tensile Strength	<u>.</u>							

ASTM A325										
		Ter	nsion	Tightening Torque Range (ft lbs) (Min-Max)						
Bolt Size	трі	MIN	МАХ							
				Galv + Wax	Plain					
1/2"	13	12,000	14,000	50 - 58	100 - 117					
5/8"	11	19,000	23,000	99 - 120	198 - 240					
3/4"	10	28,000	34,000	175 - 213	350 - 425					
7/8"	9	39,000	47,000	284 - 343	569 - 685					
1"	8	51,000	61,000	425 - 508	850 - 1,017					
1 1/8"	7	56,000	67,000	525 - 625	1,050 - 1,256					
1 1/4"	7	71,000	85,000	740 - 885	1,479 - 1,771					
1 3/8"	6	85,000	102,000	974 - 1,169	1,948 - 2,338					
1 1/2"	6	103,000	124,000	1,288 - 1,550	2,575 - 3,100					

ASTM A325 torque tightening table.

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

S

<sup>Note: 1) Bolt used is Plain Bolt size ¹/₂'
2) Max torque is 117 ft-lb which equal to 158.63 Nm.</sup>

APPENDIX D

Laboratory experiment pictures.



Tightening bolt using adjustable torque wrench.



UNIVERSITI TEKNIKAL MALAYSIA MELAKA



DAQ used: GUNT PT 500.04.



GUNT software.



MATLAB coding.