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FAULTY BEARING VIBRATION DIAGNOSTIC & MONITORING

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS

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PIRAVIN THIRAN A/L SRI THARAN

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

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2022

DECLARATION

I declare that this thesis entitled “Faulty Bearing Vibration Diagnostic & Monitoring” 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 : Piravin

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Date : 17/1/2022

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 :

Supervisor Name : Ts. Dr. Nor Azazi Bin Ngatiman

Date : 17/1/2022

DEDICATION

I dedicate my thesis to my mother, project supervisor and my friends. A special gratitude from me goes to my mother, Pakkaim A/P Munisamy for her love and support for me in completing this thesis. My eternal thanks goes to my project supervisor Ts. Dr. Nor Azazi Bin Ngatiman for his guidance and teachings throughout the process of completing this thesis sucessfully. Finally, my heartfelt appreciation goes to my friends who gave me their support, guidance and kind words throughout the process of completing this thesis.

ABSTRACT

Vibrations is something that is unavoidable and will occur in machinery. Over a period of time, this vibration magnitude increases and becomes detrimental to the machinery if it is not monitored or reduced to a safer level. Researchers around the world are continuously conducting studies on bearing vibrations to improve or propose a solution to problems that arise due to the bearing vibrations. Many components can cause these vibrations especially bearings where it moves in a oscillating pattern which causes the machinery to vibrate in a certain frequency and can effect the machine's performance if it is left undetected and diagnosed. High vibration magnitudes indicate that the bearing is faulty and needs to be diagnosed and if left untreated it can increase expenditure to correct the failure and reduce the machine's lifetime. Bearings usually experience increase in vibration magnitude as it experiences damages to it over time as bearings are exposed to constant motion throughout its operation. Defective rolling element that comes into contact with another element surface causes the generation of impact force which results in an impulsive bearing response. Due to this increase in vibration magnitude, machinery experiences poor performance. Due to this it is paramount that the bearing's vibration condition is always monitored and if there is an increase in its vibration magnitude it should be diagnosed immediately. To remedy this, vibration signal analysis can be done as it is an effective vibration monitoring technique which this thesis has done. This thesis focuses on the roller bearing vibrations under normal and damaged conditions where an experiment at speeds of 400 rpm, 800 rpm, 1200 rpm and 1600 rpm under six different bearing conditions were conducted to measure each of the condition's vibration levels. This bearing's vibration was then analyzed using the MATLAB and Excel software through Vibration Statistical Analysis (VSA). Through the results, there is an increase in the transient components where it increases together with the running speed as the speed increases. Through the graphs also, it can be seen that the vibration with frequency increases in amplitude as the speed increases. Through z-freq data scattering and its coefficient, it is observable that all the dots spreads across the affix and annex frequency where through this it can be said that the scattered data shows a clear pattern as the speed increases. RMS for conditions A, B, C, D, and E can be seen that the RMS increases as the speed increases. R^2 for each of the bearing conditions have a value of 0.9103, 0.9351, 0.9205, 0.9389, 0.7199 and 0.3592 respectively. It can be said that conditions A, B, C, and E has the closest accuracy in the speeds of 400 rpm, 800 rpm and 1200 rpm compared to the other type of conditions and speed. Conclusively, it can be said that time domain is not suitable for fault prediction as compared to the R-Squared method as in time domain, the graph difference between the faulty and good conditions are similar to the frequency domain graphs. This thesis presents a method for predicting the condition that produces the specific vibration through the RMS and R^2.

ABSTRAK

Getaran adalah sesuatu yang tidak dapat dielakkan dan akan berlaku di dalam sesebuah jentera. Dalam satu tempoh masa, magnitud getaran ini akan meningkat dan akan menjadi lebih memudaratkan kepada jentera tersebut jika ia tidak dipantau atau dikurangkan ke tahap yang lebih selamat. Penyelidik di seluruh dunia secara berterusan menjalankan kajian tentang getaran galas untuk menambah baik atau mencadangkan penyelesaian kepada masalah yang timbul akibat getaran galas. Banyak komponen boleh menyebabkan getaran ini terutamanya galas di mana ia bergerak dalam corak berayun yang menyebabkan jentera bergetar dalam frekuensi tertentu dan boleh menjejaskan prestasi mesin jika ia tidak dapat dikesan dan didiagnosis. Magnitud getaran yang tinggi menunjukkan bahawa galas itu rosak dan perlu didiagnosis dan jika tidak dibetulkan ia boleh meningkatkan perbelanjaan untuk membetulkan kegagalan dan mengurangkan jangka hayat mesin. Galas biasanya mengalami peningkatan dalam magnitud getaran kerana ia mengalami kerosakan padanya dari semasa ke semasa kerana galas terdedah kepada gerakan yang berterusan sepanjang operasinya. Elemen gelek yang rosak yang bersentuhan dengan permukaan elemen lain menyebabkan penjanaan daya hentaman yang mengakibatkan tindak balas galas impulsif. Disebabkan peningkatan dalam magnitud getaran ini, jentera mengalami prestasi yang lemah. Disebabkan ini, ia adalah penting untuk memantau keadaan getaran galas sentiasa dan jika terdapat peningkatan dalam magnitud getarannya, ia harus didiagnosis dengan segera. Untuk mengatasi masalah ini, analisis isyarat getaran boleh dilakukan kerana ia merupakan teknik pemantauan getaran yang berkesan yang telah dilakukan oleh tesis ini. Tesis ini menumpukan perhatian kepada getaran galas penggelek dalam keadaan normal dan rosak di mana eksperimen dijalankan pada kelajuan 400 rpm, 800 rpm, 1200 rpm dan 1600 rpm di bawah enam keadaan galas yang berbeza telah dijalankan untuk mengukur setiap tahap getaran keadaan. Getaran bearing ini kemudiannya dianalisis menggunakan perisian MATLAB dan Excel melalui Vibration Statistical Analysis (VSA). Melalui keputusan yang ditemui, terdapat peningkatan dalam komponen sementara di mana ia meningkat bersama-sama dengan kelajuan larian apabila kelajuan meningkat. Melalui graf juga, dapat dilihat bahawa getaran dengan frekuensi meningkat dalam amplitud apabila kelajuan meningkat. Melalui serakan data z-freq dan pekalinya, dapat diperhatikan bahawa semua titik merebak merentasi frekuensi affix dan annex di mana melalui ini boleh dikatakan bahawa data yang berselerak menunjukkan corak yang jelas apabila kelajuan meningkat. RMS untuk keadaan A, B, C, D, dan E boleh dilihat bahawa RMS meningkat apabila kelajuan meningkat. R^2 bagi setiap keadaan galas masing-masing mempunyai nilai 0.9103, 0.9351, 0.9205, 0.9389, 0.7199 dan 0.3592. Boleh dikatakan bahawa keadaan A, B, C, dan E mempunyai ketepatan yang paling hampir dalam kelajuan 400 rpm, 800 rpm dan 1200 rpm berbanding dengan jenis keadaan dan kelajuan yang lain. Secara konklusinya, ia boleh dikatakan bahawa domain masa tidak sesuai untuk ramalan kerosakan berbanding kaedah R-Squared kerana dalam domain masa, perbezaan graf antara keadaan rosak dan baik adalah serupa dengan graf domain frekuensi. Tesis ini membentangkan kaedah untuk meramal keadaan yang menghasilkan getaran spesifik melalui RMS dan R^2.

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In the Name of God, the Almighty, the Most Gracious, the Most Merciful

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I would also like to express eternal gratitude and thanks from the bottom of my heart to my mother Pakkiam A/P Munisamy, for her encouragements, prayers and support and which has been the pillar of strength for me in completing this thesis. My eternal thanks also goes to all the individual(s) who had provided me the assistance, support and inspiration to embark on my study especially my friends. I will always appreciate all that these people have done for me in completing this thesis.

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LIST OF SYMBOLS AND ABBREVIATIONS

x_i - Data

R^2 - R-Squared

RMS - Root Mean Square

Z-freq - Z-Frequency

VSA - Vibration Statistical Analysis

DAQ - Data Aquisition System

FFT - Fast Fourier Transform

N - Number of Data Points

Σ - Total Sum

rpm - Rotation per Minute

Hz - Hertz

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CHAPTER 1

INTRODUCTION

1.1 Background

At present time, bearings are one of the most major component present in machinery. Bearings in a machine are mechanical components that are rolling elements located in a machine where it supports rotating or oscillating elements and tranfers load between the machinery components. These rolling or oscillating elements can be shafts, axels, wheels etc. present in a machinery. Bearings plays a vital role in a machines performance.

As bearings are constantly in motion they are one of the primary sources of vibrations in a machinery. Due to this it is paramount that the bearing vibration condition is always monitored and if there is an increase in its vibration magnitude it should be diagnosed immediately to prevent serious problems from occuring and to reduce the costs needed to correct the arisen serious problem.

Being one of the major part of a machine or a system, bearings are expected to maintain their shape, dimmension and strength throughout the expected lifespan of the bearing. Additionally, the bearing’s ability to reduce the frictional forces is crucial to the performance and efficiency of a machine or system

Bearings experiences high rotational forces during machine operation. The material that these bearings are made usually are able to withstand these high forces. However, bearings are the most common point of failure in a machine as they are usually exposed to vibrations and rotational forces.

In the real world, bearings experience wear, cracks, and chipping where these damages results in the increase of the magnitude of the bearings vibration level. Three major bearing components typically experience damage which are rolling element, inner ring and outer ring (Aondolumun Aye, 2014). This thesis focuses on this three damages conditions.

1.2 Problem Statement

Bearings usually experience increase in vibration magnitude as it experiences damages to it over time. Rolling element bearing failure is one of the major causes of rotating machinery breakdown (Lou, 2001). These damages occurs due to the fact that the bearings are exposed to constant motion throughout its operation. Defective rolling element that comes into contact with another element surface causes the generation of impact force which is resultingin an impulsive bearing response (Saruhan et al., 2014).

Due to this increase in vibration magnitude, machinery experiences poor performance. This problem may eventually lead to complete machine failure or breakdown. As optimum performance and long lifespan are required for a machine to be usefull in its usage, it is important that vibrations produced by these bearings are measured and analyzed where the analysis can be used to reduce and possibly elimitae the vibrations thus ensuring quality, parts lifespan and performance.

This thesis focuses on the bearing’s vibration that they produce when they are in operation. Research was carried out to find the effect to the vibrations produced due to bearings with defects and bearing without defeects. The research aims to analyze the vibration levels of the bearings through machine learning and signal analysis thus enabling better decision making concerning the bearing’s use and lifespan. Adequate condition monitoring of the bearing’s vibtrations ensures reliable operation of mechanical equipment under complex operating conditions (Sierra-Alonso et al., 2021).

1.3 Research Objective

Based on the background and probklem statetment which have been stated, the objectives for this thesis are as follows:

a) To measure the vibrations of nomal and defective bearings using accelerometer.

b) To analyze the vibration data of the bearings via various Vibration Statistical Analysis methods.

c) To verify the analysis done through coefficient of determination (R^2).

1.4 Scope of Research

This projects thesis focuses on the measurement of the vibrations of the bearings. The bearing’s vibrations are measured under normal and defective conditions. Through the vibratin data obtained via the measurements, the data was then analyzed via various Vibrational Statistical Analysis methods. Finally this thesis also aims to verify the analysis that has been done via the statistical analysis methods through machine learning techniqe.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today’s machinery orientated society, bearing’s usage has become abundant where it can be found in almost all machinery. A bearing is usually at the heart of machines that require rotational movement and reduction of frictional forces. People who go by their daily life usually are not aware of the presence of the bearings around them or how it functions and its necessity. Industrial machinery mostly incorporates rotating element which are supported by bearing for continuous and proper application (Sharma et al., 2017).

A bearing is made up of intricate parts that work together with each other to produce the desired outcome of smooth supported movement. These parts produce vibrations when they are operational and this thesis focuses on these vibrations, particularly under normal, outer ring fault, inner ring fault, and roller bearing fault conditions.

This chapter aims to present the research information based on major topics and minor topics that are related to this thesis. Every information present in this chapter is gathered from journals, books, and internet sources. The information gathered were summarized and analyzed. Figure 2.1 below shows the topics that are discussed in this literature review.

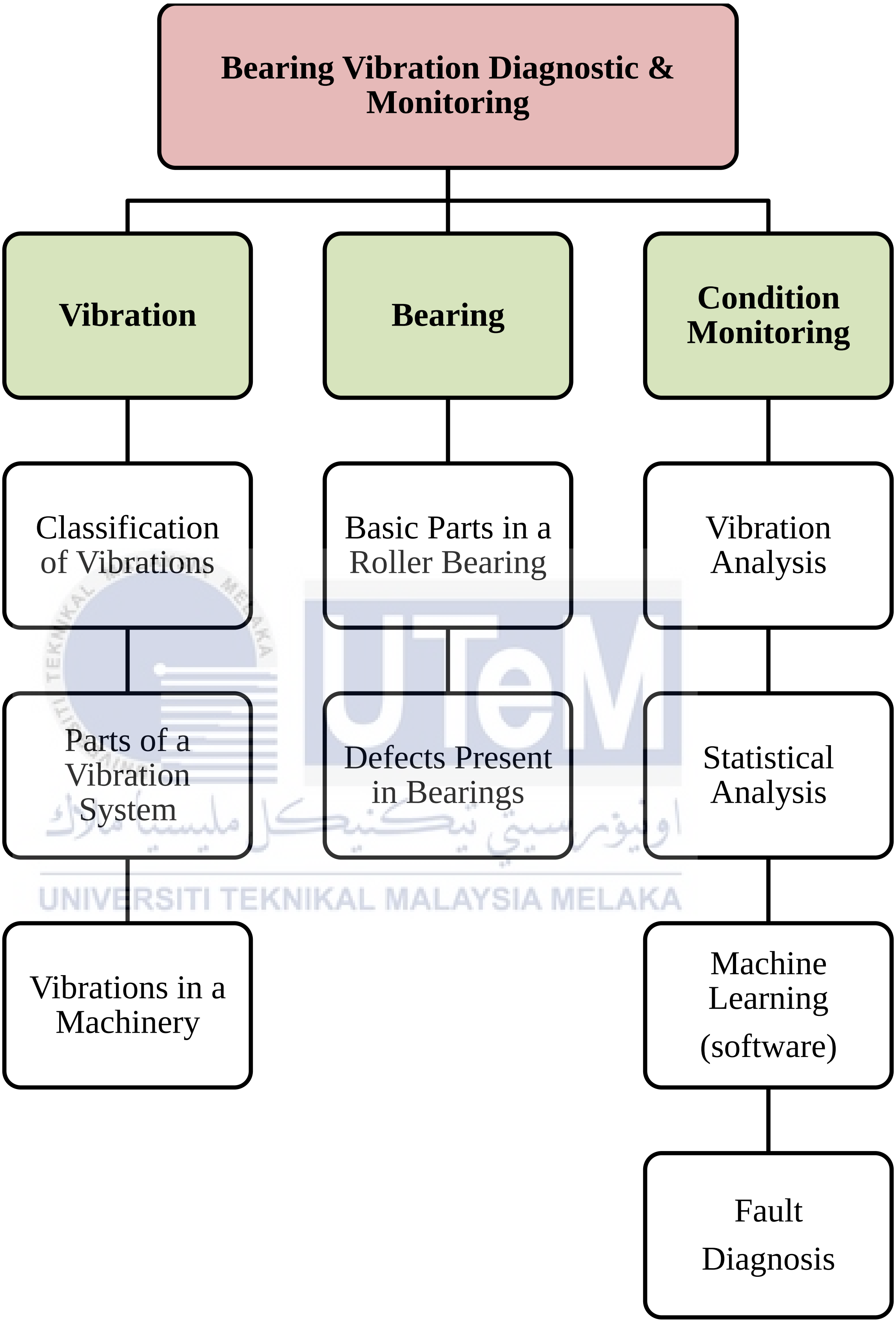


Figure 2.1 Literature Review K-Chart

2.2 Vibrations

The motion of displacement from the point of equilibrium for a system of connected bodies or component or particle is called vibration. Vibrations usually occurs if a system is displaced from its equilibrium where it moves to and fro through its equilibrium point. Vibration theory concerns with the oscillatory motion of physical system where the motion can be harmonic, periodic or general which amplitude varies with time (A. Shabana, 2018).

Vibrations are generally undesireable in machinery, equipment and system as it increases the overall vibratition magnitude which has great detrimental effects to the machinery, equipment and system. In an engine, vibrations causes loosening of mounts (Ahirrao et al., 2018). Even though the engine is the main sorce of vibration in a vehicle, there are other vehicle components that also contribute to the vibrations such as the bearings, suspension, wheels, road conditions and so forth.

Due to this, it is paramount that vibrations are reduced to ensure that mishaps does not occur. This thesis/project plans to measure and analyze the vibrations produced by the roller bearings as they are the most common types of bearings and diagnose it. This will directly contribute to the reduction of the magnitude of vibrations.

2.2.1 Classifications Of Vibrations

Generally,vibrations can be classified into two (2) types which are free vibrations and forced vibrations. Free vibrations is a vibration that occurs on its own with no outside factors causing the vibrations. There are no external forces that react on the system in free vibrations (A. Shabana, 2018). Forced vibrations on the other hand is the complete opposite of the free vibrations where an exciting force continuosly supplies energy to the system to vibrate. Forced vibrations are caused by external excitations (A. Shabana, 2018).

Forced vibration exists for two (2) states of excitation which are determinic or periodic excitation and random citation. Figure 2.2 and Figure 2.3 below shows the waveforms of these two (2) excitations.

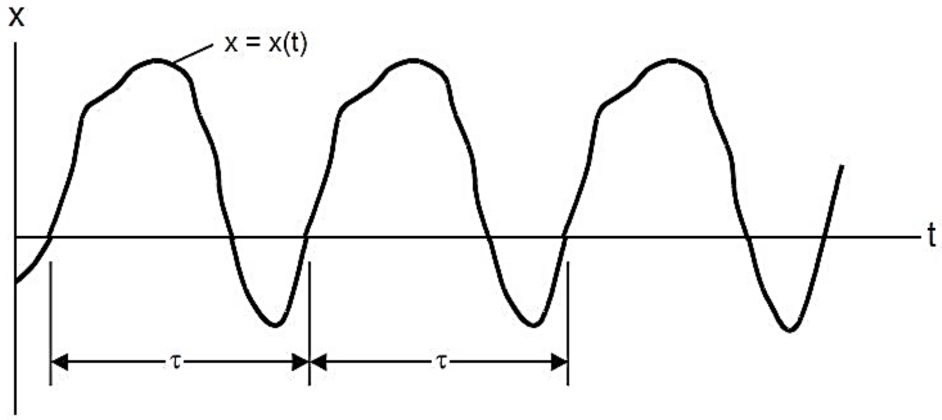


Figure 2.2 Determinic (Periodic) Excitation Waveform (Dukkipati, 2007)

Figure 2.3 Random Excitation Waveform (Dukkipati, 2007)

Bearings produces forced vibrations which can be caused by loose fittings, cracks, overload or missalignment which can cause damages to the bearing itself. The vibrations of bearing due to outerring, inner ring and rolling element damages are monitored and analyzed in this thesis/project.

2.2.2 Parts of a Vibration System

A vibration system usually consists of three (3) elements. The elements are means for storing potential energy, means for storing kinetic energy and means by which energy is lost gradually (Dukkipati, 2007). The Figure 2.4 shows these elements in a simple setup.

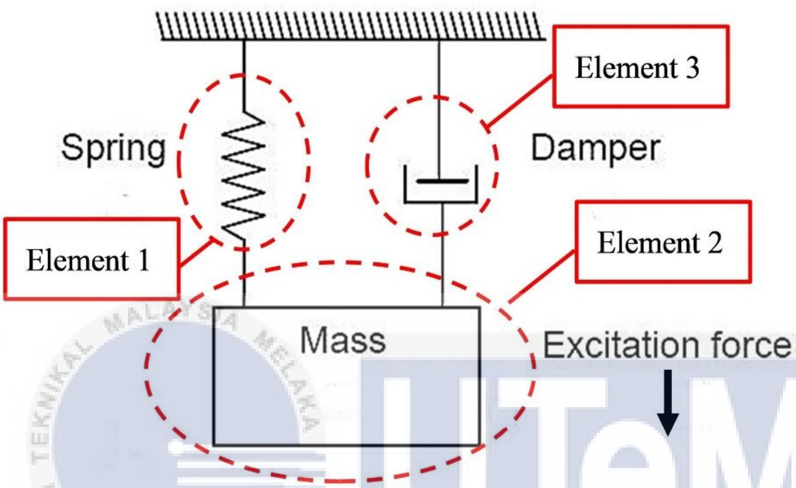


Figure 2.4 Vibration Sytem Elements

From the figure above, the spring represents the means of storing potential energy element, the mass represents the means for storing kinetic energy element, and the damper represents the means by which energy is lost gradually element.

In an undamped vibrating system the potential energy is converted to kinetic energy and the kinetic energy in converted to potential energy. In a damped system however, energy is dissipated during each vibration cycle where it should be restored via an external source if the vibrations is to be maintained in a steady state.

2.2.3 Vibrations in a Machinery

Naturally machinery tends to vibrate, even the ones which are optimally working. This is due to the fact that there will always be small minuscule defects, faults or flaws. Due to these minuscule problems, the vibrations that are produced can be inferred as expected vibrations or innate vibrations. Only when these vibration levels increase that problems arise as well. Vibration's magnitude can increase due to several factors such as cracks, misalignment, unbalance, excessive loads, high temperature and along with others.

Engine produces vibrations caused by unbalanced forces from engine parts during engine operation (Ramachandran & Padmanaban, 2012). External factors such as tire conditions, road conditions, suspension and especially faulty bearing are acontributors to the engine vibrations.

Vibrations have a drastic effect on the performance of a machine, equipment or system where it can cause parts to become undone or loose, loose efficiency and may lead to noise pollution. Vibrations also effects the comfort of oneself as the vibrations may be heard or felt outside by a person if it is in excessive amount. Unacceptable vibration levels and stress are generated due to rotating unbalance in individual and support structures (Radhakrishna et al., 2012).

2.3 Bearing

Rolling element bearing are crucial machinery element where it plays a vital role rotating machinery where the machinery is totally dependent on the health of the rolling element bearing (Jagdale & Diwakar, 2018). Rolling element bearing's rolling element are confined between two bearing rings called the outer ring and inner ring (Hecke, 2016).

When defective rolling element comes into contact with other element surface, in impact force is generated which results in an impulsive response of the bearing (Saruhan et al., 2014). Due to these, this thesis aims to mitigate this problem by monitoring and diagnosing the roller bearing’s vibrations.

2.3.1 Basic Parts in an Roller Bearing

A roller bearing has for basic parts whicwork in tandem with each other to produce rotational movement. The basic parts of a roller bearing is shown in figure below.

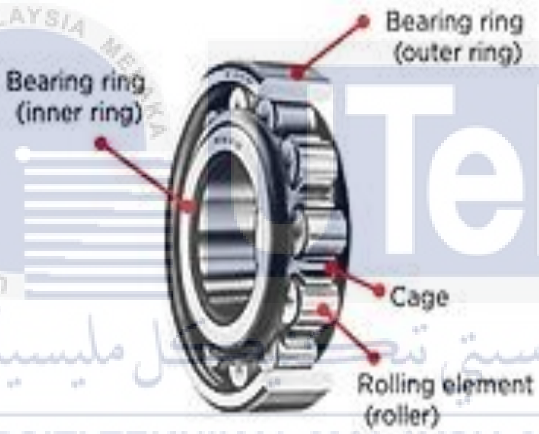


Figure 2.5 Roller Bearing Basic Parts

2.3.1.1 Inner Ring

The smaller ring located on the innermost part of the bearing. It has grooves along it to form a raceway for the rolling element. The inner ring are usually finished to precise tolerance to ensure a smooth and tight fit is achieved on the place where it is mounted

2.3.1.2 Outer Ring

The outermost part of the bearing and the bigger size of the two rings in the bearing. It also has a groove to form a raceway for the rolling elements. The same precise finish as the inner ring are also implemented here.

2.3.1.3 Rolling Element

The rolling element (cylindrical rollers) are what seperates the inner ring and the outer ring while permitting rotation with minimal frictional forces. Rolling elements dimensions are precise to a micro level to ensure smooth movement of the bearing.

2.3.1.4 Cage

Cage or retainer are used to seperate the rolling elements from each other while maintaining a cnstant space between the two rings to guide the rolling elements accurately in its rotational path and prevent the rolling elements from falling out.

2.3.2 Defects Present in Bearings

Bearing defects usually occur on the components such as inner ring, outer ring, and rooling elements. As the bearings tend to experience wear and damage, it is safe to say that the bearings are one of the major contributor to machinery vibrations. In reality, roller bearings failures may lead to a more major failure in a machinery (Saruhan et al., 2014).

As bearing damage leads to increase in vibrations, this project/thesis focuses on monitoring and diagnosing it.

2.4 Condition Monitoring

Condition monitoring is the process of monitoring the parameters of an equipment or machinery or a structure where significant cahnge in the parameters are moitored to indicate defect or failure. Condition monitoring is a predictive maintenance tool used to predict defects and failures before it occurs. Condition monitoring's main goal is to sense a fault that has reached symtomatic level (Laakso et al., 2002).

There are three (3) important elemets in an effective condition monitoring. The first element is the data acquisition or collection. The second element is the data processing where the data collected is processed and conditioned to be able to be read. The third and final element is the decision making process where the data collected and processed is used to come up with a course of action.

2.4.1 Vibration Analysis

Vibration analysis is a condittion monitoring technique. The operating and mechanical condition of an equipment is determined using vibration analysis (Alsalaet, 2012). Usually an accelerometer is used to measure the magnitude of the vibration levels to be used in the vibration analysis. Vibration spectrum analysis is a mature fault diagnosis technique low calculation burden which can be applied to different machinery (Nembhard, 2015).

Vibration analysis utilizes two (2) main components in its analysis which are frequency spectrum and time waveform. Understanding the frequency spectrum and time waveform relationship is crucial in analyzing the vibration energy. Time waveform can be converted to frequency spectrum by utalizing Fast Fourier Transform (FFT).

2.4.1.1 Fast Fourier Transform (FFT)

Fast Fourier Transform (FFT) is among the most fundemental tool in computing frequency representation of signals. Thus FFT is applied widely in vibration analysis as vibrations produce signals. FFT supplies the information needed to determine the vibration causes through the vibration amplitudes as a frequency function.

In FFT waveforms are simply the sum of series of simple sinusodial frequncy from different frequencies, amplitudes and phases. Fourier evaluation works by measuring the presence of every every frequency component. Figure 2.6 below shows an example of a vibration signal FFT.

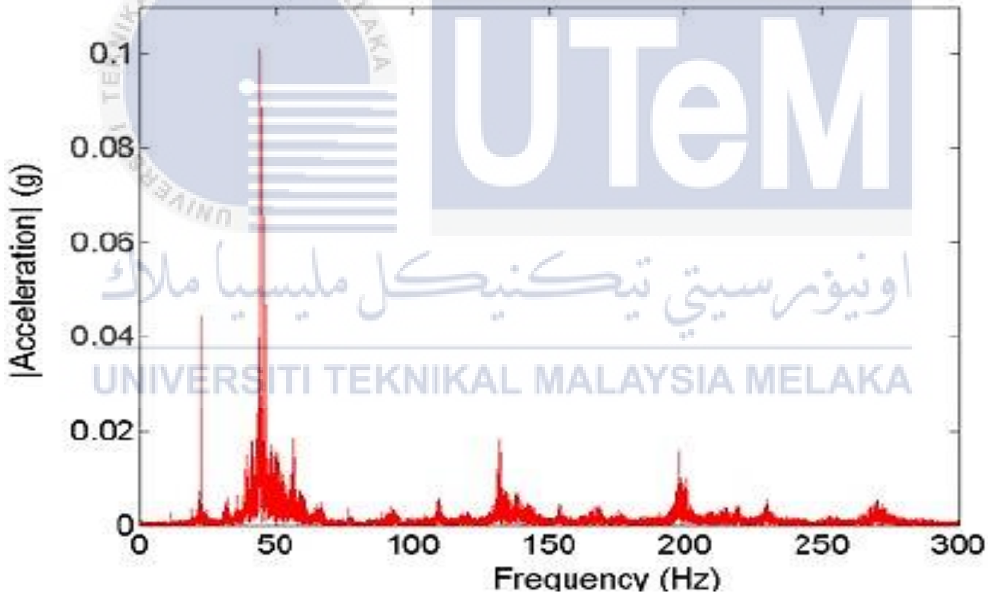


Figure 2.6 Vibration Signal FFT

(Retrieved from: https://www.researchgate.net/publication/267794546_A_study_of_ambient_vibrations_for_piezoelectric_energy_conversion/figures)

2.4.1.2 Spectrum Analysis

Spectrum analysis or spectra analysis is a form of vibration analysis where it takes modal analysis and natural frequency into consideration. Spectrum analysis is concentrated to obtain a rapid response during which some data is lost (phase).

This spectrum analysis separates the obtained vibrations into its discrete frequencies to easily identify a problem. Spectrum analysis encompesses the passing of unstable time domain facts through FFT. Signals are analyzed over different frequency ranges to obtain a better understanding of a trouble present. Figure 2.7 shows a spectrum analysis example.

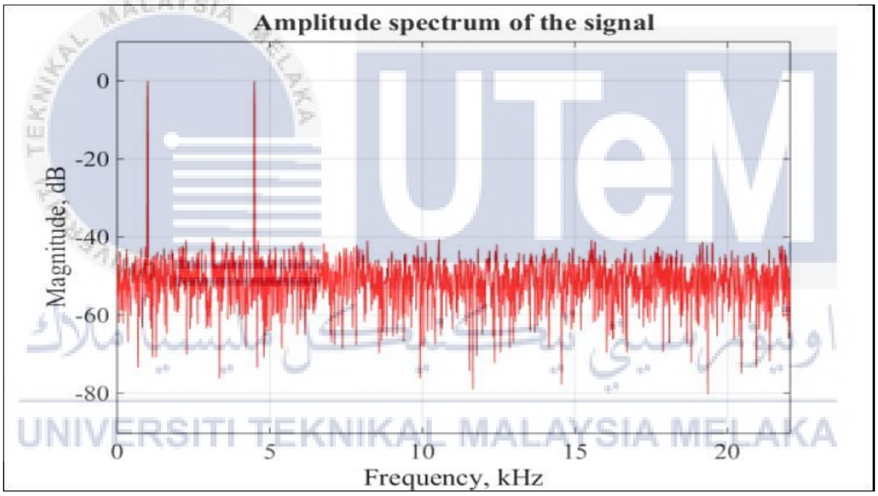


Figure 2.7 Spectrum Analysis

(Retrieved from: https://www.mathworks.com/matlabcentral/fileexchange/42170-spectral-analysis-with-matlab-implementation)

2.4.1.3 Frequency Domain Analysis

Frequency domain analysis involves FFT technique also. Through frequency domain analysis, vibration’s characteristic can be interpreted. Signals are mostly represented with frequency area through it’s spectrum, frequency, harmonic additives, amplitudes and phase/segment.

Frequency domain produces a signal shape that is compact and expressive which allows the spectral components to be seperated. Figure 2.8 shows a frequency domain signal.

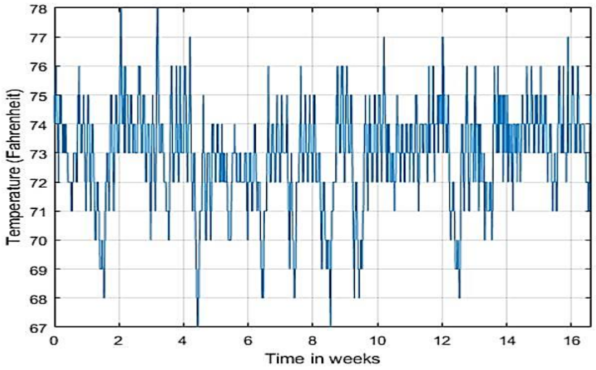


Figure 2.8 Frequency Domain Graph

(Retrieved from: https://www.mathworks.com/help/signal/ug/practical-introduction-to-frequency-domain-analysis.html)

2.4.1.4 Time Domain Analysis

Time domain is signal processing used in vibration signal analysis so operational signal obtained can be easily described (Mohamed, 2015). Time domain analysis is used to describe the information obtained via the vibration signal as time function.

In time domain analysis, the nonlinear structures/complex input resources are usually executed numerically using MATLAB and linear area analysis is done via analytical answers analysis. Figure 2.9 below shows a time domain graph.

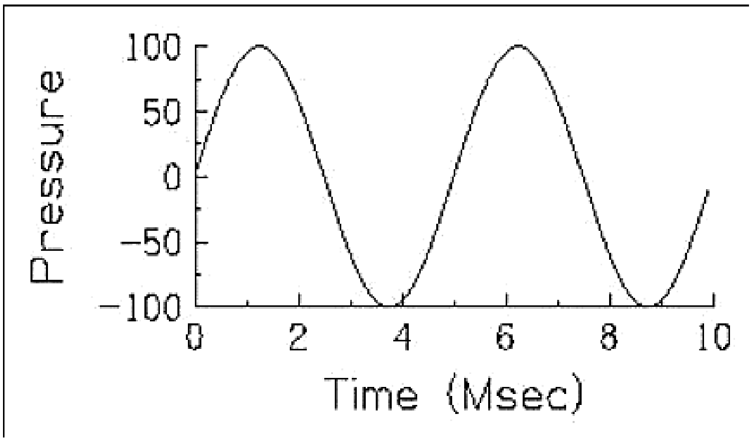


Figure 2.9 Time Domain Graph

(Retrieved from: http://www.asel.udel.edu/speech/tutorials/acoustics/time_domain.html)

2.4.1.5 Time-Frequency Analysis

Time-frequency can be utalized in non-stationary random processes analysis and process in a innate and methodical manner (Hlawatsch & Matz, 2010). Frequency analysis performed at non-stationary event’s analysis is the time frequency analysis done to overcome/determine problems.

Time-frequency analysis is a combination of spectral and envelope analysis. In time frequency analysis, vibration signal is represented in time domain and frequency domain terms. Time-frequency analysis includes techniques such as Short Time Fourier Transform (STFT), Wavelet Transform (WT), Hilbert-Huang Transform (HHT), Winger-Ville Distribution (WVD), etc.

Two (2) types of time-frequency representation could be used to characterize non-stationary and noisy vibration signal where STFT can be applied for engines.

2.4.2 Statistical Analysis

As this project/thesis requires input of data obtained from signal acquisistion of the barings when hey are in operation, it requires statistical analysis to analyse and interpret the data collected. Statistics is the methodology of collecting, analysing, interpreting and drawing conclusions from a set of data (Isotalo, 2001). In statistical analysis, signals can be utalized to compute scalar parameters such as mean, standard deviation, skewness, Root Mean Square (RMS), crest factor, Kurtosis and so on.

2.4.2.1 Root Mean Square (RMS)

Root Mean Square (RMS) is utalized to derive the average of a constantly varying value. It can be used to analyse signals obtained in vibrations. The RMS formula is shown in equation 2.1 below.

$$RMS = \sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}} \tag{2.1}$$

Where N is the number of data points and x_i is each data.

2.4.3 Machine Learning (Software)

In this day and age, the world is moving towards technology even more for their tasks. One such task is processing large amount of data in a short time to produce a decision that resembles human decision. This technology is callled as Artificial Intelligence (AI). In order for the AI to be able to make decisions, the data has to be fed into the system for it to know what to look for and what to output. This is called machine learning where it works by learning from the data input into the system.

Machine learning can be utalized to pin point problems that might arise in a machinery or system. This project/thesis uses the MATLAB and Excel softwares to analyse the roller bearing vibrations data to produce an ouput.

2.4.3.1 Matrix Laboratory (MATLAB)

Matrix Laboratory (MATLAB) is programming and numeric computing platform used to analise data, develop algorithms, and create models (MathWorks, n.d.). It can also be utalized in the application of embedded system, wireless comunications, data analytics etc. MATLAB is widely used in engineering field for its versatility and compute prowess.

This project/thesis utalizes the MATLAB software to acquire, analyze and interpret the roller bearing vibrations data in computing the data to generate an output of vibration.

2.4.4 Fault Diagnosis

Component malfunctions in an automobile are the usual cause of many road accidents besides human negligence. Proper fault diagnosis carried out on automobile engines helps to reduce these accidents by providing early warnings (Tse & Tse, 2014).

In an vehicle, fault diagnosis is performed on the engine via vibration analysis from the vibraion signals produced by the various parts in a vehicle during operation to monitor the vibration levels to ensure the vehicle is performing optimally and in good condition.

Nevertheless, an engines’s health status inspection and the corresponding internal combustion processes are typically time consuming and expensive as they must be carried out by experienced mechanics using expensive equipment (Tse & Tse, 2014). Thus, this project/thesis aims to monitor one of the vehicle components which is the bearing in normal and damaged operating conditions.

CHAPTER 3

METHODOLOGY

3.1 Introduction

As stated in the previous chapters, bearing faults or damages will occur over time. This project/thesis focuses on the roller bearing outer ring damage, roller bearing inner ring damage and roller bearing rolling element damage as well which can affect the bearing's performance and increase its vibration levels. The bearing's vibration levels under normal (healthy) operation and damaged operation were monitored and measured.

This was done to determine and diagnose the vibration magnitude these faults cause on a bearing earlier and to prevent the bearing's vibration to deteriorate further causing more problems to the system or machinery it is in. Vibration signal analysis was carried out through the MATLAB software to monitor and analyse the vibration signals of the bearings obtained during their operation.

Accelerometer sensors were used to measure these vibrations which was then analyzed through Vibration Statistical Analysis methods. The analyzed data was then used for verification through R^2 (coefficient of determination). Figure 3.1 below shows the flow chart of the process of this project/thesis to be easily understood.

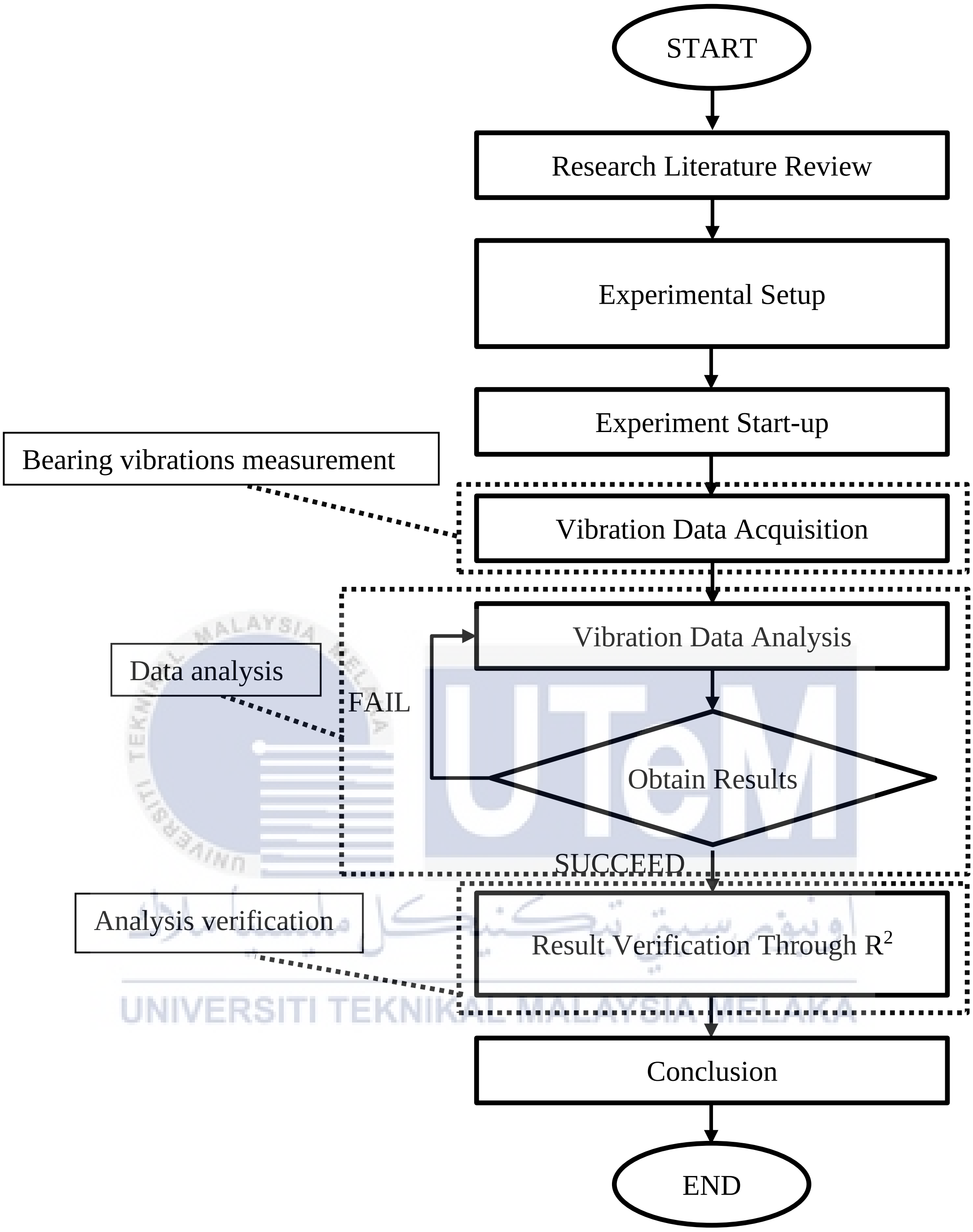


Figure 3.1 Project Flow Chart

3.2 Research Design

This study focusses on monitoring the vibration signals produced by the roller bearing's operation in damaged condition and normal condition. The experiment was carried out by measuring the magnitude of the vibrations for each condition where the data obtained was then used in performing vibration analysis. The vibrational data were compared and analyzed in the MATLAB software where the frequency domain, time domain, and Z-frequency graphs were obtained. ISO 13373:2017 standard (condition monitoring and diagnostic of machines vibration condition monitoring) was utilized in the comparing and analyzing process of the vibrational data. Standards such as ISO 18431-2:2004. (Mechanical vibration and Shock-Signal Processing-Part 3: time domain windows for Fourier Transform Analysis) and ISO 18431-3:2014 is also important (Mechanical vibration and shock-signal processing-part 3: methods of time frequency analysis) were utilized as well.

3.3 Experimental Setup

The experiment was conducted under six (6) different bearing conditions including a normal bearing.

Figure 3.2 Six (6) Bearings

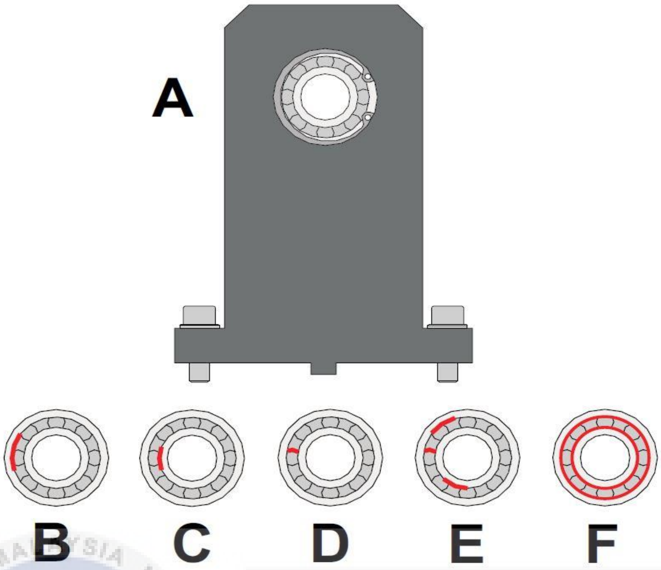


Figure 3.3 Six (6) Bearing Conditions

The six (6) types of bearing condition were set up as:

1. A = Undamaged roller bearing (normal/healthy bearing)
2. B = Roller bearing with outer ring damage
3. C = Roller bearing with inner ring damage
4. D = Roller bearing with rolling element damage
5. E = Roller bearing with B, C, and D damages simultaneously
6. F = Roller bearing with severe damages

Each of the bearing condition was run at speeds of 400 rpm, 800 rpm, 1200 rpm and finally at 1600 rpm. An average measurement out of three trials were obtained which was then utilized in the statistical analysis process. The experimental setup is as figure below.

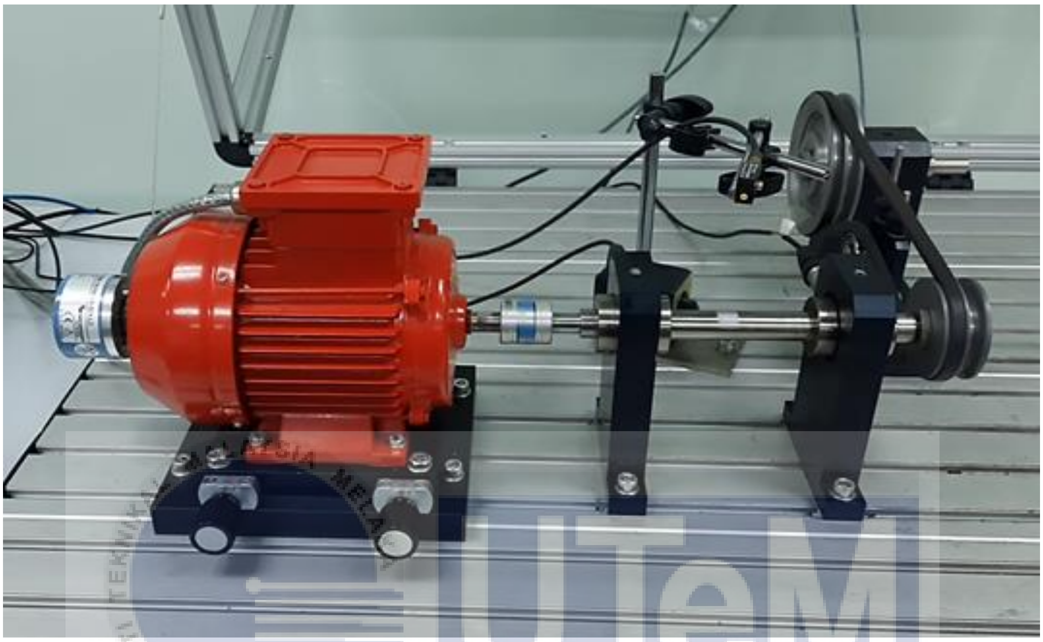


Figure 3.4 Experimental Setup

Figure 3.5 8-Channel Front-End m+p VibPilot Data Acquisition (DAQ)

3.4 Parameters

The parameters which were used in the experiments were the rotating speed, the sampling rate and the duration of data collection. The rotating speeds were set to four speeds which were 400 rpm, 800 rpm, 1200 rpm, and 1600 rpm and the sampling rate was 3200. The duration the data was collected was set to one (1) second. The experiment was run three (3) times for each speed and each condition where an average was obtained.

3.5 Vibration Measurement

Measuring the vibration signal is the most paramount part in this project/thesis where the vibration level signals are the useful information from the roller bearing to deduce how the roller bearing is performing under different conditions. Two accelerometers were used to measure the vibrations of the six (6) condition bearings.

Accelerometer 1 was connected after the bearing while Accelerometer 2 was connected before the bearing where Accelerometer 1 was connected to Channel 1 and Accelerometer 2 was connected to the Channel 2 of the DAQ. The DAQ was then connected to the laptop running the SO analyzer software which was used to initiate the measurement process and to measure the readouts.

Each of the bearing condition was run under four (4) different speeds which were 400 rpm, 800 rpm, 1200 rpm, and finally 1600 rpm. The bearing conditions each were run a total of three (3) times for each speed where the average value was obtained to be used in the Vibration Statistical Analysis.

3.6 Data Analysis

The vibration measurements were fed through MATLAB software to analyze the vibration signals. Once that was accomplished, the data was then used to obtain the Root Mean Square (RMS), time domain graph, frequency domain graph, and Z-Frequency (Z-freq) coefficient values. Vibration signal analysis (VSA) technique was used in this process where the raw data obtained via statistical parameter can be proceeded for further analysis

3.7 Data verification

This is a process which improves the collected vibrational measurements to obtain a greater understanding of the data information. Excel software was used to obatin the R-Squared (R^2) values and the data distribution graph. The R^2 waas ensured to be more than 0.9 for it to be reliable.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis of the experiment which were obtained through the stated methodology. Vibration Signal Analysis (VSA) was carried out on the measured vibrational data where the MATLAB and Excel softwares were utilized in the analysis.

R-Squared (R^2) which is a coefficient of determination approach was then used to compare and verify the analysis done on the roller bearing vibrational measurements. Obtaining both normal and defective roller bearing's vibration magnitude ensures the success of this experiment where optimal and compromised running conditions can be examined and compared.

The roller bearings were run under six (6) different conditions which are undamaged roller bearing, roller bearing with outer ring damage, roller bearing with inner ring damage, roller bearing with rolling element damage, roller bearing with B, C, and D damages simultaneously, and roller bearing with severe damages. These conditions were each labled A, B, C, D, E, and F respectively.

All the bearing conditions were run at speeds of 400 rpm, 800 rpm, 1200 rpm, and finally at 1600 rpm. The vibrational results of these speeds on the six (6) bearing conditions are represented in figures in this chapter.

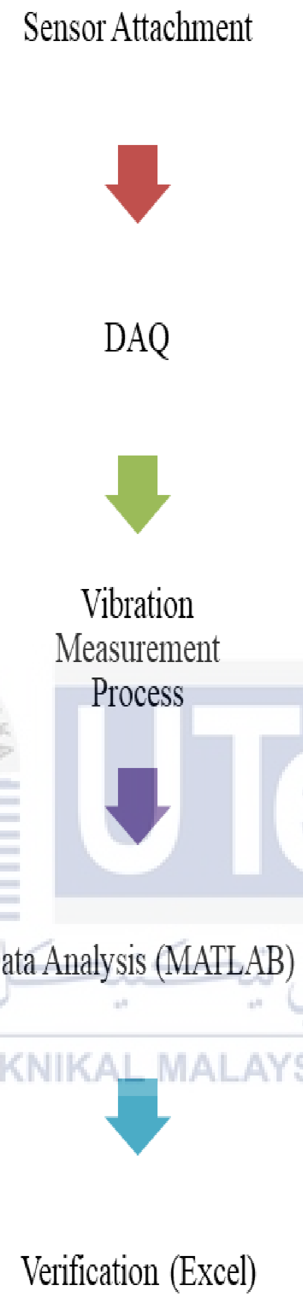


Figure 4.1 Thesis Experiment Flow

4.2 Calibration Result

Prior to starting the experiment, the equipment used to measure the roller bearing’s vibration levels were callibrated to ensure that the equipment are functioning properly and there is no errors in the mesurement process and consistant measurements are made. The callibration process was performed using the Calibration Exciter Type 4294 which is a calibration sensor meter. The Calibration Exciter Type 4294 runs at a frequency of 159.1 Hz where it also can reach a max amplitude of 160 Hz. This callibration process is critical in ensuring the accelorometer used in the vibration measuring process are able to produce correct readings. The time domain and frequency domain graphs of the calibration are as figure below.

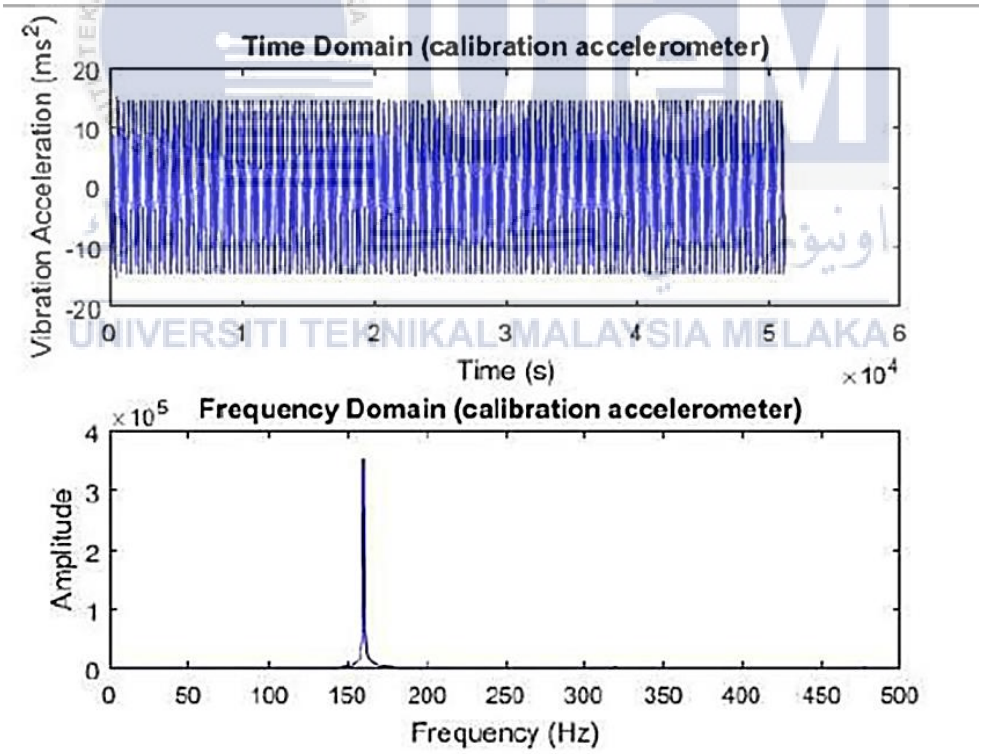


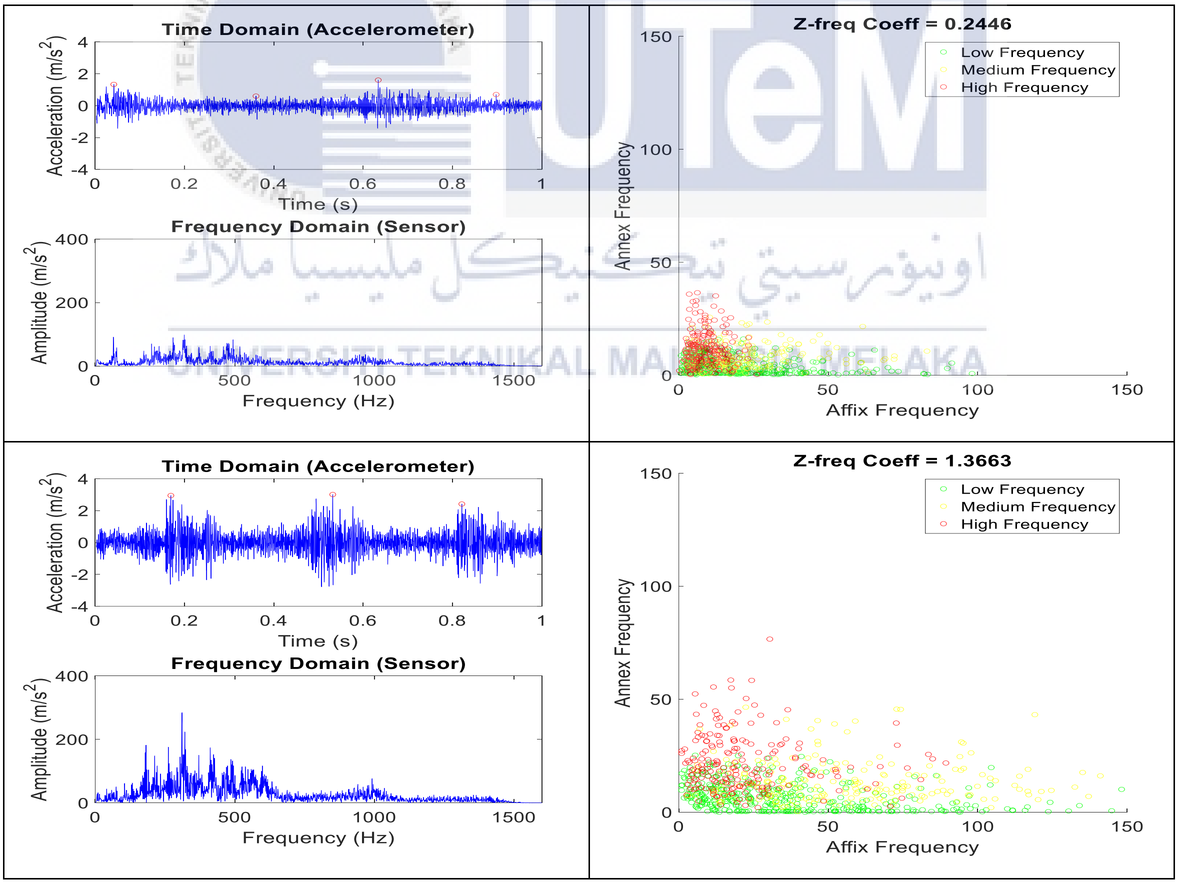
Figure 4.2 Time Domain and Frequency Domain Graphs of the Acclelerometer Calibration

4.3 Roller Bearing Monitoring

The experiment utilized two (2) accelerometer sensors labeled S1 (Channel 1) and S2 (Channel 2) which were connected to before and after the roller bearing respectively. SO Analyzer software was used to collect the vibrational measurements from the roller bearings with different conditions.

The time domain graph, frquency domain graph, and Z-freq scattering together with its coefficient were obtaine through the MATLAB software which were obtained via the vibrational data analysis. An average data out of three (3) trials was used for this analysis.

4.3.1 Condition A (Undamaged Roller Bearing)



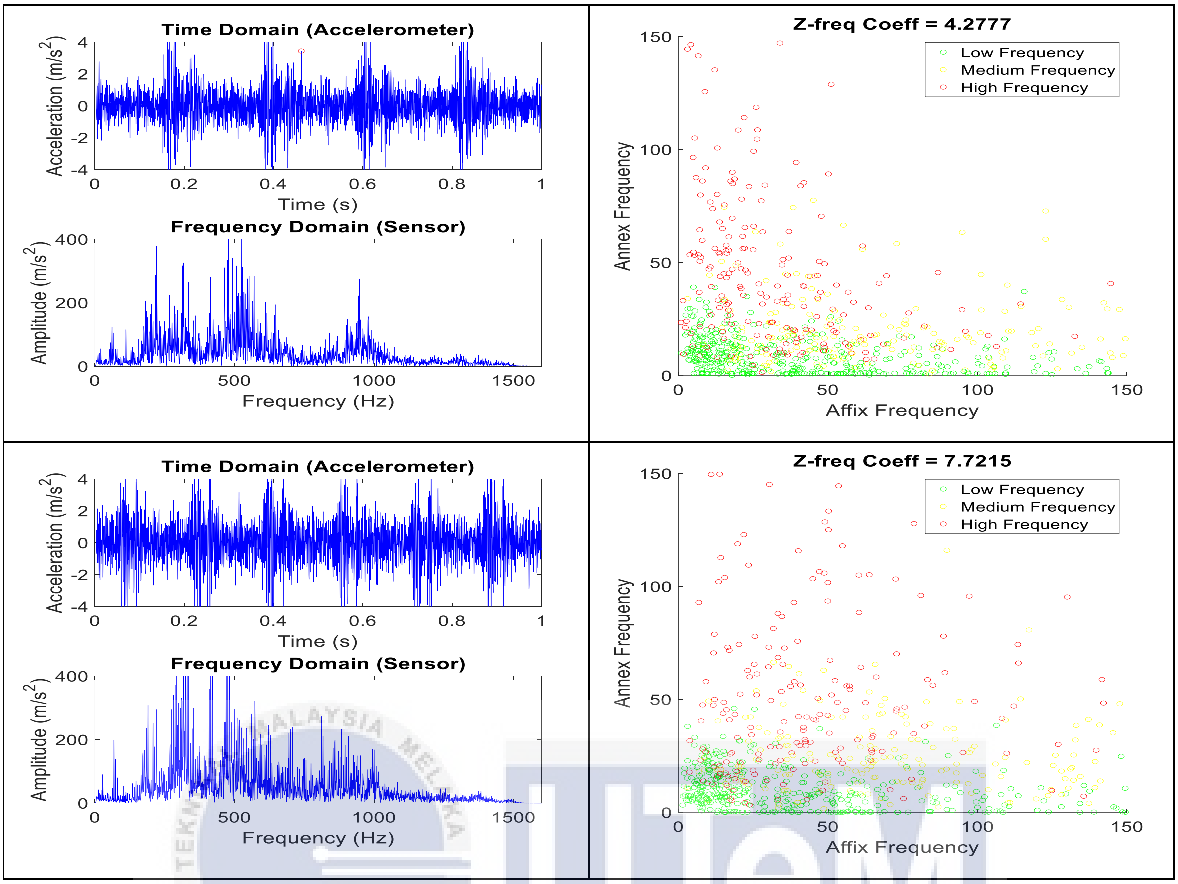
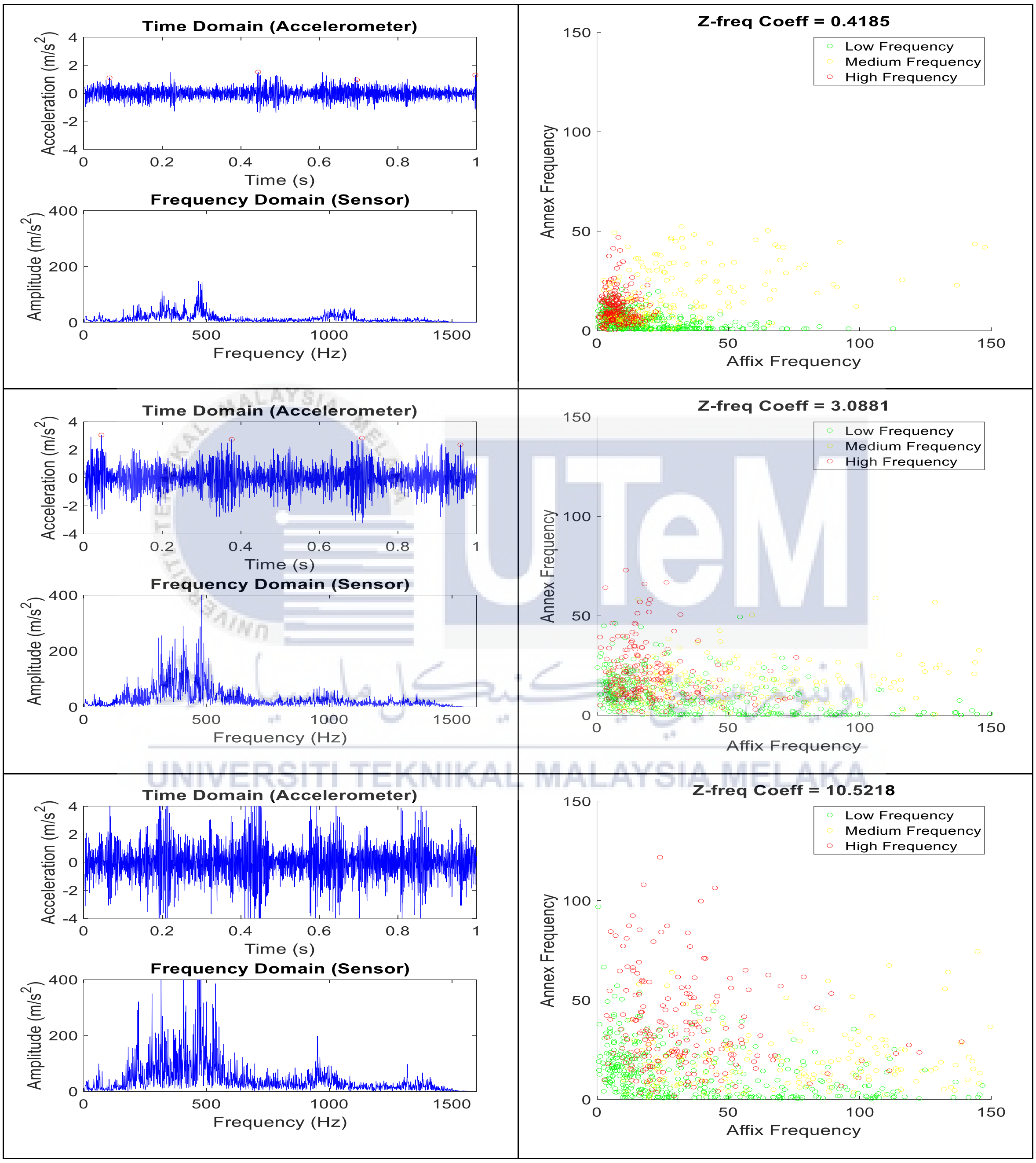


Figure 4.3 Z-freq Scattering for 400 rpm, 800 rpm, 1200 rpm, 1600 rpm for Condition A Roller Bearing

The time domain graph, frquency domain graph, and Z-freq scattering for the four speeds the Condition A roller bearing was run are shown in Figure 4.2. From these graphs it can be stated that the waveform data demonstrates an increase in the transient components where it increases together with the running speed. Through the graphs also, it can be seen that the vibration with frequency of 1000 Hz or lower increases in amplitude as the speed increases. As the speed increases from 400 rpm to 1600 rpm, the vibrations acceleration also increases over the time period.

Through Figure 4.2 Z-freq data scattering and its coefficient, it is observable that the red dots spread across the annex frequency constantly and the green dots does not spread so much. All the dots can be observed to be spreading across the affix frequency. Through this it can be said that the scattered data shows a clear pattern as the speed increases. This indicates that the vibration levels on the roller bearing increases as the speed increases constantly.

4.3.2 Condition B (Roller Bearing with Outer Ring Damage)



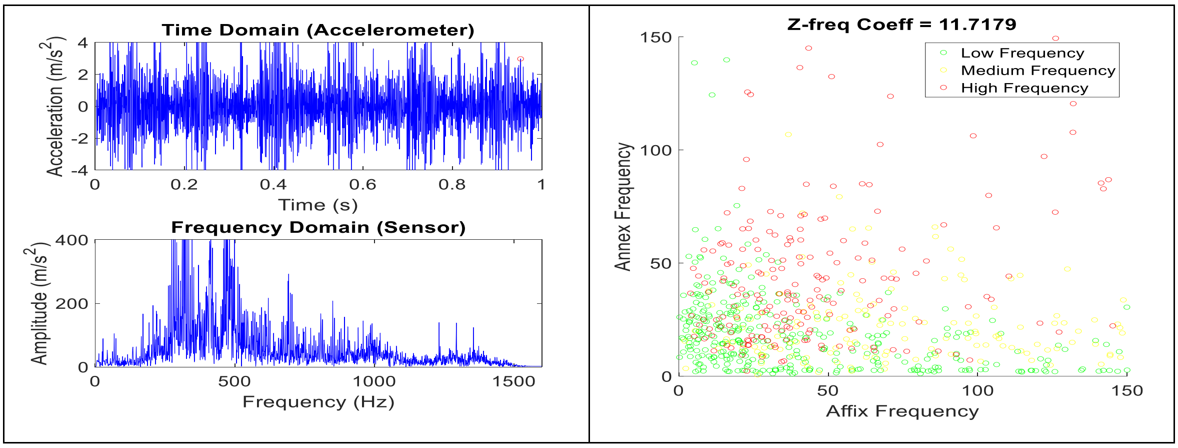


Figure 4.4 Z-freq Scattering for 400 rpm, 800 rpm, 1200 rpm, 1600 rpm for Condition B Roller Bearing

The time domain graph, frquency domain graph, and Z-freq scattering for the four speeds the Condition B roller bearing was run are shown in Figure 4.3. From these graphs it can be stated that the waveform data demonstrates an increase in the transient components where it increases together with the running speed as well. Through the graphs also, it can be seen that the vibration with frequency of 1500 Hz or lower increases in amplitude as the speed increases. As the speed increases from 400 rpm to 1600 rpm, the vibrations acceleration magnitude also increases over the time period.

Figure 4.3 also shows the Z-freq data scattering and its coefficient where it is observable that both the red and green dots spread across the annex and affex frequency constantly and the green dots can be observed to be spreading across the affix frequency. Through this it can be said that the scattered data shows a clear pattern as the speed increases. This indicates that the high frequency vibration levels on the roller bearing increases as the speed increases constantly where the high frequency vibration becomes more random as speed increases.

4.3.3 Condition C (Roller Bearing with Inner Ring Damage)

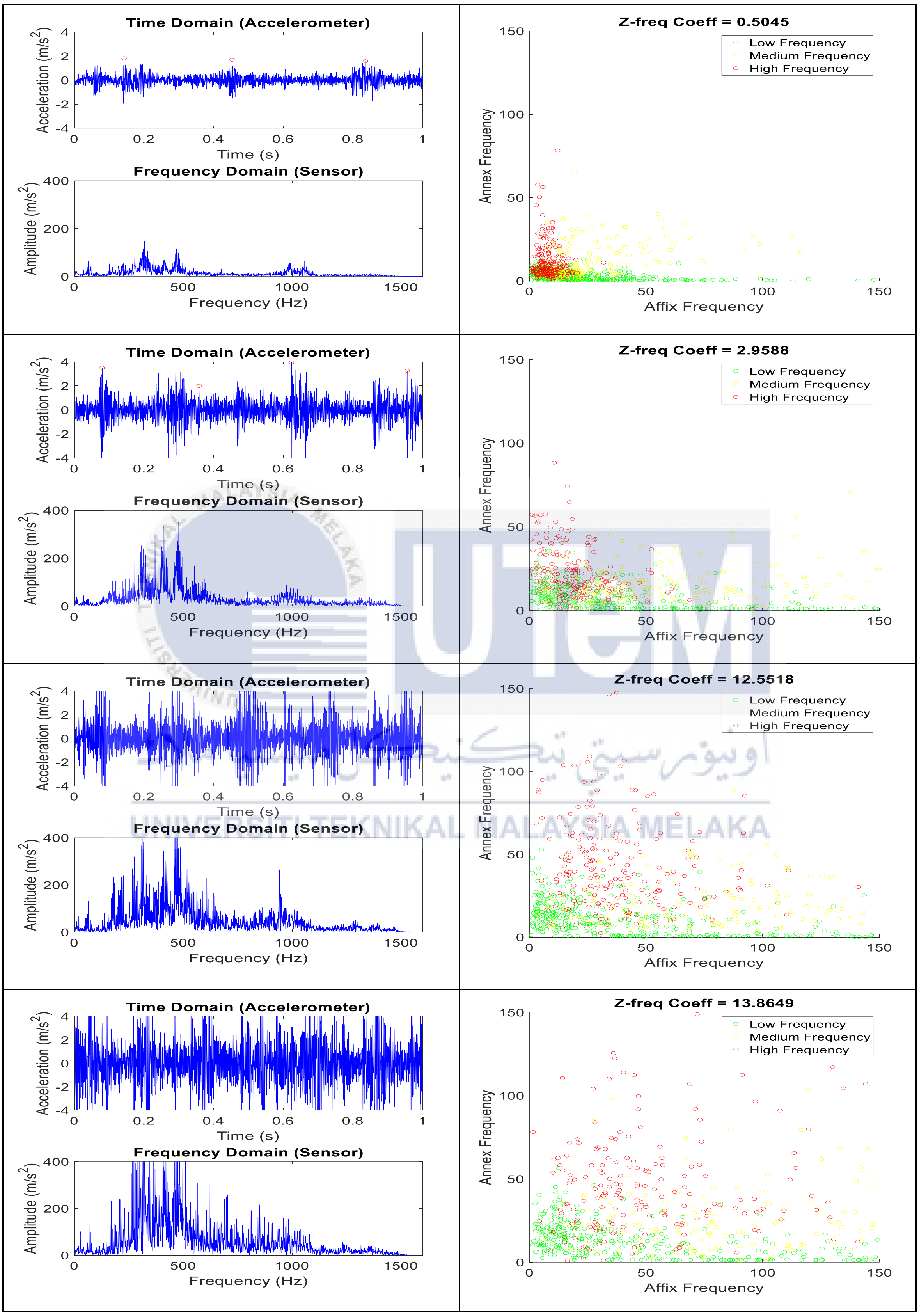
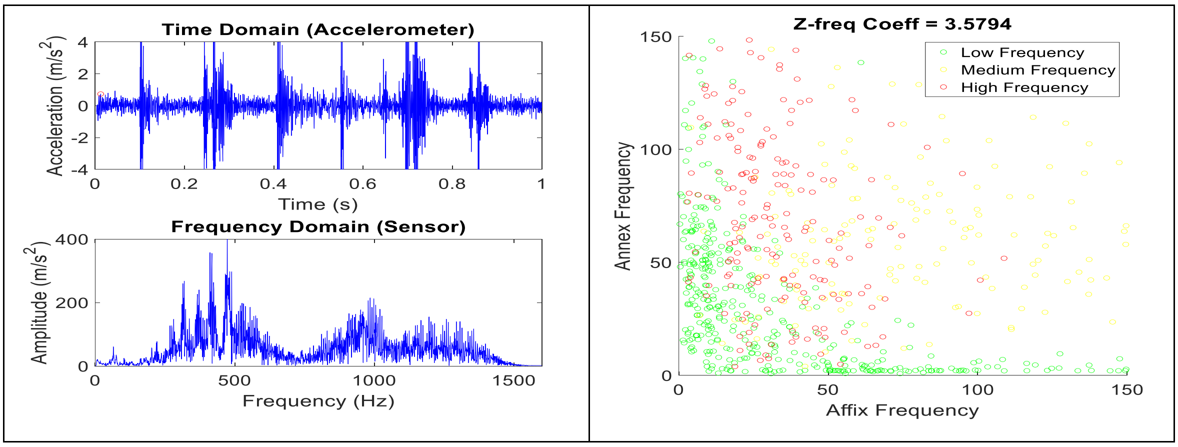


Figure 4.5 Z-freq Scattering for 400 rpm, 800 rpm, 1200 rpm, 1600 rpm for Condition C Roller Bearing

The time domain graph, frquency domain graph, and Z-freq scattering for the four speeds the Condition C roller bearing was run are shown in Figure 4.4. From these graphs it can be stated that the waveform data demonstrates an increase in the transient components where it increases together with the running speed as well. Through the graphs also, it can be seen that the vibration with frequency of 1000 Hz or lower increases in amplitude as the speed increases. As the running speed increases from 400 rpm to 1600 rpm, the vibrations acceleration magnitude also increases over the time period.

Besides that, Figure 4.4 also shows the Z-freq data scattering and its coefficient where it is observable that both the red dots spread across the annex frequency constantly as the speed increases and the green dots can be observed to be spreading across the affix frequency when the speed increases as well. Through this it can be said that the scattered data shows a clear pattern as the speed increases. This indicates that the low frequency vibration levels on the roller bearing does not drastically increase as the speed increases constantly which is opposite to the high frequency vibrations where the high frequency vibration becomes more random as speed increases.

4.3.4 Condition D (Roller Bearing with Rolling Element Damage)



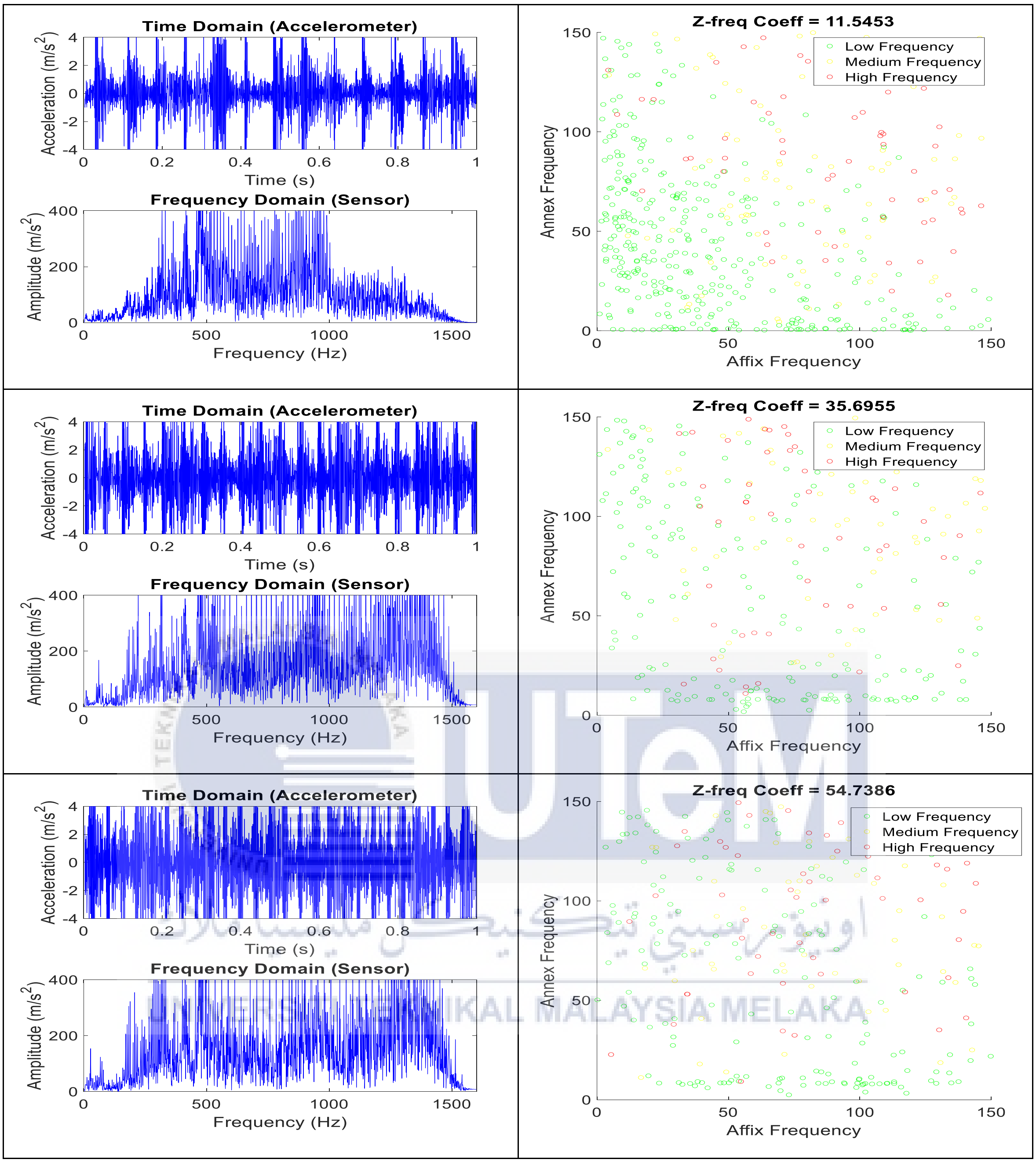
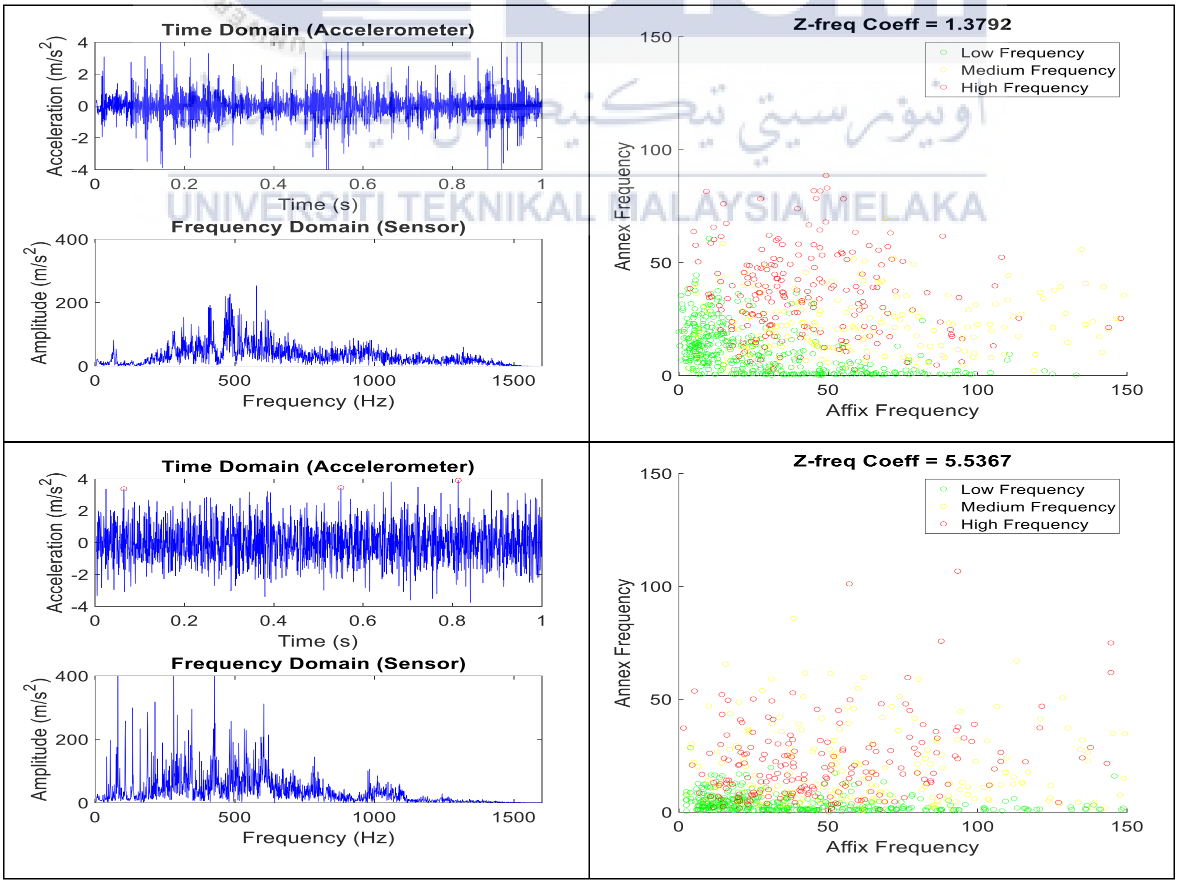


Figure 4.6 Z-freq Scattering for 400 rpm, 800 rpm, 1200 rpm, 1600 rpm for Condition D Roller Bearing

The time domain graph, frquency domain graph, and Z-freq scattering for the four speeds the Condition D roller bearing was run are shown in Figure 4.5. From these graphs it can be stated that the waveform data demonstrates an increase in the transient components where it increases together with the running speed as well. Through the graphs also, it can be seen that the vibrations with frequency of 1500 Hz or lower increases drastically in amplitude as the speed increases. As the running speed increases from 400 rpm to 1600 rpm, the vibrations acceleration magnitude also increases drastically over the time period.

Moreover, Figure 4.5 also shows the Z-freq data scattering and its coefficient where it is observable that all the red, yellow and green dots spread across the annex and affix frequency drastically as the speed increases where the green dots can be observed to be spreading across the annex frequency more when the speed increases. Through this it can be said that the scattered data shows a clear pattern as the speed increases. This indicates that all the the low, medium and high frequency vibration levels on the roller bearing drastically increase as the speed increases constantly. Via this it can be said that roller bearing’s rolling element damage causes a great increase in the bearing’s vibration magnitude.

4.3.5 Condition E (Roller Bearing with B, C, and D Damages Simultaneously)



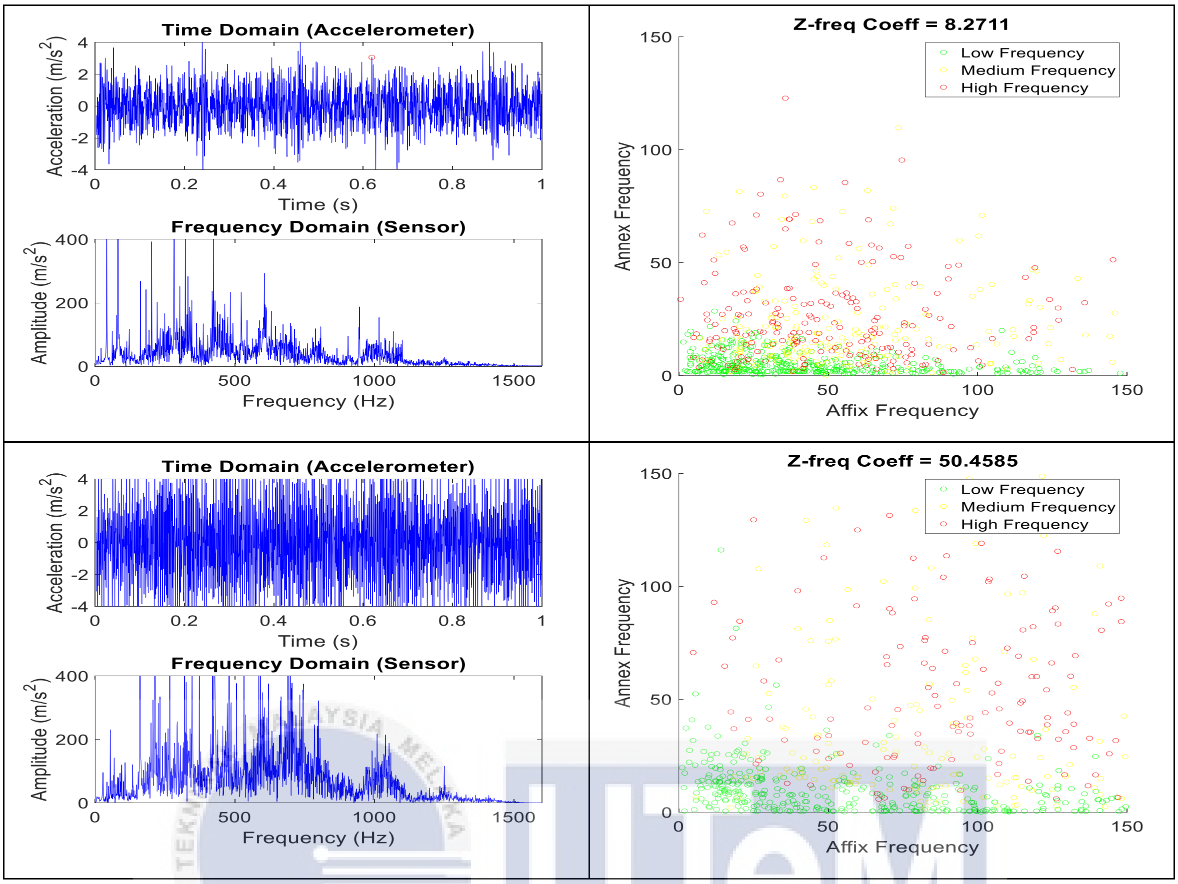
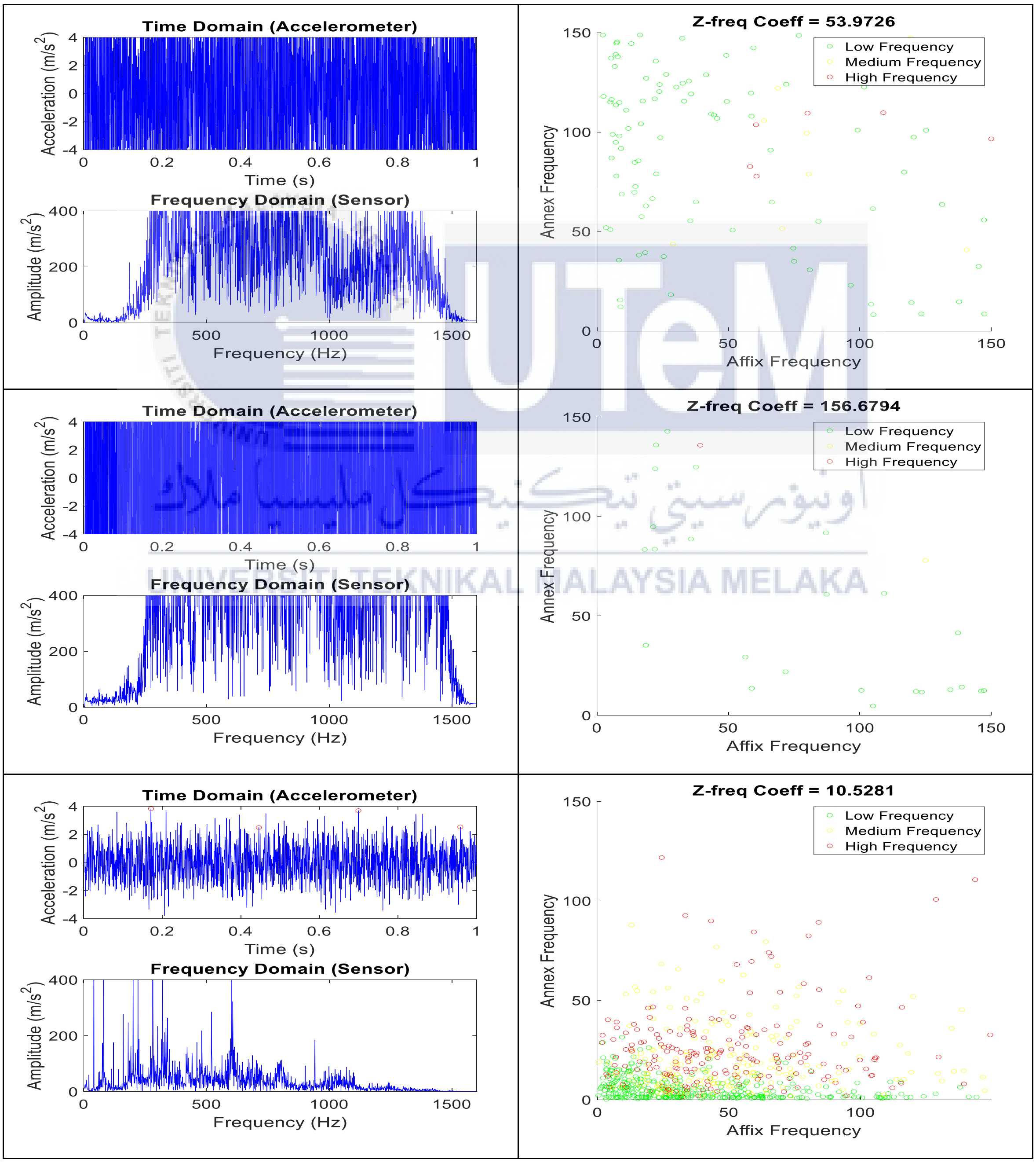


Figure 4.7 Z-freq Scattering for 400 rpm, 800 rpm, 1200 rpm, 1600 rpm for Condition E Roller Bearing

The time domain graph, frquency domain graph, and Z-freq scattering for the four speeds the Condition E roller bearing was run are shown in Figure 4.6. From these graphs it can be stated that the waveform data demonstrates an drastic increase in the transient components where it increases together with the running speed as well. Through the graphs also, it can be seen that the vibrations with frequency of 1000 Hz or lower increases drastically in amplitude as the speed increases. As the running speed increases from 400 rpm to 1600 rpm, the vibrations acceleration magnitude also increases radically over the time period.

Figure 4.6 also shows the Z-freq data scattering and its coefficient where it is visable that the red and yellow dots spread across the annex and affix frequency drastically as the speed increases where the green dots can be observed to be spreading across the affix frequency more when the speed increases. Through this it can be said that the scattered data shows a clear pattern as the speed increases. This indicates that all the medium and high frequency vibration levels on the roller bearing radically increase as the speed increases constantly. Due to this, it can be said that damges B, C, and D occuring simultaneously on a roller bearing causes a great increase in the bearing's vibration magnitude.

4.3.6 Condition F (Roller Bearing with Severe Damages)



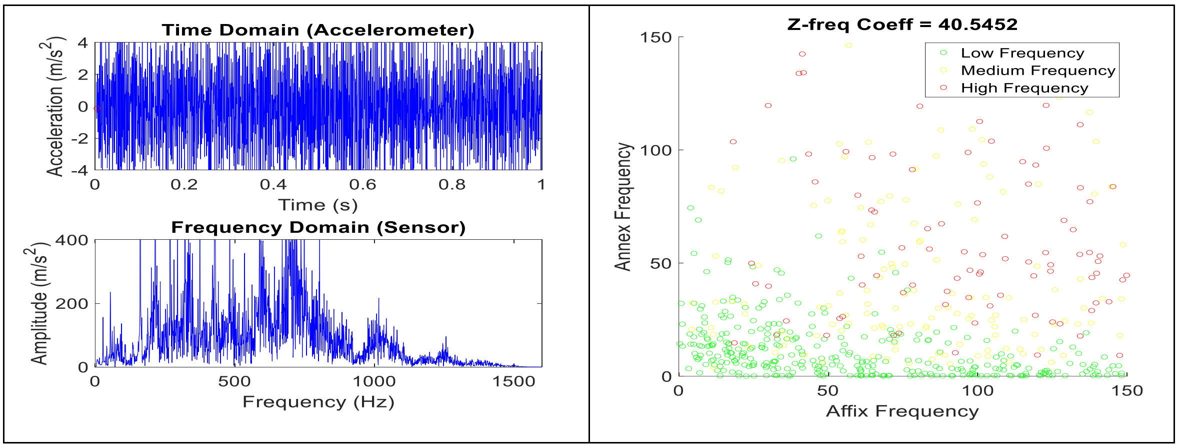


Figure 4.8 Z-freq Scattering for 400 rpm, 800 rpm, 1200 rpm, 1600 rpm for Condition F Roller Bearing

The time domain graph, frquency domain graph, and Z-freq scattering for the four speeds the Condition E roller bearing was run are shown in Figure 4.7. From these graphs it can be stated that the waveform data demonstrates an radical increase in the transient components where it increases together with the running speed as well. Through the graphs also, it can be seen that the vibrations with frequency of 1500 Hz or lower fluctuates where it incrases and decreases drastically in amplitude as the speed increases. As the running speed increases from 400 rpm to 1600 rpm, the vibrations acceleration magnitude also radically fluctuates over the time period.

Figure 4.7 also shows the Z-freq data scattering and its coefficient where it is visable that the red and yellow dots spread far apart across the annex and affix frequency drastically as the speed increases where the green dots can be observed to be spreading across the affix frequency more when the speed increases. Through this it can be said that the scattered data shows a clear pattern as the speed increases. This indicates that all the medium and high frequency vibration levels on the roller bearing radically increase as the speed increases constantly. Due to this, it can be said that severe damages occuring on a roller bearing’s rolling element damage causes a radical increase in the bearing’s vibration magnitude.

4.4 Root Mean Square (RMS)

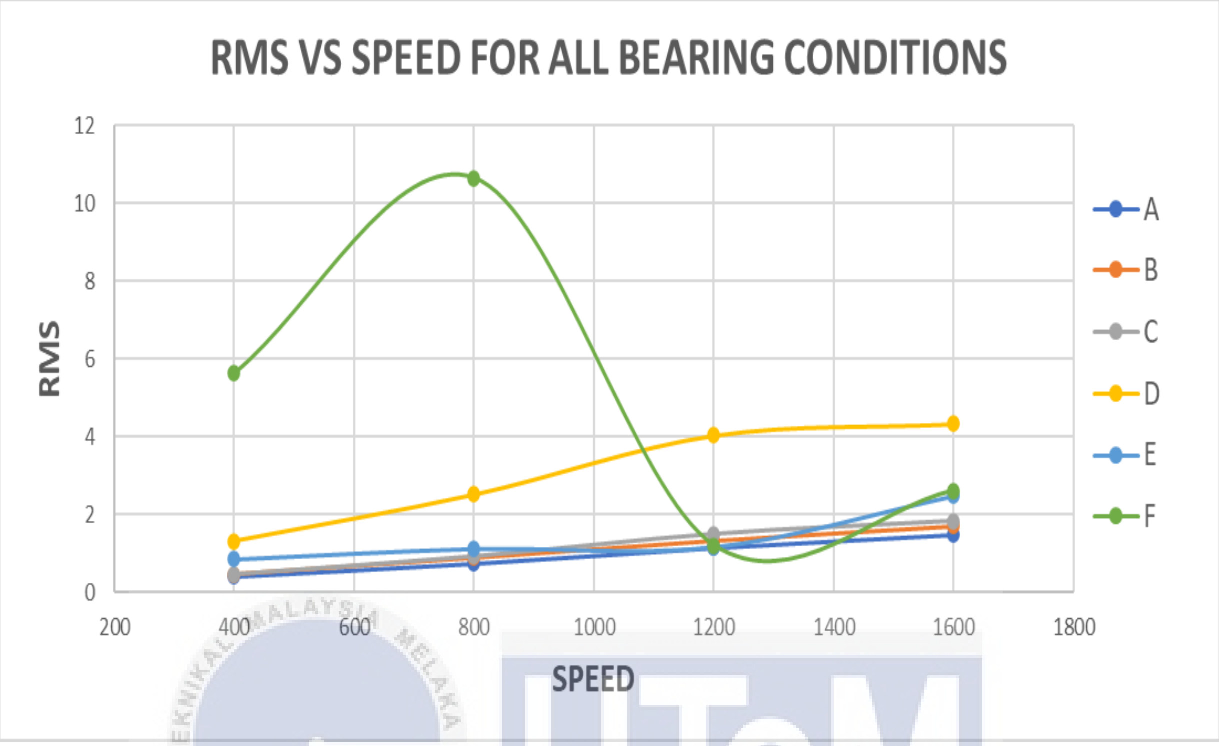


Figure 4.9 RMS for All the Roller Bearing Conditions

Table 4.1 RMS Values of All Roller Bearing Conditions

Speed	Condition A	Condition B	Condition C	Condition D	Condition E	Condition F
400	0.4189	0.4605	0.476	1.3277	0.8522	5.6331
800	0.7517	0.8867	0.9371	2.5203	1.1249	10.6532
1200	1.1491	1.3306	1.5133	4.0351	1.1712	1.2108
1600	1.4841	1.7065	1.8471	4.3298	2.4874	2.6229

In terms of RMS from Figure 4.8, for conditions A, B, C, D, and E it can be seen that the RMS increases as the speed increases from 400 rpm to 1600 rpm. This corresponds with the RMS values obtained through the MATLAB sofware in Table 4.1. For condition F however, it can be seen that the RMS value fluctuates drastically as the speed increases from

400 rpm to 1600 rpm. This is beacuse of the irregularity of the data obtained due to the severity of the damages on the bearing which radically influences the roller bearing’s vibration levels.

4.5 Z-Frequency (Z-freq)

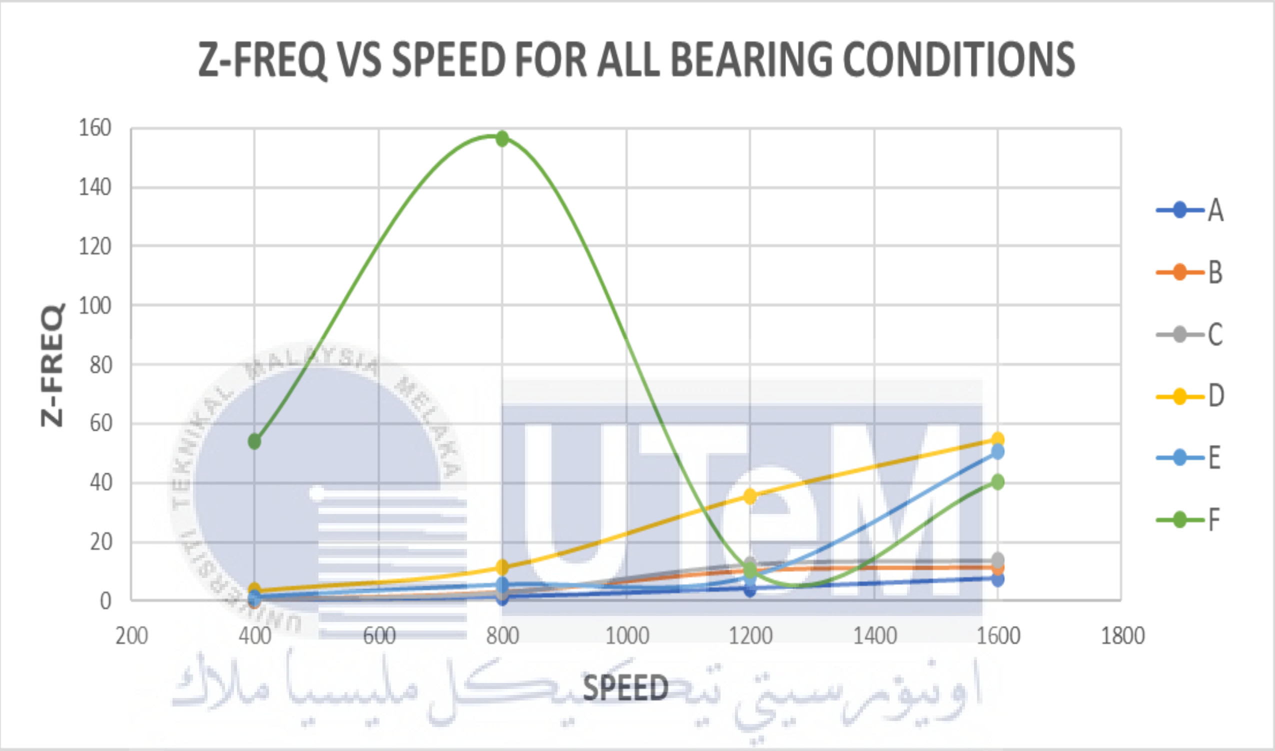


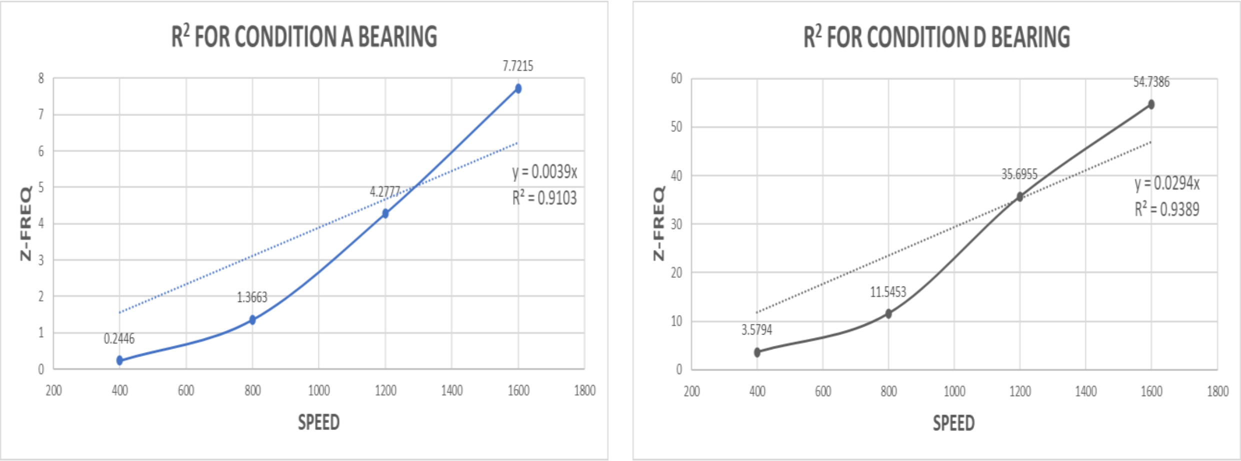
Figure 4.10 Z-freq for All the Roller Bearing Conditions

Table 4.2 Z-freq Values of All Roller Bearing Conditions

Speed	**Condition A**	**Condition B**	**Condition C**	**Condition D**	**Condition E**	**Condition F**
400	0.2446	0.4185	0.5045	3.5794	1.3792	53.9726
800	1.3663	3.0881	2.9588	11.5453	5.5367	156.6794
1200	4.2777	10.5218	12.5518	35.6955	8.2711	10.5281
1600	7.7215	11.7179	13.8649	54.7386	50.4585	40.5452

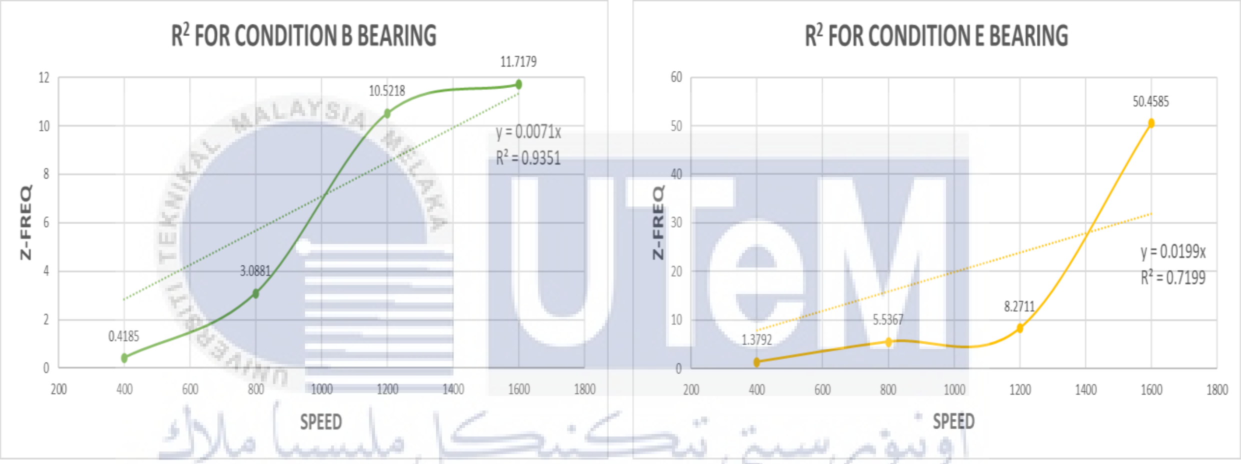
In terms of Z-freq from Figure 4.9, for conditions A, B, C, D, and E it can be seen that the Z-freq coefficient increases as the speed increases from 400 rpm to 1600 rpm. This corresponds with the Z-freq coefficient values obtained through the MATLAB sofware in Table 4.2. For condition F however, it can be seen that the Z-freq coefficient value fluctuates drastically as the speed increases from 400 rpm to 1600 rpm. This is also beacuse of the irregularity of the data obtained due to the severity of the damages on the bearing which radically influences the roller bearing's vibration levels causing it to fluctuate.

4.6 R-Squared (R^2)



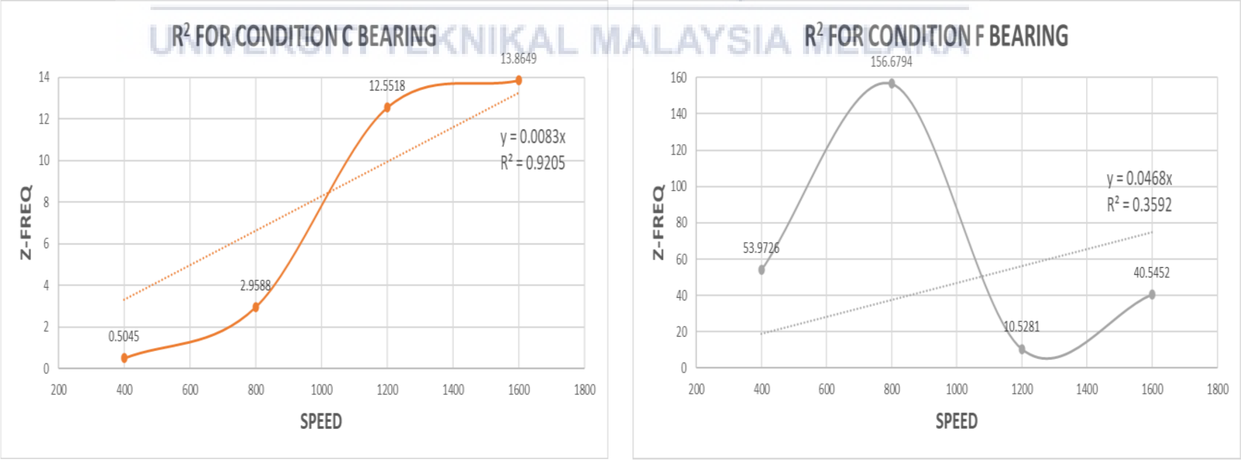
Condition A

Condition D



Condition B

Condition E



Condition C

Condition F

Figure 4.11 R-Squared (R^2) for All the Roller Bearing Conditions

Figure 4.10 above shows the R^2 for each of the bearing condition. From the figure above, for conditions A, B, C, and D the R^2 value is more than 0.9 where conditions A, B, C, and D have R^2 value of 0.9103, 0.9351, 0.9205, and 0.9389 respectively. As the R^2 value is more than 0.9, the data collected and the analysis done can be said to be reliable where it can be used to predict a roller bearing vibration outcome. R^2 value for condition E on the other hand is 0.7199 where the data and analysis done is somewhat reliable as the minimum reliable R^2 value is 0.6. Finally for the R^2 value of the condition F roller bearing, the value of 0.3592 is due to the irregularity of the data obtained due to the severity of the damages on the bearing which radically influences the roller bearing's vibration levels causing it to fluctuate. Due to this, it can be said that severe damages to the roller bearing will drastically increase the roller bearing's performance and also reduce the eficiency the roller bearing opperates.

4.7 Data Distribution

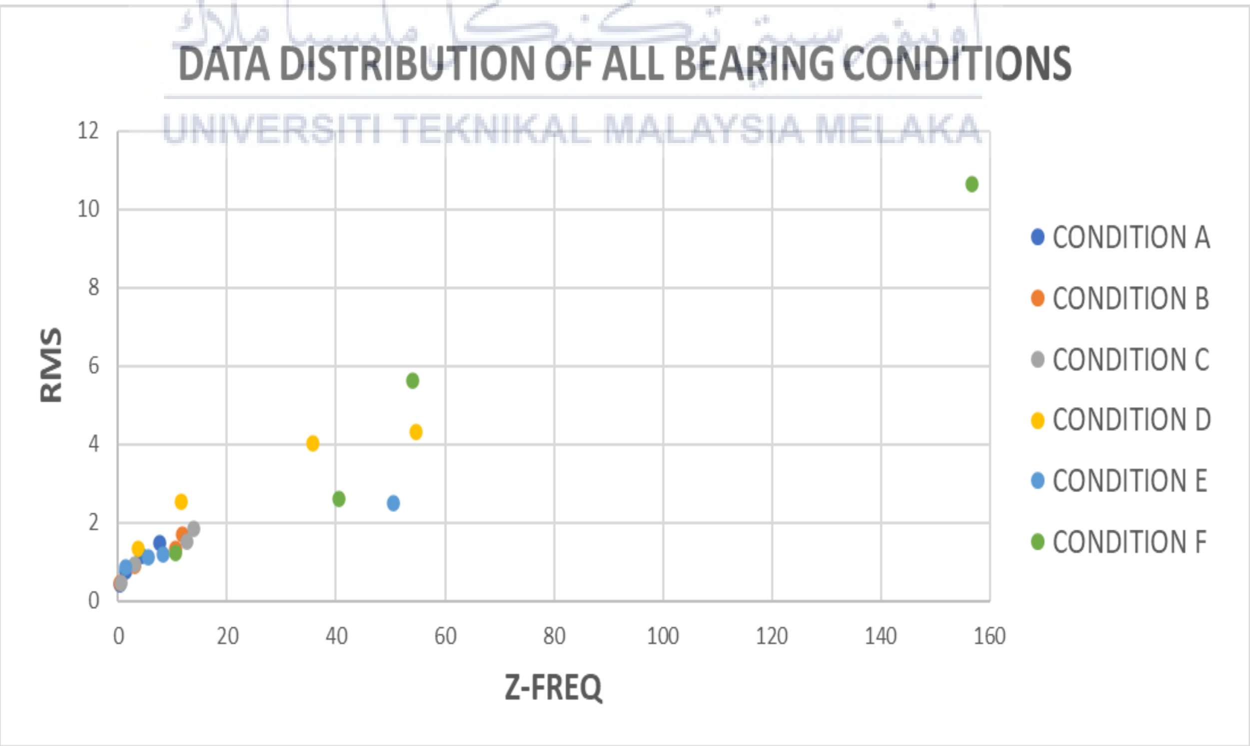


Figure 4.12 Data Distribution for All the Roller Bearing Conditions

The Figure 4.11 shows the data distribuation for each of the roller bearing condition where it compares the data acquired from the RMS and Z-Freq coefficients. The figure above shows a upward trend as both the Z-freq and RMS increases. This corresponds with the increase in four (4) running speeds where the speeds are 400 rpm, 800 rpm, 1200 rpm, and 1600 rpm respectively. Based on the figure above it can be said that conditions A, B, C, and E has the closest accuracy in the speeds of 400 rpm, 800 rpm and 1200 rpm compared to the other type of conditions and speed.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In practice, there are many ways that the roller beaaring vibrations may be reduced or removed. This thesis focused on the analysis of the vibrational data obtained from the roller bearing. The data was analyzed through Vibration Statistical Analysis methods. It can be deduced that fault diagnosis of bearings using condition monitoring and Vibration Statistical Analysis methods is one of the most crucial studies or analysis in the rotating equipment field.

When the bearings of normal and damaged conditions were run in the four different speeds, the emerging output can be utilized to identify the variety of bearing faults that occur which can be futher used in diagnosig faults related to the bearing vibrations.

Through the analysis performed via the MATLAB software to obtain the results, it can be said that time domain is not suitable for fault prediction as compared to the R-Squared method as in time domain, the graph difference between the faulty and good conditions are similar to the frequency domain graphs.

This thesis presents a method for predicting the condition that produces the specifiv vibration through the RMS and R^2. The proposed methodology is effective and robust in order to obtain good results utilizing only fairly accurate information and with a minimum network measurements. The main feature of the approach is that it establishes a simple and effective identification model for the roller bearing vibrations.

Overall, the research presented in this thesis has succeeded in making a contribution to the set out objectives where all the objectives were acheived diligently.

5.2 Recommendations

For future improvemets of this study/thesis, other variety of bearings under more conditions could be studied to to acquire a better understanding of Vibration Signal Analysis (VSA). This data then can be useed to make bearings more reliable and able to know the condition the bearing is operating. Besides that a more advanced equipment could be used to measure the vibrational data in greater accuracy.

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APPENDICES

APPENDIX A FYP 1 Gantt Chart.

Progress	Weeks														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project briefing	🟧	🟧	🟧	🟧											
Project Title Selection	🟧														
Chapter 1 Completion						🟧	🟧	🟧							
Chapter 2 Completion								🟧	🟧	🟧	🟧	🟧	🟧		
Chapter 3 Completion													🟧	🟧	
Report completion and Draft submission														🟧	
Report and Presentation Video submission															🟧
BDP weekly Logbook	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	

APPENDIX B FYP 2 Gantt Chart.

PROGRESS	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
PROJECT BRIEFING	COMPLETED								COMPLETED						
EXPERIMENTAL SETUP		COMPLETED													
DATA COLLECTION				COMPLETED											
RESULT ANALYSIS						COMPLETED									
RESULT VERIFICATION										COMPLETED					
CONCLUSION & RECOMMENDATION												COMPLETED			
WEEKLY REPORTING (LOOGBOOK)	COMPLETED														
PROJECT REPORTING					COMPLETED										
4 PAGES SUMMARY														COMPLETED	
PRESENTATION & SLIDES														COMPLETED	

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

TAJUK: **FAULTY BEARING VIBRATION DIAGNOSTIC & MONITORING**

SESI PENGAJIAN: **2020/21 Semester 1**

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