A STUDY OF VIBRATION FEATURES FOR ROTATING SPECIMEN UNDER CYCLIC LOADING

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In the name of ***ALLAH*** *whose guidance, help and grace was instrumental in making this humble work reality. Dedicated to my beloved father, mother, friends, without them and his/her lifetime efforts, my pursuit of higher education would not have been possible and I would not have had change to study for mechanical course. Also to my supervisor, Mr Mohamad Zairi and co-supervisor, Mr.Che Ku Eddy for their guide and help especially in finishing this project report.*

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ABSTRACT

This thesis presented about a study of vibration features for rotating specimen under cyclic loading. From statistical, about 90% of the machines are a failure due to fatigue phenomena, thus need to monitor the fatigue behaviour on component (early detection) to avoid machine breakdown. The main objectives of the project are to measure vibration response during cyclic loading and study the response under frequency domain analysis. The equipment involves are fatigue testing machine, accelerometer, and data acquisition (DAQ). The position of the accelerometer was placed near to the bearing housing. Then, create a block module using DASYLAB software to record the data. Result shows, signal at y-axis are dominant compared to the x-axis and z-axis. Signal value at y-axis is higher because of force applied are parallel to the y-axis that perpendicular to the specimen (vertical axis displacement). Signal at x-axis is lowest compare to the others axis, because at x-axis is parallel to the specimen. Thus, from this result more focus on y-axis data. For mild steel, at forces 250 N, the specimen fractured at 7769 cycles with amplitude value is 8.50, followed by 200 N at 23 238 cycle and 150 N at 100 510 cycles with amplitude 7.30 and 5.70 respectively. For low carbon steel, at 250 N the specimen fractured at 9400 cycles with amplitude value 9.59, higher than other load, at 200 N the specimen fractured at 24 300 cycle and 150 N at 137 749 cycles with amplitude value is 7.90 and 7.60, respectively. From the result, with constant force applied, the value of amplitude increase when the number of cycle increases. This is because, the power that transmits from the motor to the specimen will reduce the stiffness on the specimen, and the resistance will decrease. This increased loads can accelerate crack growth and ultimate failure can affect the changing amplitude for the specimen.

ABSTRAK

Tesis ini mengkaji tentang ciri-ciri gelombang terhadap spesimen yang berpusing di bawah beban kitaran. Objektif utama kajian ini adalah merekod kesan gelombang semasa experiment dijalankan dan mengkaji kesan daripada beban kitran dengan menggunakan analisis frequensi. Alat yang digunakan dalam experiment ini adalah mesin fatigue testing, accelerometer (sensor), dan data acquisition (DAQ). Kedudukan sensor adalah berdekatan dengan kotak bearing. Perisian DASYLAB digunakan sebagai medium untuk merekod data dengan membuat modul-modul khas. Daripada dapatan kajian, menunjukkan isyarat gelombang pada paksi-y lebih tinggi dari paksi-x dan paksi-y. Ini kerana, kesan daripada bebanan yang dikenakan keatas specimen adalah selari dengan paksi-y. Manakala, isyarat gelombang pada paksi-x paling rendah berbanding paksi lain. Ini kerana, paksi-x adalah selari dengan kedudukan spesimen. Nilai pada paksi-x, dan paksi-z adalah rendah, maka hanya dapatan kajian pada paksi-y sahaja diambil. Untuk data pada bahan keluli lembut, pada beban 250 N, spesimen patah pada kitaran 7769 dengan nilai amplitude ialah 8.50. Di ikuti pada beban 200 N dan 150 N, spesimen patah pada kitran 23238 dan 100510 dengan masing-masing nilai amplitude 7.30 dan 5.70. Manakala, pada bahan keluli carbon rendah pada beban 250 N, spesimen patah pada kitaran 9400 dengan nilai amplitude ialah 9.59. Di ikuti pada beban 200 N dan 150 N, spesimen patah pada kitran 24300 dan 137749 dengan masing-masing nilai amplitude 7.90 dan 7.60. Daripada dapatan kajian, menunjukkan nilai amplitud meningkat, bila bilangan kitaran meningkat. Ini kerana, kuasa yang dipindahkan oleh motor terhadap spesimen akan mengurangkan tahap rintangan didalam spesimen akan memberi kesan peningkatan terhadap nilai amplitud. Penambahan bebanan yang lebih tinggi, maka meningkatkan kadar keretakkan dan tahap rintangan untuk spesimen patah akan memberi kesan peningkatan nilai amplitude.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

F	Force
σ	Stress
ε_p	Plastic strain
N	Number of cycles
$x\ (f)$	Fourier transform
$x\ (t)$	Continuous function (in time)
A	Amplitude ratio

LIST OF ABBREVIATIONS

3D	Three Dimensional view
FFT	Fast Fourier Transform
DASYLab	Data Acquisition System Laboratory
MATLab	Matrix Laboratory
MAX	Measurement and Automation Explorer
ASTM	American Society for Testing and Materials
JIS	Japanese Industrial Standards
STFT	Short Time Forier Transform
CNC	Computer Numerical Control

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

In the nineteenth century, the failure of some mechanical components subjected to the nominal stress well below the tensile strength of the material aroused some interest among a few engineers of that time. The fact that puzzled these early engineers was that a component such as bolts or a shaft made from a ductile material such mild steel could fracture suddenly in what appeared to be a brittle manner. These were no obvious defect in workmanship or material, and the only features common to these variables in a cyclical manner. This phenomenon of failure of the material when subjected to a number of varying stress cycles become known as fatigue, since it was thought that a fracture occurred owing to the metal weakening.

Fatigue material is a very complex process, which is still today not fully understood and it is known as (material subjected to a repetitive load and will eventually fail at load much lower than that required to cause fracture on single application of the load).

1.2 PROBLEM STATEMENT

About 90 % of the machines are a failure due to fatigue phenomena. This kind of phenomena can affect any part of components shaft such as crankshaft in engine, steering shaft in car system, lathe machine especially the rotate the specimen part, grinding machine of cutting tools, aircraft wings, nuclear reactor and turbines. Fasteners and joint also face the fatigue behavior (Jen et al., 2006). Fatigue cracks are potential sources of catastrophic failures in rotors (Darpe, 2007). Many companies prepared the product design up to 10^8 cycles of lifetime. High costing and leads time to test fatigue failure by using conventional testing especially in to check material structure. To overcome this problem, high frequency fatigue cyclic loading such as piezoelectric are used (Marines et al., 2003). By using accelerometer, can monitor the status of the fatigue behavior of components and can predict the when fatigue failure will occur. Others word, early failure detection on components. This report is more focusing on study the vibration features of the shaft component under cyclic loading by monitoring vibration response during rotation by using accelerometer. This is for early detection of fatigue behavior on the specimen.

1.3 OBJECTIVES OF THE PROJECT

From problem statement above, the objectives are:

(i) To measure the vibration response during cyclic loading.
(ii) To study the vibration response of the specimen under frequency domain analysis.

1.4 SCOPES

Scopes of the project are:

(i) Focus on high cycle fatigue stages.
(ii) For fatigue testing the material is low carbon steel and mild steel, which are in solid form.
(iii) Accelerometers were used to measure vibration response, and measurement are involving three dimension axis; x-axis, y-axis and z-axis.
(iv) Ranges of force that can apply to the specimen are 150 N to 250 N and the speed of rotation motor are totally fixed.

1.5 PROJECT FLOW CHART

Figure 1.1 shows the project flow chart. Start with defining the background of study that relate to the topic, to identify the main problem of the research. Followed by, objective of research and scope of the study. This section is discussed about general theory about fatigue and related problem. Next section, more on reviews of any material such as journal, articles as references. Then, in the methodology section, decide the material, dimension of the specimen, parameters that involves. For last section, more result analysis of data experiment.

Gantt chart for FYP 1 are shown Figure 1.2, the overall activities for final year project one. Start with a briefing from supervisor and co-supervisor, discuss about the related topic. Current progresses are behind schedule within one week because need more understanding the theory. Next activities are learning software. Install DASYLAB software at week three and learn basic theories of DASYLAB such as sampling, block size, and others module function to support experimental and next is finding journal that related to the topic. Both activities are also behind the schedule as plan because my supervisor had suggested a certain technique to improve for my block diagram experiment. There are misunderstandings about of this topic, for this topic does not have to do modal testing, thus co-supervisor ask focus on vibration response of shaft component. For specimen material, need to check the grade of low carbon steel by using a spectrometer at casting laboratory. The rest of activities are following schedule, except check draft report with supervisors, which has earlier a week. For FYP 2, more on fabricated the specimens for experimental testing, run experiments. Discuss the data from the experiment with a supervisor. Then, do the draft report and prepare for presentation.

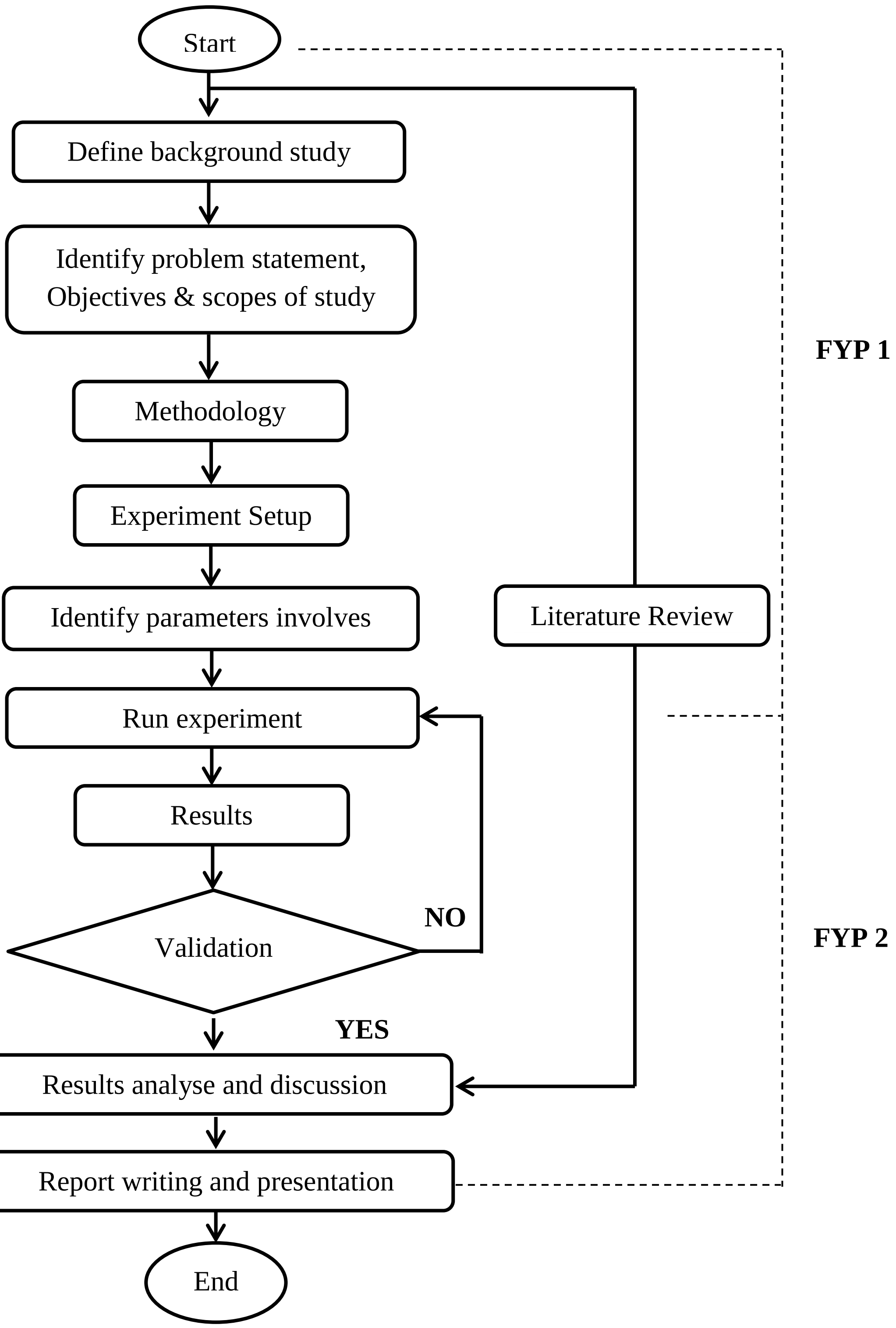


Figure 1.1: Project flow chart

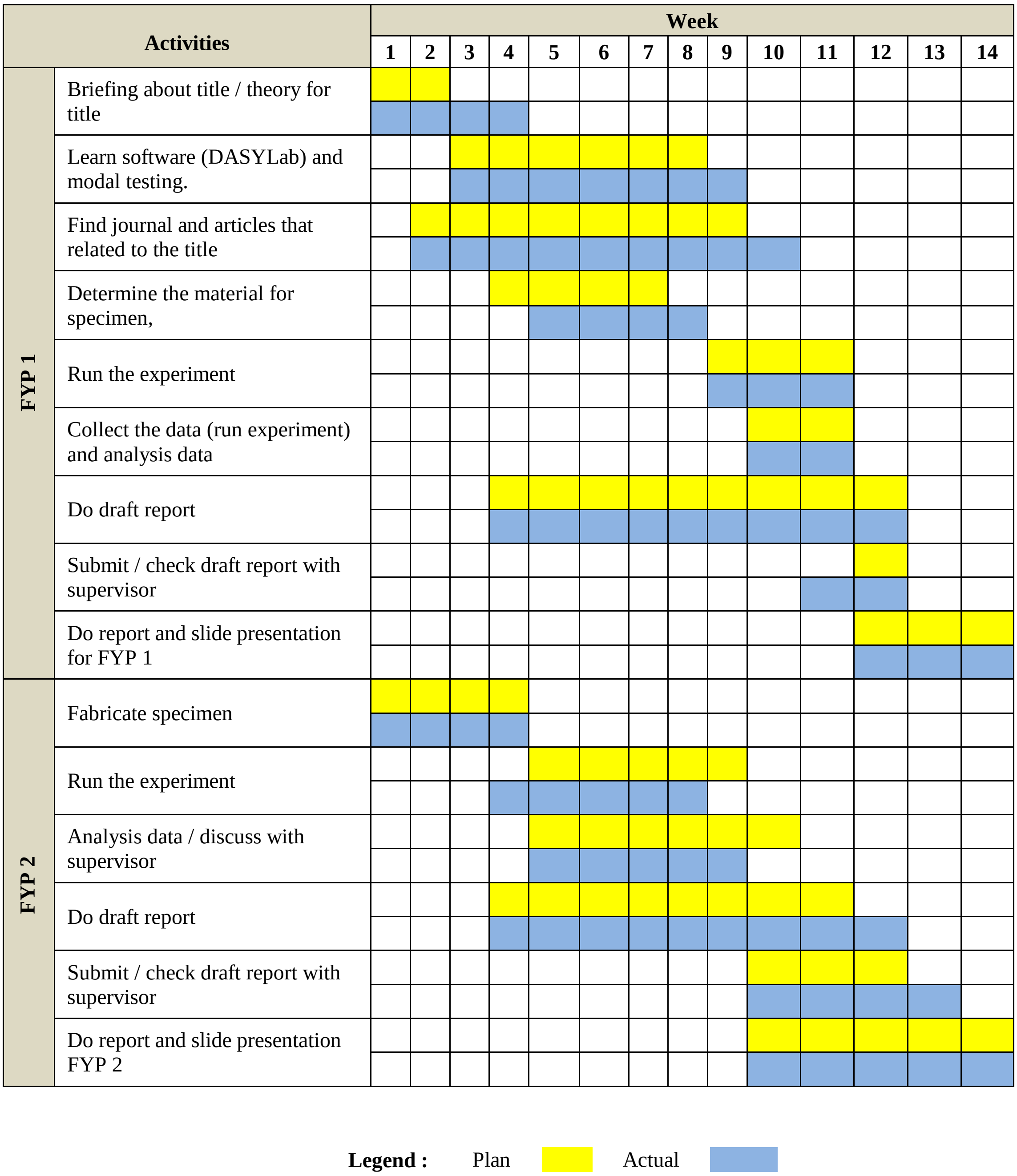


Figure 1.2: Gantt chart

1.6 THESIS STRUCTURE

Chapter 1 introduces the background of the study. It more detail by discussing about fatigue phenomenon, the problem statement is related to the topic of the research, then followed by the objectives, scope of the study, project flow chart and last is the structure of the thesis.

Chapter 2 presents the information on fatigue theory, stress cycles, and fatigue strength testing. It also discuss on damage process in low and high cycle fatigue. Discuss about signal section, which is time domain, and frequency domain. Use a module in DASYLAB software to covert time domain to frequency domain.

Chapter 3 explaining about method to conduct the experiment. Include the apparatus that involves for the experiment. Setting or set up the equipment and software. Flow chat are provides to show the overall outline for the experiment starting with software setting until data analysis. Discuss specimen preparation and handling the experiment.

Chapter 4 begins with the introduction. It explains about the groups of data, which is divided into two different types of material such as mild steel and low carbon steel. Proceed with frequency domain analysis. There are two main groups of graphs, amplitude versus cycle and frequency domain. For frequency domain, their graphs provided for each force that apply to specimens, which is represent 3D axis (x-axis, y-axis and z-axis). Then, fracture surface that shows the comparison about fatigue fracture beach marks between two materials with the same forces.

Chapter 5 presents the conclusion from data taken and some recommendations to improve the accuracy of the result for future works progress.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, discuss about general fatigue, stress cycles, and fatigue strength testing. It also discuss on damage process in low and high cycle fatigue. In signal section time domain, and frequency domain with analysis of FFT been discussed.

2.2 FATIGUE

The damage of the material in fatigue starts in the crystalline structure and become visible in a later stage by plastic deformation, formation of micro-crack on slip bands, coalescence of micro cracks and finally propagation of main crack. Figure 2.1 shows the sample of fatigue crack surface. Many factors that affect the subject such as different materials

Figure 2.1: Sample of fatigue crack surface.

Source: A.S Yasir (2012)

In a narrow sense, the term fatigue of materials and structural components means damage and damage due to cyclic, repeatedly applied stresses. This phenomenon occurs as a result of stress reversals in the time history. In a wide sense, it includes a large number of phenomena of delayed damage and fracture under loads and environmental conditions. (Wu et al., 1997)

It is expedient to distinguish between high-cycle and low-cycle fatigue. Plastic deformations are small and localized in the vicinity of the crack tip while the main part of the body is deformed elastically, then one has high-cycle fatigue. If the cyclic loading is accompanied by plastic deformation in the bulk of the body, then one has a low-cycle fatigue. Usually we say low-cycle fatigue if the cycle number up to the initiation of a visible crack or until the final fracture is below 104 or 5.104 cycles.

2.3 DIFFERENT PHASES OF THE FATIGUE LIFE

After more microscopic information on the growth of small crack became available, it turned out that nucleation of micro crack generally occurs very early in fatigue life in spite of early crack nucleation, microcracks remain invisible for a considerable part of the total fatigue life (Krupp, 2007). Once crack become visible, the remaining fatigue life of a laboratory specimen is usually a small percentage of the life.

After a microcrack has been nucleated, crack growth can still be a slow and erratic process, due to the effect of the micro structure, example grain boundaries. However, after some microcrack growth has occurred away from the nucleation site, a more regular growth has occurred away from the nucleation site, a more regular growth is observed (Schijve, 2004).

Figure 2.2 shows the different phases of the fatigue life and relevant factor. This is the beginning of the real crack growth period. It consists two periods such as crack initiation and crack growth period.

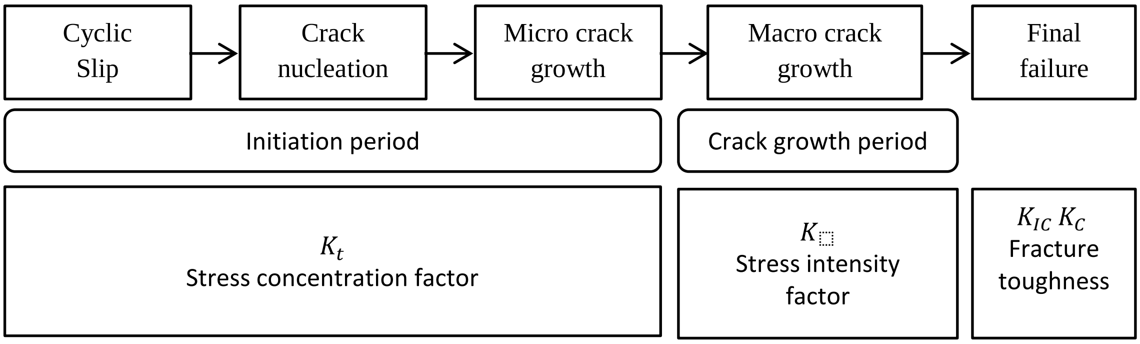


Figure 2.2: Different phases of the fatigue life and relevant factors.

Sources: Schjve (2004)

2.4 STRESS CYCLE

About three factors that influence fatigue phenomena such as large enough variation in the applied stress, maximum tensile stress of sufficiently high value and large number of cycles of applied stress. Steady stress, σ_m and variable stress, σ_a are two major components in a fluctuating stress. Stress range, σ_r is refer to the difference maximum stress and minimum stress in cycles as in equation 2.1.

$$\sigma_r = \sigma_{max} - \sigma_{min} \tag{2.1}$$

The alternating stress is one-half stress range, shown in equation 2.2;

$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{\max} - \sigma_{min}}{2} \tag{2.2}$$

Average mean stress as explain in equation 2.3;

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \tag{2.3}$$

For presenting the fatigue data, two ratios frequently are used in equation 2.4 and equation 2.5 respectively.

Stress Ratio:

$$R = \frac{\sigma_{min}}{\sigma_{max}} \tag{2.4}$$

Amplitude Ratio:

$$A = \frac{\sigma_a}{\sigma_m} = \frac{1 - R}{1 + R} \tag{2.5}$$

For basic terminology of fatigue phenomenon, by referring the figure 2.3 below, it shows the fully reversed loading cycles whereby the value maximum stress and minimum stress are equal. Usually these kind of fluctuating stress is used in fatigue testing, which a sinusoidal cycle is superimposed as shown in figure 2.3. However, fully reversed loading are not totally from actual loading applications (Roylance, 2001).

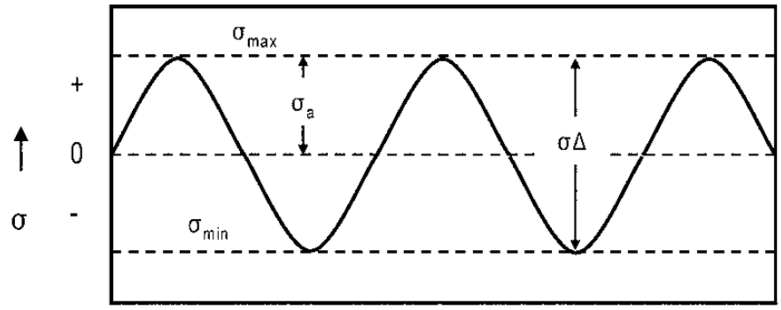


Figure 2.3: Fully Reversed Loading

Source: www.asminternational.org (2008)

In figure 2.4, explain about the situation whereby applied stress and cyclic stress are greater than zero. It not necessarily to have the values of maximum stress with minimum stress is equal.

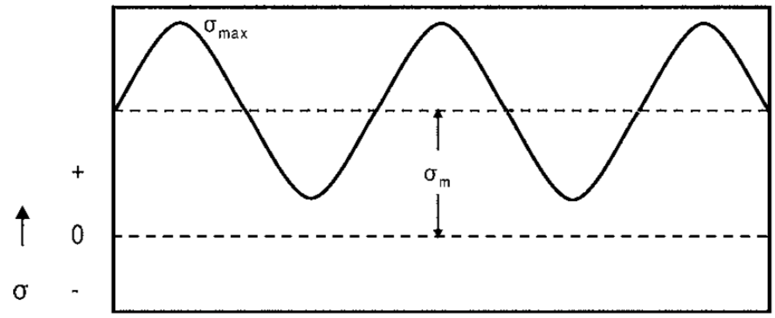


Figure 2.4: Tension-tension with applied Stress

Source: www.asminternational.org (2008)

Irregular cycles are the last type of loading cycles as figure 2.5, which are subjected to random loads during the service. Most of engineering structures are exposed to random loading in service, which means the fatigue growth life will affect by load sequence (Huang et al., 2005). There are many calculating models of crack propagation life under spectrum loading, such as Wheeler model, Willenborg model. These entire calculating models are based on plastic zone correction theory.

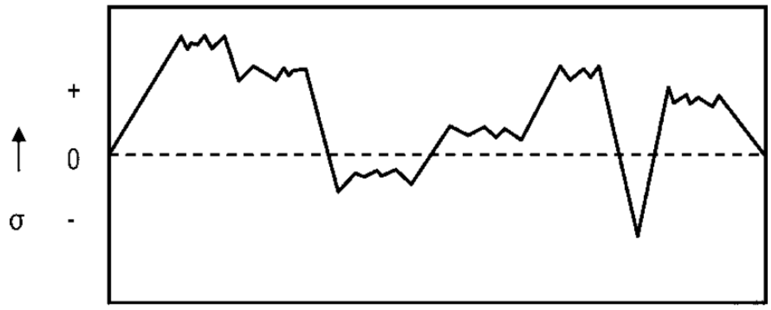


Figure 2.5: Random of Spectrum Loading

Source: www.asminternational.org (2008)

2.5 FATIGUE STRENGTH TESTING

A failure that results from such cyclic loads is called a fatigue failure. Since many structural components are subjected to cyclic loads it is necessary for the design engineer to have some quantitative measure of the material's ability to withstand such repeated loads. Quantitative data for the fatigue properties of a given material are obtained by subjecting a number of standard specimens to cyclic loads until fracture occurs**.** (Wu et al., 1997). The objective of the fatigue strength or fatigue limit test is to estimate a statistical distribution of the fatigue strength at a specific high-cycle fatigue life. Among many fatigue strength test methods, the staircase method (often referred as the up-and down method) is the most popular one that has been adopted by many standards to assess statistical of a fatigue limit. In this test, the mean fatigue limit has to first estimated, and a fatigue life test is then conducted at a stress level a little higher than the estimated mean. If the specimen fails prior to the life of interest, the next specimen has to be tested at a lower stress level. Therefore, each test is dependent on the previous test results, and the test continues with a stress level increased or decreased. Figure 2.6 explains theoretically about the strength of fatigue that related to the cycle. From this graph, can predict the number of cycles with load applied. For more precise, the test need to run about two or three specimen to get the average of the data.

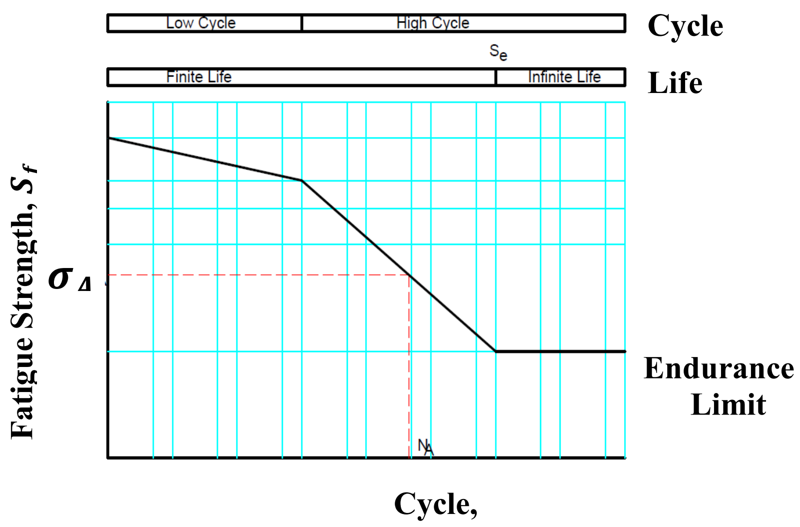


Figure 2.6: Fatigue strength versus cycle

Source: Schijve (2004)

2.6 FATIGUE FAILURE STAGES

Fatigue is a gradual process of damage accumulation that proceeds on the various levels beginning of the scale of the crystal lattice, dislocations and other objects of solid state physics up to the scales of the structural components. According to the Stress-life, the strain –life and linear elastic fracture mechanics are the three major approaches that usually used to analyze the fatigue life. In addition, strain-life mostly suitable with low cycle of fatigue whereby its approach to analyze the data that collected from automotive components (Abdullah et al., 2010). But, strain based approach is more appropriate than stress-based approach (Wu et al., 1997)

Three or four stages of fatigue damage are usually distinguishable. In the first stage, the damage accumulation occurs on the level of grains and intergranular layers. The damage is dispersed over the volume of a specimen or structural component, or at least, over the most stressed parts. At the end of this stage, nuclei of microscopic cracks originate, example, such aggregates of micro cracks that are strong stress concentrators and under the following loading, have a tendency to grow. Surface nuclei usually can be observed visually (at least with proper magnification). Figure 2.7 shows the fatigue crack initiation. Presistent slip bands (PSB) are areas that rise above (extrusion) or fall below (instruction) the surface of the component due to the movement of material along slip planes. This leaves tiny steps on the surface that serve as stress risers where tiny cracks can initiate. These tiny crack called microcracks that nucleate along plane of high shear stress which is often 45º to the loading direction.

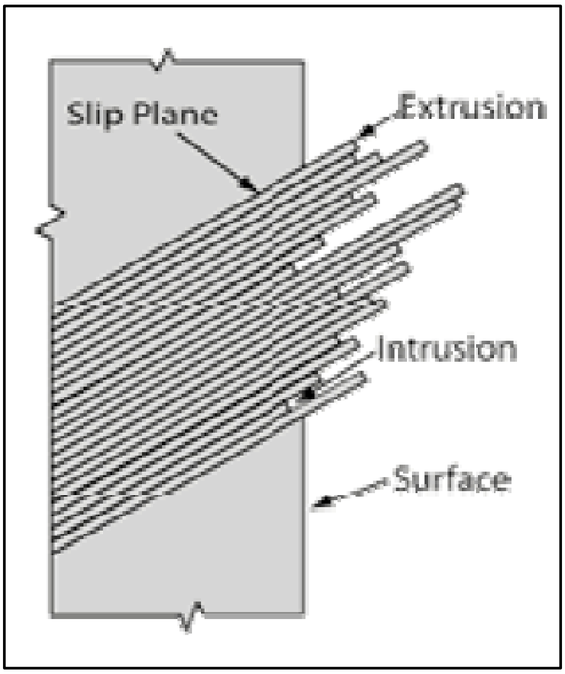


Figure 2.7: Fatigue crack initiation

Source: Krupp (2007)

The most common reasons for crack initiation in components are included notches, cones, or other geometric inconsistencies in the component. Material inclusions, impurities, defect or material loss due to wear or corrosion and mechanical or thermal fatigue. Once a crack has been initiated, repeated loadings can cause the crack to lengthen. Depending on the stress level and the number of load cycles applied, crack growth can be stable, with a predictable rate; unstable, with imminent failure; or occasionally a decrease or cessation of growth altogether.

The second stage is the growth of cracks that depth is small compared with the size of the cross section. At the same time, the sizes of these cracks whose depth is small compared with the size of the cross section. At the same time, the sizes of these cracks are equal to few characteristic scales of microstructure to several grain sizes. Such cracks are called small cracks. Most of them stop growing upon meeting some obstacles, but one or several cracks transform into microscopic, “long” fatigue cracks that propagate in a direct way as strong stress concentrators. This process forms the third stage of fatigue damage. The fourth stage is a rapid final fracture due to the sharp stress concentration at the crack front and/or the expenditure of the material's resistance to fracture. Figure 2.8 explain about the fatigue crack propagation behavior of many materials were divided into three regions. Region I is the fatigue threshold region , region II encompasses data where the rate of crack growth changes roughly lineraly with a changes in stress intensity fluctuation. In region III, small increases in crack growth rate since the material is nearing the point of unstable fracture.

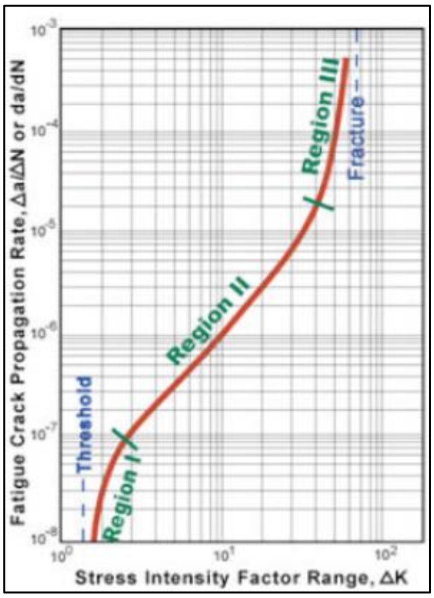


Figure 2.8: Fatigue crack propagation rate

Source: Krupp (2007)

2.7 S-N CURVE

Usually the S-N curve used to illustrate the fatigue behavior. This is because during testing time and energy are consumed. The monitoring S-N curve at high cycle fatigue method was being exposed since 1998 (Liu et al., 2010). Figure 2.9 Life Cycle of 1045 Steel and 2014-T6 Al, and Figure 2.10, S-N Curve Approximation shows the life cycle of 1045 steel and 2014-T6 and S-N curve approximation. The local stress concentration domains as well as near the damaged or weakest grains. The initial slip planes and micro cracks in grains are oriented mostly along the planes with maximal shear stresses. Small cracks are inclined, at least approximately, in small directions. There is an example of S-N curve and approximation of Endurance limit.

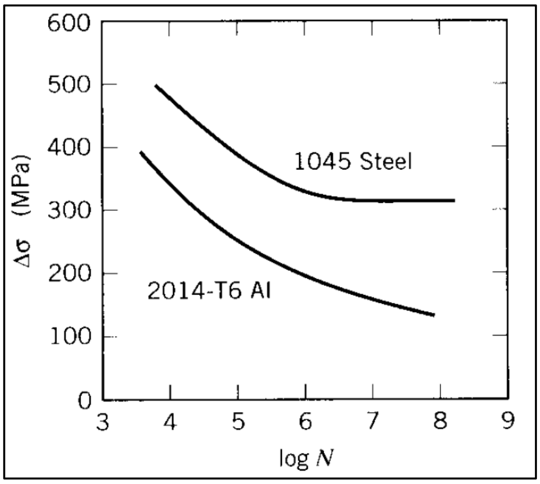


Figure 2.9: Life Cycle of 1045 Steel and 2014-T6 Al

Source: A David Roylance (2001)

Endurance Limit

S-N curve approximation

Endurance limit

Steel	$S_n' = 0.5 \times S_u$		@ N=10^6
Titanium	$S_n' = 0.45...0.6 \times S_u$		
Cast Iron Aluminum	$S_n' = 0.4 \times S_u$		@ N=10^8
Magnesium	$S_n' = 0.35 \times S_u$		
Nickel alloys	$S_n' = 0.35...0.5 \times S_u$		
Cooper alloys	$S_n' = 0.25...0.5 \times S_u$		

Figure 2.10: S-N Curve Approximation

Source: A David Roylance (2001)

2.8 FATIGUE CYCLE

Fatigue cycles were divided into two main topics, low cycle fatigue and high cycle fatigue. Both are different condition such as number of cycle and regions in the stress strain graph. For low cycle fatigue closely relates with elastic modulus, refer Figure 2.11, stress versus strain curve. The life of material decreases when plastic strain occurs. This stage involves a low number of cycles whereby its range is below 100,000 cycles (Darpe, 2007). Commonly this stage is present as plastic strain, $\Delta\varepsilon_p$ in log scale versus number of cycles.

According to Coffin-Manson relation theory as in equation 2.6

$$\frac{\Delta\varepsilon_p}{2} = \varepsilon_f' \, (2N_f)^c \tag{2.6}$$

Whereby $\Delta\varepsilon_p/_2$ refers to the plastic strain amplitude, ε_f' for fatigue ductility coefficient and c is the fatigue ductility exponent (-0.5 until -0.7 for many metals)

High cycle fatigue is a major concern in designing and durability of engineering components and structure. This stage involves a large number of cycles whereby its range are to 10^8 cycles (Marines et al., 2003). However, the range of nonferrous metals is 5 x 10^8 cycles. Other researchers mention that, very high cycle fatigues are exceeded 10^7 loading cycle (Liu et al., 2010). For scaling, the number of cycles in plotting stress, S versus number of cycles, N usually uses a log scale. Many companies are designing the product or components that exceeding 10^8 cycles, mostly for Aircraft Company, automobile especially engine parts, and railways with the cycles up to 10^9 cycles. Figure 2.11, shown stress versus strain respectively, by comparing to the low cycle fatigue, high cycle fatigue is more about plastic region.

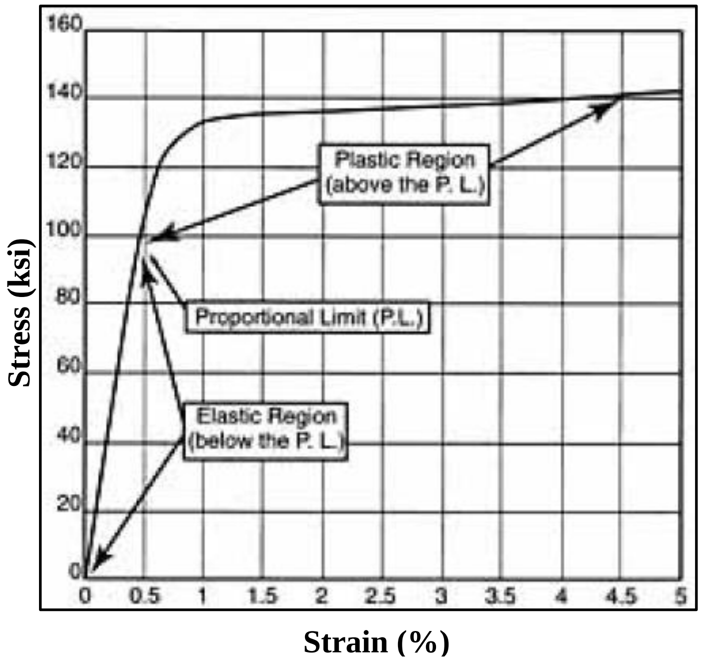


Figure 2.11: Stress versus strain curve

Source: DeLuca (2008)

2.9 SIGNAL ANALYSIS

Time domain, frequency domain and modal domain are commonly used for looking at a problem that is interchangeable. There are three ways to detect a problem are interchangeable. In this experiment, only use time and frequency domain. Time domain is a record what are happens to a parameter of the system versus time. Meanwhile from time domain are usually expressed as a stress or strain time history (Halfpenny, 1999). Simple statistical parameters evaluated over the measure time domain signal, it can give some interesting information about potential defects. As an example the peak and root mean square value are referred to the overall vibration level. These statistical parameters are simple to implement, but rather insensitive tools for defect detection. The Figures 2.12 and Figure 2.13, shows that simple spring-mass system was attach a pen to the mass whereby constant papers were past slowly to record the movement of the mass and the time domain with signal not visible respectively. As a result, the graphs show a time-domain view of displacement.

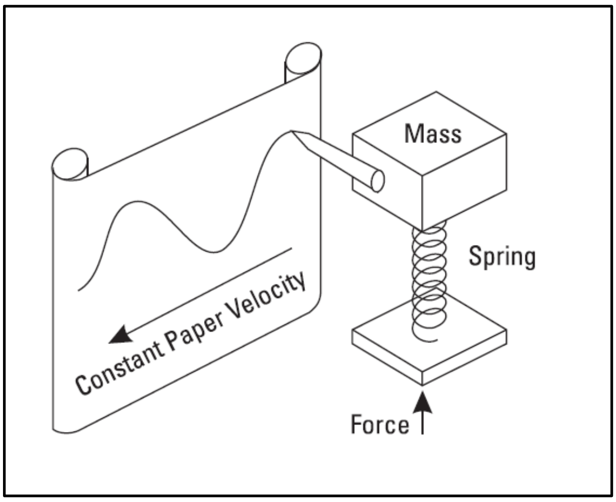


Figure 2.12: Simple spring mass system

Sources: Fundamental of Signal Analysis (2000)

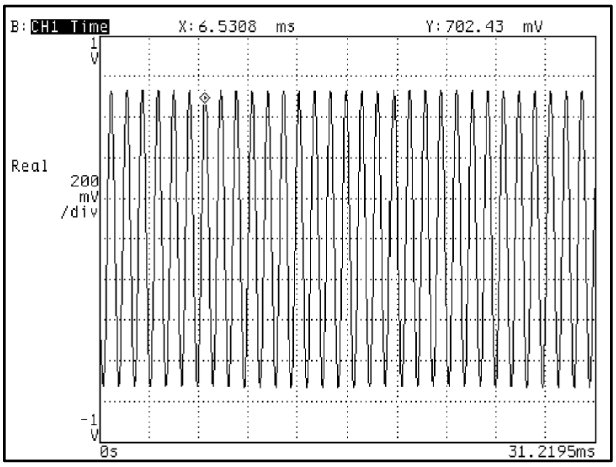


Figure 2.13: The Time domain with signal not visible

Sources: Fundamental of Signal Analysis (2000)

The frequency domain can be derived by using Fast Fourier analysis of the time waveform. For the graph, it shows the vibration response versus frequency, which is introducing the condition of a machine. When the machines begin to fail, the level of vibration and its frequency domain are totally changed from the original condition. The location of failure can be identified by comparing the frequency domain for the machine that in broken condition with frequency domain for machine in good condition. For rotational machines, each cycle are in machine generate detectable frequency (Singiresu, 2011) as illustrated in Figure 2.14 shows the form of wave that is composed of two signal sine waves. Thus, monitoring the increase in the level of vibration in high-frequency range of the spectrum is an effective method of predicting the condition of rolling element.

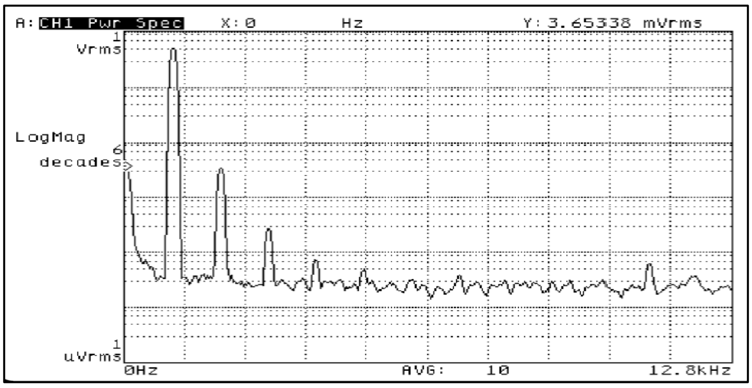


Figure 2.14: Frequency domain

Sources: Fundamental of Signal Analysis (2000)

2.10 FREQUENCY RESPONSE MEASUREMENT

Figure 2.15 illustrates about basic measurement scheme for vibration respectively. This figure, explain the overall system flow, whereby the transducers act as converting tools that convert the motion vibrating body to the electrical signal. Vibration machine is about focus on the test rig of the experiment as illustrate figure 3.4 respectively, experiment setup. In this research, transducers are accelerometer, which a device that transform mechanical quantities into electrical quantities. The signals were collected by using signal conversion instrument which called data acquisition (DAQ) and need to display by using data acquisition laboratory (DASYLAB) software by creating block module. The output signals are shown on a display unit recorder. Raw data are collected were in the form of time domain, which is amplitude versus time. By using DASYLAB software, all data can transfer from time domain to frequency domain for data analysis in order to study the vibration of the experiment.

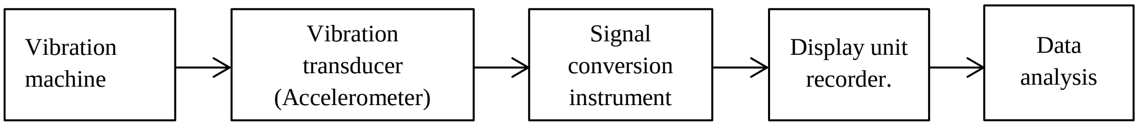


Figure 2.15: Basic Vibration Scheme.

Source: Singiresu (2011)

2.11 FOURIER TRANSFORM AND SHORT TIME FOURIER TRANSFORMS

Fourier transform is one of the simplest methods for oscillatory waveform based on the sinusoid. It is also one of the fundamental methods used for spectral analysis of data. But this method is only applicable and valid for the periodic and stationary data that represent linear processes. Fourier transform can be theoretically calculated by the equation 2.7. It is expressed in a frequency - time domain. (Mrsnik et al., 2012)

$$x(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}\, dt \tag{2.7}$$

Where x (f) = Fourier transforms, j=$\sqrt{-1}$ and x (t) = Continuous function in time.

The limitation of Fourier Transform is that it only gives a global energy-frequency representation of a data sequence. This method is also not significant if the data is non-stationary. It cannot operate when there is a change in frequency of the signal. Thus, at that particular time, the location of the leaks cannot be located. Furthermore, this method is unable to show the frequencies vary with time in the spectrum. But the most disadvantages are that the Fourier Transform has only frequency resolution instead of time resolution. So, in order to overcome the limitations of the Fourier Transform, the Short Time Fourier Transform has been proposed and developed. It is the method of dividing the non-stationary signal into small segments or portion. (Schwarz et al., 1999)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains about method how to conduct the experiment and collect the data. Figure 3.1 shows the flow chart, which are overall outline for the methodology parts. Start with experiment setup, which is shows the experiment test rig with several vibration measurement equipment involves. Followed by experiment procedure, focus on handling fatigue testing machine and record the data. Then proceed to specimen preparation. These parts, brief about the specimen specification such as diameter, and length. Besides, the chemical composition and general physical properties of the material selected were included. Also, discuss about detail machining process, steps to handle machinery and machining parameters that need to consider fabricating the specimen.

Proceed to vibration measurement which is vibration equipment setting for collecting data. Shows the position of the sensor, data acquisition, and step to create a block module to experiment with specific parameters involve. Then, fatigue testing experiment for collecting the data. The surface of fractured specimens needs to capture using optical measurement machine for fatigue beach marks for comparison between loads applied.

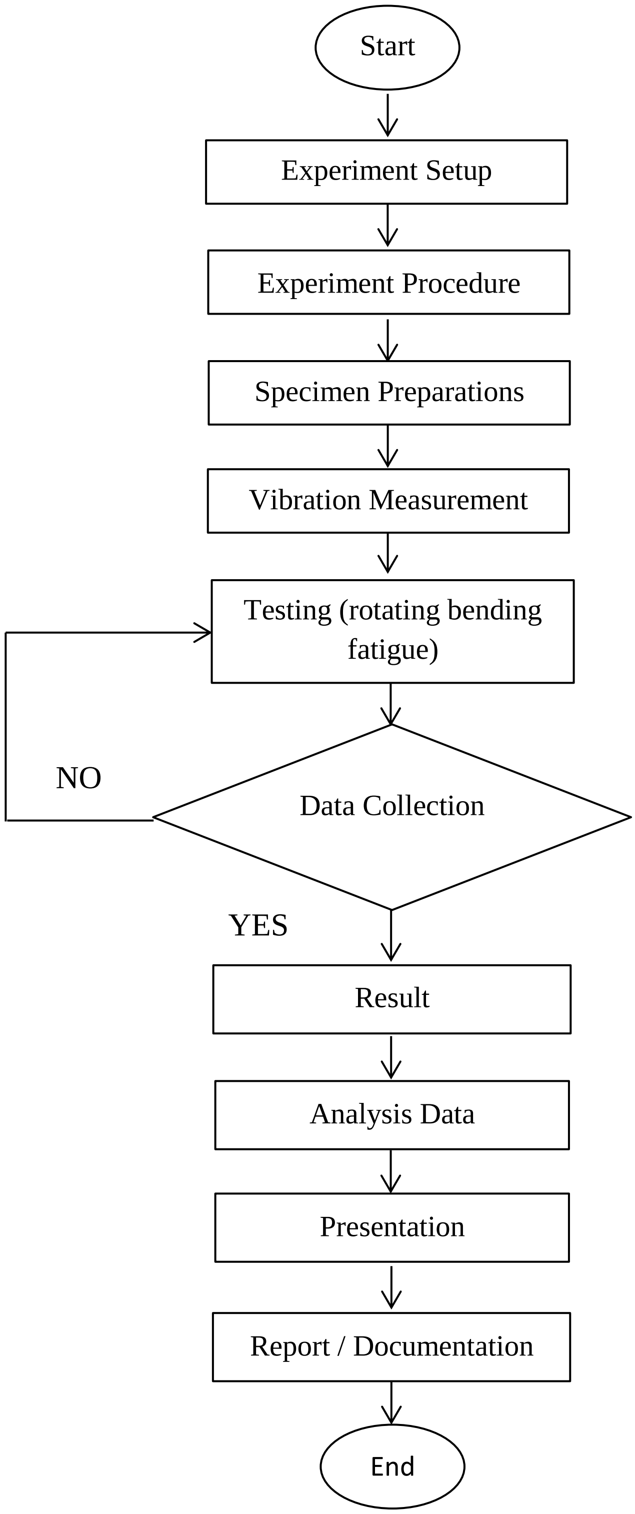


Figure 3.1: Flow chart of the experiment

3.2 EXPERIMENTAL SETUP

Figure 3.3 overview experiment setup. The main equipment are computer, accelerometer and DAQ. The rest is fatigue test machine parts, which are, can refer Tables 3.1 for a list of components. Figure 3.3 shows the positions of specimens and the location of the accelerometer. The sensors were placed near to the bearing housing (Mohamed et al., 2011). At the left side part of specimen are clamped and the other side is attached to bearing whereby the bearing already holds with load gauge. The function of this part is to apply and control forces on the specimen. As a safety precaution, protective hood will avoid breaking specimen. A force that can apply between 0 N until 300 N.

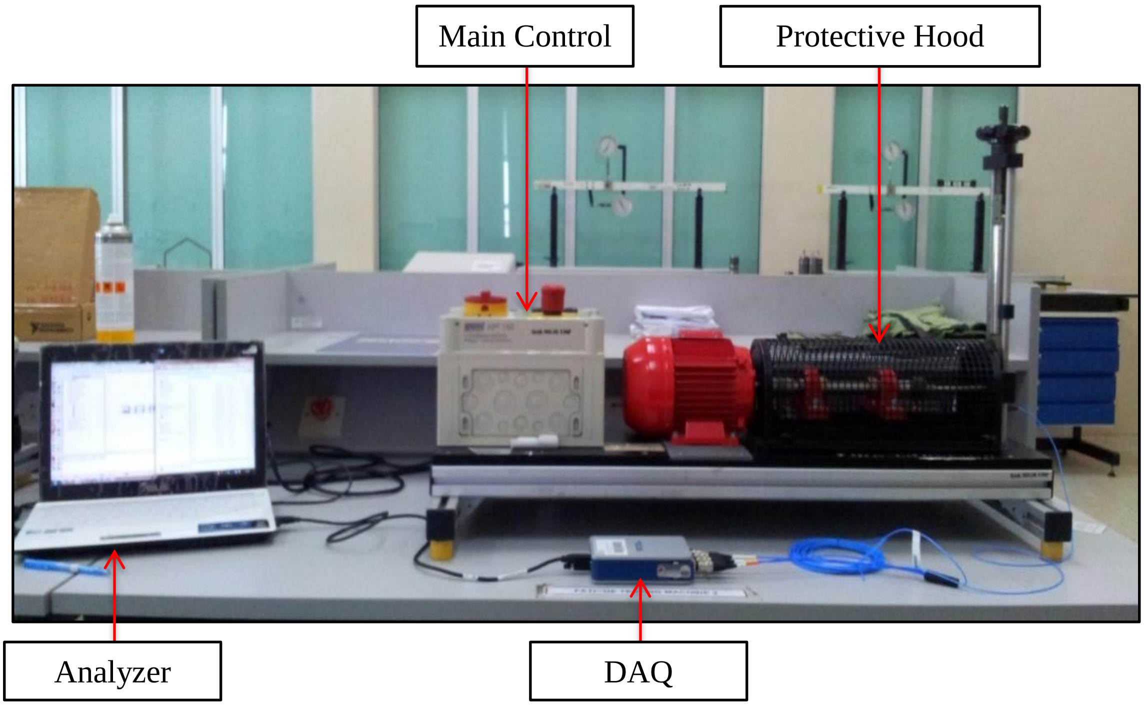


Figure 3.2: Experiment Setup

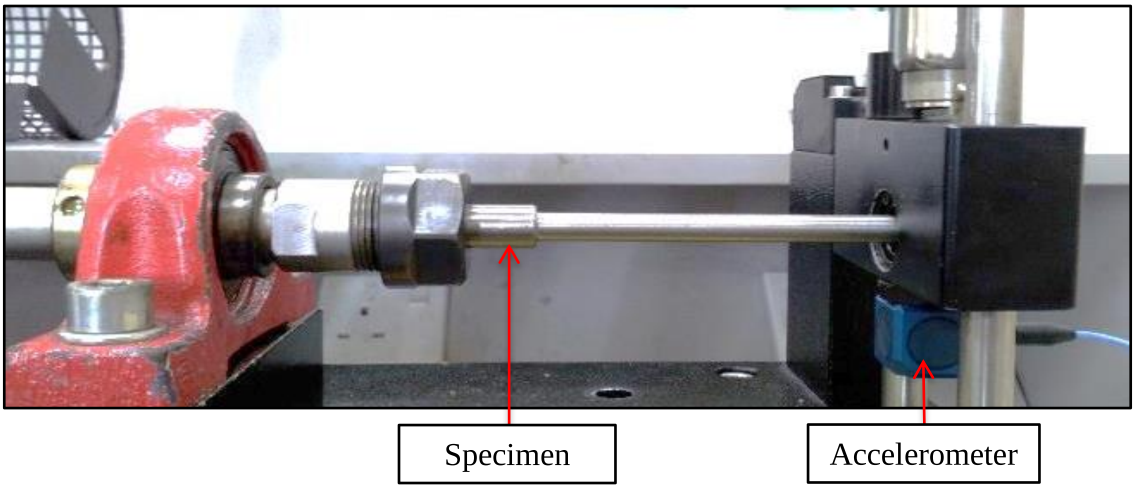


Figure 3.3: The position of specimen in fatigue testing machine

Figure 3.4 below the applied load and position accelerometer in the experiment. The loads (load gauge) that apply are perpendicular to the specimen (at right side of the specimen). Wax is used on the accelerometer surface to make sure the accelerometer does not move during machine are running. The ball bearing were attached in bearing housing to hold the specimen when load is applied. The positions of accelerometer need to put nearest to the bearing housing to get better signal results.

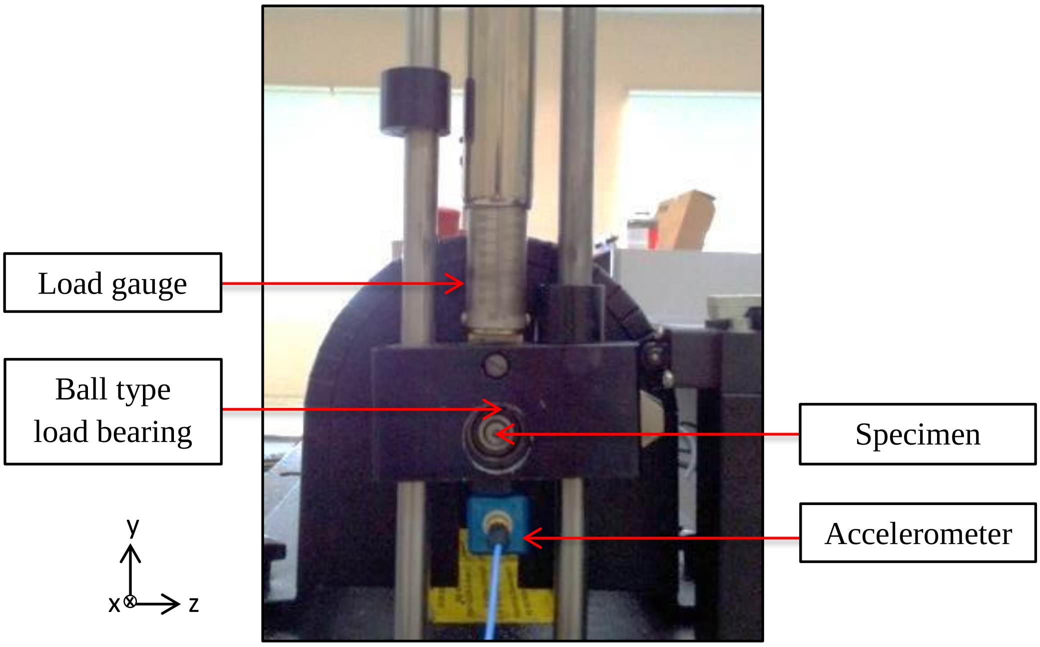


Figure 3.4: Applied Load and Position of Accelerometer

3.2.1 Experiment Procedure

The aims of this experiment are to measure the vibration response for rotating specimens during cyclic loading. Thus, for vibration measurement setups already shown in figure 3.2, until figure 3.4, where all the equipment is involved. Figure 3.5 shows the flow of experimental procedures. The constant and variable parameters need to determine before run the experiment. The experiment parameter for this experiment shown in Table 3.1 below:

Table 3.1: Experiment parameters

Parameters	**Value**
Frequency (Hz)	50
Temperature (^{o} C)	20 – 25 (room temperature)
Load (N)	250 – 190
Stress ratio, R	-1

After setting the parameters, the experiment will be carried on by following the procedures:

1. Put accelerometer as illustrate figure 3.3. Then, setting MAX and DasyLab software.
2. Put the specimen in the shaft at the fatigue testing machine and tight it using spinners.
3. Switch on the machine, during rotation applied forces. Protective hood is used for safety precaution.
4. Click button RUN in DASYLAB software. The data are for the experiments are recorded.
5. Repeat the step (2) until (4) by changing specimen.
6. For plotting data, software Matlab are used to plot the graph.

Before running fatigue testing machine, the following thing is properly checked:

1. EMERGENCY OFF switch was released.
2. Switch was on by using master switch for the machine.
3. Reset the counter by using the RST button and the display of counter show zero
4. The motor is started by using a motor control switch.
5. The spindle was running smoothly and true.
6. The counters are counted correctly.

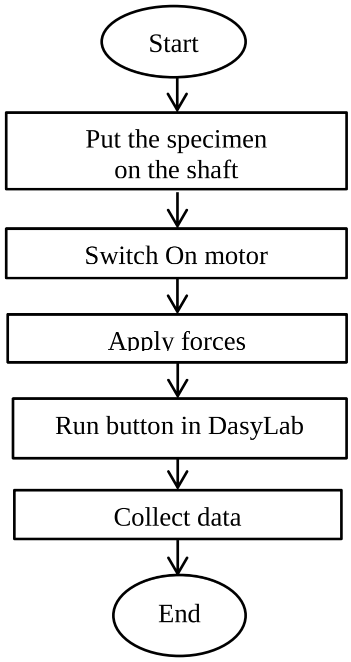


Figure 3.5: Flow of experiment procedure

3.2.2 Specimen Preparation

Before doing the machining process for the raw material, the type of material needed to select. Raw material needs to cut into four pieces by using bandsaw machine in 150- mm each. Next, the specimens are needed for machining using lathe machine either by conventional or computer numerical control (CNC) machine. The dimensions of the specimen are referring to specification ASTM E467 as shown in Figure 3.6.

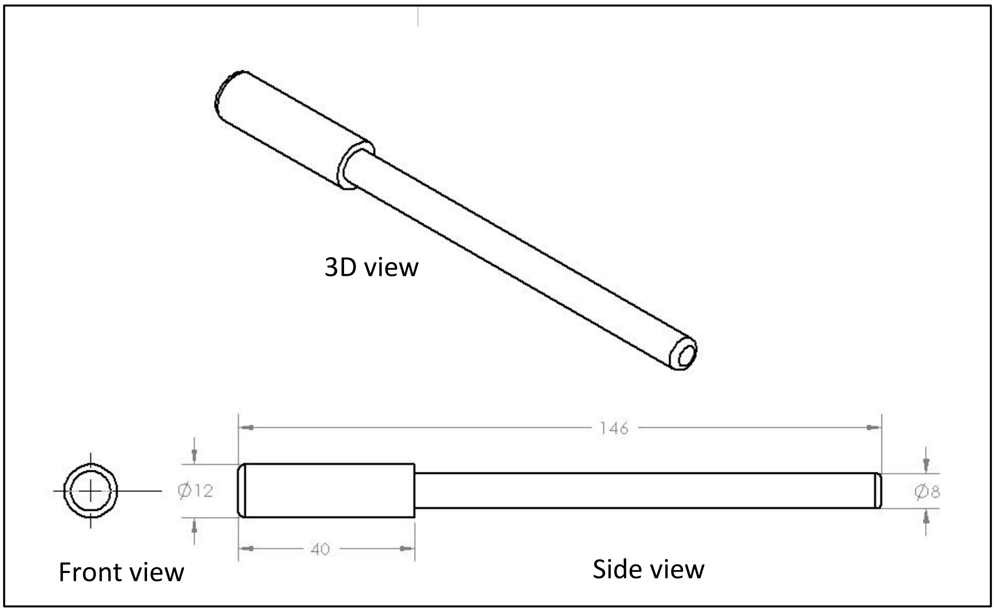


Figure 3.6: Specimen for fatigue testing (unit in mm)

The materials for this project are Mild steel and Low carbon steel. The material properties of the materials are shown in Table 3.2. The raw materials are provided in the form of round rod with 20 mm of diameter. Generally, the raw materials available in round shape, square bar, and rectangle bar.

Table 3.2: Composition of the material

Material	Minimum Properties		Chemistry	
Mild Steel (1018)	Ultimate Tensile Strength, Mpa	440	Iron (Fe)	98.81-99.26%
	Yield Strength, Mpa	370	Carbon (c)	0.18 – 0.23%
	Elongation	15.0%	Manganese (Mn)	0.6 – 0.9%
	Rockwell Hardness	B71	Phosphorus (P)	0.04% max
			Sulfur (S)	0.05% max
Low Carbon Steel (JS4051)	Ultimate Tensile Strength, Mpa	600	Iron (Fe)	99.08-99.53%
	Yield Strength, Mpa	496	Carbon (C)	0.18-0.23%
	Elongation	10%	Manganese (Mn)	0.3-0.6%
	Rockwell Hardness	B89	Phosphorus (P)	0.04% max
			Sulfur (S)	0.05% max

The machine process are required to fabricate this specimen are turning process. The specimen that needs to fabricate is eight quantities, which are four units from low carbon steel material, and four units are from the mild steel material. The parameters involve are spindle speed, the feed rate and the depth of cut. The spindle speeds need to calculate by using equation 3.1, where by involve cutting speed and diameter of workpiece. For feed rate calculation are needed to follow equation 3.2. Calculated machining parameters for turning operation as shown in Table 3.3.

$$RPM = \frac{cs \times 1000}{\pi \times d} \tag{3.1}$$

Where:

cs = cutting speed

d = workpiece diameter

The feed rate calculation:

The feed rate v_f (mm/min).

$$v_f = f \times N \tag{3.2}$$

Where:

f = feed

N = spindle speed

Sample calculation for spindle speed:

Recommendation cutting speed = 60-135 m/min

Diameter of workpiece = 20 mm

From equation. 3.1

$$RPM = \frac{cs \times 1000}{\pi \times d}$$

$$= 955 \text{ rpm}$$

Sample calculation for feed rate:

Recommendation feed = 0.15-1.1 mm/rev

Spindle speed = 1600-990 rpm

From equation 3.2

$$v_f = f \times N$$

$$= 0.15 \times 1600 = 240 \text{ mm/min}$$

Table 3.3: Machining parameters

Machining parameters	Value
Spindle speed (rpm)	990
Feed (mm/rev)	0.22
Feed rate (mm/min)	217
Depth of cut (mm)	0.2

The step to use a Lathe Machine:

1. The power supply is about to switch the machine on
2. Set the cutting tool. To ensure the cutting tool is centralized, dead centers are used.
3. Attach the low carbon steel bar to the spindle and clamped to the chucks. The low carbon steel bar is hold tight.
4. Set up the spindle speed to the highest speed first which is 1600 rpm. Set 0,0 point for x and z axis of cutting tool.
5. Do the facing process first in x axis to make sure the cutting tools are truly centralize. If any nipple, repeat the step three. Then set the x axis to zero.
6. Set the z axis to zero when the cutting tool slightly touches the work piece in z direction
7. The work piece then being machined following shape in drawing dimension in figure 3.2.

8. Set up the value feed rate from table 3.2.
9. During the machining process, the depth of cut is being cut slowly with the value of 0.2mm
10. After that process, the work pieces are measured using vernier caliper.
11. Repeat the step by changing work pieces.

Figure 3.7 shows the raw materials, in the form of round shape with diameter 20 mm and length 120 mm. Figure 3.8 shows the machining process by using the conventional lathe machine. The function tail stock is to hold the specimen to avoid bending occur when a cutting tool was moving. Figure 3.9 illustrates specimen that finishes after the machining process respectively. The surface roughness for all low carbon steel and all mild steel specimens are same but different in type material.

Figure 3.7: Raw Material

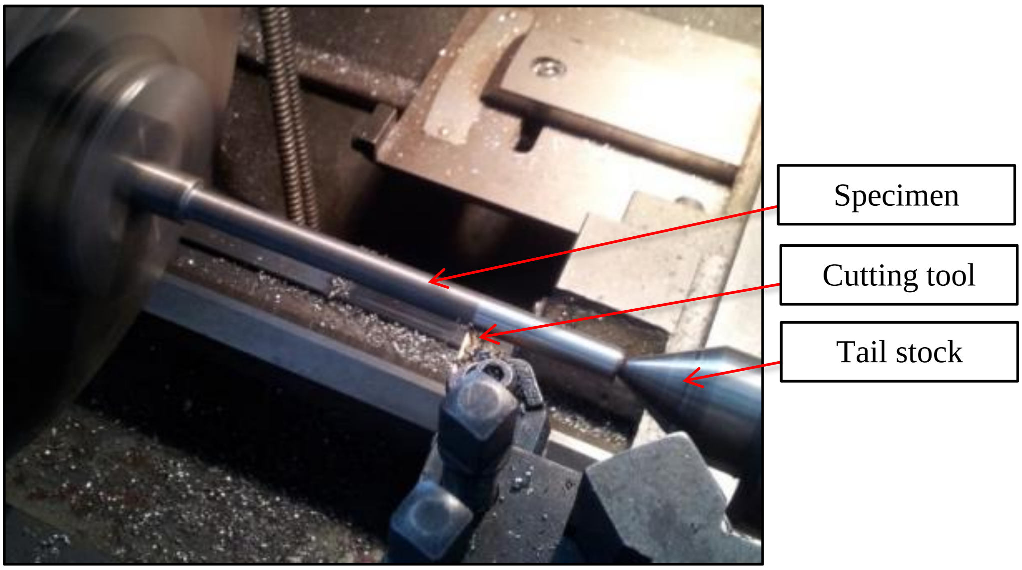


Figure 3.8: Machining Process

Figure 3.9: Finished Specimen

3.2.3 Vibration Measurement

For collecting the data, there are equipment and software that involve in this experiment to achieve the first objective of this project. The vibration measurement equipment is involved DAQ and accelerometer. Software used is measurement and automation explorer (MAX) and data acquisition system laboratory (DASYLAB) software.

MAX is software that provides access to National Instruments product. Generally, this software can configure National Instruments hardware and software. It also can backup or replicate configuration data and edit channels, tasks, interfaces, scales and virtual instruments. It can execute system diagnostics, view devices and instruments connected to the system.

This software is to standardize the value of sensitivity for all three channels and to check whether the equipment is connected or not. Connect computer and accelerometer with DAQ. Create a new file in a data neighborhood by selecting a NI - DAQmx task. The type of measurement for analog input is acceleration and it's same for all channels. The mode for acquisition is continuous sample. Figure 3.10 shows, detail setting MAX software, from the figure channels setting refers to the 3 dimension axis are used, x-axis for channel 1, y-axis for channel 2, and last channel for z-axis. The value of sensitivity for all channels can refer Table 3.4, these values depend on the brand of an accelerometer that already provided.

Table 3.4: Value of sensitivity for axis

Channels	Sensitivity (mVolt/g)
X-axis	98.3
Y-axis	99.4
Z-axis	97.6

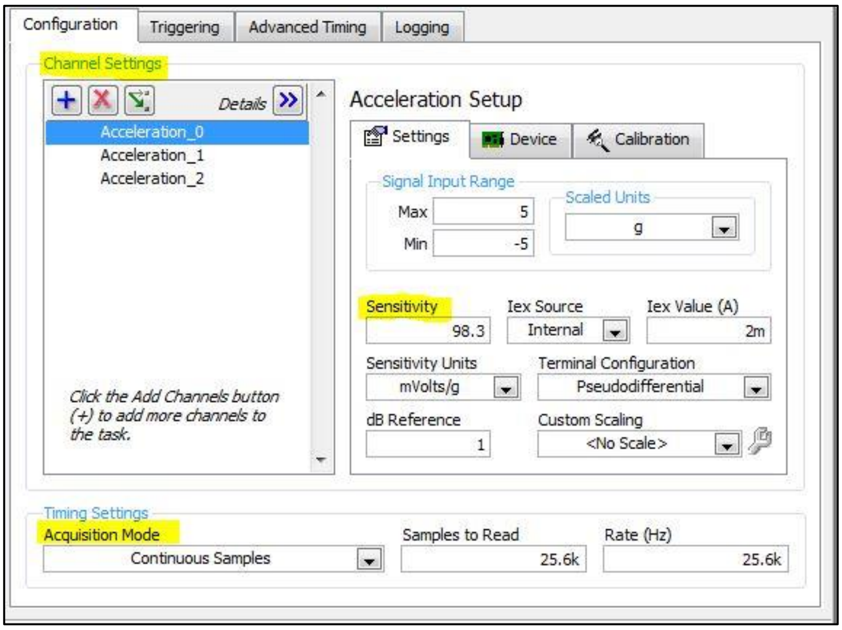


Figure 3.10: Setting in MAX software

Generally, the functions DASYLab software creates complex applications in minimal time without programming, which mean does not coding code to make the application. However, build worksheets using graphical functions and implements real-time operations, including PID control. Can provide standard real-time displays for example display graph. With software can refer library that provided for computational functions including FFT analysis. Has a generator functions to simulate inputs. This is easy for users to test their blog diagram system. This software can support data acquisition hardware from Montgomery County Campus and other vendors.

First, connect DAQ with the computer, and then select synchronization with MAX Configuration in hardware setup. For this block diagram the sampling value are 2,000 and 4096 for block size. As mention earlier in Chapter 1, the measurements are involving 3D axis, which means there are three channels involve. Regarding the number of channels, channel zero refers to x-axis, channel 1 for y-axis and last channel for z-axis. Use digital filter module, whereby the filter type are low pass with limit frequency are 50 Hz and filter order are five. All settings in digital filter must same value with three channels. To display the time domain data, add Y-T chart module and connect with digital filter. The graph will show an amplitude versus time. Set autoscaling in Y-T chart setting to get automatic full display data.

Use the data window module to multiply non-periodic signals with a window function. This module prepares data channels for Fast Fourier Transform. There are many types of window such as rectangle, flattop, Hanning, hamming, Poisson, turkey, and Blackman others type can refer in data window setting, can use any type of windowing but it depends on condition of experiments. For this experiment, recommend use hanning type. This is because, Hanning it is a cosine shaped weighting function that forces the beginning and its end of the sample interval to the zero. It is mostly as a bell shaped. The block size in data window must same as setting earlier.

Convert time domain to the frequency domain by using FFT module. Select Real FFT of a real signal and unclick the FFT without the power of two at operation option. For displaying frequency domain data, add Y-T chart module with the same setting at displaying time domain data. Then, the graph will display amplitude versus frequency.

For collecting the data of the experiment, add write data module and connect with Y-T chart at time domain and frequency domain. The data are saved in ASCII file format, tab application in ASC II sets to separate data in column. Switch module and digital meter are optional to use. Complete block diagram can refer Figure 3.11.

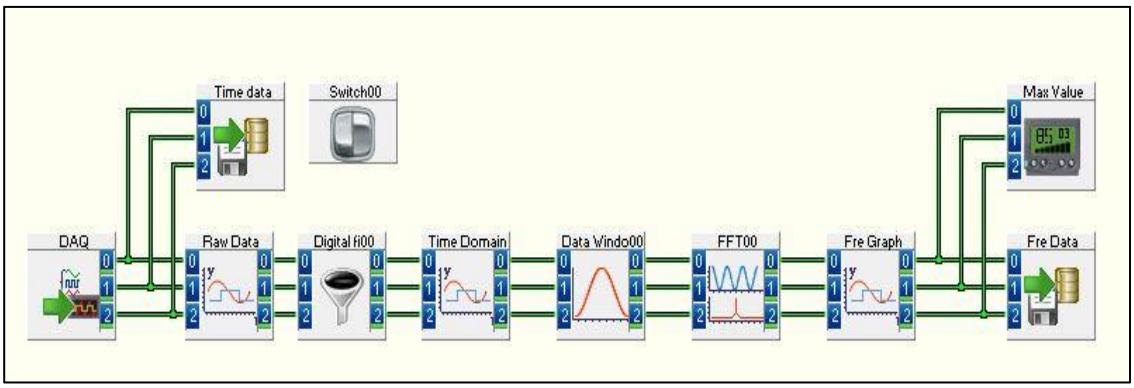


Figure 3.11: Block diagram

Figure 3.12, the layout of block diagram, these layouts are shown the frequency and time domain data. For time domain graph, the data after use digital filter. Maximum value for display the maximum value of frequency, which means can monitor the changing of amplitude in frequency domain graph. Start and stop button for running and stop the program. This layout is optional to use, but easy for users to monitor the value change during the experiment.

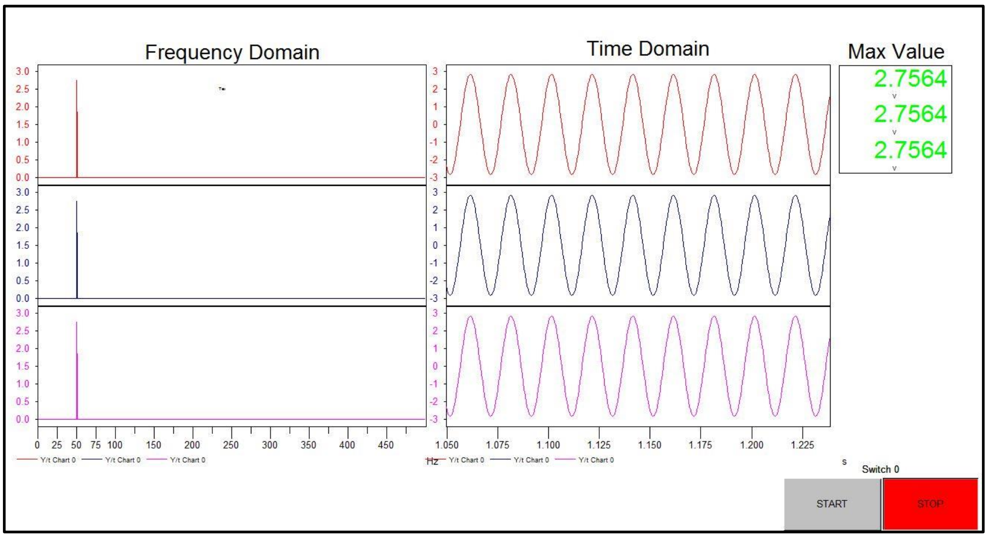


Figure 3.12: Layout for block diagram

3.2.4 Fracture surface optical measurement

Figure 3.13 shows the optical measurement. The applications for these machines are measured the electronic parts such as printed circuit boards. Can measure, two dimension profiles on metal and plastic parts. Also, can measurement on small features on micromechanical parts. This machine consist of three adjustments, x and z-adjust for horizontal movement (base movement) and y-adjustment for vertical movement. (Optical camera). For this experiment, only take pictures on the fracture surface to see fatigue beach marks on specimens. Figure 3.14, shows Quadra-Chek 300 is to advance digital readout with an enhanced, colour touch-screen interface. It includes patented Measure Magic technology and is ideal for the measurement of 2-D and 3-D features. Crosshair, optical edge detection and video edge detection systems for 2-D measurements can be automated with CNC motion control options. The QC-300 is also available for manual 3D systems. QC-300 series readouts can be used with inspection tools such as measuring microscopes, optical comparators, optical edge detection, video systems, video edge detection and manual coordinate measuring machines. For this experiment, take pictures on the surface of the specimen for surface comparison between forces applied.

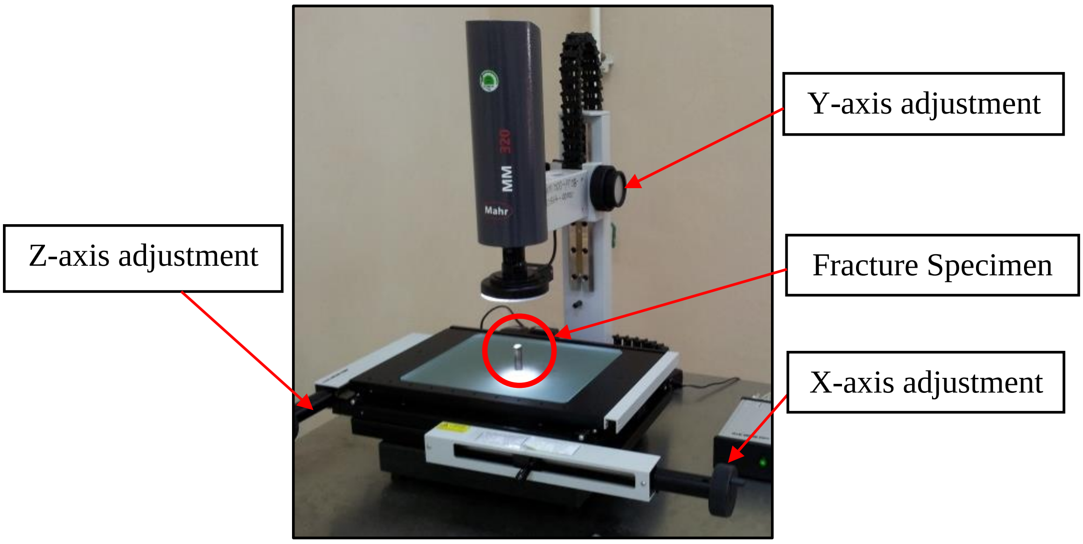


Figure 3.13: Microscope Marvision MM 320 - Mahr

Figure 3.14 : Quadra-Chek 300

3.2.5 CONCLUSION

This chapter discussed the work progress for experiment for the project. Which is, shows about the arrangement of equipment setup. Besides, detail procedures for software setting with several parameters that need to consider also were discussed after do the experiment setup. For software setting, brief about detail related module to create the block diagram in DASYLAB to record the data from the experiment. Then, for fabricating the specimen, sample calculation were shown clearly with related formula, and also steps to handle the machine, make the specimens.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

For collecting data, two groups of data have been collected which is a different type of material, mild steel and low carbon steel. Each material has three different forces that apply to specimens, 150 N, 200 N and 250 N. Every single force measured in 3D axis (x-axis, y-axis and z-axis). The speed for rotating fatigue test machine is 2800 rpm that already fixed. Figure 4.2 until Figure 4.9, shows the data from the experiment. The rest of figures are discussed about the fracture surface of the specimen. The block size of each data is 4096, which is sampling rate size is 2000.

4.2 FREQUENCY DOMAIN ANALYSIS

Data from the experiment which is, time domain were converted into frequency domain signal. The result obtained is a power spectrum in the frequency domain for the signals that has been analyzed. Use Matlab software to plot the graph. Figure 4.1 shows, the boundary condition of specimen in fatigue testing machine. From the figure, the position of the y-axis is parallel to the forces that apply at the end of right side and perpendicular with specimen, where by the left side of specimen are fixed.

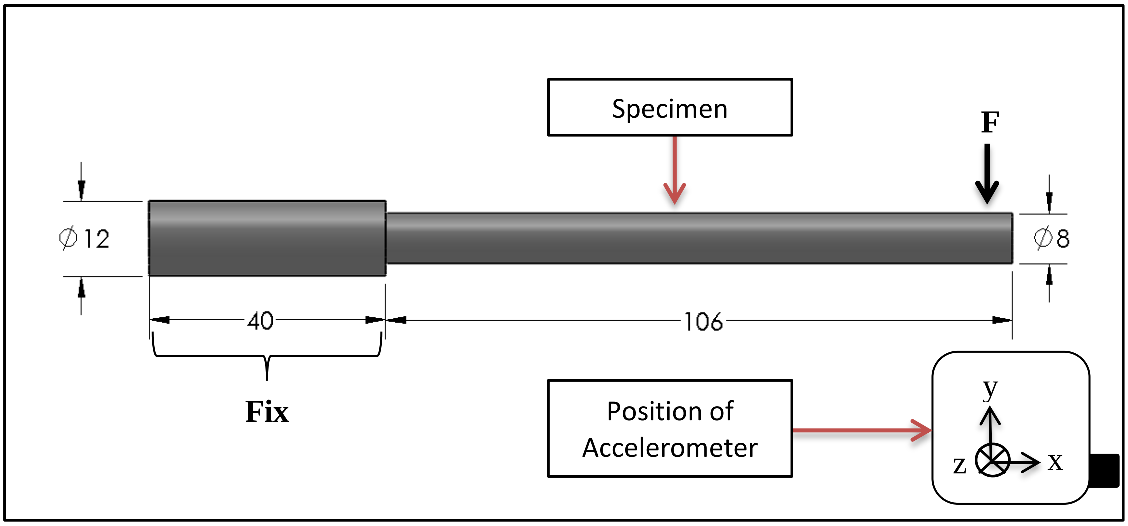
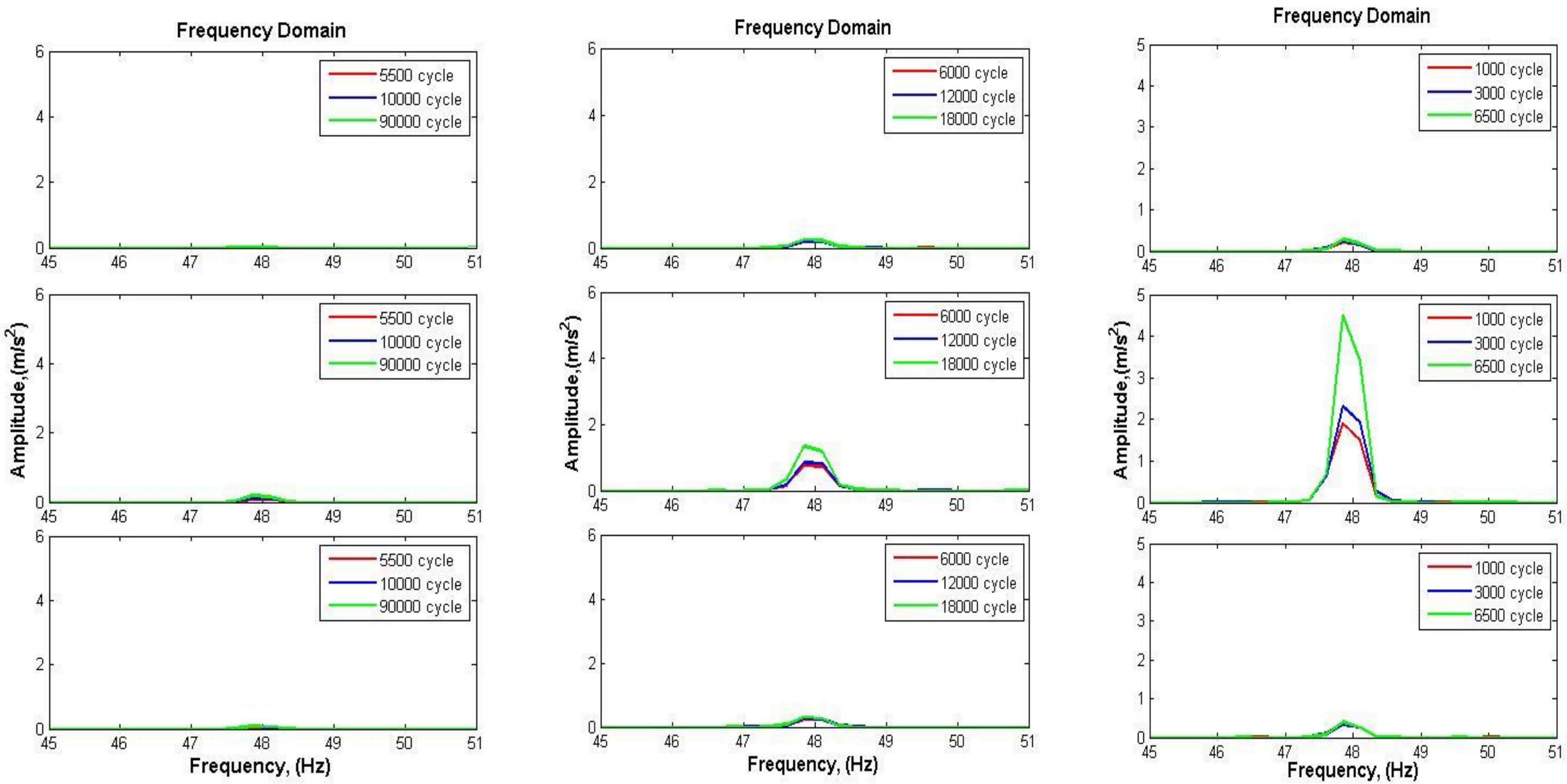


Figure 4.1: The boundary condition of specimen in fatigue testing machine.

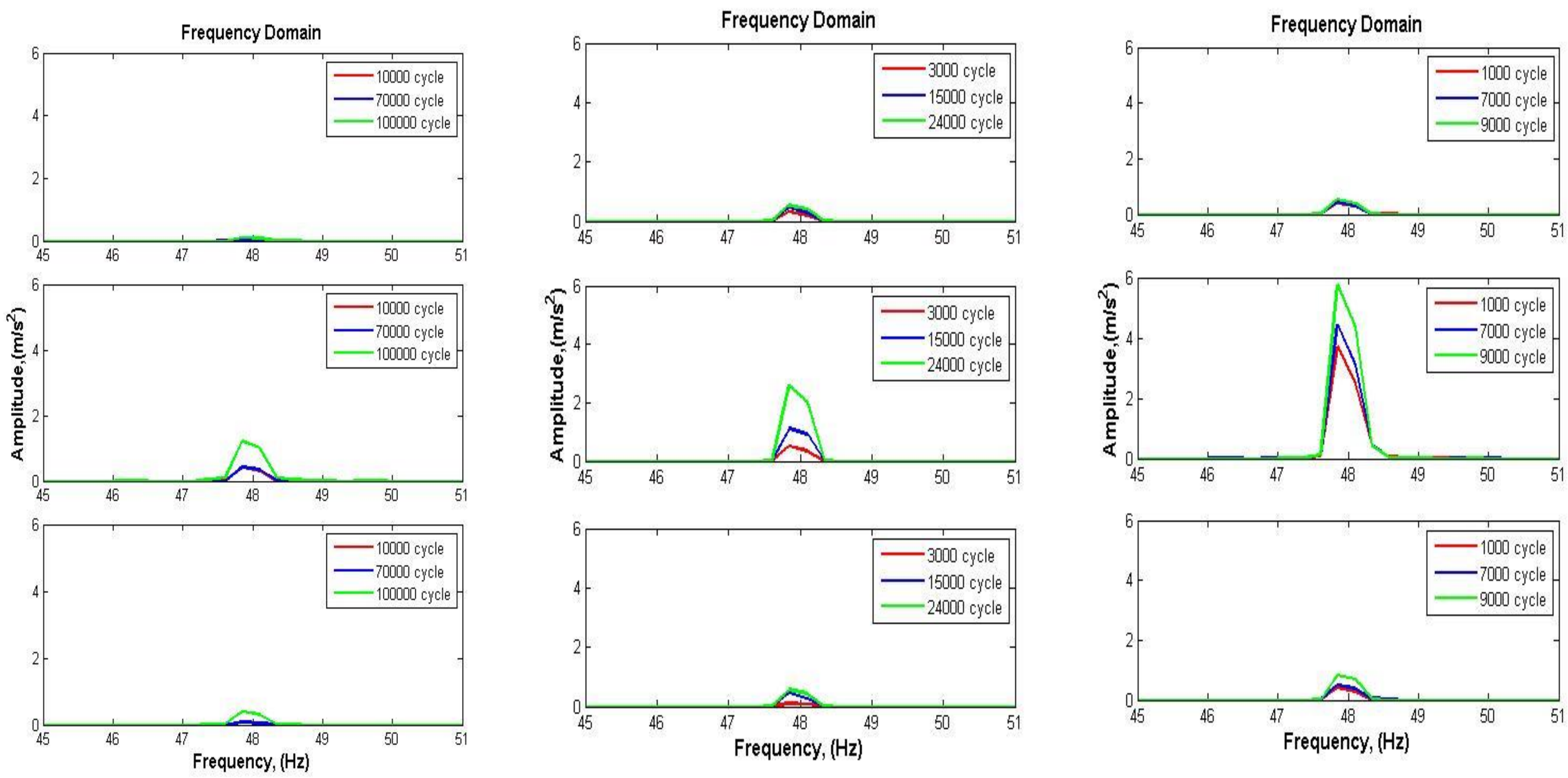
Figure 4.2 and Figure 4.3, shows that, the frequency domain graph for mild steel and low carbon steel, respectively. For the top graph is x-axis, middle graph is y-axis and the rest graph is the z-axis respectively. As illustrate in all the graphs, the vibration signal at y-axis is dominant compare to the x-axis and z-axis. This is due to the forces apply are perpendicular on the specimen, which means force acting through the y-axis as shown in Figure 4.1. While the value at x-axis is the lowest compared to other axis because of position of the specimen are parallel to the x-axis. Refer appendix A2 for Matlab graph coding.

From the result, there are the small value of vibration signal at x-axis and z-axis. Especially the signal value at forces 150 N for mild steel, the value at x-axis and z-axis about 0.01 and 0.06 respectively at a certain number of cycles, it's almost zero compared to the amplitude at y-axis about 0.290. Also for low carbon steel, the value for the amplitude at x-axis is 0.05, 0.07 at z-axis and 1.22 at y-axis. Thus, from small value at both axis, study on frequency domain analysis only considers vibration signal at y-axis. Amplitude at 250 N is higher than 200 N and 150 N for both materials. This is because, high load was applied to specimen, and it will increase the amplitude as number of cycle increase. This will cause the specimen will fracture rapidly due to resistance on specimen decrease.



(a) (b) (c)

Figure 4.2: Frequency domain for mild steel with different forces at certain cycle, (a) Forces 150 N, (b) Forces 200 N, (c) Forces 250 N



(a) (b) (c)

Figure 4.3: Frequency domain for low carbon steel with different forces at certain cycle, (a) Forces 150 N, (b) Forces 200 N, (c) Forces 250 N

Figure 4.4 until Figure 4.9 illustrates graph amplitude versus cycle for both materials respectively. Refer Appendix A2 for Matlab graph coding. From the graph shows, the frequency domains are recorded from different cycles until it fractured. The vibration amplitude increase due to stiffness value changes on specimen. With constant forces applied to the specimen, the amplitude keeps increasing until the specimen fractured. As illustrated in Figure 4.4 until Figure 4.9, the red circle are points where the specimen is fractured. From the mild steel graph shows on Figure 4.4 until Figure 4.6 at force 250 N the specimen is fracture are 7769 cycles with amplitude value is 8.50, compared to the 200 N fractured at 23 238 cycles with 7.30 values of amplitude 150 N fractured at 100 510 cycles with amplitude value is 5.70. For low carbon steel which is forced at 250 N is 9400 cycles with amplitude value is 9.59, 200 N fractured at 24 300 cycles with amplitude is 7.90 and 150 N is 137 749 cycles with amplitude at 7.60. From the data, clearly that more forces were applied the signal will increase. The time taken for the specimen to fracture also reduces.

The power that transmits from the motor to the specimen will affect the specimen stiffness become soft until the specimens are fracturing. The specimen experience three stages before fracture, which is first stage is fatigue threshold region, then stage two is encompass data where the rate of crack growth changes roughly linearly with changes in stress intensity fluctuation. In stage three, there are small increases in crack growth rate since the material is nearing the point of unstable fracture. With continues cyclic loading, the growth of the dominate crack or crack will continue until the remaining uncracked section of the component can no longer support the load. At this point, the fracture toughness is exceeded and the remaining cross-section of the material experinces rapid fracure. This rapid fracture overload fracture is the third stage of fatigue failure.

Crack growth can be encouraged by factors other that applied load. Environmental effect, such as corrosion due to exposure to the water or other solvents, as well as component wear can result in an overall loss of the material in the component cross section, increasing the stress carried by the remaining material. This increased stress can accelerate crack growth and ultimate failure.

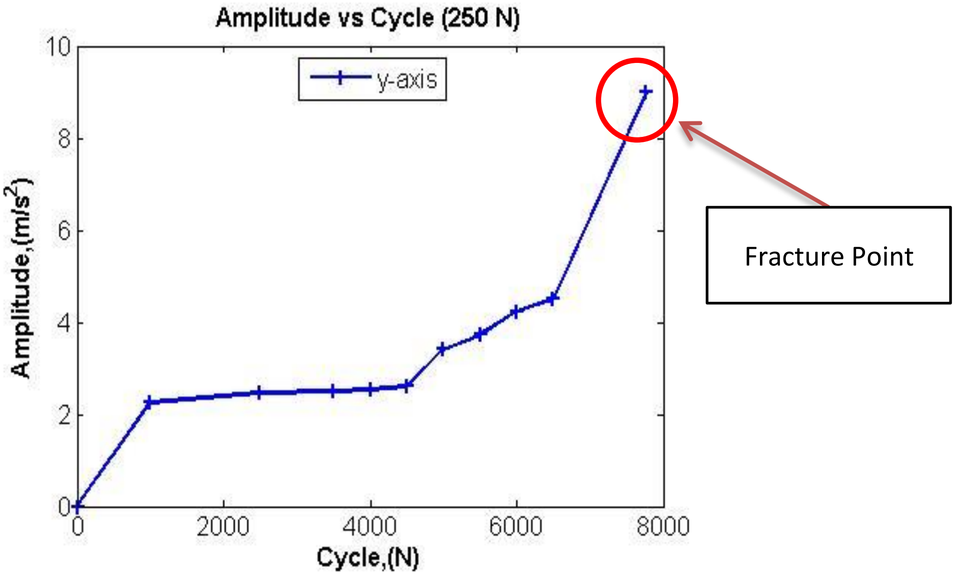


Figure 4.4: Amplitude versus cycle for mild steel with force 250 N

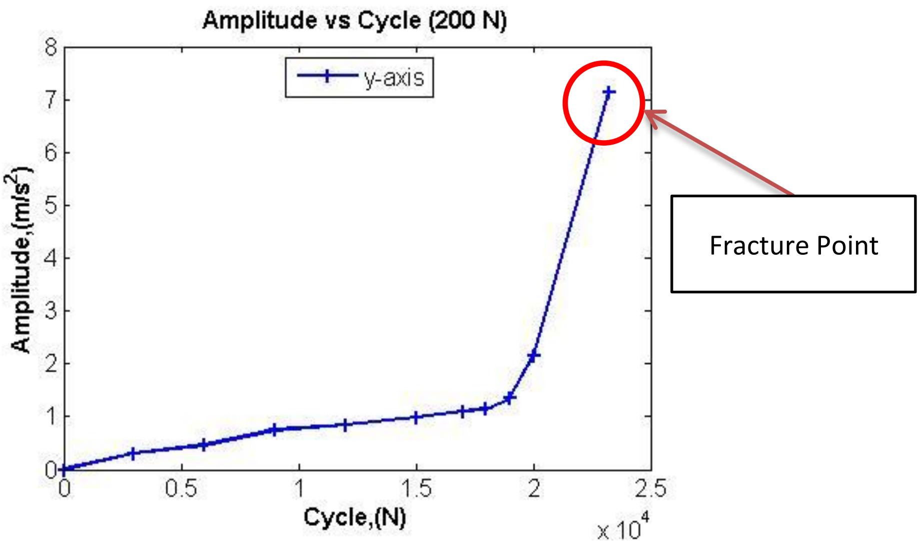


Figure 4.5: Amplitude versus cycle for mild steel with force 200 N

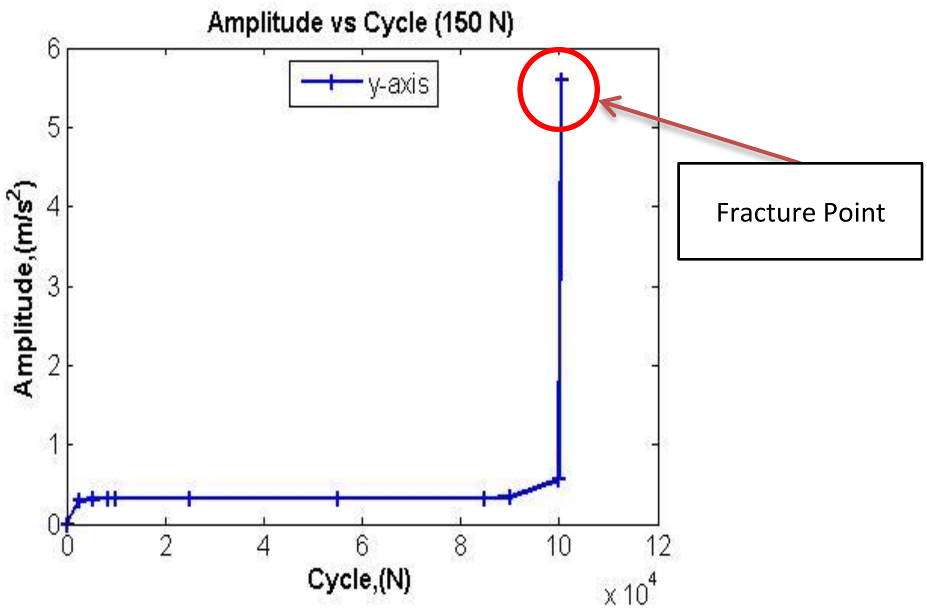


Figure 4.6: Amplitude versus cycle for mild steel with force 150 N

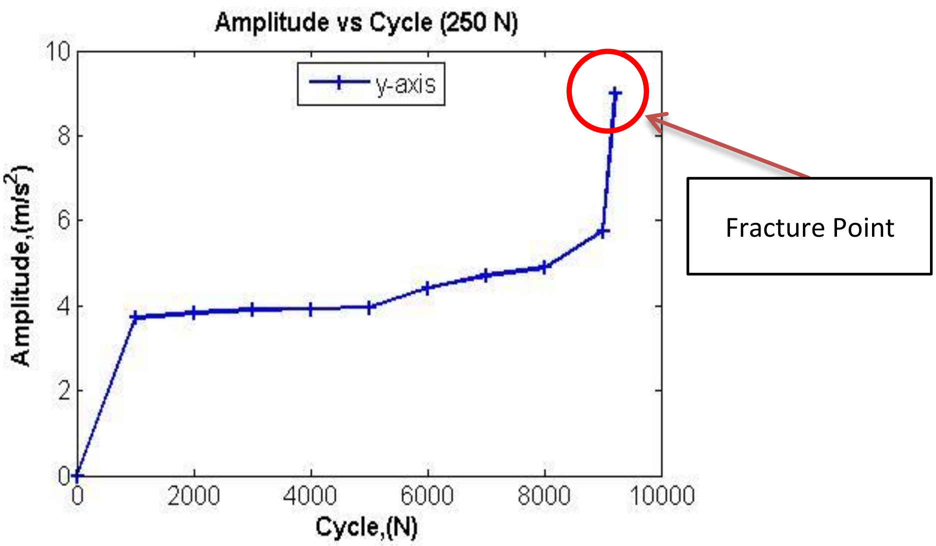


Figure 4.7: Amplitude versus cycle for low carbon steel with force 250 N

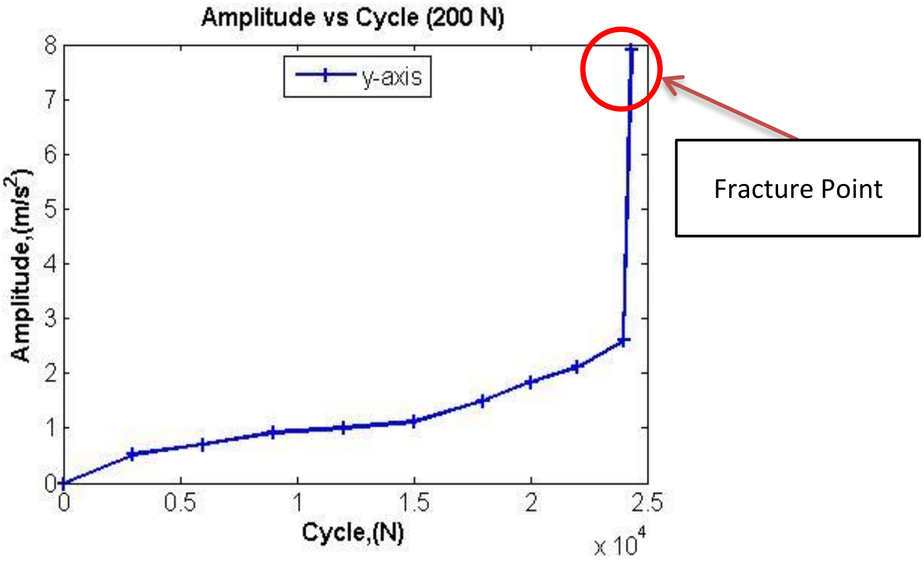


Figure 4.8: Amplitude versus cycle for low carbon steel with force 200 N

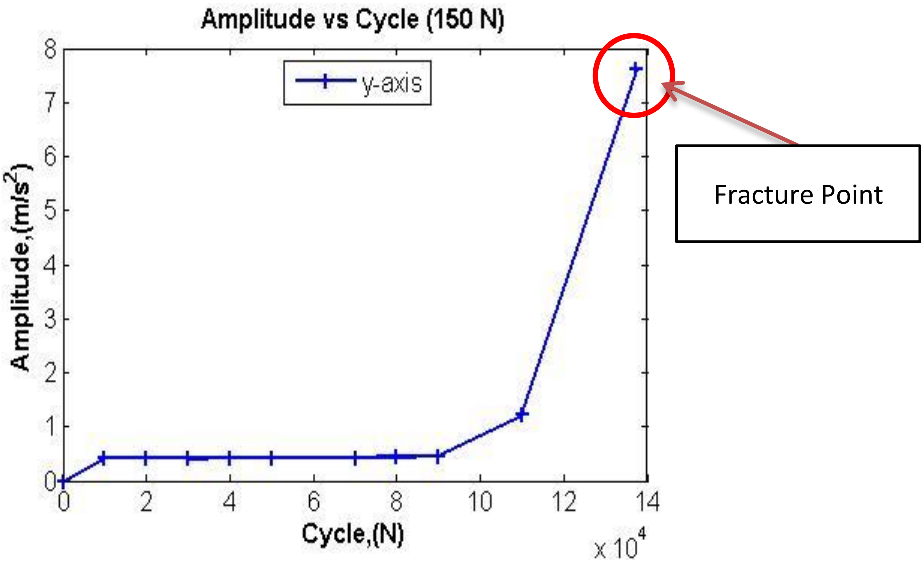


Figure 4.9: Amplitude versus cycle for low carbon steel with force 150 N

4.3 FRACTURE SURFACE

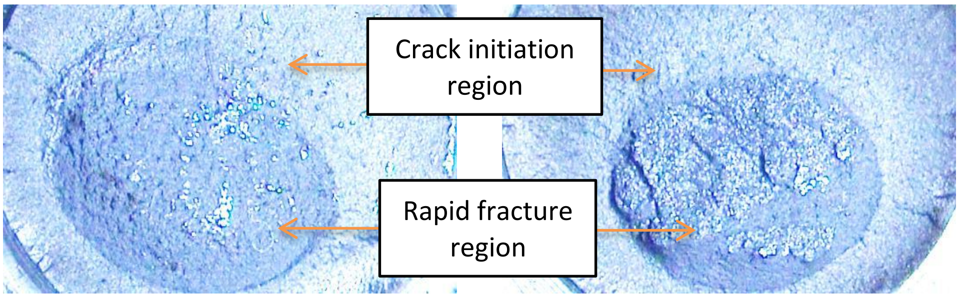
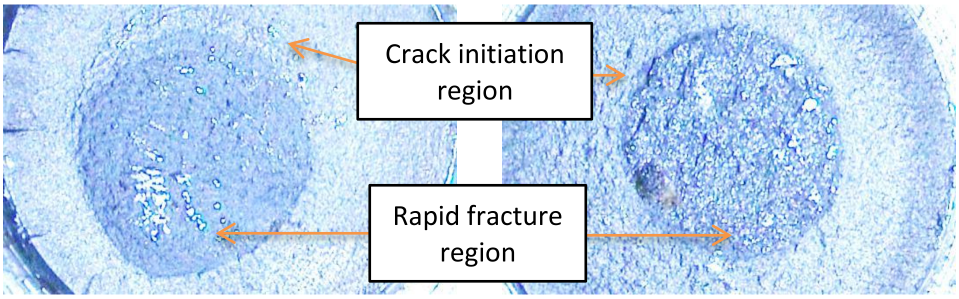
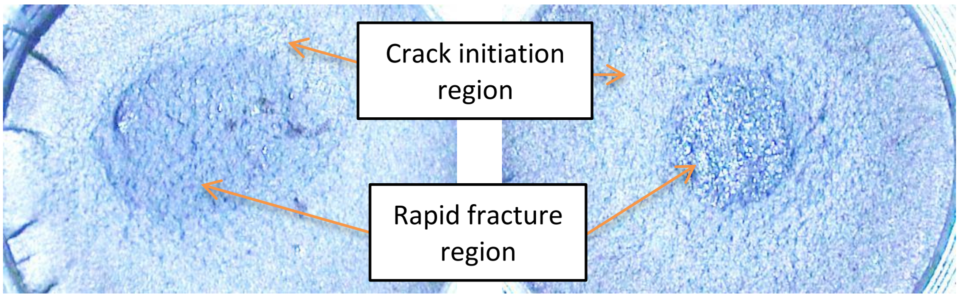
The fracture surfaces on failed specimens have been analysed by using optical microscope. Figure 4.10 shows the failed specimens that were used in rotating bending fatigue test. Table 4.1, shows the fracture surface on failed specimens.

Figure 4.10: Failed Specimens

4.3.1 Comparison fracture surface

Table 4.1 shows a fracture surface comparison. This an image taken by using optical measurement, at force 250 N shows the rapid fracture is in dark area larger than rapid fracture at forces 200 N and 150 N. For forces 200 N, the size rapid fracture is bigger than forces 150 N smaller than forces 250 N. Crack initiation may occur at any points, which are normally discernible to being seen by the naked eye. This failure occurs when each part of the specimen is subjected to alternating compression and tension under load. A crack can start at any point on the surface where there is a stress riser.

Table 4.1: Fracture surface comparison between two different materials

Force	Mild Steel	Low Carbon Steel
250 N		
200 N		
150 N		

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The objective of this study is to measure the vibration response during cyclic loading and study the vibration response of the specimen under frequency analysis. From the data, shows that there are vibration signal occur in 3D axis. Value of vibration signal at y-axis is higher compared to the others axis. For the second objective is to study the vibration response under frequency domain analysis. From the data that collected, amplitude values for all axis are changing due to the force apply to specimen, especially at y-axis. This because vertical displacement occurs at y-axis due to forces apply are at y-axis. Besides, the power from the motor that transmit to the specimen also can affect the stiffness of specimens become soft after experience cyclic loading or the resistance of the specimen is decreased during rotation with constant force applied. There are small values of vibration signal on x-axis because the left side of the specimen is fixed. This is will reduce the vibration signal. If more forces apply, it will be reduced time taken for specimen to fracture. These projects were done successfully with achieving the project objective. However, during the project stage, a few problems occurred such as the machining process problem, experiment apparatus problems and software problem. These problems need to solve in order to get a better result obtained, there is some conclusion can be drawn from the current study:

1. Based on the result for mild steel material. Specimen with applied loads 250 N fractured at 7769 cycles with amplitude value is 8.50. For 200 N and 150 N, the specimens fractured at 23238 cycles and 100510 cycles with amplitude value is 7.30 and 5.70 respectively.

2. For low carbon steel result, Specimen with applied loads 250 N fractured at 9400 cycles with amplitude value is 9.59. For 200 N and 150 N, the specimens fractured at 24300 cycles and 137749 cycles with amplitude value is 7.90 and 7.60 respectively.

The main factors for fatigue more on crack growth, environmental effect such as temperature and corrosion on the specimen will affect the result because it can loss the material in the component cross section. Increased stress will accelerate the crack growth and ultimate failure will undergoes rapid.

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5.2 RECOMMENDATION

Some recommendations need to be discussed to get better accuracy of the results, there are some different approach or method can be followed while conducting the experiment. Several recommendations will discuss based on the study.

5.2.1 Specimen Machining

Since the specimens for this experiment are needed to fabricate, it is better for machining it by using Computer Numerical Control (CNC) machine instead of by using the conventional lathe machine. This is because CNC machine can do the machining process in more detail and precise in term of surface roughness, diameter, length, and better surface finishing. There is some limitation using lathe machine to fabricate the specimen, the machine is manually operated to turning the raw material becomes fatigue specimen geometry. The lathe machine also are not precisely perfect in dimensioning setting and tool insert setting compared to the CNC machine, that only use a computer system to do the coding the dimension of specimens.

5.2.2 Strain Gage for Alignment and Machine Service

Highly recommend to use strain gage to set the alignment of the specimen at machine instead of using naked eye. This can be determined the position of the specimen either good position or not. The correct alignment of the specimen in the testing machine is important to assure that the central axis of the specimen coincide with the loading axis of the machine. Do the service on the fatigue testing machine. Recommend change new bearing before start the project. After running an experiment (for one specimen), apply grease to bearing. This is because, the conditions of bearing will affect the precision of vibration signal during collecting data.

5.2.3 Number of Specimen

The number of specimens is one of the important aspects that must consider in any testing method. It is recommended to increase the number of specimens in this test in order to reduce the error of the result by taking the average value of all specimens used. In this experimental test, only one specimen has been used for each applied stress.

5.2.4 Future Work

The fatigue life of the material depends on many factors such as notched geometry, residual stress and environment condition. On the other hand, the temperature surrounding also can has been an effect on fatigue life. Therefore, the further researches on all these factors are recommended to be investigating how those factors affected the test result. There are many engineering structures in elevated temperature such as turbine blade, airplane body, and the shaft itself for example increase the temperature as heat generated caused by friction between gear motor and the shaft.

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APPENDIX A1

Matlab Coding Graph for Frequency Domain

```
A = data(1:4096,2);
B = data(1:4096,1);
C = data(1:4096,3);
D = data(1:4096,4);
E = data(4097:8192,2);
F = data(4097:8192,1);
G = data(4097:8192,3);
H = data(4097:8192,4);
I = data(8193:12288,2);
J = data(8193:12288,1);
K = data(8193:12288,3);
L = data(8193:12288,4);

figure (1)

subplot(3,1,1)
plot(F,E,'r',J,I,'g',B,A,'b','LineWidth',2)
axis ([45 51 0 5])
title('Amplitude vs Cycle','FontWeight','bold','FontSize',12)
xlabel('x-axis','FontWeight','bold','FontSize',12)

subplot(3,1,2)
plot(F,G,'r',J,K,'g',B,C,'b','LineWidth',2)
axis ([45 51 0 5])
xlabel('y-axis','FontWeight','bold','FontSize',12)

subplot(3,1,3)
plot(F,H,'r',J,L,'g',B,D,'b','LineWidth',2)
axis ([45 51 0 5])
xlabel('z-axis','FontWeight','bold','FontSize',12)
```

APPENDIX A2

Matlab Coding Graph for Amplitude versus Cycle

```
%data range
data(1:11);
A=data(1:11,1)
B=data(1:11,2)
C=data(1:11,3)
D=data(1:11,4)

figure(1)
plot(A,B,'-+r',A,C,'-+b',A,D,'-+g','LineWidth',2)

%Setting graph properties
set(gca,'FontSize',16)
xlabel('Cycle,(N)','FontSize',20)
ylabel('Amplitude,(m/s^2)','FontSize',20)
title('Amplitude vs Cycle','FontSize',20)
legend('z-axis','y-axis','x-axis')
set(legend,'Orientation','horizontal','Location','North')
```