MICROPITTING AND WEAR ASSESSMENT OF ROLLER BEARING

MUHAMMAD NAFIZ BIN HAMIDI

UNIVERSITI SAINS MALAYSIA

2022

MICROPITTING AND WEAR ASSESSMENT OF ROLLER BEARING

by

MUHAMMAD NAFIZ BIN HAMIDI

Thesis submitted in fulfilment of the requirements for the degree of Bachelor of Engineering (Mechanical Engineering)

July 2022

DECLARATION

This work has not previously been accepted in substance for any degree is not being currently submitted in candidature for any degree.

Signed…………………………………………………..(Muhammad Nafiz Bin Hamidi)

Date………………………………………………………………………..(24/7/2022)

STATEMENT 1

This thesis is the result of my own investigations except where otherwise stated. Other sources are acknowledged by giving explicit references.

Bibliography/references are appended.

Signed…………………………………………………..(Muhammad Nafiz Bin Hamidi)

Date………………………………………………………………………..(24/7/2022)

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for photocopying and interlibrary loan, and for the title and summary to be made available outside organizations.

Signed…………………………………………………..(Muhammad Nafiz Bin Hamidi)

Date………………………………………………………………………..(24/7/2022)

ACKNOWLEDGEMENT

I would like to present my deepest gratitude towards all parties who are involved in aiding and providing helping hands while completing this final year project. First and foremost, I would like to express my sincere appreciation to my supervisor, Dr. Nurul Farhana binti Mohd Yusof for the continuous support and valuable guidance that has facilitated me in finishing this project. Her patience, motivation and prodigious knowledge helped me throughout the research and writing of this thesis. I am very grateful for all the guidance that has been given especially in overcoming obstacles and problems that I have been facing during the process of completing the project. Besides, my sincere thanks also go to the authority of the School of Mechanical Engineering University Sains Malaysia for providing the necessary facilities to complete this research. Next, I would like to express my gratitude towards the staffs of Microscopy Lab of School of Mechanical Engineering, Mr. Mohd Ashamuddin Hashim and Mohd Idzuan Said who had greatly helped and assisted the experiment and research. Last but not least, honourable mention goes to my family and friends for their continuous supports and encouragement which helped me spiritually throughout the project. Overcoming hardship and challenges have been easier with their presence.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF SYMBOLS

Cu	Copper
Ra	Average roughness of profile
Nm	Nanometer
Mm	Millimeter

LIST OF ABBREVIATIONS

IFM	Infinite Focus Microscope
CNC	Computer Numerical Control
USM	Universiti Sains Malaysia

LIST OF APPENDICES

PENILAIAN LUBANG-LUBANG MIKRO DAN KEHAUSAN GALAS PENGGELEK

ABSTRAK

Galas penggelek digunakan dalam pelbagai aplikasi seperti dalam industry automotif dan peralatan atau jentera-jentera berat. Sangat penting untuk memastikan bahawa galas tidak gagal kerana ia boleh menyebabkan kegagalan mesin. Lubang-lubang mikro merupakan salah satu fenomena paling biasa yang ditemui pada permukaan galas dan boleh menyebabkan kegagalan pada galas. Lubang-lubang mikro dipengaruhi oleh beberapa faktor seperti topografi permukaan, bahan yang digunakan, beban, pelincir, suhu, kelajuan, nisbah lambda dan nisbah gelongsor kepada gulung. Pelincir biasanya digunakan dalam aplikasi galas penggelek untuk mengawal geseran dan haus pada galas yang boleh memberi kesan ke atas kadar pembentukan lubang-lubang mikro. Tujuan kajian ini dijalankan adalah untuk menyiasat lubang-lubang mikro dan haus pada galas penggelek yang dilincirkan menggunakan gris minyak sawit. Eksperimen dijalankan menggunakan rig ujian penggelek. Permukaan penggelek diimbas menggunakan mikroskop pada beberapa kitaran untuk memerhati proses pembentukkan lubang-lubang mikro pada permukaan. Didapati permukaan penggelek yang dilincirkan dengan gris sawit bersama bahan tambahan bersaiz nano mengambil masa paling lama (150000 kitaran) untuk rosak. Isipadu haus dan kedalaman lubang-lubang mikro adalah yang paling kecil iaitu 20747 μm^3 dan -4.4 20747 μm masing-masing berbanding dengan keadaan pelincir yang lain.

MICROPITTING AND WEAR ASSESMENT OF ROLLER BEARING

ABSTRACT

Rolling element bearing is used in many applications such as in automotive industries, and heavy equipment or machinery. It is important to make sure that the bearing does not fail because it could lead to the failure of the machine. Micropitting is one of the most common phenomena that can be found on the bearing surface that can lead to the failure of the bearing. Micropitting are affected by several factors such as surface topography, material, load, lubricant, temperature, speed, lambda ratio and slide to roll ratio. Lubricant is usually introduced into the rolling contact of the roller bearing in order to control the friction and wear of the bearing which can have an effect on the rate of micropitting formations The purpose of this study is to investigate the micropitting and wear of the roller bearing lubricated with palm oil grease. The experiment is carried out using the roller test rig. The roller surface is scanned using a microscope at a few cycles to observe the progress of the surface micropitting. It is found that the roller surface lubricated with palm grease with a nano additive took the longest time (150000 cycles) for the surface to damage. The wear volume and micropitting depth are the smallest which are 20747 μm^3 and -4.4 µm as compared to the other lubricating conditions.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Micropitting phenomenon can be found in gears operation. However, it can also occur in rolling element bearing. It can happen within the first few hours of the roller bearing operation which leads to destructive wear. Actually, micropitting is not an immediate serious failure mode. However if not prevented, it may lead to other failure modes such as pitting, spalling and scuffing (Liu et al., 2019). For roller bearing case, micropitting is a degenerative condition. As the failure goes on, the progress of a structure in roller bearing which is called raceway will wears away. The high stress concentrations will lead to raceway fatigue earlier than it should be. The raceway fatigue will then lead to erosion process of the raceway and cause reduction of the bearing life. The roller bearing schematic diagram is shown in figure 1.1 below. In this figure, it shows the components of a roller bearing.

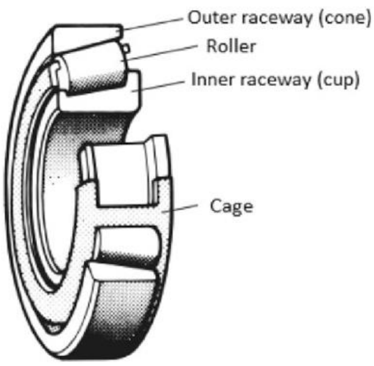

Figure 1.1 Roller bearing schematic diagram (Mobley, 2001)

Lubricant is usually used in a roller bearing applications in order to reduce friction and avoid metal to metal contact between the rolling elements and their raceways. Additives are sometimes added in order to improve the performance of it in term of reducing wear and friction between surfaces. Some previous works have shown that many anti-wear additives may introduce micropitting damage especially to hard steels that is subjected to rolling contact (Lainé et al., 2009). It is because the anti-wear additives will form a protective layer that will protect the surface from wear. The protective layer produced will preserve the initial surface roughness and high peak asperities. This situation will keep a high stress at asperity level for high number of stress cycles since the surface is rough and contain high peak asperities (Brizmer et al., 2013). High stress at asperity level will increase the risk of micropitting. This research is going to focus on rolling contact for ball bearing mechanism.

However, the aforementioned phenomenon also depends on other factors such as type of additives used and size of the additive’s particles. The type of additives used need to be considered because some additives can chemically react with the roller surfaces. For example, Zinc Dialkyl Dithiophosphate (ZDDP) will react with the contacting surface and hence increasing the friction that also cause high local stress at the asperity level. So, the possibility of micropitting will also increase (Brizmer et al., 2013). When the friction increases, the micropitted area will also increase. It is because as the friction increase, the temperature of the surface will also increase which will lead to reduction in lubricant viscosity. As the viscosity decrease, the film thickness will also decrease which in turn can increase the micropitted area (Ueda et al., 2022).

The additive’s particles size also plays an important role in reducing wear and controlling micropitting. As mentioned before, anti-wear additives will help reducing the wear on bearing or gear surface but at the same time will introduce micropitting.

This is only true if the additives used is in micro size. However, if the additive's particles size is smaller than that which is in nano size, it can help reduce the wear and micropitting at the same time. It is because the smaller nanoparticles will be deposited into the valleys of the worn surface and hence will help repairing it. This phenomenon is called mending effect and it will also reduce the average surface roughness, Ra value since the deep valley is being filled by the nanoparticles (Pena-Panas et al., 2018).

1.2 Problem Statement

Lubricants in roller bearing can help prevent the micropitting phenomena by separating roller and inner race. When both surfaces are separated, both surfaces will not be in contact. This prevent elastic or plastic deformation, which can lead to micropitting. Recently, additives are added to the lubricants in order to enhance the lubricant performance like improving the anti-friction, chemical and physical properties of the base oils. However, the additives used might promote micropitting which is a form of fatigue failure on a material's surface. For example, copper nanoparticle (Cu) is an anti-wear additive that preserves the contacting surfaces from wear and prevent micropitting. It is necessary to identify the effect of additives used in lubricating grease and its properties on micropitting propagation.

1.3 Objectives

- To investigate the micropitting and wear mechanism of roller bearing lubricated with palm oil-based grease.

- To measure the roller bearing wear/material loss when lubricated with palm oil grease with and without additives.

- To evaluate the performance of palm oil grease lubricant with and without additives.

1.4 Scope of Work

This study, it involves experimental work where the roller bearing will be tested inside the test rig. The test is stopped at certain period for surface characterization. Lastly, the propagation of micropitting will be monitored by using Alicona Infinite Focus Microscope.

CHAPTER 2

LITERATURE REVIEW

2.1 Micropitting Definition

Micropitting can be classified as surface contact fatigue that is mostly found in roller bearings and gears. This micropitting has the same feature as pits corrosion and cracks. Pits corrosion is a pit, hole or cavity that is found on a product surface caused by corrosion or rust. The only difference between the micropitting and pits corrosion is the size between two of them. The micropits is in the scale of a few microns or tens of microns in terms of depth, length, and width. The direction that cracks propagates is different in wheel and gear. In gear, the crack will propagate towards the pitch on the pinion line while on wheel, the crack propagates away from the pitch line (McCormick, 2019). According to A. Oila and Bull, the crack propagates at a certain low angle which is less than 30 degree and several cracks can merge together which will cause continuous loss of material (Vrček et al., 2020). Figure 2.1 below show the micropitting phenomenon that occur in roller bearing.

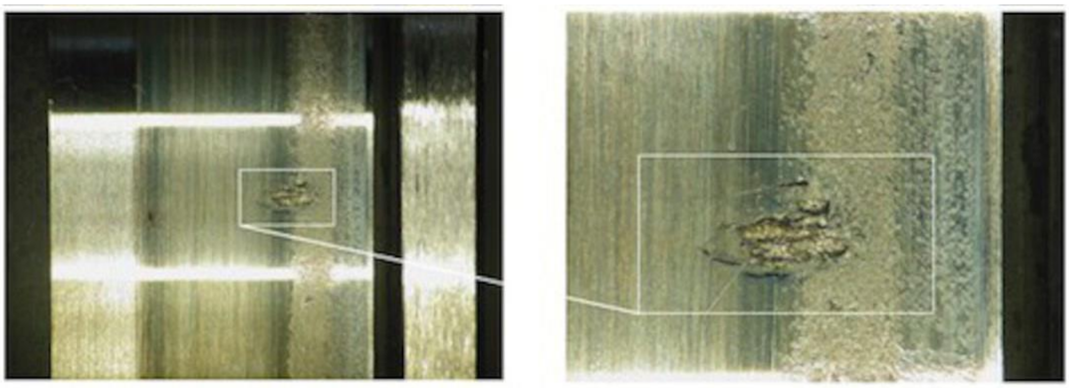

Figure 2.1 Micropitting in roller bearing (Morales-Espejel & Brizmer, 2011)

2.2 Micropitting Measurement

Oila & Bull, (2005) had conducted an experiment in order to measure the micropitting in roller bearing applications. In the experiment, eight different sample of roller bearing made by using different grade of steel were being tested. A two-disk machine with a three-phase motor was used to rotate the lower roller bearing shaft. Load was applied and the experiment was stop at the following cycles of 1.8×10^5, 3.6×10^5, 5.4×10^5 and 7.2×10^5 cycles to examine the roller surface condition by using light microscopy and optical profilometry. The light microscopy was used to magnify the surface of roller while the optical profilometry was used to obtain image and surface contour map of the surface. The image and contour map were used for the measurement of the total micropitting area, number of pits and mean area of the pits. The results obtained from all eight roller samples have similar pattern which are as the cycle increase, all the micropitting parameter mentioned above is also increase.

Besides that, a roughness parameter that is commonly used which is the average surface roughness, Ra can also be used to observe the micropitting phenomenon on a rolling surface. It is because the average roughness is a parameter that indicate the average deviation of the asperities from the mean line in one predetermine length. The R_a value and roughness profile graph be obtained by using an infinite focus microscope. From the roughness profile graph, the deep valley of the asperities can be observed and from there, the region where the micropit will occur and initiate can be found.

Next, the physical properties of the micropitted area needed to be studied before proceeding to the measurement process. The properties are in term of the size of the micropitted area such as the width and depth of it. Micropits are typically 10–30 µm in diameter and can be up to 10 µm deep (AL-Mayali et al., 2018).

2.3 Factors That Influence Micropitting

There were some factors that will cause and affect the micropitting such as surface topography, material, load, lubricant, temperature, speed, lambda ratio and slide to roll ratio. From experimental results, it shows that when the surface roughness increase, it is more likely to undergo micropitting. Rough surface will have asperities which are the high spots on a surface and these asperities will act as stress raisers and cause crack initiation. The lambda ratio (ratio of film thickness to composite roughness) plays an important role on micropitting propagation and have less effect on micropitting initiation. Increasing the ratio either by increasing the film thickness or reducing the surface roughness can reduce micropitting because it can reduce the contact pressure. It is also found that some additives such as anti-wear and extreme pressure additives can lead to micropitting (Lainé et al., 2008).

As for the load, micropitting may happen at intermediate load that is below the pitting endurance limit. At this load, only short running times is needed to cause damage. The most compelling factor that affect micropitting is the contact pressure because higher contact pressure will cause more friction. At high contact pressure, the micropitting rate is independent of other factors. The temperature will also influence the micropitting phenomena. When the operating temperature increase, the lubricant viscosity and lubricant film thickness will decrease which in turn, will increase the rolling contact and hence, increasing the probability of micropitting. High operating speed will also increase the probability of micropitting. It is because as the operating speed increase, it will increase the operating temperature due to heat generated by friction. It is found that micropitting will be likely to occur at speed of 4 – 10 m/s (Oila & Bull, 2005).

2.4 Effects of Cu Nanoparticle Additives in Lubricant

One of the anti-wear additives used in lubricant is copper (Cu) nanoparticles. These additives have a good wear and friction reduction properties. For ball bearing mechanism, recent studies had found that the decomposition of the Cu nanoparticles in the lubricating oil is caused by local overheating due to friction between contact surfaces. The decomposition of the nanoparticles will form the thin protective film over the worn surface of the ball bearing which will reduce the wear and friction on surfaces. YU et al., (2008) had conduct an experiment to study the effect of Cu nanoparticles in 50cc oil. The experiment was conducted by using four ball tester. In the tester, one ball will rotate onto three other balls that is completely coated with lubricant. In order to determine the wear rate, wear scar diameter (WSD) on the three balls will be observed by using scanning electron microscope.

Based on the experiment results they obtained, the friction and wear curves for lubricating oil containing Cu nanoparticles increase slowly and steadily compared to pure oil which will increase drastically with higher temperature. The WSD of the ball bearing at room temperature of 50 °C, 80 °C, 110 °C and 140 °C are reduced by 13%, 16%, 21%, 23% and 25% respectively while the friction coefficient is reduced by 5%, 8%, 10%, 15% and 20% respectively. It indicates that the Cu nanoparticles perform better at higher temperature. For the mechanism, the direct contact between the two surfaces will cause the temperature to increase and hence cause the melting process of Cu nanoparticles. Besides that, the shearing force due to friction and high pressure at interface will cause the initiation of Cu nanoparticles disengagement from its organic modified layers. Protective film layer will then be created when the nanoparticles is smeared on the worn surface by shearing movement. Hence by lowering the wear rate, it will decrease the risk of micropitting (Yu et al., 2008).

Yao et al., (2008) stated that additives are usually added to grease lubricant in order to improve its performances in some aspect. Next, according to Pawlak, Klamecki, Rauchkyte et al., (2009) due to the development of nanoscience and technology, nanoparticles had become an effective additive for grease lubricants because of its unique physical and chemical properties. The nanoparticle additives give the lubricant a better property such as wear resistance abilities. Lubricating grease is prepared by using soaps as thickening agent. Example of the soaps used are lithium, sodium and calcium salts that have long fatty acid. Qiang, Anling, Yangming, Liu & Yachen, (2017) had conducted an experiment to determine the performance of lithium-based grease with Cu nanoparticle additive in rolling-element bearings applications. From the results of four-ball friction experiment, it can be seen that the wear scar diameter and friction coefficient decrease as the mass fraction of the Cu nanoparticle increase from 0% to 0.25%. However, the value starts to increase as the mass fraction is is increasing from 0.25% to 0.45%. Hence, the experimental results indicate that lithium-based grease with 0.25% of Cu nanoparticle shows the best tribological performances in term of anti-wear and friction coefficient mechanism. When the bearing is being used at high speed, the Cu nanoparticle will be dispersed in the region of bearing raceway. This gives a positive result to the bearing raceway surface because the dispersed particles provide repairing effect to the surface and hence reducing the wear mechanism (Qiang et al., 2017).

Gao et al., (2008), Sun et al., (2004) stated that nanoparticles have a good tribological properties which related to wear, friction and lubrication. Zhang, Wang, Liu & Fu, (2009) had conducted an experiment by using end-face wear testing apparatus to study the properties of Cu nanoparticles as additives in SJ 15W/40 gasoline oil by dispersing 0.5 wt% of the nanoparticles. From the results obtained, the wear loss weight for the SJ with 0.5 wt% of Cu nanoparticle additives is lower compared to base SJ oil under the conditions of increasing applied load. Besides that, the load-carying ability is also increased from 500N to 700N when 0.5 wt% of Cu nanoparticle was put on to the lubricants. The anti-wear properties of the Cu nanoparticle are the best at 400 N where the wear loss weight was reduced by 90%. Furthermore, at 300 N, the SJ added with Cu nanoparticles can reduce the friction coefficient by 46% at 300 N which indicates that it has good friction-reduction properties (Zhang et al., 2009). The graph of results obtained by Zhang et al., (2009) is as shown in figure 2.2 below.

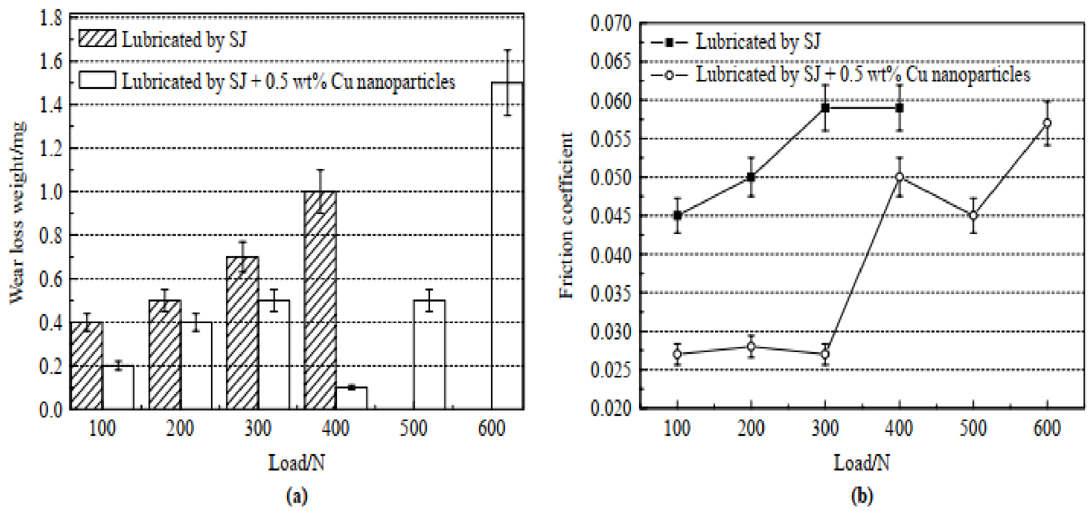

Figure 2.2 Wear loss weight (a) and friction coefficient (b) as functions of increasing normal load (Zhang et al., 2009)

2.5 Mending Effect

As have been mentioned before, additives are being added to pure lubricant for several reasons such as to reduce wear and friction at sliding interfaces. The additives are also added in order to repair the sliding interfaces and resulting in smoother surfaces. This situation is known as mending effect where the additive particles will be dispersed onto the worn surface and help repairing it by filling the valley of the asperities and making it become shallower. However, this phenomenon is highly depending on the size of additive particles used which is commonly in nano to micro size. According to previous study, smaller diameter size of additives which is in nano scale is desirable since it can provide better tribological properties and fill the valley of the sliding surface better. The smaller size particle also will provide better anti-wear properties. Figure 2.3 below shows the illustration of mending effect cause by nanoparticle (Pena-Panas et al., 2018).

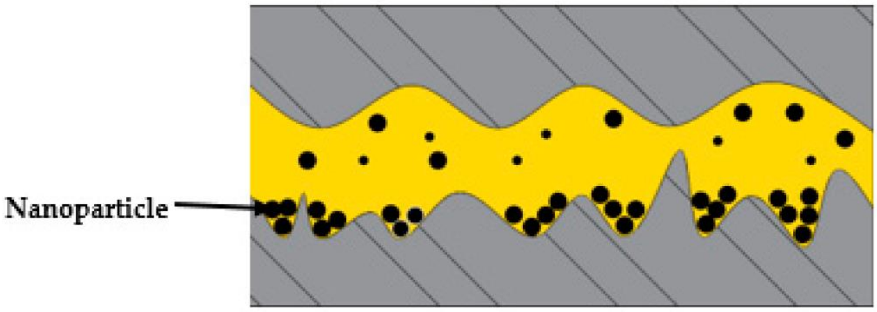

Figure 2.3 Mending effect of nanoparticle illustration (Jason et al., 2020)

Pena-Panas et al., (2018) had conducted an experiment in order to observe the effect of additive's particles diameter size on the wear and friction properties. The type of additives used was titanium dioxide (TiO_2). To study the effect of different particles size, five different diameters of TiO_2 particles was used which were 100nm, 165 nm, 300 nm and 500 nm. The lubricant used was Polyalphaolefin (PAO) oil and a block on ring tribotester under sliding condition was used for the experiment. To investigate the wear for each experiment, the wear mass loss of the ring block was obtained by measuring the weight of it before and after the experiment. The worn surfaces of the ring block were examined by using field emission scanning electron microscope (SEM) and an energy dispersive x-ray spectrometer (EDS) to determine the friction properties and also the mechanism of the TiO_2 additive's particle.

Based on the results obtained by Pena-Panas et al., (2018), for the friction force, it can be observed that smaller TiO_2 particles will results in lower friction force. Particle with 165 nm results in friction force of around 60 N while the biggest diameter which is 500 nm will result in friction force value of around 65 N. The greatest friction value was achieved in the block lubricated with PAO oil without additive which have the friction force of 80 N. The same pattern was observed for the wear mass loss where the lowest wear mass loss was observed when the particle diameter is 165 nm where the mass loss is only 3 mg and other particle size will result in mass loss around 20 – 25 mg. The wear mass loss for lubricant without additive is around 30 mg. The 100 nm diameter particle result in slightly higher friction force and wear mass loss because the particle is too small, and they will cluster together and forming a micron scale particle size.

The worn surface of the ring block was scanned by using SEM and EDS. From the results of SEM, they found that the groove present on the worn surface of block with 165 nm size additive is shallower compared to other size of additive. The worn surface for 500 nm size additive also possesses some region with micropitting. Besides that, from the result of EDS elemental analysis, they found that no titanium (Ti) element on the wear track of the surface lubricated with PAO oil without additive while the Ti element weight percent was found the most on the wear track of surface lubricated with PAO oil and 165 nm TiO_2 additive particles. So, they conclude that a smaller size additive particle will help reduce the wear, friction force and micropitting due to the repairing of the worn surface by the small particles.

CHAPTER 3

METHODOLOGY

3.1 Introduction

As this project is in the early steps, effort was put in planning the experiment. The planning process include the determination of the material to be used, number of samples to be used and the setup of the experiment. There are several things that need to be done before conducting the experiment. The flow of this project is shown in figure 3.1 below.

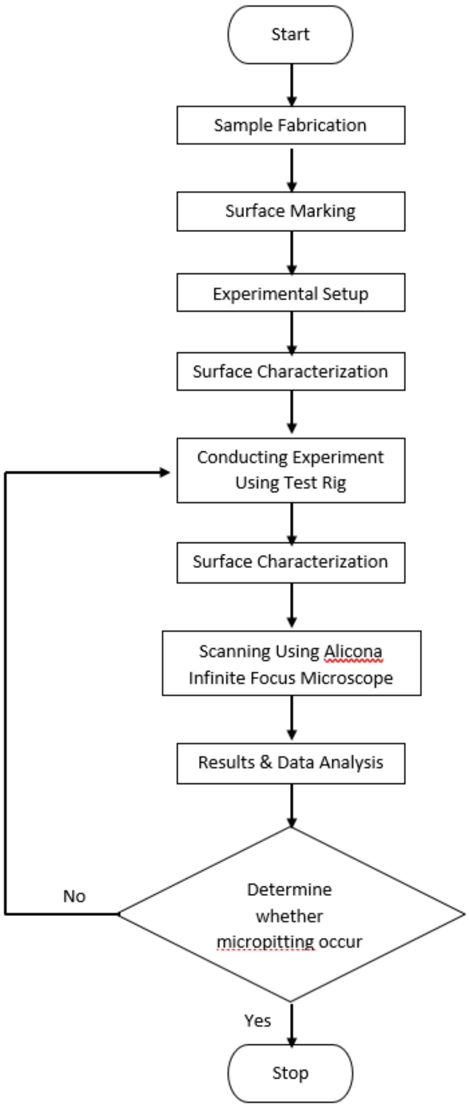

Figure 3.1 Project flow chart

3.2 Sample Fabrication

Before the experiment can be conducted, the roller bearing sample that is going to be tested need to be fabricated first. Each roller sample is divided into two parts which are top roller and bottom roller part. The material that was going to be used for the roller bearing will play an important role as it will determine how long the experiment will be. For this research, mild steel was used. Three samples were fabricated for this research because three experiments are going to be conducted under three different conditions which are running the roller bearing in dry conditions, with lubricant without additives conditions and with lubricant and Copper (Cu) nanoparticles additive. The sample was fabricated by using CNC machine by School of Mechanical Engineering technician. The roller bearing sample is shown in figure 3.2 below.

Figure 3.2 Roller bearing sample

3.3 Surface Marking

After the roller bearing sample had been fabricated, the next important step is the surface marking process. In this process, all top rollers were marked by using centre punch. Only the top roller was marked because the scanning process was done on the top roller only. The marking was done at the side region of the roller instead of the middle region so that the original surface condition of the roller is preserved. This process is important because the marked area is the area that is going to be studied for the whole experiment in order to ensure that the course of surface degradation can be studied throughout the wear process. Besides that, the marked area will also serve as reference datum for surface roughness measurement using Alicona Infinite Focus Microscope (IFM). The example of marked surface is shown in red circle in figure 3.3 below.

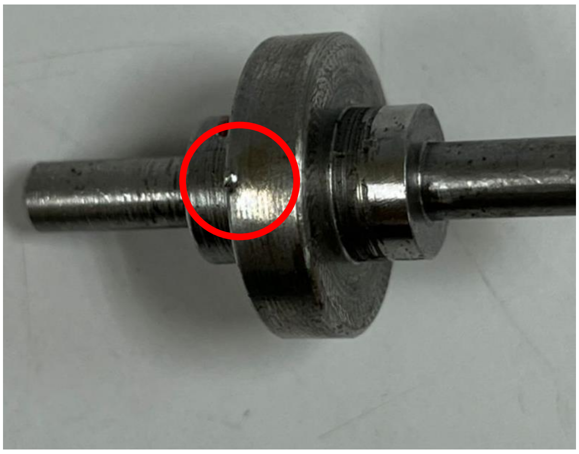

Figure 3.3 Marked area on roller bearing

3.4 Experimental Setup

The experiment was conducted by using an experimental test rig, driven by a stepper motor with the speed controlled by using an Arduino microcontroller. The top and bottom roller bearing were mounted onto the test rig. Both roller's shaft was mounted tightly to the test rig because a loose fit will cause vibration. Next, a radial load was applied on top of the roller to speed up the experiment. The Arduino microcontroller was connected to a laptop and the coding to control the stepper motor was uploaded into the Arduino Software. The stepper motor at the test rig is power up by a DC power supply. The full setup is shown in figure 3.4 and the list of all components with its respective role is shown in table 3.1 below.

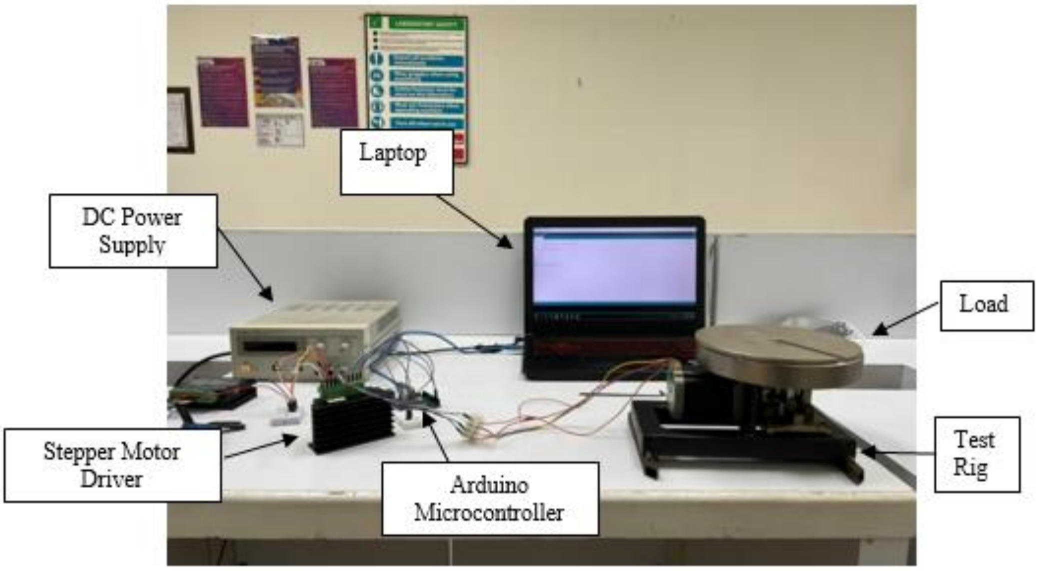

Figure 3.4 Experimental setup

Table 3.1 List of components and its functions

Components	Functions
Test Rig	Consist of stepper motor that is used to rotate the roller bearing. The top and bottom roller bearing was mounted onto the test rig
Stepper Motor Driver	To make sure that the stepper motor works the way we want it to. It is used to set the number of cycles takes by the stepper motor to complete one complete rotation. The driver also limits the current flows into the stepper motor to avoid damaging the motor
DC Power Supply	To supply voltage and current required to power up the stepper motor. Minimum of 12 V and 1.5 A is needed to power up the stepper motor at required speed.

Laptop	Connected to the Arduino microcontroller to upload the coding into it. It is also used to supply 5V of voltage to the Arduino.
Arduino Microcontroller	An electronics microcontroller used to read the coding uploaded and rotate the stepper motor at the required speed.
Load	Applied on top of the roller bearing to speed up the experiment.

3.4.1 Load Determination

The determination of the load value is also important in this project. It is because the amount of load used will affect the duration of the experiment. Insufficient load will make the experiment period become too long while excessive load can make the roller bearing bend and stop the experiment. To determine the adequate amount of load used, the formula of Hertzian contact for cylindrical surface was used since roller bearing can be categorized into line contact. All the formula used for the load determination calculation is shown below.

$$P_o = \left(\frac{\left(\frac{F}{L}\right) E^*}{\pi R^*} \right)^{\frac{1}{2}} \qquad (1)$$

$$\frac{1}{E^*} = \left(\frac{1 - v_1^2}{E_1} + \frac{1 - v_2^2}{E_2} \right) \qquad (2)$$

$$\frac{1}{R^*} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (3)$$

Where

$$P_o = Max. Hertzian\ contact\ stress$$

$$E^* = Equivalent\ Young's modulus\ of\ top\ and\ bottom\ roller$$

$$R^* = Equivalent\ radius\ of\ top\ and\ bottom\ roller$$

$$v = Poisson\,ratio$$

$$L = Length\ of\ line\ contact$$

$$F = Load\ force$$

The value of the maximum Hertzian contact stress is determined. This value must be slightly higher than the yield strength of mild steel which is the material of the top and bottom roller in order for the surface damage to occur. Excessive stress is also avoided as it may cause bending on the samples and test rig components. The yield strength value of mild steel is σ_y = 250 MPa (*Mild Steel | Density, Strength, Hardness, Melting Point*, 2021). So, the value of maximum Hertzian contact stress used in calculation is, P_o = 280 MPa. The value of other parameter and calculations made is shown below.

$R_1 = R_2 = 10\ mm \qquad E_1 = E_2 = 210\ GPa = 210000\ MPa = 210000\ N/mm^2$

$v_1 = v_2 = 0.3 \qquad L = 5\ mm$

$$\frac{1}{E^*} = \left(\frac{1-0.3^2}{210000} + \frac{1-0.3^2}{210000}\right) = 0.00867$$

$$E^* = 115380\ N/mm^2$$

$$\frac{1}{R^*} = \frac{1}{10} + \frac{1}{10} = 0.2$$

$$R^* = 5\ mm$$

Subs into eq (1)

$$280\ N/mm^2 = \left(\frac{\left(\frac{F}{5\ mm}\right)(115380\ N/mm^2)}{\pi(5\ mm)}\right)^{\frac{1}{2}}$$

$$F = 53.35\ N$$

$$m_{Load} = \frac{F}{g} = \frac{53.35}{9.81} = 5.44\ kg \approx 6kg$$

Hence, from the calculations being made, it was decided that a load of about 6 kg was going to be used for the experiment.

3.5 Conducting Experiment Using Test Rig and Lubricating Condition

The next step for this project is to conduct the experiment by using the test rig. For dry condition, the roller bearing sample was mounted tightly onto the test rig and the stepper motor was set to rotate at the speed of 50 rpm. For the lubrication condition, the stepper motor was set to 100 rpm to speed up the experiment since it is theoretically going to take longer for micropitting to occur. The stepper motor will rotate the bottom roller and it will simultaneously rotate the top roller. The experiment was stopped at predetermined number of cycles to scan the top roller bearing surface and this process was repeated until micropitting can be seen from the scanning results. The test rig used is shown in figure 3.5 below.

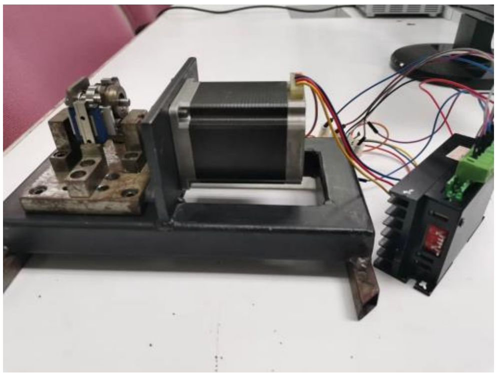

Figure 3.5 Experiment test rig

The experiment is carried out in three different lubricating conditions, which are dry, palm grease without additive and palm grease with copper nanoparticle additive. The palm grease was prepared in lab by the postgraduate students. The palm grease was prepared with the palm olein used as a mineral base oil and lithium stearate as a thickener.

3.6 Surface Characterization

Surface characterization is a crucial process to quantify a surface under investigation which is the top roller surface in this case. It is also the process to prepare the surface that was being studied for upcoming processes. This step can be divided into two which are the surface characterization before and after running the experiment. Before starting the experiment, the surface of the top roller bearing was cleaned by using Acetone because the surface conditions before the experiment need to be scan by using Alicona IFM. The cleaning process is being done to remove the debris on top of the roller surface that will affect the average roughness value and surface roughness profile obtained from the IFM.

Once the experiment had being conducted, the surface characterization process was done at certain interval of cycle of the stepper motor rotation. For example, in dry conditions the experiment was stop after the first 100 cycle and the process was done before proceeding to the scanning process. The characterization process was different for different conditions. For dry condition, there is no cleaning process of the roller before the scanning process. It is because we want the surface to naturally degrade. However, for both lubrication conditions with and without additive, after the experiment was stop at predetermined number of cycles, the roller surface was wiped and cleaned by using acetone to remove the excessive lubricant before proceeding to scanning process.

The selection of chemical used for the cleaning process is important because we want to avoid choosing a chemical that can have new chemical reaction with the roller surface. Acetone was used because it had been widely used to clean a metal surface and is proven have no chemical reaction with them (Mancuso, 2022). The bearing was then relubricated and remounted for the next process. This step was repeated from the start until the end of the experiment.

The Alicona IFM can create a three-dimensional image and find the best focus related to a known distance from the sample (Macdonald, 2014). The IFM was used to determine the surface roughness because the IFM can scan the surface topography and hence measuring the surface roughness After every predetermined cycle complete, the top roller bearing was scanned by using the IFM. For the scanning process, 10x magnification was used as it gives the best and clear scanning image for this project. The marked area was chosen as the reference point for the scanning process and only that area was scan for the measurement purpose. The scanned image of the roller surface can be viewed in both two-dimensional and three-dimensional image in order to do the measurement process. Figure 3.6 and figure 3.7 below shows the 2D and 3D image of the scanned area respectively.

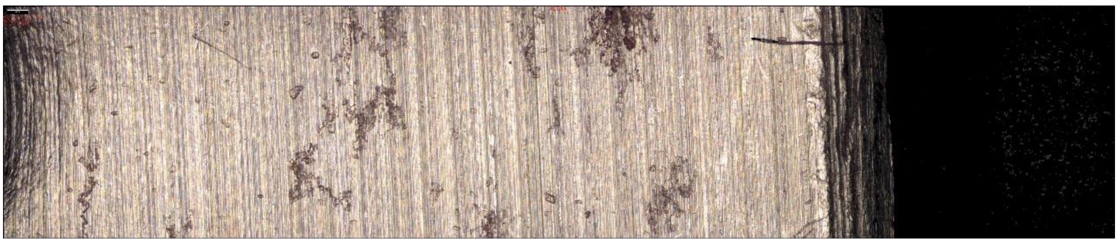

Figure 3.6 Two-dimensional scanned image

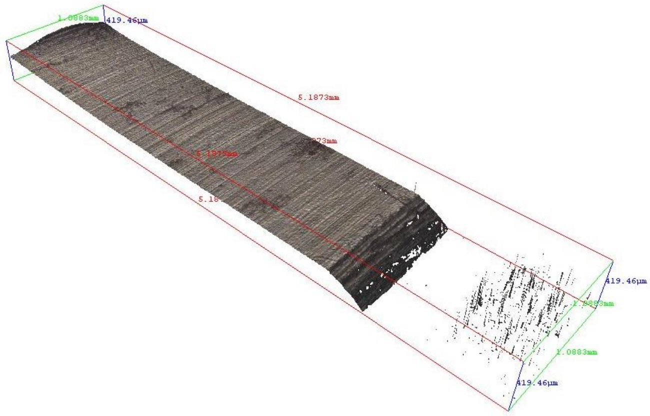

Figure 3.7 Three-dimensional scanned image

3.7 Results & Data Analysis

After the scanning process, all the results and data obtained from the Alicona IFM was analyzed. This process is important to see whether micropitting phenomena had already occur on the roller bearing surface or not. The main parameters that is being observe is the average roughness value, Ra of the scanned surface (Gadelmawla et al., 2002). The Ra is calculated by using the arithmetic average of the absolute values of the profile height deviations from the mean line, recorded within the evaluation or sample length. In this project, this Ra value is calculated by the Alicona IFM. On the 2D scanned image of the roller bearing surface, a line was drawn which will be the sample length for the Ra evaluation. The marked area on the side of the roller sample will act as the datum reference point to draw the line to ensure that the line being drawn is at the same place and same area was studied throughout the experiment. After that, a graph of the depth of the surface asperities against the sample length will be obtained. This graph will show the deviation of the surface asperities from the mean line and from there, a micropitting and surface degradation can be observed. The micropitting can be observed through the valley formation on the graph. Figure 3.8 and figure 3.9 below shows the sample length for roughness measurement and the surface profile graph respectively.

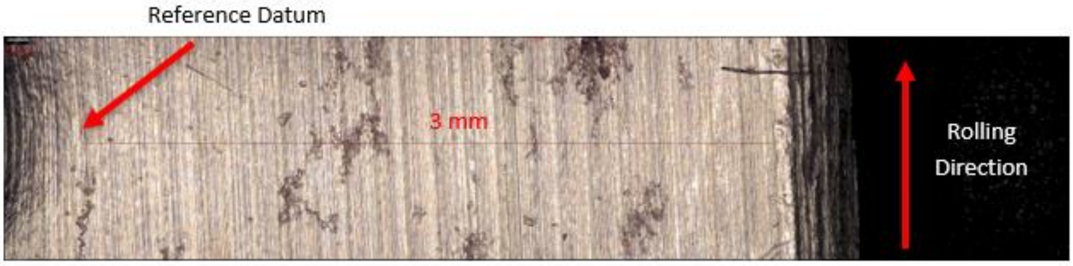

Figure 3.8 Sample length for roughness measurement

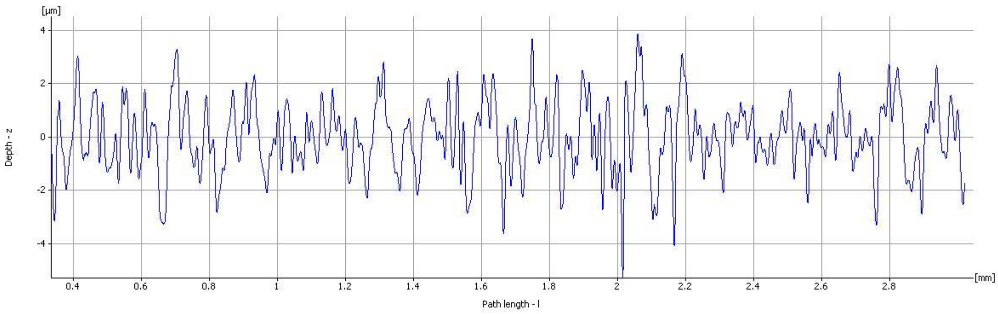

Figure 3.9 Surface profile graph

3.8 Wear Volume Measurement

The wear volume measurement process was done to compare the wear volume at a specific location on the top roller bearing surface before and after the experiment when micropitting had occur. The measurement process was done by the Alicona IFM measurement. First of all, the position where micropitting occur and is the most obvious was chosen as the place for measurement by referring to the surface roughness profile graph. The same place was then used for the sample at 0 cycle (before experiment). To select the area, a square was drawn by using the software and to increase the results accuracy, the square was drawn at almost same size. The IFM software uses an algorithm that will compute the total wear volume below the mean line between peak and valley of the surface asperities. The results for this process will tell whether surface wear process had occurred throughout the experiment. The examples of result obtained from the wear volume measurement process is shown in figure 3.10 below. Figure below shows the wear volume above and below the surface. The surface here is referring to the middle surface that separates the peaks and valley. Since we are interested in the micropitted area which can be observe from the deep valley, so we are going to take the wear volume below surface.

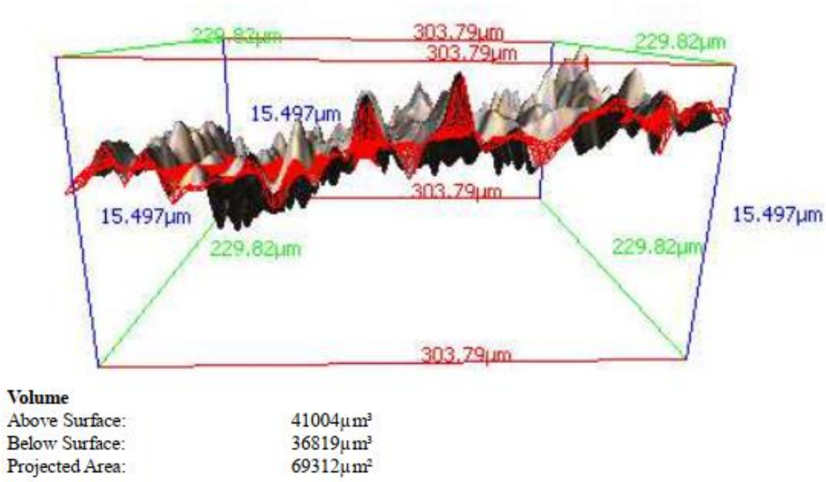

Figure 3.10 Wear volume measurement result