MICRO PITTING AND WEAR ASSESSMENT OF SPUR GEAR

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LIST OF ABBREVIATIONS

IFM	Infinite Focus Microscope
DC	Direct Current
MoS_2	Molybdenum Disulfide
POGC	Lubrication with Pure Grease Condition
POGWAC	Lubrication with Palm Oil Grease with Additive Condition
Ra	Average Surface Roughness

LIST OF APPENDICES

PENILAIAN LUBANG MIKRO DAN KEHAUSAN PADA GEAR TAJI

ABSTRAK

Lubang mikro dan kehausan merupakan salah satu fenomena yang sering berlaku di bahagian gear taji di mana ia menjadi perkara yang menyebabkan kerosakan mesin. Kerosakan pada mesin ini akan memberi kesan yang sangat besar kerana ia memerlukan seseorang jurutera untuk membaik pulih bahagian mesin yang telah rosak tersebut dan ia memakan perbelanjaan yang agak tinggi walaupun kerosakan yang dihadapi oleh bahagian gear taji tersebut hanyalah berskala kecil. Pemilihan untuk jenis pelinciran yang tepat adalah penting untuk mengelakkan sebarang kerosakan yang terjadi pada gear taji. Ia adalah satu keperluan untuk mengenal pasti pengaruh pelincir ke atas penyebaran dan kehausan lubang mikro, serta untuk mengenal pasti sebarang pengaruh penting yang mungkin berlaku apabila bahan tambahan digunakan pada sampel. Tujuan utama kajian ini adalah untuk mengkaji gelagat lubang mikro dan kehausan pada minyak asas kelapa sawit dalam gear taji dan menilai prestasi minyak terbiodegradasi berbanding dengan dan tanpa nanopartikel MoS2 sebagai bahan tambahan. Dalam kajian ini, eksperimen dijalankan menggunakan pelantar ujian gear dan ujian dijalankan di bawah tiga keadaan berbeza. Pengimbasan permukaan dilakukan untuk menilai profil permukaan gear. Kajian menunjukkan bahawa gear yang dilincirkan dengan minyak kelapa sawit dengan bahan tambahan MoS2 mempunyai kedalaman dan kehausan lubang mikro yang kecil. Ini menunjukkan bahawa bahan tambahan berjaya mengurangkan kerosakan permukaan dengan cekap dan serasi dengan minyak kelapa sawit.

MICRO PITTING AND WEAR ASSESSMENT OF SPUR GEAR

ABSTRACT

Micro pitting and wear are one of the most common phenomena in gear parts where it becomes the thing that causes machine damage. The damage to this machine will have a very big impact because it requires an engineer to repair the damaged machine parts and it consumes a relatively high cost even though the damage faced by the gear parts is only small - scale. Proper lubrication is crucial to avoid gear failure. It is necessary to identify the influence of lubricants on the dispersion and wear of micro pitting, as well as to identify any significant influences that may occur when additives are applied to samples. The main purpose of this study was to study the micro pitting and wear behaviours of palm oil base grease in spur gear and to evaluate the performance of biodegradable grease compared with and without nanoparticle MoS_2 as an additive. In this study, the experiment is carried out using a gear test rig and the test is run under three different conditions. Surface scanning was done to evaluate the gear surface profiles. The finding shows that the gear lubricated with palm oil grease with MoS_2 additive has less micropitting depth and wear. This indicates that the additive manages to reduce the surface damage efficiently and is compatible with the palm grease.

CHAPTER 1

INTRODUCTION

1.1 Research background

The gear system is a critical component that transfers both power and motion in a variety of machines and control systems. Because the gears function at their maximum load capacity, the gear teeth are frequently exposed to high contact pressure during the operation of a gear system, such as power transmission. Surface fatigue failure, such as micro pitting, will result as an outcome of this. In rolling/sliding contact settings, micro pitting is a type of surface fatigue. It's common in gears and, on rare occasions, rolling bearings. It can cause severe wear within hours of start up, and if left unchecked, it can lead to major equipment failures. Micro pitting occurs when the compressive stress at the surface of the gear tooth exceeds the surface strength, for a variety of reasons. The only option to lower compressive stress under constant load is to increase the contact area, hence surface roughness and lubricant selection are the most significant aspects.

It's also not a recent occurrence. Micro pitting has grown increasingly noticeable as gearbox design has progressed to utilize case-hardened or carburized teeth. Gearbox technology has allowed for substantial size reductions and enhanced power flow, but higher power density also means more stress on contact zones. When micro pitting occurs, microscopic pits appear on the surface that are too small to be seen with the human eye. Micro pitting can progress, resulting in an increase in the size and prevalence of micro pits. The damaged area will turn grey once the progression has reached a point where it can be seen without magnification. This gives micro pitting another name: "grey staining," which is also known as frosting and micro spalling. Micro pitting wear on gears changes the form of the tooth over time. This focuses the load and lowers the precision of the gears as they move through the mesh, speeding up the process even more. Micro pitting occurs in electrohydrodynamic lubrication (EHL) oil films where the film thickness is on par with the composite surface roughness and the load is carried by the surface asperities and the lubricant (Lainé et al., 2008). Collisions between asperities on opposing surfaces generate elastic or plastic deformation depending on local loads when asperities carry a major percentage of the load.

Ueda et al (2022) stated that sliding between gear teeth creates tractional forces, which subject asperities to shear stresses in addition to contact stress from normal loading. During run-in, the first 104 to 106 cycles of stress represent an incubation period during which damage is predominantly caused by plastic deformation at asperities.

Plastic deformation accumulates on asperities and at shallow depths below asperities due to cyclic contact and shear loads. Plastic flow generates tensile residual stresses, which, after enough cycles, lead to fatigue cracks.

A research from Ueda et al (2022) stated that micro pits nucleate, develop, and consolidate quickly after incubation. Microscopy reveals a surface that is constantly broken. The use of a gear inspection machine to inspect tooth profiles on a regular basis reveals a consistent rate of surface deterioration. Plastic deformation, followed by fracture initiation, growth, and coalescence, can be a continuous process. After only 106 cycles, the damage could be severe. When a fatigue fracture forms at an angle from the gear tooth surface, micro pitting occurs. When a branch crack connects the subsurface main crack to the surface and separates a little piece of material, it forms a micro pit. The resulting pit could be as small as 10 mm and not visible to the naked eye. Surface crack networks are typically less widespread than subsurface crack networks.

Ueda et al (2022) also stated that the main fracture erodes the surface by deepening and spreading in a fan-like pattern. As the back margins of pits split and little particles of surface material are released, micro pits grow larger. Micro pitting debris can be as small as 1 mm, and strainers may not be able to remove it. Polishing wear is common on gear teeth with micro pitting, both in areas between micro pits and in areas without micro pitting, because the particles act as polishing agents.

According to Laine (2008), wear is a process where a process of interaction between surfaces, which causes the deformation and removal of material on the surfaces due to effect of mechanical action between the sliding faces. Wear also refers to the dimension's loss of plastic deformation. Plastic deformation leads to wear; it causes the deterioration of meatl surfaces, which is known as "metallic war". Wear is the result of many things such corrosion, erosion, abrasion, chemical processes, or combinations of these factors. The processes of wear are studied in the field of tribology.

Soudmand (2020) stated that wear is a phenomenon through which the deformation of surfaces of material occurs. Common types of wear include adhesive wear, abrasive wear, surface fatigue, fretting wear, and erosive wear. Adhesive wear is unwanted displacement and debris production resulting in the creation of frictional contact between surfaces. It is visible by fretting, pits, holes, or scales transfer. Abrasive wear is loss of material resulting from sliding hard surfaces. It can be seen as scratches, grooves, or corrugations. Surface fatigue is material surface weakened by cyclic loading. It can be witnessed as tears or small holes. Fretting wear is a little shift of the contacting surfaces under load in oscillatory motion. Erosive wear is results from impact of sharp particles on a surface. First seen as changes in surface finish.

In abrasive wear, hard particles, contaminating oil, insufficient metal hardness, and hard metal with rough surface against soft metal promote wear. In erosive wear, the high velocity of sharp particles increases wears. On the other hand, in surface fatigue, cyclic stress over long periods, water, dirt in oil and particles of metal with sharp edges enhances wear. In a corrosive environment, corrodible metals, rust-promoting conditions, and high temperature facilitate wear. Specific coatings are used to prevent the effects of wear as well as to repair surfaces. This saves costly components from replacement and failure. In order to select the appropriate coating, the wear type should be identified first.

According to Amarnath and Lee (2015), micro pitting is influenced by lubricant qualities such as base stock, additive chemistry, and viscosity. Micro pitting resistance varies by lubrication, according to tests. Some lubricants may be able to stop micro pitting in its tracks once it has begun.

According to Engineering Tribology by G.W. Stachwiak, lubrication is the prevention step that being taken to reduce wear and micro pitting. By applying lubricant to gear, it can reduce the coefficient of friction by promoting sliding between tooth gear and reduce the temperature rise that is caused by rolling and sliding friction. There are three types of gear lubrication method that is used in recent market, which is grease lubrication, splash lubrication and forced oil circulation lubrication. Among all the three types of gear lubrication, each of them has different ability and limitations according to condition of gear that been applied.

According to Cann (1996), grease lubrication is lubricant method that suitable for any gear system that is open or enclosed, so long as it runs at low speed and operation is continuous with under low load condition. The needs of determining the proper quantity of grease when applying it to gear is a must as the excess grease will cause a great harmful potential to gear such as agitation, viscous drag and result in power loss. Splash lubrication, or oil bath method is type of lubricant method that is suitable for enclosed system. This type of lubrication method has several limitations, such as oil level determination and temperature limitation. The oil level must be adjusted perfectly to prevent ineffective lubrication, and it must be monitored regularly. The temperature of the gear system may rise due to lower viscosity of lubricant and accelerated degradation of lubricant. Forced Oil Circulation Lubrication is a type of lubricant method that applies lubricant to the contact portion of the teeth by means of an oil pump. There are drop, spray and oil mist methods of application.

1.2 Problem statement

Micro pitting and wear are one of the failure modes that may lead to destructive failures of gear system which results the unplanned shutdown and expensive replacement. In gear system, micro pitting often initiates at the pinion dedendum but escalates at the addendum. The assist of lubricant with additives may solve the micro pitting problem as it will aid in the reduction of micro pitting and wear between surfaces in rolling contact on spur gear. It is a need to identify the effect of additives in lubrication system for micro pitting and wear propagation.

1.3 Objectives

1.3.1 Objectives 1

To investigate the micro pitting and wear behaviours of palm oil based-grease lubricant in spur gear.

1.3.2 Objectives 2

To evaluate performance of biodegradable grease compared with and without nanoparticle MoS_2 as additive.

1.4 Scope of research

In this project, an experiment is conducted by testing the spur gear in test rig. The gear is run and will be stopped at certain period for surface characterization using Alicona Infinite Focus Microscope. In this experiment, the rolling contact of the spur gear is being investigate and the surface wear or material loss due to micro pitting will be monitored.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to micro pitting and wear

According to Li Sheng et al (2013), micro pitting is the surface failure that happen due to severe stress concentration that happen in rolling contact of the component such as bearing and gear in certain period. There are parameters such as surface roughness, and profile form which is the indicator that been used to predict the presence of micro pitting. Micro pitting usually occurs because of poor lubrication that reduce the surface roughness value of the component. The micro pitting will start to grow after certain number of contact cycles, and it will lead to another surface failure which is wear.

Based on the Engineering Tribology by G.W. Stachwiak, wear is the failure modes that happen when the surface of the component has experience deformation and material removal that is due to frequent mechanical contact. The impact of wear to the mechanical component such as bearing, and spur gear can be considered critical as critical failure because it will reduce the performance of the component itself. The solution to prevent those failure modes is by applying lubricant and additives to the mechanical component.

In this review. An experimental method to characterize micro pitting and wear by previous researchers has been investigated. This chapter also reviews the effect of different lubricant and additive for gear.

2.2 Reviews of the previous work by researchers

Experimental research made by Morales-Espejel, Rycerz and Kadiric (2018) to predict the micro pitting damage in gear teeth contact. In each test, the roller specimen's surface was examined after 6 and 10 million contact cycles. An optical microscope was used to obtain images of the surfaces, and a white light optical interferometer was used to quantify surface profiles. Images of the damaged surfaces after 6 million and 10 million cycles for all three slide-roll ratios. This journal contains examples of circumferential sections (in rolling direction) of damaged specimens. The slice reveals the existence of several short cracks ranging in length from 10 to 50 microns, as well as shallow pits, all of which are considered to be typical of micro pitting damage, showing that the generated surface damage is indeed micro pitting. The surface area affected by micro pitting was calculated by analysing surface roughness measurements collected on the interferometer using a simple, in-house built software that recognises micro pits in measured 3D surface profiles.

For each test specimen, the results of this analysis are reported, along with a value that represents the fraction of micro pitted area over the entire measured area. It is clear that greater sliding magnitude causes more micro pitting: after 10 million cycles, the micro pitted area for S = 0.3 is roughly 10%, for S = 0.15 it is about 5%, and for S = 0.05 it is just 2%. There appears to be no variation in the amount of damage documented at 6 and 10 million cycles, with the exception of S=0.15, which shows a discernible rise.

D.Mallipeddi et al. (2021) investigated the micropitting and microstructural evolution of gears throughout their early cycles of operation to failure. To further understand the micropitting mechanism, ground gears were tested on the FZG test rig, and the evolution of surface properties was extensively monitored from the initial 200 cycles to failure. This experiment utilised a characterization technique. SEM microscopy was used to observe the surface topography and microstructure of gear teeth in detail (SEM). The instrument used was a LEO Gemini 1550 with a field emission gun, and imaging was performed at a 5 kV acceleration voltage. The gear teeth were imaged macroscopically using a Zeiss Discovery V20 stereo-light optical microscope. Diamond discs were used to cut cross-sections of the teeth. To reveal the microstructural changes, the cross-sections were ground and polished down to 1 metre diamond paste in six phases.

According to the experiment, micropitting began after 2000 cycles, continued with rising cycle counts, and grew into macropits at approximately 2.2×10^7 cycles. Micropitting was found to relate to deformation of asperities and associated microstructural alterations; deformation bands and plastically deformed regions (PDR). The first deformation bands seen after 2000 cycles were limited to the outside 5 metres of surface during the running-in stage but were extended deeper with additional testing to a depth of 15 m at the end of the degradation stage. Throughout the test, plastically deformed zones detected after 200 cycles were shallower.

Gupta et. al (2021) studied the effective of lubrication in gear. In the absence of effective lubrication at the tooth interface, tribological and vibrational issues arise, resulting in energy inefficient operation, unexpected high temperature rises, and tooth failures. As a result, evaluating the film thickness parameter was critical for gaining a knowledge of when to start effective lubrication in conventional and textured gearsets using fresh and MoS2 mixed greases. The combined effects of texture and MoS2 blended grease have yielded significant increase in the contact resistance (approximately 5–9 MΩ or 110–302%) in comparison to the conventional case (without texture with fresh grease), however, in the presence of texture with fresh grease, this increase lies in the range of 3–7 MΩ or 60–109%.

Al-Tubi et al. (2015) conducted an experimental and analytical evaluation of the initiation and spread of gear micro pitting under varied stress circumstances. The micro pitting experiment is conducted in the University of Newcastle's Design Unit on a back-to-back gear test setup. The back-to-back gear test rig is based on the recirculating power loop principle, which ensures a constant torque level is applied to the tested gears while consuming very little power to drive them. The test rig is equipped to evaluate two identical gear sets with identical gear ratios. Two gearboxes are connected back-to-back via a flexible elastic shaft, which isolates the gears from vibration and prevents them from interfering with one another. Torque is applied using a van-type hydraulic torque actuator and communicated to the meshing gear sets via the shafts. The torque actuator is utilized in the test rig to allow for gradual torque application and maintenance while the rig is running via a closed electric/hydraulic loop control system. Motors are used to recycle and maintain lubricant temperature, as well as to direct lubricant to the mesh position of gear teeth. The experiment is undertaken at varied torque levels, from low to high, to ascertain the torque level and loading cycle at which micro pitting occurs and propagates. To maintain the test program's anonymity, the variable torque data are normalized as torque ratios. Gears are subjected to a constant rotational speed test. A test run of 8 million cycles is performed at each torque setting. After each loading stage and needed cycle run, a microscope (Nikon SMZ1500) is used to inspect the commencement and advancement of micro pitting on the tooth flank. At the conclusion of the test, the maximum profile deviation and effect of micro pitting are determined using a Holfler EMZ632 CNC gear measuring equipment.

This experiment yielded a few results. Micro pitting begins in the dedendum area of the pinion with a torque ratio of 0.5. This micro pitting is not progressive and remains in the dedendum area until the last test run is completed. However, micro pitting also occurs at the pinion addendum, as a result of gradual micro pitting at the wheel's dedendum. According to the profile deviation data, micropitting is less severe at the pinion dedendum than at the addendum area, but pits are deeper at the dedendum. This implies that the profile variation was caused by micropitting on the pinion dedendum. The tooth profile variation and micropitting of the wheel gear are greater than those of the pinion gear. From the root to the tip of the wheel, the wheel profile deviates. The commencing edge of the pinion tip relief may play a role in the initiation of micropitting at the wheel's dedendum. The analytical results indicate that the highest contact stresses and the thinnest specific film thickness occur at the addendum and dedendum of the pinion and wheel, respectively; the grinding cutting edges created by the tip relief of gear tooth profiles contribute to the initiation and propagation of micropitting in these areas.

Amarnath and Lee (2015) investigated surface contact fatigue failure in a spur geared system using tribological and vibration parameter analysis. They used two parallel steel shafts and two gears, a 0.75 kW direct current motor, an accelerometer, an eddy current brake, and a data gathering system to conduct the experiment. The experiment's objective is to conduct fatigue testing on a spur-geared system using various lubrication regimens. After running the spur gearbox for almost 30 hours, it was decided to conduct the trials. Fatigue testing were conducted for 8 hours per day for a total of 1200 hours. Vibration signals were captured at regular intervals while the load was 12 N m and the speed was set to 450 rpm. After post-processing the vibration signals in MATLAB 2008, vibration spectra and statistical features associated with faults were obtained. However, trials were stop every 200 hours for a variety of reasons. The primary reason is to obtain lubricant samples from the gearbox casing for oil