INVESTIGATION OF RAIN RESISTANT CHAIN LUBRICATION PERFORMANCE

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Thesis submitted to Center for Graduate Studies, Universiti Pertahanan Nasional Malaysia, in fulfillment of the requirements for the Degree of Master of Science (Mechanical Engineering)

2022

ABSTRACT

The bicycle chain is the medium of transferring the muscular power generated by the rider to the wheels to propel towards the finishing line. Chain lubrication plays an important role in friction management to achieve maximum efficiency. Every single link contributes to the sliding and rolling motion which requires optimized lubrication for maximum energy transfer. Racing under rain and dirt over a prolonged period can cause severe chain corrosion and then lead to chain break accident. This study aims to investigate rain resistant chain lubricant to have better water-repelling properties, more effective application and greater longevity. 5 types of lubricants commonly applied by riders were used as the sample in this study to compare the rain resistance performance. Therefore, understanding the working conditions such as the weather elements, environment temperature and contaminants are critical before investigating the characteristics and performance of the lubricant. Adreno chain lubricant achieved the lowest viscosity of 2.62 cSt at 100°C during testing using the ASTM D445 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids. Under the UV Light visual observation, the lowest viscosity lubricant filled up 110 links for the first test and 111 links for the second test under the observation of UV Light. Adreno chain lubricant also shows superior results in copper corrosion test compared to the commonly used mineral oil. In conclusion, Adreno chain lubricant's overall properties are significantly superior in all the testing condition and can potentially apply in other application that requires lasting and effective lubrication under challenging weather condition.

ABSTRAK

Rantai basikal menghubungkan sproket pemanduan dan pemacu untuk pemindahan tenaga. Pelinciran rantai memainkan peranan penting dalam mengurangkan geseran bagi mencapai kecekapan maksima. Setiap segmen rantai yang menggelongsor dan berputar memelukan pelinciran yang optimum supaya pemindahan tenaga dapat dimaksimumkan. Perlumbaan dalam keadaan hujan dan kotor boleh mengakibatkan kemalangan rantai putus yang disebabkan pengaratan. Kajian ini bertujuan untuk menghasilkan pelincir rantai yang mampu bertahan di dalam cuaca hujan melalui ciri-ciri tidak larut air, aplikasi yang lebih berkesan dan ketahanan yang tinggi. 5 jenis pelincir yang biasa digunakan oleh pelumba basikal digunakan sebagai sampel kajian. Setiap pelincir diformulasikan dengan campuran bahan, masing-masing mempunyai ciri-ciri khas. Oleh itu, keadaan semasa pengoperasian seperti suhu persekitaran dan bahan cemar perlu difahami sebelum melaksanakan ujikaji terhadap prestasi pelicir. Pelincir Adreno mampu mencapai kelikatan serendah 2.62 cSt pada 100 ° C semasa ujikaji menggunakan kaedah ujian piawai ASTM D445 Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids. Dalam pemerhatian visual sinar UV, pelincir kelikatan terendah mengisi 110 segmen rantai untuk ujian pertama dan 111 segmen rantai untuk ujian kedua di bawah pemerhatian sinar UV. Pelincir Adreno juga mempamerkan ketahanan tinggi berbanding dengan minyak mineral dalam ujian pengaratan kuprum. Kesimpulannya, sifat dan ciri-ciri Adreno mempunyai kelebihan dalam semua aspek ujian yang dijalankan dan berpotensi untuk digunakan pada aplikasi yang memerlukan sistem pelinciran yang berkesan dalam keadaan cuaca yang mencabar.

ACKNOWLEDGEMENT

First of all, I would like to express my sincere gratitude to Royal Malaysian Navy and National Defence University Malaysia for allowing me to pursue my tertiary level education. The whole process from documentation, thesis writing till presentation would not be possible without guidance from Dr Norwazan and Dr Ir Rosdzimin. I am also truly grateful to Irahasira binti Said for offering her insights for this thesis. It was a huge task to fulfil this thesis while holding the appointment as an Air Engineer at the Royal Malaysian Navy Air Wing Headquarters. Nevertheless, the reward tastes sweeter when the journey is bitter.

I am extremely thankful to my lovely wife Rebecca Reena Jori, for the love and support during testing times. I also place on record my sincere appreciation to everyone who had directly or indirectly offered me a helping hand in this venture. Learning is a lifelong journey; education is the key to success. The pursuit of knowledge is like an Ironman Triathlon; grit and consistency will surely bring us to the finishing line. Most importantly, giving up was never an option.

APPROVAL

The Examination Committee has met on **31st December 2021** to conduct the final examination of **Chan Jun Shen** on his master's degree thesis entitled **'Investigation Of Rain Resistant Chain Lubrication Performance'**

The committee recommends that the student be awarded the Master of Science (Mechanical Engineering).

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This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Mechanical Engineering).** The members of the Supervisory Committee were as follows.

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DECLARATION OF THESIS

Student's full name : Chan Jun Shen
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Title : Investigation of Rain Resistant Chain Lubrication Performance
Academic session : 2019/2020

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CHAPTER 1

INTRODUCTION

1.1 Background

The chain drive is one of the popular options in energy transmission because of the flexibility in application and advantages compared to other transmission systems. Chain drives are the oldest of basic machines elements and transportation industry, including bicycles (Lee & Priest, 2003). The design of the chain is comparatively straightforward and have been conceptually unchanged since the nineteenth century (Lodge et al., 2001). Chain drives are preferred in cycling for their high efficiency up to 98% and able to operate across every weather condition (Casteel & Archibald, 2013). Given the various elements exposed to chain transmission, proper maintenance through lubrication is crucial in ensuring the efficiency of energy transfer. One of the major threats for lubrication is the wash off by rainwater when the lubricant is exposed to the rain. Friction and wear are the fundamental phenomena faced by the mechanical moving parts that must be managed to achieve the desired performance.

Hence, more research on lubricants are required for friction and wear reduction to lengthen the operation life of the transmission system. Lubricants are regulated by standards applicable internationally and locally such as ASTM (American Standard of Testing Materials) or DIN (Deutsche Industrienorm). Both of the standards include the chemical and physical description of lubricants inclusive of material handling safety measures.

In the traditional lubricant market, the available lubricants are divided into two main categories which are oils and greases. One of the main properties difference between these two categories is viscosity. Such expositions are insufficient because of irregular properties during temperature change which cause the lubricant to fall between the two main categories. However, this challenge lies a great opportunity for improvement to enhance the properties of chain lubricant. The bicycle chain was taken as the sample in this study because of the huge application for bicycles in the transportation industry (H. H. Huang, 2014). This study seeks to investigate chain lubricant characteristic and properties to prolong the operational life and increase the efficiency of chain transmission. The finding also supports the sustainability of the system and environment through reduction of waste and increasing efficiency.

1.2 Problem Statement

The seamless operation and well-lubricated bicycle chain is the key to efficient energy transfer in the transmission system. However, the bicycle chain lubricant is exposed to contaminants which reduces the effectiveness of lubrication. The lack of lubrication leads to material failure and risks the operators with potentially catastrophic damage during operation.

In many long hours of operations, the lubricant is required to function effectively in any type of weather. Generally, the lubricants can perform fairly on a sunny day but poorly on a rainy day. Since the chain is exposed to rainwater and subject to dirt contamination, most of the oil-based market lubricants would wear out within a few hours of outdoor cycling. The contact with rainwater is causing the oil-based lubricant to separate from the chain surface; leaving the metal unprotected from moisture and oxidation which results in severe corrosion. Also, the weakening of corroded material affects the tolerance of the bicycle chain and causes poor energy transfer along the chain. During high power transfer, a corroded chain imposes high risk of broken chain accident that can negatively impact the cyclist. Since the chain is the hardest working mechanical part exposed to the elements, a basic understanding of lubrication and working condition parameters is important to formulate specific properties to optimize the performance of chain lubricant.

1.3 Significant of Research

This study will help to uncover the potential of having the combination features grease and oil like lubrication to overcome the limitations when exposed to wet weather. Thus, the finding in this study will redound an improved property for chain lubricant to perform in a wet weather environment and lasting effectiveness during operation. A few crucial properties were specially investigated to meet the outcome expectation, such as viscosity, copper corrosion, rain resistance and penetration performance. Hence, the great volume of market demand for chain lubricant effectiveness justifies the need for the revolution of chain lubrication through the enhancement of properties. This will help to increase the efficiency to save more raw material, cost and energy for better resource management.

1.4 Objectives

The objectives of this study are:

i. To investigate the properties of rain-resistant chain lubricant.

ii. To investigate the performance of rain-resistant chain lubricant.

1.5 Scope

In this study, bicycle chain with the narrowest gap measured was used as the sample for all the lubricant tests conducted. Full assembly of the chain includes the links, roller, side plates and pin. The main performance of lubricants being observed are viscosity, copper corrosion, water-resistance and penetration. The properties listed in the scope of study are the critical factors that influences the rain-resistant properties of the lubricant. All the tests were conducted in accordance with ASTM and DIN for result consistency. The test sequence was conducted based on an elimination process, starting from the water-resistance test as the primary criteria of elimination before the other tests were conducted.

1.6 Thesis Overview

This thesis is organized into five main chapters. Each chapter was structured to be well elaborated and completed. Chapter 2 outlines the literature review related to the study of chain lubrication. Test protocols and methods of sampling of the study are elaborated in Chapter 3. Chapter 4 includes the results collected and a comparison of properties and performance through experimental tests. Finally, Chapter 5 highlights the conclusion and identifies the limitations and also indicates the potential for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Chain Application

The chain is a simple yet reliable component that hardly needs to be improvised over the years. There has been increasing interest in chain drive development for conveying materials and timing purposes because of its cost efficiency to manufacture. Modern-day optimization focuses on validating functions and reducing frictions (Kux & Parsche, 2009). A chain can be applied for long and short distances, operate in a rough environment to withstand abrasive conditions and have very high efficiency.

The key aspect from the maintenance perspective is the robustness and relatively low maintenance cost that drives the huge market growth, especially in the bicycle industry (Roy et al., 2019). Bicycle's popularity is unquestioned, and the future of the industry is convincingly guaranteed with the recent innovation (Pucher & Buehler, 2017). The number of bicycles around the world is estimated to be more than 1 Billion units, and the chain is one of the very important components of every bicycle.

A bicycle chain is one of the primary components in a drive train to transfer muscular power to mechanical energy to move a bike forward, so the hope of marginal efficiency gains has driven the invention of various energy transfer mechanisms. Most bicycle drive train manufacturer produces chain with more than 100 links formed by side plates connected with rollers. The chain connects the driving and driven sprockets for energy transfer. Utilization of chain allows the development of gearing ratio for greater mechanical advantage, especially during the gear change to match their muscular power and the road inclination. Gear ratio selection is a significant factor in peak power production (Rylands et al., 2016). It helps the cyclist to achieve better efficiency by pedaling at a suitable cadence for variable speed. However, much uncertainty still exists in the study of the bicycle chain's performance because of the dynamic and complexity of the whole energy transfer system. The major proportion of literature reviews for chain application did not include the fundamental analysis of forces and energy transmission efficiency (Kidd et al., 1999).

2.2 Chain Efficiency

Every mechanical transmission system has its limitations and advantages. The study of mechanical efficiency encompasses lubrication, friction, and wear. Chain drives are the oldest of basic machines elements and transportation industry, including bicycles (Lee & Priest, 2003). The chain design is comparatively straightforward and has been conceptually unchanged since the nineteenth century (Lodge et al., 2001). Chain drives are preferred in cycling for their high efficiency, up to 98.6%, and operate across every weather condition (Berge & Pramanik, 2018). Another study found that cycling chain links that include pin and sleeve excluding rollers has an average efficiency of 98.8% (S. P. Zhang & Tak, 2020). Up to the present date, the chain is the most successful indirect drive system (Malizia & Blocken, 2020).

However, the chain drive is subjected to velocity fluctuations once it is elongated and requires regular lubrication. The load distribution from the tight to the slack side of the chain primarily depends on sprocket size, chain contacting surfaces, tooth pressure angle and the manufacturing material (Kidd et al., 1999). Studies were conducted to experimentally and theoretically quantify the chain drive efficiency (Spicer et al., 2001). It is known that utilizing the larger sprocket potentially boosts efficiency because of less frictional loss (Lodge & Burgess, 2004). The assumption among the research assessing chain drive efficiency is that friction makes up the major loss mechanism even though other losses exist along with the system. The chain wear by elongation will no longer align perfectly with the teeth of the sprocket. This elongation of chain pitches occurs when chain links consist of side plates and rollers being stretched by mechanical forces of the contacting sprocket teeth (Zhao et al., 2014). A chain also needs to be properly measured before being installed on the bicycle. The length must be optimum to match the gearing ratio. There should be no slack in the chain if the length is correct. Chain drives with a derailleur set-up are preferred in cycling for their high efficiency of up to 98.6% (Berge & Pramanik, 2018). However, the chain drive is subjected to velocity fluctuations once it is elongated and requires regular lubrication to function at high performance. Their operational fitness is gauged by the wear resistance of the roller drive train. (Metil'kov & Yunin, 2008). The chain wear by friction and elongation will no longer align perfectly with the teeth of the sprocket. Once exceed 3% limit, the chain has to be replaced (Piancastelli et al., 2014).

Further experimental investigations can study the irreversibility of deformation phenomena that occur when side plates and rollers are stretched by mechanical forces. The chain's elongation dampens the power transfer throughout constant cyclic loading due to the poor surface contact. A chain also needs to be properly measured before being installed on the bicycle to match the gearing ratio so that there would be no slack in the chain. The chain links articulate and reticulate multiple times throughout the start moving and static position in cycling, lubricant plays an important role in making the chain more efficient. Lubrication is significantly utilized in many systems, especially on moving surfaces to reduce erosion and friction loss (Aharonovich & Diesendruck, 2018).

Tribology's basic objectives are to contribute to the advancement of resources, energy and the environment. In the new era, the objectives have been expanded to "energy and material efficiency, emission reduction, shock absorption, reduce noise pollution, and enhance life quality" (S. wei Zhang, 2013). It was reported that 85% of lubricants are extracted from petroleum-based oils being used worldwide (Shashidhara & Jayaram, 2010). Applying an efficient lubricant can reduce the travelling time and lengthen the life of the drive train (Bill Michelsen & Provost-Craig, 2015). Furthermore, research on lubrication has great implications for the economy by reducing unnecessary wear of material in the industry because the loss of material on the scoring surface creates a higher coefficient of friction, which amplifies the wear rate. In this case, material loss occurs at the side plates, rollers, and pins of the chain. Another form of wear for metal is through oxidation and create a thin oxide layer on the chain surface. Despite this, the thin oxide coating creates a natural lubricant by allowing metal contact surfaces to shear under the application of load (Rengifo, 2015).

2.3 Tribology Theory

Tribology is a complex study because it encompasses the combined relation of friction, lubrication, and wear between two moving surfaces (P. Huang & Yang, 2014). Lubrication is achieved by introducing a layer of lubricant substance to reduce friction between contacting metal surfaces, and the role of lubricant is highly decisive. For instance, the common Coefficient of Friction values for metal-on-metal sliding ranging from 0.4-0.8 in the unlubricated system to below 0.1 for a well-lubricated system (Bill Michelsen & Provost-Craig, 2015).

The energy-efficient system is increasingly recognized as the priority in a transmission system, optimized lubricants is an option to boost energy conservation corresponding to mechanical systems in a broad scope of application (Liu et al., 2020). The bicycle chain has to be lubricated for continuing effectiveness. Thus, the fundamental of bicycle chain lubrication must be the utmost priority. Every lubricant is formulated with a mix of substances, and each serves a specific purpose to meet the requirement of working conditions. Therefore, understanding the working conditions such as the chain speed, environment temperature, and contaminants are critical before formulating the composition and substance of the lubricant. Friction, wear, and seizure of the chain can occur when the lubricating film fails. In the limited knowledge in friction and wear, plenty of randomly selected accelerated experiments were done with inappropriate bench tests and over-design to score the design's objective (Wilson, 1996). Frictional energy increases the heat of sliding surfaces, which has an impact in terms of oxidation rates, chemical reactivity and also local material properties.

Various Non-Destructive Tests can be conducted to evaluate the tribology. Properties of the material and lubricant can be tested without causing damage to the system's components. These tests are cost-effective because preventive measures can be taken before failure happen and also determine potential life extension of the equipment. Rapid and repeatability are the distinct advantage of Non-Destructive Testing that attracts industrial player to include it into the research and development.

2.4 Lubricant Composition

Lubricants are made of two major substances, base oil and additives. Generally, the choice of base oil depends on the properties required for the lubrication system. The additives are added to modify the properties so that they can be tailored to fit the requirement. The main performance parameter is viscosity, and its performance is highly dependent on the operating temperature (Wong & Tung, 2016).

Viscosity is the measure of resistance to the flow of a liquid that impacts the ability of the lubricant to be circulated on the contacting surface (Srivastava, 2014). Oils being the main ingredient of lubricant can be assigned into a few different categories, namely vegetable oils, mineral oils, and synthetic oils. Base-oil lubricants from animal fats or plant oils also have been produced because their properties tend to lubricate the moving parts of the machine (Zainal et al., 2018). Besides, this type of base oil is more environmentally friendly, biodegradable and low toxicity compared to mineral oils. Hence, the environmental aspect and application properties must be sustainable during the formulation phase of lubricant (Nowak et al., 2019). One of the significant lubricant applications is to act as a seal against dust, dirt and water (Singh et al., 2017). There are two types of lubricants; solid and liquid lubricants including oil-based type and emulsion-type (Xiong et al., 2019).

The selection of additives added into the base oil depends on the compatibility of base oil and the operating environment for optimized performance. In the current market, a huge number of advanced additives choices are available to suit the targeted application. For example, green additives have shown that 0.5wt% attapulgite nanofibers added into mineral oil effectively improve the tribological behaviour of mineral oil (Yu et al., 2021). The promising evolution of nanomaterials as lubricant additives also gaining attention in the engineering field. The major advantage of nanomaterials is the nanometer size range that fills up the friction interface, granting the combination of multiple properties, including anti-wear and extreme pressure additives as well as friction modifiers (Uflyand et al., 2019).

2.4.1 Vegetable Oils

The production process of vegetable oils involves the extraction of oil from the seeds. Vegetable oils are considered as the alternative to non-biodegradable petroleum-based lubricants because they are renewable and environmentally friendly (Prasad Chavidi & Gnanasekaran, 2017). However, vegetable oils are not widely used in industries due to the limitations of becoming rancid over a relatively short period. It also has lower oxidative stability and poor cold flow properties in a colder environment (Bill Michelsen & Provost-Craig, 2015).

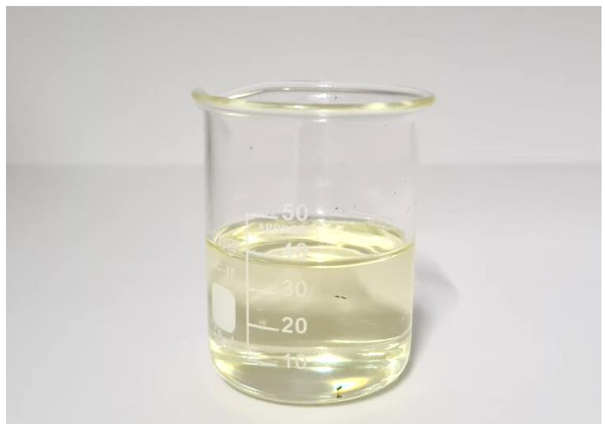

Figure 2.1 Vegetable oil filled in a beaker.

2.4.2 Mineral Oil

Mineral oil is a conventional product from various crude oil refining processes to remove wax and several deleterious substances, followed by advanced hydrogenation to produce base oil with superior quality and performance (Prince, 2010). It consists of a mixture of different hydrocarbons. Mineral oil is transparent and colourless oil composed mainly of alkanes and cycloalkanes. It is a liquid form at room temperature and retains its liquid form up to 100℃. The viscosity of mineral oil is almost constant and does not display extreme viscosity change as the temperature increase. Mineral oil also has a wide range of temperature stability and the ability to displace heat, making it a good option for a medium of heat transfer. Since it is an incompressible fluid, mineral oil also can be used as a hydraulic fluid to transfer energy. It solely uses mineral oil as chain drive lubricant offers great penetration between tight gaps between metal to metal surfaces because of its low viscosity. However, mineral oil gets removed from the metal surface during rainwater contact by gravity separation.

Mineral oil consists of 3 major elements, namely, aromatic, naphthenic, and paraffin. Aromatics are excellent for solubility. Naphthenic has very good low-temperature properties. Paraffin is highly preferred for its high viscosity index, low Sulphur content and inherent good oxidative stability. At cooler temperatures, oils tend to form wax crystals and reduce their fluidity (Nadkarni, 2007). Modern lubricants are mostly formulated from mineral oil and advance additives to achieve heat removal while minimizing friction. Recent research has found a positive effect of various additives on mineral oil's tribological performance. The tribological performance of nanocomposite as additive showed good synergistic friction-reducing and anti-wear results under the evaluation using ball-on-disk tribometer (Meng et al., 2018). In another study, TiO2 nanoparticles were added to study the friction on the chain transmission engine, resulting in a 58% decrease in internal friction torque compared to dry friction (Wozniak et al., 2020).