Faculty of Mechanical Engineering

VIBRATION CHARACTERISTICS ON BALL BEARING OPERATED WITH HEXAGONAL BORON NITRIDE NANOPARTICLES MIXED WITH CONVENTIONAL DIESEL ENGINE OIL

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in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled “Vibration Characteristic on Ball Bearing Operated with Hexagonal Boron Nitride Nanoparticles Mixed with Conventional Diesel Engine Oil” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :…….....

Name :…….....

Date :…….....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature :…….....

Supervisor Name :…….....

Date :…….....

DEDICATION

To ALLAH the Greatest in the World

To my dearest Emak, Abah and siblings,
Thank you for your support, love and patience,
To make my dream into reality.

To my supportive Supervisor,
Dr Rainah binti Ismail,
Thank you for your guidance, support and knowledge,
To change my life into a caliph.

To my friends Martini, Hajar, Wani, Faizah, Azrain, Muaz, Ain, Saidatul, Syafwan, Tino, Pak Herdy, Kak Husna, Kak Dayah, En Azhar, En Azrul, Kak Rusni and those who can't be mentioned here,

Thank you for walking along with me in this rough and tough journey together,
Every single memory will be craved in my heart.

ABSTRACT

Several developments on lubricants have been proven to reduce the friction and wear on mechanical parts. The addition of solid lubricants such as graphite, boric acid, graphene and nano-diamond showed an improved anti-wear, load- carrying and friction reduction. Therefore, as an environmentally friendly inorganic solid lubricant, hexagonal boron nitride (hBN) is chosen as an attractive performance-enhancing additive. hBN is widely used as lubricant additive, electrical insulators, materials part, aeronautics and space application. In addition, hBN nanoparticles also acts as promising additives to reduce wear and friction in tribology field. However, there is lack understanding about the performances of hBN nanoparticles in reducing the vibration characteristic on ball bearing. The aim of this research is to determine the vibration characteristics on ball bearing operated with hexagonal boron nitride (hBN) nanoparticles mixed with diesel engine oil types SAE 15W40 in the vibration monitoring condition field. This work is intended to determine the performance of hBN nano-lubricant as an additive in the reduction of rolling element bearing vibration amplitude. In this study,experimental works were conducted on the new and defected bearings submerged with different concentration of hBN nano-lubricants namely 0.0 vol.%, 0.1 vol.%, 0.2 vol.%, 0.3 vol.%, 0.4 vol.% and 0.5 vol.% of hBN nano-lubricants. The vibration characteristics were acquired using fabricated test rig, which consist of new and defected bearing, induction motor, unbalanced rotor, an accelerometer and data acquisition device. The vibration signal generated by the bearings were detected by an accelerometer placed at the top of the bearing housing measuring in vertical direction. The time waveform and amplitude spectrum were used in measuring the effect of hBN nano-lubricant on the vibration performance of the rolling element bearing. In the time waveform, the overall effect of hBN was investigated by determining the crest factor (CF) while the effect of hBN on specific faults such as outer race and inner race defects was investigated using the amplitude spectrum. The findings from the bearing vibration were supported by the tribological characteristics investigation such as wear scar diameter and agglomeration. From experimental work, 0.2 vol.% of concentration found was the optimum volume for new bearing and 0.4 vol.% of concentration of hBN gives the optimum volume of concentration for defected bearing in reducing vibration amplitude compared to the other volume of concentration.

ABSTRAK

Terdapat beberapa penambahbaikan terhadap minyak pelincir yang telah terbukti mengurangkan geseran dan haus yang terdapat pada bahagian-bahagian mekanikal. Penambahan minyak pelincir pepejal seperti graphite, boric acid, graphene and nano-diamond menunjukkan peningkatan kepada anti-haus, pembawa beban dan pengurangan geseran. Oleh itu, sebagai minyak pelincir pepejal bukan organic mesra alam, boron nitridaheksagon (hBN) telah dipilih sebagai pemangkin yang berprestasi. hBN juga digunakan sebagai pemangkin dalam minyak pelincir, penebat elektrik, bahagian mekanikal, aeronatiks dan aplikasi angkasa. Tambahan lagi, dalam bidang tribologi, hBN nanopartikel juga bertindak sebagai pemangkin yang member keputusan yang baik untuk mengurangkan geseran dan haus. Walau bagaimanapun, pelaksanaan hBN nanopartikel dalam mengurangkan getaran pada galas bebola masih mempunyai kekeliruan. Tujuan penyelidikanini adalah untuk menentukan ciri-ciri getaran pada galas bebola yang dikendalikan dengan menggunakan boron nitridaheksagon (hBN) nanopartikel bersama minyak enjin diesel iaitu SAE 15W40 dengan aplikasi kaedah pemantaun getaran. Penyelidikan ini adalah untuk menentukan prestasi hBN nanopartikel sebagai pemangkin untuk mengurangkan amplitude getaran unsur guling galas bebola. Keadah penyelidikan telah dijalankan pada galas bebola baru dan rosak yang direndam dengan kepekatan isipadu hBN yang berbeza iaitu 0.0 vol.%, 0.1 vol.%, 0.2 vol.%, 0.3 vol.%, 0.4 vol.% and 0.5 vol.%. Ciri-ciri getaran diperolehi daripada peralatan ujian yang telah dibangunkan dimana mengandungi galas bebola, alat pengesan dan data peranti pengambilalihan. Isyarat getaran yang dihasilkan oleh galas bebola baru dan rosak telah dikesan menggunakan alat pengesan yang diletakkan diatas permukaan kotak galas bebola diukur pada arah menegak. Bentuk gelombang masa dan amplitude spectrum telah digunakan untuk mengukur kesan pelincir-nano hBN terhadap prestasi getaran unsure guling galas bebola. Kesan keseluruhan pelincir-nano hBN disiasat dengan menggunakan factor rabung (CF) pada bentuk gelombang masa sementara kesan pelincir-nano hBN pada kerosakan tertentu seperti kerosakan pada dalam dan luar larian galas bebola telah ditentukan dengan menggunakan amplitude spektrum. Hasil-hasil penyelidikan yang diperoleh daripada getaran galas bebola telah disokong dengan pencarian ciri-ciri tribologi seperti "wear scar diameter" dan penggumpalan. Hasil mendapati bahawa kepekatan isipadu hBN yang optimum bagi mengurangkan amplitude getaran bagi galas bebola baru ialah 0.2 vol.% dan 0.4 vol.% adalah untuk galas bebola yang rosak berbanding dengan kepekatan isipadu yang lain.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CuO	-	Copper oxide
TiO_2	-	Titanium oxide
ZnO	-	Zinc oxide
ZnS	-	Zins sulphur
Li	-	Lithium
Na	-	Sodium
Ca	-	Calcium
Al	-	Aluminum
B-N	-	Boron- nitrogen
hBN	-	Hexagonal boron nitride
wBN	-	Wursitic boron nitride
cBN	-	Cubic Boron Nitride
IF	-	Inorganic fullerene
Al_2O_3/SiO_2	-	Alumina/Silica
COF	-	Coefficient of friction
CBM	-	Condition based monitoring
EEV	-	Energy-efficient vehicle
SEM	-	Scanning electron microscope
SN	-	signal to noise
DOE	-	Design of experiment
BPFI	-	Inner race ball pass frequency
BPFO	-	Outer race ball pass frequency
BSF	-	Ball spin frequency
FTF	-	Fundamental train frequency
RMS	-	Root mean square
FFT	-	Fast fourier transform

ANN	-	Artificial neural network
SVM	-	Support vector machine
EDX	-	Energy dispersive X-ray spectroscopy
DC	-	Direct Current
HD	-	Hydrodynamic lubrication
SI	-	International system of unit
FTIR	-	Fourier transform infrared spectroscopy

LIST OF SYMBOLS

ρ	-	Density
R_a	-	Surface roughness
F_f	-	Friction force
E	-	Young's Modulus
υ	-	Poisson's ratio

LIST OF PUBLICATIONS

JOURNAL PAPER

Apandi, N.S.R.,Ismail, R. andAbdollah, M.F., 2018. Numerical studies on vibration characteristics on ball bearing operated under hexagonal boron nitride (hBN) nanoparticles. Journal of Mechanical Engineering, 15(1), pp.84-97.

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CHAPTER 1

INTRODUCTION

1.1 Background study

A ball bearing is a round mechanical part, located between two elements comparative for each other, allowing comparative movement to occur among the elements through minimal friction. The primary function of a bearing is to ensure that free rotation of a shaft or axle occurs, with the least possible resistance. The bearing supports the axle shaft, holding it in place and the correct position. A rolling element bearing, is one of many types of bearings that providing mechanical support along with other machine components because the bearing can withstand high loads, high speeds, and having a longer lifespan.

However, this type of bearing has very complicated dynamic behaviour due to the number of rolling element except for the fixed outer race or inner race (Yadav et al., 2013). Due to the operating continually over extended periods of time, and often under high speed and high load conditions, early deterioration will often occur because of the continual rubbing against other parts, sections or adjacent components. The rubbing happens due to the development and occurrence of dry friction, causing measurable wear and tear of moving parts, coupled with unbalanced forces and couples with machine components, often causing, if not contributing to machine breakdown. Thus, the application for a suitable lubricant oil to reduce bearing friction, wear, corrosion and failure, in general, is essential. The lubricant is a combination of 90 % base oil and 10 % of

additives in a liquid form. Lubricant additives which contains the friction modifiers are commonly used to enhance the energy efficiency and lubricity as well as to alter the friction characteristics. In addition, friction modifiers can increase and sustain the friction to a required phase used in lubricating structures such as automatic transmission fluid (ATF), but also in lubricating structures such as gear oils and engine oils, it can decrease the coefficient of friction. (Tang and Li, 2014).

As nanoscience and nanotechnology advance, researchers are presently developing new and improved lubricants with the addition of nanoparticles by means of an effective friction modifiers to increase their performance regarding tribological factors (Bakunin et al., 2004). In the last few years, because of the need of reducing green-house effect and improving the petroleum economy, nanoparticles are acknowledged as a green technology and recognised as being environmentally friendly. Therefore, the advantages of using small sized of nanoparticles within the range of 0.50 nm and above as an additive for example boron nitride (BN), graphite, molybdenum disulphide (MOS_2), mica, and polytetrafluoroethylene (PTFE)used as an additive in lubricants have been recognised by the researchers. Nevertheless, these nanoparticles take a probability to agglomerate throughout the usage due to their comparatively bulky size and the tribological properties stay in poor condition in the existence of oxygen and humidity, thus it give limitation for the practical application (Coppin, 2002; Savage and Schaefer, 2012).

Past researchers have been conducted the studies regarding with the addition of nanoparticles acted as friction modifiers with the size of 2–120 nm in the lubricants used for capably reducing friction and wear. Above all, the sources of metal,carbon compound, metal sulfide, metal oxide, metal carbonate, metalborate, silicon oxide and rare earth compound for nanoparticles have been considered (Sunqing and Engineering, 1999;

Bakunin et al., 2004)and found that the tribological properties as friction modifiers were reliant for degree of crystallinitysuch as size, defect, concentration and shape (Bakunin et al., 2004).

Nanoparticles are frequently found in tribo-technology given their benefits as a lubricant additive, reducing wear and friction, as well as the ball and rolling effect, polishing effect and mending effect. There are several types of nanoparticles in use, for example copper nitride (CuO), titanium dioxide (TiO_2), zinc oxide (ZnO), zinc sulphide (ZnS) and hexagonal boron nitride (hBN). All these nanoparticles were observed as efficient in improving tribological properties. This nano-lubricant also actively reduced the wear rate of materials and this shows good quantitative agreement with coefficient of friction by dispersing the nanoparticles mixed with the conventional diesel engine oil.

The advantages of using hexagonal boron nitride (hBN) powder are that it will disperse easily in lubricating oil, grease, water and solvents. When mixed with water and binders, it will apply like paint for lubricity coating. Due to its inherent strong thermal resistance, hBN can also be used as an additive for high-temperature lubrication. In powder form, hBN can be sprayed or sprinkled onto hot surfaces to provide dry lubricity whereas in the manufacturing of electrical insulators, hBN is used as an electrical insulator in electronic componentry as a substrate for semiconductors. However, there have only a few evidences of any significant research currently available that study the potential of using hexagonal boron nitride (hBN) nanoparticles as an additive in diesel engine oil. Abdullah et al. (2013) have studied the hexagonal boron nitride (hBN) used as an additive mixed with conventional diesel engine oil SAE 15W40. They found that the coefficient of friction (COF) and wear scar diameter have been significantly reduced by mixing several concentrations of hBN nanoparticle with the conventional diesel engine oil. Their findings

showed that hBN has great potential to be explored including study toward condition - based monitoring.

Condition-based monitoring (CBM) consists of continuously evaluating the condition of a monitored machine and thereby successfully identifying faults before catastrophic breakdown occurs. Numerous condition monitoring and diagnostics methodologies were used to identify the machine faults to take corrective action. Machine fault identification can be done with different methodologies such as vibration signature analysis, lubricant signature analysis, noise signature analysis, and temperature monitoring, with the use of appropriate sensors, different signal conditioning, and analyzing instruments (Jayaswal et al., 2008). Vibration analysis techniques are the most well-known technique based on the principle that all components produce vibration for the machine and it is more versatile as it can reveal wider range of faults for the early deterioration or malfunction in machinery. The condition of faults such as rotor unbalance, rotor bends, cracks, rubs, misalignment, bearing defects and fluid induced instability can be predicted by using the vibration analysis. In bearing defects, the signals of bearing failure and type of device are the most important measures for the vibration monitoring of the bearing (Sidar et al., 2015).

Hence, this study was conducted to investigate the vibration characteristics on ball bearing when operated with hexagonal boron nitride nanoparticles mixed diesel engine oil by using CBM approach through vibration analysis.

1.2 Problem statement

Machine components including gears and bearings operates at high speed and high load condition. These extreme conditions exert pressure and vibration on the working

system. Over time, these effects can have long-term as well as short-term damaging effects on the system. Therefore, a lubricant is required to reduce the temperature, vibration and extreme pressure. The additives present in the lubricant can reduce the friction and wear between contacting surfaces. In recent years, the application of nanoparticles used as an additive for the lubricant such as TiO_2, CuO, ZnO, ZnS and hBN has received considerable attention due to its wide important role especially in improving engines performances and efficiency. However, most of these nanoparticles are costly to prepare, low stability and low thermal conductivity compared to hBN nanoparticles (Yu and Xie, 2012). Thus, it is important to develop a better understanding on the performance of hBN nanoparticles that functioning as a lubricant. This nanoparticle has been proven strong influence in reducing wear rate of materials and also showed good quantitative agreement in coefficient of friction by dispersing in conventional diesel engine oil. However, until now, none of this research has provided clarification of hBN performance for reduction in vibration amplitude. Therefore, one of the motivations for this project is to provide an extension to the performance study of currently available hBN nanoparticles when mixed with diesel engine oil. In this research project, the vibration suppression characteristics of ball bearing supplied with hBN nanoparticles additives in engine oil will be investigated.

1.3 Objectives

The objectives of this project:

- To investigate the vibration characteristics of ball bearing immersed in diesel engine oil mixed with hBN nanoparticle;

- To determine the optimum volume of concentration of hBN nanoparticles mixed with diesel engine oil in reducing the vibration amplitude on ball bearings;
- To determine the tribological properties of the hBN nanoparticles mixed lubricant.

1.4 Scopes of study

The scope of this study is to achieve the objectives of this thesis by:

- Prepare the hBN-nano lubricant samples with different percentage of volume concentrations by using ultrasonic homogenizer techniques;
- Develop the ball bearing test rig and conduct an experimental work for vibration measurement using the vibration testing;
- Determine the material characteristics of hBN nanoparticles by using the scanning electron microscope (SEM) and Fourier Transform Infrared (FTIR) Spectroscopy.

1.5 Thesis outline

The thesis investigates and describes the performance of hBN mixed diesel engine oil, in relation to vibration characteristic on ball bearings, and is structured, as follows:

• Chapter 1 (Introduction)

This chapter introduces the importance, function and types of ball bearings together with the importance of emerging nanotechnology applied to lubricants as an additive. This chapter also includes the problem statement, objectives and scopes of this study.

• Chapter 2 (Literature Review)