UNIVERSITI TEKNIKAL MALAYSIA MELAKA

VIBRATION ANALYSIS FOR GEAR BACKLASH ON SPUR GEAR

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Maintenace) with Honours.

by

AHMAD FIRDAUS BIN MOHD SULONG

B071510671

940204-11-5441

FACULTY MECHANICAL AND MANUFACTURING ENGINEERING TECHNOLOGY

2018

© Universiti Teknikal Malaysia Melaka

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: Vibration Analysis for Gear Backlash on Spur Gear

Sesi Pengajian: 2018

Saya **AHMAD FIRDAUS BIN MOHD SULONG** mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (X)

☐	SULIT*	Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972.
☐	TERHAD*	Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan.
☒	TIDAK TERHAD	

Yang benar,

.....

AHMAD FIRDAUS BIN MOHD SULONG

Lot 6909,Taman Sungai Bajar,

21700 Kuala Berang, Terengganu

Tarikh:

Disahkan oleh penyelia:

.....

KHAIRUL AMRI BIN TOFROWAIH

Cop Rasmi Penyelia

Tarikh:

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

© Universiti Teknikal Malaysia Melaka

DECLARATION

I hereby, declared this report entitled Vibration Analysis for Gear Backlash on Spur Gear is the results of my own research except as cited in references.

Signature: ……

Author : AHMAD FIRDAUS BIN MOHD SULONG

Date :

© Universiti Teknikal Malaysia Melaka

APPROVAL

This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Maintenace) with Honours. The member of the supervisory is as follow:

Signature: .....

Supervisor: KHAIRUL AMRI BIN TOFROWAIH

Signature: .....

Co-supervisor: KHAIRIL AMRI BIN KAMARUZZAMAN

© Universiti Teknikal Malaysia Melaka

ABSTRAK

Gear memainkan peranan penting untuk penghantaran kuasa antara dua mesin yang berlainan dan juga sebagai pengubah kelajuan dengan mengubah kadar nisbah pusingan gear kepada lebih rendah atau lebih tinggi bergantung kepada keperluan mesin. Penghantaran kuasa tidak boleh dihantar dengan jitu dan efektif jika terdapat kerosakan yang berlaku kepada gear. Oleh itu, kajian ini memberi tumpuan kepada kerosakan yang berlaku disebabkan oleh ruang kosong dikenali sebagai "normal backlash" pada belakang gigi gear yang tidak aktif. Tujuan kajian ini dijalankan adalah untuk menganalisa gegaran oleh spur gear disebabkan oleh "backlash" terbabit menggunakan frekuensi analisis. Selain itu, kajian ini juga tertumpu kepada kesan yang berlaku akibat dari jarak yang dihasilkan oleh "backlash" pada spur gear tersebut berdasarkan getaran terhasil daripada fenomena tersebut. Kaedah yang digunakan untuk menjalankan eksperimen ini dirujuk berdasarkan ANSI/AGMA 2002-C16 yang membincangkan tentang kadar jarak yang perlu digunakan pada "gear backlash". Getaran diukur dengan menggunakan "Vibrometer" dan menggunakan unit pecutan (m/s^2). Tiga variasi index diukur dalam kajian ini iaitu 0.003", 0.004" dan 0.005". Getaran yang paling direkodkan adalah di 0.003" dan 0.005". Getaran pada 0.004" menunjukkan getaran yang sedikit. Ini menunjukan yang "backlash" haruslah tidak terlalu rapat dan tidak terlalu jauh supaya pelincir dapat disalurkan pada gigi gear untuk mengurangkan geseran.

© Universiti Teknikal Malaysia Melaka

ABSTRACT

Gear plays important role for power transmitted between two machines and as well as the speed changing by changing the gear ratio whether to use high ratio or low ratio depends on the machine application. The power transmitted cannot be delivered at high efficiency and effectively if there is defect occur at the gear. The purpose of this study is to analyse the vibration of spur gear on normal backlash defect by using frequency analysis. Next, the objective is to observe the outcome of changing the spur gear backlash on the vibration response through the experiment. The method use for spur gear backlash experiment is based on the ANSI/AGMA 2002-C16 which discussed about the tooth thickness and backlash measurement of cylindrical involute gearing. Vibration measured using Vibrometer and the unit scale is acceleration (m/s^2). Three variation index of backlash which is 0.003", 0.004" and 0.005" has been tested. The high vibration recorded is at 0.003' and 0.005". The 0.004" shows a low vibration than the others. This shows that the backlash must be in perfect index, not too closes and not too wide in order to create a flow between the teeth gear to avoid the friction from direct contact.

© Universiti Teknikal Malaysia Melaka

DEDICATION

To my beloved parents, Mohd Sulong Bin Hussin and Mariam Binti Ibrahim and siblings for their prayers to me until I can finish this research with flying colour. I also dedicate my work for my supervisor, co-supervisor and friends for never ending supported and additional idea for me throughout this research to finish this research.

© Universiti Teknikal Malaysia Melaka

ACKNOWLEDGEMENTS

Alhamdulillah, all thanks should be praise to Allah as He help and ease me so much to complete this project successfully. This research project won't be complete without people surrounding me who give a lot of support and help.

Respect, love and thanks to my family members – my father, my mother who gave so much moral support throughout this process. Not forgotten for my siblings who encourage me a lot. Thanks for your understanding and support.

I would like to thanks my supervisor, Khairul Amri bin Tofrowaih who guide me and help me throughout this whole process of completing this research project. He also helped me so much and gives his best despite having a lot of works and responsible to deliver. Without him, I do believe that this project won't complete.

I would like to also thank to all my friends who help me by discussing this project. Thank you to all the people who get involved with this project. I do wish this research would be helpful for future reference.

Thank you.

© Universiti Teknikal Malaysia Melaka

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS ii

LIST OF TABLES vi

LIST OF FIGURES vii

LIST OF APPENDICES x

LIST OF ABBREVIATIONS xi

CHAPTER 1 INTRODUCTION 1

1.0 Introduction 1

1.1 Background of Study 1

1.2 Problem Statement 3

1.3 Objectives 5

1.4 Scopes 5

CHAPTER 2 LITERATURE REVIEW 6

2.0 Gear as a Power Transmitter 6

2.1 Spur gear 8

2.1.1 Spur gear nomenclature 9

2.2 Vibration 11

2.2.1 Vibration Severity 12

© Universiti Teknikal Malaysia Melaka

2.2.2 Vibration analysis 15

2.2.2.1 Frequency Analysis 16

2.2.2.2 Spectrum Analysis 18

2.3 Defects 24

2.3.1 Backlash 24

2.3.1.1 Types of backlash 26

2.3.1.2 Calculation of Backlash 28

2.3.1.3 Backlash limit 30

2.3.1.4 Center Distance 31

2.3.1.5 Gear Rattles 32

2.4 Lubrication 33

2.4.1 Grease 33

2.4.2 Oil Lubrication 34

CHAPTER 3 METHODOLOGY 35

3.1 Flow Chart 35

3.2 Sample and Equipment Preparation 36

3.2.1 Standard V belt 36

3.2.2 V Belt Pulley 37

3.2.3 Motor 37

3.2.4 Spur gear 38

3.2.5 Dial Indicator 39

© Universiti Teknikal Malaysia Melaka

3.2.6 Accelerometer 40

3.3 Experiment setup 42

3.3.1 Vibrometer setup 42

3.3.2 Experiment Machine setup 42

3.3.2.1 Measuring the backlash 43

3.3.2.2 Motor foundation stabilization 44

3.3.2.3 V belt tension 45

3.3.2.4 Align the shaft 46

3.3.2.5 Backlash setup 46

3.3.2.6 Lubrication 47

3.3.2.7 The Whole Experiment Diagram 48

3.3.2.8 Preliminary Results 49

CHAPTER 4 RESULT AND DISCUSSION 50

4.0 Result and analysis 50

4.1 Result and analysis with oil lubrication 50

4.1.1 0.003” backlash index 50

4.1.2 0.004” backlash index 51

4.1.3 0.005” backlash index 52

4.2 Result and analysis with grease 55

4.2.1 0.003” backlash index 55

4.2.2 0.004” backlash index 56

© Universiti Teknikal Malaysia Melaka

4.2.3 0.005” backlash index 57

4.3 Frequency Analysis 60

4.3.1 Backlash on gear using oil lubricant 60

4.3.2 Backlash at Pinion using oil lubricant 62

4.3.3 Backlash at gear using grease 63

4.3.4 Backlash at pinion using grease 65

4.4 Comparison analysis 66

CHAPTER 5 CONCLUSION AND RECOMMENDATION 71

5.0 Conclusion 71

5.1 Project potential 72

5.2 Recommendations 72

REFERENCES 73

APPENDICES 76

© Universiti Teknikal Malaysia Melaka

LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1:	Vibration severity index	**10**
Table 2.2:	Vibration index evaluation zone	**10**
Table 2.3:	Machinery class in vibration index	**11**
Table 2.4:	AGMA standard for allowable and tolerance	**24**
Table 2.5:	AGMA standard for backlash range	**24**
Table 3.1:	Specification of Classic V-Belt	**27**
Table 3.2:	Specification of spur gear	**29**
Table 4.1	0.003” backlash vibration rate	**50**
Table 4.2	0.004” backlash vibration rate	**51**
Table 4.3	0.005” backlash vibration rate	**52**
Table 4.4	0.003” backlash vibration rate	**55**
Table 4.5	0.004” backlash vibration rate	**56**
Table 4.6	0.005” backlash vibration rate	**57**
Table 4.7	Gear backlash vibration rate towards frequency	**60**
Table 4.8	Pinion backlash vibration rate towards frequency	**62**
Table 4.9	Gear backlash vibration rate towards frequency	**63**
Table 4.10	Pinion vibration rate trends using grease	**65**
Table 4.11	Peak and lowest vibration rate using oil lubrication	**66**
Table 4.12	Peak and lowest vibration rate using grease	**67**

© Universiti Teknikal Malaysia Melaka

LIST OF FIGURES

FIGURE	TITTLE	PAGE
Figure 2.1:	Gear boxes	7
Figure 2.2:	Illustration of simple gear train	7
Figure 2.3:	Illustration of compound gear train	7
Figure 2.4:	Illustration driver and driven gear concept	8
Figure 2.5:	The single spur gear nomenclature	9
Figure 2.6:	Meshing spur gear nomenclature	10
Figure 2.7:	Stress-strain diagram	11
Figure 2.8:	Bolt deterioration cause by vibration	12
Figure 2.9:	Illustration transformation from time domain to frequency domain	17
Figure 2.10:	Difference of time domain and frequency domain	17
Figure 2.11:	Illustration of vibration signal transfer process	18
Figure 2.12:	Elements in spectrum analysis domain	19
Figure 2.13:	Normal gear mesh spectrum	20
Figure 2.14:	Gear tooth wear spectrum	20
Figure 2.15:	Gear tooth load spectrum	21
Figure 2.16:	Gear backlash spectrum	21
Figure 2.17:	Gear misalignment spectrum	22
Figure 2.18:	Gear cracked or broken tooth spectrum	23
Figure 2.19:	Gear hunting tooth spectrum	23
Figure 2.20:	Illustration of gear backlash	25

© Universiti Teknikal Malaysia Melaka

Figure 2.21:	Illustration of normal and circumferential gear backlash	26
Figure 2.22:	Illustration of angular backlash	27
Figure 2.23:	Illustration of radial backlash	27
Figure 2.24:	Illustration of axial backlash	28
Figure 2.25:	Equation of operating pitch diameter	28
Figure 2.26:	Equation of circular tooth thickness	29
Figure 2.27:	Equation of transverse gear backlash	29
Figure 2.28:	Center distance positioning	32
Figure 2.29	Influence of shear rate on viscosity	34
Figure 2.30	Oil splash method	34
Figure 3.1:	Classic V type belt	36
Figure 3.2:	Driver pulley	37
Figure 3.3:	Driven pulley	37
Figure 3.4:	Alternating Current (AC) motor	38
Figure 3.5:	Name plate of AC motor	38
Figure 3.6:	Experimental simple gear train	38
Figure 3.7:	Dial indicator	40
Figure 3.8:	Flexural accelerometer	41
Figure 3.9:	Accelerometer mounting location	41
Figure 3.10:	Vibrometer	42
Figure 3.11:	Section A of experiment	43
Figure 3.12	Section B of experiment	43
Figure 3.13	Measuring backlash using dial indicator	44
Figure 3.14	Shim located for unbalanced motor	45

© Universiti Teknikal Malaysia Melaka

Figure 3.15	Tension meter	45
Figure 3.16	Bolt adjusting location for backlash	46
Figure 3.17	Oil level for gear lubrication	47
Figure 3.18	Manual Grease Gun	48
Figure 3.19	Illustration of experiment assembly	48
Figure3.20	Preliminary result for normal gear at 1500rpm	49
Figure 3.21	Preliminary result for normal gear at 1200rpm	49
Figure 4.1	Vibration rate graph trends of 0.003’ backlash	51
Figure 4.2	Vibration rate graph trends of 0.004” backlash	52
Figure 4.3	Vibration rate graph trends of 0.005” backlash	53
Figure 4.4	Vibration rate graph trends of 0.003” backlash	56
Figure 4.5	Vibration rate graph trends of 0.004” backlash	57
Figure 4.6	Vibration rate graph trends of 0.005” backlash	58
Figure 4.7	Gear vibration rate trends using oil	61
Figure 4.8	Pinion vibration rate trends using grease	62
Figure 4.9	Gear vibration rate trends using grease	64
Figure 4.10	Pinion vibration rate trends using grease	65

© Universiti Teknikal Malaysia Melaka

LIST OF APPENDICES

APPENDIX	TITTLE	PAGE
Appendix 1	Gantt Chart Final Year Project 1	75
Appendix 2	Gantt Chart Final Year Project 2	76
Appendix 3	Calculation on gear and pinion for speed and frequency	77

© Universiti Teknikal Malaysia Melaka

LIST OF ABBREVIATIONS

RPM	Revolution per minute
FFT	Fast Fourier Transform
Hz	Hertz
ISO	International Organization for Standardization
Apps	Application
CPM	Cycles Per Minute/unit
CBM	Condition Based Monitoring
RCA	Root Cause Analysis
GMF	Gear Mesh Frequency
Hp	Horsepower
kW	Kilowatt
AGMA	American Gear Manufacturer Standard
PUR	Polyurethane
AC	Alternating Current
PC	Personal Computer
mm	millimetre
kg	kilogram
FCM	Fault Condition Monitoring

© Universiti Teknikal Malaysia Melaka

CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter will cover subtopic of background, problem statements, objectives and scope of the study. The background of the topic is a short introduction and briefing about the project title which includes vibration analysis, frequency domain, and spur gear backlash.

1.1 Background of Study

Gear is considered one of the greatest inventions made by human. Its purpose is to simplify human work and make the work to run smoothly in the industry. H. P. Bloch and F. K. Geitner define gear as a machining element that it functions is to deliver the motion by engaging teeth (Heinz P. Bloch, 1997). That means, the gear depends on the teeth to move the motion in order to deliver the power to other components or parts. Dr. P. Arulmozhi stated that gear is the most effective methods to transmit power by using rotary motion concept from the main power source by variation of speed whether increase the speed or decrease the speed, depends on its application (Dr. P.Arulmozhi, 2017).

Gears commonly used in the automotive industry as its function is to deliver the motion and transfer the torque by changing the ratio which is depends on application whether to use high ratio or low ratio. There are many types of gear that has been created such as spur gear, helical gear, bevel gear, and worm gear. Each types of those

© Universiti Teknikal Malaysia Melaka

gear works in different assembly condition, for example the spur gear function is to deliver the power at horizontal axis while bevel gear use to transmit power at 90° angle, but still their purpose is same which is transmit the torque and deliver the motion. The advantages of gear as power transmitter are it has low slip, has high efficiency delivering, easy power transmission and can transmit motion between non-parallel intersecting shafts. The application of gears can be seen at the hoist, watches, lathes and milling machines.

There are many methods to measure the gear defects or failure and its mean time before it reach failure period such as vibration analysis, thermal analysis, and noise analysis. It makes easier to predict the maintenance that need to be applied on machine based on its current condition which is condition based maintenance (CBM) instead of conventional method that use physical sense to monitor the condition of machine or equipment such as eye sight or touch for vibration. The conventional method more towards run to failure principle and do not have exact data and information of the machine. The disadvantages of conventional method are, it is unpredictable where the worker cannot predict the next maintenance for equipment replacement or overhaul. This brings difficulties in order to anticipate when the manpower and parts will be needed for maintenance. The other disadvantage is high risk especially when it involve with high pressure, temperature and dangerous fluid. It could possibly cost employee life and people around the plant. So, the predictive maintenance through condition based monitoring is one of the efficient methods to monitor the performance of the machine throughout its lifespan. The vibration analysis is a type of diagnostic in order to detect the failure through abnormal reaction from the system or machine. G. Vachtsevanos indicates that there are three main aspects in diagnostic which started

© Universiti Teknikal Malaysia Melaka

with detection, second is isolation and lastly is quantify the fault (George Vachtsevanos, 2006). The vibration of the machine can be measured using vibrometer which appeared the scale of vibration in respect of acceleration unit.

There are many defects that occur at the gear which lead to vibration and one of them is backlash. Backlash is a defect that related with clearance that located at the back of non-operation or non-contact tooth. N. M. Ghazaly et al has proposed that the backlash can be defined as the excess thickness space of a tooth compared to the conjugated tooth thickness (Nouby M. Ghazaly, 2014). In other words, the gear backlash is a huge gap that occurs between the teeth at the backside of it. C. H. Wink proposed that the factors of backlash are due to gear run-out, gear mesh misalignment due to deflections, circular tooth thickness clearance and center distance drift away (Wink, 2016).

1.2 Problem Statement

The vibration is the most common problem occurs on the machine and it can be a method of problem detection on the machine by using vibrometer equipment. The vibration can affect the performance of machine in term of efficiency. There are many defects that can be related to gear caused by vibration and one of them is gear backlash. It is essential to determine the clearance of backlash that produces high vibration based on vibrometer reading.

According to N. M. Ghazaly et al, generally gears are being designed to operate at center distance to introduce backlash in order to accommodate space constraints and geometry changes due to thermal growth but due to misalignment and other faults, the center distance is drifted away not as it designed for (Nouby M. Ghazaly, 2014). The

© Universiti Teknikal Malaysia Melaka

gear backlash is depends on the center distance, if the center distance is out of it original position, the backlash will become liability and will affect the machine performance or system. S. Liu et al has indicates that the transmission backlash is one of the factors that affect the stability of the system (Shuang Liu, 2017).

Ernesto Rocca and Ricardo Russo indicate that the lightly loaded gear may experience the vibro-acoustic phenomenon known as gear rattles when they oscillate within their backlash gap (Ernesto Rocca, 2011). The gear rattles is an acoustic sound that produced when the unloaded gear undergo backlash movement, this sound will affect the vibration monitoring process as accelerometer is very sensitive to internal distraction.

Excessive vibration will produced if there is no lubrication as a third medium of gear movement. The excessive vibration can bring damage to machine and can cause a high risk of hazard to the worker. So lubrication is one of the ways to overcome the vibration. The oil and grease are two types of lubrication with different uses. These two types of lubrication produce different result in vibration experiment. These two lubrications have its influences on the backlash vibration.

© Universiti Teknikal Malaysia Melaka

1.3 Objectives

Based on the problem statement discussed above, the objectives of this study are listed below:

1. To analyse the differences of vibration rate between the lubrication oil and grease on the backlash.
2. To observe the effect of gear backlash from its lowest index to highest index which from 0.002” to 0.005”.

1.4 Scopes

The experiment will be conducted at Vibration Laboratory located at factory 1 using backlash frame. The allowable and limits of spur gear backlash use are from 0.002" until 0.005" based on changed of center distance. The process of investigating the spur gear backlash is by using vibrometer which its limitation for acceleration peak rage is from 1.0 m/s^2 to 199.9 m/s^2, and its vibration reference based on the ISO 10816 vibration severity. The sensor for vibration detection is by using Flexural Accelerometer. The experiment use oil and grease as lubrication.

© Universiti Teknikal Malaysia Melaka

CHAPTER 2

LITERATURE REVIEW

2.0 Gear as a Power Transmitter

In the past two decades, there are many studies on gear aim to gain better improvement in terms of minimizing the defects and to achieve high efficiency of performance. Gear use to deliver the motion and also as a power transmitter. Gear has high efficiency in term of delivering the power because it has very less percentage of slip. G. Bagade et al describes that gear function is for power transmission and with other application depends on the work requirement (Ganesh Bagade, 2017). Gears is a rotary part that tends to delivered the power or motion and change the speed of motion by gear ratio through engaging between two meshing teeth. Gear train is a concept that has been implemented for gear assembly. R. L. Norton indicates the gear ratio measurement influence the assembly of gear train based on the work application and requirement (Norton, 1999). Gear train works based on the ratio that has been measured for the industry use, whether to have high torque or the low torque depends on the industry application. Gear train usually can be seen in the vehicles gear box as shown in Figure 2.1. There are two types of gear train which is simple gear train and compound gear train as shown in Figure 2.2 and Figure 2.3 respectively. Basic gear train moved by two major gear which is driver gear and driven gear as shown in Figure 2.4. The driver gear is the gear that connects to the power source for first rotation motions while the driven gear, also known as pinion is a gear that meshes with drive gear to deliver the

© Universiti Teknikal Malaysia Melaka