

**PROJECT COMPLETION REPORT
FOR
SHORT TERM RESEARCH GRANT**



**IDENTIFICATION OF DEFECTS IN ROTATING GEARS USING
VIBRATION HEALTH MONITORING SYSTEM**

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ABSTRACT

The purpose of this research is to study wear mechanism and propagation of gear rotating components. The gear test rigs are design and develop for on-line vibration health monitoring system. This research exhibit the effects of wear propagation over time toward vibration level in a system using vibration analysis, in order to detect defects of rotating gears. The vibration signals of helical gear were collected and then analyzed using Fast Fourier Transform (FFT) technique. During the experiment, the sample of gear lubricant was collected in order to investigate the quality of wear characterization of the rotating gear. The lubricant is analyzing using wear debris analysis. Besides, the particle sizes of debris are also measured. From the study, it was found that the maximum amplitude of GMF value is 1.124 mm/s when 30 kg of load is applied to the rotating gear. The value is influenced by the occurrence of the debris and contaminant in the gear lubricant. The ferrous particle that presented show the certain wear mechanism happen on helical gear.

TABLE OF CONTENTS

Acknowledgement	i
Abstract	ii
Table of Contents	iii
List of Tables	v
List of Figures	vi
Chapter 1	1
Introduction.....	1
1.1 Background	1
1.2 Problem Statements.....	2
1.3 Objectives.....	3
1.4 Scope of Study	4
Chapter 2.....	5
Literature review	5
2.1 Introduction	5
2.2 Defect Mechanism and Propagation	6
2.3 Vibration Analysis.....	9
Chapter 3.....	13
Methodology	13
3.1 Introduction	13
3.2 Gear Test Rig Development.....	13
3.3 Experimental Design Configurations	15

3.4	Vibration Data Measurement	16
3.5	Wear Debris Analysis.....	17
Chapter 4.....		20
Result and discussion.....		20
4.1	Vibration Analysis Result	20
4.2	Wear Debris Analysis.....	23
Chapter 5.....		31
Conclusion and recommendation.....		31
5.1	Conclusions	31
5.2	Recommendation.....	32
References.....		34
BIBLIOGRAPHY.....		36

LIST OF TABLES

Table 1: Type of adhesion.....	7
Table 2: The vibration severity based on ISO standard 2372.....	12
Table 3: Experimental configuration	16
Table 4: Result of GMF value	21
Table 5: Wear debris analysis result	27

LIST OF FIGURES

Figure 1: The frequency spectrum in the beginning of the experiment.....	10
Figure 2: The frequency spectrum after two weeks operation.....	11
Figure 3: The schematic design of test rig.....	14
Figure 4: Gear rotating test rig.....	14
Figure 5: Accelerometer	15
Figure 6: Oscilloscope	17
Figure 7: Comparison of the GMF values	22
Figure 8: Particle size of Experiment 2.....	23
Figure 9: Image of particle under microscope at 16 th hours 27 th hours	24
Figure 10: Particle size of Experiment 1.....	25
Figure 11: Image of particle under microscope at 52 nd hours.....	25
Figure 12: Image of particle under microscope at 57 th hours	26
Figure 13: Contaminant at 60 th hours	28
Figure 14: Contaminant at 55 th hours	29
Figure 15: Contaminant at 35 th hours	29
Figure 16: Dust contaminant at 25 th hours.....	30

CHAPTER 1

INTRODUCTION

1.1 Background

Many industrial companies have been bothered with machineries failures that are caused by defects that occurred on the gears drive which, used as a propeller for certain machine compartments. Gear drives components that usually experiencing distress are gears, bearings, shafts and seals.

Gears are round plate that consisting teeth around the side which are commonly used in industrial and domestic usages. They are widely used to propel machinery in order to carry out certain tasks and other simple mechanisms by transmitting torque to another part with identical teeth. The geared devices come with many different numbers of teeth per inch which varied the speed, torque and rotating direction. Gears are the part commonly used in drive train system of certain machineries compartments. Different type and size of gears are being used to carry out different tasks. The tasks carried out are according to the size of the machineries itself. Those rotating gears are widely used in various industrial sectors. They can be found in energy generator, automobile, industrial machineries and others. Gears are used to transmit power through torque or rotary motion from shaft to another shaft through gears on each shaft. Gear designs are basically referring to several parameters depending to the torque needed to be

transmitted at specific required speed. While, the area of contact during gears meshing will dictate the load capacity of the gears.

The defects of the gear will happen eventually after a long operational time. However, the lifespan of the gears can be prolonging by eliminating the sources of defects such as imbalanced of the rotating parts, misalignment of the shaft and others. The examples of gear defect which usually can be seen on the gears tooth are pitting, scuffing, spalling, scoring and etcetera. These defects are basically are a result of repeated surface or rub-surface stresses during gear meshing that goes beyond the endurance limit of the materials that caused surface fatigue. These defects will cause the vibration level in the system to rises and exceeding the normal vibration level. The defect on certain gears can be detected using several methods such as visual and sound inspection, however, the analysis on the lubricant used and vibration analysis is proven to give out better result.

Vibration is one of mechanical phenomenon whereby it oscillating about its' equilibrium point. The vibration level in every machines are impossible to be eliminated because there will always be a vibration due to gears meshing, however, the level of unwanted vibration should be monitored and minimized. Therefore, vibration analysis is compulsory to be monitor from time to time periodically. However, vibration based systems require extensive interpretation by trained diagnosticians to create algorithms that indicate impending failures (Dempsey,2000). These excessive vibration may contributed to undesired sound and motion, energy wasting, reducing performance of the system, shorten the life span or even causing catastrophic failure to the machineries or system.

1.2 Problem Statements

The companies in industrial field are looking forwards to extend the their machinery lifespan, thus by identifying the defects on the components such as gears at the early stage can helps to make it happen by indicating the minor damages such as gears defect before it leads to

major damages in future, for example machines breakdown then contributed to delay on the production line of the companies.

Besides extending the lifespan of the machinery, the reduction cost of the maintenance activity also possible. The expenditure is cut down by only replacing the parts that identified experiencing failure such as gear that defected and avoiding any major failure. Moreover, the production line will be smooth, if the maintenance processes are scheduled accordingly to the defects indicator.

Therefore, this study is carried out in order to help us to recognize and monitor the defect of the rotating components such as gears. Moreover based from the previous study it found that, failures associated with gears represent the cause of extended outages and are typically caused by gradual deterioration and wear (Elforjani et al. 2012).

1.3 Objectives

The main interest of this research is to monitor the defect in rotating gears using vibration health monitoring system. The main objectives are as follows:

- a) To develop gear test rig for on-line vibration health monitoring system.
- b) To determine the vibration severity of the rotating gears that run under certain conditions.
- c) To study wear characterization of the rotating gear that run under certain conditions.

1.4 Scope of Study

From the objectives, the scope of study is design and narrowed down to become more specific in order to make sure the clear view of the research is given.

- a) The first step is to design and fabricate the gear test rig based on the current industrial condition. The component of the gear test rig consists of bearings, shafts and driven by DC electric motor. An accelerometer is used as a sensor component to monitor the health condition of the gear. The sensor is attached to the driven gear bearing housing in order to capture the vibration signal.
- b) A number of experimental tests are conducted where several parameters are taken into consideration such as speed, load and time. Simple Design of Experiment (DOE) is constructed in order to help the experiment run smoothly.
- c) Data measurement of vibration signals are collected analyzed using vibration analysis technique.
- d) The wear debris analysis is conducted in order to investigate the wear characteristics study of the rotating gears. The wear particles are observed and the measurement sizes are gathered.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the literature reviews of project are discussed. The content of this chapter discuss about the previous study which obtained from the published journal collected. From the previous study, the expectation data collection and result are developed. The result from the previous study, is then use to be compared with the data collected during the experimental period.

Furthermore, the theories established from knowledge and ideas of researchers and accredited intellectual will be discussed. The theories related to the title of vibration analysis on the rotating gears in order to identify the defects are going to be used as the reference to compare and validate the result obtained in the research.

The previous studies are also discussed in this chapter. From the previous studies, ideas are fostered to be used to determine the methods of data analysis, which going to be used in the next chapter, Methodology. The data analysis methods will listed in this chapter, then, choose based on the most accurate result obtained and convenient.

2.2 Defect Mechanism and Propagation

Defect is defined as imperfection or slight change in the original geometries or physical of something. However, defects on the gear are said to the deformation that occurred eventually. Gears defect occurred due several factors such as vibration, poor maintenance procedure which initiate from machineries poor installation or manufacturer. Gear defects or wear are categories into two mechanisms which is considered as causes of wear. The wears are occurred due to:

- a. Mechanically mechanism
- b. Chemically-mechanical mechanism

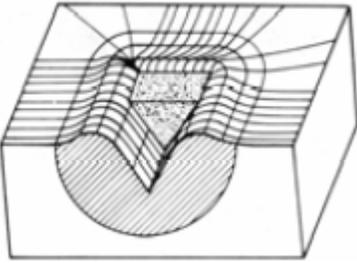
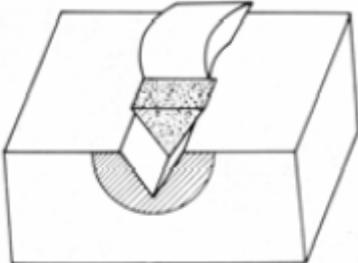
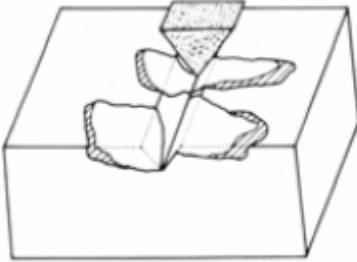
Mechanically dominated wear mechanism is a mechanism of wear that only caused by the mechanical only. There are two examples of wear mechanisms that are contributed mechanically to the wear propagation of the structures such that surface fatigue and abrasion.

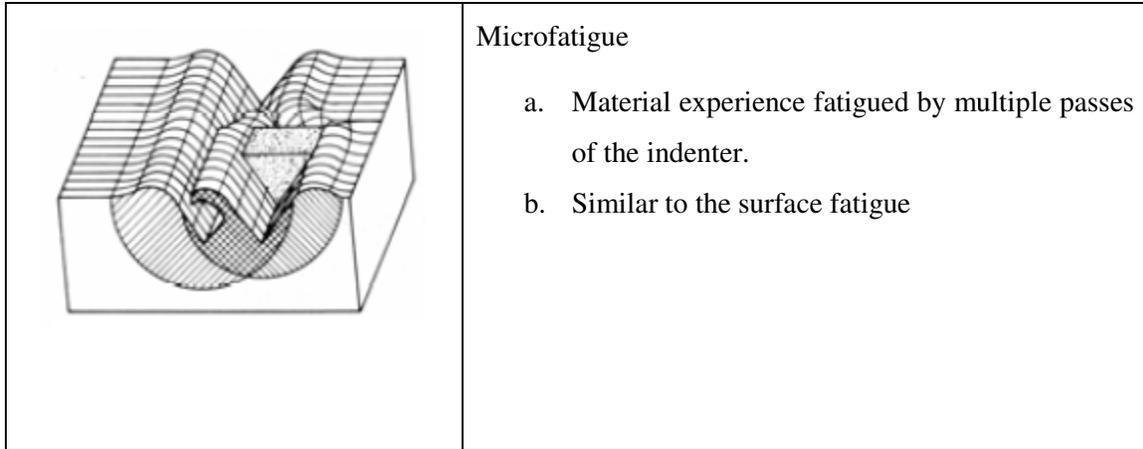
The surface fatigue occur due to crack initiate and propagate, that usually take place at the surface or in certain depth below the surface depend on the contact situation and microstructure of the materials illustrated in Figure 1. This problem can be overcome by controlling the temperature of the system, since, it affecting the lubricants viscosity, besides, increasing the endurance limit of the materials.

Next, abrasion is the other type of wear mechanism which only focusing on the mechanical mechanism. This mechanism of wear occurred when there is a hard or sharp particle or lump that imposed on or moving on a softer surface. The abrasion in material can be overcomes by increasing the harness and hardness ratio, besides, ductility of materials. Since the hardness of materials and material ductility are inversely proportional to each other, thus, the optimum combination should be considered. There are four sub-mechanisms that depend on the structure of the tribosystem and the properties of the materials in contacts. The sub mechanisms are as following in Table 1.

Table 1: Type of adhesion

(Source: Vingsbo 1979)

Illustration	Description
	<p>Microploughing</p> <ol style="list-style-type: none">A certain fraction on the grooved materials is just shifted to the edges of the rimVolume is constant
	<p>Microcutting</p> <ol style="list-style-type: none">The grooved materials are cutting out the surface and producing chip.The volume is reduced
	<p>Microcracking</p> <ol style="list-style-type: none">The grooved material was dragged along the surface causing cracks underneath and beneath the groove.Volume of the structure remains constant, but, become less dense.



There are also some wear mechanisms that caused by both chemical and mechanical. These wear mechanisms, affected by the change in the materials due forces endurance. They are adhesion and tribochemical reaction.

Adhesion is wear mechanism that explained by the micro joints or friction welded. This happened due to both body and counter body are plastically deformed with subsequent destruction of any intermediate layer. The boundaries of this joint takes place within the non-cold region underneath the contact area. The materials from the body may be transferred to the counter body or vice versa. The sliding wear of overheated or unlubricated surfaces is showing the result of adhesion. This mechanism is explained in Figure 2. The mechanism of wear can be stop or reduce by lubricating the surface.

Lastly, the tribochemical reaction between the contact surfaces is the wear mechanism that contributed by both chemically and mechanically. The materials in both body and counter body experienced chemical reaction due to interfacial medium and environment. This reaction will stop the adhesion. However, there are films or layers formed on the surfaces as effect of the reaction which can be seen in Figure 5. Quinn (1983), has stated that the wear rate as function of physical, chemical and mechanical properties of the reaction products. Moreover, he also states that wear is brought about by spalling off an oxide layer, which has reached its critical thickness of the layer due to the oxidation of materials.

2.3 Vibration Analysis

The vibration is an oscillating motion that exists in every structure about their static equilibrium position, the motion is continuous, repetitive and often periodically. In certain area, the vibration can be beneficial such as vibration for energy harvesting field. However, the vibration may cause many undesirable effects, for examples fatigue, breakage, and wear to the structure, improper operation of equipment, noise pollution, and etcetera. The vibration can be categorized into few groups which are:

- a. Free vibration – vibration occur with no external force and oscillating at natural frequency
- b. Force vibration – there is forces applied to the system
- c. Damped / undamped vibration – system with/without damper.

In the rotating machineries, vibration is considered as one of the predominant factors for failures that occurred. Vibration in the rotating rotor cannot be eliminated because the vibration will eventually occurred, at least once-per-revolution frequency component. This is because it is impossible to make any rotor perfectly mass balanced. All machinery has their specific allowable vibration level which is crucial to machine durability, reliability, and life is rarely disputed. In case of this research which implies gears, the vibration from the gear meshing is also in consideration. Thus, vibration analysis on the rotating machineries is necessary and convenient to monitor the machineries performance.

Vibration level should monitors periodically. This is because the vibration level of the system can lead to the beginning of wear before it propagate and causing excessive vibration in the system until the system experience failure. There are several existing techniques of vibration analysis being used to monitor the machineries performance and prevent the major damages from happening by doing Preventive Maintenance.

Fast Fourier Transform, FFT Spectrum is an algorithm to compute the Discrete Fourier Transform (DFT) and its inverse by converting time domain signal to frequency spectrum and vice versa for machineries vibration monitoring. This technique is chosen over other techniques since, this experiments carried out are basically a machineries simulation.

Figure 2 shows the frequency spectrum at the beginning of the gear rotating which obtained during the experiment (Peng & Kessissoglou 2003). The gear type used in the experiment is worm gear. According to Peng and Kessissoglou, the amplitude of the shaft running speed recorded at approximately to 1.4 mm/s, which is quite high for the beginning run. This is might be because of the imperfection of the original manufactured surfaces of the worm gears and the use of the Vitrea oil which cannot provide appropriate boundary lubrication between the surfaces of the gears. Even though is high, the value is still in the acceptable condition according to the ISO standard as shown in Table 2.

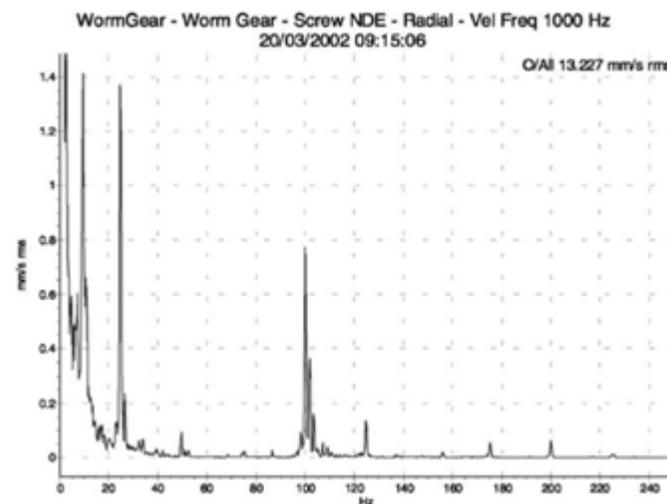


Figure 1: The frequency spectrum in the beginning of the experiment
(Peng & Kessissoglou, 2003)

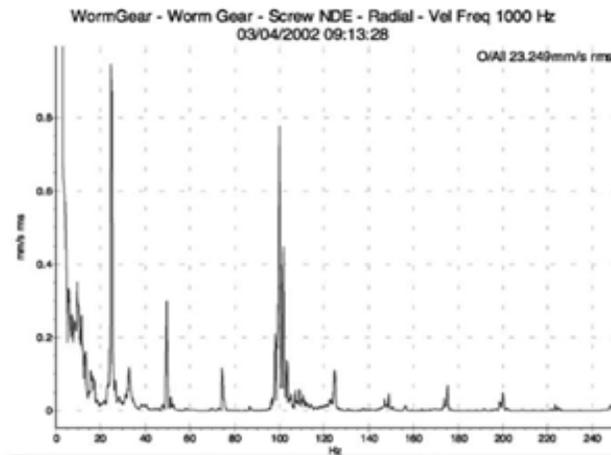


Figure 2: The frequency spectrum after two weeks operation

The experiment where continue until two weeks. After two weeks, the amplitude of the running frequency reduced gradually approximately to 0.1 mm/s referring to Figure 2. This decreasing in the vibration signal can be attributed to a reduction in wear due to the smoothing of the scratched surface using the more viscous Trivela lubricating oil (Peng & Kessissoglou 2003).

From the most of the techniques discussed, the values of vibration severity usually obtained. Thus, the values obtained are used as the indicators when the machineries requiring for maintenances or proper surveillance based on the standards of vibration severity in specific machinery are set by International Standards Organization. This standard was made and agreed by the committees based on frequency range of vibration (speed of machinery), type and size of machine, service expected, mounting system, effect of machinery vibration on surroundings. The Table 2 below shows the alarm data from ISO standard 2372.

Table 2: The vibration severity based on ISO standard 2372

RMS velocity range of vibration severity		Vibration severity for specific classes of machines			
Mm/sec	in/sec	Class 1	Class 2	Class 3	Class 4
0.28	0.01	Good	Good	Good	Good
0.45	0.02				
0.71	0.03				
1.12	0.04	Acceptable	Acceptable	Acceptable	Acceptable
1.80	0.07				
2.80	0.11	Monitor closely	Monitor closely	Acceptable	Acceptable
4.50	0.18				
7.10	0.28	Unacceptable	Unacceptable	Monitor closely	Monitor closely
11.20	0.44				
18.00	0.71			Unacceptable	Unacceptable
28.00	1.10				
45.00	1.77				

CHAPTER 3

METHODOLOGY

3.1 Introduction

These chapters are discussed about the technique and procedures that taken in order to make sure that the objectives are successfully meet. The content of this chapter are focusing on the process development of the test rig, equipments involved, experimental setup and also the design of experimental configurations. Besides, the techniques of analysis used in this study are also explained.

3.2 Gear Test Rig Development

The test rig is design and develops to monitor the wear and defects propagation of the rotating components. In this study, the test rig are consists of bearings that holding two parallel shafts which driven by electric motor and it is attached with gears at each ends were setup. The DC type electric motor which powered by 15 kW was used to drive the shaft. The shaft were rotates using flat belt. Figure 3 and 4 has shown the design of the test rig that consists of lubricant tank, bearings and bearing housing, gears and shafts, electric motor, and also loads lever and weight.

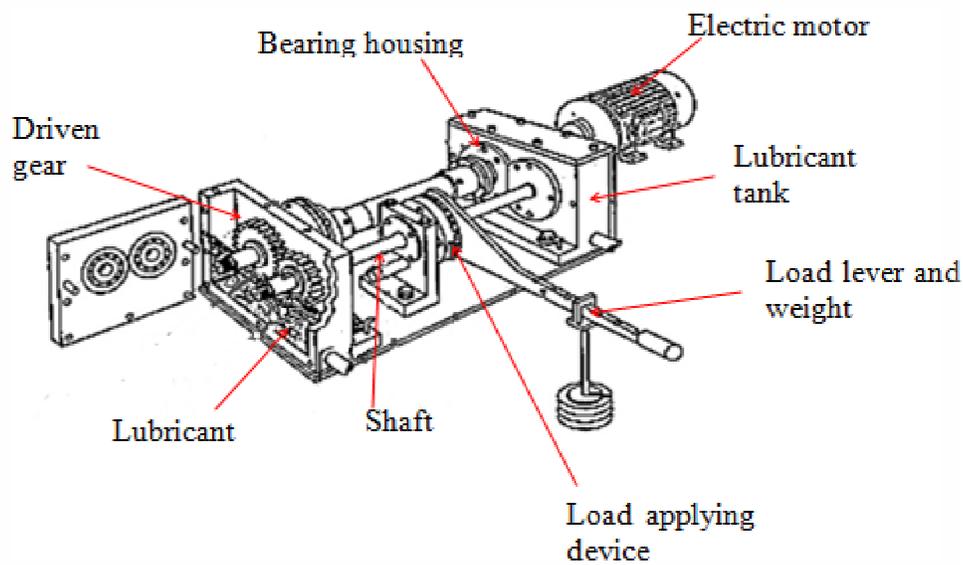


Figure 3: The schematic design of test rig



Figure 4: Gear rotating test rig

Since the aim of the study is to implement on-line health monitoring system, transducer which is accelerometer type is used to help the monitoring activity. It is actually a device that converts one form of energy into another and provided an electrical signal in response to a quantity, property, or condition that is being measured. The accelerometer used the general sensing method upon which all accelerometers are based

where acceleration acts upon a seismic mass that is restrained by a spring and converts a physical force into an electrical signal, which measured in pico Coulomb per g (pC/g), where g is stands for unit of gravity force. In this study, during experiment the accelerometer are attached near the bearing housing of the driven gear tank using heat resistance wax. Figure 5 shows the location of the accelerometer which is attached to the bearing housing.

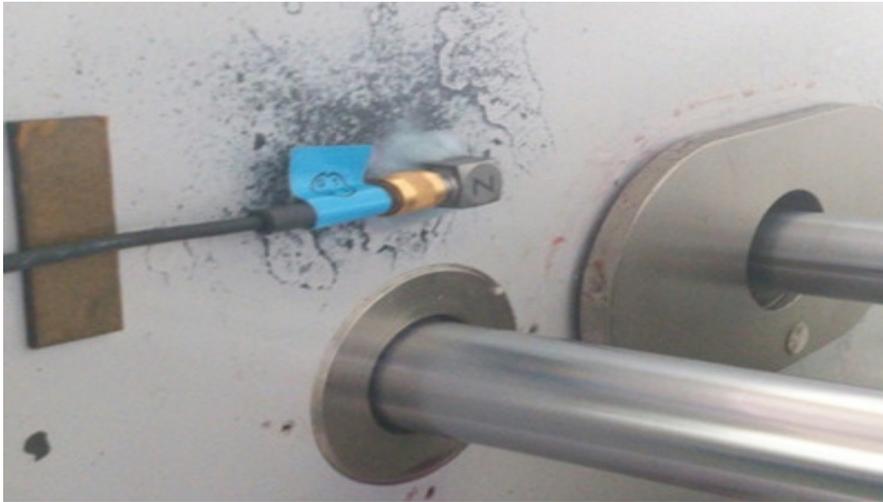


Figure 5: Accelerometer

3.3 Experimental Design Configurations

Since the parameters of experiment are the elements that effecting the result or the experiment outcome therefore parameters setting is the most important part in this study. The fixed parameters are time and rotating speed. In this study, the rotating speed used is 1000 rpm and each experiment is set to 60 hours. The gear type used in this study is helical gear types which have 35 gear teeth. The manipulated parameter is load that applied to the rotating shaft. There are several set of loading conditions are tested as shown in Table 3.

Table 3: Experimental configuration

Experiment No.	Load applied (kg)	Time (hours)
1	15	60
2	30	60
3	35	60

3.4 Vibration Data Measurement

The data measurement is the process carried out after the equipment was setup. The data is collected based of the vibration signal obtained from the accelerometer) which is placed on the bearing housing of the driven gear. The signal from the transducer is convert into an electrical signal, which is then, be amplified and display on the oscilloscope in form of time waveforms. For accurate vibration signal result, the accelerometer should be attached to the gears since the aim of this study is to investigate the rotating gears but since the accelerometer used is wired so the attachment should be locate at bearing housing.

Oscilloscopes are used to display the change of an electrical signal over time, such that voltage and time describe a shape which is continuously graphed against a calibrated scale. This shape is commonly referred to as a waveform, and makes it easy to view voltage changes over time, allows measurement of peak-to-peak voltage, the frequency of periodic signals, the time between pulses, the time taken for a signal to rise to full amplitude (rise time), and relative timing of several related signals.

Figure 6 shows the oscilloscope used in the experiment. The oscilloscope display is automatically transfers into the computer system. In the computer, the data is display through Tektronix DPO 4000 software. Then, the data was recorded or save in notepad file (.txt). The

data was taken every an hour gap. Besides that, the images of the specimen gears are captured every three hours to observe the physical conditions of the rotating gear.

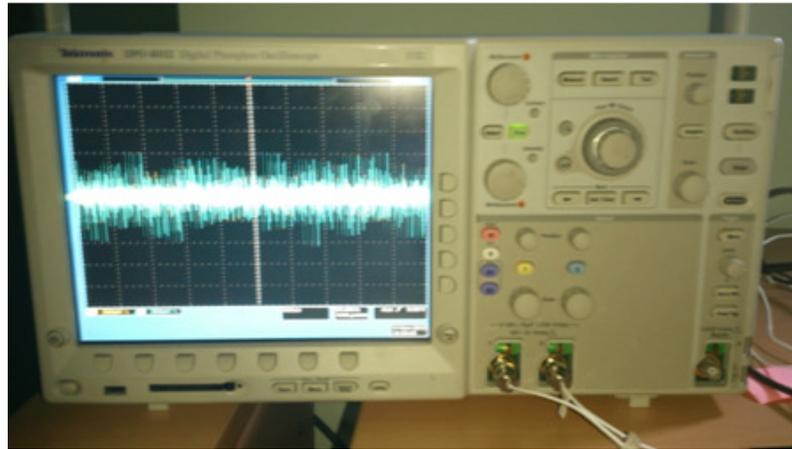


Figure 6: Oscilloscope

3.5 Wear Debris Analysis

Wear debris analysis is also known as one of the condition monitoring technique of tribosystems. There are reasons for measuring the quantity of wear debris by using lubricants oil because wear debris analysis is usually to determine the wear rates of various components of a machine. Analysis of debris or particle consists of metallic and non-metallic. The metallic particle is a wear condition that separates in different size and shapes of metallic dust from components like bearings and gears or coupling. Metallic wear debris also can be differentiated or classified by type particle morphology into several classes, for example; rubbing, cutting, spherical, laminar, fatigue chunk and severe sliding wear particles (Sondhiya & Gupta, 2012).

Wear debris analysis one of technique machinery condition monitoring and it can be call wear debris monitoring method. Wear debris monitoring involves the regular assessment of changes in debris characteristics by one or more of the many techniques that available. But under same principle of wear debris analysis where the wear debris found in a lubricant will form part of size distribution that changes progressively as the surface deterioration increases. There are