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IDENTIFICATION OF SURFACE AND SUB-SURFACE DEFECTS IN GEAR BY USING THERMOGRAPHIC TECHNIQUE

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ABSTRACT

Gear is one of the most common components used in machine. Gear failure is usually associated with temperature. To estimate the life expectancy of gear, there are a few factors to be considered such as loads, helical angle, speed, gear face width, gear surface roughness, force and lubrication properties. This project is conducted to see the relation between temperature and early gear failure. The estimation of gear life expectancy by using a comparison between the theoretical calculation for helical gear with pitting at 1000 rpm speed and experimental result obtained from the operation of a gear test rig is discussed. For the experiment, three load weights are used; 15 kg, 30 kg and 35 kg for the operating duration of 60 hours. Both result from theoretical and experimental is based on thermal analysis. The calculation obtained based on BS ISO 6336-2 result in the theoretical life expectancy of gear with15 kg load of 23 hours, 30 kg of load weight at 16 hours while for gear with 35 kg load at 15 hours. The experiment conducted showed insignificance temperature changes even though the highest temperature recorded is 38°C and the lowest temperature at 29°C. The experiment result shows that at 15 kg of load weight, damage started to occur at the 85^{th} hour while at 30 kg load, gear damage started at 60^{th} hour. For the 35 kg of load weight, the time where damage started to occur is at 120^{th} hour. Due to insignificance temperature changes, thermal analysis can be disregard when involving new and barely worn gear.

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LIST OF SYMBOLS

σ_H	Application Factor
σ_{HO}	Nominal Value of Stress Relation At Pitch Pint
K_A	Application Factor
K_V	Dynamic Factor
$K_{H\beta}$	Face Load On Stress Relation factor
$K_{H\alpha}$	Horizontal Load On Stress Relation Factor
$Z\varepsilon$	Relation Ratio Factor
β_b	Helical Based Angle
α_{wt}	Stress Across Pitch Cylinder Angle
α_t	Stress Across Reference Cylinder Angle
Z_{NT}	Life Stress Relation Factor
Z_L	Lubrication factor
Z_V	Speed Factor
Z_R	Roughness Factor
Z_X	Size Factor
$S_{H\lim}$	Safety Factor

CHAPTER 1

INTRODUCTION

1.1 Research Background

The purpose of this report is to predict the life expectancy of gear using thermal analysis. Gear is a machine that is used as a medium to transmit power by using rotary motion with the help of gear tooth movement. Gear has been used for more than three thousand years and is regarded as an important element in current machinery [1]. However, frequent gear usage will result in gear tooth damage and eventually will cause the gear to be malfunctioned.

Gear failure can be divided into two main categories. The first one is the failure on gear tooth while the second failure is when the damage occurs on gear tooth surface [2-5]. The failure on gear tooth is mainly caused by alignment problem. These problems can be reduced, even eliminated by practicing correct procedure when assembling gear. Failure on gear tooth surface is usually caused by critical operation parameters such as loading, lubrication oil and applied speed [3-5] and will resulted in temperature increase and eventually will cause further damage on the gear.

Due to these problem, this project is conducted to investigate and predict the life expectancy of gear by using thermal analysis. There are lots of methods that can be applied to predict gear life expectancy such as vibration analysis, oil analysis,wear debris analysis and also thermal analysis. A standard to determine gear life expectancy which consists of mathematical equations has been developed by organizations such as AGMA, BS and ISO. These equations is based on the gear design, manufacturing process, operation and expertise in experimental work.

Life expectancy prediction and verification of these standards is a research approach that represents actual use of gear [6].

1.2 Problem Statement

Gear is defined as machine element that is used to transmit power using shaft rotation with the help of gear tooth movement. However, the frequent gear usage will cause gear damage due to friction that occurs on gear when it is in rotary movement. Friction from the gear movement will develop heat energy that will cause gear temperature to increase and affect the condition of gear tooth. This research is conducted to investigate gear life expectancy using thermal analysis to prevent sudden gear tooth failure.

1.3 Objective

The objective of this project is to predict the life expectancy of helical gear using the method of thermal analysis with varied loading.

1.4 Scope of Work

Experimental work is required to achieve the objective of this project. Thermal analysis will be conducted using helical gear that is attached to a test rig. When the test rig is in operation, temperature data will be taken and analyzed using the method of graph trend. Based on the data obtained, it will be compared to British standard calculations. The comparison is required to find the starting point of gear onset failure which will help to predict life expectancy of gear.

1.5 Result Prediction

It is predicted that higher loading will increase the gear temperature. Therefore, the result obtained from this project will provide the information to predict gear life expectancy corresponding to the applied load.

CHAPTER 2

LITERATURE REVIEW

2.1 Gear Parameter

When gear moves, its tooth surface will rotate and slide against each other. This gear movement will lead to a clash between two gear teeth causing shear stress and resulting in gear tooth damage. Oil is used to lubricate the movement of the gear teeth thus prevent damage to the surface of the gear teeth. Oil is also used as a cooling agent to avoid temperature becomes too hot. Gear design parameters are used to evaluate the durability of the gear. These parameters are pitch line velocities, helical angle, axial velocity, the width of the face gears, gear pressure angle, gear surface roughness, power and lubricating properties [8].

Helical gear angle is located between the gear teeth and the axial axis of the pitch circle (see Figure 2.1). Most angle helical gear values are between 5° to 20°. Larger helical angle will produce greater axis thrust. If the helical angle is lower, pitch line velocity will be higher. Thus, if the velocity increases, this will cause the heating due to friction between the air and fuel mixture trapped in the gear teeth. This effect causes the surface temperature of the gear tooth to be higher and can lead to thermal problems [8].

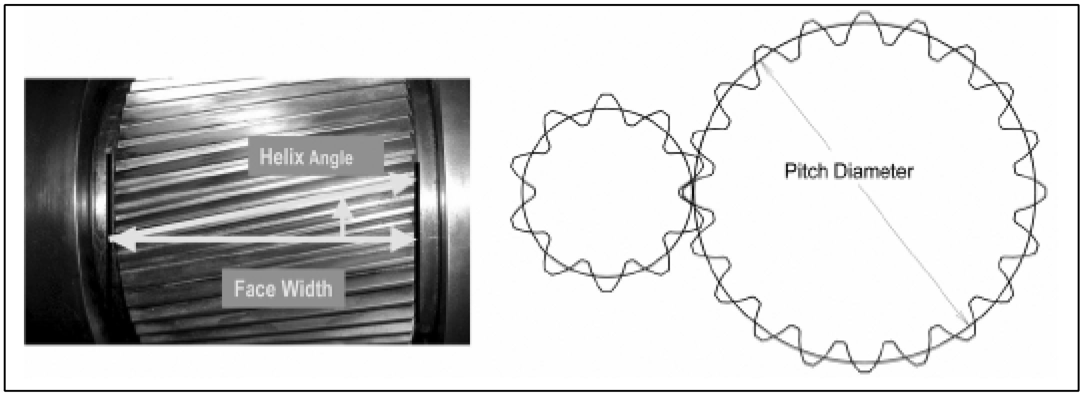

Figure 2.1 : Helical angle, face width and pitch diameter of a helical gear [8]

Pressure angle is the slope of the gear tooth on the pitch circle. The most common pressure angle for helical gears is 20°. Rough surface gear will result in larger friction between gear teeth. Greater friction means higher temperature will be produced that will reduce oil viscosity where oil film will be thinned. Lower viscosity can increase the risk of damage to a gear [8].

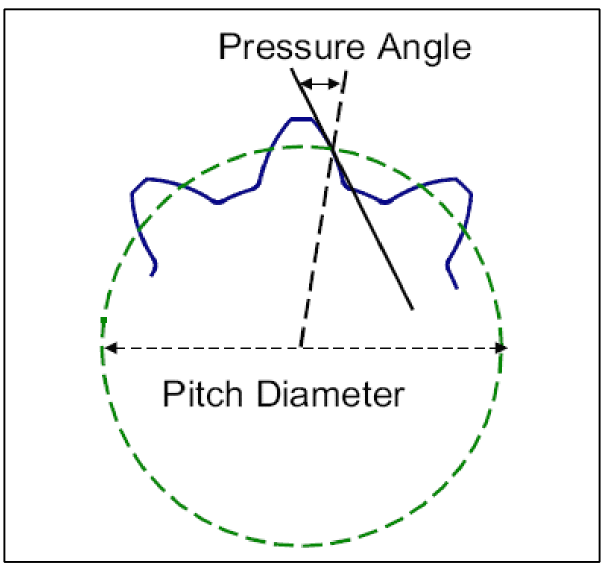

Figure 2.2 : Pressure angle [8]

2.2 Introduction of Gear Failure

When the gear moves, its tooth surface will rotate and slid against each other. This movement will lead to a clash between two gear teeth causing shear stress and damage to the gear teeth. Type of damage that often occurs on the gear teeth is as follows:-

1. Scuffing
2. Chipping
3. Wear
4. Pitting
5. Spalling

2.2.1 Scuffing

Scuffing occurs when oil thickness is less than composite roughness on gear due to clashing of metals [8]. Figure 2.1 shows the damage caused by scuffing.

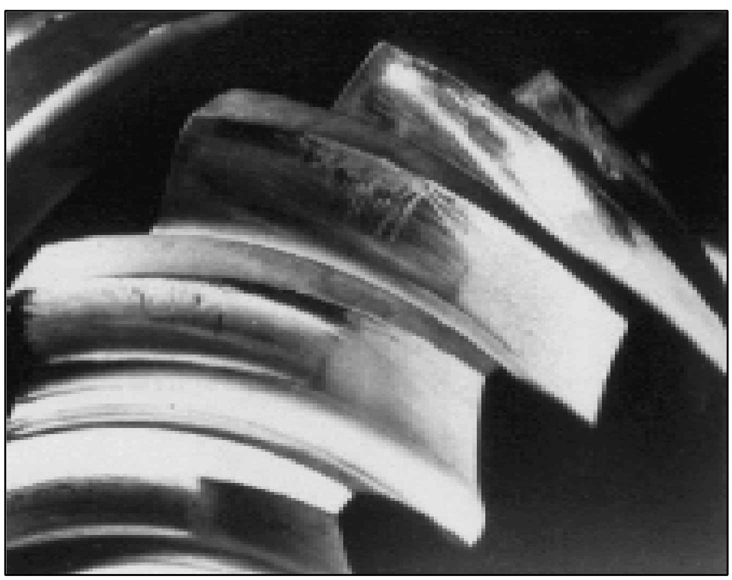

Figure 2.3: Scuffing [9]

2.2.2 Chipping

Gear teeth debris is one of the effects of failure on the gear, but the effect was not generally due to the gear teeth. It usually occurs as a result of outside force such as foreign object in the unit, loose gear installation or failed teeth from another gear.

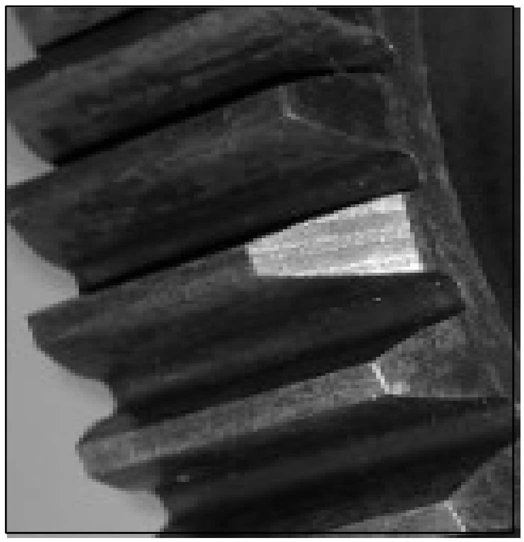

Figure 2.4: Gear tooth debris [9]

Damage caused by scuffing and pitting is normally not regarded as gear teeth wear.

2.2.3 Wear

Wear is defined as the removal or transfer of metal from the surface of the gear tooth. Wear will result in thickness reduction of gear teeth and also change the contour of gear teeth [8].

2.2.4 Pitting

Surface damage such as pitting can be classified into two groups:

1. Micropitting
2. Macropitting

Micropitting are phenomenan where there is a small hole on the gear teeth. Micropitting happens when the oil film between the elements is equal to the average thickness of the roughness of the two surfaces. When this happens, part of the loading is supported by the oil film. Collisions between gear teeth will cause temperature increase and oil viscosity decreased which will cause gear clash and further damage. Damage to the surface of the gear teeth is known as micropitting. Micropitting can have a huge impact on the surface, causing increased pressure and damage. Micropitting can also lead to secondary failure as macropitting, scuffing, and flexural bending. Micropitting size is difficult to see with naked eye and can only be detected with the aid of vision such as the lens.Micropitting on gear design which will cause an increase in loading on gear, vibration, temperature, and will produce noise [8].

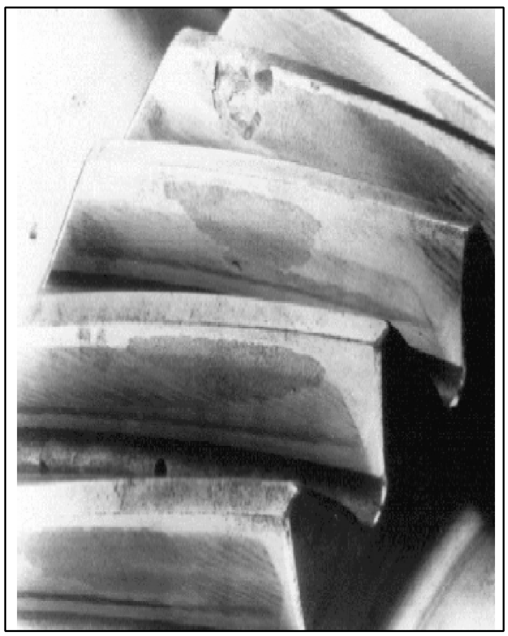

Figure 2.5: Micropitting [9]

However, macropitting also is a phenomenon that occurs on the surface of damaged gear teeth. It usually happens if there are high asperities or metal clashing on the gear teeth. Macropitting occurs due to failure pressure of the collision caused by gear tooth .Spalling is caused by macropitting, and can be considered as the final stage of macropitting. Normally, in the use of high spped gear, surface finishing is usually very thin and the oil film is usually thick enough to prevent contact between metals [8].

Figure 2.6: Macropitting [9]

2.2.5 Spalling

Spalling is a term used to describe a situation where the damage occurred in majority part of a gear tooth surface. Spalling can also be considered as the final stage of macropitting. Spalling is caused by high stresses that occur on the surface of the gear tooth surface. Even though gear tooth surface is hardened, defects such as spalling on the surface or subsurface of the gear teeth can occur due to improper heat treatment.

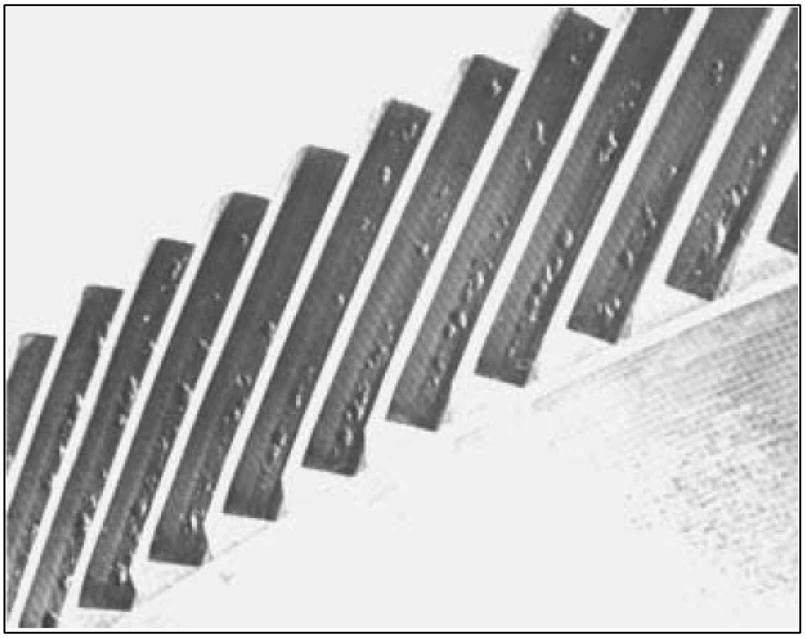

Figure 2.7: Spalling [9]

2.3 Gear Damage Identification

Referring to the Martinaglia 1972, it is indicated that high speed helical gear is interrupted by the non-uniform temperature distribution over the gear surface. At a very high speed, overheating of the oil and gear can occur when gear is in operation. Thermal method is a technique that allows measurement or visualization of temperature on the surface with sufficient accuracy. This technique does not require any contact with the surface; therefore, it has the advantage of not disturbing the operation when the machine is working [10]. Good performance and easy to use has made this technique very popular in the maintenance engineering sector. This technique has been used in various sectors such as mechanical, electrical, petrochemical, material, medical, and structures, buildings, etc. [11].

There are lots of available methods to determine temperature reading such as:-

1. Infrared Thermography
2. Thermocouple
3. Laser Thermometer

2.3.1 Infrared Thermography

One method of measuring the temperature or the heat is to use infrared thermography. This method is a technique that allows measurement and visualization. Visualization can be done because there are cameras that enable high-resolution images to be captured with the exact temperature at which different in the area to be studied.

Most of these cameras make thermal transient capture. These transients are presented by means of image sequences, which allows us to obtain the temperature evolution of a captured image, as well as to calculate various statistical parameters related to the heat map [10]. Infrared cameras do not measure temperature directly on surface. Camera detector device is sensitive to flashes produced by objects in research. This device can capture the electromagnetic spectrum in the infrared band, ranging from 0.78 μm to 1000 μm [12].

The study of damage using thermal image and vibration signals were conducted and it was found that test performance using vibration data is better than the heat image. It is stated that the data from the vibration produces better results in determining the damage to the machine [12]. In contrast to studies that have been conducted, infrared thermography technique can provide very valuable information in diagnosing damage that occurring in the machine [10].

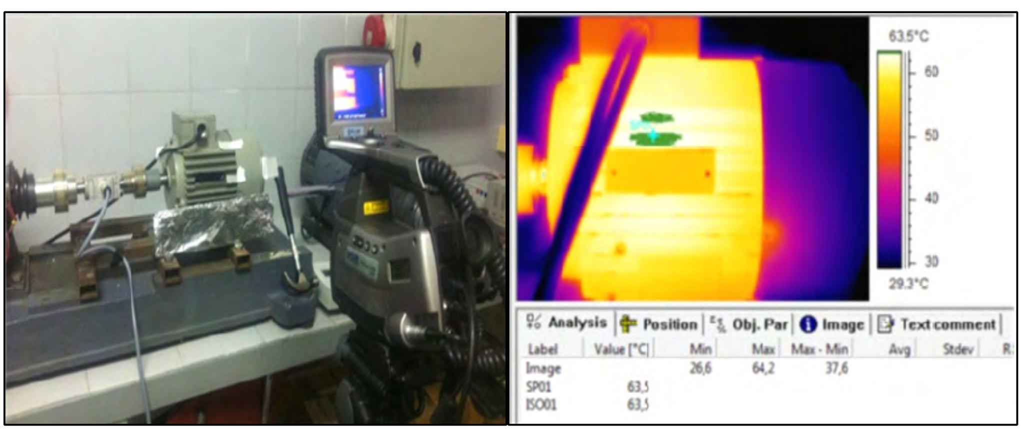

Figure 2.8: Infrared Thermography Technique [10]

2.3.2 Thermocouple

Thermocouple is a temperature measuring device consisting of two different conductors made contact with each other at one or more places. Due to ease of use, and relatively low cost, thermocouple is widely used to measure temperature. However, thermocouple has a weakness in terms of temperature measurement accuracy in measuring temperature.

Figure 2.9: Thermocouple

2.3.3 Laser Thermometer

In this report, verification of thermal analysis for helical gears on a test rig is studied. This aim of this study is to obtain temperature data on helical gears during operation. In this study, a simple method of measuring temperature is to use a mini infrared temperature. Mini infrared temperature is used because it has the same characteristics with infrared thermography for not disturbing the surface of the gear when the gear is operating. Mini infrared temperature is a thermometer that measures the temperature from the radiation produced by this object. Sometimes it is called laser thermometers or temperature pistol to reflect the ability of these devices to measure temperature from a far distance. By knowing the amount of infrared energy released by object, the temperature of the object can be determined.

Based on the information available, laser thermometer is more expensive than thermocouple but many infrared radiation is applied in measuring the temperature in the area where blackouts are high or the temperature is high. Because the infrared sensor can measure far from the point of measurement, vibration problems can be eliminated. In addition, laser thermometer has a fast response to temperature changes [13].

Figure 2.10 : Laser thermometer

2.4 Comparison Between Themocouple & Laser Themometer

Temperature measurement can be achieved using a variety of sensing mechanisms. Temperature measurement system usually consists of sensors, conveyor systems, external power supply system (for some types of systems), and the wiring that connects the system components. Temperature measurement sensors that are commonly used in engineering applications are thermocouple dan infrared (IR) thermometer [13]. The table below shows a comparison between each system of temperature measurement: -

Table 2.1: Comparison between various heat sensors [13]

Thermocouple	RTD	IR thermometer	IC sensor	Thermistor
Advantages				
• Self-powered • Simple • Rugged • Inexpensive • Many applications • Wide temperature range • Fast response	• More stable at moderate temperatures • High levels of accuracy • Relatively linear output signal	• Fast response • Non-contact • $T < 3000\,^{\circ}C$ • Less sensitive to vibration • Less sensitive to interference	• Relatively linear • High output • Inexpensive	• High output • Fast • Two-wire ohms measurement
Disadvantages				
• Nonlinear output signal • Low voltage • Reference required • Accuracy is function of two separate measurements • Least sensitive • Sensor cannot be recalibrated • Least stable	• Expensive • Self-heating • Lower temperature range	• Expensive • Must be protected • Affected by emissivity of target	• $T < 200\,^{\circ}C$ • Slower response • Self-heating	• Nonlinear • Limited temperature range • Fragile • Current source required • Self-heating

Based on Table 2.1, it is shown that the use of a thermocouple is less accurate than using a laser thermometer. Compared to laser thermometer, thermocouple exceeds both the number of advantages and also disadvantages. Inaccurate temperature calculation; less sensitive and unstable readings is the reason why thermocouple is not selected in this research. Laser temperature is chosen due to its quick response. Because of its capability of measuring long distances, vibration problems can be avoided when taking temperature readings.

2.5 BS ISO Calculation

In this project, the standard theory as AGMA (American Gear manufactures Association), ISO (International Standards Organization) and BS (British Standard) is very useful to predict life expectancy for machine components under certain failure modes. In this paper, assuming a