UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THERMAL BEHAVIOR OF VENTILATED DISC ROTOR USING FINITE ELEMENT METHOD

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

by

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I hereby, declared this report entitled THERMAL BEHAVIOR OF VENTILATED DISC ROTOR USING FINITE ELEMENT METHOD is the results of my own research except as cited in references.

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ABSTRAK

Setiap objek bergerak memerlukan brek untuk memperlahankan kelajuan mereka untuk mengelakkan daripada berlaku perlanggaran. Kereta memerlukan brek disk untuk mengurangkan kelajuan apabila bergerak. Penggunaan brek secara berterusan boleh menyebabkan penjanaan haba semasa setiap proses brek berlaku. Faktor-faktor yang boleh menjejaskan pengagihan suhu di sekitar brek kenderaan ialah kelajuan, jenis bahan untuk pembuatan brek, faktor geseran dan tekanan brek pada pad. Tujuan utama penyelidikan ini adalah untuk mengkaji tingkah laku suhu piring brek pengudaraan dan membantu para jurutera menghasilkan reka bentuk brek disk yang terbaik dan mengurangkan kerosakan pada brek kereta. Model brek disk dan analisis dilakukan menggunakan Catia V5 dan Altair Hypercrash bagi mendapatkan analisis suhu untuk menentukan pengedaran suhu dan tegangan Von Miss untuk disk pengalihudaraan dengan sifat bahan yang sama bagi meningkatkan prestasi brek disk. Perbandingan antara kelajuan dan tekanan brek yang diperoleh dari 'finite element' dilakukan dan semua nilai yang diperoleh daripada analisis kurang daripada nilai yang dibenarkan. Oleh itu, reka bentuk terbaik dan sesuai dicadangkan berdasarkan prestasi cakera.

ABSTRACT

Every moving object requires a braking device to slow them down in order to avoid from the collision. For cars, the disc brake system is used to reduce their speed as a vehicle moving from a place to another destination. Repetitive braking of the vehicle may cause heat generation throughout each braking event. Factors that can affect includes temperature distributions at brake rotor disc includes speed, material properties, the coefficient of friction and brake load. The main purpose of this research is to study the thermal behavior of ventilated disc rotor to assist engineers to improve the design of rotor and reducing brake fade. In the present work, the CATIA V5 software is used to construct a 3-dimensional model disc brake model that consist of pad friction material and brake rotor. The Altair finite element software is used to conduct the coupled thermal-structural analysis to illustrate the temperature distribution and Von Misses stress occurrence towards the ventilated disc rotor subjected to the thermal loading condition set-up. A comparison between rotational speed and brake pressure simulation studies show the effect of the temperature distribution is directly influence by the parameters setting.

DEDICATION

To my beloved parents,

My mother, who is a strong an gentle soul taught me to trust in Allah, believe in hard work and that so much could be done with little.

My father, for earning an honest living for us and for supporting and encouraging me to believe in myself.

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CHAPTER 1

INTRODUCTION

1.1 Overview

This research is carried out to study the thermal behavior of ventilated disc rotor by using finite element method. The brake can be divided into two types which are drum brake and disc brake system as shown in **Figure 1-1**. However, this research only focuses on thermal behavior of the disc brake. Basically, the disc brake system consists of a brake disc rotor, two brake pads and a caliper (SAE International, 2007). During braking events, kinetic energy is changed into heat energy that absorbed by the disc rotor and pads. Temperature can exceed the critical value for a given material because of the frictional force between brake pads and rubbing surface. This phenomenon can leads to undesirable effects, such as brake fade, local scoring, thermo-elastic instability, premature wear, brake fluid vaporization, bearing failure, thermal cracks and thermally excited vibration as referred to (Lee and Yeo, 2000; Gao and Lin, 2002). Disc rotor will be designed using CATIA V5 first before export into the Hypermesh software. This simulation will produce a result of thermal behavior of the disc rotor such as heat flux and stress during the braking process. This study will help engineers to produce the best design of disc rotor to tackle brake ware problem.

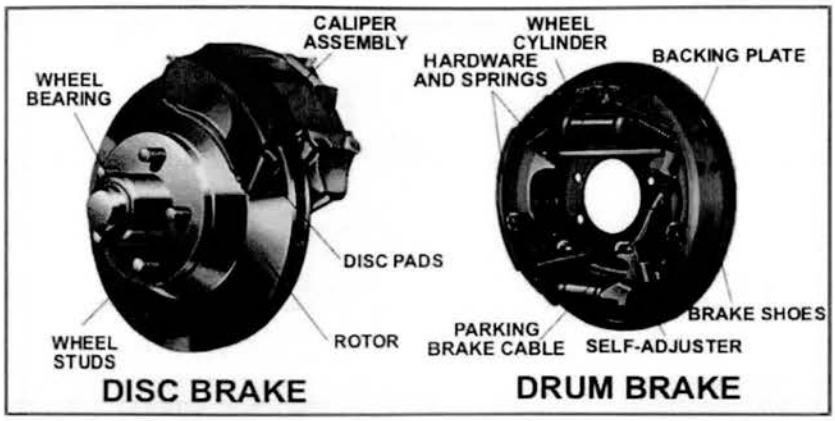

Figure 1-1: The component of the disc brake and drum brake (Motorist, 2018)

1.2 Aim and Objective of Research

1.2.1 Aim

This research is carried to investigate the thermal performance of a disc brake system subjected to the effect of rotational speed and brake pressure. Disc rotor, pads, and caliper will be redesign using the real dimension of disc brake of Malaysian car. Disc rotor will undergo simulation in Hypermesh and Hypercrash software to study thermal behavior of the brake system. From the simulation, results of temperature will be obtained. This simulation will also consider the effect of disc rotational speed and brake pressure.

1.2.2 Objectives

- To study thermal behavior of ventilated disc rotor using finite element method.
- To investigate the effect of rotational speed and brake pressure towards braking performance

1.3 Scope of Study

This research will cover a transient analysis method of the ventilated disc to study the heat transfer during braking phenomenon. Type of disc that will be used is ventilated disc of the front left disc of Proton Wira 1.5 as shown in **Figure 1-2**.

Figure 1-2: Disc rotor for Proton Wira 1.5

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

When brakes applied to the car, heat generation takes place on the disc brake rotor due to friction between pads and rubbing surface of the disc. So researcher needs to eliminate and dispersed away from the temperature across the disc brake cross-section. This thermal analysis is carried out because of the condition of braking is very severe. The transient analysis will determine the temperature distribution and other quantities under the circumstance that change over a period of time (Chandana & Reddy, 2017).

2.2 Experiment Approach for Brake Thermal Analysis

Before computers are commonly used in the worldwide, analytical methods were used by the engineers to determine the integrity of a design. The analytical method is defined as the set of techniques that enable us to know qualitatively or quantitatively the composition of any material and chemical state in which it is located. As stated by Dike (1976) complicated parameters of disc brake design such as temperature dependent material properties, real brake disc geometry, and complex boundary conditions could be simplified to explore the temperature response of brake disc by using mathematical equations for conduction of heat in an isotropic solid. But, for real and complex problem

that involve complex properties and boundary conditions, numerical methods are more suitable.

Finite element (FE) methods are the most popular numerical methods which have been evolved in this century. Narayana et al. (2012) stated that the ventilated type disc brake is the best possible design for the present application and the best material is S-2 Glass Fiber. The major role in cooling the disc and gives a good high temperature resistance is the ventilation system. They found out that the disc brake design is secure based on the strength and rigidity standard because all the value of temperature filed and stress filed are below than the allowable values. According to Vijay Kumar B P et al.(2016), the thermal to static structural analysis which gives thermal stresses and their corresponding displacements on the disc brake rotor due to the application of temperature. However, they have discovered the finite element for the two wheelers disc brake rotor. There were three analysis that they used; Thermal Analysis, Coupled-Field Analysis and Modal Analysis.

Disc brake rotor with hexagonal vents profile and material of aluminum metal matric (AL-MMC) composite gives the best possible combination for the present application (Gnanesh, 2014). ALMMCs have more beneficial due to their light weight, better wear resistance and thermal conductivity compared to stainless steel and cast iron that used in this research. AL-MMC also contributes to the increase of ac-celebration and reduces the braking distance. It also provides less noise and wears in the braking system. Anyhow the disc rotor has a different shape of profiles which are vented circular profile rotor disc, vented triangular profile rotor disc, and vented hexagon profile rotor disc. At

the beginning of the process, the temperature of the disc on the contact surface of the two-dimensional model and averaged solution of spatial solution during braking with the constant deceleration sharply rises and have reached the maximum value and rapidly stops on the lower level (Adamowicz and Grzes,2011). Meanwhile, the temperature after the initial moment of time will increase approximately linear if the velocity of the vehicle is constant (Adamowicz and Grzes, 2011). In this research, MD Patran/MD Nastran software package was used to developed the transient finite element analysis of rotating axisymmetric disc and immovable non-axisymmetric pad as illustrated in **Figure 2-1** below.

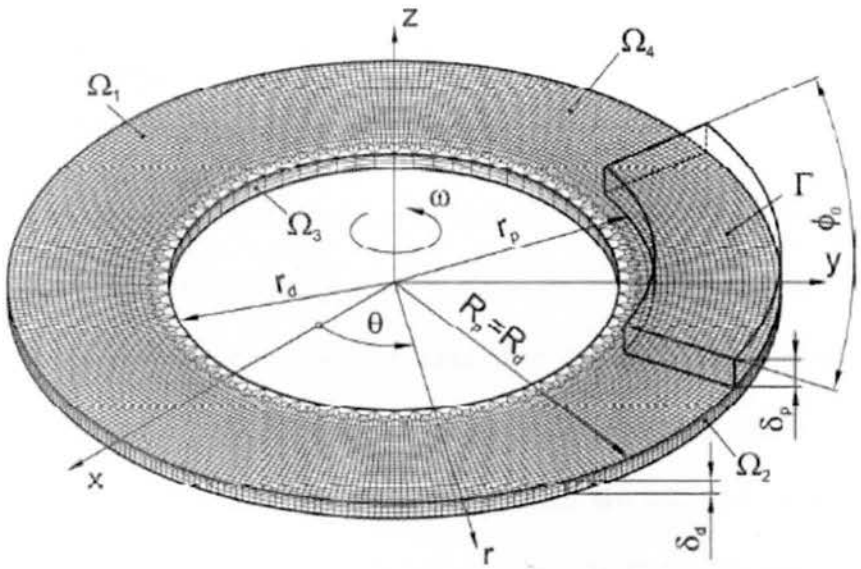

Figure 2-1: Disc Model

In order to compare the obtained solution of the temperature evolution on the disc friction surface with the two-dimensional representation of the constant heating, the researchers have implemented non-axisymmetric thermal load due to frictional heat generated during single braking process into a three-dimensional model that previously

studied by (Talati and Jalalifar, 2009). Two different types of the FE models were investigated namely two- and three-dimensional configuration was proposed to verify the transient numerical analysis. **Table 2-1** indicates the material properties adopted in the analysis which are the same for both types of FE models.

Table 2-1: Material properties (Talati and Jalalifar, 2009)

Material properties	**Disc**	**Pad**
The coefficient of friction, μ	0.5	
Heat transfer coefficient, h [W/(m^{2}K)]	60	
Ambient temperature, T [°C]	20	
Thermal conductivity, K[W/(mK)]	43	12
Heat capacity, C [J/(kgK)]	445	900

In Grzes's other research, titled Partition of Heat in 2D Finite Element Model of Disc Brake. His study seeks to analyze the heat partition ratio of the temperature distribution of two different geometrical types of solid disc brake (during emergency brake application) using nine formulas (theoretical and experimental). Number of factors over heat partition ratio that affects the temperature fields are included in this study. An appropriate model is required in order to calculate the temperature during braking where a sufficient number of variables are include to obtain reliable outcomes (Grezs , 2010). During the process, separation of heat between two sliding bodies depends on the relative velocity thermophysical properties of materials, interface contact length, the amount of wear debris (third body) are varies.

All-terrain vehicles or also known as ATV have been used world-wide either by military or civilian (Nagarjuna et al., 2013). Nowadays engineers and scientists are using Finite Element analysis to do simulation in engineering world as it is one of the useful design tools in this century. The fundamental parameters that involved in brake squeal phenomenon have demonstrated by Hassan et al. by using finite element analysis. Besides, a fully coupled thermo-mechanical model of disc brake system has successfully developed by them to analyze the disc brake squeal phenomenon. In this research, a simple annular ring of the disc brake which in contact with brake pad is designed (Hassan et al., 2014).

Nonetheless, this research is only limited to thermal and stress analysis. In order to represent real dimensions of most of the automotive brake pad that available in the market, the pad has a dimension 60-degree of arc shape while the thickness setting is 11mm (Hassan et al., 2014). Disc rotor has a dimension of 68 mm, 115 mm for inner and outer radius and thickness of 10mm. The disc has two nodes as reference point **Figure 2-2**. As a result, this research has obtained stress, temperature distribution, and also the lateral displacement of the annular ring (Hassan et al., 2014). The applied pressure is set to (P=2MPa) and the coefficient of friction is (μ = 0.3) are remain constant.

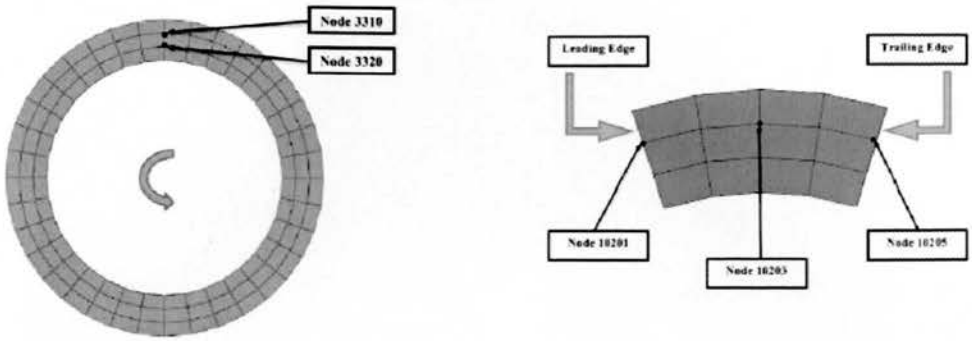

Figure 2-2: Nodes Position (Hassan et al., 2014)

From deformation point of view, stainless steel can offer higher brake performance than cast iron and carbon-carbon composite while from a stress point of view, cast iron could give a better performance than carbon-carbon and stainless steel (Parab et al., 2014). Comparison between cast iron, stainless steel, and carbon-carbon composite was carried out to study for deformation, stresses and temperature performance. Modeling is done using CATIA software while Finite Element Analysis (FEA) is done using ANSYS. **Figure 2-3** indicates three-dimensional solid disc rotor model in Catia with a dimension of 0.22 m diameter and 0.011 m thickness (Parab et al., 2014).

A tetrahedral three-dimensional element with nodes (iso-parametric) is used for the meshing of the disc as shown in **Figure 2-4** (Parab et al., 2014). As the temperature varies significantly, the simulation was refined in the contact zone (disc-pad). **Table 2-2** shows the material properties of the disc brake.