UNIVERSITI TEKNIKAL MALAYSIA MELAKA

NUMERICAL ANALYSIS OF AUTOMOTIVE BRAKE SYSTEM SUBJECTED TO THERMAL LOADING

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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APPROVAL

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

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ABSTRAK

Penyelidikan ini bertujuan untuk mengkaji tingkah laku tekanan hubungan antara permukaan bahan geseran dan permukaan cakera pemutar. Geometri bahan geseran dan cakera pemutar dilukis menggunakan perisian Catia sebelum dimasukkan ke perisian Hypermesh untuk meneruskan simulasi brek. Simulasi ini akan menjalankan 2 analisis iaitu analisis modal dan analisis tekanan. Analisis modal di mana komponen sistem brek menjalani analisis bebas manakala untuk analisis tekanan, tekanan dan halaju tertentu digunakan terhadap bahan geseran dan cakera pemutar untuk mensimulasikan sistem brek. Dari analisis ini, tekanan pada permukaan bahan geseran boleh diperolehi dan juga suhu cakera pemutar boleh diperolehi. Data hasil tekanan dan suhu ditunjukkan dalam laporan ini.

ABSTRACT

This research aims to study the contact pressure behavior between the friction material surface and rotor disc surface subjected to thermal loading condition. Friction material and rotor disc geometry have been build using CATIA software before further exported to Hypemesh to proceed with numerical simulation of the braking system. The simulation undergoes two different type of analysis; modal analysis and contact pressure analysis. Modal analysis where the components of the braking system undergo free analysis while for contact pressure analysis, specific pressure and specific velocity are applied to the friction material and rotor disc to simulate braking system in function. The results show that thermal loading has a significant impact on the contact pressure and lining temperature distribution which are crucial to effective braking.

DEDICATION

This report is dedicated to my beloved parents, my siblings and my friends who always support me during this final year project work. Last but not least, my final year project group mates who always helped each other to complete my final year project research.

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LIST OF ABBREVIATIONS

CEA	Complex Eigenvalue Analysis
CEM	Complex Eigenvalue Method
DPHI	Dual Pulsed Holographic Interferometry
ESPI	Electronic Speckle Pattern Interferometry
FEA	Finite Element Approach
FEM	Finite Element Method
PDE	Partial Differential Equations
CAD	Computer Aided Design
EMA	Exponential Moving Average

CHAPTER 1

INTRODUCTION

1.1 Research Background

This project is carried out to study the contact pressure behavior between the brake pad surface and rotor disc surface. This contact pressure occurs as there is friction force that produced during the surface contact between the brake pads and the rotor disc. The brake system components are illustrated as in Figure 1.1 and Figure 1.2. The design of the brake pads and rotor disc will be done by using CATIA in order to proceed for the simulation stage. The design will undergo two modal analysis to collect the natural frequency from the simulation for separate of brake pads and the rotor disc and the other natural frequency from the brake pads and the rotor disc that have been combined in order to undergo the simulation in one system. The outcome from this project will assist brake designer to predict the occurrence of squeal problem that will tackle the brake squeal noise issue. It can help the designer in order to redesign the rotor disc to be more efficient for the braking system as studies related to thermal performance is also carried out in the present research.

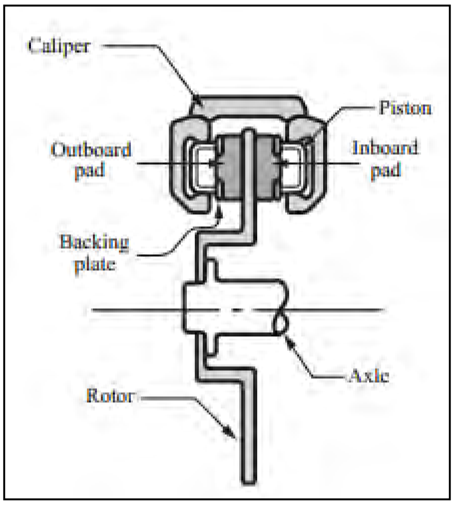

Figure 1. 1: Cross section of a simplified disc brake (Kinkaid et al., 2003)

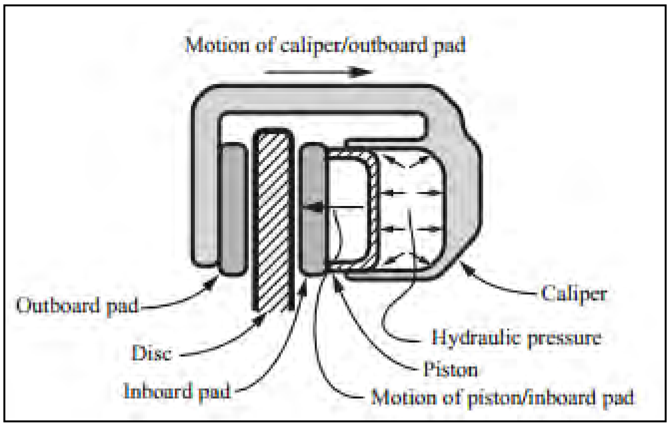

Figure 1. 2: Schematic of a simple floating caliper design for a disc brake (Kinkaid et al., 2003)

1.2 Statement of the Purpose

1.2.1 Aim

This project will assist brake designer to ensure the effectiveness of the braking system by observing the contact pressure at the friction material surface. The problem will be solved by redesign the design of the rotor disc and besides that by changing to more suitable material of the brake pads. This research will undergo simulation in order to observe the contact pressure applied to the surface of the friction material while braking.

There are two simulations that will do in this research in order to get two different results that are modal analysis and contact pressure analysis. The frequency will be obtained from modal analysis with separate of brake pads and rotor disc and from contact pressure analysis will obtain a result for contact pressure at friction material and temperature at disc brake. This analysis will consider the effect of friction properties, material properties, and brake pressure.

1.2.2 Objective

I. To study contact pressure at the surface of the friction material subjected to thermal loading conditions.

II. To carry out finite element analysis that show the contact pressure patent of the brake system during braking events.

1.3 Scope

This project will investigate the contact pressure at the surface of the friction material during braking. The disc brake that will be used is rear left disc brake rotor (solid disc) from Proton Iswara as shown in Figure 1.3. This project will only cover temperature effect at the disc brake by using hypermesh software.

Figure 1. 3: Proton Iswara brake disc components

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

There are three general categories of noise related to the automatic brake disc. These categories are classified according to the frequency range in which they occur. Firstly, the low-frequency disc brake that usually occurs between 100 Hz and 1000 Hz. There are 3 types of brake noise that are a grunt, groan and moan. This phenomenon happens as the brake rotor and lining interface produce friction and the energy is transmitted as a vibration. The noise types in this category are known as judder, groan and hum (Kinkaid et al. 2003).

Secondly, for the low-frequency squeal is defined as brake noise that occurs between 1000 Hz to 5000 Hz. This happens related to vibration that involving bending or twisting motion of the brake pad and the transverse motion of the disc. This phenomenon is known as modal ‘locking’ that the noise generation can be related to the frictional excitation coupled (Hassan, 2017).

Lastly, for the high-frequency squeal can be classified that the squeal usually occurs at a frequency above 5000 Hz. As the friction-induced excitation, the noise is generated that causing the coupled resonance of the rotor and the other brake components (Hassan, 2017).

Potential design guidelines to tackle squeal (Hassan, 2017):

- Rotor's material properties
- Pad friction's material properties
- The geometrical structure of disc brake (cheek thickness, the number of the vane, back plate thickness and material of the slotted friction)

Under the brake application, the disc brake generates the noise and vibration that classified as brake squeal. Even the phenomenon does not affect the performance of the braking systems, it can give a negative impression to the vehicle (Ouyang et al., 1999).

Many research has been done in order to tackle the brake squeal problems. So, by modifying the brake disc, it can eliminate the brake squeal that has been caused by self-excited vibration. Besides that, by using the Finite Element Method the further studied have been done to study the relationship between the shape of the brake disc and its vibration mode (Nishiwaki et al., 1989).

The brake squeal is a self-exciting vibration that occurs due to friction that causes from contact of pads and disc motor. This phenomenon occurs when there is a variation of friction coefficient that sliding velocity between disc rotor and the pads has a negative slope because of the dry friction (Matsushima et al., 1998).

2.1.1 History of Brake Disc

Based on the observation from Kinkaid et al. (2003), the history of the brake disc is started from the British engineer that is Frederick William Lanchester (1868 – 1946). In 1902, the description for the brake disc is that consist disc of metal that connected to the rear wheels of the vehicle. The disc will contact to the edge of the pair of pads that will slow the vehicle. From this era, it has shown that there is development in the brake system. Besides that, in 1903 drum brake has been introduced and is used to the vehicle as the brake system from Mercedes and Renault. During 1860 – 1930, the electromagnetically brake disc has been introduced from the American inventor, Elmer Embrose Sperry. After all, from the development of the brake system is being further improved from material and actuation method used. On the other side, in the 1950s there is the evolution of the spot-type disc brake that is similar to the present brake system today. This evolution is presented by Dunlop, Girdling and Lockheed Corporations. From the usage of the rear brake disc, there have applied the brake disc system to the front wheel that can provide higher power of braking force that can reduce time to stopping a vehicle.

2.2 Experiment Approach for Contact Pressure

Based on the research, Kinkaid et al. (2003) have state that there are several types of experiment that can be divided in order to study about the experiment approach for brake squeal. Firstly, the classical experiment that started by H.R. Mills in 1930s that investigate the brake squeal for the drum brake. In his investigation, he tried to show the relation between the decreasing of the coefficient of friction and the increasing of the sliding velocity that can lead to the squeal. Unfortunately, the investigation that he carried out does not give a definitive conclusion.

After 2 decades, Fosberry and Holubecki undergo another experiment on brake squeal but this time is for the brake disc system. From their investigation, most of the squeal occurred with the decreasing of the coefficient of friction but they have found out that the characteristic of the brake pads has no relation to the brake squeal phenomenon. From their investigation, it shows that the rotor is the resonant member that vibrate in a transverse mode with diametral nodes but the brake pads centre are located at the anti-nodal point from the vibration. For the next experiment by Spurr, the brake pads are machined in order to decrease the contact area to the rotor disc. He observed that squeal phenomenon occurred when the contact strip is close enough to the leading edge of the pad that shown in Figure 2.1. The squeal can be tackle or reduce when the contact strip is moved toward to the trailing edge of the pads.

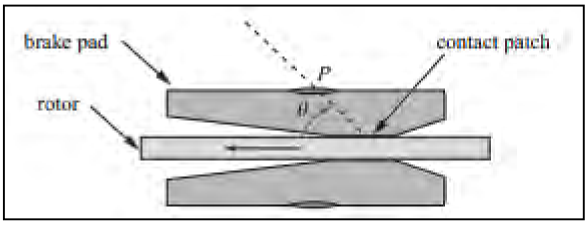

Figure 2. 1: Contact strip (N.M. Kinkaid et al., 2003)

Besides that, from the study by Kinkaid (2003), he stated that the vibration based work by Felske who is working with Volkswagen AG that carried out the experiment by using the holographic interferometry and, in particular DPHI. The experiments on the vibration of the squealing brake system always get the good data by the researcher during 1980s until 1990s. From the data collected, it has been verified and clarified by another researcher by using another optical measurement technique that is ESPI. By using both methods (DPHI and ESPI), it can measure 3 type of dimensional displacement of the imaged object that is a technique used, principle and isolated various squeal mechanisms.

In 1978, Felske has assumed that the squeal phenomenon is the mechanism of couple vibration from the disc brake assembly. The outcome that he had found is the greater the coefficient of friction to the rubbing surface, the more the tendency for the squeal to occur. From the experiment conducted by Felske, during squeal, the main reason that leads to the squeal noise is the vibration of the pads of the friction material and the brake calipers. He also said that some of the braking system, the squeal frequency is depending to the mode of the brake components. Felske also reported that the maximum amplitude of the vibration of the pads during squealing is 3µm. the result is the same as the data experimented done by Frosberry and Holubecki in 1961.

Six years later, Murakami that works with Nissan Motor Company also uses DPHI to undergo experiment for the brake squeal. What he has found that he agreed to the conclusion from Felske that the squeal is generated by the coupled vibration of the disc brake system. He also had known that the squeal will increase when the natural frequency of the pads, calipers and the rotor disc were too close to each other. In 1984, Ohta had done the same experiment for the brake squeal by using the holographic interferometry. From the experiment, he had found out that the maximum amplitude of vibration of the rotor disc in the squealing rotor disc brake system is 20µm**.** On the other hand, Nishiwaki who is working with Toyota Motor Corporation has observed the individual modal response of the rotor, brake pads, and caliper by using the electromagnetic vibration exciter. The outcomes show that the modes and the frequency of the components are same under both condition. They have agreed that the rotor disc is vibrated by diametral bending mode which remains stationary to the fixed observer during the disc rotating. They also found out that the pads also vibrate during the squealing and they decided to eliminate the number of a cooling fin in the vented disc brake rotor that they conclude by modifying the rotor disc could solve the brake squeal issue. Nishiwaki also concluded that the natural frequency and mode of the stationary rotor also affect the vibration modes and the frequency of the squealing disc brake system.