THERMAL STRESS ANALYSIS ON HEAVY TRUCK DISC BRAKE ROTOR BY USING FINITE ELEMENT ANALYSIS (ABAQUS)

RUSELI KIEN

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Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

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‘I approve that i have read this thesis thoroughly and in my opinion, this thesis is has fulfilled the criteria covering all the aspects of scope and quality and satisfied to be Awarded for Bachelor of Mechanical Engineering (Thermal-Fluid).’

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ABSTRACT

Braking system is the most important component in all kinds of vehicles. While braking, most of the kinetic energy is converted into thermal energy and increase the disc temperature. Problems such as premature wear of brake pads and thermal cracking of brake discs are attributed to high temperatures. Consequently controlling the temperature profiles and thermal stresses are critical to proper functioning of the braking system. This research project consists of thermal stress analysis on heavy truck brake disc rotor for steady state & transient analysis. The variation of thickness will cause the thermal stress occur during the friction between the pad and disc. The dissipated heat transfer during the periodic braking via conduction, convection and radiation which also affected the thermal distribution of rotor. To determine the thermal stress analysis of brake disc rotor, transient finite element techniques are used to characterize the temperature fields of the ventilated rotor with appropriate thermal boundary conditions. In order to get the stable and accurate result of element size, time step selection is very important and all these aspects are discussed in this paper. The findings of this research provide a useful design tool and improve the brake performance of disc brake system.

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ABSTRAK

Sistem pembrekan adalah merupakan komponen terpenting dalam keenderaan. Sewaktu membrek, hampir kesemua tenaga kinetik ditukarkan kepada tenaga haba dan meningkatkan suhu cakera brek. Masalah yang sering berlaku adalah seperti kesan pramatang pelapik brek dan juga tegasan terma yang berlebihan dalam cakera brek adalah berpunca daripada kesan pemindahan suhu tinggi. Oleh itu adalah penting untuk mengawal suhu dan kesan tegasan terma untuk sistem pembrekan berfungsi dengan baik. Projek penyelidikan ini merupakan projek yang melibatkan analisis tegasan terma ke atas cakera brek bagi kenderaan berat untuk keadaan mantap serta keadaan berubah dengan masa. Ketebalan yang berbeza-beza akan menyebabkan proses tegasan haba berlaku semasa geseran di antara pad brek dan cakera disk. Pemindahan haba semasa pembrekan berkala dipindahkan melalui konduksi, perolakan dan juga sinaran menjejaskan taburan terma bagi cakera disk. Untuk menentukan terma analisis tegasan bagi cakera brek, teknik unsur terhingga digunakan untuk menunjukkan bagaimana tegasan terma itu dipindahkan ke seluruh permukaan cakera brek kesan daripada peningkatan suhu dengan menggunakan syarat-syarat sempadan yang sesuai. Untuk mendapatkan hasil keputusan yang tepat, pemilihan langkah-langkah yang sesuai adalah penting dan segala aspek mengenainya dibincangkan dalam kajian ini. Berdasarkan hasil daripada penemuan penyelidikan ini, ianya boleh digunakan sebagai rujukan awal dalam proses rekabentuk cakera brek yang berongga.

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NOMENCLATURE

A_s	=	Surface Area
A_f	=	Projected Frontal Area
CFD	=	Computational Fluid Dynamics
D	=	Aerodynamic Drag Force (N)
D_o	=	Outer Diameter of Rotor
D_i	=	Inner Diameter of Rotor
E_b	=	Braking Energy
FD	=	Finite Difference
FE	=	Finite Element
FFT	=	Fast Fourier Transform
h	=	Convection Heat Transfer Co-efficient
H_z	=	Hertz
l	=	Characteristic Length
$\dot{q}$	=	Mass Flowrate
N	=	Revolution per Minute
ρ_{air}	=	Density of Air
r_o	=	Outer Radius of Rotor
T_s	=	Surface Temperature
v	=	Velocity
v_{ave}	=	Average Velocity
ω	=	Angular Velocity
	=	Specific heat kJ/kgK
h	=	Convective heat transfer coefficient (W/m^{2}k)

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Nu	=	Nusselt number
Q	=	Thermal energy
Q_{cond}	=	Conduction heat flow rate kW
Q_{rad}	=	Radiation heat flow, kW
VA	=	Vane angle
Vnu	=	Vane offset
	=	Thermal diffusivity, m^2/s
	=	Angular velocity, rad/s
	=	Stefan Boltzmann constant, W/m^2K^4
	=	Emissivity
	=	Friction coefficient

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CHAPTER I

INTRODUCTION

1.0 Background of Research

The disc brake is a device for slowing or stopping the rotation of a wheel. The brake caliper is forced mechanically or pneumatically against both sides of the disc of the heavy truck to stop the vehicle. The friction between the pads with the disc rotor of the heavy truck leads to heat flux generation which can be significantly can decrease the braking performance. The rate of heat generation is due to the kinetic energy and potential energy were transferred into thermal energy during the braking process are depends on the vehicles mass, velocity, and rate of deceleration. The large amount of heat is created and has to be absorbed by brake components in a very short space of time and the allowable temperatures of the brake and surrounding components have a limited amount of thermal energy a brake can be stored. The absorbed heat must be effectively dissipated through the ventilated disc rotor to achieve satisfactory performance of the braking system. The cooling process of heat transfer is dissipated through convection, conduction and radiation. The finite element analysis is used to predict the thermal distribution inside the rotor in steady state and transient condition.

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1.2 Objectives of the Study

The research focuses on thermal stress analysis on the solid state condition and during the transient condition to show the temperature distribution of disc brake of the heavy truck. The main objectives of this study are:

- To understand the working principles, components, standard & theories through a literature study.
- To understand the working principle of FEA software (ABAQUS).
- To analyze the thermal distribution on brake disc when the friction occur at the each cycle of the repeating braking and also the effect of the thermal distribution.
- To clearly justify the result of the thermal stress analysis of the front brake disc rotor.

1.3 Scope

The scopes of the thermal stress analysis on brake disc rotors are:

- Literature review on the working principles, components, standard and theories.
- Construction of 2D & 3D model of disc brake rotor
- FE model (Meshing of geometry model)
- Finite element analysis on steady state & transient analysis which shows the temperature distribution of disc brake rotor
- Final justification of the thermal stress analysis on the heavy truck brake disc rotor.

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1.4 Problems of Statement

The kinetic energy of a vehicle increases with the square of its velocity which makes it possible to stop a vehicle within a shorter period of time. This leads to very high power rates transmitted to the rotor disk. The kinetic energy of the heavy truck is transformed into heat energy which is can't dissipate fast enough into the air stream from the brake to the ventilated brake disc rotor.

There are two main problem of brake disc related with thermal such as excessive heat and severe thermal distortion. For heavy truck its required high power rates transmitted to brake pad to stop the rotor disc within shorter period of time. The friction between the brake pad with brake disc rotor produce the non-uniform excessive heat along the rotor surface due the rotor is rotating**.** The different temperatures in shorter period of time create thermal stress which caused by the changing of disc thickness. The high energy required to be handled by the rotor can lead to disk surface failure. In particular, it is recognized that repeated severe brake application under high speed driving may lead to thermal cracking of brake rotors due to inelastic cyclic strain accumulation .The rate of heat dissipated out from the rotor is low due to the short braking period as the conduction and convection are not large enough to take it all away. Thus the surface temperature rises much more rapidly than the main body of the disk and undergoes higher expansion. If the temperature gradient is steep enough, compressive plastic strain are generated at the surface and while cooling afterwards tensile residual stresses are induced which may be great enough to cause surface failure in one cycle . Thermal judder occurs as a result of non-uniform contact cycles between the pad and the disk brake rotor, which is primarily an effect of the localized Thermo-Elastic Instabilities (TEI) at the disk brake rotor surface. Localized TEI act at the friction ring surface generating intermittent hot bands around the rubbing path which may in turn leads to the development of hot spots, (D.Eggleston, 2000)

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1.5 PSM Structure

The structure of this research is as follows:

Chapters 1 introduce the objective of the research, scope of the work and also include the problem of statement.

Chapter 2 provides basic information on the selected model heavy truck, the working component of brake disc, theory of the heat transfer inside the rotor, the information about the finite element analysis and includes a detailed review of the relevant background literature.

Chapter 3 describes the heat flux analysis of the heavy truck and also the calculation of the cooling process at the brake disc surface due to the force convection.

Chapter 4 provides the step used of the finite element modeling by using ABAQUS software.

Chapter 5 includes the result thermal stress analysis of the both condition at the each cycle of the repeated braking and followed by the validation of the result by using the analytical solution method.

Chapter 6 covers the conclusion based on the result of the experiment and the suggested recommendation of the research in the future.

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CHAPTER II

LITERATURE REVIEW

2.1 Overview

In this chapter, the working principle of the typical components of commercial vehicle (heavy truck) brake disc rotor are explained and the heat flux generated due to the friction are absorbed by the brake disc rotor itself and the heat dissipated through the atmosphere via convection, conduction and radiation to the nearby component. The increasing temperature due to frictional heat generation cause axial and radial deformation of the rotor along with pad expansion. The resulting change in shape affects the contact between the rotor and pad surface area and thus will influence the load distribution at the friction interface that can lead to the disc surface failure. The discussion concepts of the heat transfer are explained including the boundary condition, thermal transient and also modeling consideration. The finite element analysis (ABAQUS software) is being used for detailed visualization of where structures bend or twist and indicates the distribution of stresses inside the rotor surface. The history of brake disc development and the typical component of air disc brake will be discussed at the next section.

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2.2 Introduction of Braking System

The most important system in any commercial vehicle and critical for its safe operation is a brake system. The brake system are used ensure the safety control of a vehicle during the braking and enable the vehicle to a smooth stop within the shortest possible distance under the emergency situations, normal operation and also parking brakes.

The efficient brake system on any type of vehicle are must be able to provide the necessary braking torque to the wheel to control the vehicle while dissipate the heat flux generated due to the friction between the brake pad with the brake disc rotor. The braking action is usually achieved by mounting the brake on the wheel as known as the foundation brakes that apply a braking torque directly on the wheel. The another type of braking actions is by using the brakes on the transmission shaft of the vehicle that generates higher braking force at the wheel compare to the foundation brakes but can only provide low braking torque at low vehicle speed, (T.K. Garrett, 2001).

This research focused on the air brake disc system which widely used in commercial vehicle such as trucks, tractor-trailer combination and buses. Truck brakes rely on friction and brake lining material to provide sufficient torque to slow and stop a vehicle weighing as much as 80,000 pounds within a reasonable distance. Repeated or continuous brake use (such as on long or steep hills) generates high temperatures that cause the brake linings to lose effectiveness either from fading or disintegration. Thus, on a 60 percent grade, an 80,000-pound tractor-trailer requires 167 times more braking power than a 3,000-pound passenger car, even though the tractor-trailer weighs only 27 times more sources from National Highway Traffic Safety Administration of USA.

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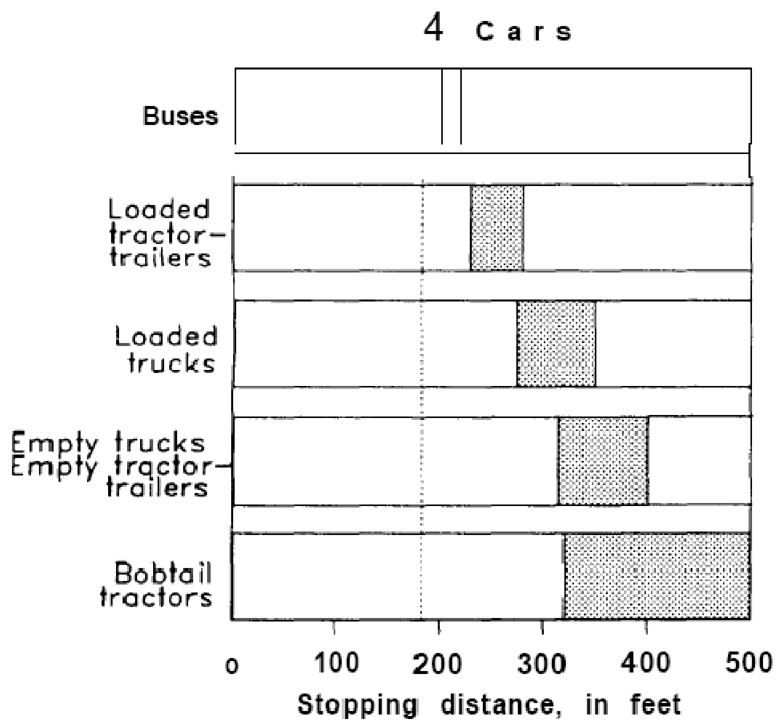

Figure 2.1 Stopping distances of heavy air braked vehicles from 60 mph on dry road (Source: NHTSA, 1988)

The commercial vehicle brakes are designed and balanced for fully loaded condition and this result excessive heat generated. The braking performance of commercial vehicle is governed by the Federal Motor Carrier Safety Regulation (FMCSR) Part 393. These regulations specify the stopping distance, deceleration and brake force that should be achieved during stopping.

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2.3 History

The early years of automotive development were an interesting time for the designing engineers where the period of innovation without established practice and virtually all ideas were new ones and worth trying. The development of the braking system is quite rapidly, however the design of many components stabilized in concept and so it was with brakes; the majority of vehicles soon adopted drum. The need for an efficient braking system became more relevant as the speed of the cars increased especially for emergency stop purpose.

Figure 2.2 Early model braking system

The early disc brakes design were patented by Frederick Willian Lanchester at Birmingham factory in 1902 but still not as effective at braking as the contemporary drum brakes of that time and was soon forgotten. Another important development occurred in the 1920's when drum brakes were used at all four wheels instead of a single brake to halt only the back axle and wheels such as on the Ford model T. The disc brake was again utilized during World War II in the landing gear of aircraft. The developments in both England and America were very much influence by the results of the racing cars using disc brakes and resulted in the adoption of this system to the mass produced family cars during the 1960s.

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