ANALYSIS OF TEMPERATURE DISTRIBUTION IN DISC BRAKES

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ANALYSIS OF TEMPERATURE DISTRIBUTION IN DISC BRAKES

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This thesis is submitted as a fulfillment of the requirements for the award of the degree of Master in Mechanical Engineering

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May 2007

I declare that this dissertation entitled **"ANALYSIS OF THE TEMPERATURE DISTRIBUTION IN DISC BRAKES"** is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 10th MAY 2007

To my loving wife, Siti Norfaezah Bt. Mohsangosehek, my daughter, Khayra Zafirah Bt. Azriszul, my mother, Zamaliah Bt. Suratdi, my family and my supporting friends

...

"THANK YOU for your support"

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ABSTRACT

Disc brake have been used for many years and still improving in terms of it temperature reach. Many methods have been introduced in order to simulate and predicting the temperature reach of the disc brake (i.e. Lumped analysis, one dimensional analytical method, two dimensional numerical, and three dimensional numerical method). These numerical simulations are range from finite difference to finite elements with their own assumptions. In this report three independent directions of heat flows is determining in order to find it importance in the solution accuracy of temperature reach in brake disc by using Normalizing and order of magnitude analysis which have been introduced by Ludwig Prandtl in his analysis of fluid flow. The results of order of magnitude will be validated with finite difference simulations.

ABSTRAK

Penggunaan brek cakera telah lama digunakan dan masih lagi berkembang dari segi pembaikan suhunya. Pelbagai kaedah telah diperkenalkan bagi menganggarkan suhu yang dicapai oleh brek cakera dari segi simulasi dan eksperimen. Kaedah simulasi yang digunakan termasuk kaedah *Finite Difference* dan *Finite Elements* dengan pelbagai pertimbangan atau anggaran yang di kemukakan. Di dalam laporan ini, kaedah analisa yang digunakan adalah *Normalising* dan *Order of Magnitude* bagi mencari kepentingan setiap aliran haba di dalam brek cakera. Kaedah *Order of maginitude* ini telah diguna pakai oleh Ludwig Prandtl didalam kajian bendalir. Hasil dari analisa diatas akan dibuat perbandingan dengan hasil simulasi.

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LIST OF SYMBOLS & ABBREVIATIONS

θ	Dimensionless temperature difference
k	Thermal Conductivity
C_p	Specific heat Capacity of material
ρ	Density of material
E	Heat Energy (J)
q_z	Heat flow in z-direction (i.e. thickness of disc)
q_r	Heat flow in r- direction (i.e. radius of disc)
q_ψ	Heat flow in ψ-direction (i.e. angular of disc)
A	Area (m^2)
T	Temperature (^oC)
ω	Angular velocity (1/s)
t	Time (s)
α	Thermal diffusivity
L	Thickness of disc
R_d	Radius of disc
t*/Fo	Fourier number
T_b	Surface temperature (^oC)
T_∞/T_o	Ambient temperature (^oC)
h	Convective heat transfer coefficient ($W/m^{2\circ}C$)
Bi	Biot number
q"	Heat flux (W/m^2)
Δx	Incremental thickness of disc (m)
V_{car}	Velocity of the car (m/s)
μ	Coefficient of friction
R_{tire}	Tire radius
Ø	Angle of brake pad

ω_{disc}	Angular velocity of disc (1/s)
ω_{tire}	Angular velocity of tire (1/s)
V_1	initial velocity, m/s
V_2	end velocity, m/s
ω_1	initial angular velocity (1/s)
ω_2	end angular velocity (1/s)
M	Mass of the car (kg)
I	Mass moment of inertia (kgm^2)
Eb	Energy of braking (J)
V_{enter}	velocity of a point enter a brake pad (m/s)
V_{exit}	velocity of a point exit from a brake pad (m/s)
t_{pad}	duration of a point inside the brake pad (s)
ρ_R	rotor/disc density (kg/m^3)
ρ_p	brake pad density (kg/m^3)
C_R	rotor/disc specific heat (Nm/kg^oC)
C_p	brake pad specific heat (Nm/kg^oC)
k_R	rotor/disc thermal conductivity (W/m^oC)
k_p	brake pad thermal conductivity (W/m^oC)
q''_R	Heat flux going into rotor (W/ m^2)
q''_p	Heat flux going into brake pad (W/m^2)
R_{mean}	Mean radius of brake pad position from center of disc (m)
F_f	Frictional Force (N)
F_n	Normal Force (N)
A_p	Area of brake pad in contact with disc surface (m^2)
$\ddot{\theta}$	Angular acceleration (m/s^2)
m	mass of the disc (kg)
S	displacement of the car (m)
a	acceleration (m/s^2)

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CHAPTER 1

INTRODUCTION

The safe motor vehicles should have continuous adjusting of its speed to changing traffic conditions. The brakes along with tires and steering systems are the most important safety measure, critically in avoiding accident in motor vehicles. Its must perform safely under a variety of operating conditions including slippery, wet, and dry roads; when a vehicle is likely or fully load; when braking straight or in a curve; with new or worn brake lining; with wet or dry brakes; when applied by the novice or experienced driver; when braking on smooth or rough roads; or when pulling a trailer.

These general uses of the brakes can be formulated in terms of three basic functions where braking system must provide:

- Decelerate a vehicle including stopping.
- Maintain vehicle speed during downhill operation
- Hold a vehicle stationary on a grade.

Deceleration of a vehicle involves the change of the kinetic and potential energy (if any) into thermal energy. Important factors that a design engineer must consider when designing a brake includes braking stability, brake force distribution, tire/road friction utilization, braking while turning, pedal force modulation, stopping distance, in-stop fade, and brake wear (brake design and safety).

Maintaining vehicle speed on a downhill is involving the change of potential into thermal energy. Important considerations during this operation are brake temperature, lining fade, brake fluid, vaporization in hydraulic brakes, and brake adjustment of air brakes. There are two types of brake that are usually being used in automobile which are disc brake and drum brakes. Drum brake is a brake in which friction is caused by a set of shoes or pads that press the inner surface of the rotating drum. The disadvantages of the drum brakes over the disc brakes is that when the drum brakes is heated by the frictions between the pads and the rotating drum, the drum will expanded and due to the expansion of the material and the brakes must be further depressed to obtain effective braking action. This increase of pedal motion is known as brake fade and can lead to brake failure in extreme circumstances. For this reason drum brakes have been superseded in most modern automobiles and light trucks with at least front wheel used disc brakes.

Disc brake is a device used in automotive to decelerate a car from high speed to a lower speed or stops. It has been used since 1960's and consists of two blocks of frictional materials which are pressed against each side of rotating annular ring of ferrous material which is the disc either mechanically or hydraulically. The two blocks of frictional materials so called 'pads' is rigidly fixed to the body of cars to reduce the rotational speed of the disc. During this application the pads will give constant frictional forces to the disc and the disc will have friction contact between them and heat will be generated during this applications. Since the pads do not cover all area of the disc, therefore the heat produces will be conducted radials, axially or circumferentially. This heat will be conducted through the disc by conduction and some of it will be dissipated to the surrounding by convection, radiation and some will be conducted to the other components of the car. Simultaneously the disc surface will increase in temperature as a results of this friction contact and because of this, several attempt have been done to analyze this transient heat flows in order to improve the dissipation of the heat from the surface of the disc. As we know, this resulting high temperature on the disc can cause warping which is due to excessive heat build up which soften the metal and can allow it to be disfigured. It can also create abnormal deposits if the brake pad is used above its temperature range which creates 'sticky' spot on one area of the surface of the disc and will grab every revolution of the disc which creates abnormal movement of the cars. Thermal cracking can also resulted from high temperature gradients in the disc. Thermal cracking often happens in drilled disc where a small cracks of the disc outside edges of the drilled holes near the edge of the disc due to the rotor uneven rate of expansion in severe duty environments. If this mass is removed, the stress will be increased in the rotor due to not enough heat sinks in the rotor. This problems can made the brake malfunction which results in catastrophically accidental cars. This heat variation also is used to analyze the thermal performance of the disc brake where for the effectiveness stop the surface temperature and the associate temperature gradient through rotor material are the critical evaluations. It is shown that an effectiveness stop at high deceleration temperature gradients of sufficient magnitude can develop in rotor material that causes surface rupture. In this report we are concern with analytical method for predicting the temperature variations of the disc and with the time.

1.1. Proposed Project.

This project is about to derive the equation of temperature variation in brake disc where a mathematical equation has to be made in order to predict the thermal behavior of the disc brake. This equation then will be validated with simulations analysis of temperature distribution in disc brake using coding programmed. This result then will be furthered for future analysis such as thermal cracking, warping and thermal stress in disc brake

1.2. Objectives

The objective of these project is to develop the equation of the temperature variations of the brake disc axially, radially and circumferentially with respect to time where it is a three dimensional equations. By using the Order Magnitude of Analysis, this equation will be analyzing whether the three axes are all important to predict the temperature variations of disc with respect to time. Finalize equations is then being used using appropriate software to get the temperature variations of the disc in graphical method.

1.3. Scope of the Project

This problems is an unsteady thermal distributions where its involved three direction of heat flow (r, θ, z). From the derived equations it is then required to find which independent direction or axis of heat flows is important in determining temperature of brake disc. To find this direction flow, the order of magnitude analysis plays its part to analyzing all the three directions of heat flow. The complexity of this project is related to the boundary conditions where there are convection which is force convection, natural convection and also radiation. The force convection is due to the movement of the car and the natural convection is due to the temperature difference between the disc and the air surrounding. Centrifugal force is also much involved in this heat dissipation due to the disc is rotated. To solve this problem the numerical methods must be selected due to its complexity.

CHAPTER 2

LITERATURE REVIEW

The derivation of the equations of temperature variation for the surface temperature rise on brake disc has been long attempted in order to predict the surface temperature of the disc for a given physical properties and inputs. Knowledge of this actual temperature that occurs at the interface between a pad of friction material and the mating metal disc during braking is the vital area of interest to the brake designer.

During the preliminary rotor sizing stage of the design process, the lumped parameter rotor model is an extremely valuable tool. It provides information regarding bulk or spatially averaged temperature of the entire rotor. The results and the agreement obtained with measured temperature variations not only validate the order of magnitude analysis and the numerical procedure but also the brake input power distributions. Lumped parameter models combined with one dimensional model are also formulated and developed to predict the thermal loading of the brake disc rotor. The lumped model can predict transient bulk rotor temperature while one-dimensional model provides peak surface as well as bulk temperature.

One-dimensional transient model governing equations have been used for many years in order to obtain peak surface and bulk temperature. It can also be used to investigate the brake disc temperature distributions in one direction. Newcomb [1] used method of the Laplace transformation in solving the one-dimensional governing equations in which the disc is assumed to be a semi-infinite slab in analyzing single stop and repetitive braking using these methods. He assumes that:

- the disc is homogenous, that it is heated / cooled only at the friction surfaces
- that the total energy of braking flows only into the disc
- circumferential temperature gradients can be neglected because of the rate of disc rotations is so high
- the effective rate of heat generations at any point is the average for the whole brake.

He also assumed that the deceleration rate during braking is constant, and conduction to and cooling from the hub, flange, brake fluid, pad and pad holder is neglected. The disc material properties and heat transfer coefficient is also assumed to be invariant with temperature increase. Agrawal [2] using the Fractional Derivatives approach to solve one-dimensional governing equations for thermal analysis of the disc brake which is differs little from Newcomb's approach. Limpert [3] includes energy absorbed in pads into the consideration in his analysis. He details the analysis by considering the heat flows into the hub, caliper and flange as well as temperature distribution in continued braking and includes the radiative heat transfer in his analysis of disc brake.

Steady state two dimensional analyses of temperature and heat distribution in disc brake are introduced as an improvement to the one-dimensional analysis to predict the temperatures during multi stop driving schedule. Limpert [3] has been detailed analyze the temperature response of a solid-rotor disc. The effect of varying heat transfer coefficient is introduced and fade in the form of decrease in brake effectiveness as well as the effects of burnished and unburnished brakes are taking into consideration. He used finite difference method to compute rotor temperatures where the node points were plotted in radial and axial directions inside the brake. The coefficient of friction was assumed to be a function of brake temperature and the heat transfer coefficient of the solids rotor also was assumed to be the speed dependent in his report. Each part of the brakes such as the hub, flange and bolt of the brake were applied with difference heat transfer coefficient from all boundaries. Sheridan et. al