A STUDY ON THE EFFECT OF DISC GEOMETRY ON THERMAL CAPACITY OF DISC BRAKE ROTOR USING FINITE ELEMENT ANALYSIS

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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To my lovely parents Mr. Khalid b. Yaakob and Mrs. Hadijah bt. Md Dewa

ACKNOWLEDGEMENT

I would like to take this golden opportunity to acknowledge the guidance, assistance and advice from many people that I have come in contact with throughout the process in preparing the project report. First and foremost, to my dedicated supervisor, Mr. Muhd Ridzuan Bin Mansor, thank you so much for the support, advice, guidance, and encouragement throughout the project.

My sincere grateful also goes to my parents Khalid Bin Yaakob and Pn. Hadijah bt. Md Dewa, my brother, and sisters for their encouragement and always be with me when I really need their support.

Gratitude also goes out to Dr. Zahir b. Hassan, our Head of Mechanical Department (Automotive), for his advice, guidance and knowledge during progrees of this project.

Last but not least, I would also like to express my special thanks especially to all my friends for their wonderful kindnesses in giving support and encouragement during the process of this project and also for those who give an idea and advice to improve the research and my technical skills.

Thank you.

ABSTRACT

This study is to investigate the heat distribution on disc brake within the braking system for Formula Varsity race car and do a comparison between theoretical and simulation result of the disc brake rotor. The temperature changes on the disc brake during the deceleration providing the heat distribution. The distribution of temperature depends on the various factors such as material used, design, surface roughness of disc brake and others. The execution of the analysis is done by using ABAQUS software where it shows area that has been affected by braking heat flux. This method is functional with the usage of coefficient heat transfer to calculate the thermal capacity of the disc brake rotor. The result for all rotors are accepted to be use on Formula Varsity race car where Yamaha LC135 rotor is 555.20^{0}C, Yamaha RXZ 135 rotor is 360^{0}C, Honda Wave 125 rotor is 394.41^{0}C and Modenas GT128 rotor is 384.66^{0}C but Yamaha RXZ 135 rotor is suitable to be implemented on Formula Varsity race car.

ABSTRAK

Kajian ini dijalankan bagi mengkaji pengagihan haba yang berlaku pada brek disk ketika sistem brek pada kereta lumba Formula Varsity dan melakukan perbandingan keputusan antara kiraan dan simulasi. Perubahan suhu pada brek disk ketika nyahpecutan menghasilkan pengagihan haba. Pengagihan suhu adalah bergantung kepada saiz, rekabentuk,permukaan kasar brek disck dan sebagainya. Pelaksanaan analisis dilakukan dengan menggunakan perisian ABAQUS dimana ia menunjukkan kawasan yang terlibat dan kawasan yang bebas. Kaedah simulasi ini berfungsi dengan penggunaan pekali pemindahan haba untuk mendapatkan analisis terma dan analisis tegangan. Keputusan untuk semua brek disk boleh digunakan pada kereta lumba Formula Varsity dimana brek disc Yamaha LC135 adalah 555.20^{0}C, Yamaha RXZ135 adalah 360^{0}C, Honda Wave 125 adalah 394.41^{0}C dan Modenas GT128 adalah 384.66^{0}C tetapi brek disc Yamaha RXZ135 adalah rotor yang sesuai untuk digunakan pada kereta lumba Formula Varsity.

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NOMENCLATURES

LRO = lateral run out

CATIA = Computer Aided Three-dimensional Interactive Application

CES = Cambridge Engineering Selector

GI = grey cast iron

v_o = inertial velocity (m/s)

v_f = final velocity (m/s)

v = velocity(m/s)

a = deceleration (m/s^2)

s = distance (m)

Δx = stopping distance (m)

Δt = braking time (s)

ΔE = kinetic energy (J)

m = mass of vehicle, without driver (kg)

L = braking energy (J)

t = thermal flow (J/s)

R_p = radius of disc ,outer (m)

Ri = radius of disc,inner (m)

$A_{surface}$ = braking surface (m^2)

W_R = load distribution at rear

μ_i = initial coefficient

n = number of holes

$q_{specific}$ = heat flux (W/m^2)

$\tilde{\omega}$ = angular velocity (s^{-1})

Re = Reynold number

υ = air kinematic viscosity (m^2/s)

hr = convection heat transfer coefficient (W/m^2 k)

ka = air thermal conductivity

Dp = outer diameter disc (m)

Di = inner diameter disc (m)

Dii = 2^{nd} inner diameter disc (m)

$\wr$ = depth of cross drill (m)

Pr = prandatl number

d_h = hydraulic diameter (m)

ρa = air density (kg/m^3)

μa = air absolute viscosity(kg/m.s)

$n^{1/3}$ = number of holes from 1/3 part

σ = stress (N/m^2)

F = load (N)

A = area (m^2)

δ = elongation (m)

L = length (m)

CHAPTER 1

INTRODUCTION

1.1 Introduction

Disc brake is one important component in the car. Most modern cars have disc brakes on the front wheels, and some have disc brakes on all four wheels. This is the part of the brake system that does the actual work of stopping the car. The most common type of disc brake on modern cars is the single-piston floating caliper.

The disc brake or disk brake is a device for slowing or stopping the rotation of a wheel. A disc brake, usually made of cast iron, is connected to the wheel and or the axle. In the process of performing this function, the brakes absorb either kinetic energy of the moving member or the potential energy given up by objects being lowered by hoists, elevators etc. The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in the surrounding atmosphere to stop the vehicle, so the brake system should have following requirements:

i. The brakes must be strong enough to stop the vehicle with in a minimum distance in an emergency.
ii. The driver must have proper control over the vehicle during braking and vehicle must not skid.
iii. The brakes must have well anti fade characteristics example their effectiveness should not decrease with constant prolonged application
iv The brakes should have well anti wear properties.

There are many types of brake. The most commonly used nowadays in a vehicle is disc brake. Most modern cars have disc brakes on the front wheels, and some have disc brakes on all four wheels. This is the part of the brake system that does the actual work of stopping the car. The main components of a disc brake are brake pads, a caliper (which contains a piston) and a rotor (which is mounted to the hub) (http://auto.howstuffworks.com).

A brake disc is usually made of cast iron, but in some cases, it may be made of composites such as reinforced carbon-carbon or ceramic-matrix composites. Iron or scientifically known as Ferum accounts for more than 95% by weight (wt%) of the alloy material, while the main alloying elements are carbon (C) and silicon(Si). The amount of carbon in cast irons is 2.1 to 4 wt%. Cast irons contain an appreciable amount of silicon, normally 1 to 3 wt%, and consequently, these alloys should be considered ternary Fe-C-Si alloys. The principle of cast iron solidification, however, is understood from the binary iron-carbon phase diagram, where the eutectic point is at 1,154 °C (2,109 °F) and 4.3 wt% carbon. Since cast iron approximates this composition, its melting point of 1,150 to 1,200 °C (2,102 to 2,192 °F) is about 300 °C (572 °F) lower than the melting point of pure iron. (http://www.buzzle.com/articles/properties-of-cast-iron)

Every automakers try to improved their braking system. The latest technology is using ceramics as a material to make a disc brake. Porsche was the first automaker to use ceramic brakes on a production car. it offered discs made of a novel ceramic composite material to reduce the weight of a special sport model.

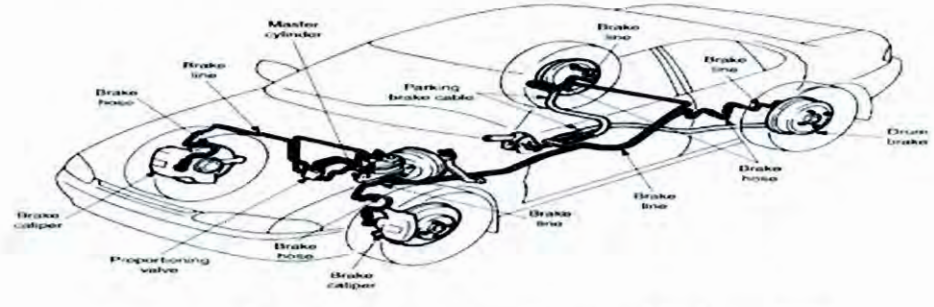

Figure 1.1 Braking system layout (Owen and Eichhorn,2001)

1.2 Problem Statement

Brakes are machine elements that absorb kinetic energy in the process of slowing down or stopping a moving part. Brake capacity depends upon the unit pressure between the braking surfaces, the coefficient of friction, and the ability of the brake to dissipate heat equivalent to the energy being absorbed. In braking system, disc brake is used mostly for automotive application. High speed, traffic jam, downhill and sharp cornering will gives a different value of temperature and thermal stress. During the braking process, the maximum temperature and thermal stress are difficult to determine due to the rotor size, rotor design, material used and etc.

Braking failure will occur when the temperature exceeds the allowable temperature on the rotor. When the brakes overheat to a great degree, the metal in the brake rotors develops hard spots. These are known as hot spots. The hot spots resist the friction from the brake shoes and pads. Because the shoes or pads have nothing they can grasp, there's no friction. Consequently, braking power is lost.

Disc brakes operate with a large cast-iron rotor attached to the vehicle axle that rotates. The diameter of disc brake rotor give an influence to the efficiency of a brake to stop vehicle which means the larger disc brake rotor produce higher efficiency. Larger surface area which allows easier heat transfer. The brake rotor gets cooled by its surrounding environment and smaller rotor being cooled by its environment due to thermodynamics versus the rate of the increase of heat due to friction. Disc brakes dissipate heat quickly because the rotors and pads are open, which also reduces tire wear and with less rebound over potholes and rough roads, keeps tires in contact with the road more effectively. Consistent tire-to-road contact produces consistent steering efficiency and vehicle handling stability.
(http://www.carbibles.com)

The problem we faced on Formula Varsity race car is braking system which is the geometry of disc brake rotor.The geometry is not suitable because the rotor is large. What are the team doing currently is just plug and play from the motorcycle part to the car. For large disc brake rotor, the thermal capacity is high but heavy

while for small disc brake rotor, the thermal capacity is low but lightweight. There are 3 types of rotors we used for this case study. Firstly, the solid rotor. The volume is large and the quantity of thermal capacity to absorb is high but the time of thermal to dissipate out of the rotor is long. It is because the thickness of rotor is thick. Second, cross drill rotor. The volume is low and the quantity of thermal capacity to absorb is low but the time of thermal to dissipate thru the air is fast. It is because the thickness is thin compare to the solid rotor. Lastly, ventilated rotor. The volume is large and the ability of thermal capacity to absorb is high compare with cross drill while the time of the thermal to dissipate is intermediate between solid and cross drill rotor. It is because the ventilated rotor has internal fins between the two friction surfaces. The fins are arranged to create a centrifugal air pump inside the rotor. As the rotor spins, the fins draw air into the centre of the rotor and dis-charge it from the edges. Student chooses the 5 type of rotors to investigate the disc brake rotor in terms of temperature of surface, temperature of distribution, thermal stress valve and displacement also weight and costing.

In this project, student will investigate the suitable disc brake between disc brake Yamaha RXZ, LC 135, Modenas GT128, and Honda Wave 125 for UTeM Formula Varsity race car. Every motorcycle has a different type of disc brake although the engine capacities are the same. In order to solve the problem, FEA software is used. CATIA is used to draw the disc brake while ABAQUS is used to perform finite element analysis such as thermal stress analysis.

1.3 Objective

The objective of this project is to study the effect of different rotor designs on the maximum surface temperature and temperature distribution for the disc brake rotor.

1.4 Scope

In this project, student is divided into two, namely scope of work and scope of study. To define the scope, scope of work includes develop 3D model of rotor design using CAD software, perform load analysis based on UTeM 2010 Formula Varsity race car specification and perform linear transient thermal analysis using ABAQUS/CAE finite element software while scope of study includes the types or design of rotor, rotor that suitable to be used and the way to fulfill the objective.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

UTeM Formula Varsity is an international student racing competition that challenges students to design, manufacture and race their single seat open-wheel formula style racing car in real track condition. This event is inspired by similar student based formula style racing events such as Formula SAE and Formula Student. The aim of the event is to provide a platform for Malaysian students which have interest in motorsport engineering to put into practice their engineering knowledge and skills in developing a working model of a formula style racing car. The event hope to foster the tie and collaboration between all Malaysian and international higher education institutions especially among the students as well as to help create the needed competent human capitals for our country automotive industries.

The objectives of the event are:

i. To give the realistic exposure to the student in the aspect of automotive engineering and product development in general.
ii. To explore creative thinking and robustness as this program involved the soft skills and also apply the classroom textbook theories to the real working experience.
iii. To search for prospective motorsport racer and engineers.
iv. To promote career and excellence in motorsport industry.

Figure 2.1: Logo of Formula Varsity UTeM 2010
(http://formulavarsity.utem.edu.my/)

A literature review was conducted to investigate the past research that has been done in many areas related to this work. In addition, description, histories, functions and theory of disc brake rotor will be discussed in this chapter. Furthermore, theory of finite element method related to thermal analysis will be presented as well in this chapter.

Figure 2.2 : Location brake system at Formula Varsity race car

2.2 BRAKE SYSTEM REVIEW

2.2.1 Introduction

A typical automobile braking system comprises of a braking device having different components, which are used for slowing or stopping down a vehicle. More precisely, these devices decrease or stop the speed of a moving or rotating body by absorbing kinetic energy mechanically or electrically. They are widely used in motor vehicles, buses, trucks, trains, airplanes, and other types of automobiles. The worldwide automobile industry is currently witnessing rapid innovative developments day by day. According to a research study by Frost & Sullivan, there is likelihood that after 2010, the global automotive industry will start using brake-by-wire systems instead of hydraulic braking systems. The various technologies such as electro mechanical braking system and the electronic wedges brake are soon going to replace the older braking systems. With the help of these brake-by-wire systems,