Thermal Effects of Disc Brake Rotor Design for Automotive Brake Application

K. Shahril, M. Ridzuan, M. Sabri

Abstract—The disc rotor is solid, ventilated or drilled. The ventilated type disc rotor consists of a wider disc with cooling fins cast through the middle to ensure good cooling. The disc brakes use pads that are pressed axially against a rotor or disc. Solid and ventilated disc design are same which it free with any form, unless inside the ventilated disc has several ventilation holes. Different with drilled disc has some construction on the surface which is has six lines of drill hole penetrate the disc and a little bit deep 12 curves. From the thermal analysis that was conducted by using ANSYS Software, temperature distribution and heat transfer rate on the disc were obtained on each design. Temperature occurred on the drilled disc was lowest than ventilated and solid disc, it is 66% better than ventilated while ventilated is 21% good than solid disc.

Keywords—Disc Brakes, Drilled Disc, Thermal Analysis, ANSYS Software.

I. INTRODUCTION

Brake system is the most important part in a vehicle. Certain vehicles have their own safety devices to guide the vehicle completely function to stop the car. The function of the brake system is to reduce or stop the rotation of the wheel. The operation of brake in condition to reduce the speed or stop the vehicle is brake pads are forced mechanically clamp against the disc rotor on both surfaces. They are compulsory for all of the modern vehicles and the safe operation of vehicles. In short, brakes transform the kinetic energy of the car into heat energy, thus slowing its speed.

Generally, the disc rotor is made of gray cast iron, and is solid, ventilated or drilled as shown in Fig. 1. The ventilated type disc rotor consists of a wider disc with cooling fins cast through the middle to ensure good cooling. Proper cooling prevents fading and ensures longer pad life.

Some ventilated rotors have spiral fins which creates more air flow and better cooling. Spiral finned rotors are directional and are mounted on a specific side of the vehicle. The solid type disc rotor is found on the rear of four wheel disc brake systems and on the front of earlier model vehicles. Drilled brake rotors, as the name implies, have holes drilled in them. Having the holes drilled into any of brake parts may differ from others, especially the brake rotors after all, a rotor full of holes means that there's less surface area for the brake pads to grab and stop the car but there are a few reasons drilled rotors make sense. When the brake pad grabs the rotor, it creates friction, which creates heat. If that heat can't escape, it leads to break fade, which reduces the brakes' stopping power.

The second reason is gas build up. The materials used in some older types of brake pads caused gas to build up between the rotors and pads. That gas also limited stopping power. The last reason is water. If a car drives through a puddle, a carwash or even a rainstorm, the brake rotors can get wet. A wet brake rotor is slippery and difficult for the brake pads to grab. Having drilled holes on a brake rotor makes it easy for heat, gas and water to be quickly moved away from the rotor surface, keeping the brake performance strong. The additional task for the brake disc is to induce air movement, as air moving over the rubbing surface of the disc reduces the heats built up [1].

II. PROBLEM STATEMENT

Excessive thermal loading can result in surface cracking, judder and high wear of the rubbing surfaces. High temperatures can also lead to overheating of brake fluid, seals and other components. Based on the design configurations, vehicle friction brakes can be grouped into drum and disc brakes. The drum brakes use brake shoes that are pushed in a radial direction against a brake drum. The disc brakes use pads that are pressed axially against a rotor or disc. This braking moment will produce a different value of temperature distribution and thermal stress. The higher value of temperature during braking will give negative effect to the brake system for example brake fade, premature wear, brake fluid vaporization, bearing failure, thermal crack, and thermal excited vibration [2].

Very difficult to exactly model the brake disk, in which there are still researches are going on to find out transient thermo elastic behavior of disk brake during braking applications. There is always a need of some assumptions to model any complex geometry. These assumptions are made, the difficulties involved in the theoretical calculation and the importance of the parameters that are taken and those which
are ignored. In modeling the things that less importance and have little impacts on the analysis a negligible. The assumptions are always made depending upon the details and accuracy required in modeling.

The assumptions which are made while modeling the process are given below:-
1. The disk material is considered as homogeneous and isotropic.
2. The domain is considered as axis-symmetric.
3. Inertia and body force effects are negligible during the analysis.
4. The disk is stress free before the application of brake.
5. Brakes are applied on the entire four wheels.
6. The analysis is based on pure thermal loading and thus only stress level due to the above said is done the analysis does not determine the life of the disk brake.
7. Only ambient air-cooling is taken into account and no forced convection is taken.
8. The kinetic energy of the vehicle is lost through the brake disks i.e. no heat loss between the tire and the road surface and deceleration is uniform.
9. The disk brake model used is of solid type, ventilated and drilled.
10. The specific heat of the material used is constant throughout and does not change with temperature.

III. BRAKE COMPONENTS AND FUNCTIONS

A disc brake system usually consists of break disc rotor, two brake pads and a caliper. The combination of these components allows the rotating wheel to experience severe braking in a short stopping distance. The braking surface is the area on which the braking action of the friction material takes place [3]. Fig. 2 illustrated the disc brake system components on a passenger vehicle.

![Fig. 2 Brake disc system components](image)

The centre part of the brake disc has a circular aperture, which is located on the wheel hub. It is surrounded by a number of holes for the wheel studs. The brake disc rotates along with the wheel. The normal load, produced when the brake is actuated result in the generation of an in friction force at the disc. This in turn produces a brake torque about the centre of rotation of the wheel as shown in Fig. 3.

![Fig. 3 Schematic Diagram of Force and Moment Acting on Wheel](image)

The reaction to the brake torque is seen in the brake force, between the tire and ground, which slow the vehicle [4]. The ventilated brake disc is a one-piece casting with the grooves and for passenger vehicle with cooling fins between the two braking surfaces.

IV. HEAT CONVECTION

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion. It involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfers. This energy is carried away from the surface by convection that is motion of the air removes the heated air near the surface and replaces it with cooler air. The finding by Sheridan (1988) suggested that 90% of the heat generated during braking is transferred by convection to the ambient air [5].

The major aim of designing brake discs is to improve the convection dissipation of disc braking systems. In operations of braking systems, convection is the most important mode of heat transfer, dissipating the highest proportion of heat to surrounding air. The current research focuses on heat convection of disc rotors [6].

\[ Q_{\text{conv}} = hA_c(T_e - T_w) \]  

(1)

V. BRAKE DISC DESIGN

Fig. 4 shows the isometric discs geometries that created in CATIA V5 after all the dimensions have been recognized. From the top to bottom image are solid disc, ventilated disc, and lastly drilled disc.
Solid and ventilated disc design are same which it free with any form, unless inside the ventilated disc has several ventilation holes. Different with drilled disc has some construction on the surface which is has six lines of drill hole penetrate the disc and a little bit deep 12 curves. Fig. 5 shows the detail brake disc design and part names at the disc construction to represent the dimension easily. Table I shows nominal dimensions on each part in unit millimeter except for the row number of vanes.

VI. MATERIAL PROPERTIES

Table II below shows the material properties for Gray Cast Iron G3000 that was use in the analysis of the brake disc.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>NOMINAL DIMENSIONS ON EACH PART OF BRAKE DISC</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOLID</td>
<td>VENTILATED</td>
</tr>
<tr>
<td>‘A’ Outside Diameter</td>
<td>254</td>
</tr>
<tr>
<td>‘B’ Thickness</td>
<td>20.7</td>
</tr>
<tr>
<td>‘M’ Diameter</td>
<td>100</td>
</tr>
<tr>
<td>‘C’ Spigot Diameter</td>
<td>62</td>
</tr>
<tr>
<td>‘D’ Internal Flange Diameter</td>
<td>121.3</td>
</tr>
<tr>
<td>‘E’ Eye Diameter</td>
<td>170</td>
</tr>
<tr>
<td>‘F’ Mounting Flange Thickness</td>
<td>8.2</td>
</tr>
<tr>
<td>‘G’ Mounting Offset</td>
<td>38.2</td>
</tr>
<tr>
<td>Air Gap</td>
<td>Nil</td>
</tr>
<tr>
<td>Drilled Hole</td>
<td>Nil</td>
</tr>
<tr>
<td>* Number of Vanes</td>
<td>Nil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE II</th>
<th>MATERIAL PROPERTIES FOR GRAY CAST IRON G3000 [7]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, ( \rho ) (kg/m(^3))</td>
<td>7280</td>
</tr>
<tr>
<td>Poisson’s ratio, ( v )</td>
<td>0.26</td>
</tr>
<tr>
<td>Thermal Expansion, ( \alpha ) (µm/m.K)</td>
<td>10.5</td>
</tr>
<tr>
<td>Elastic Modulus, ( E ) (GPa)</td>
<td>176</td>
</tr>
<tr>
<td>Conductivity, ( k ) (W/m.K)</td>
<td>46</td>
</tr>
</tbody>
</table>

Metallic iron containing more than 2% dissolved carbon within its matrix (as opposed to steel which contains less than 2%) but less than 4.5% is referred to as gray cast iron because of its characteristic color. Considering its cost, relative ease of manufacture and thermal stability, this cast iron (particularly, gray cast iron), is actually a more specialized material for brake applications particularly the material of choice for almost all automotive brake discs. To work correctly, the parts must be produced at the foundry with tightly monitored chemistry and cooling cycles to control the shape, distribution and form of the precipitation of the excess carbon. This is done to minimize distortion in machining, provide good wear characteristics, dampen vibration and resist cracking in subsequent use [8].

VII. RESULT

From the thermal analysis that was conducted by using ANSYS Software, temperature distribution and heat transfer rate on the disc were obtained on each design. The analysis was conducted by using gray cast iron as a material for the three types of disc design which is solid, ventilated and drilled.
Fig. 6 shows the image temperature distribution on solid, ventilated and drilled disc by using gray cast iron. According to Fig. 7, the graph is easily to understand that solid disc gives the highest temperature during the simulation then it followed by ventilated disc with value 847.9 K and 828 K respectively. Contradiction to drilled disc result the lowest temperature with 788.6 K. This is caused the design play a main role in creating temperature distribution.

Fig. 8 shows total heat transfer for each design by using gray cast iron as the material. Solid disc indicated the lowest in heat transfer about 0.779 MW while ventilated is 0.946 MW. The greatest heat transfer for this simulation is drilled disc since its advance geometry give heat dissipates efficiently thus makes the disc fast cooling.

VIII. CONCLUSION

It can be conclude that drilled disc is more efficient than another types of disc since it can dissipate heat quickly after the braking force generate on the disc surface. The drilled geometry itself helps the heat dissipate from the surface cause the air easily flow around the disc and it is called convection heat transfer so that the temperature occur on the drilled disc also lowest than ventilated and solid disc. As gray cast iron applied to drilled disc, it is 66% more better than ventilated while ventilated is 21% good than solid disc.
REFERENCES


