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Thermal Analysis of disc Brakes Rotor: A comparative Report

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Abstract

In this paper, authors present our results of thermal analysis of disc brake rotor used by two-wheelers in India. The aim of this paper is to realize the purpose of the holes in the disk brake. Thermal analysis is done for two different models of rotors. One is a simple rotor without vents and holes and the other perforated (consists of holes). Researchers have tried to analyze the heat loss from a rotor which is considered to be heated by disc brake friction when in use. Researchers analyze the heat loss taking into account convection and radiation. The results are compared for both the discs. The initial condition assumed here is that the vehicle has stopped completely by application of brakes. Both the rotors are of same dimensions.

The geometry of disc brake rotor is made in Solid-Works. The heat transfer analysis is done using ANSYS software. The analysis helps us to understand which of the two models is better in terms of performance, heat loss and manufacturing cost and hence extensively used in motorcycles in real world.

Keywords: Thermal analysis; Disc brake rotor; Natural convection; Solid-Works; ANSYS; Heat loss; manufacturing cost.

1. Introduction

Disc brakes are an important component of our automobiles. They are employed to halt the vehicle or to slow the vehicle to a required velocity from a given initial velocity. Disc brake is a device which is used to convert kinetic energy into thermal energy by means of friction. The primary function of a brake rotor is to act as a friction surface, generating an opposing torque to a shaft [1]. Belhocine, Abu Bakar andBouchetara[2] stated that Passenger car disc brakes are safety-critical componentswhose performance depends strongly on the contact conditions at the pad-to-rotor interface.The primary components of a disc brake are:

1. The brake pads
2. The calliper, which contains a piston
3. The rotor, which is mounted to the hub

A disc brake system consists of a brake disc, a brake calliper and brake pads. When the brake pedal is applied, pressurized hydraulic fluid squeezes the brake pad friction material against the surface of the rotating brake disc, i.e. rotor.The result of this contact produces friction which enables the vehicle to slow down or stop.During braking, energy is transferred to the rotor in the form of heat. McPhee and Johnson[1] have said that when the kinetic energy of the vehicle is converted into heat, this causes excessive heating of rotors. The kinetic energy is transformed into the thermal energy, by means of dry friction effects, which then is dissipated into the surroundings [3]. As a result, the brake rotor must also serve as an efficient energy dissipation and storage device.The conditions which are assumed in this study are as follows:

1. The vehicle is completely stopped after the application of brakes.
2. The material properties of the rotor are isotropic.

3. The rotor is assumed to be at a uniform temperature.
4. Heat is transferred to the surroundings through natural convection as well as radiation.

To determine the temperature distribution in discs, it is necessary to solve theappropriate heat transfer equations. The solution of this problem depends on the physical conditions existing at the boundaries of the medium and on the conditions existing in themedium. Huajiang Ouyang,Abd Rahim Abu-Bakar and Lijie Li [4] noted that the heat transferred due to friction is

$$q = \mu p v$$

where μ is the friction coefficient, v is the sliding velocity of the disk at the point of contact and p is the contact pressure at the interface, q is the amount of heat generated by friction. To stop the vehicle, friction material in the form of brake pads is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc [5]. Friction causes the disc brake and attached wheel to slow or stop. For the exposed region of the disk and brake pads, it is assumed that heat is exchangedwith the environment through convection as well as radiation. Therefore, convection surface and radiation surfaceboundary condition are applied as:

$$q_1 = h \times A \times (T_o - T_s) \quad \text{And}$$

$$q_2 = \varepsilon \times \sigma \times A \times [(T_0)^4 - (T_s)^4]$$

whereq_1 is the heat dissipated from the rotor by convection, q_2 is the heat dissipated from the rotor by radiation, h is the average heat transfer coefficient, A is the area of the rotor in contact with the surroundings , T_o is the surface temperature of disc brake rotor and T_s is the ambient temperature, ε is the emissivity of the rotor, σis the Stefan – Boltzmann constant.

2. Literature Review

Gao and Lin [6] have presented an analytical model for the determination of the contact temperature distribution on the working surface of a brake. Dufre´noy[7] proposed a macrostructural model of the thermomechanical behaviour of the disk brake, taking into account the real three-dimensional geometry of the disk–pad couple. Contact surface variations, distortions andwear are taken into account. Formation of hot spots as well as non-uniform distribution of the contact pressure is an unwanted effectemerging in disk brakes in the course of braking or during engagement of a transmission clutch. If the sliding velocity is high enough, this effect can become unstable and can result in disk material damage, frictional vibration, wear, etc. [8].

3. Design of Brake Rotors

Both the rotors were drafted in Solid-works 2012.It is a multiplatform CAD/CAM/CAE software developed by DASSAULT systems. Both the rotors are of identical size. The dimensions of rotor are given in table 1.

Table 1: Parameters of automotive brake disc

Parameters	Dimensions
Outer disc diameter, mm	288
Inner disc diameter, mm	68
Disc Thickness, mm	25
Disc Height,mm	66.3
Clamp hole diameter,mm	15.3
Number of clamp holes	5

SOURCE: https://www.youtube.com/watch?v=3Fk1bCMJchw

The material used for the analysis of disc brake rotor is structural steel and its properties are given in table 2. The geometry of both the rotor models are as shown in fig.1 and fig 2 respectively. Fig.1 shows the solid rotor model. The rotor surface is plain and there are no holes or any other profiles to increase the dissipation of the heat. Heat transfer from the disc to the atmosphere takes place only on the outer surfaces of the rotor. Fig.2 shows the perforated rotor (consisting of holes). The air flow is provided to increase heat dissipation but it results in less area available for radiation in this study.

Table 2: Thermoelastic properties used in simulation

Properties	Values
Thermal Conductivity(W/m ^{0}C)	46.6
Density (kg/m^3)	7850
Specific Heat, (J/kg^{o}C)	434
Poisson's ratio	0.3
Thermal Expansion, (10^{-6} /^{o}C)	12
Elastic Modulus , E (GPa)	200

SOURCE: ANSYS engineering data

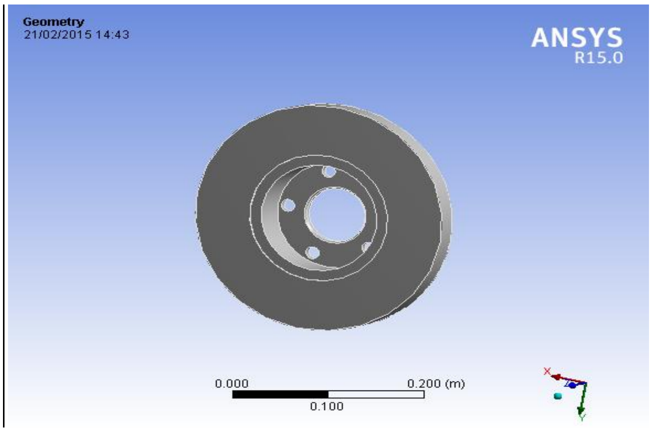


Fig.1: Solid Rotor Model

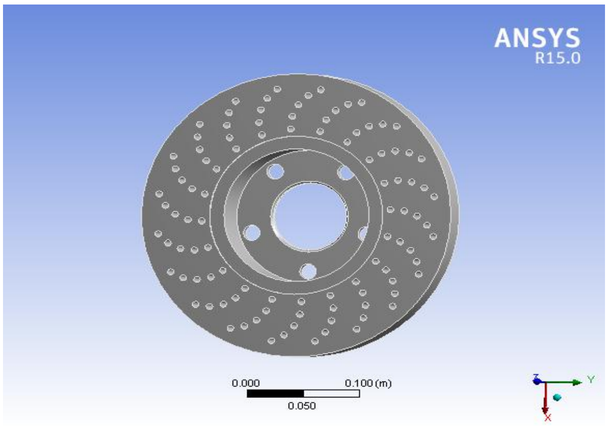


Fig.2: Perforated Rotor

4. Analysis

ANSYS software was used for the analysis of both types of brake rotors. ANSYS has been the pioneer in the application of computational methods to solve the engineering design over 40 years. The main module used in this work is transient thermal analysis.In the Transient thermal analysis, the Temperature distribution at different time intervals is determined. Convection as well as radiation boundary conditions were simultaneously applied on both the rotor models. Based on the results obtained the betterperforming design is found out and values are given in ***the table3***

5. Results

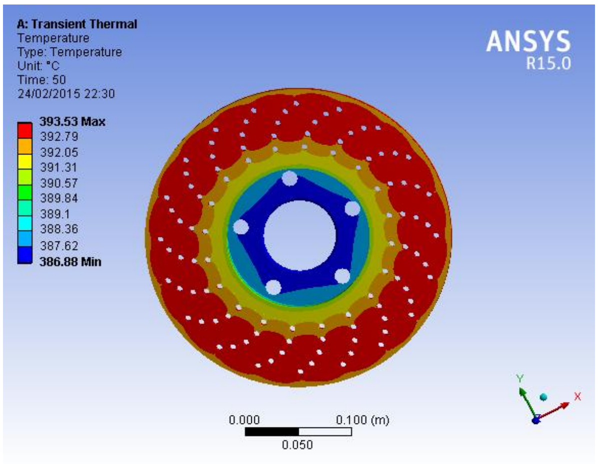
Belhocine and Bouchetara [4] found that the high temperature attained by a disc brake rotor is 400^{o}C. So authors have assumed the initial temperature to be 400^{o}C.The analysis of both the models was done and results are as shown in fig. 3 and fig. 4. It was observed that inspite of holes present in the perforated model, the minimum temperature attained by both the bodies after time t = 50 sec is almost equal but the temperature distribution in perforated model is much better as there is less temperature difference compared to simple disc. Hence, the perforated disc without holes is better regarding heat dissipation as compared to perforated rotor model. This paper presents a comparison made between two different discs of same materials and of same dimensions, the only difference that one is perforated. Both are at same temperature and thermal analysis was done in ANSYS software to determine which one is better regarding temperature distribution at the end of 50 Seconds.

TABLE. 3 Maximum and minimum temperature for simple disc at different time intervals

TIME (S)	MAX. TEMP (^{o}T)	MIN. TEMP (^{o}T)
1.e-002	400.01	399.96
10	399.31	396.82
20	398.36	394.11
30	397.34	391.52
40	396.30	389.04
50	395.25	386.69

TABLE. 4 Maximum and minimum temperature for perforated disc at different time intervals

TIME (s)	MAX. TEMP (^{O}C)	MIN. TEMP(^{O}C)
1.e-002	400.01	399.96
10	398.96	396.93
20	397.64	394.26
30	396.28	391.69
40	394.91	389.23
50	393.53	386.88



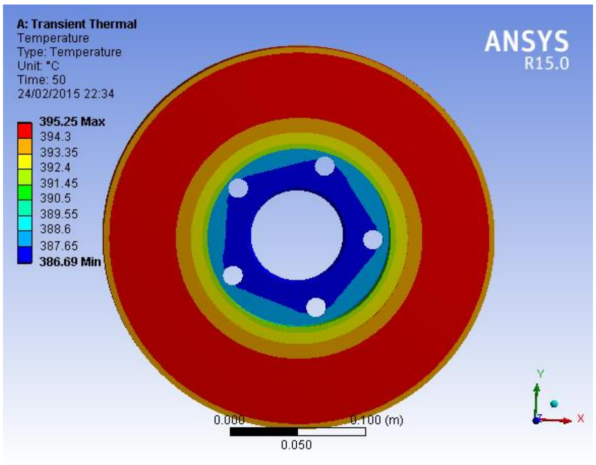


Fig.3: Results of thermal analysis of perforated modelFig.4: Results of thermal analysis of simple model

Conclusion

In this paper, authors have compared two types of rotors as one rotor without holes and the other one perforated on the basis of heat dissipation. Objective of this paper is to determine whether the holes in the perforated rotor tends to aid the heat dissipation.Both the rotors are of same dimensions and same material and subjected to same operating conditions and then analyzed with same boundary conditions. Transient thermal analysis was done on ANSYS workbench to find out the best amongst the two. The results are as expected. The perforated model is expected to be more effective. The perforated disc proved to be more efficient as maximum temperature of the body after 50 seconds is less than that of simple disc. However, this is just one aspect of the detailed analysis. Next step will be to analyse the Thermal Stresses due to thermal expansion. Structural analysis can be done on both the discs to determine the cumulative effect of temperature,i.e. thermal stresses and deformation (if any) due to thermal expansion.

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