Effect on Brake Cooling with Different Wheel Geometry

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Abstract - *Improving brake cooling has commanded substantial research in the automotive sector, as safety remains paramount in vehicles of which brakes are a crucial component. To prevent problems like brake fade and brake judder, heat dissipation should be maximized from the brakes to limit increasing temperatures. This project is a CFD investigation into the impact of existing wheel centre designs on brake cooling through increased cross flow through the wheel. The new study brings together the complete wheel and disc geometries in a single CFD study and directly measures the effect on brake cooling, by implementing more accurately modelled boundary conditions like moving ground to replicate real conditions correctly. It also quantifies the improvement in the cooling rate of the brake disc with a change in wheel design, unlike previous studies.*

***Key Words*: To prevent problems like brake fade and brake judder**, **CFD investigation**

1. INTRODUCTION

The problem of overheating brake discs is a significant problem in automobiles. It leads to issues such as brake fade due to heating of brake fluid and other components, brake judder, vapour lock and also thermal stresses and cracking, and has a pernicious effect on the effectiveness of the braking system and compromises the safety of the passengers. This problem has driven the significant research resources invested in improving cooling of brake discs leading to creation and optimization of ventilation geometries like vanes, and cross drilled holes in a brake disc.

In this research, Theoretical analysis to find the variation in heat transfer coefficient with Reynolds number and numerical simulation attempt has also been done with different forced convection turbulent flows.

 Most research aimed at improving brake cooling focuses on the brake disc geometry and hence it has seen significant and consistent innovation and improvement. The primary form of heat dissipation from the brake disc is in the form of conductive and convective heat transfer; radiation can be neglected due to its low contribution. Conduction and Convective heat transfer are impacted by the flow both inside the brake disc and also on the outside surfaces. The outside flow has often been ignored in many studies which simulate the brake disc in free stream conditions ignoring the wheel completely. The outer flow is affected by the geometry external to the brake disc which comprises of the wheel geometry and car bodyworks. In this project, the effect of wheel centre geometries on brake cooling rate is quantified for an isolated rotating wheel without the rest of the car, and conclusions have been drawn about its effectiveness as a solution for improving brake cooling. Wheel centre geometries have been heavily researched for their contribution of up to 25% of total drag force on the car, but their impact on brake cooling remains a scantly studied topic. The airflow is qualitatively explained along with the variation of wheel centre geometries.

2. Review of Literature

Prof. R. J. Jani [1] Braking is a process which converts the kinetic energy of the vehicle into mechanical energy which must be dissipated in the form of heat. During the braking phase, the frictional heat generated at the interface disc-pads can lead to high temperatures. This high temperature rise of the rotor reduces the coefficient of friction between pad and rotor, which reduces braking efficiency. Excessive thermal loading can also 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 component. Thus, how to select better geometrical design variables and improve thermal performance of automotive brake rotors is a task that the vehicle designers and researchers are often confronted. For this review paper, work done in this field by different author is reviewed and it is concluded that vented rotor is best rotor design and vane number have greater effect in heat removal capacity of vented rotor.

Ananya Bhardwaj [2] Improving brake cooling has commanded substantial research in the automotive sector, as safety remains paramount in vehicles of which brakes are a crucial component. To prevent problems like brake fade and brake judder, heat dissipation should be maximized from the brakes to limit increasing temperatures. This research is a CFD investigation into the impact of existing wheel centre designs on brake cooling through increased cross flow through the wheel. The new study brings together the complete wheel and disc geometries in a single CFD study and directly measures the
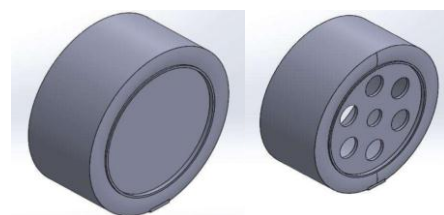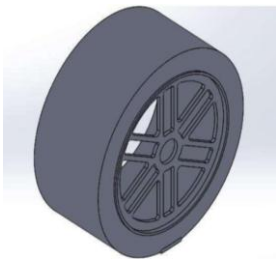

Figure 1 Wheel geometry V1 & V2

Figure 2 Wheel geometry V3

effect on brake cooling, by implementing more accurately modelled boundary conditions like moving ground to replicate real conditions correctly. It also quantifies the improvement in the cooling rate of the brake disc with a change in wheel design, unlike previous studies.

3. Aim and Objectives

3.1 Aim

Aim of project is to find the heat transfer co-efficient on different wheel geometry.

3.2 Objectives

Objective of project is to determine the heat transfer co-efficient to provide proper cooling of wheel Centre by different geometry.

4. DESIGN AND DEVELOPMENT OF TEST RIG

4.1 CAD model of disc brake rotor

The designs of Disc Brake Rotors of various commercial cars available in the market were studied. The following design was chosen as a good representative of rotor design for the current market with regard to the material availability and manufacturing limits.
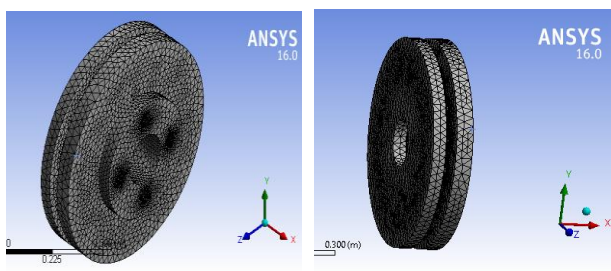

Figure 3 CAD Model of disc brake

Table -1: Material properties of disc brake rotor

Sr.No.	Property	Value
1.	Density	8.07 kg/ m³
2.	Thermal Conductivity	17 W/ m K
3.	Melting Point	1673 K
4.	Specific Heat	530 J / K
5.	Thermal Expansion	18 x 10⁻⁶m/ K
6.	Tensile Strength	620 MPa
7.	Compressive Strength	310 MPa
8.	Young's Modulus	205 GPa
9.	Poisson's Ratio	0.275

4.2 CAD model of wheel geometry

Geometry 1: 18×10^{-6}

8.07 kg/ m³

This is first sample wheel geometry of project. It is made in CREO parametric software version 3.0 student edition. Geometry has outer diameter of 342.4 mm and it consists of 8 numbers of circular holes having diameter of 55 mm.
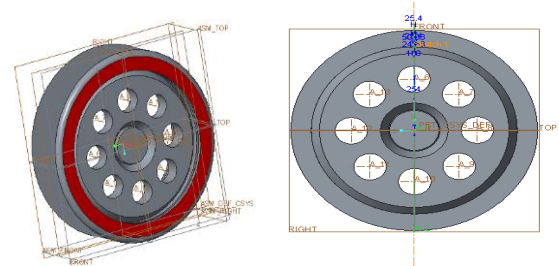

Figure 4 sample geometry 1

Geometry 2:

This is second wheel geometry of project. It having outer diameter of 350.6 mm and 4 vanes for cooling of brake disc.

Figure 5 sample geometry 2

Geometry 3:

This figure shows standard wheel geometry of Tata nexon having wheel diameter of 396.78 mm and 5 vanes to provide cooling of brake disc. This wheel geometry use in experimental analysis.
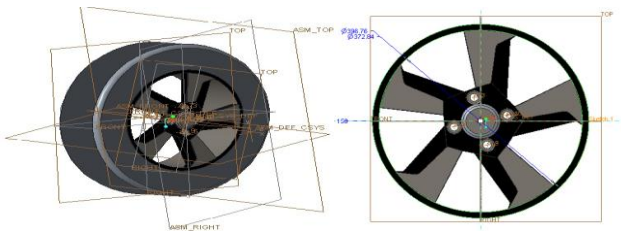
Figure 6 sample geometry 3

Geometry 4:

This figure shows standard design and dimension of Honda city wheel geometry. Which is used in actual experiment work.
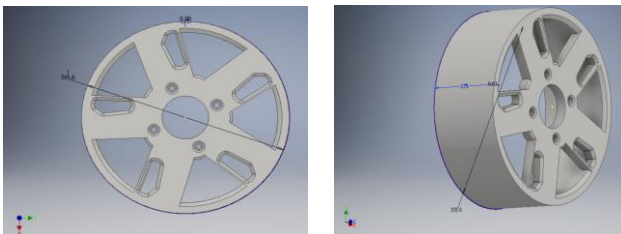

Figure 7 sample geometry 4

4.3 Analysis

4.3.1 Theoretical analysis

Assumptions of analysis:

a) The material of disc brake rotor is isotropic.

b) The disc brake rotor is uniformly decelerating.

c) The ambient temperature of air is 28^0C.

d) The heat generated is uniformly conducted in the rotor.

Let the initial angular velocity of the rotor Ω be 47.75 rad/ s. The values of following are previously known:

μ = Coefficient of friction between rotor and pad=0.7

p = Fluid Pressure = 1 MPa

r = Inner radius of rotor = 40 mm

R = Outer radius of rotor = 120 mm

a) Calculation of Heat Flux:

The heat flux entering the contact area of rotor and pad can be approximated as the value of power used while braking.

Power used in braking can be calculated as:

F = 2μpa = 1919.089 N

T = 2μpa(R-r) = 136.25 N*m

P = T x Ω = 6491.97 W

Heat flux Q = P/A = 91842.58 W/m^2

b) Calculation of Heat Transfer Coefficient:

$$Re = \frac{\rho vD}{\mu} = \frac{vD}{\vartheta}$$

Where

ρ = Density of air

V = Velocity of air = 18.6 m/s (Taken from research paper)

D = Diameter of the disc rotor

μ = Dynamic viscosity of air

ϑ = Kinematic viscosity of air= 15.812 x 10^{-6} m^2/s

$$Re = \frac{18.6 \times 0.300}{15.812 \times 10^{-6}}$$

Re = 352896.53 (Turbulent flow)

Prandle number P_r = 0.7

Validity = $5 \times 10^5 \leq R_e \leq 10^7$ and $0.6 \leq P_r \leq 60$

$$N_u = \frac{hL}{Kair} = 0.037 \times R_e^{0.8} \times P_r^{\frac{1}{3}}$$

$$\frac{hL}{Kair} = 0.037 \times (352896.53)^{0.8} \times P_r^{\frac{1}{3}}$$

$$\frac{hL}{Kair} = 900.9187$$

$$h = \frac{900.9187 \times K_{air}}{L} = \frac{900.9187 \times 0.0286 (\frac{w}{m}.k)}{0.300}$$

$$h = 85.8875 \text{ W}/m^2 k$$

4.3.2 Experimentation

The motor is runs at 940 rpm which is reduce to around 455 rpm with the help of belt and pulley arrangement for the rotor. The ambient air temperature is around 28°C. Radial temperature distribution was observed to be negligible when measured with the help of infrared thermometer.

At this rpm value, following temperature results in degree Celsius were obtain:

Table -2: Experiment result

	T_1 (℃)	T_2 (℃)
Except wheel	36.91	69.1
With wheel	35.8	53.7

5. RESULT AND DISCUSSION

5.1 Experimental result

The theoretical result could be summarized as:

Heat transfer co-efficient (h) = 85.88 W/m^2. K

The experimental result could be summarized as:

Q = hAΔT

We know that,

Q = mC_pΔT

Q = 233.90 W

Heat transfer co-efficient (h) = $\frac{Q}{A\Delta T}$ = 76.93 W/m^2. K

5.2 Discussion

The temperature difference obtained theoretically is very large because of the following plausible reasons:

a) The material of rotor cannot be isotropic.

b) The ambient temperature may not be constant 280C due to environmental factors.

c) The heat entering the rotor cannot be exactly equal to frictional power used in braking due thermal contact resistance, heat loss in brake pads and other parts of the caliper.

d) The conduction losses are assumed to be negligible.

e) The analysis is a steady state analysis which can be achieved after significant time lapse only.

f) The rotor does not accelerate and decelerate uniformly.

g) The dynamicity of the problem is very difficult to achieve theoretically.

h) The percentage value after installation of wheel on brake disc rotor is around 10.23% respectively.

6. CONCLUSION

In this conclusion, the experimental and theoretical values are calculated. The heat transfer co-efficient values are different in both the condition. It is around 8 .9575 W/$m^2 k$ Significantly, also consideration of percentage value of with wheel and Without Wheel is around 10,23%. This percentage value had resulted that air - flow passing through wheel geometry affect the brake cooling.

7. REFRENCES

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