DESIGN OF DISC BRAKE ROTOR USING STATIC STRUCTURAL AND THERMAL PERFORMANCE ANALYSIS

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Abstract-- ***Automotive braking systems are one of the most important safety systems of vehicles. They are mainly used to decelerate or stop a vehicle from an initial speed to required speed. Braking is a process of reducing the kinetic energy of wheel by the application of mechanical force, reduction of kinetic energy is accompanied by the generation of heat energy on the surface of the rotor disc. This excessive thermal loading can result in surface cracking and high wear of brake contact surfaces, these can also lead to overheating of brake fluid, seals and other components. The main task of reducing the surfaces temperature of brake rotor can be achieved by a few modifications in design by using vents in the rotor disc. A detailed study of structural and thermal analysis for the modified disc rotors such as solid, vented and vented with cross-drilled disc rotors is presented in this paper. The design carried out using CATIA V5 and the analysis is done by using ANSYS WORKBENCH 16.2 Software's. Finally, the required profile and material which has less thermal stresses and structural deformation is observed by comparing the obtained results in the analysis.***

Key Terms **- Braking system, Disc Brake, Thermal and Structural Analysis, CATIA V5, ANSYS WORKBENCH 16.2.**

I. INTRODUCTION

Brakes help to decelerate the vehicle and eventually stop in a certain time at a certain stopping distance or the braking distance. The function of brakes is based on the law conservation of energy.
In this process, the brakes which absorb either kinetic energy of the moving member or the potential energy given up by objects being lowered by hoists, elevators, etc.[2,10] The energy absorbed by brakes is dissipated in the form of heat to the surrounding atmosphere, so for the effective functioning a braking system should have the following requirements:

- The brakes must be strong enough to stop the vehicle within a minimum travel distance.
- The driver must have proper control over the vehicle during braking and avoid interlocking.
- The brakes must have good anti-fade characteristics i.e. their effectiveness should not decrease with a constant prolonged application.
- The brakes should have good anti-wear properties.

1.1 *The Function of a braking system*

When a certain amount of force is applied on the brake lever or pedal, the push rod which is connected through the lever or pedal to master cylinder piston transmits the force to it, This movement allows the master cylinder piston to slide and push the return spring inside the bore of the master cylinder which generates pressure in the reservoir tank, At this moment a primary seal allows the brake fluid of reservoir tank to flow over it into the brake hosepipes. [12, 3] A secondary seal ensures that the brake fluid from escaping to another side. Then the fluid enters into cylinder bore of caliper assembly via brake hosepipes and pushes the caliper piston or multiple pistons, at this time the piston ring rolls with the piston, then the caliper piston pushes brake pad. This movement causes brake pads to apply force on the brake disc which creates friction force and opposes the rotational motion of the brake disc/rotor. In this way, a disc brake system contributes to stop or slow down a vehicle.

1.2 *Types of braking systems*

Generally, regenerative braking and friction braking system are commonly used in vehicles. A friction brake generates frictional forces as two or more surfaces rub against each other. Based on the design configuration, vehicle friction brakes can be grouped into drum and disc. [7, 8] If brake disc is a solid body, the area of contact between disc and pads is more. In disc brake system a ventilated disc is widely used in automobile braking system for improved cooling during braking in which the area of contact between disc and pads remains same.

1.3 *Disc brake rotor*

Disc brakes can be vented or non-vented. Vented type have two discs or rotors connected to one another via vents or extrudes and thus have a larger surface area while non-vented disc brakes have a single disc with relatively smaller surface area. [13] Also, depending on the performance required and amount of heat to be dissipated; different types of disc rotors are equipped in an automobile.

1.4 *Types of disc brake rotors*

A. Solid disc brake rotor:

These are the most standard, flat-faced disc rotors and are generally equipped on almost every commercial vehicle. These rotors provide a maximum surface area contact with brake pads while braking and thus have better braking power. However, in this type of rotors, there is no escaping of built-up gas during braking which in turn causes brake fade and pad glazing.

B. Vented disc brake rotor:

A vented rotor typically consists of an inner and outer disc connected by ribs. This setup allows them to dissipate heat at a faster rate which can contribute to the reduction of "brake fade".

C. Vented with cross-drilled holes:

As the name implies, drilled disc rotor have holes drilled through the entire thickness of the disc. Drilling holes through metal, especially in rotors, may seem to be counterintuitive as holes reduce the surface contact area between the pads and rotors. [9] However there are a few other benefits of having drilled rotors.

II. LITERATURE REVIEW

Most of the research work in automobile sector concentrates on building up an efficient braking system, a lot of research concentration is still going on in providing the efficacy profile of the braking system, with disc rotor being the most important part.

From the research works which are based on the concept of modeling of the disc rotor system, this paper presents, three models for analyzing the structural and thermal stress using the computational methods.
The computational techniques used for modeling and analysis in this paper are

i. CATIA V5 Software for modeling of disc rotors.
ii. ANSYS WORKBENCH 16.2 Software for analysis of disc rotors.

- Design of disc brake rotor by Mit Patel, Mansi Raval, Jenish Patel [1]. The main purpose of this study is to analysis the thermo-mechanical behavior of the brake disc during the braking phase.
- Manjunath T.V. Dr. Suresh P.M [4], the disc brake is a device for slowing or stopping the rotation of the wheel. Repetitive braking of the vehicle leads to heat generation during each braking event. Transient thermal and structural analysis of the rotor Disc of disk brake is aimed at evaluating the performance of disc brake rotor of a car under severe braking conditions and thereby assisting in the disc rotor design and analysis.
- VirajParab, KunalNaik, Prof A.D. Dhale [5], Disc (rotor) aim of the project is to design, model a disc. Modeling is done using Catia. Structural and thermal analysis is to be done on the disc brakes using three materials stainless steel and cast iron and carbon-carbon composite. Structural analysis is done on the disc brake to validate the strength of the disc brake and thermal analysis is done to analyze the thermal properties.
- Swapnil R. Abhanag, D.P. Bhaskar [6], every single system has been studied and developed in order to meet safety requirement. Instead of having an airbag, good suspension systems, good handling, and safe cornering, there is one most critical system in the vehicle which is a brake system.

III. METHODOLOGY

The methodology involves the technology utilized for performing the designing and analysis of the object.

- Design of disc brake rotors
- Material selection
- Analysis of disc brake rotors.
  - Static structural analysis
  - Steady state thermal analysis
  - Transient thermal analysis
- Evaluating results from the analysis.
- Comparing the results of three disc brake rotors for different iterations

3.1 *Design of disc brake rotors:*

Designing the three different models of disc brake rotors such as solid, vented and vented with cross-drilled holes using the ISO standard dimensions of Audi A6 car.

3.1.1 *Dimensions:*

Parameter name	Parameter value (units)
Outer diameter of disc rotor	288 mm
Inner diameter of disc rotor	135 mm
Hole diameter	68 mm
Caliper piston diameter	62.5 mm
Thickness of solid disc rotor	10 mm
Thickness of vented and vented with drilled holes disc rotors	25 mm
Vented thickness	10 mm

Drilled hole diameter	10 mm

Table 1: Dimensions of disc brake rotor

3.1.2 *Designed profile:*

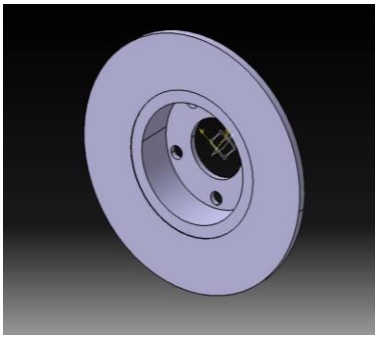

Fig 1: Solid disc rotor

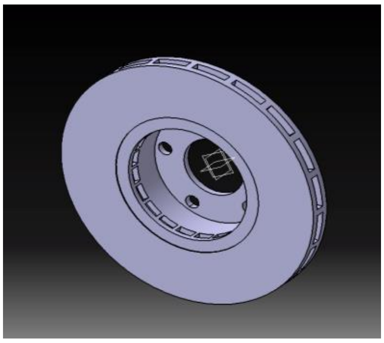

Fig 2: Vented disc brake rotor

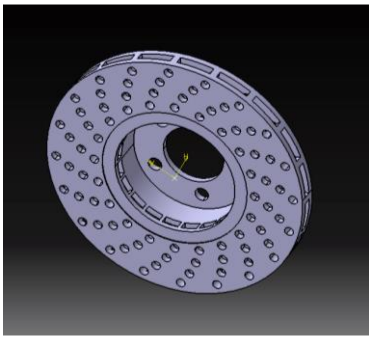

Fig 3: Vented with cross-drilled holes disc brake rotor

3.2 *Material selection:*

The material used for analysis of three different types of disc brake rotors is Grey cast iron.

3.3 *Analysis of disc brake rotor:*

After designing three different disc brake rotors in CATIA V5 those three profiles are imported to ANSYS WORKBENCH 16.2 for further analysis such as static structural analysis, and transient thermal analysis.

Parameter name	Parameter value (units)
Mass of the vehicle	1600 Kg
Top Speed	120 km/hr or 33.33 m/sec
Rim diameter	431.8 mm
Wheel diameter	831.8 mm
Caliper piston diameter	44 mm
Coefficient of friction	0.7

Table 2: Parameters required for boundary conditions

3.3.1 *Static structural analysis:*

Static analysis is performed over a structure when the loads and boundary conditions remain stationary and do not change over time; it is assumed that the load or field conditions are applied gradually.

Steps involved in this analysis are:

- Meshing: Done with relevance center 0.1 and fine element size. The elements used for meshing of the solid, vented and vented with cross drilled disc rotors are tetrahedral three- dimensional elements with 10 nodes (iso-parametric). In this simulation, the meshing is refined in the contact zone (disc pad), this is important because in this zone the temperature varies significantly.

- Boundary conditions:

Frictional force	4962.7634 Newton
Rotational velocity	79.116 rad/sec

Table 3: Static structural analysis boundary conditions

- Solving model:
  Once the conditions are applied, the model is solved for three factors:
  a. Total deformation
  b. Equivalent stress
  c. Equivalent elastic strain

3.3.2 *Steady state thermal analysis:*

A steady-state thermal analysis determines the temperature distribution and other thermal qualities under steady state loading conditions. A steady-state loading condition is a situation where heat storage effects varying over a period of time can be ignored.

Steps involved in this analysis are:

- Meshing: Similar to static structural analysis.
- Boundary conditions:
  The following table gives a brief description of the initial boundary conditions applied on the disc rotor solid, vented and vented with drilled holes for the steady-state thermal analysis.

Heat flux (W/m^2)	14529155.3233
Film convective heat transfer coefficient (W/m^2-k)	38.11
Radiation	22-27 degrees

Table 4: Steady state thermal analysis boundary conditions

- Solving model:
  Once the conditions are applied, the model is solved for three factors:
  a. Temperature
  b. Total heat flux

3.3.3 *Transient thermal analysis:*

The transient thermal analysis determines the temperature and other thermal quantities that vary over time, engineers commonly use the temperature that a transient thermal analysis calculates as input to structural analysis for thermal stress heat transfer applications. A transient thermal analysis follows basically the same procedure as a steady state thermal analysis [11].

Steps involved in this analysis are:

- Meshing: Similar to static structural analysis.
- Boundary conditions:
  The following table gives a brief description of the initial boundary conditions applied on the disc rotor solid, vented and vented with drilled holes, for the transient thermal analysis.

Temperature	Step 22-800 degree Celsius
Film convective heat transfer coefficient (W/m^2-k)	From imported convection data (stagnant air-horizontal cyl)

Table 5: Transient thermal analysis boundary conditions

- Solving model:
  Once the conditions are applied, the model is solved for three factors:
  a. Temperature
  b. Total heat flux

IV. Results and Discussion

Comparing the results of three disc brake rotors for different iterations:

Type of analysis		**Solid disc brake rotor**	**Vented disc brake rotor**	**Vented with cross-drilled holes**
Static structural analysis	Total deformation	6.9295e-003 mm	1.3884e-003 mm	1.5535e-003 mm
	Equivalent elastic strain	1.6498e-005	1.5204e-005	4.6913e-010
	Equivalent stress	1.8123 MPa	1.5961 MPa	2.9003 MPa
Steady state thermal analysis	Temperature	935.43°C	930.97 °C	925.72 °C
	Heat-flux	0.7734 W/mm²	2.4876 W/mm²	2.6018 W/mm²
Transient thermal analysis (operating temperatures 22-950°C)	Temperature	950°C	950°C	950°C
	Heat-flux	4.3159 W/mm²	5.7478 W/mm²	6.417 W/mm²

Table 6: Summarized results

Static structural analysis: On applying of 4962.7634 N of load on the three disc brake rotors i.e. solid, vented, vented with cross-drilled holes, the minimum deformation is found on vented and vented with cross-drilled disc rotors when compared with solid brake disc rotor.
Similarly, the strain and stress values are also in the desirable limits for vented with cross-drilled rotor.

Steady state thermal analysis: On engaging the disc rotor with a particular load the heat will be generated due to friction between brake pads and surface of disc rotor, so the rate of heat generated should be dissipated at a faster rate, on comparing the three profiles, the vented with cross-drilled holes rotor is generating the least temperature i.e. 925.72°C which is less compared with the other two.
Similarly, the heat flux is also higher i.e. 2.6 W/mm^2 this enables the dissipation of heat at a faster rate.

The same kind of phenomenon is also observed in transient thermal analysis.

For the same amount of temperature generation the heat flux for the vented with cross-drilled holes disc brake rotor is high i.e.5.37 W/mm^2.
Here the steady-state thermal analysis of the profile is selected with the help of thermal stress concentrated diagrams are presented.

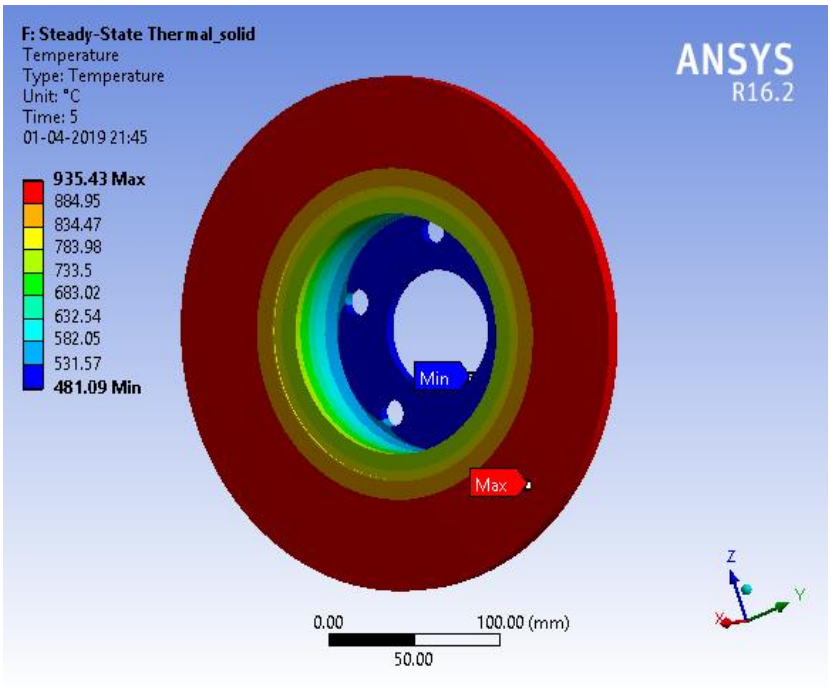

Fig 4: Solid disc brake rotor

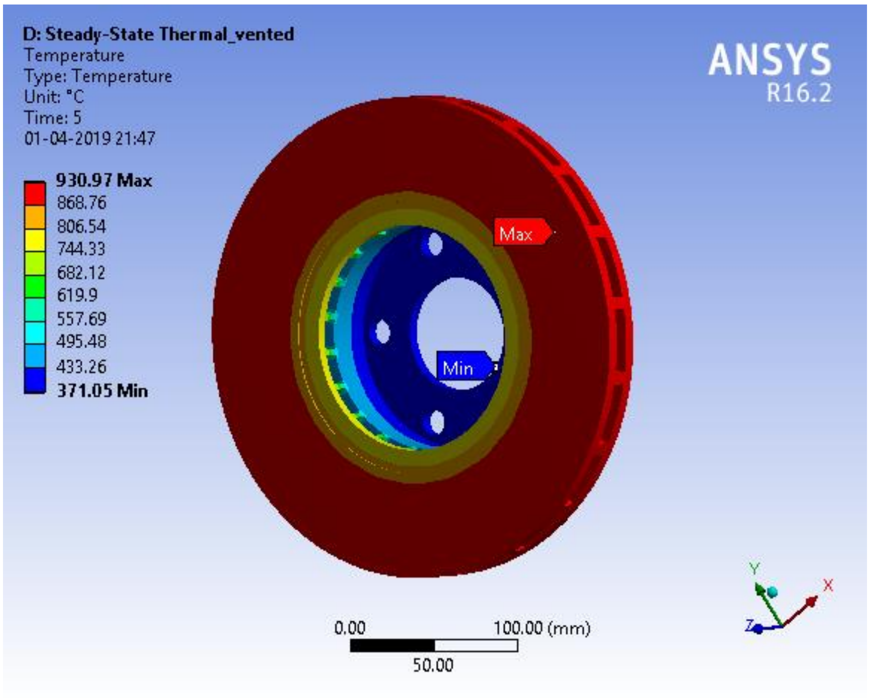

Fig 5: Vented disc brake rotor

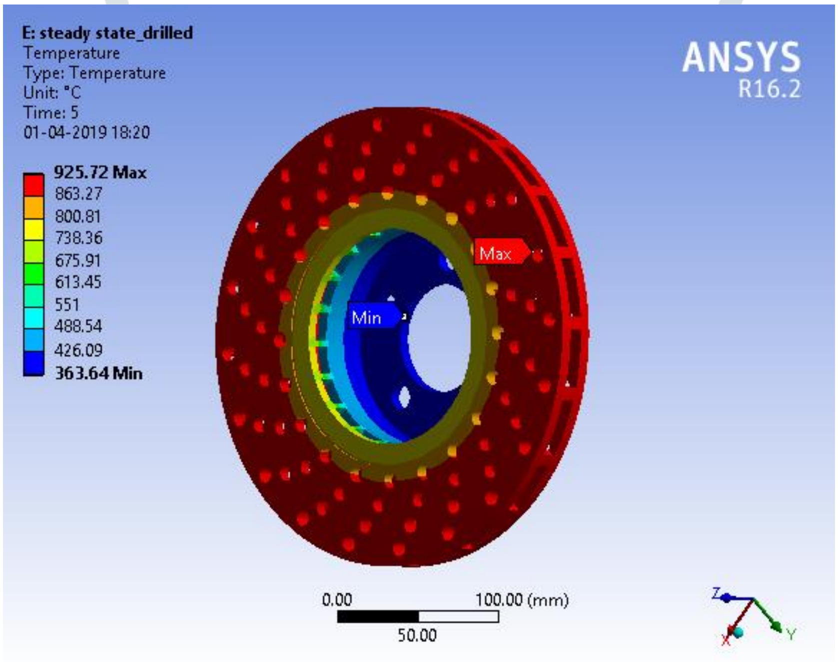

Fig 6: Vented with cross-drilled disc brake rotor

V. CONCLUSION

The figures which are shown above reveals the thermal stress concentration for the proposed three profiles. From these three profiles, the vented with cross-drilled disc brake rotor bares the maximum thermal stresses induced in the material i.e. grey cast iron and also dissipates the heat generated at a faster rate. So vented with cross-drilled disc brake rotor is preferred because of less deformation, high strain and stress along with high heat flux when compared with other two disc brake rotors i.e. solid and vented.

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