Structural Analysis of Automotive Disc Brakes

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***Abstract* - The braking system plays the crucial role in the safety of a vehicle and its design poses a critical challenge. The heat dissipation and thermal performance of ventilated brake discs strongly depends towards on the aerodynamic characteristics of the air flow through the rotor passages.**

In this thesis, the 3D CAD models for Solid disc and discs with different fin configurations namely, Straight Elliptical fins, Backward curved fins and Forward curved fins are designed. Each finned model disc with 12, 24 and 36 number of fins were developed using Catia V5R20. The 3D FE models have been developed for the above disc configurations using Hypermesh V11 and to know the structural strength of the disc brake, due to the introduction of fins commercial structural analysis ANSYS13.0 was used. It was observed that the introduction of fins is having a very little effect on the structural strength of the discs. Hence Forward curved disc with 36 numbers of fins is suggested for higher structural strength.

Key Words* – *Brake, Structural Analysis, Disc, Fins, Ansys.

I. INTRODUCTION

The disc brake or disk brake is a wheel brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The brake disc (or *rotor* in American English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads, mounted on a device called a brake caliper, is forced mechanically, hydraulically, pneumatically or electro magnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade.

Disc-style brakes development and use began in England in the 1890s. The first caliper-type automobile disc brake was patented by Frederick William Lanchester in his Birmingham, UK factory in 1902 and used successfully on Lanchester cars. Compared to drum brakes, disc brakes offer better stopping performance, because the disc is more readily cooled. As a consequence discs are less prone to the "brake fade"; and disc brakes recover more quickly from immersion (wet brakes are less effective). Most drum brake designs have at least one leading shoe, which gives a servo-effect. By contrast, a disc brake has no self-servo effect and its braking force is always proportional to the pressure placed on the brake pad by the braking system via any brake servo, braking pedal or lever, this tends to give the driver better "feel" to avoid impending lockup. Drums are also prone to "bell mouthing", and trap worn lining material within the assembly, both causes of various braking problems. The aerodynamic characteristics of the mass flow were found to be reasonably independent of rotational speed, but highly dependent upon rotor geometry. Johnson et al. [2] used PIV (Particle Image Velocimetry) to measure air velocities through a high solidity radial flow fan utilized as a vented brake rotor. Choi and Lee [3] performed a transient thermo-elastic analysis of disc brakes in repeated braking applications, using a finite element method with frictional heat generation. Grieve et al.[4] performed parametric sensitivity studies to define suitable design-material combinations for a disc brake prototype.

For solid rotors, the highest temperature occurs on the surfaces of the rotors. To decrease the maximum temperature, the most effective way is to increase the thickness of the rotors. However, the increase is limited by the pistons. Materials also have effects on the rotor's temperature. From this research, steel is a better alloy to dissipate heat from the rotors. But in practical design problems, the thermal performance is not the only requirement. From the perspective of stiffness, friction resistance and cost, the cast iron material is common used in industry.

The powerful simulation packages HYPERMESH and FLUENT give more accurate solutions to fin and pillar post rotors. From the sensitivity studies, the fin rotors have better cooling performance.

The objective of current study is to estimate Von Mises Stress generated in solid discs. The combinations of various fin configurations namely Straight Elliptical, Backward Curved, Forward curved and the various numbers of fins (12, 24 and 36) are studied to predict the effect of these variables on the performance of disc brakes. The drawings for the Solid disc are modelled. The 3D CAD models were developed for various disc configurations, namely Solid disc, discs with Straight elliptical fins, Backward curved fins and Forward curved fins with 12, 24 and 36 fins were created using CATIA V5R20. The 3D FE models were created for the above mentioned disc configurations using HYPERMESH V11. The static structural analysis was carried out to assess the effect of fins on the structural integrity of various disc models considered. The result plots were taken using ENSIGHT post processor. The results were shown with the help of graphs and tables for better understanding. Conclusions about the effect of fin geometry and number of fins were mentioned.

The brake disc is the disc component of a disc brake against which the brake pads are applied. The design of the disc varies somewhat. Some are simply solid cast iron, but others are hollowed out with fins or fins joining together the disc's two contact surfaces. The weight and power of the vehicle determines the need for ventilated discs. The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily-loaded front discs.

Discs are usually damaged in one of four ways: scarring, cracking, warping or excessive rusting. Service shops will sometimes respond to any disc problem by changing out the discs entirely, this is done mainly where the cost of a new disc may actually be lower than the cost of labor to resurface the original disc. Mechanically this is unnecessary unless the discs have reached manufacturer's minimum recommended thickness, which would make it unsafe to use them, or fin rusting is severe (ventilated discs only). Most leading vehicle manufacturers recommend brake disc skimming (US: turning) as a solution for lateral run-out, vibration issues and brake noises. The machining process is performed in a brake lathe, which removes a very thin layer off the disc surface to clean off minor damage and restore uniform thickness.

II. PROBLEM DEFINITION

The 3D CAD model has been developed using commercial 3D modeling software CATIA by adopting the following drawing of OEM XYZ model.

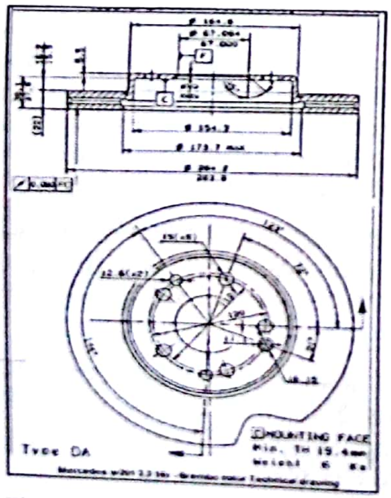

Fig.1 Drawing of OEM XYZ Rotor

The technical drawing of Rotor is shown in Fig 1. The various models considered for simulation were shown in the Figure 2 to 5.

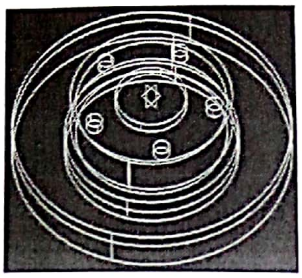

Fig.2 Solid Rotor

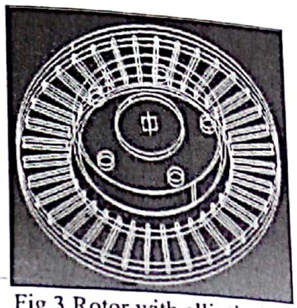

Fig.3 Rotor with elliptical fins

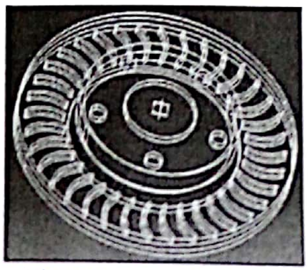

Fig.4 Rotor with Backward curved fins

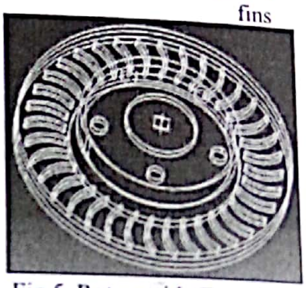

Fig.5 Rotor with Forward curved fins

The 3D FE models will be developed for the various geometries using hexahedral elements with the help of HYPERMESH V11.0

The FE models of Solid Rotor, Rotors with different Fin configurations are shown below in Fig 6, 7, 8 and 9.

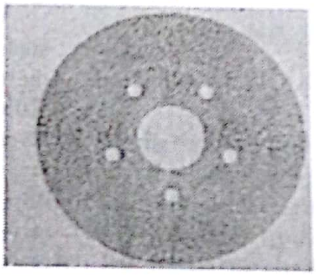

Fig.6 F.E. model of Solid Rotor

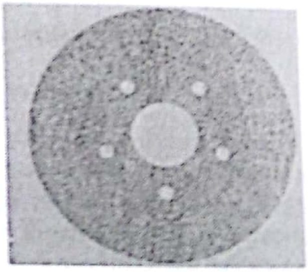

Fig.7 F.E. model of Rotor with elliptical fins

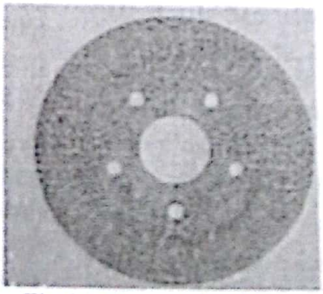

Fig.8 F.E. model of Rotor Backward curved fins

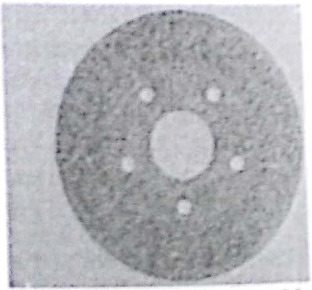

Fig.9 F.E. model of Rotor with with Forward curved fins

The brake disc specifications considered for the analysis will be tabulated

Vehicle Specifications	Disc Brake Specifications
Manufacturer = OEM	Brake Disc Thickness (mm): 21.9
Model = OEM XYZ	Brake Disc Type: Vented Disc
Year of Manufacture = 1998	Centering Diameter (mm): 67.0
Curb weight = 1600 Kg	Fitting Position: Front Axle
	Height (mm): 48.2
	Minimum Thickness (mm): 20.0
	Number of Holes: 5
	Outer Diameter (mm): 262.4

Table.1 Vehicle specifications

III. ANALYSIS AND RESULTS

With introduction of fins the strength of the disc may reduce as material is removed for fins. So static structural analysis is carried out for the models obtained from the analysis.

The results of Von-Mises Stress distribution at pressure of 10 bar for 1 solid model and 3 models of finned discs such as Straight, Backward and Forward curved are presented in this section

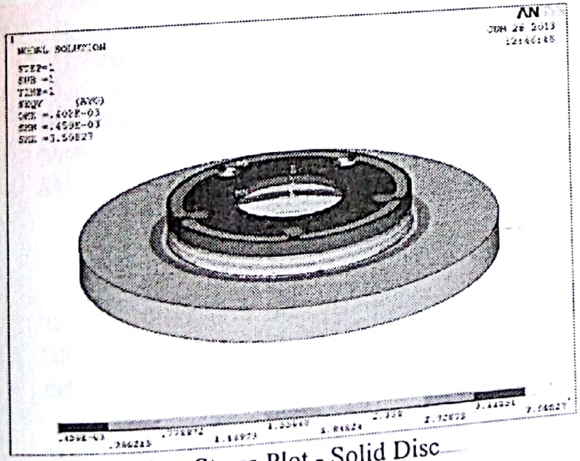

Fig.10 Von-Mises Stress Plot - Solid Disc

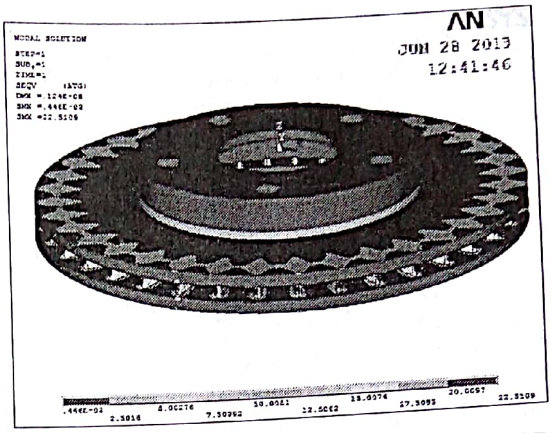

Fig.11 Von-Mises Stress Plot -Straight Elliptical Disc

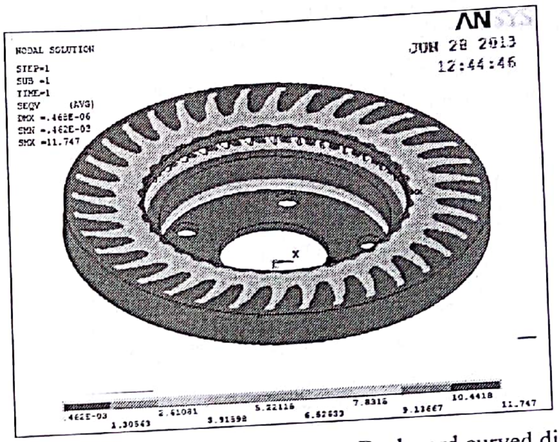

Fig.12 Von-Mises Stress Plot – Backward curved disc

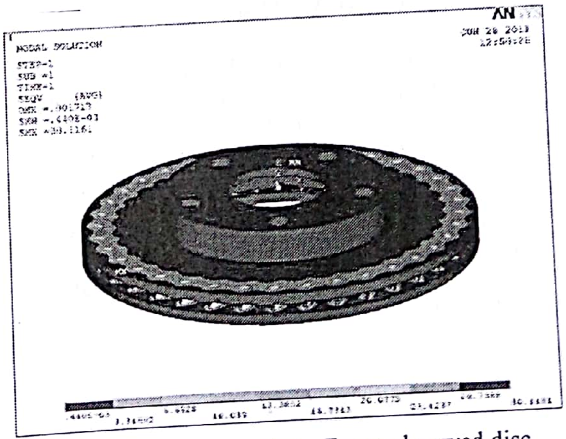

Fig.13 Von-Mises Stress Plot – Forward curved disc

The Von-Mises Stress distribution in the solid disc at a velocity of 40 mph is shown in Fig.10, for Straight elliptical rotor at a velocity of 40 mph with 36 fins is shown in Fig.11, for Backward curved rotor at a velocity of 40 mph with 36 fins is shown in Fig.12 and for Forward curved rotor at a velocity of 40 mph with 36 fins is shown in Fig.13 respectively.

The values of Von-Mises Stress from the above figures 10,11,12 and 13 are listed below.

- Solid Disc (with no Fins) - 3.50827 N/mm^2
- Straight Elliptical Fins - 22.51 N/mm^2
- Backward Curved Fins – 30.12 N/mm^2
- Forward Curved Fins - 11.747 N/mm^2

Even though the Solid disc is having less Von-Mises stress value when compared to the other disc models with fins, the maximum stress value is with in the allowable range even after the introduction of fins, by considering the enhancement in the heat transfer characteristics, we can go for the fin additions.

The variation of VonMises Stress with respect to number of fins, for various fin shapes is shown in Fig.14.

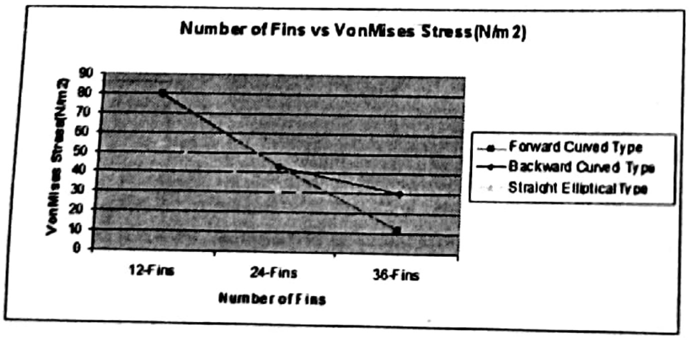

Fig.14 Number of Fins vs. VonMises Stress

From Fig.14 it is observed that the VonMises Stress is decreasing as the numbers of fins are increasing from 12 to 24 and 24 to 36. From Fig.14 it is clear that the Forward curved fins with 36 numbers of fins are having lowest VonMises Stress compared to the other.

The values of VonMises Stress for Solid disc and discs with different fin shapes namely Straight elliptical fins, Backward curved fins and Forward curved fins for 12 fins, 24 fins and 36 fins are shown in the Table 2

Fin Shape	Number of Fins	Von Mises Stress (N/mm2)
Solid	--	3.51
Straight Elliptical Fins	12-Fins	54.88
	24-Fins	31.90
	36-Fins	22.51
Backward Curved Fins	12-Fins	79.19
	24-Fins	42.80
	36-Fins	30.12
Forward Curved Fins	12-Fins	79.98
	24-Fins	43.11
	36-Fins	11.75

Table.2 Values of VonMises Stress

From Table 2 it is observed the addition fins are adding strength in the axial direction and due to that the stresses are reduced as the numbers of fins are increased from 12 to 36.

But it may be possible that if we increase the number of fins further it may lead to decrease in the structural strength of the discs and gives rise to higher stresses. But in the current thesis, it is limited to 36 fins only.

The structural integrity of the rotor configurations were checked at a brake pressure of 10 bar.

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IV.FUTURE WORK

More detailed geometrical optimization of finned rotors is desired. The structural strength of the disc may also depend upon thickness of the fin, inner and outer radius of the fin. By varying these parameters optimum design of disc can be obtained.

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