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Structural Analysis of Rotor Disc of Disc Brake

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ABSTRACT

The purpose of this research is to analyse different types of disc brake rotors, which are commonly used in Automobile industry and to propose a new design of brake rotor. Analysis of brake rotor includes Structural analysis and Steady state for each design structural analysis is used to determine the deformation and the Von Misses stress established in the disc for the both solid and ventilated disc with two different materials to enhance performance of the rotor disc. A comparison between the existing brake rotors and proposed new design is carried out and based on the results the best design is found out by ANSYS software.

Keywords: Ansys Workbench, Disc Brake, Modelling, Solidworks, Structural Analysis.

I. INTRODUCTION

The disc 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 callipers [1.1]. 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 calipers, is forced mechanically, hydraulically, pneumatically or electromagnetically 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. Compared to drum brakes, disc brakes offer better stopping performance, because the disc is more readily cooled. A schematic diagram is shown in the figure.

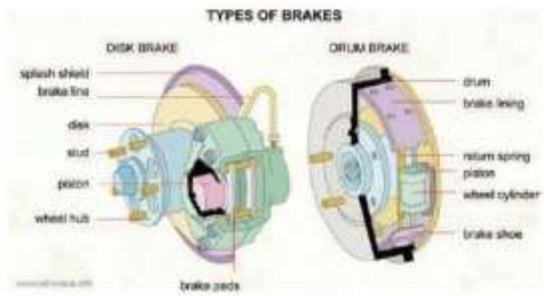

Fig:1.1 Disc Brake and Drum Brake.

Theory of brakes

Disc brakes: Shoes or pads contract and provide compressive frictional force on the outer surface of a rotating Disc. It is a circular metal Disc on which the pads are mounted. Usually it is made up of cast iron material. The

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design of Disc brakes is varied depending on the application, amount of exposure, thermal properties of the material and the amount of heat dissipation required when brakes are applied and the total mass to be stopped [1.1] .This project report will contain the design of a Disc brake rotor, and analyze results of Structural and Thermal Analysis at a later stage.

Drum brakes: Shoes or lining expand and rub against the inside surface of a rotating drum. Drum is again made up of cast iron material and mounted in the wheel hub in such a manner that the liner pads attach themselves to the inner surface of the drum and during the braking process, the shoe or brake lining expand or move outwards, due to the cam and spring action, to attach themselves to the brake drum which provides friction and causes the drum to retard or stop its rotating motion. Drums are usually heavier than Disc brakes [1.1] and occupy significantly more space due the lining and drum it and hence its application in commercial vehicles is somewhat restricted .Generally it is noticed and observed that Disc brakes provide a better stopping performance and at the same time they are safer and cost efficient, the incorporation of 4 wheel Disc brakes have been increased from the former front Disc brakes and rear drum brakes system. However, the drum type brakes are better at performance when the mass of the automobile increases, and thus, drum brakes are common in heavy automobiles.

Hydraulic brakes: This type of braking system is one of the basic types of braking and as per its name; this braking system uses a fluid called the brake fluid for its braking mechanism. Ethylene Glycol is one common and most typically used brake fluid. The brake fluid helps in transferring pressure applied by the operator/driver on the brake pedal to the actual braking mechanism which is located near the wheels of the vehicle [1.2].

The most common arrangement of hydraulic brakes consists of the following:

(i) A lever or a brake pedal

(ii) Pushrod or actuating rod

(iii) Master cylinder assembly

(iv) Hydraulic lines

(v) Brake calliper assembly

Working of hydraulic brakes: As the driver presses the brake pedal or the lever, the push rod exerts a force called the braking force on the pistons placed in the brake master cylinder located just behind the brake pedal of the vehicle causing the brake fluid to flow into the pressure chamber [1.2]. Consequently, overall pressure in the entire system increases which in turn forces the fluid to flow through hydraulic lines, which are nothing but pipes through which through which the fluid can easily flow, towards one or more callipers based on the hydraulic braking system design. The callipers are also designed accordingly that sufficient force is applied to the Discs or drums to provide required frictional force for braking.

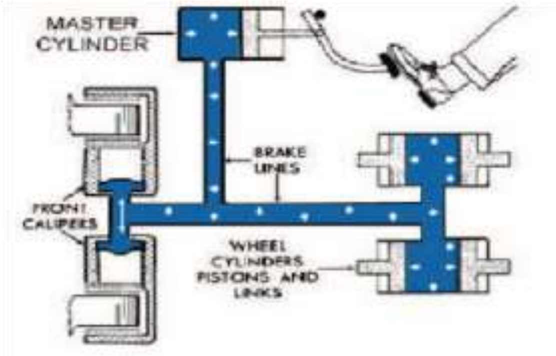

Fig:1.2 Working of hydraulic Brake.

II. TYPES OF DISC BRAKE ROTORS

Mainly, disc brakes can be vented or non-vented. Vented have two discs or rotors connected to one another via vents or protrudes and thus have larger surface area while non-vented are just a single disc having relatively smaller surface area. Also, depending on the use, performance required and amount of heat to be dissipated; different types of Disc rotors are equipped in an automobile. Essentially, there are four types of brake Disc rotors:

Normal disc rotors: These are the most standard, flat faced Disc rotors and are generally equipped on almost every commercial use vehicle. These rotors provide the maximum surface area touching the brake pads while braking and thus, have a better braking power.[2.3]

Drilled disc rotors: As the name implies, drilled Disc rotors have holes drilled through the entire Disc thickness. Now drilling holes through a metal especially something like rotors may seem to be counterintuitive as having holes reduces the surface attachment area for the pads and rotors.[2.3]

Slotted/grooved disc rotors: Slotted brake rotors use slots carved into the flat metal surface to move air, heat and water away from the surface of the rotors. Slotted brake rotors are popular with performance car drivers because the type of driving they do puts a lot of stress on the rotors.[2.3]

Fig:2.3 Types of Disc Brake Rotor.

Design and Analysis of Disc Rotor

Material selection

Brakes are of utmost importance in an automobile and safety of the operator and passengers depend directly on the braking system, the material for the disc rotors must be chosen appropriately. Many materials are widely available in the market like ceramic components, carbon-carbon composites, stainless steels and cast iron components; grey cast iron is adapted for rotors because of its strength and thermal properties, high temperature resistance and availability.[2.1]

Table 2.1: properties of materials.

Material properties.	Grey cast iron.	Stainless steel.
Density (kg/m^3)	7200	7750
Young's Modulus (GPa)	125	193
Poisson's ratio	0.25	0.31
Thermal Conductivity (W/m-K)	54.5	424.15
Specific Heat (J/kg-K)	586	753
Coefficient of friction	0.25	0.40

III. DESIGN CALCULATIONS FOR DISC BRAKE ROTOR THE BRAKE PEDAL:

The brake pedal exists to multiply the force exerted by the driver's foot. From elementary statics, the force increase will be equal to the driver's applied force multiplied by the lever ratio of the brake pedal assembly:

$F_{bp} = F_d \times \{L_1 \div L_2\}$

where,

F_{bp}= the force output of the brake pedal assembly

F_d= the force applied to the pedal pad by the driver = 370 N (By thumb rule)

L_1 = the distance from the brake pedal arm pivot to the output rod clevis attachment

L_2= the distance from the brake pedal arm pivot to the brake pedal pad($L_1/L_2 = 4$)

The master cylinder: Assuming incompressible liquids and infinitely rigid hydraulic vessels, the pressure generated by master cylinder is equal to :

$Pmc = Fbp/Amc$ where,

P_{mc}= the hydraulic pressure generated by the master cylinder.

A_{mc} = the effective area of the master cylinder hydraulic piston =0.000285 m.

Brake fluid, brake pipes and hoses: Assuming no losses along the length of the brake lines, the pressure transmitted to the calipers will be equal to:

$Pcal = Pmc$ where,

P_{cal}= the hydraulic pressure transmitted to the caliper.

The caliper, Part I: The one-sided linear mechanical force generated by the caliper will be equal to:

$Fcal = Pcal \times Acal$ where,

F_{cal}= the one-sided linear mechanical force generated by the caliper.

A_{cal}= the effective area of the caliper hydraulic piston(s) found on one half of the caliper body = 0.0007068 m.2

The caliper, Part II: The clamping force will be equal to, in theory, twice the linear mechanical force as follows:

$FClamp = Fcal \times 2$

where,

F_{Clamp}= the clamp force generated by the caliper. **The brake pads:** The clamping force causes friction which acts normal to this force and tangential to the plane of the rotor. The friction force is given by:

$F_{friction} = F_{Clamp} \times \mu_{bp}$

$F_{friction}$= the frictional force generated by the brake pads opposing the rotation of the rotor. μ_{bp}= the coefficient of friction between the brake pad and the rotor= 0.4 (assumed).

The rotor: This torque is related to the brake pad frictional force as follows:

$T_r = F_{friction} \times R_{eff}$ where,

T_r= the torque generated by the rotor.

R_{eff}= the effective radius (effective moment arm) of the rotor (measured from the rotor center of rotation to the center of pressure of the caliper pistons). This torque generated by the rotor will be equal to the torque required to stop the vehicle. In this report, the following values are assumed:

- Mass of the vehicle = 300 kg.
- Maximum velocity of the vehicle = 80 km/hr or 22.22 m/s.
- Stopping Distance = 11.69 m.
- Tire Size = 23 in diameter that is 584.2 mm with 7 mm thickness
- Disc flange or thickness = 16 mm.
- 50-50 wheel bias that is equal braking force is generated in all the4 wheels of the vehicle. Total force generated during braking to stop the car, F = m*a, a = deceleration during braking = v2/2s = 22.222/2 x 11.69= 21.12 m/s2

F= 300 x 21.12

F= 6336 N.

Torque required stopping the vehicle,

T_r= F/4 * R_w

T_r= 6336/4 x 0.2921 T_r= 462.54 N-m.

As mentioned in above formulae,

F_{bp}= Fd* (L_1/L_2)

F_{bp}= 370 x 4

F_{bp}= 1480 N.

P = F_{bp}/A_{mc}

P_{mc}= 1480/0.000285

P_{mc}= 5192982.456 Pa

P_{mc}= P_{cal}= 5192982.456 Pa

Fcal= Pcal * Acal

F_{cal}= 5192982.456 x 0.0007068 F_{cal}= 3670.4 N.

Clamping Force = 2F_{cal}.

F_{clamp}= 7340.8 N.

$F_{friction}$= Frictional force generated on the rotor during braking process.

$F_{friction}$= 7340.8 × 0.4

$F_{friction}$= 2936.32 N

Torque generated by the rotor during braking = Ffriction* Reff= 462.54

Therefore, the effective rotor radius R_{eff}= 0.1575 m. Thus, the Effective Rotor Radius is 0.1575 meters that is 6.2 inches or 157.5 mm. And thus, the effective diameter is 315 mm. Based on this effective diameter, the outer diameter of the disc is decided to be 381 mm and the inner diameter to be 125 mm.

Kinetic Energy developed during braking,

KE = ½ mv2

KE = ½ x 300 x (22.22)2

KE = 74059.26 J

Total Braking Energy/Heat required for the vehicle is equal to the total Kinetic Energy generated by the vehicle,

Thus Heat (Q) generated,

Q_g= 74059.26 J

Since assumption of 50-50 wheel bias is made, this heat will be equally distributed in the 4 wheels of the car, thus equally distributed in the 4 rotors. So, heat generated in 1 rotor, Qg= 18514.815

Now, the stopping time of the vehicle will be velocity/deceleration, t = v/a t = 22.22/21.12 t = 1.05 sec.

Hence, power generated in one rotor

$P = Q_g/t$

P = 18514.815/1.05

P = 17633.16 Watts.

Thereby, we can calculate the heat flux through one disc rotor with 0.381m outer diameter and 0.125m inner diameter.

Heat flux = 4 * P/3.14 * $(D_o^2-D_i^2)$

Heat flux = 4 x 17633.16/3.14 x (0.3812 – 0.1252)

Heat flux = 173408.3233 Watts/m2.

IV. FIGURES AND TABLES

1. Withouthole.

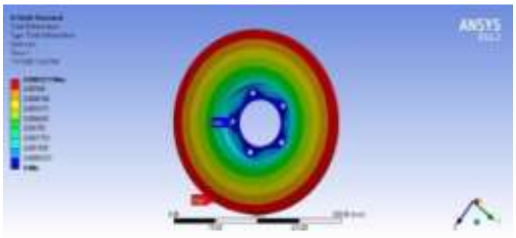

Fig: 4.1DeformationGrey Cast Iron(Without Hole).

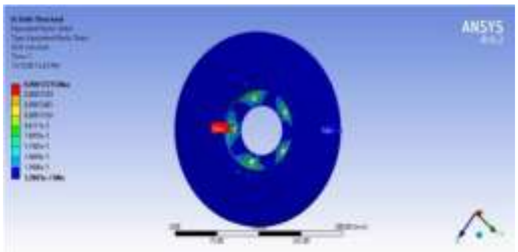

Fig: 4.2 Strain Grey Cast Iron(Without Hole).

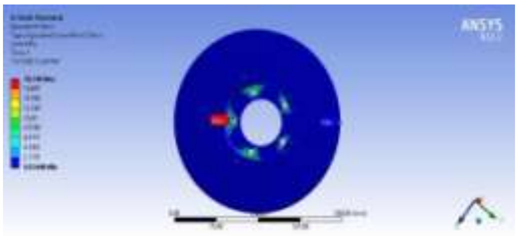

Fig: 4.3Stress Grey Cast Iron (Without Hole).

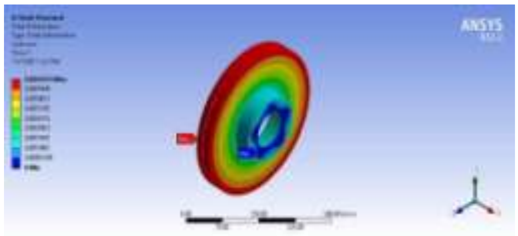

Fig: 4.4Deformation Stainless Steel

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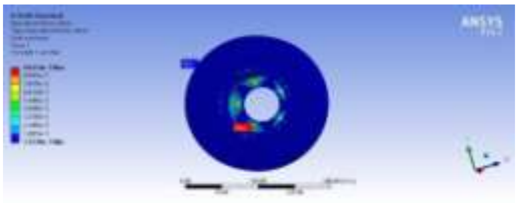
(Without Hole).



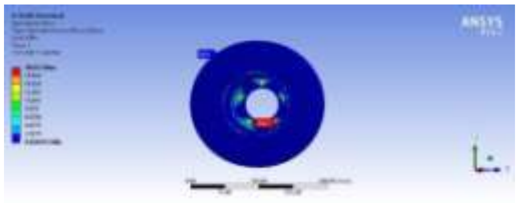
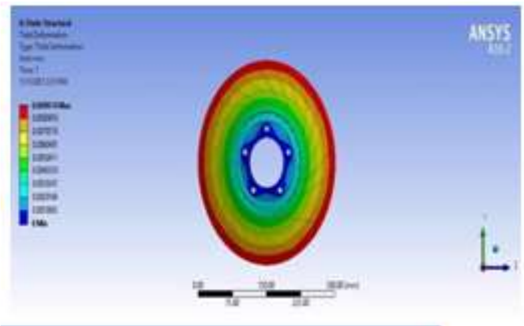


Fig: 4.5 Strain Stainless Steel (Without Hole). Fig: 4.6Stress Stainless Steel (Without Hole).

Table 4.1: Comparison between Deformation and Strain and Stress. (Without Hole).

	Stainless steel.		Grey Cast iron.	
	Minimum	Maximum	Minimum	Maximum
Deformation.	0	0.047074	0	0.0083273
Strain.	1.5739	9.6114	3.285	0.00017275
Stress (vonvises).	0.028453	18.023	0.0344	18.746

2. With hole.



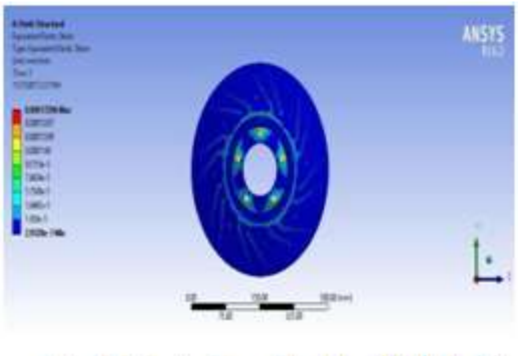
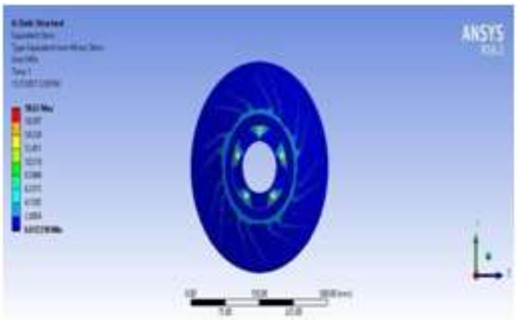


Fig. 4.7 Deformation Grey Cast Iron (With Hole) Fig: 4.8 Strain Grey Cast Iron (With Hole)



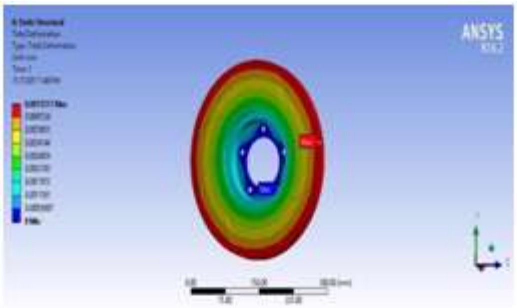


Fig: 4.9 Stress Grey Cast Iron (With Hole) Fig: 4.10 Deformation Stainless Steel (With Hole)

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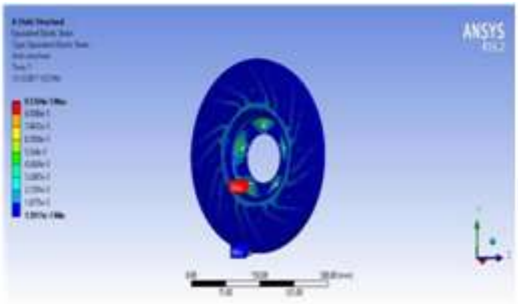

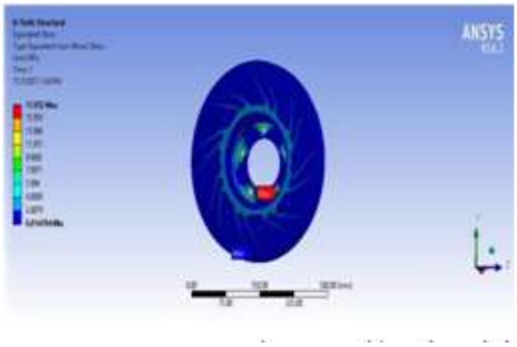

Fig: 4.11 Strain Stainless Steel (With Hole)   Fig: 4.12 Stress Stainless Steel (With Hole).

Table 4.2: Comparison between Deformation and Strain and Stress. (With Hole).

	Stainless steel.		Grey Cast iron.	
	Minimum	Maximum	Minimum	Maximum
Deformation.	0	0.0051217	0	0.009074
Strain.	1.5911	9.5704	2.952	0.00017206
Stress (von-vises).	0.014794	17.952	0.012318	18.67

V. CONCLUSION

Disc brake rotor was analysed for temperature and thermal stresses using analytical calculations and finite element analysis. A method of analytical calculation and Finite element analysis was given. A step by step procedure of finite element analysis was developed so that anybody can follow the methodology for similar analysis. Generally the present study can provide a useful design tool and improve the brake performance of disk brake system. The present study can provide a useful design tool and improve the brake performance of disk brake system. From the above Table we can say that all the values obtained from the analysis are less than their allowable values. Comparing the different results obtained from analysis. It is concluded that ventilated type disk brake is the best possible for the present application. By observing analysis results, managing stainless steel is best material for DiscBrake

VI. ACKNOWLEDGEMENTS

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