DESIGN AND STRUCTURAL ANALYSIS OF BRAKE DISC BY VARYING BRAKE PRESSURE

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Abstract:
A brake is a device utilizing which artificial frictional resistance is applied to the moving elements to stop the machine's motion. Various forces are to be considered while applying the brake for the braking effect's effective performance. Initially, the driver's force on the brake pedal is multiplied as per the pedal ratio, and this multiplied force is carried to the brake pads in the disc caliper. As a result, the frictional force is developed at the disc surface's contact area and brake pads. This developed frictional force obstructs the motion of the vehicle. The magnitude of the frictional force developed at the disc surface's contact surface, and brake pads basically depends on the force developed at the brake pedal due to the pedal ratio. In this paper, brake performance is studied under varying brake pressure. This brake pressure depends upon the pedal ratio. Along with the theoretical analysis, software like ANSYS is used to determine the disc's sustainability under varying loads obtained by varying force applied on pedal and pedal ratios.

1.INTRODUCTION

A brake is a mechanical device that inhibits motion by absorbing energy from a moving system. It is used to slow or stop a moving vehicle, wheel, or axle to impede its travel, which is most commonly done by friction.

1.1 Disc brake:

The disc brake is a device for slowing or stopping the rotation of a road wheel. A brake disc (or rotor in U.S. English), usually made of cast iron or ceramic, is connected to the wheel or the axle. To stop the tire, the friction material is mechanically, hydraulically,pneumatically, or electromagnetically pushed against both sides of the Disc in the form of brake pads. The disc and attached wheel are caused by friction to slow or stop.

Figure 1.1:Disc Brake

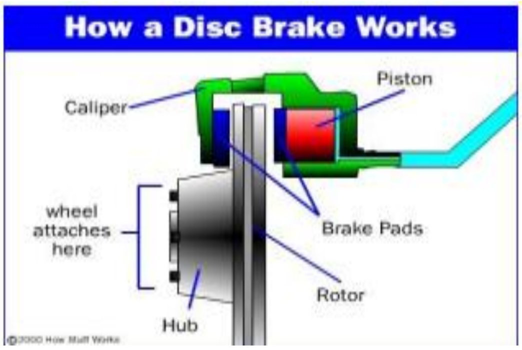

Figure 1.2 Functioning of a disc brake

2.LITERATURE REVIEW

Manjunath et al. [1] done a transient thermal and structural analysis of disc brake rotor disc using ANSYS workbench to evaluate the performance of disc brake rotor of a car under severe braking conditions and for analyzing the thermomechanical behavior of dry contact of the brake disc during the braking phase. Coupled thermal- structural analysis was done to determine the deformation and von-mises stresses induced in both the solid and ventilated Disc with two different materials to enhance the performance of the Disc.T.Jayakumar[2] performed design and analysis of disc brake and compared the mechanical performances of a conventional brake disc system and perimetral brake disc system using Pro-E and ANSYS. Brake-disc was simulated under three different loading conditions like torsional, lateral, and residual stress simulation. Two static tests were then conducted to find the maximum stresses in the conventional disc brake system and perimetral brake system using FEM. The disc brake showing better performance was determined.G.Ranjith Kumar et al. [4] performed to design, analyze, and optimize solid and ventilated disc brake using solid works, hyper mesh, and ANSYS. The thermal -structural analysis was done to determine the deformation and von misses stresses induced in the Disc.Ventilated brake disc was modeled and assembled using solid works and imported to ANSYS to evaluate the stress fields and deformation induced in the Disc by application of pressure on pads and conditions of tightening of the Disc.Mahmood Hassan Dakhil et al. [5] carried out a steady-state structural analysis of Disc to investigate the temperature across the Disc using ANSYS 12 software for getting the optimized design of Disc. A finite element package was used for determining the temperature distribution, the variation of stresses, and deformation across the disc brake. Cast iron and stainless steel were used as disc brake materials. Swapnil et al. [6] modeled standard disc brake of two-wheelers, and then thermal analysis and modal analysis was done to determine the deflection, heat flux, temperature of the disc brake. Carbon ceramic matrix disc brake material was used for calculating normal force, shear force and piston force, and also the braking distance. Structural analysis was also carried out by coupled field analysis so as to suggest the best combination of material, flange width, and wall thickness of the brake disc that yields a low-temperature variation across the Disc, less deformation, and minimum von-mises stresses.

3.Types of forces acting on the brake disc:

Tangential force F_T = frictional coefficient X Clamping force.

Clamping force F_C= brake pressure X area of caliper piston * no. of pistons.

Force on brake pedal= force applied by driver X pedal ratio.

- Braking torque: is the moment of a braking force about the center of rotation.

Work is done by brake = kinetic energy of vehicle = heat dissipated from the surface.

=>T.F X distance travelled = Mass X $(velocity)^2$ /2

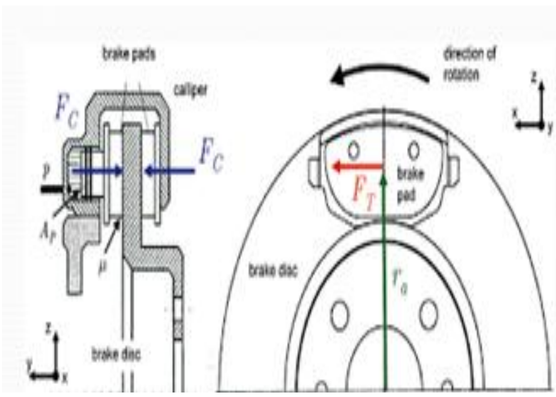

Figure 1:Forces acting on a braking system

3.1 Brake pedal ratio:

Brake pedal ratio= X/Y

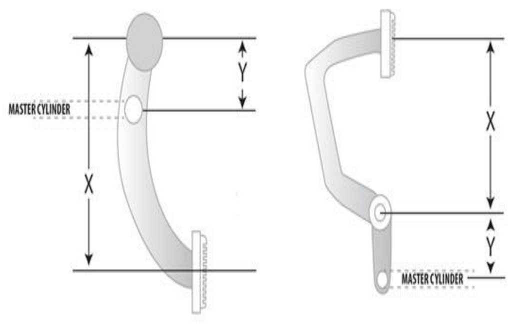

Figure 3.2.1: Brake pedal ratio

3.2 Determining the pedal ratio:

In this case, the overall length of the pedal is considered as 18 cm. By varying the length of "Y," i.e., the height of connecting rod of the master cylinder, the pedal ratio varies

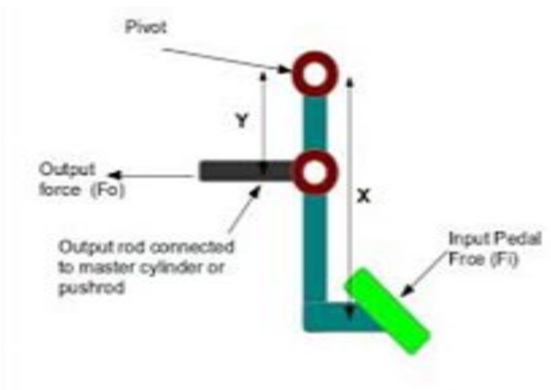

Figure 3.2: Determining the pedal ratio

- <u>Case 1:</u> The length of "X" is considered as 3 cm.

the pedal ratio obtained = 6: 1

- <u>Case 2:</u> The length of "Y" is increased by 1cm.

the pedal ratio obtained is X:Y = 18:4 = 4.5:1

- <u>Case 3:</u> The length of "X" is decreased by 0.5 cm.

the pedal ratio obtained is X:Y = 18:2.5 = 4.5: 0.625

3.3Theoretical output:

Table 3.1: Values of pedal ratio and pedal force

Pedal ratio	Pedal force
6:1	1200N
4.5:1	1500N
4.5:0.65	1200N

Table 3.2: Parameters and their values

Parameters	Values
Frictional coefficient	0.4
Master cylinder diameter	10mm
Caliper piston diameter	25.4mm
No. of calipers used.	02
Velocity	45km/hr
Pedal length	18cm

4.DESIGN OF A DISC BRAKE

4.1 Modeling of disc brake:

Modeling of disc brake is done in Solid Works.Solid Works is a solid modeler and utilizes a parametric feature-based approach to create models and assemblies. Based on the above theoretical conclusions and material properties, a brake disc has been designed.

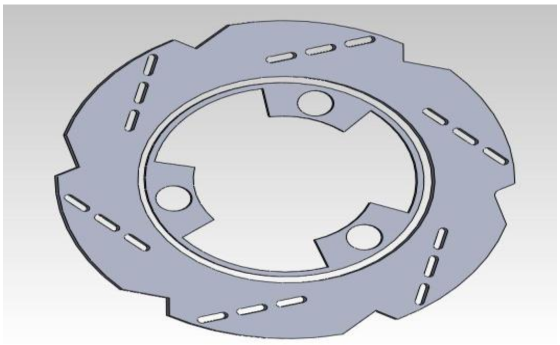

Figure 4.1- Modeling of a brake disc in SOLID WORKS

4.2 Disc brake properties:

- A 200 mm diameter disc is used for the design and analysis of brake performance.

Table 4.1: Grey cast iron properties

PROPERTIES	VALUES
Density	7200kg/m3
Young's Modulus	110Gpa
Poisson's ratio	0.28
Thermal conductivity	53.3-54
Specific heat	506J/kg-k

5.STATIC STRUCTURAL ANALYSIS OF DISC BRAKES

5.1 Analysis of the Disc:

Static structural analysis is done in ANSYS software.

Table 5.1: Material properties of grey cast iron

Ultimate tensile strength of grey cast iron	140-450Mpa
Yield strength	98-276Mpa

Factor Of Safety (FOS):

FOS=allowable working unit stress/ working stress (allowable stress)

In a static structural analysis, the FOS value ranges between 2 to 3. If the FOS value is below the range, the Disc cannot sustain the given pedal force and pedal ratio. The braking force which is obtained for different pedal ratios and pedal forces applied is tabulated as given below-

Table 3.2: Values of braking force obtained by varying pedal ratios and pedal forces

Pedal Force	Pedal Ratio	Braking/Tangential Force(F_T)
1200N	6:1	35996.72N
1200N	4.5:1	26336.06N
1200N	4.5:0.625	46175.89N
1500N	6:1	44996.04N
1500N	4.5:1	33747.84N
1500N	4.5:0.625	53996.12N

Based on the above values and calculations, the results obtained in ANSYS are-

5.2 Results:

CASE 1: Pedal force=1200N, pedal ratio=6:1, Braking Force=35996.72N

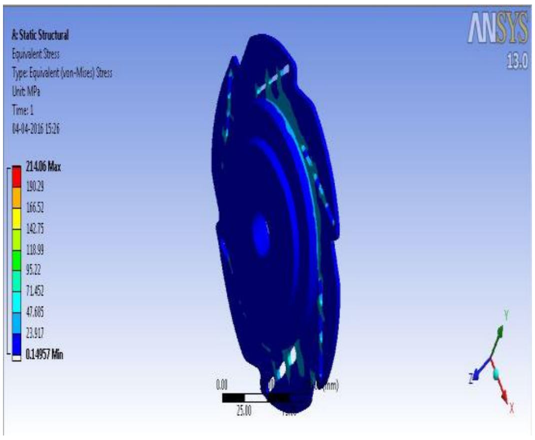

Figure5.1:Case 1

FOS=450/214.06=2.1

CASE 2: Pedal force=1200N, pedal ratio=4.5:1, Braking Force=26336.06N

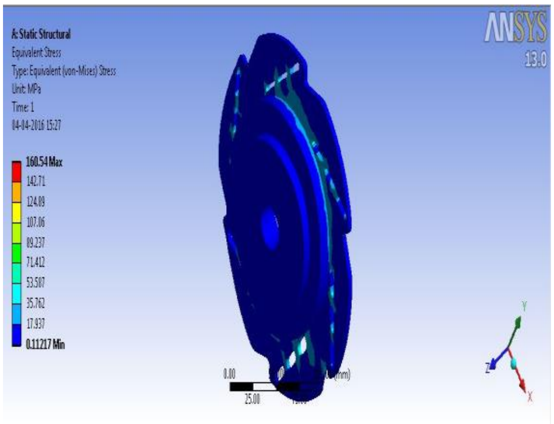

Figure 5.2: Case 2

FOS=450/160.54=2.8

CASE 3: Pedal force=1200N, Pedal ratio=4.5:0.625, Braking Force=46175.89N

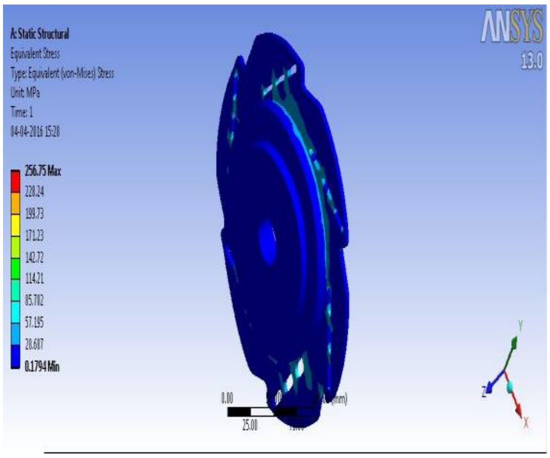

Figure 5.3: Case 3

FOS=450/256.75=1.75

CASE 4: Pedal force=1500N, Pedal ratio=6:1, Braking Force=44996.04N

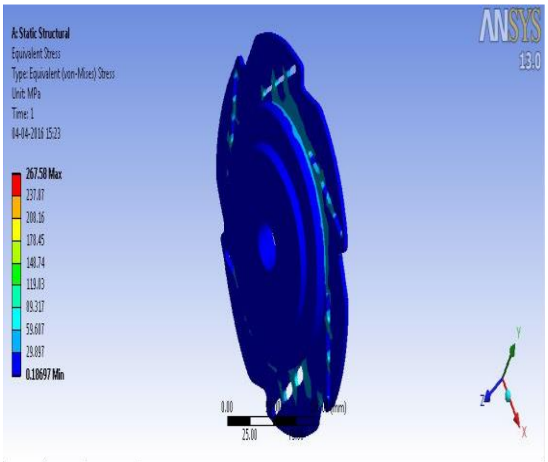

Figure 5.4: Case 4

FOS=450/267.58=1.68

CASE 5 : Pedal force=1500N, Pedal ratio=4.5:1, Braking Force=33747.84N

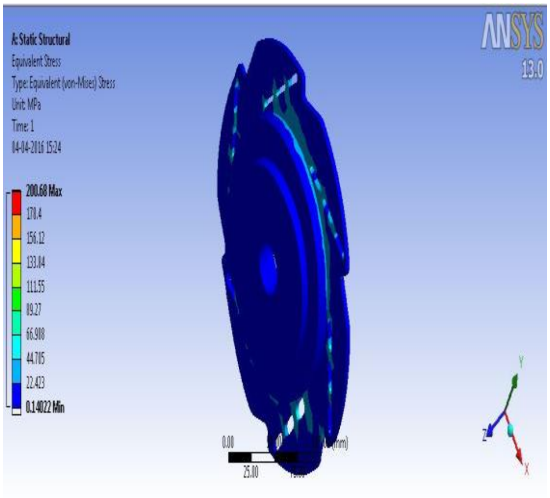

Figure 5.5: Case 5

FOS=450/200.68=2.2

CASE 6: Pedal force=1500N, Pedal ratio=4.5:0.625, Braking Force=53996.223N

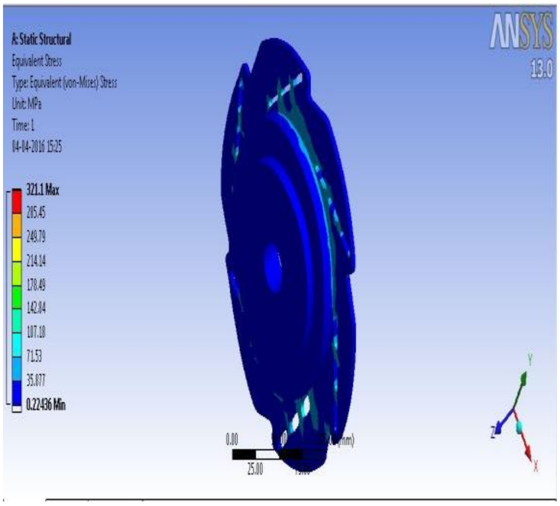

Figure 5.6: Case 6

FOS=450/321.1=1.40

5.3 Comparing the FOS obtained for different Pedal forces and Pedal Ratios

Table 4: Factor of Safety obtained for different cases

Pedal forces	Pedal ratios	Factor Of Safety(FOS)
1200N	6:1	2.1
1200N	4.5:1	2.8
1200N	4.5:0.625	1.75
1500N	6:1	1.68
1500N	4.5:1	2.2
1500N	4.5:0.625	1.40

6.1 CONCLUSIONS

- Based on the theoretical conclusions and considering the Disc's material properties, a static structural analysis is done on the brake disc designed in SOLID WORKS.
- As per the analysis, the factor of safety is the basic criteria that determine the sustainability of the Disc
- When the structure is steady, the Factor of Safety (FOS) ranges between 2 – 3.
- As per the comparisons made from the FOS and from ANSYS, when the pedal force is 1200N, and the pedal ratios are 6:1 and 4.5:1, the FOS are 2.1 and 2.8, respectively. Hence the Disc is sustainable. When the pedal force is 1500N, and the pedal ratio is 4.5:1, the FOS is 2.2. Hence in this case, too, the Disc is sustainable.
- Hence, as the Brake performance is evaluated by the varying pedal ratios and pedal force other than the standard 6:1 ratio, a slight variation, which resulted in a 4.5:1 ratio, gives more sustainable results under respective load conditions.

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