

Design, Development and Analysis of Hydraulic Disc Brake System for Formula Student Race Car

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ABSTRACT: The main objective of this paper is design and development of hydraulic disc brake system for FORMULA STUDENT race car. The research done is concentrated on working and effectiveness of mechanism and design a system such as caliper selection, master cylinder selection and pedal assembly to obtain highly efficient braking system for vehicle as per the requirements. The design process consists of first determining the braking parameters and forces acting on each axle and analyze it. After analyzing and optimization of the geometry the entire system is been manufactured. The braking system was designed to be lightweight and compact while still providing adequate braking power for locking of all four wheels of the vehicle. The paper discusses the theory and basic design criteria of the hydraulic disc braking system. The design obeys the rules stated by FSAE rulebook and FORMULA BHARAT RULEBOOK 2019.

KEYWORDS: Braking system, Caliper Selection, Wheel locking, Braking power, Braking parameters.

I. INTRODUCTION

As buildup formula vehicle one of the main part is to design braking system. In compliance with good suspension system, good handling, safe cornering, there is one most critical system which is braking system. Without braking system in the vehicle will put driver in an unsafe position. The hydraulic disc brakes is an arrangement of braking mechanism which uses brake fluid typically containing ethylene glycol, to transfer pressure from controlling mechanism to the braking mechanism. Hydraulic brakes works on the principle of Pascal's Law which states that "Pressure at a point in a fluid is equal in all directions in confined space". According to this law when pressure is applied on fluid it travels equally in all directions so that uniform braking action is applied on all four wheels. The disc brake is a wheel brake which slows rotation of the wheels by the friction caused by pressing brake pads against brake disc with a set of calipers.

II. BRAKING SYSTEM METHODOLOGY

The braking system had to provide enough braking force to completely lock the wheels at the end of a specified acceleration run, but remain small enough to fit inside of the front wheels and also prove to be cost effective. The braking system was designed by first determining parameters necessary to produce a given deceleration, and comparing to the deceleration that a known braking system would produce.

Certain assumptions about the car had to be made before the necessary calculations could be performed. It was assumed that the car would weigh 230kg, and the location of the car's CG was approximated based on the positions of the engine and driver. A deceleration of 1.5g was assumed, since the car would not likely be decelerating at a rate faster than this. Using this information, the amount of the car's weight on both the front and rear set of tires under deceleration could be determined. From this information the normal forces and frictional

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forces experienced by the tires can be determined to produce given deceleration rate.

With the help of friction forces the next step is to be determined braking torque. Brake torque is the simply amount of torque required to produce given deceleration.

$$\text{Torque}_{\text{brake}} = R_{\text{tire}} \times F_{\text{friction}}$$

With the bracket or ques required at the front and rear tires and compare it with the brake torque developed by the caliper. By comparing the torques the caliper selection are finalized. By keeping all above information into account the below parameters are finalized.

- Disc diameter – 55 mm PCD of the Disc – 100 mm
- Size of bolts- M6 (8.8 grade with metal lock nuts)
- Thickness of the disc- 4mm
- Calipers-Vespa double pistoncaliper(withborediameter30 mm)

III. BRAKING SYSTEM SPECIFICATIONS

Table -1: Braking System Parameters

Sr.No.	Parameters	Value
1	Driver Force	400 N
2	Leaverage Ratio	6:1
3	Master Cylinder Diameter	19.05mm
4	Area Of Master Cylinder	285.022 mm ²
5	Caliper Piston Diameter	30 mm
6	Area Of Caliper Piston	706.85 mm ²
7	Tire Diameter	10 Inch
8	Disc Thickness	4mm
9	Wheel Base	1600mm
10	Mass Of Vehicle	230kg
11	Weight Of Vehicle	2256.3n
12	Height Of Cg	310mm
13	Cg From Front Axle	880mm
14	Decelearation	1.5g
15	Velocity	16.66m/s

- Front calliper: Vespa double piston callipers having bore dia. 30mm
- Rear callipers: Vespa double piston callipers having bore dia. 30mm
- Master cylinder : Maruti 800 tandem master cylinder having bore diameter 19.5 mm
- Pedal ratio : 6:1

IV. BRAKE CALCULATIONS

- Deceleration $a = 1.5 \times 9.81 = 14.71 \text{m/s}^2$
- C.G. height= $y_{cg} = 310 \text{mm} = 0.31 \text{m}$
- Distance of C.G. from front axle = $X_{cg} = 880 \text{mm} = 0.88 \text{m}$
- Wheel base = $b = 1600 \text{mm} = 1.6 \text{m}$
- Rolling radius = $r = 205 \text{ mm} = 0.205 \text{m}$ Mass of car = 230 kg

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- Normal Forces On Front And Rear Tyres-

$$N_{\text{rear}} = 585.45 \text{ N}$$

$$N_{\text{front}} = 1670.85 \text{ N}$$

$$\% \text{ Of Normal Force On Front Tyre} = 74.05\%$$

- Braking Torque Required, $\mu = 1.5$
- Frictional Forces On Front Tires $F_f = 2506.275 \text{ N}$
- Frictional Forces On Rear Tires $F_r = 878.175 \text{ N}$
- Braking Torque On Front Tires
- $T_{rf} = 513.786 \text{ N-M}$ (Required)
- Braking Torque On Rear Tires
- $T_{rr} = 180.025 \text{ N-M}$ (Required) Pressure = 8.42 N/mm^2

Stopping distance:

Stopping distance is the distance measured between brake applied by the driver and the vehicle gets complete stop. The distance travelled by the vehicle when brake is applied. The stopping distance depends upon several factors including deceleration rate, percentage of grade for operation, vehicle speed, road surface characteristics.

Stopping distance, $d = 8 \text{ m}$

Brake Torque Developed-

$$T_d = 1104.096 \text{ N-M (Developed)}$$

By comparing torque required for braking and the torque developed by caliper, we preferred the Vespa calipers for our vehicle.

V. BRAKE DISC

The brake disc is used to stop the car/motorcycle with the help of calliper pads. The calliper pads are actuated by a fluid present in the hydraulic circuit. The wheel assembly of the car consists of knuckle (upright), stub, hubs, bearings and disc. The brake discs are mounted on the hub which is connected to the wheels directly. The disc is mounted behind the hub. The knuckle have a special arrangement for mounting a calliper on it. The part of the disc is inserted in the space present between the calliper pads. The part of the disc which is in contact with the calliper pads is known as pad area on the disc.

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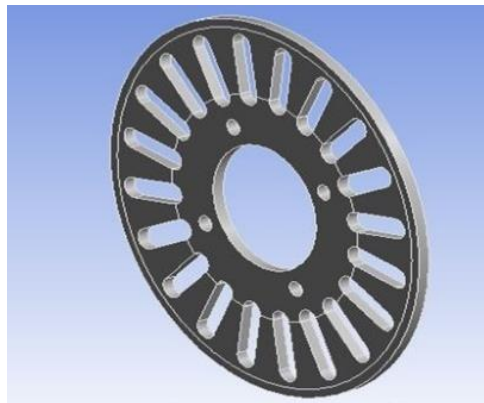


Fig -1: Brake Disc

5.1 Thermal Analysis Of Brake Disc:

For analysing the discs some assumptions are to be done as well as calculations of some parameters are required. Considering mass of the car is 230 kg. Now considering the car is travelling at a speed of 65 km/hr on a race track (formula race track) and it suddenly applies a brake which decelerates the car and at the end car stops. During the steady state thermal analysis the disc get analysed for maximum temperature distribution on the pad area of the disc in order to understood proper heat dissipation takes place through the disc surface.

Initial temperature (ambient temperature) = 22° C

- Velocity = 65 km/h = 17.67 m/s
- Mass (M) = 230 kg
- Weight = 2256 N
- Coefficient of friction between road and tyre (μ) = 0.8
- Brake disc diameter = D = 0.155 m
- Axle weight distribution (γ) = 0.4
- Percentage of kinetic energy that disc can absorb $\phi = 0.9$
- Acceleration due to gravity (g) = 9.81 m/s²
- Coefficient of friction between disc and pads = (μ) = 0.3
- Kinetic energy of the system can be given as,
K.E. = 6463.8 J Deceleration Time (t),
 $v = u + at$ t = 2.85 sec
- Braking power (pb) = K.E. / t pb = 2268 W
- Heat flux = (Q) = Pb/A
= 120195 W/m²

But the distribution of braking torque vehicle is about 64:40 and the heat flux for single disc can be evaluated by dividing total heat flux by two. And by considering the weight distribution factor, the heat flux Q is equals to 23040 W/m^2 .

5.2 Analysis of Brake Disc

We used ANSYS for the analysis and validation of the design.

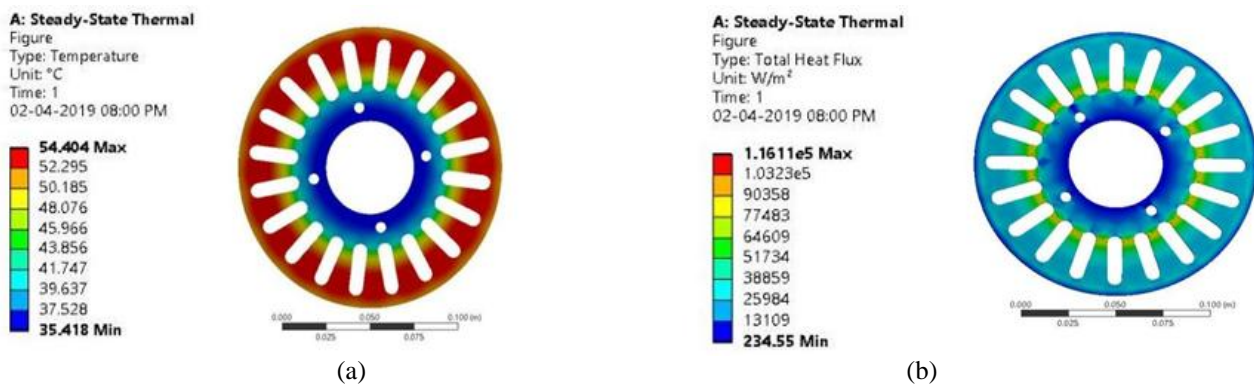


Fig -2: (a)Steady state thermal analysis of Temperature distribution through disc, (b). Steady state thermal analysis of total heat flux through disc.

5.3 Brake Pedal

The pedal design is important, especially at the contact point from the foot of the driver, because that is where the most force would be applied. In general, the brake pedal needed to take a 2000 N force, but needed to also be lightweight for design points. Also, the height of the pedal pad should be about the average height of the length of a male's foot from heel to sole, about 270 to 290 mm , but be able to accommodate smaller and larger sized feet. The Brake Pedal is manufactured in aluminium by considering factor of safety 1.2.

The brake pedal is designed according to design procedure of bell crank lever. The master cylinder pivot is about 35mm above the brake pedal pivot. For designing the brake pedal the pedal ratio is considered as 6:1 and the driver force considered as 400 N.

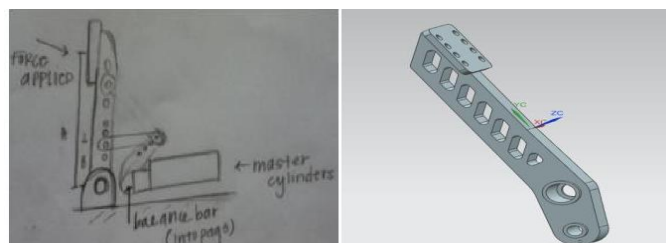


Fig -3: Brake Pedal Initial and Final Design Sketch.

5.4 Analysis of Brake Pedal

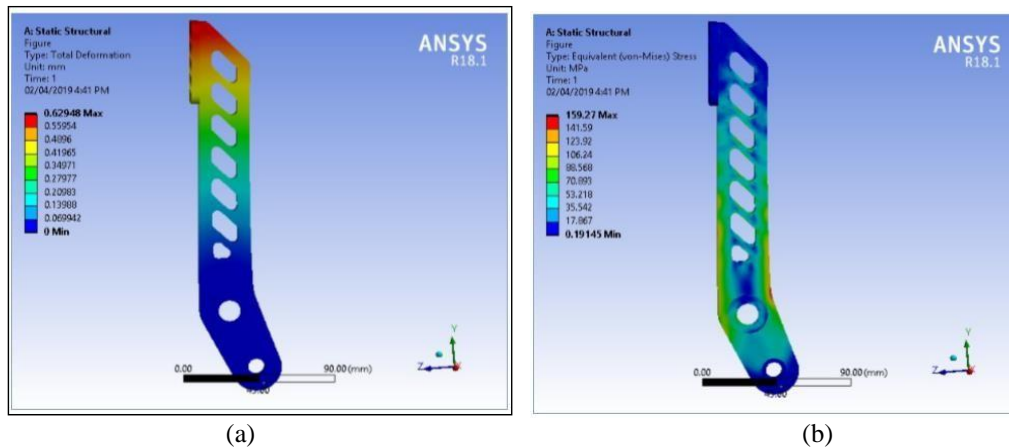


Fig. 4:(a) Static Structural Analysis of Total Deformation Of Brake Pedal, (b) Static Structural Analysis Of Equivalent (Von-Mises) Stress.

To eliminate small objects, connected component labelling is applied to the resultant image.(c) represents text detection by applying second set of criteria which eliminates all the objects whose area is less than 300 and filled area is less than 500.

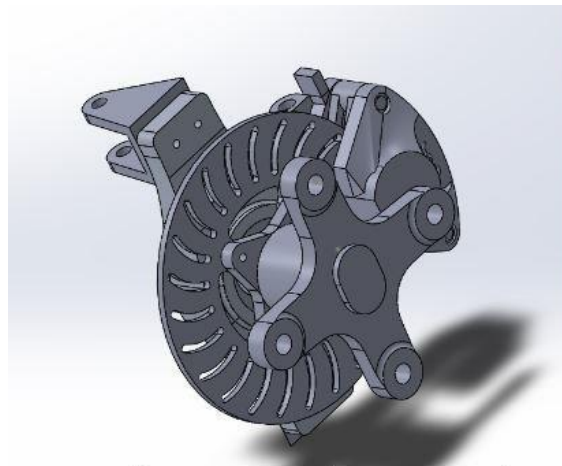


Fig -5: Brake disc & caliper assembly

VI. CONCLUSIONS

It was necessary to design a braking system which is light in weight and compact while still provides adequate stopping power and to cover these aspects we selected hydraulic braking system. While doing this project we understood how an effective braking system should be designed, manufactured and optimized. This Project has cleared our basic knowledge about mechanical system design. This idea has given us hands on experience on designing a hydraulic braking system which is very useful for future.

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