

Design & Development of Dual Circuit Brake System for FSAE

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ABSTRACT: This paper converse information about the study of design of dual circuit brake system used in FSAE. Formula racing car brakes undergo massive loading not only mechanical but also thermal as well. A brake is a mechanical device which slowing or stopping a moving object or preventing its motion. The objective of this work is to investigate and analyze the temperature distribution of rotor disc during operation using Ansys. Biasing is the most important concept in case of dual master cylinder brake system. Bias bar with a spherical bearing is designed to execute the function of biasing operated by single pedal. For this first we developed a rotational method to find out required ratio between front and rear braking forces to achieve maximum braking efficiency and to lock all the four wheels at the same time for the fulfilment of SAE SUPRA rules. After that according to data of braking forces, we have analyzed the brake disc against the structural and thermal stresses so that it meets the design requirements of the FSAE regulations.

KEYWORDS: master cylinder calculations, pedal design, Ansys, calculations etc.

I. INTRODUCTION

The most important part of a vehicle is Brake system. Brakes are required to stop the vehicle within the possible distance and it is done by converting kinetic energy of the vehicle into heat energy by friction which is dissipated into atmosphere. The brakes are strong enough to stop the vehicle within the least possible distance. Brakes should also be consistent with safety. The driver should have a good control over the vehicle during panic braking. During the panic brake the vehicle should not skid. The brakes should have proper characteristics and their effectiveness should not decrease with application. A disc brake assembly consists of Disc rotor that rotates with the wheel, Caliper assembly attached to the steering knuckle, disc pads that are mounted to the caliper assembly. In the vehicle when brakes are applied by the driver, vehicle slows down with gradual weight transfer from rear to front. This weight transfer is also seen in case of cornering of the vehicle, where the weight transfer takes place in lateral direction. This leads to change in the required braking force at different wheel. In case of hydraulic disc brake system, hydraulic cylinder i.e. master cylinders are used to pressurize the fluid. With the use of same bore of master cylinder, with the same caliper piston area it becomes difficult to distribute the braking force at different wheels. This makes it troublesome to lock all the four wheels. Hence it is important to compensate with the change in the weight transfer. To provide the more relative braking force at front we can increase the front disc diameter, pad area, caliper piston area or by reducing the bore diameter of front master cylinder than rear.

II. RELATED WORK

In automobile industry it is essential to produce the Compact and reliable Brakw system in order to increase the vehicle performance. Also, lot of forces during torque, acceleration and sudden braking conditions are also applied directly during dynamic condition. This article shows the design of FSAE braking system. [1] We presented in detail design procedure of the design of master cylinder for a formula student race car. The type of braking systems used generally are calculated. The models of the components in the braking system are made using Catia V5R21 and the Finite element analysis of the components is done using ANSYS Workbench. dynamic analysis of the designed brake pedal is performed. To find the diameter of master cylinder we find first deceleration. Braking torque required (Tr). A sudden



torque applied to brake drum or brake disk to decelerate the motion is called braking torque. Brake torque is the force applied at the brake wheel to stop the motion of the moving equipment. The force exerted by the caliper, multiplied by the effective radius of the system equals the brake torque. Material selected for Brake Pedal is Aluminium 6061. It has properties 6061 has an ultimate tensile strength of at least 290 MPa, as well as it light weight as compared to the Mild Steel, Brake pedal is meshed by square meshing and the meshing is (1mm) meshing. Due to the application of brakes to the car, heat generation takes place on the disc brake rotor due to friction. When brake pad is pressed against the rotor, friction between rotor and brake pads produces heat.

III. DESIGN PROCEDURE OF FSAE BRAKE SYSTEM

- CALCULATIONS FOR MASTER CYLINDER DIAMETER**

Brake Standards:-

Stopping distance- 5m

Deceleration- 15.625 m/s²

Dynamic weight transfer- 592.34 N

Weight transfer Front- 100+60.38 = 160.38kg (64.15%)

Weight transfer Rear- 150-60.38 = 89.62 kg (35.84 %)

Braking torque required- 89.52 Nm

Front brake force on two wheels

Fb front axle- 3906.25*64.15/100 = 2471.09 N

Rear brake force on two wheels

Fb rear axle = 3906.25*35.84/100 = 1434.76 N

- Dynamic Weight Transfer

When a vehicle travelling with certain speed is suddenly stopped the front suspension goes into jounce whereas rear spring experiences re-bound. This happens because some part of the rear axle weight gets transferred to the front axle and this is called dynamic weight transfer. Dynamic weight transfer value in any vehicle during the worst occurring condition is so selected that the vehicle should remain stable without losing the ground contact to safeguard the passengers. In order to comply with above mentioned condition, dynamic weight transfer value is limited to less than the static weight acting at the rear axle so that the rear wheels does not lose the ground contact. This value of dynamic weight transferred,

(Wd) due to braking can be calculated by equation,

$$Wd = (D * H_{tcg} * \text{Mass of vehicle}) / (\text{Wheel base})$$

Where,

D = Deceleration

H_{tcg} = Height of C.G

$$Wd = (15.625 * 9 * 25.4 * 250) / (1565)$$

$$Wd = 592.34 \text{ N}$$

Front dynamic weight

$$W_{df} = W_{sf} + ((W_t * H_{tcg} * D) / (W_b))$$

$$W_{df} = 100 + ((15.625 * 9 * 25.4 * 250) / (1565 * 9.81))$$

$$W_{df} = 160.38 \text{ Kg (64.15\%)}$$

Rear dynamic weight (W_{dr})

$$W_{dr} = W_{sf} - ((W_t * H_{tcg} * D) / (W_b * g))$$

$$W_{dr} = 150 - ((15.625 * 9 * 25.4 * 250) / (1565 * 9.81))$$

$$W_{dr} = 89.52 \text{ Kg (35.849\%)}$$

Braking torque required (T)

A sudden torque applied to brake drum or brake disc to decelerate the motion is called braking torque. Brake torque is the force applied at the brake wheel to stop the motion of the moving equipment. The force exerted by the caliper, multiplied by the effective radius of the system equals the brake torque.



$Tr = Wd * u * \text{Effective radius of tire}$

$$Tr = 570.58 * 0.7 * 0.22365$$

$$Tr = 89.32 \text{ Nm}$$

Total braking force (Fb)

The normal reaction on the wheel is one of the key factors to consider for varying the braking force because the braking force mainly depends on the coefficient of friction between the tire and the ground and normal reaction on the wheel.

$D = Fb / \text{Mass of vehicle}$

$$15.625 = Fb / 250$$

$$Fb = 3906.25 \text{ N}$$

Required Calculations

Front brake force on two wheels

$$Fb \text{ front axle} = 3906.25 * 64.15 / 100 = 2471.09 \text{ N}$$

Rear brake force on two wheels

$$Fb \text{ rear axle} = 3906.25 * 35.84 / 100 = 1434.76 \text{ N}$$

Braking torque generated (Tg)

$Tg = Fb * \text{Effective wheel radius}$

$$Tg = 1235.54 * 0.22365$$

$$Tg = 276.32 \text{ NM}$$

Frictional Force on one disc (Ff)

Fictional Force refers to the force generated by two surfaces that contacts and slide against each other. These forces are mainly affected by the surface texture and amount of force impelling them together. The angle and position of the object affect the amount of frictional force.

$Ff = Tg / \text{effective radius of disc}$

$$Ff = 276.32 / 0.0748$$

$$Ff = 3694.11 \text{ N}$$

Total clamping force on one disc

It is the actual force which clamps rotor in order to decelerate the vehicle. While

calculating total clamping force, mechanical leverage and hydraulic leverage must be considered. Mechanical leverage is a force multiplier which varies according to pedal design. And hydraulic leverage is obtained due to area ratio of caliper pistons to master cylinder bore.

Total clamping force applied on rotor by braking system is given by below equation,

$$Ftc = Ff / u^2$$

$$Ftc = 3694.11 / 0.35$$

$$Ftc = 10554.6 \text{ N}$$

Output force by caliper (Fc)

It is the force which is produce by caliper piston during driver press the pedal.

$$Fc = Ftc / 2$$

$$Fc = 5277.3 \text{ N}$$

Master Cylinder outlet pressure (P)

It is the pressure generated in overall system to stop the vehicle.

$$P = Fc / Ac$$

Ac = Area of caliper piston

$$Ac = (\pi/4) * D^2$$

$$Ac = (\pi/4) * (31.75)^2$$

$$Ac = 791.73 \text{ mm}^2$$

Area of Master Cylinder

$$A = (F * L) / P$$

$$A = (200 * 5) / 6.66$$

$$A = 150.15 \text{ mm}^2$$



Diameter of Master Cylinder

$$A = (\pi/4) * D^2$$

$$150.15 = (\pi/4) * D^2$$

$$D = 13.82 \text{mm}$$

Required Calculations Rear

Rear brake force on two wheels

$$F_b \text{ rear axel} = 3906.25 * (35.84/100) = 1434.76 \text{N}$$

Rear brake force on one wheels

$$\text{Rear brake force on one wheels} = (1434.76/2) = 717.38 \text{N}$$

Braking torque generated (Tg)

$$T_g = F_b * \text{Effective wheel radius}$$

$$T_g = 717.38 * 0.22365$$

$$T_g = 160.44 \text{NM}$$

Frictional Force on one disc (Ff)

$$F_f = T_g / \text{effective radius of disc}$$

$$T_g = 160.44 / 0.0723$$

$$F_f = 2219.08 \text{N}$$

Total clamping force on one disc

$$F_{tc} = F_f / \mu$$

$$F_{tc} = 2219.08 / 0.35$$

$$F_{tc} = 6340.22 \text{N}$$

Output force by caliper (Fc)

$$F_c = F_{tc} / 2$$

$$F_c = 6340.22 / 2$$

$$F_c = 3170.11 \text{N}$$

Master Cylinder outlet pressure (P)

$$P = F_c / A_c$$

A_c = Area of calliper piston

$$A_c = (\pi/4) * D^2$$

$$A_c = (\pi/4) * 31.75^2$$

$$A_c = 791.73 \text{mm}^2$$

Area of Master Cylinder

$$A = (F * L) / P$$

$$A = 200 * 5 / 4$$

$$A = 250 \text{mm}^2$$

Diameter of Master Cylinder

$$A = (\pi/4) * D^2$$

$$250 = (\pi/4) * D^2$$

$$D = 17.84 \text{mm}$$

While going to the generated calculations some parameter are change by various iterations to achieve more value than required. Some varying parameters are given below

Decide pedal leverage (l)=6

Diameter of Master Cylinder=15.875mm

Biasing bar force distribution=60:40

Generated Calculation Front

Calculate Master Cylinder outlet pressure (P)

$$P = (F * L) / A$$

Where,

A=Area of Master Cylinder

F= Pedal force =240N



L= Pedal leverage = 6
Master cylinder diameter 15.875mm
 $A = (\pi/4) * D^2$
 $A = (\pi/4) * 15.875^2$
 $A = 197.73 \text{ mm}^2$

Output force by caliper (Fc)

$$F_c = P * A_c$$

Where,

P = Master Cylinder outlet pressure

A_c = Area of caliper piston

$$A_c = (\pi/4) * D^2$$

$$A_c = (\pi/4) * 31.75^2$$

$$A_c = 791.73 \text{ mm}^2$$

$$F_c = 7.27 * 791.73$$

$$F_c = 5755.87 \text{ N}$$

Total clamping force on one disc (F_{tc})

$$F_{tc} = F_c * 2$$

Where,

F_c = Output force by caliper

$$F_{tc} = 5755.87 * 2$$

$$F_{tc} = 11511.74 \text{ N}$$

Frictional Force on one disc (F_f)

$$F_f = \mu_2 * F_{tc}$$

Where,

μ_2 = Coefficient of brake pad

F_{tc} = Total clamping force on one disc

$$F_f = 0.35 * 11511.74$$

$$F_f = 4029.109 \text{ N}$$

Braking Torque generated (T_g)

$$T_g = F_f * \text{effective radius of disc}$$

Where,

F_f = Frictional Force on one disc

$$T_g = 4029.109 * 0.0748$$

$$T_g = 301.377 \text{ N.m}$$

Braking Force on one wheel (F_b)

$$F_b = T_g / \text{Effective wheel radius}$$

$$F_b = 301.377 / 0.22365$$

$$F_b = 1347.50 \text{ N}$$

Braking Force on two wheels (F_b)

$$F_b = 1347.50 * 2$$

$$F_b = 2695.01 \text{ N}$$

Cross check the every parameter it must be greater than required value. If e torque generated it must be greater than torque required.

Generated Calculation Rear

Calculate Master Cylinder outlet pressure (P)

$$P = (F * L) / A$$

Where,

A = Area of Master Cylinder

F = Pedal force

L = Pedal leverage = 6

Master cylinder diameter = 15.875mm

$$A = (\pi/4) * D^2$$



$$A = (\pi/4) * 15.875^2$$

$$A = 197.73 \text{ mm}^2$$

$$P = (160 * 6) / 197.73$$

$$P = 4.85 \text{ N/mm}^2$$

Output force by caliper (F_c)

$$F_c = P * A_c$$

Where,

P = Master Cylinder outlet pressure

A_c = Area of caliper piston

$$A_c = (\pi/4) * D^2$$

$$A_c = (\pi/4) * 31.75^2$$

$$A_c = 791.73 \text{ mm}^2$$

$$F_c = 4.85 * 791.73$$

$$F_c = 3839.89 \text{ N}$$

Total clamping force on one disc (F_{tc})

$$F_{tc} = F_c * 2$$

Where,

F_c = Output force by caliper

$$F_{tc} = 3839 * 2$$

$$F_{tc} = 7679.78 \text{ N}$$

Frictional Force on one disc (F_f)

$$F_f = \mu * F_{tc}$$

Where,

μ = Coefficient of brake pad

F_{tc} = Total clamping force on one disc

$$F_f = 0.35 * 7679.78$$

$$F_f = 2687.923 \text{ N}$$

Braking Torque generated (T_g)

$$T_g = F_f * \text{effective radius of disc}$$

Where,

F_f = Frictional Force on one disc

$$T_g = 2687.923 * 0.0723$$

$$T_g = 194.33 \text{ N.m}$$

Braking Force on one wheel (F_b)

$$F_b = T_g / \text{Effective wheel radius}$$

$$F_b = 194.33 / 0.22365$$

$$F_b = 868.98 \text{ N}$$

Braking Force on two wheels (F_b)

$$F_b = 868.98 * 2$$

$$F_b = 1737.96 \text{ N}$$

Cross check the every parameter it must be greater than required value. If Take torque generated it must be greater than torque required.



Required		Achieved	
Front Brake Force On Two Wheels	2471.09N	Front Brake Force On Two Wheels	2695.01N
Brake Force On One Wheel	1235.54N	Brake Force On One Wheel	1347.50N
Torque Generated On One Wheel	276.32N	Torque Generated On One Wheel	301.37N
Frictional Force On One Disc	3694.11N	Frictional Force On One Disc	4029.11N
Total Clamping Force On One Disc	10554.6N	Total Clamping Force On One Disc	11511.76N
Output Force By Caliper	5277.3N	Output Force By Caliper	5755.80N
Output Pressure By Master Cylinder	6.66N/mm ²	Output Pressure By Master Cylinder	7.27N/mm ²
Area of Master Cylinder	150.15mm ²	Area of Master Cylinder	197.93mm ²
Diameter Of Master Cylinder	13.82mm	Diameter Of Master Cylinder	15.875mm
Leverage	5	Leverage	6

IV.CATIA MODEL OF BRAKE PEDAL

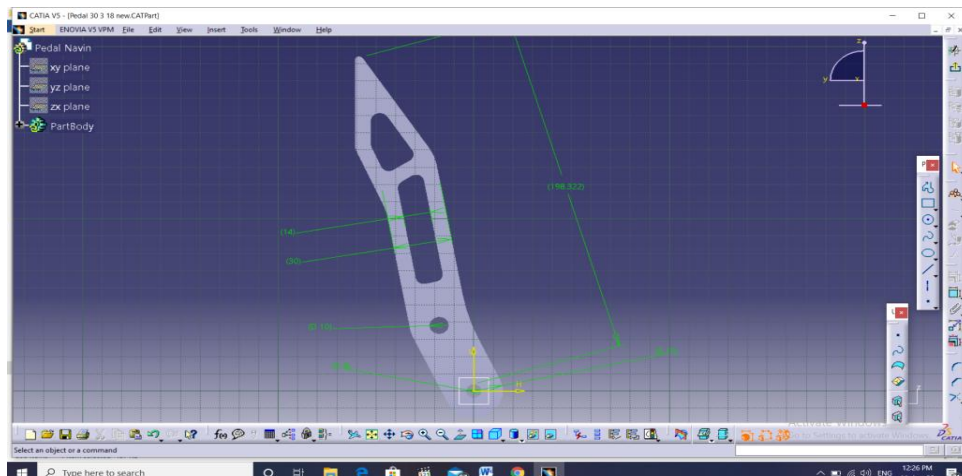


Fig.1 CATIA model Brake Pedal

Material selected for Brake Pedal is Aluminium 6061. It has properties 6061 has an ultimate tensile strength of at least 290 MPa, as well as it light weight as compared to the Mild Steel. Final height of brake pedal 203.5mm (8 inch), diameter of Biasing bar hole is 10mm. Thickness of pedal is 30mm, pivot point hole diameter is 8mm. The pedal leverage is important parameter in pedal design. Pedal ratio, or mechanical leverage is the ratio calculated from the length from the pivot point of the pedal to the center of the foot pedal, divided by the length from the pivot point to the master cylinder pushrod. Pedal leverage is simply a means of increasing the brake force without increasing your leg effort. The Pedal leverage increases brake force without pushing harder on the pedal.

V. STATIC AND DYNAMIC ANALYSIS

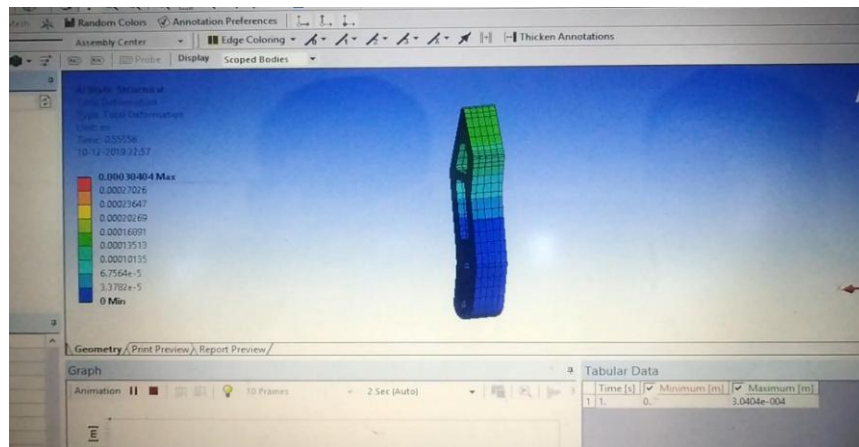


Fig. 2 Ansys of Pedal

At design stage, CATIA is used and ANSYS is used for analysis. on the basis of past research & specifications, material selection is done. the pedal arm profile on the basis of stress, mass & volume, and deformation results achieved on ANSYS. Force applied on front face by driver is about 500-600N, but we have designed by considering maximum force on front face is 2000N as per FSAE rule.

VI. METHODOLOGY

- Firstly, we started the work of this project with literature survey and gathered many research papers which are important to this topic.
- Based on mechanical properties we selected the suitable material
- We did calculations and 3D model design.
- After that we selected the materials for the components based on mechanical properties.
- Result may calculated based on testing.
- The components will be manufactured and then assembled together.
- The testing will be carried out and then result and conclusion of topic will be drawn.

VII. CONCLUSION

- After we selected the materials for the components based on mechanical properties. We have done the calculations for the components. After doing the calculations of components, the 3D model is done with the help of CATIA software. The components will be manufactured and then assembled together. The testing will be carried out and then results and conclusion will be drawn.
- After going through various components of braking system, the paper lay down a methodology for analysis of different components. Even for some critical components more than one methods are employed to ensure the durability of design.
- These analysis steps need to be followed many time in single component to obtain a perfect model. Since, the paper covers methodology for analysis of different components along with introduction to load calculation in most of the cases. So, it can be useful for other students for solving these type of models.
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