MONOBLOCK BRAKE CALIPER DESIGN AND ANALYSIS

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Abstract – *When it comes to safety of a vehicle, quality of braking system plays a vital role in it. Effective braking is also an important criteria of vehicle performance. Brake caliper is a crucial part of the system and whole system is built with consideration of its strength. A mono-block custom made caliper gives an advantage of reduced size, weight and effective braking compared to OEM. This paper studies designing of brake caliper for a FSAE car, where primary focus is reduction of size and weight without compromising the mechanical strength and stiffness. The Computer Aided Design (CAD) model is made on Solidworks 2017 and analysis of stress and deformations is done on ANSYS Workbench 18.1.*

Key Words: Braking system, Brake Caliper, FSAE, ANSYS, Computer Aided Engineering (CAE), Solidworks, FEA, Braking torque, thermal analysis.

1. INTRODUCTION

In any automobile braking system brake caliper plays a vital role as the clamping force provided for the friction and braking torque is applied by friction pads held by brake caliper. When force is applied on the brake pedal by the driver pressure is applied on the pistons in caliper which pushes the brake pads to the surface of brake disc resulting into a friction force which thereby reduces the speed of the vehicle. The designed layout of fixed two piston caliper is given below:

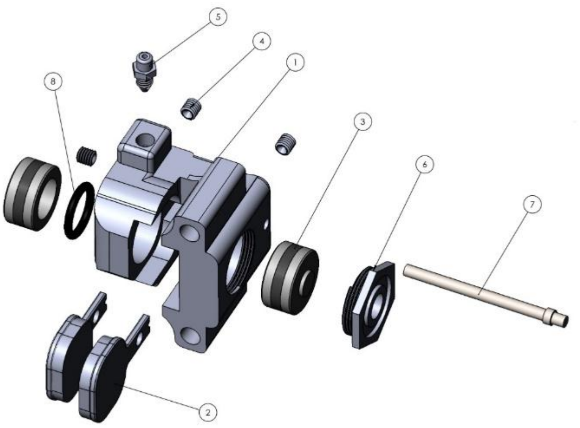

Fig -1: Exploded view of brake caliper

1. Caliper body
2. Friction pads
3. Piston
4. Grub screws
5. Bleed screw
6. Cap
7. Dowel pin
8. Oil seal

This brake caliper is mainly held on the upright or knuckle of the suspension assembly of a vehicle. The pressure distribution between the friction pads should be uniform so as to ensure that pad wear and heat distribution is even. Braking torque generated is the most important parameter in braking, must be greater than the torque required to stop the vehicle. This is achieved by applying clamping force on the rotor with friction pads which causes reactive forces and thereby induces stresses in the body of caliper. The clamping force applied results in friction forces and this generates heat which is then dissipated by pads and rotor i.e. kinetic energy of vehicle is converted into heat energy due to friction. This increases the temperature in disc and also the caliper body through heat transferred by brake pad. This heat may cause thermal deformation in caliper body.

2. METHODOLOGY

This research begins with some basics calculations for the required and obtained braking torques. These calculations helped us to determine some crucial parameters for the calipers like bore diameter, contact area of pad etc. in order to continue with the design. Safety of student driver is of paramount importance in designing an FSAE race car and also its rule and regulations. So the primary focus maintained throughout the designing process is safety, optimization of weight and efficiency of the system. After considering these factors a CAD model was designed on Solidworks 2017 software and analysis was performed on ANSYS 18.1 to get an idea of stresses developed and also the possible deformations. Also thermal analysis is performed to find out increase in temperature of the body due to heat transfer from brake pads after the application of brakes for a time interval. Also results were concluded with ideas of further optimization.

3. FLOWCHART

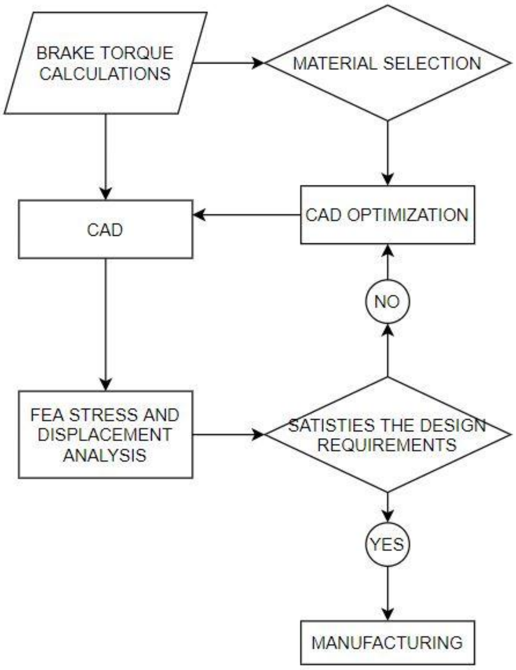

Fig -2: Flowchart of methodology

4. DESIGN

4.1 Design calculations:

The design calculation was done in two parts:

1.) Required braking torque.

2.) Obtained braking torque.

For required braking torque: Required braking torque gives the value of braking torque that needs to be applied at a particular deceleration to lock the wheel.

During braking there is longitudinal weight transfer so we start by calculating the weight transfer using the formula.

$$\frac{m * g * cght}{wb}$$

Where m = mass of car.

g = maximum deceleration.

cght = height of CG.

wb = wheelbase.

Then to this weight transfer static weight was added according to the weight distribution. So,

Total normal load at front axle = weight transfer + static weight*weight distribution.

Total normal load at rear axle = weight transfer - static weight*weight distribution.

Hence we get the total normal load acting on the each front and rear axel. So to calculate total normal load on each tyre we divide the values by 2.

To calculate the required torque for locking of the wheels:

= normal load on single wheel*radius of the wheel*coefficient of friction between the tyre and the road surface.

Values Considered for calculations:

Mass of car, m (with driver) = 240 kg.

C.G height = 0.254m.

Deceleration = 1.6g.

Wheelbase = 1.55m.

Weight distribution = 45:55.

Coefficient of friction = 2.3.

Wheel radius = 0.2032.

Now using the above mentioned formulas we got:

Longitudinal weight transfer = 62.93 kg.

Static Weight Front = 108 kg.

Static Weight Rear = 132 kg.

Dynamic Weight front = 170.93 kg.

Dynamic Weight Rear = 69.07 kg.

Total normal load at front axle = 1676.82 N.

Total normal load at rear axle = 677.58 N.

Normal load each tyre front = 838.41 N.

Normal load each tyre rear = 338.79 N.

Required braking torque front each wheel = 391.84 Nm.

Required braking torque rear each wheel = 158.34 Nm.

Obtained braking torque:

This helps us to estimate the braking torque that we can achieve.

If Obtained braking torque>required braking torque

Then the wheels will lock and the design is safe.

We consider a force applied on master cylinder by the foot of the driver this force is calculated as follows:

$$\frac{force\ applied\ by\ driver * pedal\ ratio * brake\ bias}{inclination\ of\ master\ cylinder}$$

We know that the hydraulic braking system works on the principle of Pascals law.

The force applied by calipers was calculated

We used master cylinders from ap racing so we knew the bore diameter and also the force applied by the driver.

For the caliper side , the number of pistons and diameter of the pistons was iterated so as to get the obtained torque more as compared to the required braking torque.

$$\frac{Force\ on\ master\ cylinder * Area\ of\ piston * no.of\ pistons}{Area\ of\ master\ cylinder\ bore}$$

So obtained braking torque = Force applied by calipers * coefficient of friction between brake pads and rotor * effective radius.

Values Considered for calculations:

Force applied by driver : 60kg.

Pedal ratio = 1.4.

Brake bias = 0.5

Master cylinder inclination = 70 degrees.

Master cylinder diameter front = 15.875mm.

Master cylinder diameter rear = 17.78mm.

Coefficient of friction = 0.55

Effective radius = 0.0795 m

Force applied by driver = 1204.66 N.

Force applied by calipers front = 11950.25 N.

Force applied by calipers rear = 4763.33 N.

Obtained torque front = 522.52 Nm.

Obtained torque rear = 208.27 Nm.

Hence Obtained braking torque > required braking torque so the design is safe.

4.2 Bore diameter calculations

As soon as the driver applies force, pressure is experienced by master cylinder piston. This pressure remains constant in brake lines due to incompressible brake fluid and the pressure is converted to clamping force on the caliper side of the brake lines. The magnitude of clamping force is dependent on the bore diameter of caliper piston and the number of pistons. Friction pads press against rotor due to clamping force and thereby producing the friction force for the braking torque. As mentioned earlier generated braking torque should be greater than the required braking torque to stop the vehicle. Hence bore diameter and number of pistons are calculated with the following formula:

$$Clamping\ force(Fc) = \frac{Required\ braking\ torque}{Effective\ rotor\ radius * \mu}$$

Hence, after getting clamping force the diameter and number of pistons as mentioned earlier was iterated according to the equation given below and depending upon the availability of space and pressure in the system(P).

$$D = \sqrt{\frac{4 * Fc}{\pi * n * P}}$$

From iterating for various values of diameter of piston and no. of pistons, number of pistons for brake caliper was finalized as 2 and the diameter was set as 25mm also considering the size of the brake pads.

4.3 Seal Groove design

When continuous actuation of brakes take place the pistons tries to move out for which we need to have a retraction mechanism after the application to avoid piston drag and piston moves back to original place. Oil seal will also avoid fluid leakage. This seal deforms and stores energy as the piston moves out and with release of the pedal, it pulls piston back, releasing the energy. So in this design we took into consideration use of an oil seal to properly seal and avoid any leaks. For this we had to make a groove on piston's body for the oil seal also needed to decide the dimensions and material of oil seal.

Dimension of oil seal was decided using the following formula:

$$Oring\ I.D. = \frac{Groove\ diameter}{\%\ of\ stretch\ desired + 1}$$

$$Max\ Oring\ O.D = \frac{(\frac{Min\ Bore\ dia - Max\ Groove\ dia}{2})}{(1 - \frac{Max\ \%\ Compression}{100})}$$

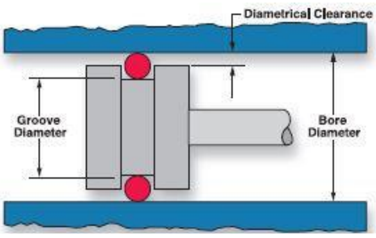

Fig -3: Cross section of oil seal

By taking into consideration the following factors

The dimensions of oil seal were decided to be

- Inner diameter 18mm
- Outer diameter 24mm
- Thickness 3mm
- Width 3mm
- Material selected was nitrile rubber since it has the following properties :
    1. Pressure rating 200bar
    2. Temperature rating 150 degree C

4.4 Design considerations

The caliper body was designed considering the factors like:

- The wheel assembly package.
- Ensuring a passage for the fluid to flow either side.
- Keeping the overall weight minimum.
- Rotor swept area.
- The thickness of the rotor
- Provision for mounting of brake pads
- Radial or axial mounting of caliper on the upright
- Dimensions of bleeder valve

Caliper could be of two types i.e. floating caliper and fixed calipers. We have decided to go for fixed calipers as we are using floating rotors and also fixed calipers are smaller in size hence are light weight and helps in better packaging.

Also we decided to go for MONO BLOCK caliper instead of standard two block calipers:

Advantages of Mono block calipers are

- Proper stress distribution
- Less chances of failure due to fatigue
- Less deflection compared to two block calipers
- Less chances of leakage through joints

4.5 Model

After completing the calculations and deciding the necessary parameters like mounting, bore diameter, bleed screw position etc. the 3D model of brake caliper was designed on Solidworks 2017 software. Other factors taken into consideration during designing includes:

- Packaging
- Passage for flow of brake fluid
- Overall weight
- Rotor swept area and thickness
- Brake pad mounting
- Mounting of calipers on upright
- Dimensions of bleeder valve

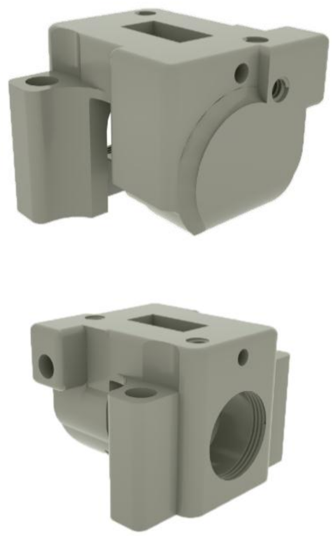

Fig -4: Final design of brake caliper body

4.6 Material

The material considered for the caliper body should be rigid to avoid deflections and light in weight to reduce the final weight of assembly. But, most significant property considered for selection of the material is the modulus of elasticity as, for a brake caliper, stiffness is more essential than strength. The commercial vehicles mostly prefer cast iron brake calipers due to its low cost, good machinability and high modulus of elasticity. But the main disadvantage of using cast iron is its high density. Aluminum provides sufficient modulus of elasticity for this application and also its low in weight and equally good at machinability. Then according to availability two aluminum alloys in the market are 6061 and 7075. For the main body of the caliper chosen aluminum grade is 7075. This was selected as it has a high strength to weight ratio than that of aluminum grade 6061.Also it has better corrosion resistance properties than aluminum 6061. All the parts of the caliper like cap and piston were made of 6061 alloy and anodized after manufacturing to avoid further corrosion.

5. FINITE ELEMENT ANALYSIS

The model was analyzed by applying pressure and forces on caliper body. Static structural and thermal analysis was carried out on the software ANSYS 18.1. This paper studies structural analysis of mounted brake caliper on upright and thermal analysis of the same due to heat generated by friction in rotor.

5.1 Material Properties

Table -1: Material considered AL7075

Density	2700 kg/m3
Young's Modulus	72 GPa
Yield Tensile Strength	503 MPa
Ultimate Tensile Strength	509 MPa
Poisson ratio	0.33

5.2Meshing

For accurate results in FEA good mesh is very important. In order to improve the quality of mesh parameters like aspect ratio, skewness should be taken into consideration. The average mesh quality of above 0.8 is considered acceptable. Different meshing techniques can be used to achieve this quality. Out of the element types tetrahedral elements were the most suitable for this model as they capture the curvatures more accurately than in any other method.

For refining proximity and curvature was used in order to ensure finer mesh along the curved regions and varying cross sections. A fine mesh with element size of 0.1 mm was obtained consisting of 1703769 nodes and 1187207 elements.

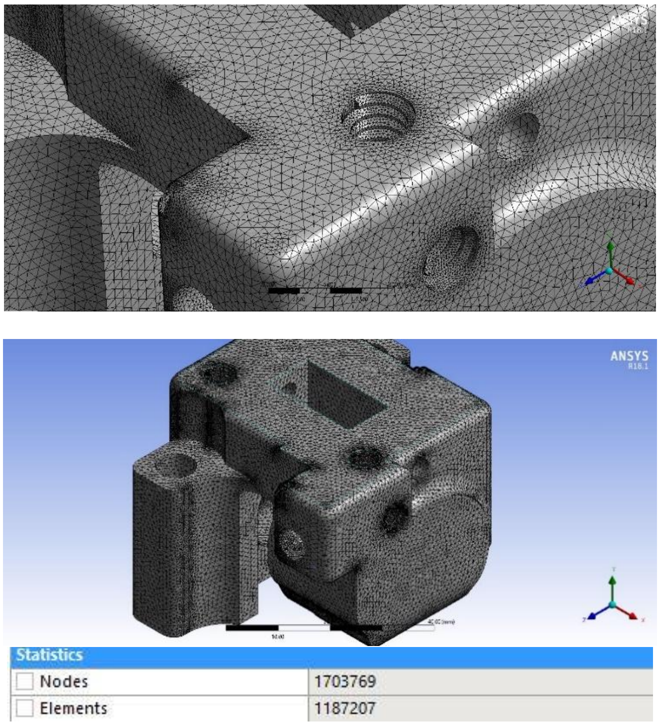

Fig -5: Mesh model of brake caliper body

5.3 Boundary Conditions

For static structural analysis, according to the calculations done earlier the forces and supports contributing to the stresses on the caliper are:

1. Forces:
    - Reaction on caliper due to the pressure on piston housing. Pressure applied 10MPa.
    - Reaction on the caliper body due to clamping force=4763.33N.

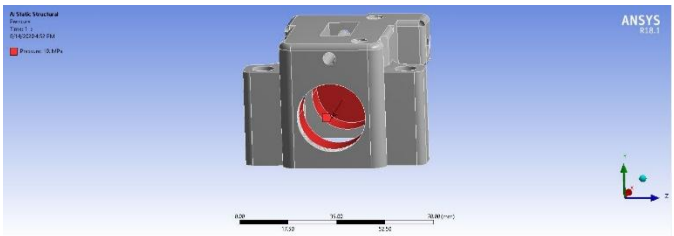

Fig -6: Pressure acting on piston housing

2. Supports:
    - Cylindrical support is given at the mountings.

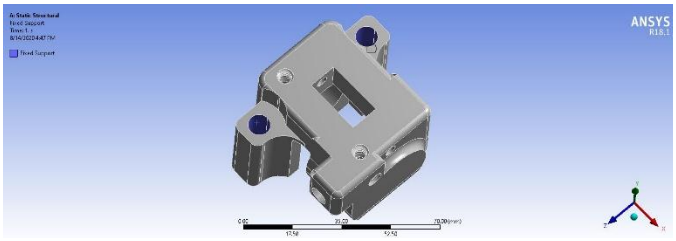

Fig -7: Fixed supports given on mounting points

For thermal analysis, maximum temperature of 350 degrees C was given at the surface of pad in caliper assembly and resulting maximum temperature obtained on the caliper body is obtained after 6s. This was done on ANSYS transient thermal.

5.4 Results

Following are the results obtained from the Static Structural analysis done using ANSYS Workbench 18.1:

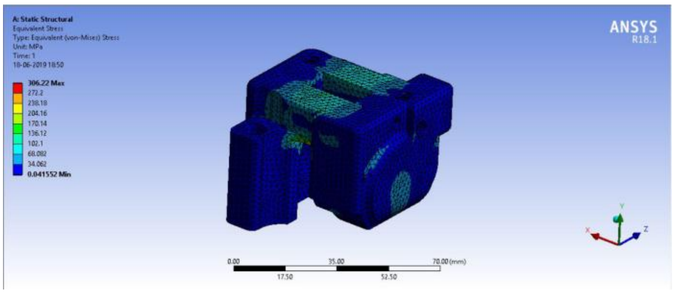

Fig -8: Total deformation

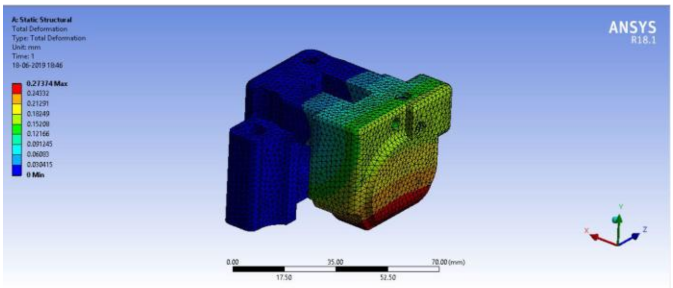

Fig -9: Equivalent stress

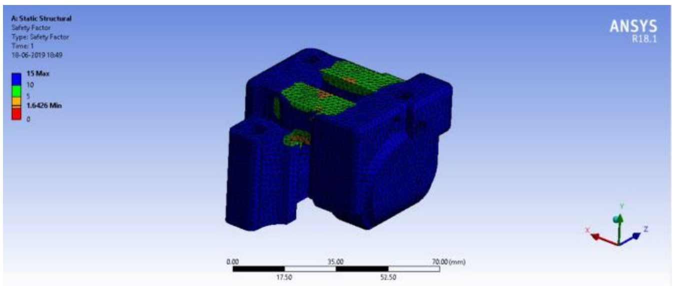

Fig -10: Safety factor

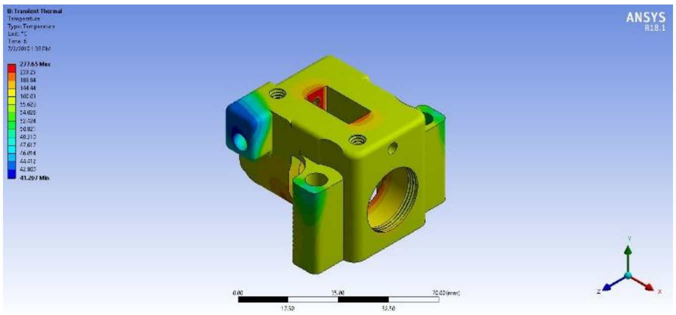

Fig -11: Temperature of body

Table -2: Results of performed CAE analysis

	Minimum	Maximum
Total deformation	0 mm	0.2734 mm
Equivalent stress	4.1e-02 MPa	306.22 MPa
Safety factor	1.6426	15
Temperature	41.2 C	277.65 C

6. CONCLUSIONS

Based on the work presented in this paper, it has been concluded that:

Rear brake custom calipers for FSAE car were developed and designed with considerable amount of reduction in weight as compared to OEM brake calipers whilst fulfilling the requirements defined during calculations and load cases.

This gives an indication for the steps that can be taken in future to improve upon the design as this brake caliper are the first of their kind within the team.

There are various areas which can be improved in the future:

- Proper temperature analysis during cyclic testing of calipers.
- Manufacturing of the calipers using additive manufacturing processes and generative design.
- Even better integration of the overall wheel package.

7. REFERENCES

[1] Brake Handbook, Fred Puhn(1987)

[2] Finite Element Methods and Applications in Engineering using ANSYS –*Erdogan Madenci, Ibrahim Guven.*

[3] Rudolf Limpert (2011). Brake Design and Safety. Society of Automotive Engineers, Inc.

[4] Heat and Mass Transfer by R.K. Rajput

[5] Industrial Heat-Transfer Calculations by Mohammad G. Rasul

[6] Heat and Mass Transfer by Rudramoorthy, R

[7] Joseph R. David (1993). ASM Specialty Handbook: Aluminium and Aluminium Alloys. ASM International.

[8] Thirupathi Chandrupatla, AshokD.Belegundu, “Introduction to finite element in Engineering”,2003.

[9]] D. Majcherczak, P. Dufrenoy and M. Nait -Abdelaziz, Thermal simulation of a dry sliding contact using a multiscale model –Application to the braking problem, Thermal stresses 2001, Osaka (Japan), pp. 437-440, Juin, 2001.

[10] A. Belhocine, M. Bouchetara, Thermal behavior of full and ventilated disc brakes of vehicles, Journal of Mechanical Science and Technology, November 2012, Volume 26, Issue 11, pp 3643–3652