DESIGN OF DUAL PISTON FIXED CALIPER FOR AN ALL TERRAIN VEHICLE

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Abstract

A brake is a mechanical device that inhibits motion by absorbing energy from a moving system. It is used for slowing or stopping a moving vehicle, wheel, axle, or to prevent its motion, most often accomplished by means of friction. Brakes are the most important safety subsystem of each vehicle. Effective braking is a critical factor determining the performance of any vehicle. With the enrichment of performance of vehicle, the importance of proper braking also increases. This paper studies a conceptual design of a hydraulic dual piston fixed brake caliper for an All-Terrain Vehicle (ATV), primarily focusing on reducing the size and weight, optimising cost, with inbuilt cooling system, without compromising its strength, stiffness and low piston drag. Computer aided design model of a brake caliper is created in Solidworks 16 and structural analysis is done in ANSYS 17.0 .

Keywords : *FEA, Brake Caliper, Braking System, Piston Drag, ATV, Piston Retraction, SolidWorks 16, ANSYS Workbench 17.0, Braking Torque*

INTRODUCTION

In braking, a brake caliper plays a very important role as the final clamping force on a brake rotor is applied by the friction pads held by caliper. When driver applies brakes, pressure is applied on the back side of piston pushing the friction pads against brake rotor resulting in frictional force on brake rotor and slows the vehicle down. A layout of the designed dual piston fixed caliper is shown in *Figure 1 (a) and (b).*

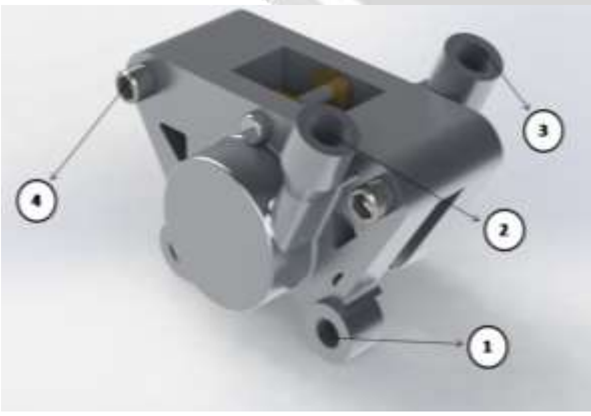


Figure 1 (a)

Isometric View of Brake Caliper

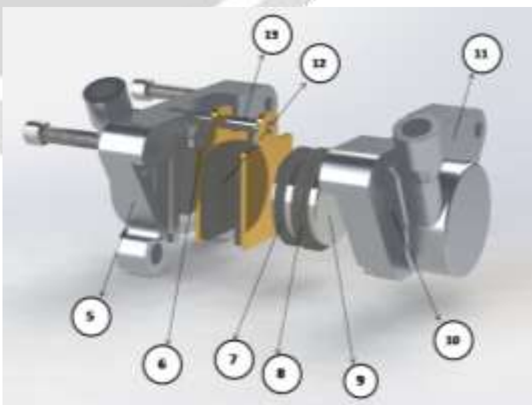


Figure 1 (b)

Exploded view of Brake Caliper

1- Mounting Holes (M8) 2- Inlet Port 3 -Bleeding Port 4- Caliper Body Joining Bolt

5 - Caliper Body 1 6 - O – Ring 7- Dust Seal 8- Oil Seal

9- Piston 10- Cooling Duct 11- Caliper Body 2 12- Brake Pad

13- Pad Retaining Pin

A brake caliper which is mounted on upright mainly holds the friction pads, while the clamping force is applied by the piston. The pressure distribution over the friction pads must be uniform so as to ensure even pad wear and heat distribution. Braking torque generated being the key parameter in braking, must be greater than the torque required to stop the vehicle. This is achieved by applying clamping force on the brake rotor which causes reactive forces thereby inducing stresses in the caliper body. The applied clamping force results in frictional force and generates heat which is dissipated by rotor and pads i.e. the kinetic energy of a vehicle is converted into heat which increases the disc temperature. This heat may be transferred to the caliper body through the brake pads causing thermal deformation.

PROCESS OF BRAKING

When the driver senses an obstacle he first takes time to react called *reaction time* which is around **0.037 secs** . Then he applies the brakes which takes him around **0.022 secs** called *brake actuation time.* Then there arises a deceleration condition for the vehicle but still it takes some time to reach time to reach peak value of deceleration which takes time around **0.14 secs** . Then the four wheels get locked and the wheel skids on the road and due to friction coefficient between the road and the tyres the vehicle stops and comes to rest.

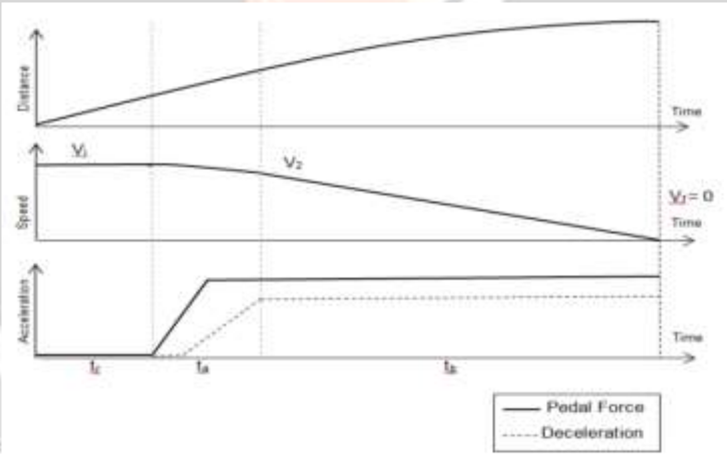


Figure 2
Process of Braking

TYPES OF CALIPERS

Depending on working mechanism

· Floating Caliper
· Fixed or Opposed Piston Caliper

· **Floating Caliper**

In a floating caliper, piston is on the inboard side of the caliper while the caliper is mounted on a guiding pin which acts as a cylindrical support. The guiding pin allows linear movement of the caliper along its axis. The friction pads on the outboard side are continuously in contact with the brake rotor which prevents the bending of the rotor. When brake pedal is actuated, the pressure is applied on back side of the piston which forces the friction pads against the rotor. The reaction force forces the caliper to slide over the guide pin leading to clamping of the rotor.

· **Fixed Caliper**

Fixed type caliper has pistons on both sides of the rotor and can be directly fixed to the mountings on the uprights. Pistons from both the sides force the friction pads to apply force on brake rotor. Fixed caliper does not require extra mounting bracket which is necessary in floating type caliper for sliding. The major advantage of fixed caliper over a floating caliper is the even wear of the friction pads.
A fixed caliper is preferred for providing better performance in terms of braking.

Depending on Number of Pistons

Number of pistons in a caliper significantly affects its performance. Calipers can be made with single or multiple pistons depending upon torque requirement and space availability. The number of pistons needs to be switched to two or three depending upon the requirement. The only disadvantage of using double or triple piston caliper is added number of leakage sources.

Depending on Caliper Body

Brake caliper can be made as a single body called monobloc caliper or in two parts called split type caliper. The major problem in a caliper being deflection under the application of clamping force, the caliper is made in two parts and then joined together by fasteners.

SEAL GROVE GEOMETRY

It is well known that the design of the seal groove assembly in the brake caliper greatly influences the braking performance. The rubber seal performs the dual function of sealing the piston bore and retracting the caliper piston after a brake apply. However, the seal function is affected by the configuration of the seal groove, as well as the friction at the piston/seal and groove/seal interfaces. The material properties of the rubber seal are also important design parameters. Issues such as fluid displacement, piston retraction, piston sliding force, and brake drag are some of the critical brake performance parameters that must be considered in every caliper seal-groove design.

The need to increase piston retraction (thereby reducing drag) often conflicts with the requirement to reduce piston travel (i.e. reducing displacement) during brake application. This is one of the major challenges in the seal-groove design.

It is noted that the deformation of the seal in the seal groove assembly during brake application is Governed by a set of design parameters that can be broadly classified as follows:

• **Material parameters** – time-dependent, non-linear material properties that govern the deformation of the rubber seal material, and consequently the braking performance.
• **Groove geometry** – geometric parameters that prescribe the kinematic boundaries of the seal deformation.
• **Friction parameters** – which defines the resistance to seal sliding at its interfaces with the caliper piston and seal groove.
• **Surface contact parameters** - describes the nonlinear contact behaviour of the seal at its interfaces with the seal groove as well as with the piston.
• **Temperature and environmental parameters** – time, temperature, and service conditions that affect the seal rubber material behaviour, and consequently the braking performance.

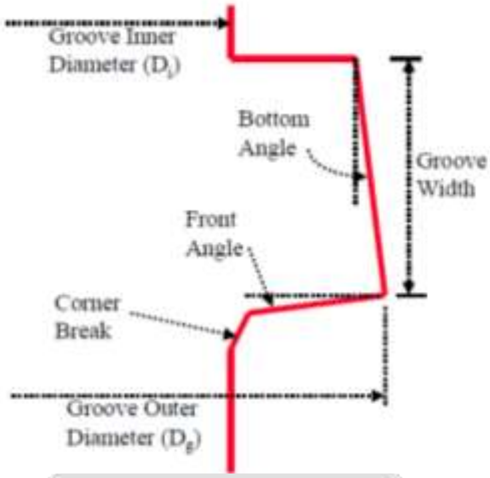


Figure 3
Basic Diagram of Seal Groove Geometry

The groove denoted, shows the piston retraction seal groove in which front taper angle allows deformation of the seal, while the bottom taper angle ensures easy insertion of the piston. After the installation of seal, inner diameter of the groove is less than outer diameter of seal which provides the necessary radial squeeze. At the front corner, a chamfer is given, called corner break, to allow excessive deformation of seal. A radial squeeze of around 12%-18% is provided in the seal for the prevention of leakage. Another seal is used for preventing dust entering into piston – fluid interface in the caliper cylinder, which is called dust seal.
As seals are hard to manufacture, thus OEM seal used in Bajaj Pulsar 220 (Rear Caliper) is chosen. The Groove inner diameter and groove outer diameter is chosen as per the dimension of the seal. Corner Break of 0.5mm is provided at 45 degrees. The front angle and bottom angle provided are 5 degree and 2 degree respectively.

Figure 4 (Seal Groove of proposed Caliper Design)

MATERIALS

The caliper body must be rigid as well as light weight. In most of the commercial vehicles, cast iron is used, but that makes the assembly very heavy due to high density of cast iron. Aluminium alloys can be used for the manufacturing of caliper considering its lower weight, and is used in most of the bike calipers. Alloys such as CuBe (Copper Beryllium) can be used considering its low density(60% lighter than aluminium), but is very costly .Thus Aluminium Alloy 7075 T6 is selected for the caliper body.

Pistons can be made from aluminium alloy or alloy steel. But steel makes the piston heavier. A heavier piston will result in later braking due inertia of the piston. The seals used are OEM, thus the material is predefined. But the characteristics of the material can be discussed. While selecting material these are to be kept in mind, compatibility with brake fluid, temperature operating range, fluid pressure range, hardness, tensile strength, compressibility and failure modes. The properties of seals vary with time and temperature. Various materials available for seals are Thermoplastic elastomers, Rubber, Rigid thermoplastics, etc.

"Vespa KBX" OEM brake pads are to be used as they match our design requirements. It is very cost efficient and readily available. The backing plate is mild Steel and pad is metal sintered. Manufacturing brake pads will be 5 times more costly than OEM brake pads.

CALCULATIONS

The calculations are for the designed custom calipers used in front and rear of the vehicle. In rear inboard braking is used, thus there is only 1 caliper used in the rear. The Master Cylinder used is Bosch Tandem Master Cylinder. The bore diameter of the master cylinder is 19.05mm and stroke length is 32mm.

The pedal force is found out as 350 N by using a Load Cell.
Pedal force = 350 N
Force applied on master cylinders,
force applied on pedal x pedal ratio x biasing ratio = 350 x 6 x 0.5 = 1050N

Area of the master cylinder = 285.364 mm. Sq

Pressure in master cylinder = Force in master cylinder/ area =1050/285.364 = 3.679 N/mm. sq = 37.515 kg/cm. Sq
In case of panic braking, let us assume, the driver puts in extra effort, thus increasing pressure. So rounding off the pressure generated = 40 kg/cm.sq . The pressure generated in master cylinder will be constant through out the braking circuit. The pressure generated at caliper is also same as that of generated at master cylinder.
Thus using the principle of thick cylinders, we can calculate the outer radius of the caliper cylinder.

Let internal radius be r
Let external radius be R
Let Pressure generated be P1.

Pressure generated is equal to radial stress at inner radius (σ_{ri}) = P1
Radial stress generated at outer radius = σ_{ro} = 0
Let us assume that limiting tensile stress be 300 MPa = 3059 kg/cm². (Tensile Strength of aluminium 6061 T6)
Thus hoop stress at inner wall = $\sigma_{\Theta i}$ = 3059 kg/cm²
When one end of the thick cylinder is restricted, and one end is free. Thus longitudinal stress is also produced = σ_l

Let 'a' and 'b' be 2 constants.
Thus from Lame's theory, we have :

σ_{ri} = P1 = b/r² - a ------------------------------ (1)
σ_{ro} = b/R² - a = 0 ------------------------------(2)
$\sigma_{\Theta i}$ = b/r² + a ----------------------------------(3)

b/(16)² - a = 40 ------------------------------(4)
b/(16)² + a = 3059------------------------------(5)

Adding (4) and (5) , we get
= b = 512000 ; a = 1059.
Rewriting (2) we get ,
-b/R² = a
(or) R² = b/a
(or) R² = 483.47
(or) R = 21.98mm = 22 mm

Thus the outer diameter must be at least 22mm to withstand the pressure due to braking,

Longitudinal stress = σ_l = P1(r)² / (R² - r²) = 44.912 kg/cm².

Design of the caliper is done thereafter using the following data.

Finite Element Analysis (FEA)

This model was analysed by applying the forces and pressure. Static structural analysis of the CAD model was carried out in ANSYS 17.0. A Structural analysis calculates deformations, stresses, and strains on model in response to specified constraints. Analysis provides the information about model.
For instance, a static analysis gives us if the material in our model will stand stress and if the part will break (stress analysis), where the part will break (strain analysis), and how much the shape of the model changes (deformation analysis).After the numerical calculations, all the parameters such as bore diameter, seal groove, mounting, etc. are decided and then the CAD modelling of the caliper was done using
SolidWorks 16.
Material selected for caliper is Al – 7075 T6.
The following parameters are required for the analysis of caliper design

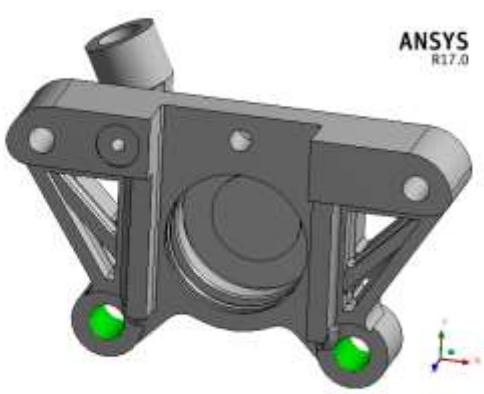
Sl. No.	Parameter	Value
1	Density	2700 kg/m³
2	Young’s Modulus	72 GPa
3	Ultimate Tensile Strength	572 MPa
4	Yield Tensile Strength	504 MPa

Meshing

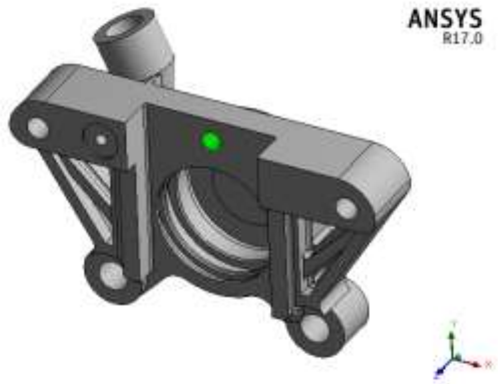
The different parameters like aspect ratio, skewness were considered to improve the mesh quality. Out of the different element types like hex dominant, sweep etc. Tetrahedral elements were considered as they capture the curvatures more accurately than in any other method. Proximity and curvature was used in order to ensure finer mesh along the curved regions and varying cross sections. The number of elements and nodes are 104107 and 174208 respectively.
Mesh size is taken as 1mm and refinement factor 2 was used in stress concentration zones.

Figure 5
Meshed Model of one caliper body in ANSYS 17.0

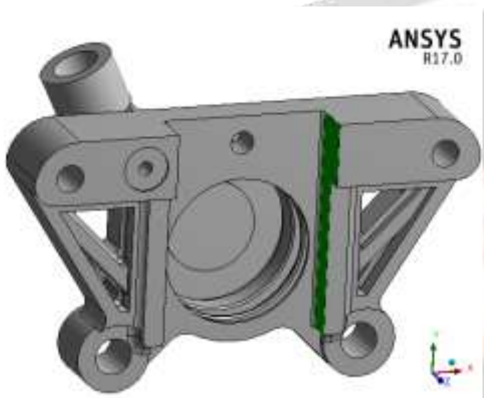
Following Loads are taken by the caliper body :
1. Hydraulic pressure applied on cylinder walls
2. Force generated at Pad Pin Hole during complete braking.
3. Forces on friction pad mounts that transferred form pad during complete braking.



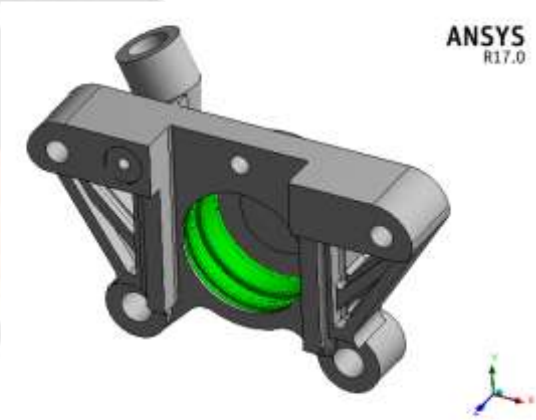
(a) Fixed Support at Mounting Points



(b) Force exerted at pin hole during braking (x- dir)



(c) Force on Pad Rest Area during braking (x – dir)

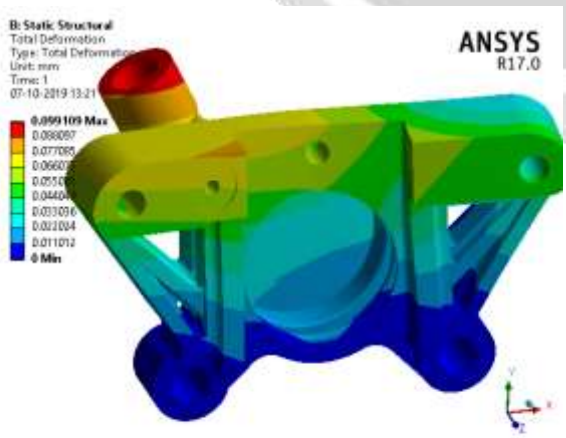


(d) Pressure exerted on cylinder walls

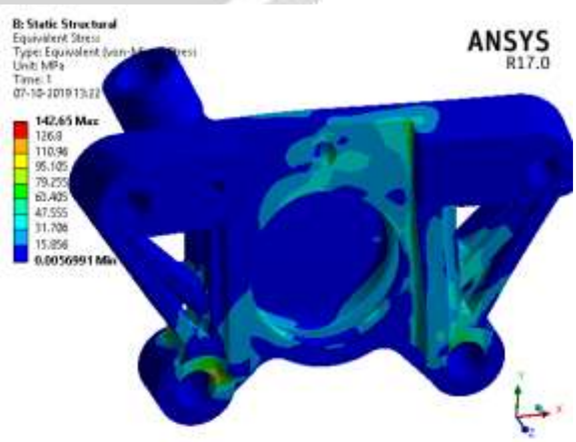
Figure 6
Boundary conditions for Static Structural Analysis

Analysis Results:

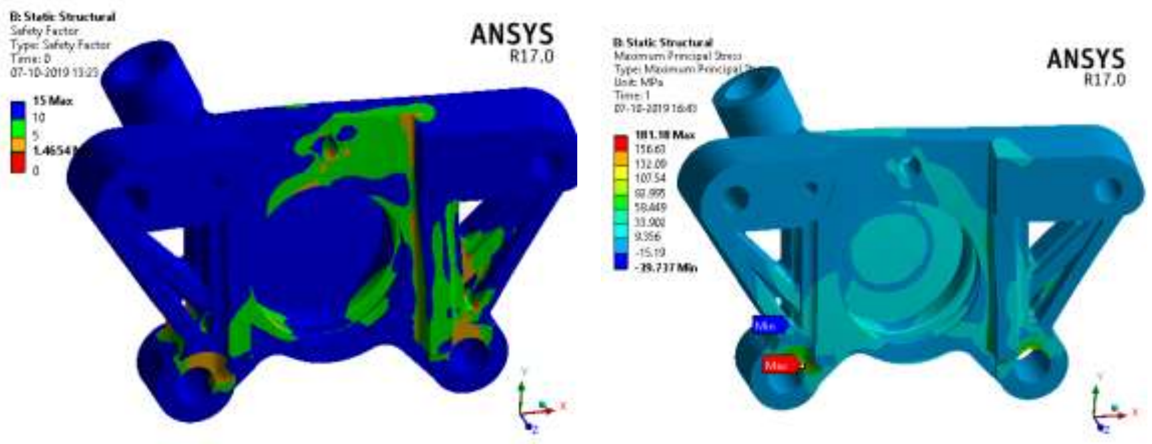
Results obtained from static structural analysis with ANSYS Workbench 17.0 are as shown in following figures:



(a) Total Deformation



(b) Equivalent stress distrbution



(c) Factor of Safety (for 30000 cycles) (d) Maximum Principal Stress Generated

Figure 7
FEA Results

CONCLUSIONS

This paper studies the conceptual design of a hydraulic dual piston fixed caliper. The various theories regarding types of calipers and seal groove geometry were also discussed. The factors affecting the seal and piston displacement was also discussed and the way it is applied into design was also shown. Material selection for caliper was discussed. The uniqueness of the design lies in –
(i) The caliper is lightweight, weighs 312 grams, where as OEM dual piston calipers weigh about 500 grams.
(ii) Cost reduction , as most of the customised calipers are single piece calipers, thus machining is complicated and takes time.
(iii) Provision of cooling ducts on caliper body for additional cooling advantage for brake disc.

FEA was done for the caliper model and stresses were kept in limit. Factor of safety was also found for 30000 cycles in order to analyse against fatigue failure.

BIBLIOGRAPHY

1. Rudolf Limpert (2011). Brake Design and Safety. Society of Automotive Engineers, Inc.
2. William D. Callister and Jr. David G. Rethwisch "Material science and engineering", Eighth Edition.
3. "Design of Machine Element Third Edition by V. B.Bhandari.
4. Okon D Anwana, Han cai, H.T. Chang "Analysis of Brake Caliper Seal Groove Design" , Delpi utomotive System.
5. T. Stolarski, Y. Nakasone & S. Yoshimoto (2006). Engineering Analysis with ANSYS Software. Elsevier Butterworth-Heinemann.
6. " Advanced Mechanics of Materials" by Dr. Kamal Kumar, Dr. R.C. Ghai