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Design and Analysis of a Brake Caliper

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ABSTRACT
Safety aspect in automotive engineering is of prime importance. Effective Braking system along with good suspension systems, good handling and safe cornering is very important for determining the performance of the vehicle. The objective of this work is to design, analyze and investigate the strength and stiffness of the brake calliper during braking operation using ANSYS Workbench 15.0This analysis is further used to identify the critical locations of low stiffness on the brake calliper and also aimed at evaluating the performance of brake calliper under severe braking conditions. Hence best suitable design is suggested based on the performance and strength criteria.

Keywords: *Brake calliper, Braking system, Analysis*

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I. INTRODUCTION

Braking system is an energy converting system that converts vehicle movement into heat while on application of clamping force using friction pads on brake rotor. This is done by applying pressure on back side of piston pushing the brake pads against the rotor disc causing frictional force at contact and inhibiting the motion of the vehicle. The components of a brake calliper are as follows:

1. Calliper body
2. Piston
3. Retraction seal
4. Scrapper seal
5. Friction pads
6. Bleed port
7. Fluid inlet port

Figure 1 Exploded View of Brake calliper

The main function of the caliper is to support the brake pads and the clamping force is applied by the piston. Important aspects of a caliper is low weight but at the same time high stiffness. High stiffness and an evenly distributed pressure on the pads are necessary to achieve optimal braking force. An evenly distributed pressure results in evenly heat distribution which is crucial for wear and to avoid noise which occurs by variations in disc temperature. These characteristics are a result from the choice of material, manufacturing precision and the design of caliper

Belhocine Ali and Bouchetara Mostefa (2013) [1], analysed the thermomechanical behavior of thedry contact between the brake disc and pads during the braking phase. The thermal-structural analyse is then used to determine the deformation and the Von Mises stress established in the disc, the contact pressure distribution in pads.

Anders Forsman and Mikael (2009) [2], investigated the possibility to improve the performance ofthe brake caliper for a GM project. The aim is to design a caliper with less amount of material but with the same stiffness. The delimitations are that the manufacturing costs should be unchanged and the design should work without modifications of the surrounding parts.

II. DESIGN PARAMETERS AND CALCULATIONS

The calculation and verification of braking force is a crucial step in the design process of an automobile as the braking system directly factors as a good control and safety feature in the product. While designing, the main objective is to generate more braking force than ideally required to account for inefficiencies in mechanical linkages and hydraulic systems.

The design methodology of brake caliper is as follows.

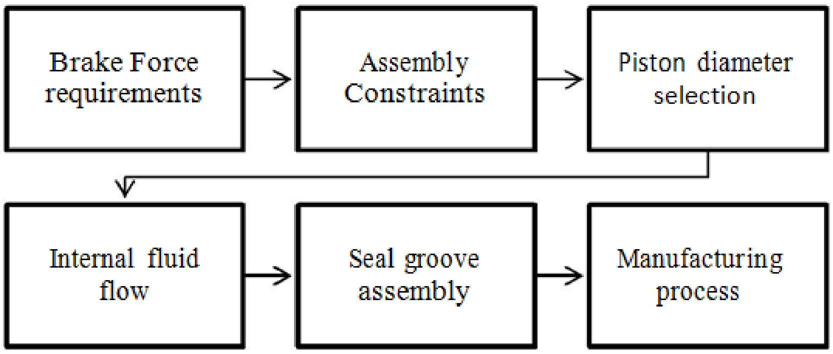

Figure 2 Methodology for design of caliper

III. MATERIAL SELECTION OF CALIPER

Caliper is a component of braking system which is used for applying the required torque on the rotor. The customised caliper housing must be lightweight and also the loads that will be coming on the housing.
In the graph of tensile strength vs. Density the aluminium materials are only allowed because aluminium is lightweight and higher grade of aluminium gives us higher strength to sustain under loading. From different materials, high grad e aluminium 7075 T6 is finalised.

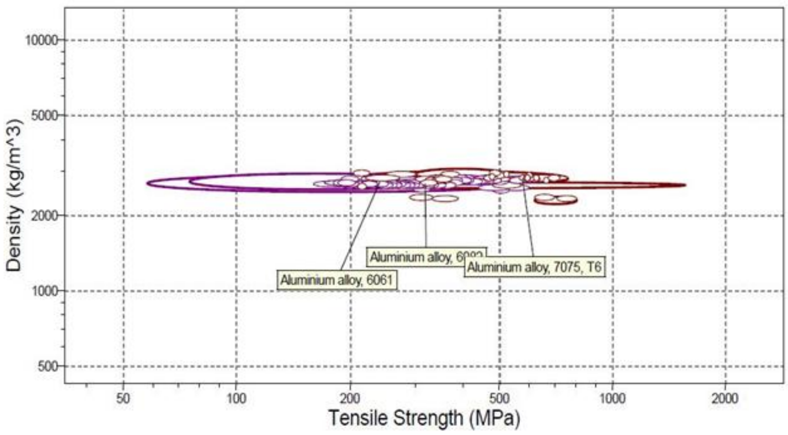

Figure 3 Ashby chart for material selection

IV. BORE DIAMETER CALCULATIONS

When the driver applies brakes, the pedal force gets converted into hydraulic pressure in the master cylinder. This pressure, which acts as an actuating force, is transferred through the brake fluid to the caliper mounted on the disc. Here the actuating force gets converted into the clamping force. Magnitude of this force depends upon the bore diameter and number of pistons in the caliper. The clamping force pushes the friction pads against brake rotor thereby generating a frictional force between them which is responsible for braking torque. The generated braking torque must be greater than the required braking torque to stop the vehicle. Required braking torque on a particular wheel is calculated from the load on the

$Fc = Tr/re \ X \ 1/\mu$

The above equation gives us the magnitude of clamping force which is applied on the rotor by the piston. The diameter and number of pistons can be decided by performing iterations based on the above equationand depending uponspace availability.

The piston diameter is nothing but the bore diameter of caliper. A clearance fit has to be provided between the piston and the caliper bore in the absence of any seals. A step is also provided at the bottom of the bore to prevent the piston from touching the bottom surface of the caliper and to increase the space for the brake fluid to apply the required pressure.

V. SEAL GROOVE GEOMETRY

The pressure in the brake fluid is lead through brake lines down to the caliper. The caliper is mounted on the brake corner and holds the brake pads. The cylinder in the caliper has a seal groove where a seal fits into. This seal prevents the brake fluid from leaking out between the cylinder and the piston. During brake apply, pressure forms inside the cylinder and pushes the piston and the brake pad out towards the disc and creates friction which generate braking torque. The seal groove has a special geometric design which helps the piston to retract after braking. The seal sticks to the piston and deforms with the piston travel, see figure 3. When the pressure is removed, the seal will strive to return to its origin shape and create a roll-back of the piston. This roll-back can be controlled depending on how the groove is designed geometrically. [2]

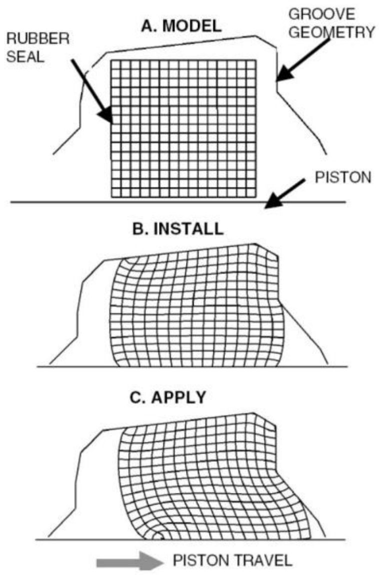

Figure 4 Deformation of seal in seal groove

VI. MODELING OF CALIPER

Modelling of caliper was done as per requirement of the piston diameter and assembly constraints in the wheel rim. Parametric modelling was used in modelling of left and right part of caliper which is symmetric.

Figure 5 CAD Model of Brake Caliper

VII. FINITE ELEMENT 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 CATIA V5. This model was analyzed by applying the forces and pressure. Static structural analysis of the CAD model was carried out in ANSYS 15.0. Following material parameters were considered.

Table 1 Properties of Al 7075

NO	Parameter	Value
1	Density	2700 kg/m^3
2	Young's Modulus	72 GPa
3	Yield Ten sile Strength	503 MPa
4	Ultimate T ensile Strength	590 MPa

Meshing

The different mesh parameters like aspect ratio, skewness were considered too improve the mesh quality. Out of the different element types like hex dominant, sweep etc. tetra 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.

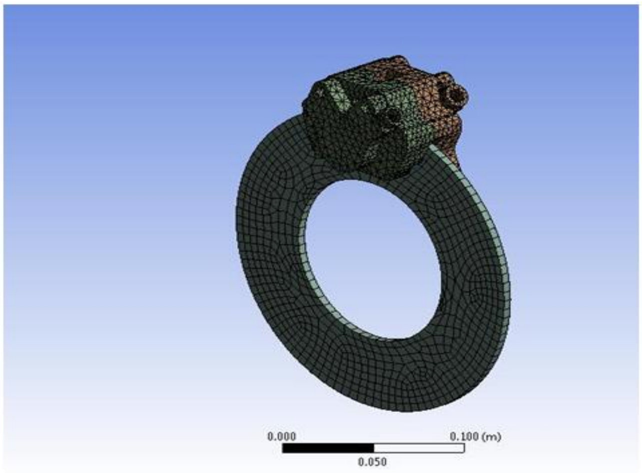

Figure 6 Meshed Model of a Brake Caliper

Caliper body is subjected to mainly following three loads:

1. Reaction on caliper due to the hydraulic pressure applied on piston
2. Reaction on the caliper body due to clamping force
3. Frictional force on pad, transmitted to the friction pad mounts.

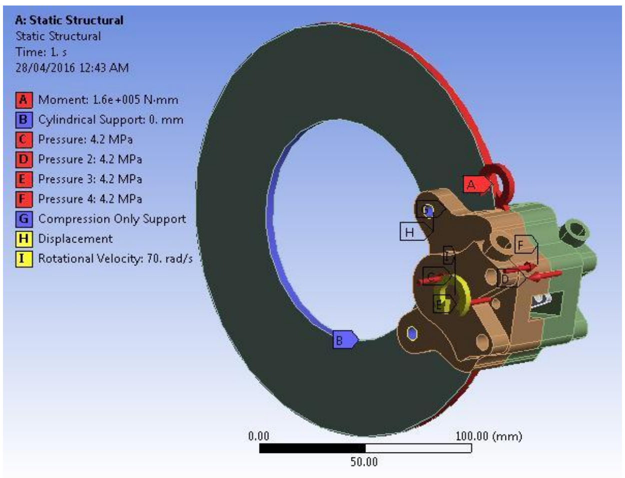

Figure 7 Loading Conditions for Brake Caliper

The piston diameter and the bore diameter are calculated according to required braking torque.
This magnitude of clamping force is applied on the rotor by the piston. T e diameter and number of pistons can be iterated according to equation depending upon the rim size i.e. space availability.

The piston diameter was selected to be 28 mm as per availability of rubber seal.The piston diameter is nothing but the bore diameter of caliper. There is clearance fit between the piston and the caliper bore in absence of any seals. A step is provided atthe bottom of bore to prevent the back side of piston from touching the bottom surface of caliper and to increase the space for fluid to apply pressure.

VIII. RESULTS AND DISCUSSIONS

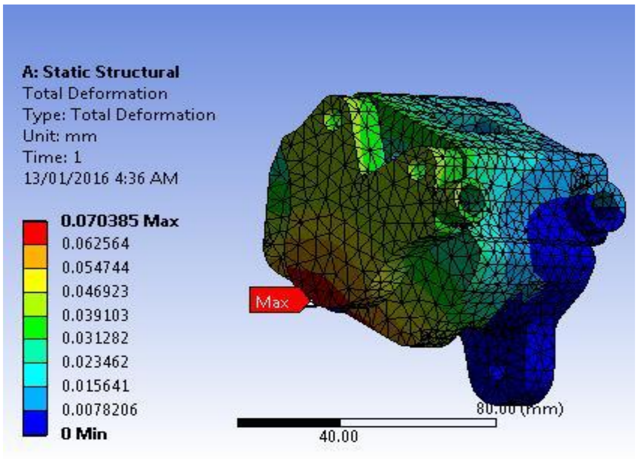

Figure 8 Total deformation of a brake caliper

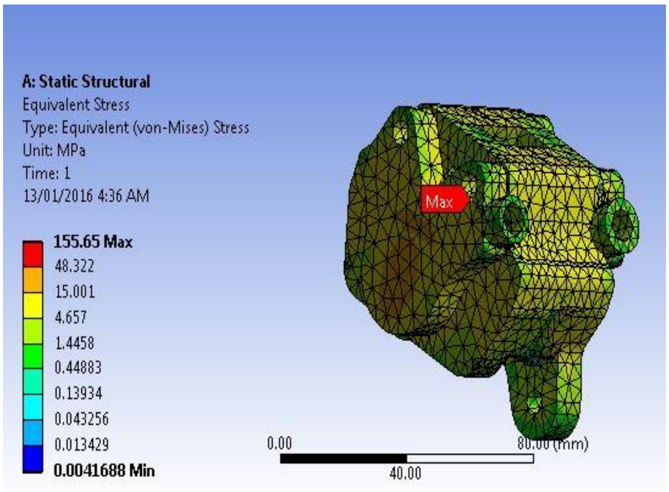

Figure 9 Equivalent stress (von-misses) of a brake caliper

Table 2 Deformation & Stress variations

δ_{max}mm	0.070385
σ_{max}(MPa)	155.65
FOS	3.25

The stress results show that factor of safety for the designed model is within limits Thermal stresses were neglected as their effect is negligible. The parameters decided could help in further lowering the manufacturing cost and weight.

IX. CONCLUSION

The following comments could be concluded:

1. Determination of the braking force is the most crucial aspect to be considered while designing any braking system. The generated braking force should always be greater than the required braking force.
2. The calculation of required clamping force helps us to decide the diameter and the number of pistons to be used. Space and assembly constraints are also an important factor while designing the caliper body.
3. The seal groove geometry is pivotal to the operation of the caliper as it allows the piston to retract after the required clamping force has been applied.

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