Design and Skeletal Anatomization Hydraulic Brake Cylinder

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Abstract— This project represents the detailed design procedure to moderate and to terminate the locomotion of the vehicle with the conversion of automobiles momentum into heat energy by originating friction between brakes pads and hydraulic rotor. The brake system which functions on the concept of hydraulic is known as hydraulic brake system. In hydraulic brake systems, hydraulic brake cylinders are used to originate pressure through a fluid. In the existing work, magnesium alloys and polypropylene materials are used for the design of hydraulic brake cylinders and reservoir respectively to minimize the weight to increase the momentum of the vehicle and to increase the mileage of the vehicle. The goal of this project is to attain less weight and strengthen the master cylinder with magnesium alloys in place of aluminium metal. Where polypropylene has good properties to use as reservoir material. The hydraulic brake cylinder is shaped in solid works and anatomization is executed using ANSYS.

Keywords: Hydraulic Brake Cylinder, Aluminium, Magnesium Alloys, Polypropylene, Ansys

I. INTRODUCTION

Developing a formula student car from concept to completion involves breaking the vehicle down into various subsystems that require knowledge in both mechanical and electrical engineering. In every subsystem's design, the braking is the greatest factor, as it produces the constraints that dictate how each subsystem can interface with overall system. The goal of a braking system is to control the vehicle in the way that maximum friction develops with road during driving along with the consideration of weight of the vehicle to decrease fuel rate consumption and to increase efficiency of the vehicle.

To help in achieve this goal in the available time with good performance, various tasks set. This includes research of the Formula students' rules, which were adopted from FSAE rules. The project aims to uncover any problems with the TEAM SUPER INGITE's previous year vehicle and then use these findings, coupled with appropriate research, to create a low weighted and strongest economical master cylinder in brake system that possesses to improve performance. To achieve these major aims, project work will focus on several basic objectives. Firstly, and most importantly, flaws present in the 2020 vehicle must be removed or improved upon; clearly it is important that the project improves on the past car in some way otherwise all work would be a waste of time. Hence in the proposed procedure, And the structural analysis was done using ANSYS software and SOLIDWORKS software for the development of Formula student car to maximize its performance.

A. Background

1) Software:

The designing procedure of master cylinder in the thesis will be heavily reliant of software. The software used for modelling master cylinder is SOLID WORKS software which is the student version for computer aided design. SOLID WORKS used to model a master cylinder with the rest of vehicle to see how they interact. And the analysis part is done by using ANSYS software to find structural, stress and pressure parameters.

B. Design motivation

And Go-kart is another event which motivated us to do this project which is purely based on the vehicle's performance with the lower weight. The main motto of this event is to make participate the students with lower weight and high-performance vehicles. As everyone knows that lower weighted vehicle gives good performance with economical fuel rate. So, we decide to decrease the weight of the vehicle which results in high-performance. As a result, we took this project in a smaller scale which is nothing but design of master cylinder with magnesium alloy.

In automobile cars, one of the most important parameters which maximize the performance of the vehicle is diminishing the heaviness of the vehicle. Fabricating the lower heaviness automobile car leads to use of a minimum fuel rate to enhance the performance. Generally, performance can be enhanced with the inclusion of power or rebate of weight or both. Nowadays, the requirement of a luminous vehicle is quite enormous which results to enhance its performance and maintain. To achieve less weight vehicles, many components need to be replaced by lighter weight material in which the brake master cylinder or hydraulic master cylinder is one of the components which is considered for the fabrication of less weighted material.

C. Classification of Braking System

The evolution of braking system from vintage carts to modern cars, from vintage carriages to modern trucks has given us various different purpose braking systems which are classified on the basis of various needs and purposes of an automobile vehicle.

1) On the Basis of Power Source:

The power source which carries the pedal force applied by the driver on brake pedal to the final brake drum or brake disc in order to decelerate or stop the vehicle the braking systems are of 6 types –

1) Mechanical brake system
2) Hydraulic braking system
3) Air or pneumatic braking system
4) Vacuum braking system
5) Magnetic braking system
6) Electric braking system

D. Types of brakes

Brake is a mechanical device which is used to convert momentum or kinetic energy of a vehicle into heat energy to retard or halt the motion of the vehicle by means of friction.

1) Mechanical brakes: Mechanical brakes are which act by generating frictional forces between two surfaces which moves against each other. The capacity of mechanical brakes depends upon the surface area of friction generating area and applied force on the lever. And mechanical brakes are used in heavy vehicles.
2) Hydraulic brakes: Hydraulic brakes are which converts the K.E into heat energy by the means of incompressible fluid with the working principle of pascals law. Master cylinder is a device which consists of a fluid reservoir, piston and returning spring and it is a device which is used to convert the applied force into pressure. When the lever is pressed then the piston tends to move the incompressible fluid in the master cylinder towards the drum and the piston retains its position with the help of returning spring after the relief of the lever.

Main components in hydraulic brakes are:

- Master cylinder
- Calliper
- Brake fluid
- Brake lines
- Fluid reservoir
- Pads

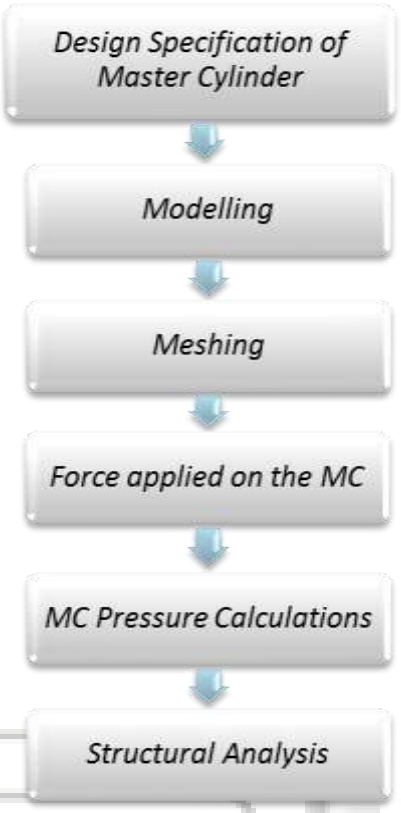
3) Pneumatic brakes: It is a type of frictional brake in which compressed air act as a medium to apply the pressure to the brake pad to halt the vehicle. It is used in large heavy vehicles, particularly those having multiple trailers which must be linked into the brake system, such as trucks, buses, tailers and semi-trailers, in addition to their using railroad trains.
   - Air brakes are mainly used in heavy vehicles like busses and trucks because hydraulic brakes fail to transmit high brake force through greater distance.
   - The chances of brake failure are less in case of pneumatic brakes.
   - High end cars these days are using air brakes system due to its effectiveness and fail proof ability.
4) Vacuum brakes: Vacuum brake is a type of brake which works via atmospheric pressure acting on the piston of vacuum cylinder. And the vacuum is taken from the intake manifold.
   - Vacuum brakes were used in old or conventional trains and are replaced with air brakes now days because of its less effectiveness and slow braking.
   - Vacuum brakes are cheaper than air brakes but are less safe than air brakes.
5) Electric brakes: It is a type of friction brake controlled by an electric current. When the electricity is in action, it will magnetize the brake magnet to attract to the drum face which actuates the arm and pushes the shoes against to the drum. It can be seen on medium duty trailers like caravans and consumer-grade car trailers. It is related to the electromagnetic track brake used in railways which also use electric current to directly control the brake force.

II. LITERATURE REVIEW

This survey includes the study of different research papers on brake calculations, design, analysis and material modification which may help to attain a much stronger, lighter and effective brake system.

1) Lane Eichhorn, Clifton E Owen, Ken Layne, Jack Erjavec. [1] dissertated their view on hydraulic brake cylinder, in all the Vehicles brake system was controlled by single master cylinder till 1967, after several makers added dual piston master cylinder for the better safety of the vehicle with certain limitations.
2) Daimlerchrysler. [2] introduced diagonally split hydraulic master cylinder in the year 1978 which is commonly used in all the major vehicles. Where front and rear wheels of the vehicles are connected in diagonal to the different master cylinder for the safety of the vehicle and the driver in case of failure of one of the master cylinders.
3) C. J. Buynacek and W. L. Winterbottom. [3] introduces the design and improvement of semi-solid metal aluminium master for vehicle-based applications and it also helps to continue for further research on reducing the weight and to develop the design by changing the material which is also helps on concentrating reduction of manufacturing cost through different technologies
4) Jeri S. Culp. [4] features numerous innovations and it has been developed mainly for the purpose of highway and recreational vehicles uses. To achieve less weight vehicles, many components need to be replaced by lighter weight material in which the brake master cylinder or hydraulic master cylinder is one of the components which is considered for the fabrication of less weighted material.
5) W. L. Green (1968) and Johnberninger (1973). [5]. Both utilized an energy approach to model a hydraulic cylinder cushion while Berninger approach included additional first principle equations similar to those used during the analysis conducted for the project detail in this report.
6) Esposito (2003). [6]. Hydraulic cylinder provide high power density for moving heavy loads, But if the cylinders are allowed to reach end of stroke at full speed, sudden deceleration can cause excessive impact. Therefore, a cushioning mechanism was designed to decelerate the cylinder piston and reduce the speed at which impact occurs.
7) Norvelle (1995). [7]. Cylinder cushions meter the flow leaving the cylinder case causing pressure to increase. When the area of the piston is exposed to this accumulating pressure, a force develops that oppose the motion of the piston-rod assembly causing deceleration. With the importance of accurately metering the fluid leaving the cylinder to create a resisting force, there is a value in predicting the pressure response, that is the cushion pressure as a function of time, generate when the fluid is metered by the cushioning mechanism orifice.

III. METHODOLOGY



A. Magnesium alloys:

Magnesium based alloys are the lightest and strongest metal which is found in today's era. Magnesium alloy are light metals like aluminium and strongest metals like titanium alloys. And the strength to weight ratio of this material is very high.

Due to good cast-ability, high strength and corrosive resistance AZ91 alloy is most predominantly used in cast magnesium alloy which contains large intermetallic compounds distributed along grain boundaries.

Element	Al	Zn	Mn	Si	Mg
Content	8.98	0.64	0.26	0.02	Bal

Table 3.1: Chemical composition of AZ91 magnesium alloy.

Aluminium is the most abundant metal in the Earth's crust (8.1%) but is rarely found uncombine in nature. It is usually found in minerals such as bauxite and cryolite. These minerals are aluminium silicates. Most commercially produced aluminium is extracted by the Hall–Héroult process. Aluminium has only one naturally occurring isotope, aluminium-27, which is not radioactive.

Properties	Units	Values
Density	Kg /m3	1810
Specific heat	J/kg k	1020
Thermal conductivity	W/m k	146
Melting heat	J/kg	3.7x10^5
Dynamic viscosity	Kg/m s	1.72x 10^-5
Boiling temperature	K	1380
Thermal expansion coefficient	1/K	1.1 x 10^-5
Liquidus temperature	K	870
Solidus temperature	K	740
Surface tension	N/m	-0.64 x 10^-3

Table.3.2 – Properties of AZ91 magnesium alloy.

1) Key Properties of Magnesium alloys:

– Lightweight
– Low density (two thirds that of aluminum)
– Good high-temperature mechanical properties
– Good corrosion resistance

2) *Polypropylene*:

Polypropylene is in many aspects similar to polyethylene, especially in solution behaviour and electrical properties. The methyl group improves mechanical properties and thermal resistance, although the chemical resistance decreases. Polypropylene belongs to the group of polyolefins and is partially crystalline and non-polar. Its properties are similar to the polyethylene, but it is slightly harder and more heat resistant. It is a white, mechanically rugged material and has a high chemical resistance. The methyl group improves mechanical properties and thermal resistance, although the chemical resistance decreases. The properties of the PP depend on the molecular weight and molecular weight distributions, crystallinity, type and proportion of comonomer and the isotacticity.

Property	Value
Density [g/cm³]	0.9
Poisson's ratio [-]	0.42
Thermal expansion [µm/m-°C]	100 – 180
Thermal Conductivity [W/m-K]	0.15
Specific Heat Capacity [J/g-°C]	1.8
Heat transfer Coefficient [W/m2K]	24.5
Friction Coefficient [-]	0.1

Table 3.3: Material properties of PP.

B. Introduction to SolidWorks:

Solid works is a solid modeler which uses a parametric feature approach is initially developed by Creo/Pro engineer to generate models and assembly parts. The geometry of the models is determined by constraints values which is referred as parameters. Parameters might be in the form of line, circle, numeric, tangents, concentric, etc, Solid works responds to the changes which the designer intent to create.

In solid works usually model can be generated with 2D sketch which has arcs, points, lines, splines, etc., And to get the size and location of the geometry, dimensions were added to the model. The dimensions in the sketch can be controlled independently. Where the parametric nature of solid works means that the dimensions and relations drive the geometry. Solid works also includes additional features like gear and cam follower mates, which allows to produce accurate rotational movement of an actual gear.

Finally drafting of a model can be created either from parts modelling or assemblies. Where the views, dimensions and tolerances can be added easily to the drawing as needed. And the main advantage of the solid works is it can be learned in quick time as it has many similar icons like windows function such as open, cut, print and save. While

designing a model solid works makes us to visualise the three dimensional of that models. Basically, solid works is structured in three basic types: part mode, assembly mode and drawing mode. First, we need create some parts which can be done by part mode. Then we go for assembly which is done with many parts known as sub-assemblies.

C. Design Specification of Master Cylinder:

Master Cylinder Piston Diameter: 15.7mm
MC material: Magnesium alloy

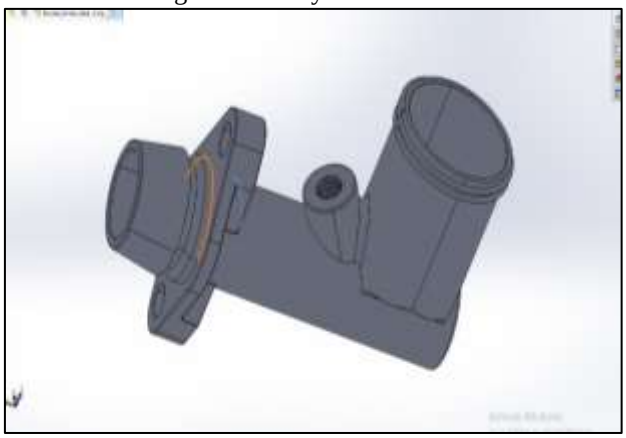


Fig. 4.1: 3D Model of Master Cylinder.

IV. ANALYSIS

A. Introduction to ANSYS:

ANSYS is a general-purpose finite element modelling and analysis packages for numerically solving a wide range of mechanical problems. These problems includes: static / dynamic structural analysis, heat transfer and fluid problem, as well as acoustic and electro-magnetic problems.

ANSYS is a finite element analysis software package which is used by engineers virtually all over the world in engineering field such as:

- Structural Analysis.
- Thermal Analysis.
- Fluid Analysis (CFD, Acoustics and other fluid analysis).
- Low and high frequency electromagnetics.

Computational fluid dynamics (CFD) is to determine the flow distributes and temperature in a fluid. ANSYS can simulate laminar and turbulent flow, compressible and incompressible flow, and multiple species. Generally, a finite element solution may be broken into the following three stages:-

1) Pre-processing
2) Solution
3) Post-processing.

B. Procedure for ANSYS analysis

Static analysis is used to determine the displacements, stresses, strains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading in response conditions are assumed. The kinds of loading that can be applied in a static analysis include externally applied forces and pressures, steady state inertial forces such as gravity or rotational velocity imposed non-zero) displacements, temperatures (for thermal strain) A static analysis can be either linear or nonlinear. In our present work we consider linear static analysis.

Properties	Units	Values
Density	Kg/m^3	1810
Thermal conductivity	W/mK	72.7
Poisson's ratio	-	0.35
Yield strength	MPa	160
Tensile strength	MPa	250
Elastic Modulus	GPa	44.8
Shear Modulus	GPa	17
Yield tensile strength	MPa	135
Yield compression strength	MPa	230
Ultimate tensile strength	MPa	210
Ultimate compression strength	MPa	327

Table 5.1: Input Parameters of the MC with Magnesium alloy for analysis.

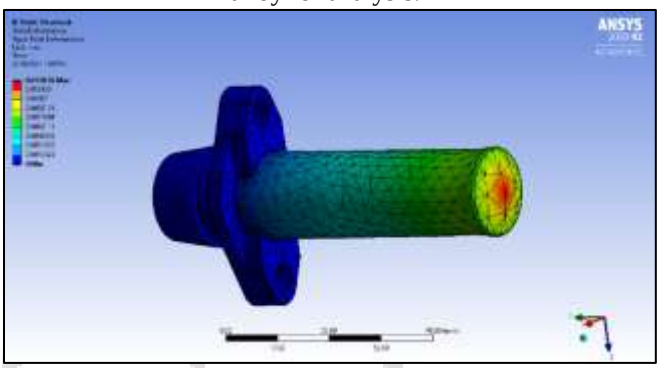


Fig. 5.1: Total Deformation of Master Cylinder Model.

Deformation is the change in the metric properties of a continuous body, meaning that a curve drawn in the initial body placement changes its length when displaced to a curve in the final placement. If none of the curve changes length, it is said that a rigid body displacement occurred. And the maximum deformation occurred in this body is 0.10136 mm under 2000 N applied force.

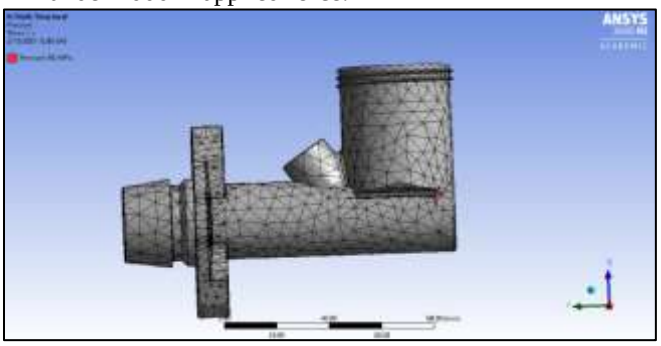


Fig. 5.2: Pressure analysis for the given Model.

It is the amount of force applied is perpendicular to the surface of objects per unit area. And the maximum pressure generated in this MC when 2000 N force is applied is 4180553.347 N/m^2.

V. CALCULATIONS

A. Torque calculation:

Pedal ratio = 5:1
Master cylinder piston diameter = 15.7 mm
Calliper piston diameter = 35 mm
Hose pipe internal diameter = 7 mm
Rotor diameter = 150 mm (front), 200 mm (rear)

Rotor thickness = 3 mm
Coefficient of friction = 0.35
Pedal force F = 30 kgs = 294.3 N
Front:
Pedal force = Applied force x 9.81
= 16.5 x 9.81 = 161.865 N
Moment = Pedal force x Pedal ratio
= 161.865 x 5
= 809.325 N
Pressure at master cylinder
= 809.325/ 0.785 x 0.0157^2 = 4180553.347 N/m^2
Force at calliper
Fc= Pressure at MC x Area of the calliper
= 4180553.347 x 0.785 x 0.035^2
= 4022.1636N
Clamping force or Braking force = No. of frictional faces x No. of pistons x Coefficient of friction x Force at calliper.
= 2 x 2 x 0.35 x 4022.1636
= 5631.0291 N
Braking torque = Braking force x Rotor diameter
= 5631.0291 x 0.140
= 394.1720 N-m
Rear:
Pedal force on rear wheel = Applied force x 9.81
= 13.5 x 9.81 = 132.435 N Moment = Pedal force x Pedal ratio
= 132.435 x 5
= 662.175 N
Pressure at rear master cylinder = 662.175/ 0.785 x 0.0157^2
= 3420452.739 N/m^2
Force at rear calliper = Pressure at MC x Area of the calliper
= 3420452.739 x 0.785 x 0.035^2
= 2106.151162N
Clamping force or Braking force = No. of frictional faces x No. of pistons x Coefficient of friction x Force at calliper.
= 2 x 4 x 0.35 x 2106.151162
= 5897.223 N
Braking torque = Braking force x Rotor diameter
= 5897.233x 0.200
= 589.7223 N-m
Total torque = Front torque + Rear torque
= 394.1720 + 589.722
= 983.8943N-m
Braking force at front tires = Braking torque at front wheels / Radius of the wheels
= 394.172/ 0.23749
= 1659.7414 N
Braking force at rear tires = Braking torque at rear wheels / Radius of the wheels
= 589.7223 / 0.23749
= 2483.1458 N

VI. RESULT

Computed master cylinder design of formula student car in the ANSYS software in dynamic conditions gives the dynamic and parameters of the vehicle which are finalised. Where the final obtained results of various parameters, dimensions and values of master cylinder are tabulated.

Parameters	Values	Units
Total load applied	2000	N
Maximum total deformation	0.10136	mm
Maximum Equivalent elastic strain	0.0012563	mm/mm
Pressure generated	4180553.347	N/m^2
Maximum von-mises stress	20.115	MPa

Table 7.1: Resulted parameter of master cylinder.

VII. CONCLUSION

Braking system is designed to moderate and to terminate the locomotion of vehicle with the conversion of automobile momentum into heat energy by originating friction between the brake pads and hydraulic rotors. The less weight and strengthen of master cylinder with magnesium alloys in place of aluminium alloys was proved through structural analysis. Hence the master cylinder with magnesium alloys is stronger and lower in weight ratio than aluminium.

1) The weight of Master Cylinder made up of Magnesium alloy is less than Master cylinder made up of Aluminium.
2) The Master Cylinder made up of Magnesium alloy can bear more stress than master cylinder made up of Aluminium.

REFERENCES

[1] Lane Eichhorn, Clifton E Owen, Ken Layne, Jack Erjavec, 2001, explains their view on single piston master cylinder and dual piston master cylinder.
[2] Daimlerchrysler, introduced about the diagonally split master cylinder.
[3] semi-solid Aluminium metal Master Cylinders written by C.J.Buynacek and W.L.Winter bottom.
[4] Lightweight Brake System written by Jeri S. Culp
[5] Green, W. L. "Cushioning for hydraulic cylinders." Hydraulics & Pneumatics (1968): 100-04 which explains the utilized energy approach to model a hydraulic cylinder.
[6] Esposito, A. Fluid Power with Applications (6th ed.). Upper Saddle River, N.J.: Prentice Hall, (2003).
[7] Norvelle, F. Fluid Power Technology. Minneapolis/St. Paul: West Pub, (1995).
[8] Thomas D. Gillespie. Fundamentals of Vehicle Dynamics. Society of Automotive Engineers.
[9] FORMULA BHARATH RULE BOOK 2021 by Formula Bharath hosted by Curiosum Tech Private Limited.

