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Design & Analysis of Master Cylinder of Hydraulic Braking System using ANSYS

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Abstract*—Master cylinder is a component of hydraulic braking system and it is just a simple piston inside a cylinder. Master cylinder is the key element of braking system which initiates and controls the braking action. A reservoir is attached to the master cylinder to store brake fluid. A master cylinder having a reservoir and a cylinder formed from a single piece of molded material. The objective of the present work is to minimize the weight to increase mileage in case of general road cars and to increase the speed of the vehicle in case of sports cars. Saving grams at different parts in a car helps us in saving some kilograms at the end of the design. The plastics have good elastic properties and are strong enough to use for master cylinder. The use of plastics in the manufacturing of master cylinder reduces the weight of the master cylinder. The master cylinder is modeled in PRO-E and the analysis is carried using ANSYS work bench. The automobile components like master cylinder can be easily modeled in PRO-E and can be easily analyzed using ANSYS.

***Index Terms*— Hydraulic braking system, Master cylinder, Pro-E, ANSYS.**

I. INTRODUCTION

Braking system is a means of converting momentum into heat energy by creating friction in the wheel brakes. The braking system which works with the help of hydraulic principles is known as hydraulic braking systems. The braking system used most frequently operates hydraulically, by pressure applied through a liquid. These are the foot operated brakes that the driver normally uses to slow or stop the car. Hydraulics is the use of a liquid under pressure force or motion, or to increase an applied force. Our special interest in hydraulics is related to the actions in automotive systems that result from pressure applied to a liquid. This is called hydraulic pressure. Since liquid is not compressible, it can transmit motion. A typical braking system includes two basic parts. These are the master cylinder with brake pedal and the wheel brake mechanism.

The other parts are the connecting tubing, or brake lines, and the supporting arrangements. Braking action starts at the brake pedal. When the pedal is pushed down, brake fluid is sent from the master cylinder to the wheels. At the wheels, the fluid pushes brake shoes, or pads, against revolving drums or disks. The friction between the stationary shoes or pads and the revolving drums or disks slows and stops them.

1.1 Master Cylinder

Master cylinder is a component of hydraulic braking system and it is just a simple piston inside a cylinder. Master cylinder is the key element of braking system which initiates and controls the braking action. A reservoir is attached to the master cylinder to store brake fluid. A master cylinder having a reservoir and a cylinder formed from a single piece of molded material. Master cylinder is a component of hydraulic braking system and it is just a simple piston inside a cylinder. Master cylinder is the key element of braking system which initiates and controls the braking action. A reservoir is attached to the master cylinder to store brake fluid. A master cylinder having a reservoir and a cylinder formed from a single piece of molded material.

The master cylinder displaces hydraulic pressure to the rest of the brake system. It holds the most important fluid in your car, the brake fluid. It actually controls two separate subsystems which are jointly activated by the brake pedal. This is done so that in case a major leak occurs in one system, the other will still function. The two systems may be supplied by separate fluid reservoirs, or they may be supplied by a common reservoir. Some brake subsystems are divided front/rear and some are diagonally separated. When you press the brake pedal, a push rod connected to the pedal moves the "primary piston" forward inside the master cylinder. The primary piston activates one of the two subsystems. The hydraulic pressure created, and the force of the primary piston spring, moves the secondary piston forward. When the forward movement of the pistons causes their primary cups to cover the bypass holes, hydraulic pressure builds up and is transmitted to the wheel cylinders.

When the brake pedal retracts, the pistons allow fluid from the reservoir(s) to refill the chamber if needed. Electronic sensors within the master cylinder are used to monitor the level of the fluid in the reservoirs, and to alert the driver if a pressure imbalance develops between the two systems. If the brake light comes on, the fluid level in the reservoir(s) should be checked. If the level is low, more fluid should be added, and the leak should be found and repaired as soon as possible.

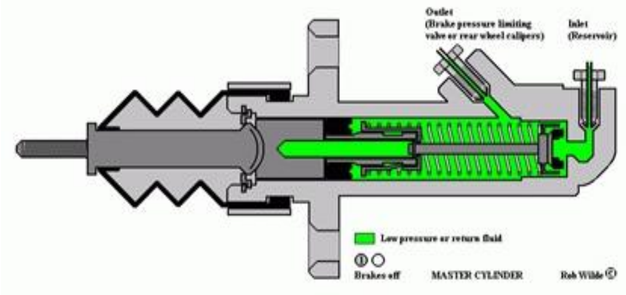

Figure 1: Master cylinder sectional view

1.2 Working of Master Cylinder

When the brakes are not applied, the piston cups of the primary and secondary pistons are positioned between the inlet port and the compensating port. This provides a passage between the cylinder and reservoir tank.

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The secondary piston is pushed to the right by the force of secondary return spring, but prevented from going any further by a stopper bolt. When the brake pedal is depressed, the primary piston moves to the left. The piston cup seals the compensating port blocking the passage between the primary pressure chamber and the reservoir tank. As the piston is pushed further, it builds hydraulic pressure inside the cylinder and is applied or transmitted to the wheel cylinders in that circuit. The same hydraulic pressure is also applied to the secondary piston. Hydraulic pressure in the primary chamber moves the secondary piston to the left also. After the compensating port of the secondary chamber is closed, fluid pressure builds and is transmitted to the secondary circuit.

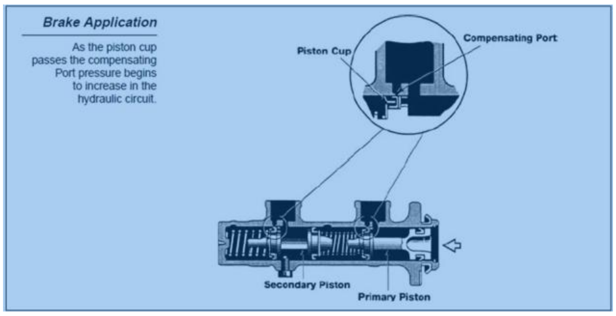

Figure 2: working of master cylinder-brake application

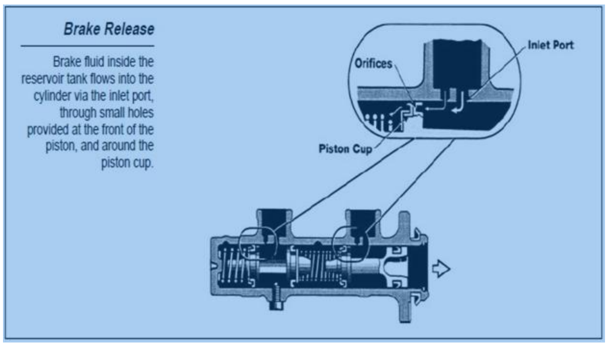

Figure 3: working of master cylinder-brake release

1.3 Design Considerations Of Master Cylinder

The basic information about brake system and its master cylinder, function, purpose, working principle, different shape and size of master cylinder, failure considerations has been taken from automotive brake system. The work done by brake system parts manufacturers tells that cost mold brake master cylinder made of cast iron was used universally in all the old car and light trucks and after that there has been increased research done on improving the mileage of the vehicle by reducing the weight. The research made a way to concentrate on reducing the weight of brake master cylinder by changing the materials. The manufacturers came up with new idea of composite master cylinder having integral body made of aluminum and reservoir made of plastic material and thus reducing the weight when compare to cost mold master cylinder made of cast iron. Those manufacturers are concentrating on reducing weight of master cylinder by changing the material and by changing the type of manufacture. This information gives basic steps for this project in taking reduction of weight further and considering plastic material to design brake master cylinder.

The second edition of brake design and safety gives basic design considerations to design safer brakes and its components. The standard of quality of brake technology as changed over the last two decades. The new design can only be achieved through proper research, through the use of sound engineering concepts and testing the results of small design changes. The information provided by the author has helped in considering engineering design concepts, safety considerations, material selection, guides, standards and practices for the project.

1.4 Polypropylene

Polypropylene is a very versatile material. It offers a great combination of properties such as lightweight, strong, high heat resistance, as well as stiffness and flexural retention. Among these and many other great properties, polypropylene is easily fabricated. Polypropylene can be subjected to a wide range of fabrication methods and applications. Polypropylene, also known as polypropene, is a thermoplastic polymer used in a wide variety of applications including automobile parts, packaging and labeling, textiles, stationery, plastic parts and reusable containers.

Polypropylene is a strong, lightweight thermoplastic that offers outstanding toughness, rigidity, and resistance to thermal deformation. Fabricators and designers value these characteristics and have come to consider polypropylene one of the most satisfactory thermoplastic resins for a wide range of applications. This unique material can be steam-sterilized or autoclaved without damage and resists environmental Stress-cracking when subjected to most chemical tests.

Several characteristics of polypropylene enable thin section oriented moldings to have virtually unlimited flex life, making it an excellent material for integral hinges in molded parts. These properties include Fatigue resistance, Ultimate tensile strength and Ultimate elongation. Polypropylene is highly responsive to injection speed and pressure and sets up quickly in the mold, enabling molders to attain high production rates. This combination of performance properties gives polypropylene a position in the injection molding field that is unique among thermoplastics. Polypropylene also demonstrates excellent chemical resistance, good abrasion resistance, good dimensional stability, and a high surface gloss on finished pieces. The versatility of this polymer makes it particularly well suited for film and fibers requiring superior strength, optical qualities, grease resistance, and moisture barrier properties.

1.5 Properties Of Polypropylene

1.5.1 Machining Properties

The machine ability of polypropylene is excellent. It may be processed on any standard machine shop equipment. Sometimes a coolant is required.

1.5.2 Density And Specific Gravity

Specific gravity, similar to relative density, is a ratio of the weight of a certain volume of material to an equal volume of water at 23°C. Determining the specific gravity of a material is done by weighing the sample in air then weighing it again, submerged in distilled water. These two weights will be entered into a formula where the specific gravity can be found. Relative Density/Specific Gravity of polypropylene is 0.095

1.5.3 Tensile Strength

Tensile strength is determined through tensile testing, which is a measurement of how much force a plastic can withstand before fracturing or breaking. Throughout the tensile testing, information such as brittleness or ductility of a material is revealed. This information is used when designing parts to be absolutely positive that the part will withstand all environmental forces it will encounter. A stress vs. strain graph, created from the tensile test, is commonly used to find out the materials tensile strength at its yielding point and its tensile modulus. Tensile or Yield strength of polypropylene is 5,000 psi

1.5.4 Tensile Modulus

The tensile modulus is a ratio of stress to elastic strain in tension. The tensile modulus of different resins may be acquired through tensile test. Tensile Modulus of polypropylene is 1.9 G Pa

1.5.5 Elastic Modulus

The elastic modulus measures the stiffness of a material, which is extremely important when it comes to designing of products. When in flex, measurements of how much force the material can withstand before deforming are taken. Elastic Modulus in Flex of polypropylene is 1.7 - 2.5 G Pa

1.5.6 Hardness

When measuring the hardness of materials, the Rockwell Hardness Test is used. The hardness is determined by penetrating the material with an indicator on a hardness testing machine. The further the indicator penetrates the sample, the larger the number measured, and the harder the material. Hardness of polypropylene is 80 - 110 (R)

1.5.7 Thermal Conductivity

Thermal conductivity is the rate at which heat is transferred through a section of material. When it comes to materials which are exposed to the most extreme temperatures, the measure of heat flow through a material is a testing essential. The molecular make-up, thickness, and density of a material, all directly relate to its thermal conductivity. Thermal Conductivity 2.8 of polypropylene is W/m K.

II. MODELING USING PRO-E

Pro /ENGINEER (Pro/E) is a program that is used to create precision three dimensional computer models. The 3-D parts created on Pro /E use a technique known as solid modeling, (as opposed to wire frame or surface modeling). Other important descriptors used to classify Pro/E include: feature-based, associative, and constraint (or parametric)-based. Pro /E is a fully parametric CAD program This means that the geometry of features (e.g., holes, slots) on a part have to be fully specified in terms of size, shape, orientation, and location. This specification allows the user to write equations (i.e., relations) which decribe how features on individual parts or multiple parts should relate to each other. For example, in an engine, if the diameter of the piston is increased or decreased, the corresponding engine block is automatically modified to match the specifications of the new piston. For the student, full parametrics means that you must have a strategy before you start modeling of what features you want and how you want to constrain them within the part. The specifications of the standard cylinder used for the present study are given in the following table.

Table 1: specifications for cylinder

Name	Symbol	Units	Dimension
Reservoir outer diameter	D_o	mm	75
Reservoir inner diameter	D_i	mm	69
Thickness of reservoir	T	mm	3
Height of reservoirs	H	mm	88
Cylinder outer diameter	d_o	mm	33.4
Cylinder inner diameter	d_i	mm	25.4
Thickness of Cylinder	t	mm	4
Height of Cylinder	h	mm	148.5

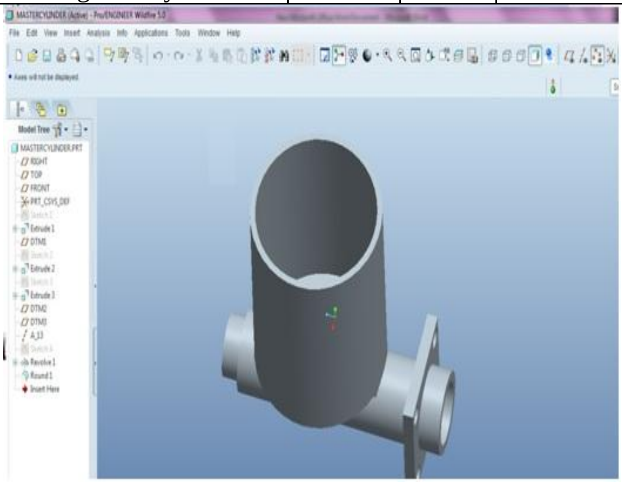

Figure 4 Master cylinder model designed in pro-E

2.1. Area, Volume & Mass For Aluminium Master Cylinder

The overall weight of the aluminium master cylinder is measured, which is 0.355kg. The formulae and calculations for weight of the aluminium master cylinder are given below.

1. Area A = πR2
   A = 0.073 m2
2. Volume V = πR2h
   V = 1.309×10-4 m3
3. Mass m = density × volume
   m = 0.355 kg

2.2. Area, Volume & Mass For Plastic Master Cylinder

The overall weight of the plastic master cylinder is measured, which is 0.355kg. The formulae and calculations for weight of the plastic master cylinder are given below.

1. Area A = πR2
   A = 0.073 m2
2. Volume V = πR2h
   V = 1.309×10-4 m3
3. Mass m = density × volume
   m = 0.124 kg

2.3. Comparing The Results

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Table 2: Results Comparison

Type of cylinder	Mass kg	Density kg/m^3
Aluminium master cylinder	0.355	2710
Plastic master cylinder	0.124	946

III. FINITE ELEMENT ANALYSIS

The finite element method is a numerical technique for solving problems which are described by partial differential equations or can be formulated as functional minimization. A domain of interest is represented as an assembly of finite elements. Approximating functions in finite elements are determined in terms of nodal values of a physical field which is sought. A continuous physical problem is transformed into a discretized finite element problem with unknown nodal values. For a linear problem a system of linear algebraic equations should be solved. Values inside finite elements can be recovered using nodal values.

The way finite element analysis obtains the temperatures, stresses, flows, or other desired unknown parameters in the finite element model are by minimizing an energy functional. Energy functional consists of all the energies associated with the particular finite element model. Based on the law of conservation of energy, the finite element energy functional must equal zero.

The finite element method obtains the correct solution for any finite element model by minimizing the energy functional. The minimum of the functional is found by setting the derivative of the functional with respect to the unknown grid point potential for zero.

Thus, the basic equation for finite element analysis is:

$$\partial f/\partial p = 0$$

Where F is the energy functional and p is the unknown grid point potential (In mechanics, the potential is displacement) to be calculated.

This is based on the principle of virtual work, which states that if a particle is under equilibrium, under a set of a system of forces, then for any displacement, the virtual work is zero. Each finite element will have its own unique energy functional.

Table 3: properties of materials

MATERIAL	YOUNGS MODULUS	POISSON'S RATIO
Aluminium	70000 N/mm^2	0.3
polypropylene	2000 N/mm^2	0.28

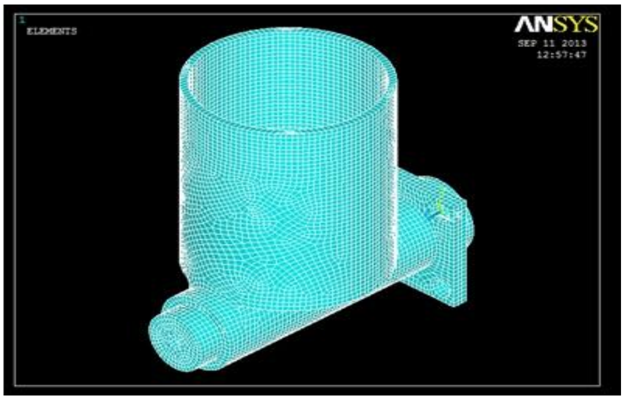

Figure 5: meshed model for brake master cylinder.

3.1. Results From Ansys

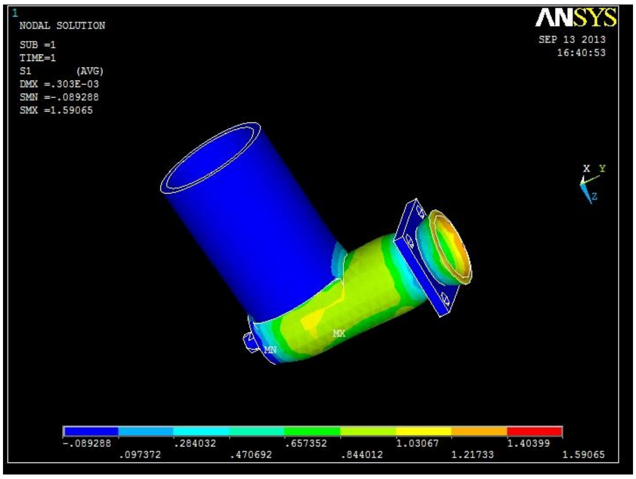

Figure 6: Principal stress on Aluminium master cylinder

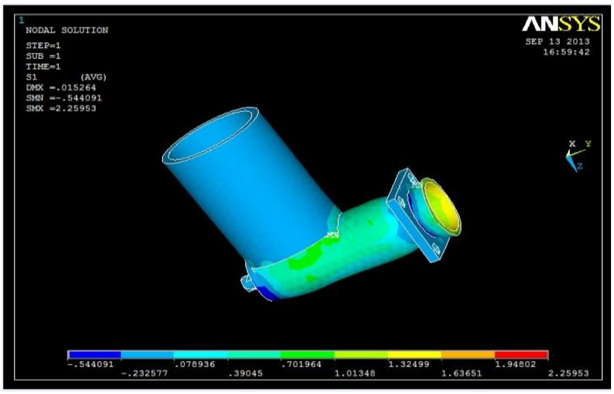

Figure 7: Principal stress on Polypropylene master cylinder

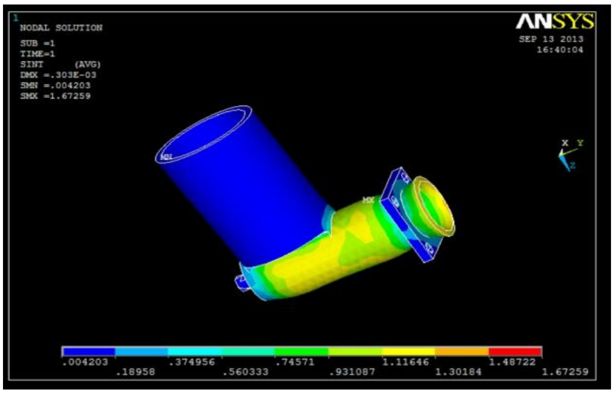

Figure 8: Stress intensity on aluminium master cylinder

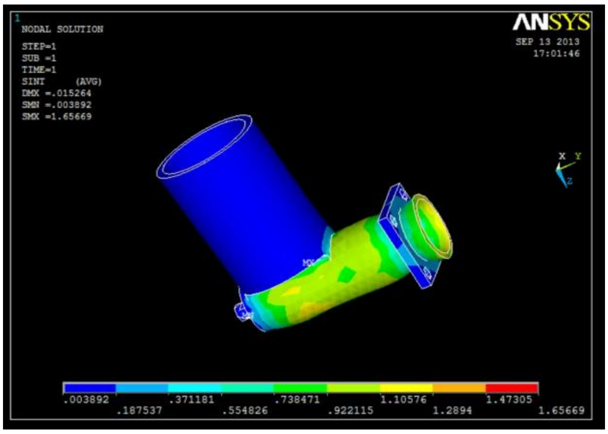

Figure 9 Stress intensity on Polypropylene master cylinder

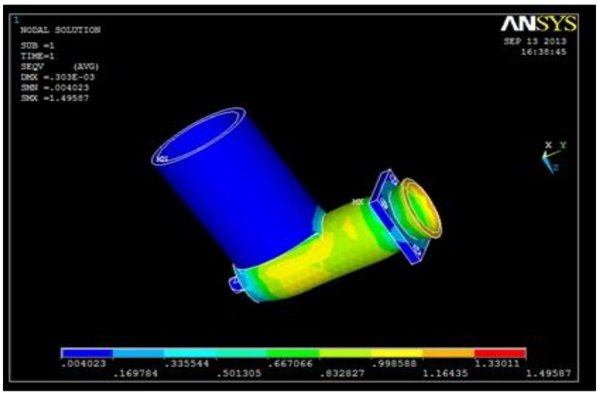

Figure 10: Stress on Aluminium master cylinder

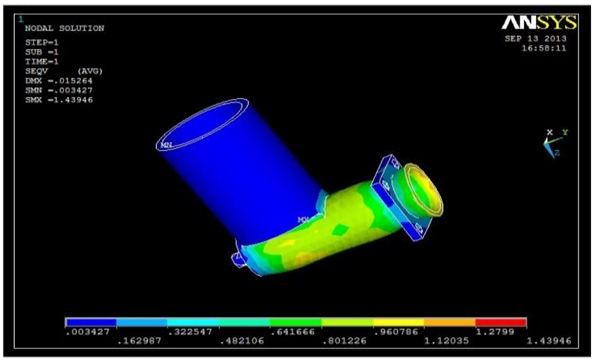

Figure 11: stress on polypropylene master cylinder

3.2. Comparision Of Results

For a pressure 3.95 N/mm^2 approximately equal to 4 N/mm^2, the maximum stress acting on the surface of polypropylene cylinder is 2.25953 N/mm^2, which is slightly higher than the maximum stress that acts on the surface of aluminium master cylinder, which is 1.67259 N/mm^2. Since the maximum stress acting the surface of cylinder is very less compare to the ultimate strength of that material, the polypropylene material can easily withstand the pressure.

IV. CONCLUSION

In this Project the design and analysis of plastic and aluminium master cylinder are performed. And it is concluded that, the plastic master cylinder is more advantages for Automobiles. The following conclusions were made:

- The weight of master cylinder made up of polypropylene i.e. 0.124 kg is less than master cylinder made up of Aluminium i.e. 0.355 kg
- The stress induced in master cylinder made up of polypropylene material is more when compared with that of master cylinder made up of Aluminium material but the stresses induced in polypropylene master cylinder is very less compare to the ultimate strength of that material.

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