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DESIGN ANALYSIS AND 3D PRINTING OF ANTI FLUID BRAKING SYSTEM

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ABSTRACT

The braking system in automobiles plays a critical role in ensuring safety and control during motion. This system converts kinetic energy into heat energy to slow down or halt the vehicle's movement. Typically comprising components such as brake pads, rotors, calipers, and brake fluid, it operates through hydraulic pressure transmission. When the driver applies force to the brake pedal, hydraulic fluid is pressurized, forcing brake pads to clamp onto the rotating brake discs, creating friction and decelerating the vehicle. Advanced systems often incorporate anti-lock braking (ABS) and electronic stability control (ESC) mechanisms to enhance effectiveness and prevent skidding or loss of control in adverse conditions. Continuous advancements in materials, design, and electronic integration continue to refine braking systems, prioritizing safety, reliability, and efficiency.

Effective braking is a critical factor determining the performance of any vehicle. With enhancement in the performance, need of an effective braking system increases. This Project work focused on the Design Analysis and 3D Printing of Anti Fluid Braking System, an optimized new mechanism and design of a brake caliper which ensures reduced size of wheel assembly, reduced weight and effective braking. This mechanism can be used in all types of vehicles without compromising its strength, stiffness and low piston drag. The main highlight of this system is that, it prevents the brake failure by developing advances in the braking system.

Keywords: Anti-fluid mechanism, Hydraulic brakes, Advancements in braking system.

1. INTRODUCTION

1.1 Preamble

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 released from the front face of the double headed piston pushing the friction pads against brake rotor with the help of retainer coil (compression or tension spring) resulting in frictional force on brake rotor and slows the vehicle down. A general layout of a Anti-fluid brake caliper is shown in Figure 1.

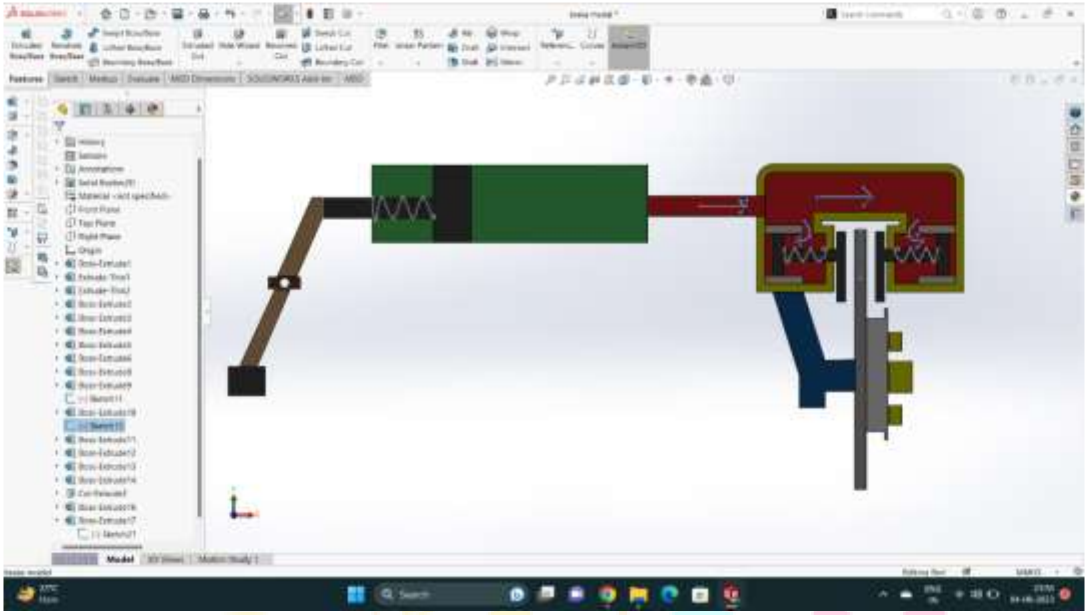

Fig 1.1: Anti-Fluid Braking System

Vertically mounted brake calipers usually hold the friction plates, while the compression force is applied by the pistons. The pressure distribution of the friction lining must be such that it ensures equal wear of the lining and power distribution. The braking torque produced is an important parameter for braking and must be greater than the torque required to stop the car. This is done by applying a clamping force to the brake at a certain distance from the center of the axle, which creates a reaction force that creates tension in the caliper body. Using the clamping force creates friction and generates heat, which is dissipated by the rotor and brake pads, meaning the car's kinetic energy is converted into heat, thus increasing the temperature of the disc. This heat is transferred from the brake pads to the caliper body, causing thermal deformation. To prevent this deformation, the friction shield must have good electrical properties.

1.2 Aims and Objectives

- The aim of the present study is to improve the safety of the automobile vehicle and preventing brake failure by developing advances in the braking system.
- To improve the breaking efficiency and safety of an automobile vehicle by updating the previous hydraulic braking system with new spring designs and the anti-fluid mechanism.
- To develop a braking system with additional safety.
- To design a reverse fluid mechanism with help of the springs.
- Slowdown the vehicle automatically in brake failure condition.

2. METHODOLOGY

2.1 Problem Identification

Hydraulic Braking System, while effective and widely used, can encounter several limitations such as fluid leakage which can occur due to worn-out seals, damaged brake lines, or corroded fittings, brake fluid contamination, brake fluid boiling, brake caliper sticking and bubbles formation due to presence of air in the system. All these factors lead to a loss of hydraulic pressure, resulting in reduced braking performance or complete brake failure which can cause damage and accidents.

The modern Anti Fluid Braking System have been developed to overcome these limitations and provide more accurate and efficient results by preventing accidental conditions by minimizing chances of brake failure. If in a worst case any brake failure occurs, this system is also capable of automatically stopping the vehicle. Thus, the problem statement of this project is to design and develop an efficient and adaptable braking system.

2.2 Methodology

Hydraulic disc brakes are widely used in automobiles, motorcycles, bicycles, and other vehicles due to their superior braking performance and reliability compared to traditional mechanical brakes. Here's how they work and their setup in Figure 2.1:

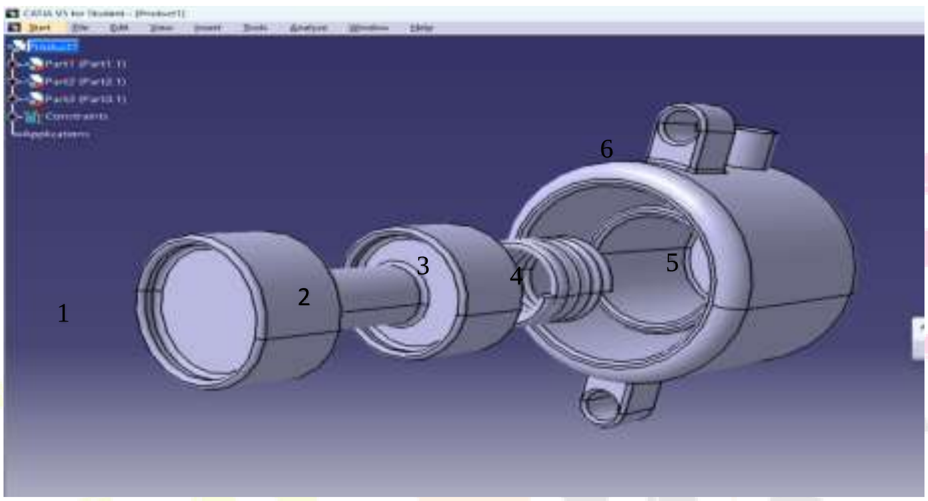

Fig 2.1: Brake Assembly

1. Double headed piston

2. Front face of inner piston

3. Retainer coil (compression spring)

4. Piston cavity

5. Caliper body

6. Fluid inlet

2.2.1. Components:

- Brake Lever: The brake lever, usually mounted on the handlebars in bicycles or motorcycles, is connected to the master cylinder.
- Master Cylinder: The master cylinder contains hydraulic fluid and a piston. When the brake lever is squeezed, it pushes the piston forward, pressurizing the hydraulic fluid.
- Brake Caliper: The brake caliper houses the brake pads and pistons. When hydraulic pressure is applied, the pistons inside the caliper push the brake pads against the brake rotor/disc.
- Brake Rotor/Disc: The brake rotor/disc is attached to the wheel hub. When the brake pads are squeezed against it, friction is created, slowing down the rotation of the wheel.

2.2.2. Construction:

- Brake pedal is attached to master cylinder as brake presses master cylinder piston moves outward.
- Master cylinder have a compression spring which pushes the cylinder piston out in no brake situation for generating pressure in the system via brake fluid.
- Brake caliper will consist with double headed piston and compression spring inside the caliper cavity.
- Brake pads will be attached to caliper piston from outside.
- Caliper is mounted on the brake disc/brake rotor.
- Brake line connects master cylinder and brake caliper.

2.2.3. Operation:

- When the brake lever is squeezed, it pulls out the master cylinder piston, which removes pressure from the hydraulic fluid inside the brake lines. As the pressure releases from hydraulic fluid travels through the brake lines to the caliper. The pistons inside the caliper are forced outward by the compression spring, causing the brake pads to make contact with the brake rotor/disc. The friction generated between the brake pads and rotor/disc slows down the rotation of the wheel, resulting in braking action.

- As the brake released the compression spring inside the master cylinder pushes the piston which creates pressure in the brake line, as the piston pushes the brake fluid inside the caliper the fluid apply pressure on inner surface of double headed piston which pushes the piston inside and the pad moves back and vehicle works smoothly without brake. The brake assembly of PLA model is shown below in figure 2.2.

Fig 2.2: PLA Model

2.2.4. Setup:

- Installation: The brake lever, master cylinder, brake lines, caliper, and rotor/disc are installed according to the manufacturer's instructions.
- Bleeding: After installation, the brake system needs to be bled to remove any air bubbles that may have entered the system. This ensures optimal brake performance.
- Adjustment: The brake pads and caliper may need adjustment to ensure proper alignment and clearance with the brake rotor/disc.
- Maintenance: Regular maintenance, including inspection of brake pads, rotor/disc, and hydraulic fluid levels, is essential to ensure the continued performance and safety of the hydraulic disc brake system.

Overall, hydraulic disc brakes offer superior braking performance, reliability, and modulation compared to mechanical brakes, making them a popular choice for a wide range of vehicles. Proper setup and maintenance are crucial for ensuring optimal performance and safety.

2.3 Advantages

- Efficiency: Anti-fluid disc brakes offer efficient braking performance with minimal effort from the rider/driver.
- Consistency: Anti-fluid brake systems provide consistent braking performance, regardless of weather conditions or brake pad wear.
- Heat Dissipation: Anti-fluid Disc brakes dissipate heat more effectively than convectional hydraulic brakes, reducing the risk of brake fade.
- Modulation: Anti-fluid disc brakes allow for precise modulation of braking force, enabling the rider/driver to control their braking power more accurately.
- Safety: Anti-fluid brakes provide better safety than other convectional brakes as it allows to slowdown and brake the vehicle in condition of brake failure which helps to avoid accidents.

2.4 Disadvantages

- Anti-fluid brake have complex structure, it's complicated to manufacture.
- High of cost than convectional hydraulic brakes.
- As the brake fluid removed from the system, vehicle will be under permanent brake.

2.5 Applications

- Its major use in automobiles is to brake the vehicles.
- Best suited for heavy load vehicles such as trucks and construction vehicle.
- The anti-fluid mechanism can be use in locomotives.

3. DESIGN AND ANALYSIS

3.1 CAD Modeling of Brake Components

3.1.1 Master Cylinder:

When selecting a master cylinder for brakes, consider factors like vehicle weight, brake system configuration, and desired pedal feel. Match cylinder bore size to caliper piston area to ensure adequate fluid displacement. opt for a dual-circuit system for redundancy and safety. Choose between single or tandem master cylinders based on vehicle design and brake balance requirements. On the basis of the calculations, we have calculated suitable parameters for the master cylinder with some standardized parameter. Figure 3.1 shows the design of master cylinder.

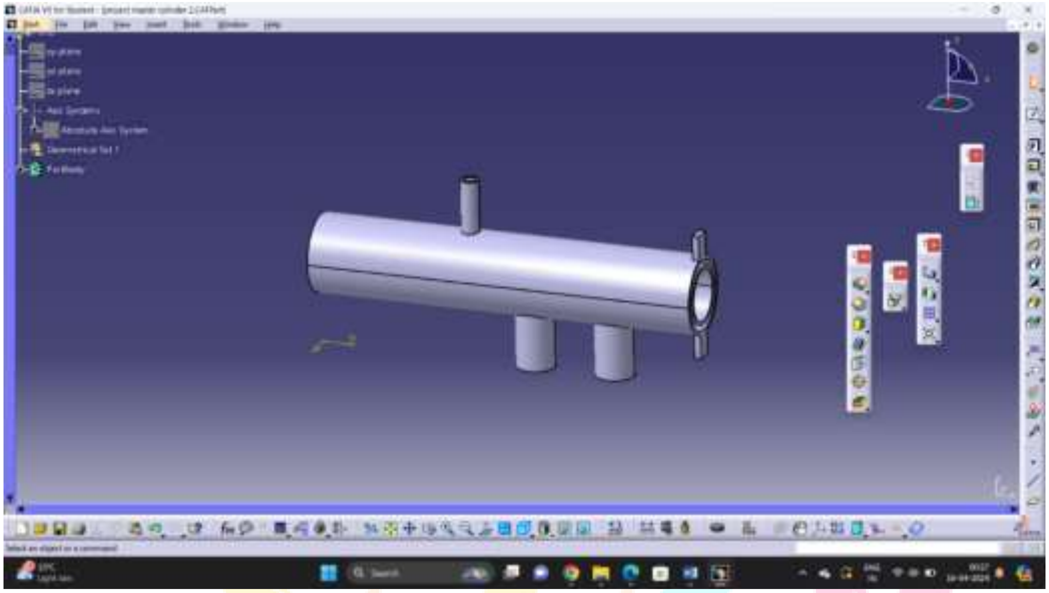

Fig.3.1: Master Cylinder

Dimensions:

- Diameter: 30mm
- Length: 150mm
- Piston Diameter: 25mm
- Brake line hoes: 10mm

3.1.2 Caliper:

Selecting a brake caliper involves considering factors like vehicle weight, braking performance requirements, and rotor size. Match caliper piston size to brake rotor diameter for optimal braking force distribution. On the basis of the calculations, we have calculated suitable parameters for the brake caliper with reference to brake force. Figure 3.2 shows the design of caliper.

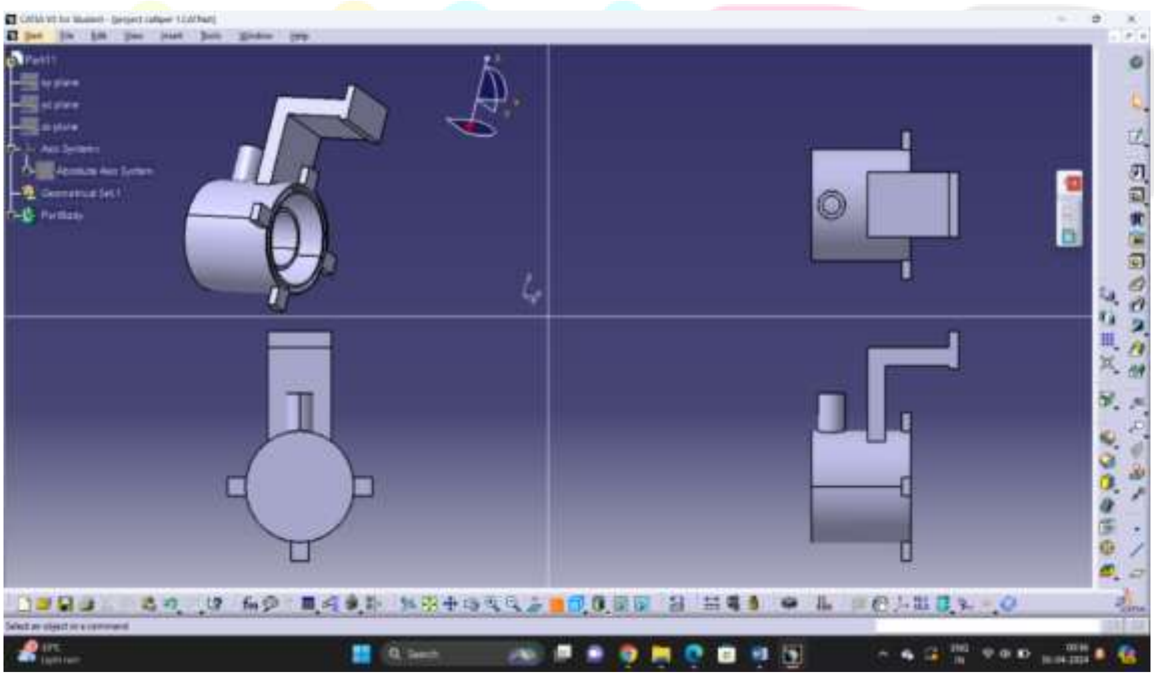

Fig.3.2: Caliper

Dimensions:

- Diameter: 65mm
- Cavity length: 40mm
- Piston Diameter: 40mm
- Brake line hoes: 10mm

3.1.3 Compression Spring:

Selecting a compression spring for a brake caliper involves considering factors like spring rate, free length, and wire diameter. Choose a spring with a rate that matches the desired pedal feel and hydraulic system pressure requirements. Ensure the spring's free length fits within the caliper cavity and its wire diameter is suitable for the application.
Hence with basis of these parameter we have calculated the suitable design for the spring as shown in figure 3.3.

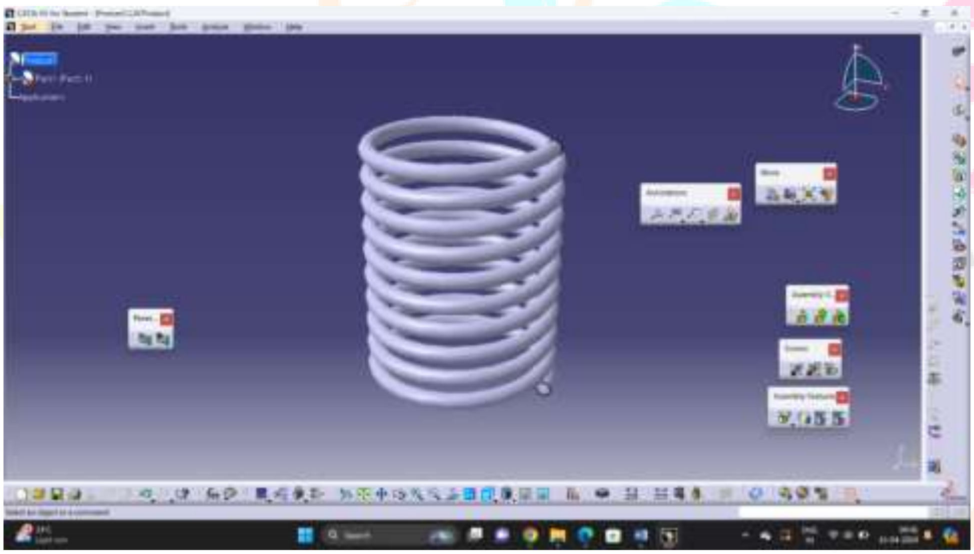

Fig.3.3: Compression Spring

Dimensions:

- Spring Diameter: 20mm
- Spring length: 35mm
- Wire thick: 2.5mm
- Pitch: 3mm

3.1.4 Assembly:

A brake caliper assembly consists of various components including the caliper body, pistons, seals, brake pads, compression spring and mounting brackets. The caliper body houses the pistons, which extend and retract to apply pressure on the brake pads. Seals ensure hydraulic fluid containment, while mounting brackets secure the caliper to the vehicle's suspension.

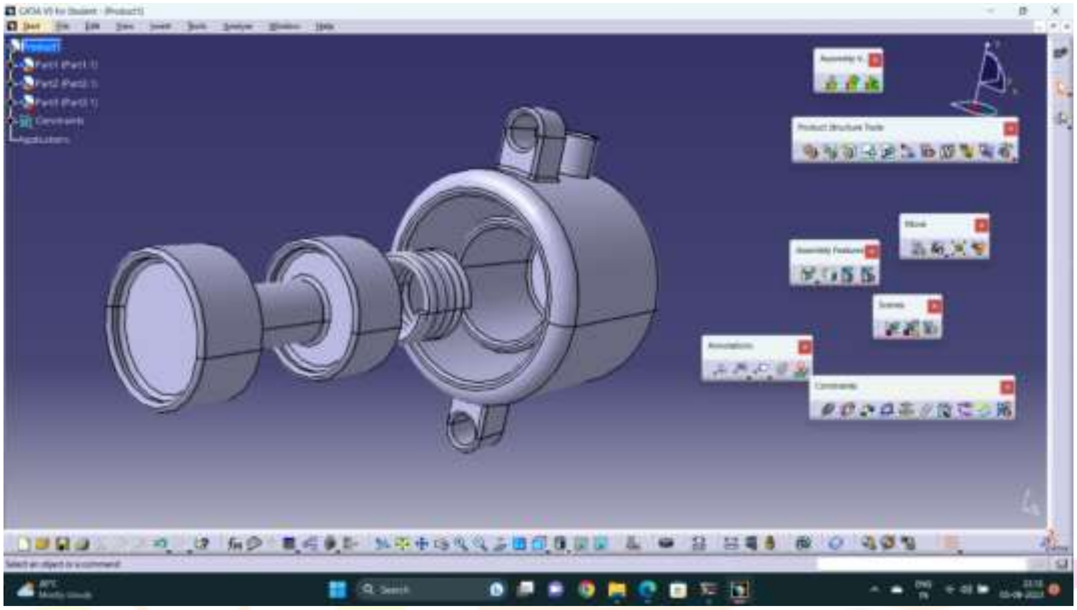

Fig.3.4: Assembly

As per the calculations we have designed a braking system with factor of safety in limit. Figure 3.4 shows the assembly of braking system.

These are the major components required to manufacture Anti-fluid brakes to work properly.

3.2 Finite Element Analysis [FEA]

3.2.1 Ansys:

ANSYS is engineering analysis software (computer-aided engineering, or CAE). By the help of this software, we can analysis all value for comparing cast iron brake disc. & other Ansys software like as
Simulation: Structural Mechanics, Metaphysics, Fluid Dynamics, Explicit Dynamics, Electromagnetics, and Hydrodynamics (AQWA).
Workflow Technology: Ansys Workbench Platform, High-Performance Computing, Geometry Interfaces, Simulation Process & Data Management. We compare all four-material alloy like as cast iron, structural steel, titanium, AL-NI-CO alloy.

3.2.2. Heat flux:

Heat flux refers to the rate of heat transfer per unit area. It is a measure of the amount of heat energy transferred through a surface per unit time. Heat flux is typically expressed in units of watts per square meter (W/m^2) and represents the flow of thermal energy across a surface, either by conduction, convection, radiation, or a combination of these mechanisms.

Statement (a):

When the brakes are applied the temperature of aluminums brake disc rises from 20ºC to 80ºC the heat flux due to change in temperature with aluminum specific heat capacity of 900 J/kg·°C will be as shown in figure 3.5.

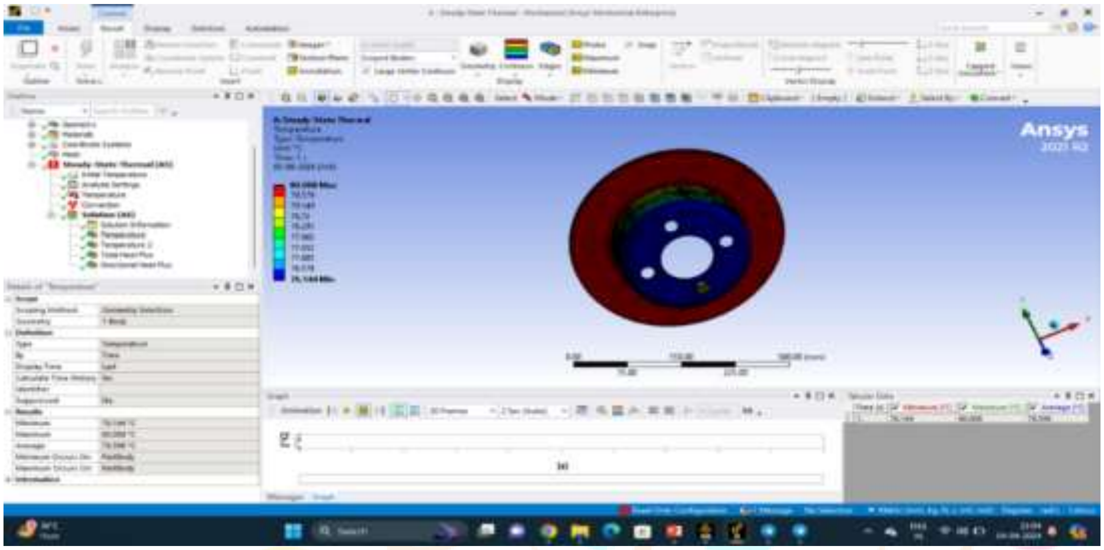

Fig.3.5: Analysis of heat flux due to temperature variation

Key Findings (a): Maximum heat flux observed in brake disc is 80.008 degree Celsius this change in heat flux is safe for design.

3.2.3. Temperature variation Graph:

Statement (b):

When the brakes are applied the temperature of aluminums brake disc rises from 20ºC to 80ºC as shown in figure 3.6.

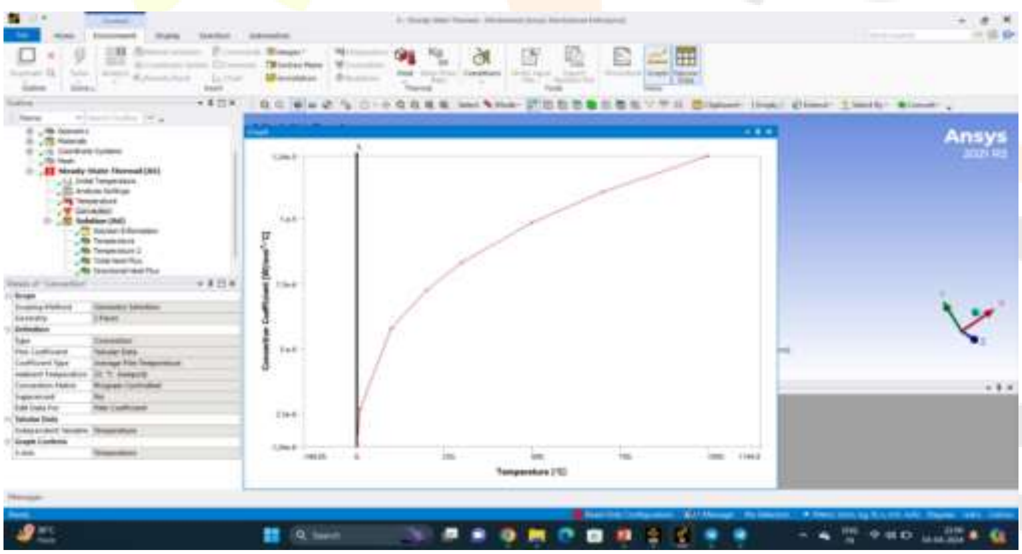

Fig.3.6: Temperature variation of aluminum brake disc

Key Findings(b): This temperature graph suggests the convectional coefficient change with respect to temperature.

3.2.4. Temperature variation:

Statement (c):
The temperature variation in the brake disc shown in figure 3.7 is given as:

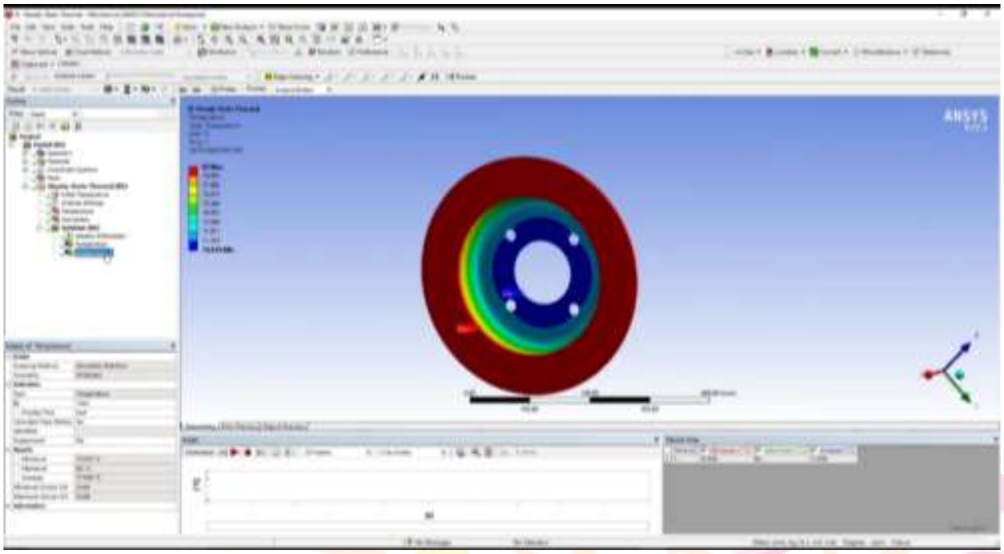

Fig.3.7: Temperature variation due to contact area

Key Findings(c): This shows the variation of temperature on the disc due to contact area.

3.2.5. Compression Spring:

Statement (d):
The deformation in static structure of the compression spring if 132.468 N force is applied is shown in figure 3.8.

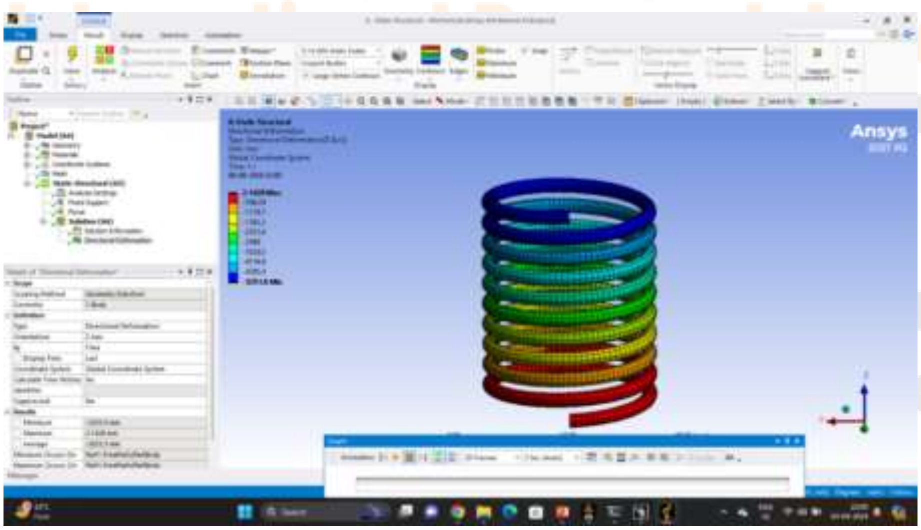

Fig.3.8: Deformation of compression spring

Key Findings(d): The maximum deformation occur on the spring is 2.1426 mm. this deformation is well with in the design tolerance limit.

3.2.6. Brake caliper thermal analysis:

Statement (e):
The deformation in the caliper body due to heat exchange between the brake caliper and the brake disc is shown in figure 3.9.

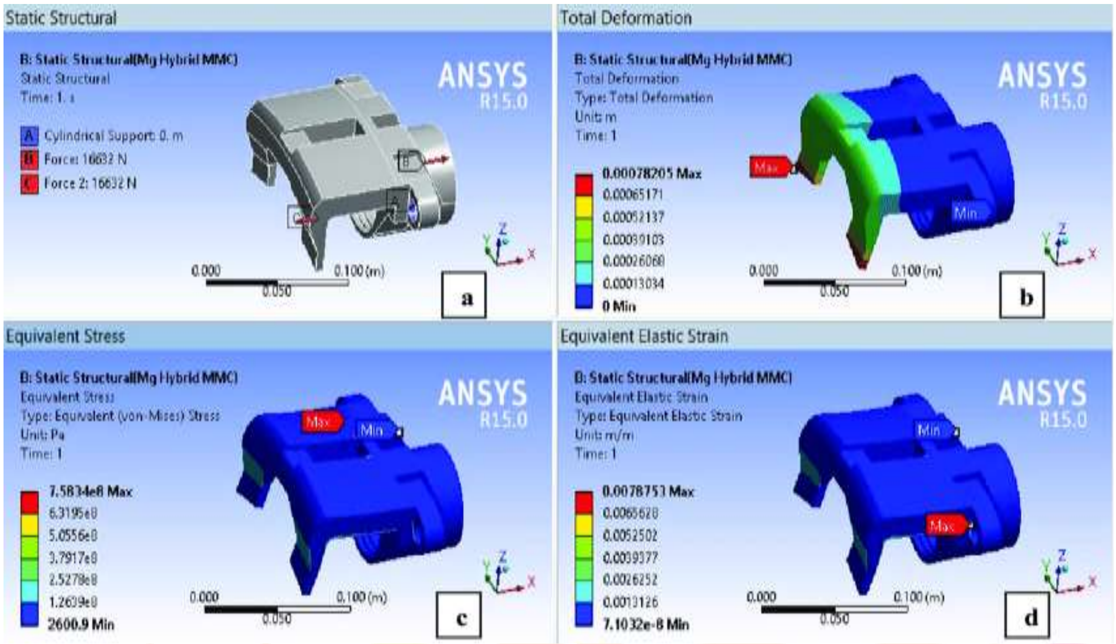

Fig.3.8: Deformation in caliper body due to heat exchange

Key Findings(e): Total deformation observed in the caliper due to load of disc is 0.00078 m max, this small deformation suggests safe design.

4. 3D PRINTING

4.1 3D Printing

3D printing, also known as additive manufacturing, is a revolutionary technology that constructs three-dimensional objects layer by layer from digital models. It involves creating objects by depositing material, such as plastic, metal, or resin, in successive layers according to the design specifications. This process enables the production of complex shapes and intricate geometries that may be challenging or impossible to achieve with traditional manufacturing methods. 3D printing finds applications in various industries, including aerospace, automotive, healthcare, and consumer goods, offering benefits such as rapid prototyping, customization, reduced waste, and on-demand production of parts and products.

4.2 Materials used for 3-D Printing

Utilizing PLA (Polylactic Acid) material for the 3D printing of our project's prototype offers a multitude of advantages. PLA, derived from renewable resources such as corn starch or sugarcane, not only aligns with our commitment to sustainability but also boasts commendable properties ideal for prototyping. Its biodegradable nature makes it environmentally friendly, while its low melting point and ease of printing facilitate rapid prototyping without compromising on quality. Moreover, PLA exhibits minimal warping and excellent layer adhesion, ensuring precise and durable prototypes that accurately represent our design iterations. By harnessing PLA in our 3D printing endeavors, we not only streamline our prototyping process but also contribute to a more sustainable and efficient future.

4.3. 3-D Printing of Prototype Parts

1. Double headed piston: A double-headed piston as shown in figure 4.1, in a braking system has two pistons instead of one, allowing for more even pressure distribution on the brake pads. This design enhances brake response, ensures balanced pad wear, and increases brake torque, particularly in high-performance applications like racing cars.

Fig.4.1: Double Headed Piston

2. Master Cylinder Piston: The master cylinder piston as shown in figure 4.2 is a component in the braking system that converts mechanical force into hydraulic pressure. It pressurizes brake fluid, which then applies force to the brake calipers or wheel cylinders, initiating braking. Its primary function is to transmit the force from the brake pedal to the brake system, allowing for precise control and modulation of braking force.

Fig.4.2: Master Cylinder Piston

3. Master cylinder: The master cylinder as shown in figure 4.3, is a key component in a hydraulic braking system. It converts the pressure applied to the brake pedal by the driver into hydraulic pressure, which is then transmitted to the brake calipers or wheel cylinders. The piston inside the master cylinder generates this hydraulic pressure, allowing for controlled braking action in vehicles.

Fig.4.3: Master Cylinder

4. Caliper: A brake caliper as shown in figure 4.4, is a component of a disc brake system in vehicles. Its primary function is to squeeze the brake pads against the brake rotor when the brakes are applied, creating friction that slows down or stops the vehicle. Essentially, the caliper houses the brake pads and contains the hydraulic pistons that apply force to the pads, allowing them to clamp onto the rotor and generate braking force.

Fig.4.4: Caliper

5. Assembly: Figure 4.5 shows the assembly of all the components in braking system.

Fig.4.5: Assembly

5. CONCLUSION

- This paper studies in detail, conceptual design and analysis of an Anti-fluid brake system. In this paper, an attempt was made to design a new Anti-fluid braking technology considering various parameters and was analyzed for its performance to brake the vehicle with good efficiency and effectivity with its spring compression mechanism as mentioned in the report.

- The prototype fabricated by 3D printing suggest that the reverse flow of fluid is possible with help of compression spring.

- Piston retraction behavior was rigorously studied on the basis of seal groove geometry, seal material and operating temperatures which contributes in determination of piston displacement, piston drag and hence the performance of caliper.

- Furthermore, other components of brake caliper system were modified to reduce the chances of brake failure and provide a safer braking system. Lubrication and selection of proper materials was done taking into account the performance.

- In analysis, mesh quality more than 0.8 was obtained for optimum discretization. Also, stresses generated were maintained up to a limit considering a reasonable factor of safety.

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