DEVELOPMENT OF BRAKING SYSTEM IN AUTOMOBILES

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Abstract - *With the goal of creating safer conditions, innovators over the years have brought new technologies to the braking system, improving upon this original idea. This project is done by creating a tri dimensional model and this model is generated by using design software Solidworks 2016. Solidworks is useful for designing different number of models as per the dimensions, as it is a versatile application. The model should be analyzed and measured which is designed in SOLIDWORKS. The obtained model is taken and geometric views are generated and following screenshots are shown. Analysis of the design is obtained by using Ansys software and following results and tables are listed in.*

Key Words: *Solidworks 2016, Ansys workbench 18.1, Design, Analysis, Braking system, Brake caliper etc*.

INTRODUCTION:

The 1800's, the first mechanisms to slow a vehicles momentum and prevent motion were tested. Today, over 100 years later, the braking system has evolved into a complex device designed to adapt to different road conditions. From the early drum brakes to modern day discs, brake system evolution has improved safety and reduced the risk of car crashes across the globe. With so many forms of brakes that have existed over the century, it is hard to pinpoint the inventor of the original brake system; however, those who designed these systems had a common goal: to make it possible for humans to control a motor vehicle.

WORKING PRINCIPLE:

A common misconception about brakes is that brakes squeeze against a drum or disc, and the pressure of the squeezing action slows the vehicle down. This is in fact a part of the reason for slowing down a vehicle. Actually, brakes use friction of brake shoes and drums to convert kinetic energy developed by the vehicle into heat energy. When brakes are applied, the pads or shoes that press against the brake drums or rotor convert kinetic energy into thermal energy via friction. Thus, brakes are essentially a mechanism to change energy types.

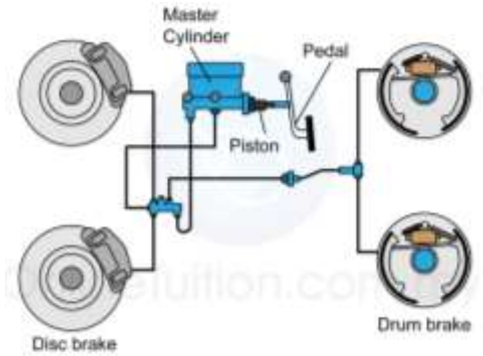

Fig – 1: Working of braking system in automobile

TYPES OF BRAKE:

Basically, there are three types of brakes which are used in automobile sectors. They are as follows:

1. Mechanical brakes: These are of two types:
   a. Drum brakes
   b. Disc brakes
2. Hydraulic brakes:
3. Power brakes: These are classified in four types:
   a. Air brakes
   b. Air hydraulic brakes
   c. Vacuum brakes
   d. Electric brakes

COMPONENTS OF BRAKING SYSTEM:

The main parts of automobile braking system include the pedal, drum and disc brakes, a brake booster and push rod, the master cylinder, valves and lines, and the emergency and anti-lock brakes.

Brake Pedal: The pedal is what that is pushed by foot to activate the brakes. It causes brake fluid to flow through the system to put pressure on the brake pads.

Fig – 2: Brake Pedal

Brake Master Cylinder:

The master cylinder is basically a plunger that is activated by the brake pedal. It is what holds the brake fluid and forces it through the brake lines when activated.

Fig – 3: Master Cylinder

Brake Lines:

Generally made of steel, brake lines are what carry the brake fluid from the master cylinder reservoir to the wheels where pressure is applied to stop the car.

Fig – 4: Brake lines

Drum Brakes:

Drum brakes are located on the rear wheels. When the brakes are applied, the pressurized fluid forces its way into the wheel cylinder of the drum brakes. This pushes the brake shoes into contact with the inside of the brake drum and slows down the vehicle. A pushrod transfers motion from one shoe to the other.

Fig – 5: Drum brake components

Disc Brakes:

Most vehicles have disc brakes only on the front wheels, though newer vehicles may have disc brakes on all four wheels. With disc brakes, the fluid from the master cylinder forces into a caliper where it presses against a piston. The piston squeezes two brake pads on a disc rotor attached to the wheel. This forces the wheel to slow down and stop.

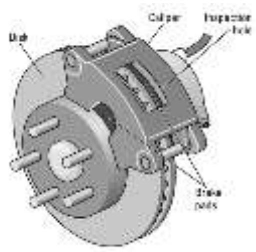

Fig – 6: Disc brake assembly

Wheel Cylinders:

The brake pads are connected to the wheel cylinders which either squeeze (disc brakes) or push apart (drum brakes) the brake pads when fluid flows into them.

Fig – 7: Wheel Cylinder

Brake Pads:

The brake pads are what actually rub against the drums or rotors. They are made of composite materials and designed to last for many, many thousands of miles.

Fig – 8: Brake pads

Emergency Brake:

The emergency or parking brake is a fully mechanical system that controls the rear brakes. Steel cables connect the parking brake to either a hand lever or a foot pedal and bypass the hydraulic system.

Fig – 9: Parking Brake

Anti-Lock:

If wheels lock up due to panic braking, steering control is lost. Anti-lock brakes detect locked wheels and rapidly pump the brakes. A computer with a series of sensors monitors the speed of the wheels and, if necessary, signals the brakes to be pulsed.

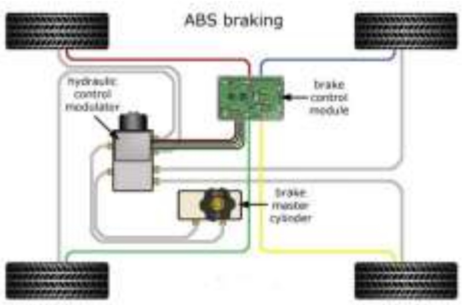

Fig – 10: ABS diagram

HYDRAULIC BRAKING SYSTEM:

Hydraulics is the use of a liquid under pressure to transfer force or motion, or to increase an applied force. The pressure on a liquid is called hydraulic pressure. And the brakes which are operated by means of hydraulic pressure are called hydraulic brakes. These brakes are based on the principle of Pascal's law.

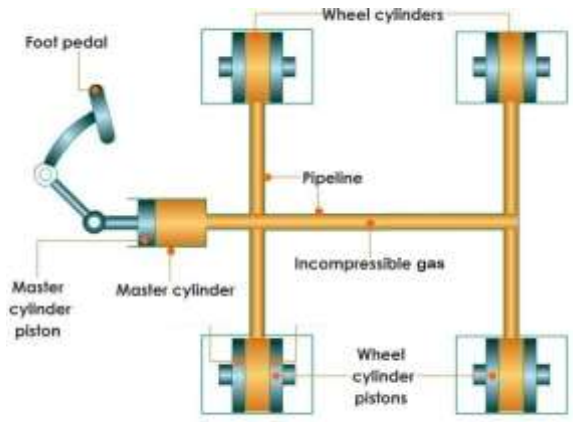

Fig – 11: Hydraulic braking system

TYPES OF HYDRAULIC BRAKES:

On the basis of frictional contact mechanism:

On this basis, hydraulic brakes are of 2 types –

(i) Drum brake or internal expanding hydraulic brakes.

(ii) Disc brakes or external contracting hydraulic brakes.

On the basis of brake force distribution:

On this basis, hydraulic brakes are of 2 types-

(i) Single acting hydraulic brakes

(ii) Dual acting hydraulic brakes

ON THE BASIS OF FRICTIONAL CONTACT MECHANISM:

WORKING PRINCIPLE OF DRUM BRAKE:

1. As the brake pedal is pressed, it compresses the fluid in the master cylinder and allows the piston of the wheel cylinder to expand outward.

2. The outward motion of the piston of wheel cylinder forces the brake shoe outward against the brake drum.

3. As the brake shoe lining touches the inner surface of the drum, and due to the friction generated in between the brake shoe and drum, the motion of the wheel reduces and vehicle stops.

4. As the force is removed from the brake pedal, the retracting springs draws the brake shoe inward and the contact between the friction lining and drum ended. Now again the brake is ready to apply.

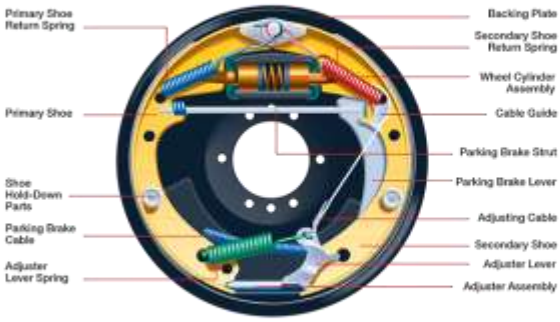

Fig – 12: Drum brake components

5. A self-adjusting screw is present at the bottom, which is used to maintain a minimum gap between the drum and brake shoe. When the lining of the brake shoe wears out than the gap between the drum and brake shoe increases, at that time the adjuster is adjusted again to maintain the minimum gap.

WORKING PRINCIPLE OF DISC BRAKE:

1. When brake pedal is pressed, the high-pressure fluid from the master cylinder pushes the piston outward.

2. The piston pushes the brake pad against the rotating disc.

Fig – 13: Disc brake components of automobiles

3. As the inner brake pad touches rotor, the fluid pressure exerts further force and the caliper moves inward and pulls the outward brake pad towards the rotating disc and it touches the disc.

4. Now both the brake pads are pushing the rotating disc, a large amount of friction is generated in between the pads and rotating disc and slows down the vehicle and finally let it stop.

5. When brake pad is released, the piston moves inward, the brake pad away from the rotating disc. And the vehicle again starts to move.

ON THE BASIS OF BRAKE FORCE DISTRIBUTION:

All the components of single acting hydraulic brakes and double-acting hydraulic brakes whether it's a drum type single acting brake or disc type single acting brake are same as mentioned above, the only difference is type of master cylinder used which decides the brake force distribution i.e. In bikes- single wheel braking or double wheel braking, In cars- two-wheel braking or all wheel braking.

1. Single Acting Hydraulic Brakes-

In single acting type of hydraulic brakes, simple single cylinder type of master cylinder is used which provides limited hydraulic pressure which can only be transferred in single direction i.e. In bikes- only single wheel, In cars – only single pair (front or rear) of wheels.

2. Double Acting Hydraulic Brakes-

In double acting type of hydraulic brakes, double or tandem master cylinder is used which provides higher brake force which can be transferred in double direction i.e. both wheels in bikes and all the wheels in cars.

AIR BRAKE:

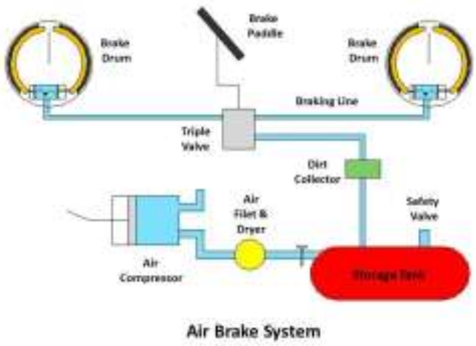

Fig – 14: Air brake system

Air brakes are used in trucks, buses, trailers and semi-trailers. This is the preferred type of braking system for these vehicles for several reasons. First, the use of air allows multiple vehicle units to be coupled so that all units have braking capability and so that all of those units' brakes may be controlled from the cab. Coupling would be infeasible if a liquid were used as the mode of transmission of force, as it is in hydraulic brakes. In addition, the use of an air brake system allows for the incorporation of an emergency braking system that utilizes parts of the service brake and parking brake systems. Emergency braking systems are required on all semi-trailers by CFR 49 393.43, as it states "Every motor vehicle, if used to tow a trailer equipped with brakes, shall be equipped with a means for providing that in the case of a breakaway of the trailer, the service brakes on the towing vehicle will be capable of stopping the towing vehicle."

AIR HYDRAULIC BRAKES:

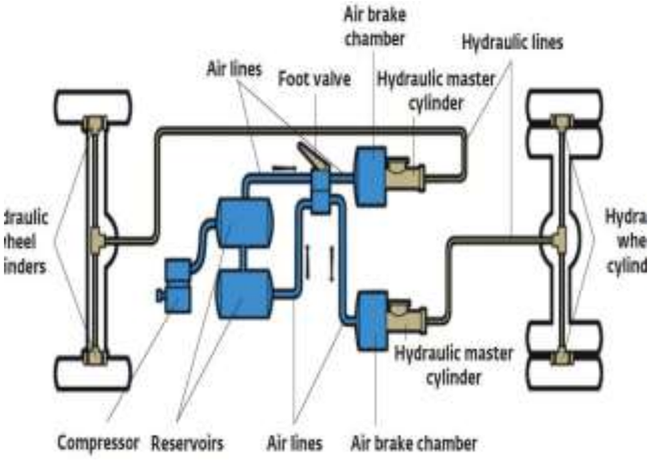

Fig – 15: Air hydraulic braking system

As the name suggests, this type of braking system is a combination of parts of an air brake system and a hydraulic brake system. It uses both air and hydraulic compression to operate the brakes. This type of braking system was created with the hopes of increasing the braking power compared to the power in a hydraulic braking system. This system is not the most common, but it can often found in trucks, trailers, cranes, and other industrial equipment. Because of all of their parts and components, these systems must be inspected often and maintained by a professional. It has a special type of power cylinder that contains a hydraulic cylinder and an air cylinder in tandem. While both of these cylinders have pistons, the important thing to note is that the pistons are not the same size. the air piston is greater in diameter compared to the piston for the hydraulic cylinder. The air piston is greater in diameter compared to the piston for the hydraulic cylinder. This means that there is more hydraulic pressure compared to air pressure during normal breaking. So, when the pedal is pressed, the valve opens and releases the pressure, which a causes braking to occur.

VACUUM BRAKE:

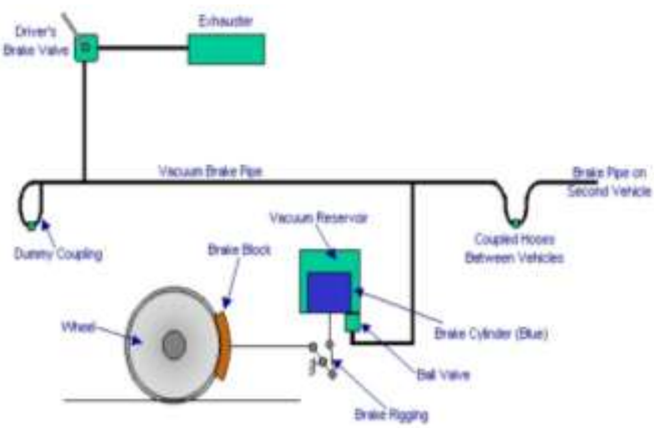

Fig – 16: Vacuum brake equipment

The fittings to achieve this are:

Train pipe: A steel pipe running the length of each vehicle, with flexible vacuum hoses at each end of the vehicles, and coupled between adjacent vehicles; at the end of the train, the final hose is seated on an air-tight plug.

An ejector on the locomotive, to create vacuum in the train pipe.

Controls for the driver to bring the ejector into action, and to admit air to the train pipe; these may be separate controls or a combined brake valve.

A **brake cylinder** on each vehicle containing a piston, connected by rigging to the brake shoes on the vehicle.

A **vacuum (pressure) gauge** on the locomotive to indicate to the driver the degree of vacuum in the train pipe.

The brake cylinder is contained in a larger housing, this gives a reserve of vacuum as the piston operates. The cylinder rocks slightly in operation to maintain alignment with the brake rigging cranks, so it is supported in trunnion bearings, and the vacuum pipe connection to it is flexible. The piston in the brake cylinder has a flexible piston ring that allows air to pass from the upper part of the cylinder to the lower part if necessary.

When the vehicles have been at rest, so that the brake is not charged, the brake pistons will have dropped to their lower position in the absence of a pressure differential (as air will have leaked slowly into the upper part of the cylinder, destroying the vacuum).

When a locomotive is coupled to the vehicles, the driver moves the brake control to the "release" position and air is exhausted from the train pipe, creating a partial vacuum. Air in the upper part of the brake cylinders is also exhausted from the train pipe, through a non-return valve.

If the driver now moves his control to the "brake" position, air is admitted to the train pipe. According to the driver's manipulation of the control, some or all of the vacuum will be destroyed in the process. The ball valve closes and there is a higher air pressure under the brake pistons than above it, and the pressure differential forces the piston upwards, applying the brakes. The driver can control the amount of braking effort by admitting more or less air to the train pipe.

ELECTRIC BRAKE:

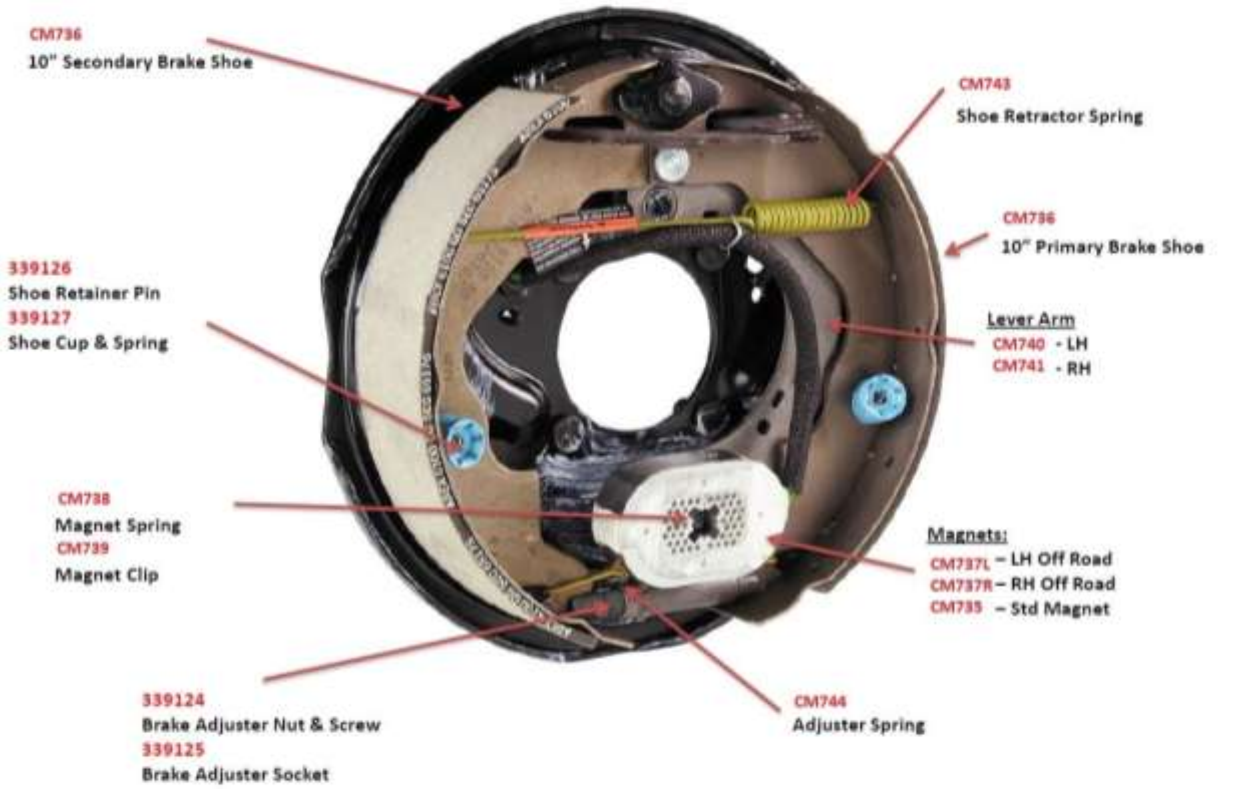

Fig – 17: Electric Braking System

The magnet in the backing plate has 2 conductor wires which tap directly into the trailer wiring. When electricity is on, it magnetizes the brake magnet. The magnet is attracted to the drum face. When it contacts this area, the friction causes it to rotate, which moves the actuating arm, and pushes the shoes out against the drum. Those shoes have a special brake pad material on them that resists the heat caused by that friction. When the shoes press against the inside of the drum, they prevent the hub, and consequently the wheel that's touching the ground from spinning.

MASTER CYLINDER

When the brake pedal is pressed, it pushes on primary piston through a linkage. Pressure is built in the cylinder and the lines as the brake pedal is depressed further. The pressure between the primary and secondary piston forces the secondary piston to compress the fluid in its circuit. If the brakes are operating properly, the pressure will be same in both the circuits. If there is a leak in one of the circuits, that circuit will not be able to maintain pressure. The design of master cylinder is done in Solidworks 2016 software. The snapshot of the design is given below.

Fig – 18: Design of master cylinder

ADVANTAGES OF HYDRAULIC BRAKES:

- Equal braking effort to all the four wheels
- Less rate of wear (due to absence of joints compared to mechanical brakes)
- Force multiplication (or divisions) very easily just by changing the size of one piston and cylinder relative to other.

DISADVANTAGES OF HYDRAULIC BRAKES:

- Even slight leakage of air into the braking system makes it useless.
- The brake shoes are liable to get ruined if the brake fluid leaks out.

BRAKE FLUIDS:

One of the important characteristics of brake fluid is its boiling point. Hydraulic systems rely on incompressible fluid to transmit force.

Liquids are generally incompressible while gases are compressible. If the brake fluid boils (becomes a gas), it will lose most of its ability to transmit force. This may partially or completely disable he brakes.

TYPES OF BRAKE FLUID:

Brake fluids are classified into 2 types:

1. Glycol based (Absorb water): DOT 3, DOT 4, DOT 5.1
2. Silicon based (Doesn't absorb water): DOT 5

DOT signifies Department of Transport.

DOT 3:

By far, DOT 3 is the most popular. It's been in use for a very long time. Fresh DOT 3 has a boiling point of 401 degrees Fahrenheit, fully degraded it drops to 284 degrees Fahrenheit. This makes your brake fluid much more likely to boil. Braking hard, going downhill for a long period, towing, or racing can speed up this process. Since DOT 3 is highly corrosive, great care should be taken. It will remove paint and should be cleaned up immediately using soap and water or a simple degreaser.

DOT 4:

DOT 4 is beginning to be used more widely in by vehicle manufacturers, but is used mostly by European car manufacturers currently. Although there are different types of DOT 4 brake fluid, it has a higher boiling point than DOT 3. These boiling points start at 446 degrees Fahrenheit. Additional additives in DOT 4 help reduce the acids that can form from moisture. While DOT 3 and 4 are technically intermixable, it is not recommended. DOT 4 is twice the cost of DOT 3 and for most, there's little benefit to switching. There are several different types of DOT 4 so be certain you use the correct type.

DOT 4 is used in some euro and domestic vehicles. DOT 4 Plus is used in Mercedes and Volvo. DOT 4 Low Viscosity is used in some BMW models. Finally, DOT 4 Racing usually has an added blue color.

DOT 5:

DOT 5 is a silicone-based brake fluid and has a very high boiling point of 500 degrees Fahrenheit. Usually it has a purple color to differentiate from the amber color of DOT 3 and 4. It doesn't absorb water quite like the glycol-based brake fluids, but it does become foamy and the air bubbles are far more difficult to bleed out. This is why DOT 5 is not recommended for an ABS system. DOT 5 is not able to be mixed with any other fluid, and is 4x more expensive than DOT 3.

DOT 5.1:

DOT 5.1 is a glycol-based brake fluid with a boiling point similar to DOT 4 racing brake fluids. Usually clear to amber in color. While it is technically intermixable with DOT 3 or 4, it is not recommended. DOT 5.1 is around 14x more expensive than DOT 3. None of the different types of brake fluids should be mixed. They can react badly with each other and corrode the brake system.

DESIGN AND ANALYSIS OF DISC BRAKE:

A disc brake is designed in Solidworks 2016. The analysis is done in Ansys workbench 18.1 to check whether the design can sustain at higher temperature and frictional force. The design of the disc brake is given below:

Fig – 19: Design of disc brake

ANALYSIS PROCEDURE (Transient Thermal):

1. Select Transient Thermal.
2. Select Engineering Data and assign Structural steel (Default) to the library.
3. Import the file to the Geometry.
4. Click on Model and set material from the Geometry.
5. Click on Sizing in Mesh and select Medium in Relevance Center.
6. Generate Mesh.
7. Insert Temperature and select outer and inner surfaces and set magnitude 1000℃.

8. Insert Convection and apply rest of the body (where wheel hub will be connected) to the geometry.

9. Import Film Coefficient and select Stagnant Air – Vertical Planes1

10. Insert Temperature, Total Heat Flux from Solution and Solve it.

The result of the analysis is given below:

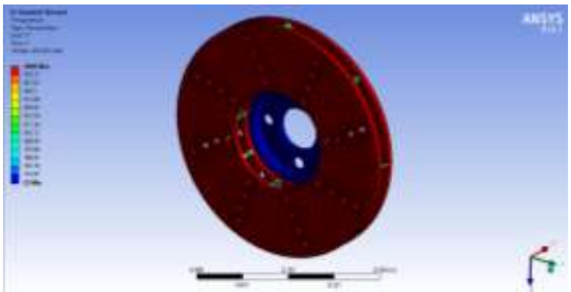

Fig – 20: Temperature analysis

This analysis shows on which part maximum temperature will generate and where minimum temperature will generate.

Minimum heat flux generated is 0.24395 W/m^2 and maximum value is 13.852 W/m^2

ANALYSIS PROCEDURE (Static Structural):

1. Select Static Structural.

2. Select Engineering Data and assign Structural Steel (Default) to the library.

3. Import the file to the Geometry.

4. Click on Model and set material from the Geometry.

5. Generate Mesh.

6. Apply Fixed Support to the faces attached with wheel hub.

7. Apply 300N to each of the outer faces.

8. Apply 50rad/s rotational velocity with respect to the axis of rotation.

9. Insert Equivalent Stress, Factor of safety, Life, Total deformation, Equivalent elastic strain and solve it.

The result of the analysis is given below:

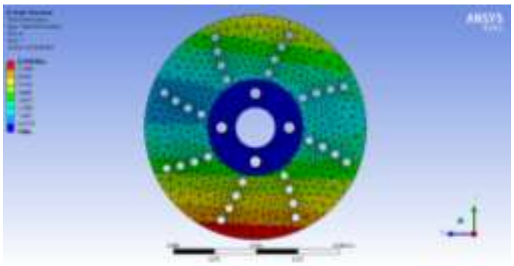

Fig – 21: Total deformation analysis

Maximum deformation occurred 8.2968 mm.

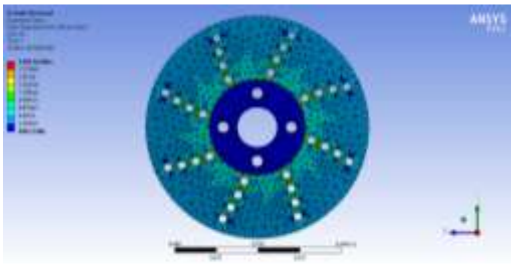

Fig – 22: Equivalent stress analysis

Minimum stress generated 4992.5 Pa and maximum value is 1.9868e+006 Pa.

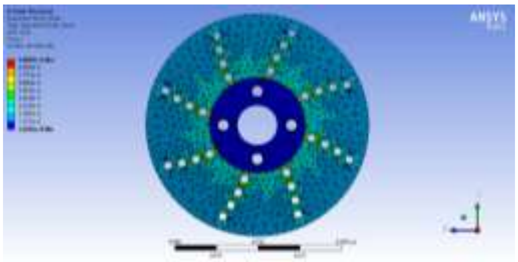

Fig – 23: Equivalent elastic strain analysis

Minimum equivalent elastic strain obtained 2.6096e-008 m/m and maximum value is 9.9603e-006 m/m.

Minimum life of the design is 1.e+009 cycles and minimum factor of safety obtained 15.

DESIGN AND ANALYSIS OF BRAKE CALIPER:

A Brake Caliper is designed in Solidworks 2016. The analysis is done in Ansys workbench 18.1 to check whether the design can sustain against frictional force. The design of the brake caliper is given below:

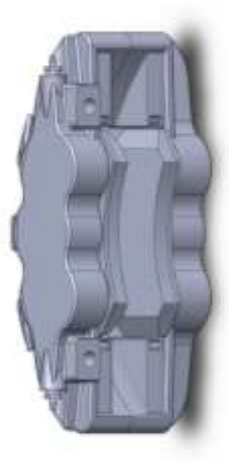

Fig – 24: Design of brake caliper

ANALYSIS PROCEDURE (Static Structural):

1. Select Static Structural.
2. Import the file to the Geometry.
3. Click on Model and Generate Mesh.
4. Apply Fixed Support to the holes attached with wheel upright (Knuckle).
5. Apply 300N to each of the brake pad.
6. Insert Equivalent Stress, Factor of safety, Life, Total deformation, Equivalent elastic strain and solve it.

The result of the analysis is given below:

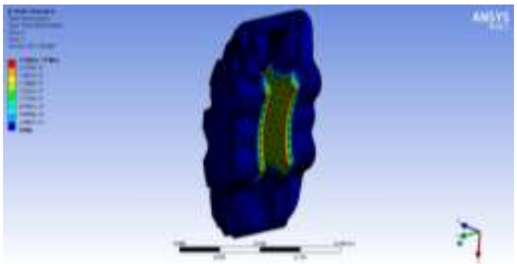

Fig – 25: Total deformation analysis

Maximum deformation can be obtained is 2.5602e-11 m.

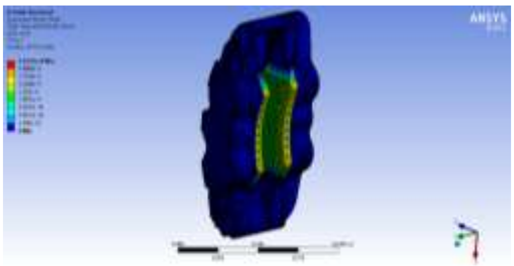

Fig – 26: Equivalent elastic strain analysis

Maximum equivalent elastic strain obtained 2.2572e-009 m/m.

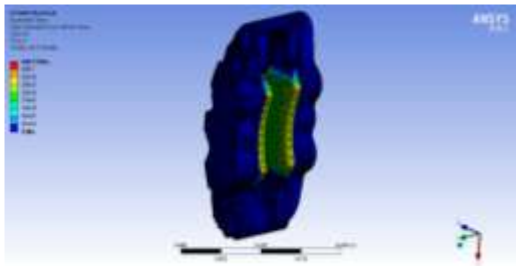

Fig – 27: Equivalent stress analysis

Maximum stress generated 449.21 Pa.

Minimum life of the design is 1.e+009 cycles and minimum factor of safety obtained 15.

CONCLUSION:

The first part of the paper discusses about the fundamentals of braking system, types of braking system, working principle of each brake, concept of master cylinder in braking system, types of brake fluid and their description. The second part of the paper consists of design and simulation of brake disc and brake caliper in Solidworks 2016 and Ansys workbench 18.1 softwares respectively.

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