DESIGN, ANALYSIS AND FABRICATION OF BRAKING SYSTEM WITH REAR INBOARD BRAKES IN BAJA ATV

Aman Sharma[1], Prakhar Amrute[2], Suryakant Singh Thakur[3], Jatin Shrivastav[4]

[1,2,3,4]*Department of Mechanical Engineering, Medicaps Institute of Technology and Management, Indore*

Abstract - *An inboard braking is an automobile technology where the disc brakes are mounted to the driveshaft or a brake shaft, rather than directly on the wheel hub. The major advantage of using this braking technology is the reduction of unsprung weight which improves handling and ride. The primary aim of this paper is to show the utility and performance of disc brakes with rear inboard braking system and to perform CAE analysis of components used in braking system.*

***Key Words*: Inboard braking, unsprung weight, disc brake**

1. INTRODUCTION

Braking system in cars is arguably the most important subsystem of a vehicle. Brakes are used to stop a moving vehicle, to prevent it from moving or to control its speed while in motion. All braking system depends upon the frictional force to stop, to control or to prevent motion [1]. An efficient braking system is required to create enough deceleration to stop the car as quickly as the driver wishes, without exceeding the driver comfort level with regard to the pedal effort and to effectively dissipate the heat generated due to friction.

Actuating system of brakes can be mechanical, hydraulic or pneumatic [2]. Modern cars mostly use hydraulic brakes. Hydraulic brakes use an enclosed fluid to transmit the pedal force to stop the vehicle. Force applied by the driver is multiplied in the braking system by a principle called Pascal's law. The law states: "a pressure change occurring anywhere in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere." Friction between the rotating disc or drum and stationary pads are used as a tool to stop the vehicle within a considerable distance.

Brakes used can be of Drum or Disc type. Usually Disc brakes are used on the front wheels and drum one on the rear given that disc brakes can provide efficient braking and bear more load in the scenario of weight transfer during the deceleration. Results based on finite element analysis are used to further improve the designing of the disc brakes.

2. NEED OF BRAKING SYSTEM

"Sprung" weight is the weight of all the parts of a car that are supported by the front and rear suspension. The "unsprung" weight includes wheels, tires, brake assemblies and other members that are not supported by the suspension system. Reduction in the unsprung weight is a very important factor in improving handling. Bigger weight resembles to more inertia. Higher inertia means more workload for suspensions to keep tires on the ground. The lower the unsprung weight, the less the work the suspensions have to do to keep the tires in contact with the road over uneven surfaces.

As the inboard braking system uses brakes rigidly mounted on the vehicle, the weight of the braking mechanism is moved from being carried by the wheels directly, to being carried indirectly by the wheels via suspension [4]. This reduces the unsprung mass of the vehicle. Most of the rear wheel drive cars have used inboard brakes. Same system can also be used on the driven wheels by using a mechanism called brake shaft.

2.1 Advantages of inboard brakes*:*

- A reduction in the unsprung weight of the vehicles on the wheel hubs, as this no longer includes the brake discs and callipers; also braking torque applies directly to the chassis rather than being taken through the suspension arms.
- Wheels don't enclose the brake mechanism allowing greater flexibility in wheel offset.
- Use of inboard brakes also facilitates the use of spool (Locking Differential) in the vehicle which helps to reduce the complexity and weight of the vehicle.

2.2 Disadvantages of inboard brakes*:*

- Individual brake shaft is used for the undriven wheels.
- Added complexity for servicing of brakes.
- Difficulty of cooling air to flow over the rotor in the rear side of the vehicle.

3. LAYOUT OF THE BRAKING CIRCUIT

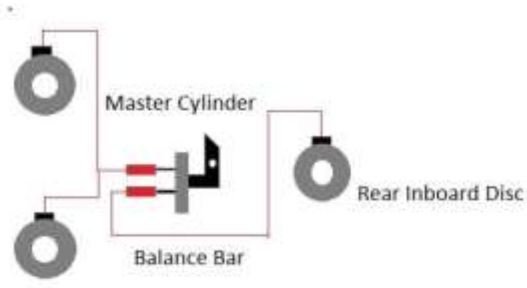

Figure 1 – Layout of the braking system

Master cylinder with required dimensions of piston is used to generate appropriate pressure in the brake circuit. Brake pedal with optimum pedal ratio is used to apply force to the master cylinder. Pedal ratio is the mechanical advantage provided by the pedal. The braking system is segregated into two independent hydraulic circuits such that in case of a leak or failure at any point in the system, effective braking power shall be maintained on at least two wheels. Each hydraulic circuit has its own OEM- style fluid reservoir. A balance bar (also called a bias bar) on dual master cylinder system divides the force from the brake pedal to the two master cylinders [5]. Balance bar works on the principle of Balancing Moments. Pressure generated in master cylinder is carried to the caliper by the brake fluid confined in the fluid lines. Brake fluids generally used are glycol- based, however silicon based brake fluid can also be used [6]. Pressure generated in the master cylinder by the force multiplied by the pedal effort is transferred to the caliper through the fluid lines. Pistons in caliper push the brake pads against the rotor to apply frictional force to decelerate and ultimately stop the vehicle.

4. CALCULATIONS

4.1 Overview of Design

The braking system uses a front/ rear split braking circuit. Two master cylinders having a bore diameter of 14mm are used. Two fixed single piston calipers on front wheels and one floating dual piston caliper on the rear inboard disc is used. Bore diameter for front and rear caliper is 30mm rear and 27mm respectively. The brake calipers are connected to the master cylinder with the synthetic rubber hoses which ensures that there is no leakage of the brake fluid.

Material for the rotor: SS420.

Material for the brake pedal: 6061 Aluminum.

It was thought critical for brake system to be designed such that the front and rear brakes lock up at the same rates. This would maximize deceleration and reduce the stopping distance.

Statics

The weight ratio of the vehicle is 35:65

Weight of the Vehicle = 200 x 9.81 = 1962 N = W

Wheelbase = L = 1270 mm

L_1=Longitudinal Distance of centre of gravity from front axle = 824.38mm

L_2=Longitudinal distance of centre of gravity from the rear axle=445.61mm

The weight on the front and the rear axle in the static conditions can hence be calculated

Front axle static load: $w_1 = (W \times L_2) / L = (2256.3 \times .44) / 1.27 = 679.74$ N

Rear axle static load: $w_2 = (W \times L_1) / L = (2256.3 \times .82) / 1.27 = 1282.25$ N

Dynamics

Height of centre of gravity = h = 424.28mm

Coefficient of Friction between Road and tires = μ_r = .6

Radius of the tyre = 267 mm

Frictional Force on vehicle = $F_f = \mu_r N = \mu_r mg = .6 \times 200 \times 9.81$ =1177.2 N

Inertial Force Due to deceleration (d) = F_i = md = 200 x d

$F_f = F_i$

1177.2 = 200 x d

d = 5.886 m/s^2

d/g = 0.6

For designing the braking system, we will have to calculate the dynamic weight transfer using the formulae as given below:

Front axle dynamic load = $w_{fd} = \{W(L_2 + (d/g)h)\}/L = \{1962(0.44 + 0.6 \times .424)\}/1.27 = 1072.14$ N

Rear axle dynamic load = $w_{rd} = \{W(L_1 + (d/g)h)\}/L = \{1962(0.82 + 0.6 \times .424)\}/1.27 = 889.85$ N

Amount of frictional torque required on the wheels to stop the vehicle

Frictional torque required at front wheels = $T_f = \mu_r \times w_{fd} \times R$ = .6 x 1072.14 x .267 = 171.75 N-m

Frictional torque required at rear wheels = $T_r = \mu_r \times w_{rd} \times R$ = .6 x 889.85 x .267 = 142.55 N-m

4.2 Calculations for Selecting the Disc

For achieving optimum braking the brakes are biased to 70 % in front wheels and 30 % in rear axle

Area of master cylinder bore = 153.86 mm^2

Area of piston cylinder bore (Front caliper) = 706.85 mm^2

Area of piston cylinder bore (Rear caliper) = 572.55 mm^2

Pedal Ratio Selected = p = 4

Pedal force by Driver = 225 N

Force at Balance Bar = 225 x 4 = 900 N

For front wheels:

Actuation force at master cylinder for front brakes = 900 x .7 = 630 N

Pressure Generated inside master cylinder = Force / Area = 630 / .000153 = 4.11 MPa

Force applied by caliper = Pressure x Area = 4.11 x 10^6 x .000706 = 2901.66 N

Clamping Force = 2901.66 x 2 = 5803.32 N

Friction force applied by brake pads on the rotor = 5803.32 x μ_d = 5803.32 x .4 = 2321.328 N

Braking torque = Frictional force x Effective Radius of the rotor

85.875 = 2321.328 x R_{df}

R_{df} = 37 mm

Disc outer radius = (37+15) mm = 52mm

Final Disc diameter = 52 x 2 = 104mm

For rear axle with inboard brakes:

Actuation force at master cylinder for front brakes = 900 x .3 = 270 N

Pressure Generated inside master cylinder = Force / Area = 270 / .000153 = 1.76 MPa

Force applied by caliper = 2 x Pressure x Area = 2 x 1.76 x 10^6 x .000572 = 2013.44 N

Clamping Force = 2013.44 x 2 = 4026.88 N

Friction force applied by brake pads on the rotor = 4026.88 x μ_d = 4026.88 x .4 = 1610.75 N

Braking torque = Frictional force x Effective Radius of the rotor

71.27 = 1610.75 x R_{dr}

R_{df} = 44.24 mm

Disc outer radius = (44.24+15) mm = 59.24mm = 60 mm

Final Disc diameter = 60 x 2 = 120 mm

5. DESIGN AND ANALYSIS OF ITS COMPONENTS

Disc and Pedal were designed in Catia V5 R20.

Thermal analysis of disc and heat flux distribution of Disc was performed in Ansys R16.2.

Displacement and Elemental Stress Analysis of Brake pedal was done in HyperMesh.

5.1 Design and Analysis of Disc

Disc material – SS420
Mesh size – 2mm
Heat Flux (1.5W/mm2) & Radiation (To Ambient)

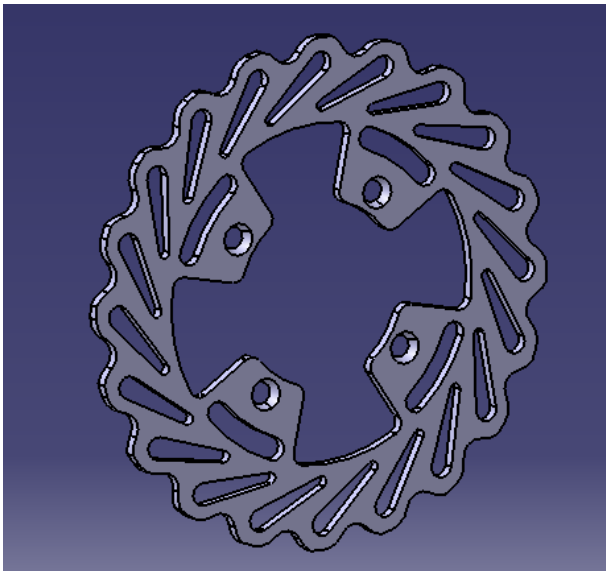

Figure 2 - CAD Model of Brake Disc

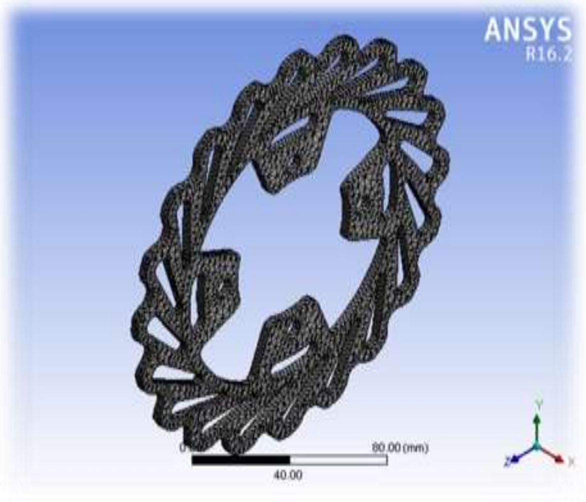

Figure 3 - FE Model of Brake Disc

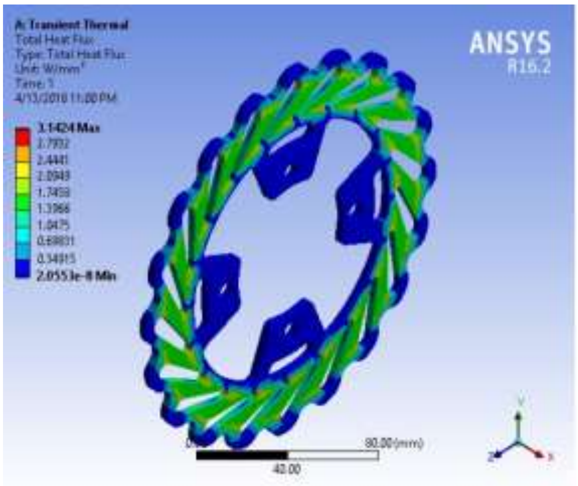

Figure 4 - Heat Flux

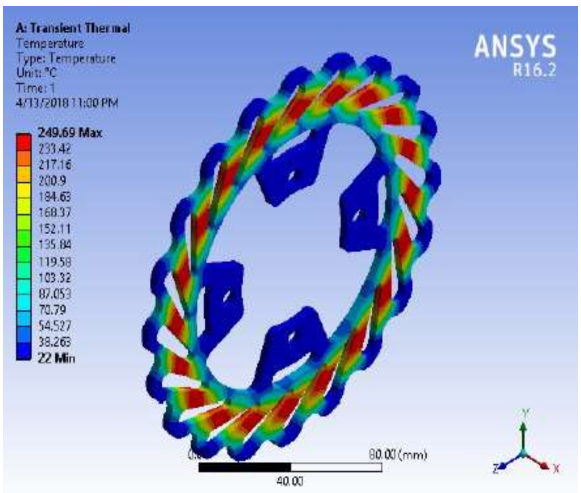

Figure 5 - Temperature

5.3 DESIGN AND ANALYSIS OF BRAKE PEDAL

Brake Pedal material – 6061 Aluminium
Mesh quality – Number of nodes – 19521
Number of elements – 79689
Loading Conditions – Pedal force applied by driver – 250 N

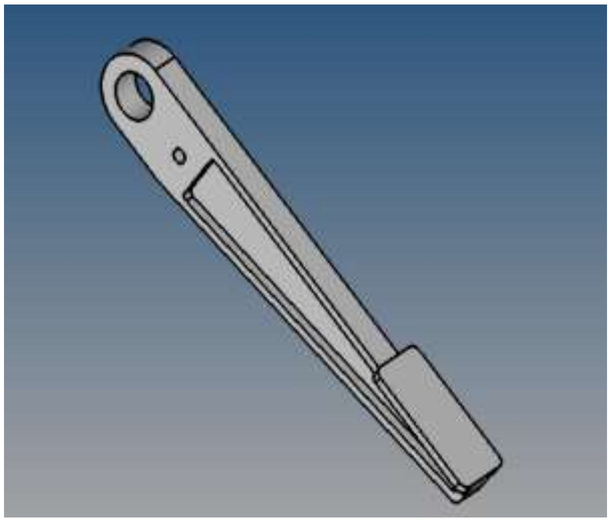

Figure 6 - CAD Model of brake pedal

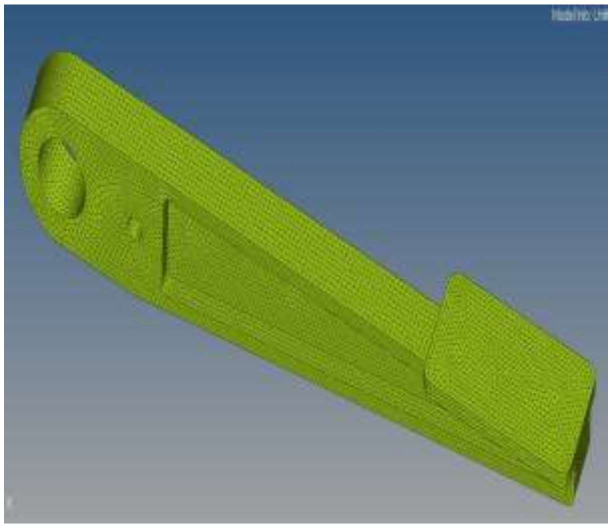

Figure 7 - FE Model of brake pedal

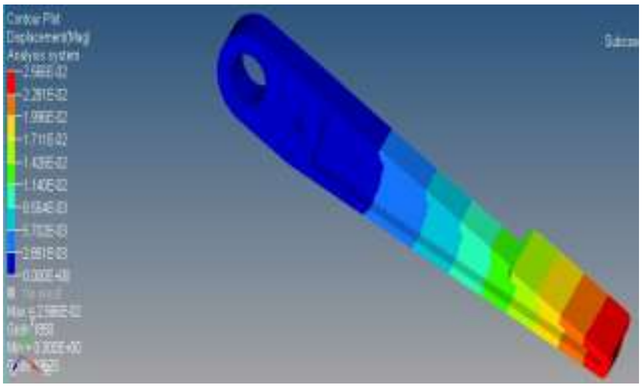

Figure 8 - Maximum displacement

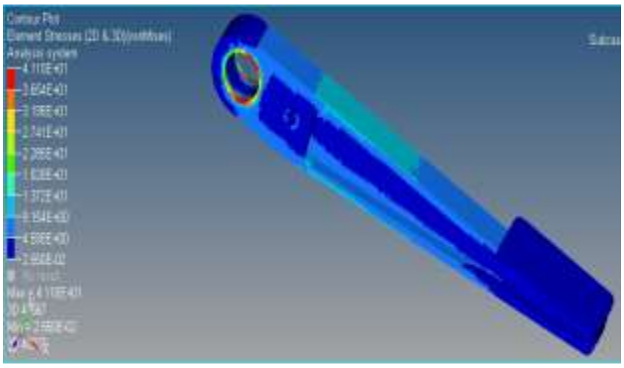

Figure 9 - Element stress result

5.4 FABRICATED PARTS AND ASSEMBLY

Figure 10 - Manufactured brake disc

Manufacturing Process – Laser Cutting

Surface finishing operation – Surface Grinding

Figure 11 - Brake pedal Assembly

Brake Pedal Manufacturing process - Milling

6. CONCLUSIONS

The brake assembly is one of the most important parts of any automotive system. The above designed brake assembly is used in BAJA ATV during BAJA SAE India 2018 and brake test during the event was cleared in the first attempt itself.

ACKNOWLEDGEMENT

We would like to thank our team members from 'Team Mechasonics' for their support during the whole process. We would also like to thank 'Prashanti Engineering Pvt. Ltd Pithampur' and 'Hindustan Equipment Indore' for the fabrication of our brake parts and Mr. Dhawal Singh Kushwaha for their constant support during the designing and fabrication of the braking system.

REFERENCES

[1] S. Mishra and S. Jandhu, "Balance bar design and motion analysis of pushrod". International Journal of Mechanical Engineering and Robotics Research. Vol.3, No.3, July 2014.

[2] P. Jain and H. Garani, "Analysis And Assessment of Dual Brake Circuits". International Journal of Mechanical Engineering and Technology. Vol.7 Issue5 September-October 2016.

[3] Swapnil R. Abhang, "Design and Analysis of Disc Brake". International Journal of Engineering Trend and Technology – Vol. 8 No. 4 2014.

[4] T. Gillespie, Fundamental of Vehicle Dynamics. SAE International, 1992.

[5] W. Milliken, D. Milliken and L Metz, Race Car Vehicle Dynamics. SAE International, 1997.

[6] Joseph Heitner, Elements of Automotive Mechanics (2nd Edition). D Van Nostrand Company.

[7] Fred Puhn, brake Handbook. HP Trade.

[8] J. Wong, Theory of Ground Vehicles. Wiley, 1993.