DESIGN AND ANALYSIS OF BRAKING SYSTEM FOR BAJA ALL-TERRAIN-VEHICLE

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ABSTRACT-*ATV is a vehicle that can move on almost all type of terrain and travels on low pressure tires. Society of automotive engineers(SAE),India organizes an ATV designing event for engineering undergraduates known as BAJA. SAE-BAJA event involves designing, fabrication and validation of a single seater four wheeled all terrain vehicle which takes part in a series of off-roading events which tests its manoeuvrability, acceleration, durability, gradability and braking characteristics. As the safety of the driver is paramount in such events there is a need to design and fabricate a safe and reliable braking system. This paper aims to use various braking component in the system and design a effective braking system considering various scenarios of the event.*

KEY WORDS: **Baja SAE, All Terrain Vehicle (ATV), Braking system, Disc rotor, Hydraulic Braking, Buggy**

1. INTRODUCTION

Baja events organised by society of automotive engineers involves designing, fabrication, validation and racing of an All terrain vehicle by following the specification as mentioned in the baja-rulebook [1]. As per American National Standards Institute (ANSI) , ATV is mechanised off-road vehicle which can move on almost all type of terrain with low pressure tires [2]. The ATV which is developed for this event is the modified version of the ATV which is defined by ANSI.

Braking system of such a vehicle plays an important role in the event and in the safety of the driver. Brakes are the mechanical devices whose basic function is to decelerate the motion of a moving vehicle or to stop a moving vehicle. The main objective of the braking system is to lock all the four wheels of the All terrain vehicle [1]. Braking system works on the principle of energy conversion in which kinetic energy is converted into thermal energy. When the brake is applied, the brake pads squeeze against the disc brake rotor and a conversion of kinetic energy into thermal energy via friction takes places which leads to effective braking [3].

The main objective is to design a fully effective braking system in the limited space allocated to it. As Baja ATV needs to be light in weight so it requires a light and compact braking system which can be reliable and can work under extreme stressful conditions. A proper selection and placement of the components of braking system in the minimum possible space is necessary.

2. OVERVIEW OF BRAKING SYSTEM

The main objective is to design a light, compact, effective and reliable braking system which can lock all the four wheels of the buggy at the same time in almost all type of terrain[1]. The focus is given to reduce the weight because weight increases the unsprung mass of the vehicle and it unbalances the vehicle. Hydraulic Disc brake is used in the ATV because it has a lot of advantage which includes but not limited to more effective braking force, light weight, better heat dissipation, more durability etc.

2.1. BRAKE PEDAL

Brake pedal is that component of the braking system which transfers the force from the foot of the driver to the push-rod of the master cylinder[3]. Brake pedal that is used in the buggy is made up of mild steel(1018) because it can withstand the force exerted by the driver on it and also the force it exerts on the push rod of master cylinder without undergoing any deformation. Pedal ratio is about 5:1 which show that the force applied by the pedal on the master cylinder is 5 times more than the force applied by the driver on it. Reverse swing pedal mechanism is used because buggy nose is small and for normal swing pedal mechanism a longer nose is required which is not available.

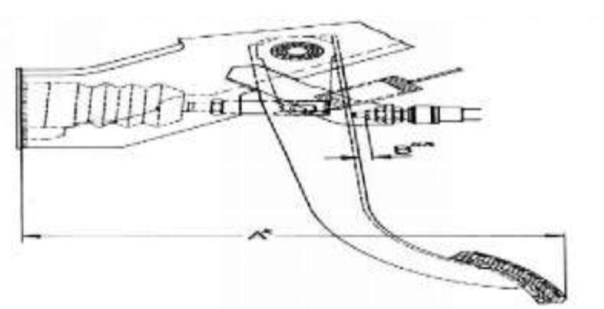

FIG-1:BRAKE PEDAL

2.2. MASTER CYLINDER

Master cylinder is a device which is used to transfer the force from the brake pedal to the brake calliper through the brake lines[3]. When brake pedal is pressed by the driver, the push road of the master cylinder is pressed by the pedal and then it creates pressure in the compression chamber of the master cylinder and tries to compress the brake fluid, but as brake fluids are incompressible, they move with a great force through brake lines to the brake calipers.

Bosch tandem master cylinder of Bore diameter 19.05mm is used because it has four outlet ports out of which two outlet ports can be connected to the pressure switches as specified in the Baja rulebook[1] and other two ports can be connected to the brake lines for effective braking and moreover it is a dual piston master cylinder due to which it can produce enough pressure even in case of failure of one piston.

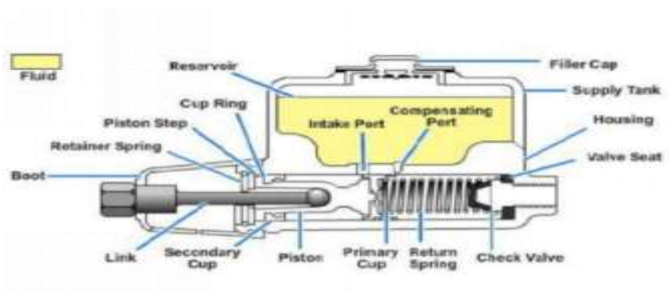

FIG-2: TANDEM MASTER CYLINDER

2.3. BRAKE HOSE

The purpose of the brake line is to transfer the pressure from the master cylinder to the brake caliper. Brake hose are classified into three types: Rubber brake hose, flexi steel-braided brake hose, Rigid steel-braided brake hose[3]. Flexi steel-braided brake hose is used in the ATV because it is quite flexible and can transfer the pressure to the brake calipers without any distortion. Moreover if Rubber brake hose would have been used then it would have expanded due to high pressure transferred by the master cylinder and moreover Rigid steel-braided brake hose also cannot be used because it cannot be installed in the buggy as it does not come in appropriate bending as required by the buggy.

FIG-3: FLEXI STEEL-BRAIDED BRAKE HOSE

2.4. BRAKE CALIPERS

Brake calipers are the devices which uses hydraulic force from the master cylinder to squeeze the brake pads against the disc brake rotor. There are two type of brake calipers: fixed calipers and floating calipers[3].Fixed type of caliper is used in the braking system as it has more clamping force than the floating type. The rim part of the buggy is very compact and moreover the diameter of the disc rotor is 6.5'',So Willwood PS1 fixed caliper addresses all these problems as it is very compact and it can be used with the disc rotor having diameter 6''-9'' in addition to that Willwood PS1 caliper is light in weight due to which it reduces the unsprung mass of the vehicle. So this caliper is used as it fulfills all the requirements of the buggy and helps in providing an effective clamping force.

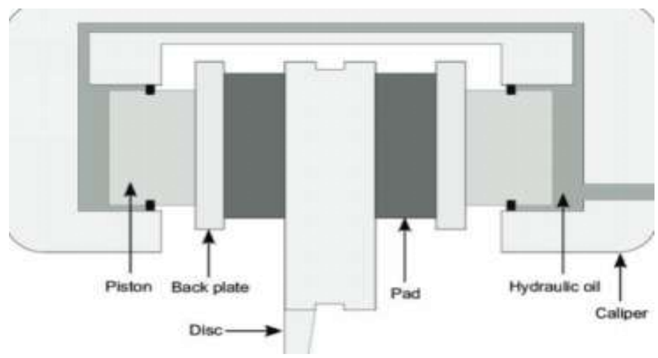

FIG-4: FIXED CALLIPER

2.5. BRAKE ROTOR

Disc brake rotor is that part of the braking system to which the brake pads are squeezed against which results in stopping of vehicle [3]. Material selection is an important process which directly influences the ability of the braking system. When the brake pads squeeze against the disc brake rotor kinetic energy is converted into thermal energy and due to this conversion of energy, the vehicle decelerates and eventually stops. In this energy conversion process heat is formed which has to be eliminated, so holes are drilled on the brake rotor. These holes are known as stud holes [3].

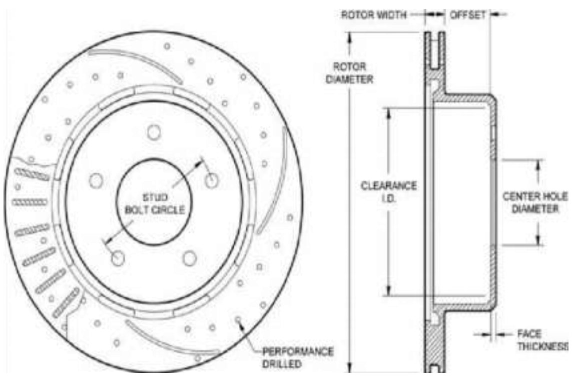

FIG-5: DISC BRAKE ROTOR

2.5.1. MATERIAL SELECTION

	GREY CAST IRON	STEEL AISI 1020	ALUMINUM 2024
Yield Strength (Mpa)	98-280	350	758
Density (g/cc)	7.2	7.87	2.8
Thermal Conductivity (W/m-K)	46	51.9	140
Specific Heat Capacity (J/kg-K)	460.5	510.8	921.1
Coefficient of Thermal Expansion (/K)	1.1×10^{-5}	1.17×10^{-5}	2.3×10^{-5}
Melting Point (deg C)	1180	1450	500
Overall Heat Transfer Coefficient (W/m^2K) (Air-Rotor-Air)	5.7	7.9	25

TABLE-1: COMPARISION OF MATERIALS

Initially Grey cast iron, Stainless steel and aluminium are considered to be analyzed so that one of them can be used as the material of the rotor. By comparing the properties in the Table-1,it is observed that the yield strength of the aluminium is highest.

Moreover density of the aluminium is lowest as compared to other two so it would be of light weight which is preferable. Aluminium has better thermal conductivity than the other two materials which could lead to better dissipation of heat throughout the rotor, but coefficient of thermal expansion is double of the other two materials, which means that the rotor material will expand on heating which is indeed a disadvantage. When melting point of the three materials are compared, it is observed that the aluminium has the lowest melting point as compared to other two.

During endurance event of the Baja, the temperature of he rotor material rises up to 300°C or even more so despite having most of the better properties than the other two, aluminium is not chosen as the rotor material. So when again comparison is done between grey cast iron and stainless steel, it is observed that steel has the better property so it is chosen as the rotor material.

Properties	
Density	0.276 lb./in^3
Specific Gravity	7.65
Melting Range	2700 – 2790°F (1482-1532°C)
Modulus of Elasticity	29 x 10^6 psi (200 GPa)

TABLE-2: PHSICAL PROPERTIES OF SS410

Stainless steel of grade 410 has low density and specific gravity which can be observed from the figures illustrated in the table-2.So stainless steel has light weight which helps in gaining better performance as well as it reduces the unsprung mass of the buggy. In addition to the density and specific gravity, melting range of SS410 is also high ,so it can withstand exposure to extreme temperature. Moreover SS410 is corrosion resistant. So it is concluded that the stainless steel of grade 410 is best to be used as the rotor material.

2.6. T-SPLITTER

T splitter is a device which divides the brake line coming from the outlet port of the master cylinder into two parts so that the pressure can be transmitted equally without any distortion to two calipers from one outlet port [3].

FIG-6: T-SPLITTER

3. BRAKE CALCULATIONS:

3.1. PRE-REQUISITE DATA FOR CALCULATION:

Mass of the Buggy:210kg

Bore diameter of the master cylinder:19.05mm

Force on pedal:300N

Coefficient of friction between brake pedal and rotor:0.40

Coefficient of friction between road and tire:0.70

Velocity of the buggy:12.5m/s

Bore radius of calliper piston:12.7mm

C.G height:394.208 cm

Wheel base:1473.2 cm

Tire radius:292.15 cm

Percentage of weight in the front:45%

Percentage of weight in the rear:55%

Pedal ratio-5:1

3.2. CALCULATIONS:

1.Bore area of master cylinder:

(π×d × d)/4 = (3.14×19.05×19.05)/4 = 284.878mm

2.Bore area of calliper piston=3.14×2.7×2.7=506.450mm ^{2}

3.Force on master cylinder: Force of pedal ×pedal ratio= 300N×5=1500N

4.Pressure generated by master cylinder = 1500/284.878 =5.265N/mm^2

5.Pressure generated by master cylinder = Pressure transmitted to all the calliper

6.Force generated by the calliper: pressure on calliper× area of calliper piston=5.265×506.450=2666.459N

7.Clamping force=2×Force generated by the calliper

=5332.918N

8.Frictional force generated between brake pads

and rotor = 5332.918 ×0.4N = 2133.167N

9.Torque generated by rotor = 2133.167 ×2.75×25.4 =149001.742N

10.Force between tire and ground=149001.742/22.1

=510.105N

11.Total braking force=sum of all the forces on all tires

=510.105×4 = 2040.420N

12.Deceleration of a vehicle in motion =2040.420/210

= 9.716m/s^2

13.Stopping distance=(12.5×12.5)/(2×9.716)

=8.04m

14.Static front weight=Total weight× 45/100)

=210×45/100) = 927.045N

15.Static rear weight=Total weight×55/100)

=210×55/100) = 1133.055N

16.Absolute weight transfer

=(9.716×394.208×210×9.8)/(9.81×1473.2) = 545.972

17.Dynamic front weight: static front weight+ absolute weight transfer=927.045+545.972=1473.017N

18.Dynamic rear weight=Static rear weight-absolute weight transfer=1133.055-545.972=587.083N

19.Dynamic front torque= dynamic front weight ×tire radius ×friction between tire and road

= 1473.017×292 .15×0.7 = 301239.341N

20.Dynamic rear torque=dynamic rear weight ×tire radius ×friction between tire and road

= 587.083×292.15×0.7 =120061.408N

21.Minimum effective rotor diameter:-

21.1.Front:-

=(2×front tire torque)/front clamping force

=(2×301239.31)/(5332.918)

=112.973mm=4.447 inch

21.2.Rear:-

=(2×rear tire torque)/rear clamping force

=(2×120061.408)/(5332.918) = 1.772 inch

22.Brake heating:-

22.1.Kinetic energy=(1/2)×m × v^2

=0.5×210×12.5×12.5 =16406.25J

22.2.Rotational energy=0.03×16406.25 = 492.18J

23.Braking time=velocity/deceleration = 12.5/9.716=1.286 sec

4. ANALYSIS OF BRAKE ROTOR

Material of the rotor: SS410

By doing FEA analysis of the material it was found that the maximum heat flux is 56425w/m^2 and maximum temperature is 45.824°C which is within the permissible limits.

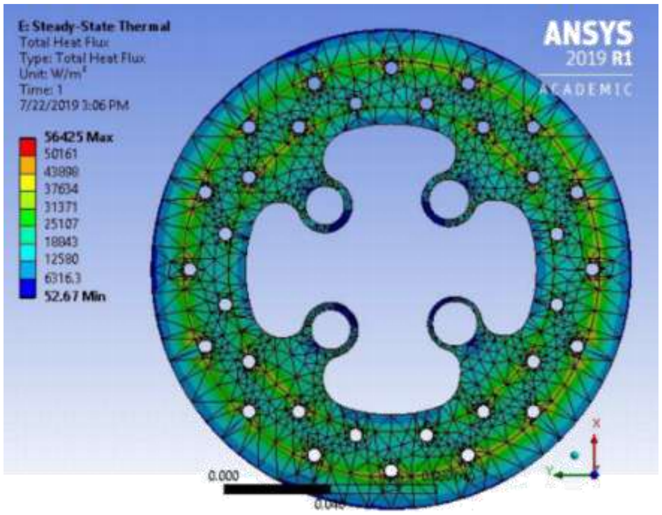

FIG-7: TOTAL HEAT FLUX

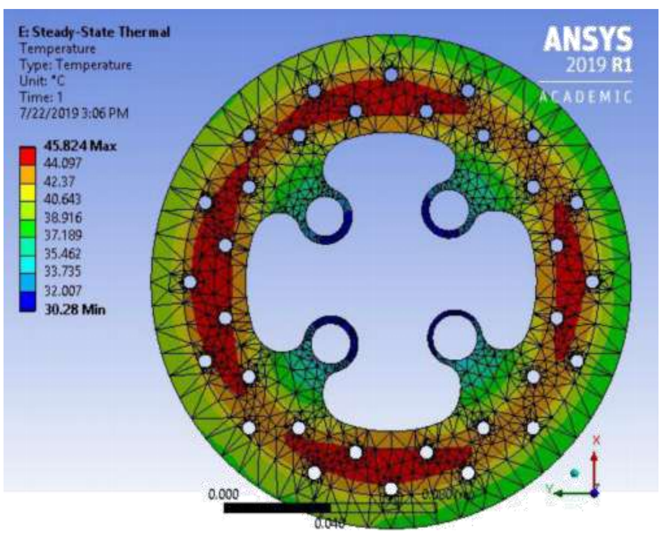

FIG-8: TEMPERATURE DISTRIBUTION

5. CONCLUSION

The designed braking system is effective, reliable and has minimum weight without any compromise in its safety standards and performance. Moreover by analyzing brake rotor it was found that the maximum temperature is obtained at the brake pad contact surface and is 45.824°C which is concluded as very much safe during the arduous endurance event of BAJA.

6. REFERENCES

[1]2020 baja-rulebook https://www.bajasaeindia.org

[2] American national standards institute https://www.ansi.org/

[3] Automobile engineering, Kirpal singh,vol-1

7. BIOGRAPHY

Sourav Pattnaik is currently pursuing B.Tech degree in Mechanical Engineering from Kalinga Institute of Industrial Technology, Bhubaneswar, Odisha, India. He is a member of Society of Automotive Engineers(SAE).