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Optimum Design and Experimental Analysis of Brake System for BAJA ATV

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ABSTRACT-***The main objective of our research paper has been focused on design and experimental analysis of brake system for All-Terrain Vehicle (ATV) which was participated in BAJA 2016. Each component of braking system was designed on CATIA-V5 whereas analyzing of stress and temperature distribution was done by ANSYS-16. The important parameters for experimental analysis of brake system were brake material, heat generation and heat distribution of disc. The material selection was based on their yield strength, thermal conductivity, cost and its availability in the market. Yield strength and thermal conductivity which was the primary requirements for a braking system. It was achieved by the austempering (yield strength 610 MPa to 1356 MPa) and sandwich rotor technique respectively to reduce the problem of fading of brakes.***

Keywords— BAJA, All Terrain Vehicle, Disc,Brake, Heat**.**

I. INTRODUCTION

The braking system in an ATV plays a crucial role in maintaining control on the vehicle by slow the vehicle quickly and reliably under varying condition. An efficient braking system can produce optimum deceleration of the vehicle as per the drive conditions, thus improving the controllability of a vehicle. There are many type of brake system that have been used since the inception of the motor car, but the principle they all used are similar.

The principle of the disc brake was first patented by Frederick Lanchester in his Birmingham factory in 1902, but was not popular until the spectacular win by Jaguar racing cars in 1957 that their advantages were visibly demonstrated to the motoring public. Since the early 1960s, disc brake system have become more common form in the most of the vehicle[1]. After seeing the advantages like less Heat Generation, better heat distribution, reduce stopping distance, better efficiency and the scope of the disc brake in the near future, therefore the main focus to improve the performance, quality and efficiency of the disc brake.

An analysis on the brakes system of our previous vehicle designed for BAJA SAE INDIA 2016 was based on its performance, so as to detect the design flaws and potential improvements that can be made to improve the design.

II. DESIGN METHODOLOGY

The key points drawn out of analysis in the previous year design was improved by the various method in the new design are as follows-

Previous year disc rotor had a problem of brake fading at higher temperature because of ineffective cooling due to inboard braking system. To overcome this, a “Sandwich” Rotor design was used in which Aluminium 7075 T6 sheet have been sandwiched SS 420 sheets. This design allows higher rate of heat dissipation because of higher thermal conductivity of Aluminium (130 W/mk) as compared to stainless steel (25 W/mk). This optimized the design of front disc rotor and achieve weight reduction by 20%.

In the previous design the two T-point type hydraulic brake switches were used which led to more number of connection points in brake line and hence more leakage points. This year, Banjo brake light pressure switches is use in which led to decrease in number of leakage points and increase serviceability of the vehicle.

In the previous design, combination of rigid and flexible brake lines was used. This time, Stainless steel braided flexible brake lines is use in which higher working pressure, negligible volume expansion as compared to rubber brake lines.

The main motive of this paper is to show the step by step procedure followed in designing the braking system for an All-Terrain Vehicle, which was designed and fabricated for participating in BAJA SAE INDIA 2018. This paper focuses on designing, fabricating and testing of different components incorporated in the braking system. During the design the main focus is to increase the performance by providing the robust system with high performance to weight ratio, optimized design as per the load and performance requirements with allowable Factor of Safety, Better heat dissipation in rear disc rotor to reduce Brake Fading, Reduction in bleeding time to increase serviceability.

III. DESIGN of BRAKE ASSEMBLY

A. Brake Configuration

Disc brake configuration is opted for both front and rear of the vehicle because of its relatively high heat dissipation capacity and less maintenance requirements than others. The configuration is:

1. *Conventional Outboard system is used in front.*

Fig. 1 Front brake assembly

2. *Inboard system is used in rear to reduce inertia which leads to increase performance of vehicle.*

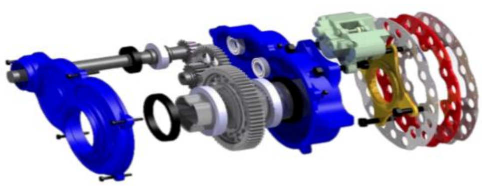


Fig. 2 Rear brake assembly

B.Pedal Assembly

1. Master Cylinder:

Lesser is the bore diameter of master cylinder, higher will be the force multiplication, lower will be the driver effort. Based on the market availability, Bosch master cylinder of bore diameter 19.05 mm has been selected because of its low bore diameter and simple and suitable mounting requirements.

2. Brake Pedal:

The brake pedal was to be designed to provide high force multiplication and hence, it reduces the driver effort. It also sustains pedal force up to 1200N which a driver can apply during panic braking.

This time, a Pedal Ratio of 6.5 was used unlike previous year's was 6. This was required to provide high braking torque in the rear equal to the torque at the spool shaft on which the rotor has been mounted. This helps in keeping the rear tyre locked in static condition when the engine is giving its maximum torque. This is beneficial in the acceleration and Hill Climb events.

C. Brake Lines:

Due to very less pressure loss in the lines, the maximum pedal force is utilized in pushing the air bubbles out of the brake line. This reduce the brake action time and make it faster.

It also helps in reducing the overall weight of the vehicle as the weight of brake lines has decreased by 56% from the last year brake lines which increase the overall performance of the vehicle.It also helps in reducing the overall weight of the vehicle as the weight of brake lines has decreased by 56% from the last year brake lines which increase the overall performance of the vehicle.

Table 1.
Brake line Pressure Ratings

Working Pressure in the system (600 N)	1980 psi
Maximum pressure in the system (1000 N)	3312 psi
Maximum working pressure of steel braided brake line	4000 psi
Maximum working pressure of rubber brake line	3000 psi
Volumetric expansion of rubber brake line	1.24 cc
Volumetric expansion of steel braided brake line	0.001 cc

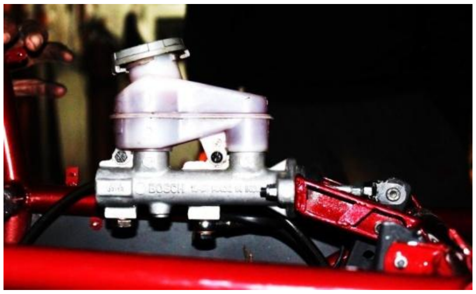


Fig 3. Brake pedal assembly with master cylinder mounting

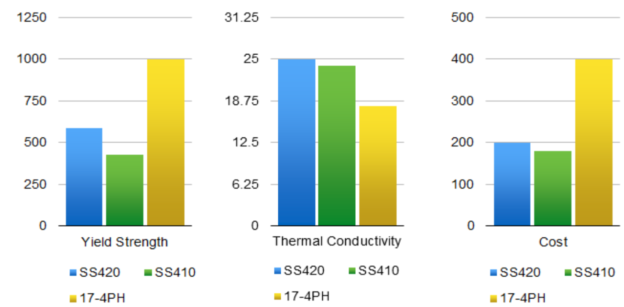


Fig. 4 Material selection with property

1. Brake Caliper

Calipers play an important role not only in application of braking force but also in the design of upright. Wilwood PS1 Brake Calipers in the front as well as rear of the vehicle was used. They have these unique characteristics:

2. Brake Rotor

Before designing a rotor, it is important to determine the dimensions of a rotor, based on the torque, heat flux calculations and the material of rotor. The calculations have been done and the final dimensions of front and rear rotor are tabulated as follows:

Table 2.
Rotor Specifications

PARAMETER	FRONT ROTOR	REAR ROTOR
Outer diameter	160 mm	210 mm
No. of mounting holes/dimension	4/6 mm	4/8 mm
PCD of mounting points	70 mm	136 mm
Thickness	3.5 mm	4.5 mm

IV. MATERIAL SELECTION

The effectiveness of the component depends on the material of the component therefore it is crucial that the material chosen provides performance, as well as cost effectiveness and ease of manufacturability.

A. Front disc rotor :

The SS420 was selected because of its good thermal conductivity, high yield strength after heat treatment, low cost, high hardness, wear resistance and corrosion resistance.

B. Front Rotor Design

The rotors being one of the most crucial part of the brakes system, it designed to sustain the braking torque applied by the calipers to efficient distribution of stresses. Also, good heat dissipation and temperature distribution is mandatory so as to avoid brake fade while long run.

As front rotors are exposed to the air passing by during the vehicle run, the convective heat transfer coefficient is good enough to maintain the temperature of the rotor at a safer level even during long run. Hence, the design was more focused on the stress distribution rather than heat distribution.

Initially, some preliminary designs have been made and checked for the stresses generated while braking, on ANSYS 14.0. Out of the results, few conclusions were made regarding the stress distribution on the rotor which are as follows:

• The compressive and tensile stresses was observed on the both sides of the caliper which were tangential in direction.

• The tangential stresses were observed even at the mounting points of the rotor.

1) Design Considerations

• Front disc rotor must have better stress flow pattern so that better stress distribution will take place.

• Disc rotor design should be optimized so that inertia of the vehicle reduces to increase the performance.

To achieve the required design prospective,decreased the rib thickness of disc from 4.8 mm to 3.8 mm. Hence, weight reduction of 19% was possible by this design optimization. For better stress flow, number of ribs was increased and so that tangential stresses can be easily distributed.

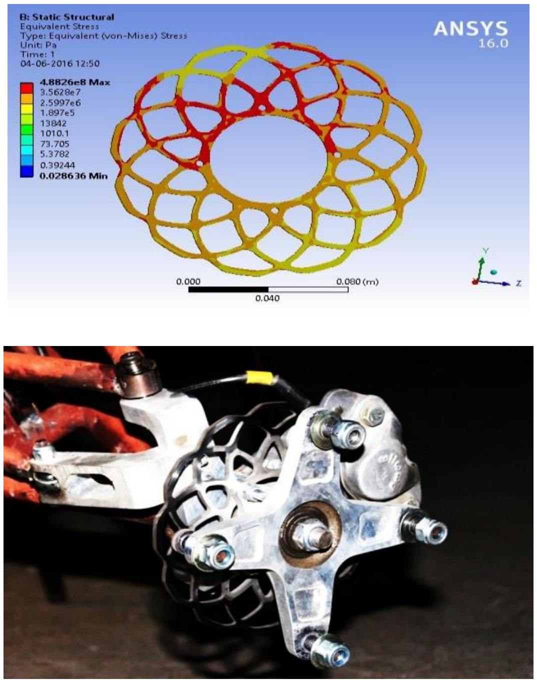


Fig.5 Present year design of disc and simulation analysis

2) Manufacturing process

- Firstly, Austempering is done on the sheet of SS420 at a temperature of 232^{o}C to 400^{o}C. At this temperature, SS420 material achieves yield strength of 1356 MPa.
- Then, water jet cutting was used in order to remove cut outs to manufacture the disc rotor.

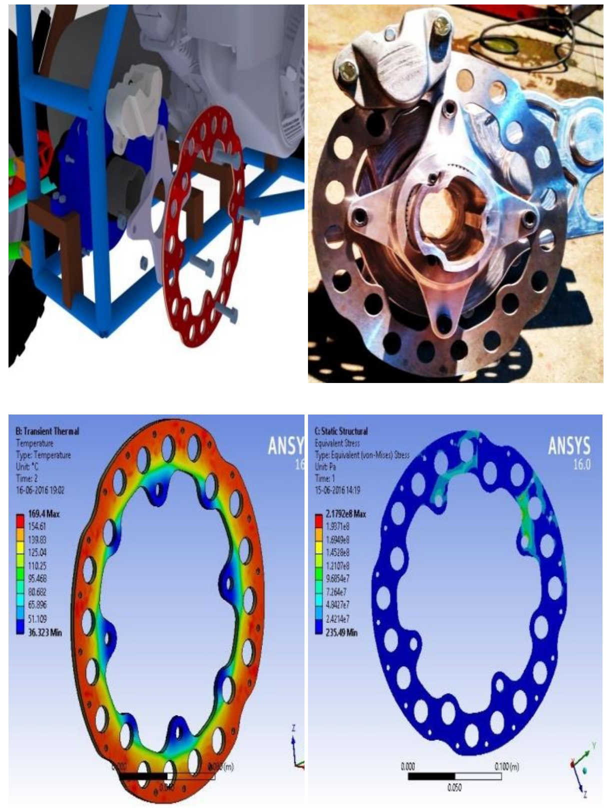
C. Rear rotor design

1) SS-Al-SS Sandwich Design

Unlike the front rotor, the rear rotor has been designed giving more emphasis to heat dissipation rather than the stress distribution. It has been done so because the rear rotor situated beside the gearbox and behind the firewall, was subjected to less ventilation which results in less convective heat transfer and eventually leads to brake fade at high temperatures.

To overcome this problem, we have used an innovative design which we call "SANDWICH ROTOR DESIGN" was use in which we have used Aluminium 7075 disc sandwiched between two Stainless Steel 420 discs was used. This lightweight design allows high rate of heat dissipation than the conventional Stainless Steel design because of high thermal conductivity of Aluminium 7075 (130W/mK) as compared to SS420 (25W/mK).

AISI 1006 Brake Rivets have been used to join the three discs together so to reduce the contact resistance and to achieve maximum heat transfer between SS420 and Aluminium sheet. To reduce contact resistance between the discs, we have also used Aluminium Foil (K= 235W/mK)



Maximum Temperature = 169^{o}C

Maximum Stress = 218Mpa

Fig. 6 Disc Mounting and simulation analysis

V. CALCULATIONS FOR THERMAL EXPANSION

A. Thermal Expansion of SS420

$$\frac{\text{change in area}}{\text{original area}} = 2\times A\times \text{change in temperature}$$

Change in area $= 2\times A\times \alpha\times(\text{change in temperature})$

$= 2\times (0.014\times 10^{6})\times(10.5\times 10^{-6})\times(160-35)$

$= 37\ \text{mm}^2$

B. *Thermal Expansion of Al7075*

Change in area = $2 \times A \times \alpha \times$ (change in temperature)

$$= 2\times (0.014\times 10^{6})\times (22\times 10^{-6})\times (100\text{-}35)$$

$$= 40 \text{ mm}^2$$

The thermal expansion of the two materials is almost same.

Table. 3
Comparison of SS-AL-SS rotor and conventional ss420 rotor

S.NO.	SS-AL-SS	ONLY SS
1	388.36	371
2	444.56	420
3	473.93	431
4	439.04	429.365
5	434.68	428.77
6	430.8	427.89
7	427.09	427.13
8	423.57	426.38

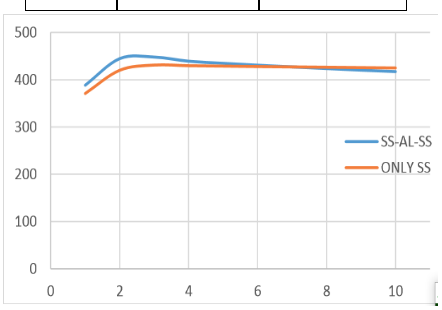


Fig 7. Cooling curve of ss-al-ss rotor and conventional ss420 rotor

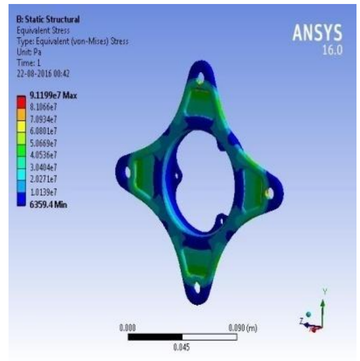


Fig 8. Adapter and Static Analysis

VI. RATE OF COOLING AND BRAKE FLUID

In SS420 normal disc cooling take place by convection only but by sandwich design, aluminium act as a heat sinker and now cooling take place by conduction and convection both. Due to which rate of cooling increases as shown in temperature vs time graph also.

A. Brake fluid

DOT 3 brake fluid of Bosch Company was selected for our vehicle and the specifications of the fluid as per the manufacturer are:

Table. 5
Brake fluid specification

Parameters	DOT3 **DOT Standard**
Dry boiling point in °C	min 205
Wet boiling point °C	min 140
Kinematic Viscosity at -40 °C	1500 max
Kinematic Viscosity at 100 °C	1.5 min
Ph value	7.0 - 11.5

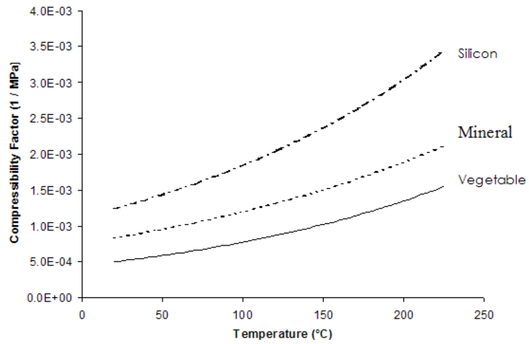


Fig 9. Variation of compressibilty of fluid with temperature

VII. CALCULATION FOR DIMENSION OF ROTOR

Braking force on disc exerted from pedal

Pedal force : 600 N
Pedal ratio : 6.5
Master cylinder bore dia. : 0.75 Inch
Caliper bore dia. : 1.12 Inch
Ratio of bore dia. :2.2304 Inch
Caliper pad and disc friction coef. :0.35
Brakingforce=$600\times6.5\times2.32\times0.35\times2$=6088.02 N
Vehicle weight consider for calculation: 230 Kg
Deceleration (a) : 0.8 g
Traction coefficient (μ): 0.8
C.G Height : 17 Inch
Wheel base : 54 Inch
C.G height/ Wheel base (γ): 0.31481
Weight distribution :Front-45% Rear-55%

Therefore, Static axel load distribution (ν) =

$$\frac{\text{static rear axel load}}{\text{vehicle weight (W)}} = 0.45$$

A. Front Disc Calculation

Dynamic normal load on the front axel($F_{zf,dyn}$) =

$(1-\nu+\gamma a)$ W =$(1-.45+0.314\times0.8)2300$
=1583.588333 N

Dynamic normal load on each tyre =

$$\frac{F_{zf,dyn}}{2} = \quad 791.7941667 \text{ N}$$

Tractive force = 791.79×0.8
= 633.435333 N
Braking torque = $633.43\times11\times0.0254$
= 176.981832 Nm

Factor safety = 1.25
Braking torque on front wheel = 176.98×1.2
=221.2202 Nm
Radius of disc = 221.227/6088.02
= 36.34 mm
Diameter of front disc = $(36.34 + 13)\times2$
=98.67 mm

Due to restrictive of the brake caliper and the design of hub, the diameter of 160 mm has been chosen for the front disc.

B. Rear Disc Calculations

Maximum torque on speed shaft :550 Nm
Radius of disc :90.34 mm
Diameter of rear disc :206.682 mm

Hence, diameter of 210 mm has been chosen for the rear disc.

VIII. HEAT FLUX CALCULATION

Mass of the vehicle consider (M) = 230 Kg

Vehicle speed (v) =58 Km/h =16.11 m/s

Braking time $= \dfrac{16.66}{0.8\times9.81} = 2.05$ sec.

Kinetic energy of vehicle $=0.5\times M\times v^2$
$= 0.5\times230\times16.11\times16.1 = 31143.85$ J

A. Rotor Heat Absorption Percentage

Some of the useful properties of the rotor and the pad are given below-

Table. 6

PROPERTY	ROTOR (SS 420)	PAD
Density (Kg/m3)	7740	2595
Specific Heat (J/Kg-K)	460	1465
Thermal Conductivity	24.9	1.212

The rotor absorption coefficient (λ) can be found by using

$$\lambda = \frac{1}{1+\sqrt{\dfrac{\rho_p\times c_p\times k_p}{\rho_r\times c_r\times k_r}}}$$

By substituting the valve in the above equation, we get

$$\lambda = \frac{1}{1+\sqrt{\frac{2595\times1465\times1.21}{7740\times460\times24.9}}}$$

Hence, the power absorbed by each of the front rotor can be given by:

$P_{fr} = 6018.22 \times 0.78 = 4694.21$ W

Similarly, Power absorbed by rear rotor is given by:

$P_{rr} = 5357.26 \times 0.78 = 4178.66$ W

Heat flux passing= Power/Area swept by pads through rear disc

= 4178.66/0.014

= 298475.71 W/m^2

B. Brake Hose Expansion

Volume increase for brake hose (V) = C × L × P (cc)

For 3/16" rubber brake hose (C)=47.58 × 10^{-6}cc/(MPa*mm)

For 3/16" steel braided hose,(C) =0.04 × 10^{-6}cc/(MPa*mm)

Length of brake line (L) = 45 Inch. = 1143 mm

Pressure in system (P) = 3312 psi = 22.8 MPa

Volume increase for rubber brake line

= $47.58\times10^{-6}\times1143\times22.8 = 1.24$ cc

Volume increase for steel braided hose

= $0.04\times10^{-6}\times1143\times22.8 = 0.001$ cc

CONCLUSION

This research paper concludes the better results for making the braking system efficient and durable.

[1]. By using the new techniques on the brake and analyzing, the best result for heat and stress distribution of disc, dimensions of rotor, and power absorbed.
[2]. The Heat Flux, Kinetic energy of the vehicle, Rotor heat absorption which improve the braking capacity of the braking system also calculated.
[3]. Reduce the stopping distance which provide the greater safety, stability and controllability during cornering the vehicle in the sharp turn.
[4]. We analyze the thermal expansion and stress distribution of the brake on the ANSYS 16.0 and brake Hose expansion.

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