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# Design of Braking System of BAJA Vehicle

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**Abstract** — *An important factor in handling of any vehicle is making it to come quick and easy stop. Retarding a vehicle in manner such that driver has complete control over it is essential. The safety while braking is paramount and is quantified by evaluating mathematical model of braking. The evaluation of model is done by calculation of braking torque and comparing it with required value. The paper discusses ideas for using various components in the system, design variables and logic behind selecting correct values of those variables. The design of braking system consists of evaluating multitude of scenarios and using them to achieve optimum, yet effective braking. The data related to them is used to extract average values of design parameters, making the theoretical calculations as realistic as possible.*

**Keywords:** *Braking system, Frictional Braking, Biasing effect, Weight Transfer, Hydraulic Pressure, Pascal's Law*

## I. INTRODUCTION

The basic function of braking system is to retard a vehicle in motion A quality braking system enables driver with range of braking effort.[1] This will allow him to feather the pedal for obtaining required amount of braking, getting desired motion while navigating corners and curves. In this way, braking system contributes majorly in terms of safety and handling. Importance of reliable braking mechanism in any vehicle is paramount.

Brakes use principle of energy conversion, transforming kinetic energy in heat, thereby retarding velocity of vehicle. This is achieved by fiction between brake rotor and pads along with clamping force applied by caliper pads. This generates large amount of heat which is dissipated to air. The components in vicinity of such high temperature exhibit excellent thermal stability.[2]

The common goal of designing braking system is to implement a fully effective braking system in allocated space. The features of system should not have interference with other assemblies, either in static or dynamic condition. Therefore, the mounting and packaging of various sub-assemblies is as unique as the design of vehicle it is implemented in. BAJA buggies require compact and light weight systems which are reliable and provide satisfactory braking under tough conditions.

This calls for proper selection of components and their placing in minimum space possible. Components such as rigid pipes are routed such that they do not hinder any other assembly on vehicle. The pedal box requires arrangement such that driver is able to actuate system on moment's notice and can comfortably ride for four hours of endurance race.

An array of calculations dictate the design procedure and validate the condition of wheel-lock. These are performed in iterations to achieve required results

## II. OVERVIEW OF BRAKING ASSEMBLY

The objective of this year's design was to produce light weight brake assembly, reliable throughout different terrains and effective to satisfy the wheel-lock condition. Weight of system is important factor since it adds to unsprung mass and becomes partial reason for unbalance. In addition, the target weight of vehicle is drastically affected by proper utilization of components

Followings are the major components of any braking system:

### 2.1 Master Cylinder:

A master cylinder pressurises braking fluid with help of driver's input. The various types of master cylinder provide designer with range of choices for intended application. A variant of such types is Tandem master cylinder. Tandem master cylinder provides split circuiting for each pair of wheels. This allows driver to brake even if one of the circuit fails due to leakage. Hence, tandem master cylinder was selected.

Due to dynamic weight transfer, front requires more braking torque than rear. This calls for measure of creating brake bias. The biasing effect can be achieved by different means. They include- use of bias bar, use of callipers with different bore and use of stepped master cylinder.[3]

Calipers of different sizes for front and rear are used to create biasing effect. After performing initial iterations of calculations, it was found out that ¾ Inch diameter cylinder satisfies requirements.

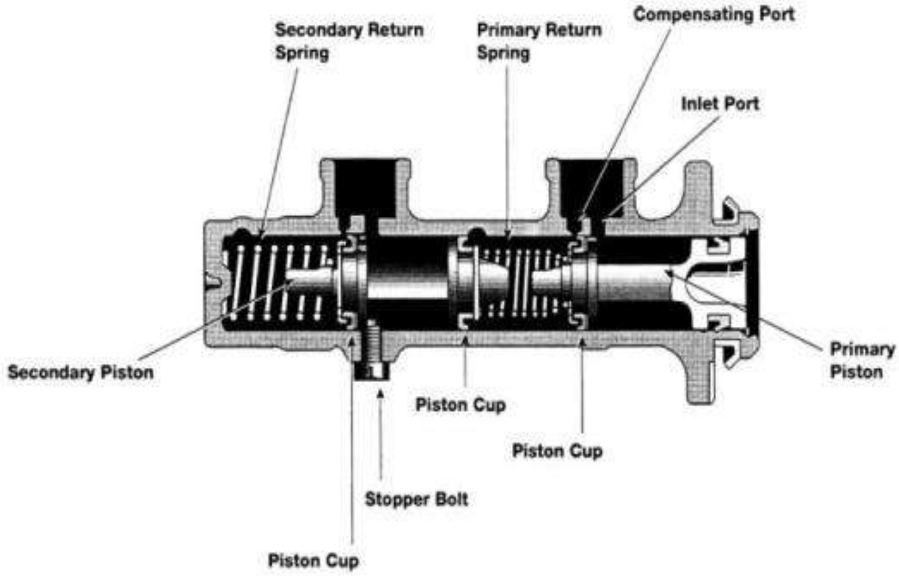



*Figure 1. Tandem master Cylinder*

**2.2 Brake Rotor:**

Main function of brake rotor is to retard motion of wheel. It applies braking torque on the same. There are two types of brakes, viz. disc brakes and drum brakes. Disc brakes are widely used since they are more efficient. They are better in heat dissipation and cool relatively quickly. Brake rotors are clamped in brake pads when brakes are actuated and withstand the compressive forces. The system uses custom brake rotor rather OEM which reduces weight of system considerably.

One of the major parameters that dictate size of brake rotor is diameter of rim. The rotor has to fit properly in packaging space available. For current BAJA vehicle, rim used was of 10-Inch diameter and hence, maximum allowed size for disc was 7 Inch of diameter, after considering size of calliper and clearance space. The minimum size of OEM disc available was 200 mm and hence it was decided to use customised disc with diameter of 175 mm.

The material used for rotor is Stainless steel of grade 410. It is highly resilient to corrosion and wear and ready to be heat treated for increased wear resistance.[4]

*Figure 2. Disc-type brake rotors: Front and Rear*

**2.3 Brake Callipers:**

Once the master cylinder and brake disc size is decided, the other two parameter, which can be varied, are pedal ratio and calliper size. Due to dynamic weight transfer, more braking force is required at the front as compared to rear.[5] The brake force distribution required is 70 % in front and 30 % in rear. It is crucial to maintain this ratio. Hence, It is logical to use a 38mm bore brake calliper in front and a 32mm brake calliper in rear. It also ensures proper brake force distribution as well as brake force balance.

***Figure 3. Floating-type brake calliper***

### 2.4 Brake Pedal Box:

The mounting of brake pedal, along with acceleration pedal should use packaging space wisely. The orientation of brake master cylinder should be such that it will not protrude out of vehicle, i.e. it must lie inside the roll-cage. The pedal should be able to trace curve without any hindrance. One of the important considerations while placing pedal box is that driver should be able to reach both pedals comfortably.[6]

The length of pedal is defined by pedal ratio to be used. Another major constraint is the space available below and behind the pedal for swinging motion. The space is highly compact as it already contains steering column and steering rack, latter covered with protective shielding, which adds up space utilised. Therefore, mounting of pedal should be such that it will satisfy required pedal ration, without obstructing any component.

## III. Braking Calculations

Following calculations are founding stones for designing the braking system. They validate that design satisfies necessary requirements:

***Table 1. Design input variables***

| Data Required for calculations | | | | |
|---|---|---|---|---|
| Sr. No. | Parameter | | Value | Unit |
| 1 | Pedal Ratio | | 5.1 | - |
| 2 | Master Cylinder Bore Diameter | | 19.05 | mm |
| 3 | Brake Rotor | Front | 175 | mm |
| | | Rear | 175 | mm |
| 4 | Weight Distribution Ratio | | 45:55 | - |
| 5 | Total Weight | | 161 | kg |
| 6 | Driver Weight | | 75 | kg |
| 7 | Wheelbase | | 56 | Inch |
| 8 | C.G. Height | | 17.14 | Inch |
| 9 | Static Weight Distribution | | 105.75 | kg |
| | | | 129.25 | kg |

### 3.1 Calculations for torque requirement:

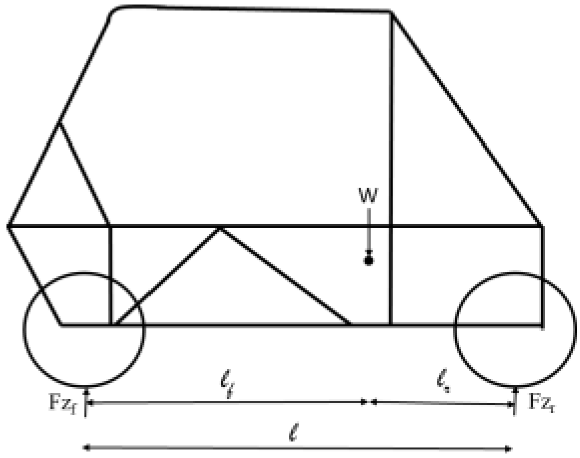



*Figure 4. Schematic representation of weight distribution*

**Abbreviations:**

$Fz_f$ – Front Axle Reaction Force
$Fz_r$ – Rear Axle Reaction Force
$Fx_f$ – Front Axle Braking Force
$Fx_r$ – Rear Axle Braking Force
$Tx_f$ – Front Wheel Braking Torque
$Tx_r$ – Rear Wheel Braking Torque
$l_f$ – Distance of front wheel centre from C.G.
$l_r$- Distance of rear wheel centre from C.G.
a – Acceleration
μ - Coefficient of friction
Δdyn – Dynamic Weight transfer

**Calculations:**

$$L_f = \frac{F_{zR} * L}{W}$$
$$= 30.8"$$
$$L_R = L - L_f$$
$$= 25.2"$$
$$\Psi = \frac{F_{zR}}{W}$$
$$= 0.55$$

Dynamic Axle Load:

$$F_{zF,\ dyn} = (1 - \psi + \chi a)W$$

Where, $\chi = \frac{C.G\ height}{Wheel\ base} = \frac{h}{L}$

$\chi = 0.3060$

Δdyn wt transfer = $\chi a W$

a = μg
μ = 0.503

Therefore, $\Delta dyn = \frac{h}{L} * a * W$
=36.211Kg

$\underline{F_{zF,dyn} = 141.961Kg}$ (1392.63N)

$F_{zR,dyn} = 93.039Kg$ (912.712N)

Front axle Braking force:

$$F_{xF} = \mu * F_{zF}, dyn$$
$$= 947.841 \text{ N}$$

Rear axle Braking force:

$$F_{xR} = \mu * F_{zR}, dyn$$
$$= 638.8988 \text{ N}$$

Torque Calculations:

$$T_{xF} = \frac{F_{xF} * 10.33'' * 25.4}{1000}$$

$$= 255.7807 \text{ Nm}$$

$$T_{xF} = 127.89036 \text{ Nm (single)}$$

$$T_{xR} = \frac{F_{xR} * 10.33'' * 25.4}{1000}$$

$$= 166.6355 \text{ Nm}$$

$$T_{xR} = 83.8177 \text{ Nm (single)}$$

**Validation of Brake Torque Requirement:**

Data:

Master cylinder bore: 19.05mm
Area of master cylinder: $2.85*10^{-4}$ $m^2$
Brake rotor: F: 175mm (72.5mm effective radius)
R: 175mm (72.5 m effective radius)
Calliper front: 38mm(area=1134.1149$mm^2$)
Calliper rear: 32mm(area=804.2477$mm^2$)
Pedal force: 250N
Pedal Ratio= 5:1
Leverage efficiency=0.8

Calculations:

$F_{mc}$ = P.R*P.F*0.8
= 1000N
$P_{mc} = \frac{F_{mc}}{A_{mc}}$ = 35.08489 bar
=3508489.318 N/$m^2$
$F_{calliper} = P_{mc} * A_{calliper} * \eta_{wc}$
$F_{calliper\ front}$ = 3899.054349 N
Force on disc = 2*0.4*3899.05
= 3119.243479 N
$F_{calliper\ rear}$ = 2765.260575 N
Force on disc = 2*0.35*2765.260
= 1995.682403 N
Torque generated:
$Torque_{front}$ = 226.145122 Nm
$Torque_{rear}$ = 140.3369742 Nm

**Results**

*Table 2. Validation of satisfaction of braking torque requirnment*

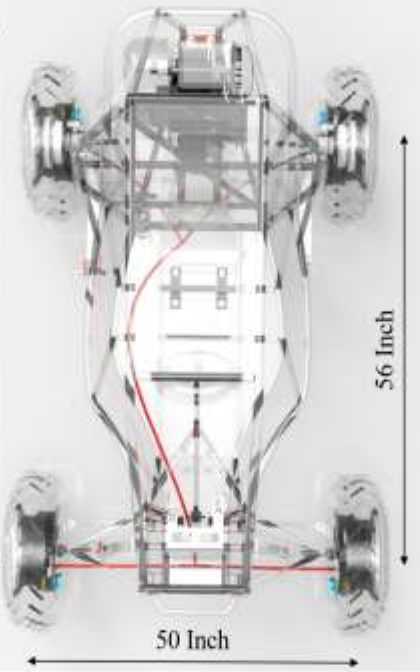
| | Required Braking Torque | Generated Braking Torque |
|---|---|---|
| Front | 127.89036 Nm | 226.145122 Nm |
| Rear | 83.8177 Nm | 140.3369742 Nm |

Hereby we can say that, torque generated at the front and rear is greater than the required torque.

## IV. Braking System Layout

The layout of braking system and specifications of components are as follows:

| Vehicle Specifications (Front) | |
|---|---|
| Tyre Size | 23*7*10 |
| Brake Disc φ | 175 mm |
| Disc Material | SS-410 |
| Disc Weight | 250 Grams |
| Calliper Bore φ | 38 mm |
| Brake Torque Required | 127.89036 Nm (Single) |
| Braking toque generated | 226.145122 Nm (Single) |
| Master Cylinder Bore φ | 19.05 mm |
| Pedal Force | 250 N |




| Vehicle Specifications (Rear) | |
|---|---|
| Tyre Size | 23*7*10 |
| Brake Disc φ | 175 mm |
| Disc Material | SS-410 |
| Disc Weight | 200 Grams |
| Calliper Bore φ | 32 mm |
| Brake Torque Required | 83.8177 Nm (Single) |
| Braking toque generated | 140.3369742 Nm (Single) |

*Figure 5. Specifications of Braking System Components.*

## V. Conclusion

After initial testing of the setup and its implementation on the vehicle, the overall adjustability of the braking system meets the design goals of possessing better and responsive braking system. The other design objective of achieving minimum stopping distance was also achieved. The calculations validate that selected specifications of braking components satisfy the design goal and their use in practice of BAJA vehicle demonstrates competitive system. We can conclude that initial objective of designing braking system for BAJA vehicle is satisfied and serves as ground for further research on said system.

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