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# Design and Evaluation of the Braking System for Solar Car

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***Abstract* - The main objective of this paper is to clarify the type of braking system to be used as primary and secondary brakes. This paper is about design and evaluation of braking system for an electric car, we have emphasized on various aspects which are required for the design and evaluation of system such as theoretical study, analytical calculations, trials on the system and comparison of analytical calculations and actual performance**

## I. INTRODUCTION

"A body maintains its initial motion until or unless an external force applied on it" a statement by Sir Isaac Newton, is been foundation for design of braking system in automobile. Design of an efficient vehicle requires not only a suitable engine as a power source but also an appropriate type of braking system. As far as the brake force concern. the braking force required to decelerate vehicle is proportional to power, weight, and speed of the vehicle. This thought gave rise to many research in the field of braking and results in its evolution due to which today we have flexibility in choosing a suitable braking system according to our need.

Braking system is most important control component of a vehicle which is required for safe driving. A brake is a device that reduces or inhibits vehicle motion by converting kinetic energy into heat energy. The conversion of kinetic energy into heat energy is a function of frictional force generated by the frictional contact between brake shoes and moving drum or disc and brake pads of braking system.

In an automobile brake is needed –

- To stop the moving vehicle.
- To de-accelerate the moving vehicle.
- For stable parking of a vehicle either on a flat surface or on a slope.
- To prevent the vehicle from any damage due to road conditions.

## II. THEORY

Brakes or braking system falls under the one of the control systems of a vehicle. Brakes does decelerate the vehicle but under controlled manner. Brakes are designed in such a manner that they should decelerated the vehicle and prevent the wheels being lock, avoiding the skidding of the vehicle at same time. There are many discoveries are made in the braking system till the date, but Friction is key element behind working of every kind of braking system. Depending upon the working principle and mechanism used the brakes are classified as;

1. Mechanical brakes: Mechanical brakes makes use of mechanical linkages to convey the brake force from peddle to the holding mechanism. Drum brakes, shoe brakes are some of the type of mechanical brakes.
2. Hydraulics brakes: hydraulic brakes make use of hydraulic fluid and hoses as a conveying media. Fluid transmits the brake force from peddle to the holding mechanism. Disc brake is the one of the examples of hydraulic brakes.
3. Pneumatic brakes: The pneumatic braking system are similar to hydraulic system, but the difference is that the working medium is air in the pneumatic system. Rest of the working is same.
4. Electric brakes: The electric brake works on fact that the electromagnetic friction produced in the armature used to decelerate the motion of rotor and slowing down the vehicle.
5. Magnetic brakes: Magnetic brakes works on same principle that of the electromagnetic brakes, difference is the friction produce is purely magnetic.

One should remember the fact that, design of braking system is significantly affected by factors such mass of the vehicle, maximum speed at which it can run, max possible braking efforts can be applied, availability of space and the effect of cost of the system on overall cost of the vehicle.

Another important part of every designer should take into account while designing a braking system is stopping distance. The stopping distance of the vehicle is the minimum safest distance within which the vehicle is decelerated and brought to rest. The stopping distance is again divided into two parts. First part is thinking distance and the other part is braking distance. The thinking distance is actual reaction time taken by driver right from detecting an object on the path to the deciding to apply brakes. One other hand the braking distance is time span counted right from the moment when driver pushes the peddle to the instance when vehicle brought to rest. The braking distance is heavily affected by effectiveness of braking system. This the reason why effective design of braking system is insisted.

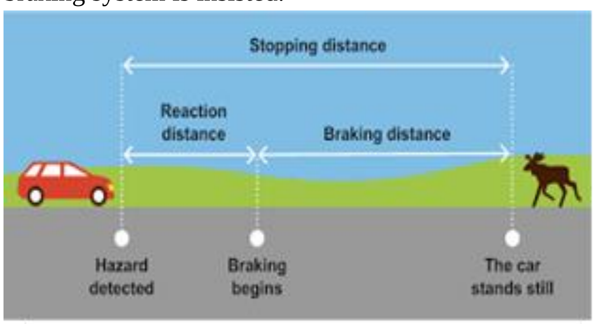


**Figure1: Reaction and Stopping distance**

## III. MATHEMATICAL CALCULATION

As we have mentioned earlier braking effect depends upon certain factors, and we need to consider them while designing the system. Hence, we have considered certain factors and their values as follow.
Mass of the vehicle=350 kg.
Maximum speed of the vehicle=40 kmph

The brake pedal-
The brake pedal exists to multiply the force exerted by the driver's foot. From elementary statics, the force increase will be equal to the driver's applied force multiplied by the lever ratio of the brake.

$Fbp = F_d \times$ Pedal ratio
$= 250 \times 6$
$= 1500$ N

Where;
Fbp=Force output of brake pedal assembly,
$F_d$=Force applied on the pedal by the driver.

The master cylinder-
It is the functional responsibility of the master cylinder to translate the force from the brake pedal assembly into hydraulic fluid pressure. Assuming incompressible liquids and infinitely rigid hydraulic vessels, the pressure generated by the master cylinder will be equal to:

$P_{mc}=F_{bp}/A_{mc}=1500/(\pi/4\times[(0.02)]^2)=47.75\times105 N/m^2$

Where,
$P_{mc}$= Hydraulic press generated by the cylinder
$A_{mc}$=Effective area of cylinder hydraulic piston

Brake fluid, Pipe, and hoses-
It is the functional responsibility of the brake fluid, brake pipes, and hoses to transmit the hydraulic fluid pressure from the master cylinder to the caliper located at the wheel ends. However, again assuming incompressible liquids and infinitely rigid hydraulic vessels, the pressure transmitted to the calipers will be equal to:

$P_{cal}=P_{mc}$

Where,
$P_{cal}$= Hydraulic press to caliper

Force Applied by Caliper-
It is the first functional responsibility of the caliper to transfer the hydraulic fluid pressure from the pipes and hoses into a linear mechanical force. Once again assuming incompressible liquids and infinitely rigid hydraulic vessels, the one-sided linear mechanical force generated by the caliper will be equal to:

$F_{cal}=P_{cal} \times Aca$
$=47.75 \times 105 \times \pi/4 \times (0.041)^2$
$=6304.21N$

Where;
$F_{cal}$ = the one-sided linear mechanical force generated by the caliper.
$A_{cal}$ = the effective area of the caliper hydraulic piston(s) found on One half of the caliper body.

Clamping Force-
The amount of force it can apply to the surface of a rotor is known as Clamping force. It is the second functional responsibility of the caliper to react the one-sided linear mechanical force in such a way that a clamping force is generated between the two halves of the caliper body. Regardless of caliper design (fi × ed body or floating body), the clamping force will be equal to, in theory, twice the linear mechanical force as follows:

$F_{camp}=F_{cal} \times 2$
$=6304.21 \times 2$
$=12608.42$ N
Where;
$F_{clamp}$ = The clamp force generated by the caliper.

Frictional force on brake pads-
The brake pads will generate a frictional force which opposes the rotation of the spinning rotor assembly. This frictional force is related to the caliper clamp force as follows:
$F_{friction}=F_{clamp} \times \mu b$
$=12608.42 \times 0.385$
$=4854.25$ N
Where:
$\mu bp$ = Coefficient of friction.
$F_{friction}$=The frictional force generated by the brake pads opposing the Rotation of the rotor.

Rotating Torque-
Generally, rotors are vented to aid in cooling and keep braking consistent and overheating. It is the functional responsibility of the rotor to generate a retarding torque as a function of the brake pad frictional force. This torque is related to the brake pad frictional force as follows:
$Tr= F_{friction} \times R_{effective}$
$=4854.25 \times 0.060$
$=291.255$ N-m
Because the rotor is mechanically coupled to the hub and wheel assembly, and because the tire is assumed to be rigidly attached to the wheel, the torque will be constant throughout the entire rotating assembly as follows:
Tt = Tw = Tr
Where.
Tt = the torque found in the tire
Tw = the torque found in the wheel
$R_{eff}$ = the effective radius (effective moment arm) of the rotor (measured from the rotor centre of rotation to the centre of pressure of the caliper pistons).

The tire-
$F_{tire}= \frac{T_t}{R_t}= \frac{291.255}{0.2169}=1342.81$ N
$F_{total}=F_{tire} \times 2 =1342.81 \times 2 = 2685.62$ N
Where;
$F_{total}$ = the total braking force reacted between the vehicle and the ground
$F_{tire}$ = the force reacted between the tire and the ground (assuming friction exists to support the force)

Deceleration of a vehicle in motion-
If a force is exerted on a body it will experience a commensurate acceleration. Convention dictates that accelerations which oppose the direction of travel are called decelerations. In the case of a vehicle experiencing a braking force, the deceleration of the vehicle will be equal to:
$G_v=\frac{F_{total}}{M_v} = \frac{2685.62}{350}=7.41$ M/S$^2$
$M_v$=Gross Mass of the Vehicle

Kinematic relationships of vehicles experiencing de-acceleration-
$SD_v =V_v^2/(A_v \times 2) =7.41^2/(7.59 \times 2)=3.62$ m
$V_v$= Velocity of vehicle = 7.41

Determining parameter related to vehicle static weight distribution-
Percent front weight = $v_f/v_t \times 100$
$V_F$= The front axle vertical force
$V_t$=The total vertical vehicle force
$V_t=M_v \times g$
$=350 \times 9.81$
$=3433.5$ N
% Front weight = $(0.33 \times v_t)/v_t \times 100 =33\%$
% Rear weight=$(0.66 \times v_t)/v_t \times 100=66\%$

The calculation for torque required-
D=434 mm,
$R_{tr}$=0.217 m,
K=Buckling force $=R_{tr}/(\sqrt{2})$,
If=Ir=MR $\times R_{tr}/(\sqrt{2})$
$= (5 \times 2) \times 0.217/(\sqrt{2})$
$=1.53$ kg.m$^2$

Angular velocity of tire
$W_f=V_v/R_{tf} =7.41/0.217 = 34.14$ rad/sec
$W_r=V_v/R_{tr} = 7.41/0.217 = 34.14$ rad/sec

Angular displacement of wheel
$\Theta_f =S_{Dv}/R_{tf} = 3.62/0.217 = 16.68$ rad/sec$^2$
$\Theta_r = S_{Dv}/R_{tr} = 3.62/0.217 = 16.68$ rad/sec$^2$
Where;
$\Theta_f$ = Angular displacement of front tyre.
$\Theta_r$ = Angular displacement of rear tyre
Transitional K.E of wheel after weight transfer

$K_{Ef} = 1/2V_{fa} \times av^2$

$= 1/2 \times (0.3334335) \times (7.59)^2$

$= 32636.57$ N-m

$K_{Er} = 1/2 \times V_{rd} \times av^2$

$= 1/2 \times (0.66 \times 3433.5) \times (7.59)^2$

$= 65273.14$ N-m

Rotational KE of wheel

$K_{Erf} = 1/2 \times If \times wf^2$

$= 1/(2\ ) \times 1.53 \times 34.14^2$

$K_{Erf} = 891.63$ Nm,

$K_{Err} = 891.63$ Nm

KE of wheel

$K_{Enetf} = K_{Ef} + K_{Erf}$

$= 32636.57 + 891.63$

$= 33528.2$N.m

$K_{Enet}\ r = K_{Er} + K_{Er}$

$= 65273.1 + 891.63$

$= 66164.73$ Nm

The torque required for two tyres;

$T_{req}\ f = \frac{KE_{net\ f}}{\theta_f} = \frac{33528.2}{16.68} = 2010.083$N.m

$T_{req}$ per wheel,

$f = \frac{2010.083}{2} = 1005.415$N.m

$T_{req} r = \frac{KE_{net\ r}}{\theta_r} = \frac{66164.73}{16.68}$

$T_{req}\ r = 3966.71$N.m

$T_{req}$ per wheel,

$r = \frac{3966.71}{2} = 1983.355$ Nm

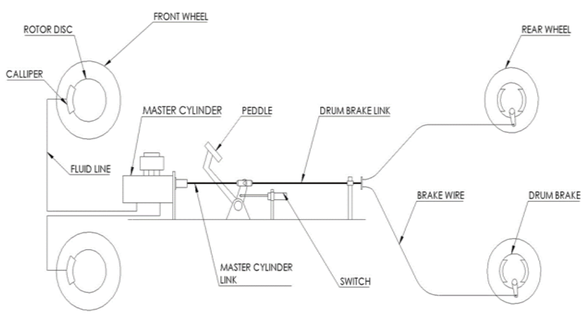


Fig-2 System layout

## IV. SYSTEM DESIGN

The figure shows the basic layout of system. The system consists of integration of two mechanisms, we have hydraulic disk brakes on front and mechanical drum brakes on rear wheels. Both the systems are actuated with help of single brake pedal.

whenever driver presses the brake pedal, peddle turns about pivot point similar arm also rotates along with the peddle, the both links are connected to arm with turntable joints, the link that connects drum brake gets pulled and at same time the link connected to hydraulic brake gets pushed forward. In this way we successfully obtained two different moments with same peddle.

## V. OBSERVATIONS

We performed various tests on the system, and evolution is done based on various parameters such as speed, braking distance, and various combinations of braking mechanisms. Whatever the readings we found during trials are given below. Following are the test conditions.

- Every time the speed of vehicle is same.
- Road is dry and made up of asphalt.
- Tires and brakes are new and unworn.

1. With disc brakes only: Initially only disc brakes are connected to actuating mechanism, there is no any contribution of drum brakes while braking.

| Trial number | Stopping Distance |
|---|---|
| 1. | 4.9 |
| 2. | 5.4 |
| 3. | 4.8 |
| 4. | 5.2 |
| 5. | 4.8 |

2. With drum brakes only: this time only drum brakes are connected to actuating mechanism while disc brakes are unattached.

| Trial number | Stopping Distance |
|---|---|
| 1. | 6.1 |
| 2. | 5.6 |
| 3. | 5.9 |
| 4. | 5.3 |
| 5. | 5.8 |

3. With combined Brake (Disc at front and Drum at rear): Now this time both the braking system are connected to the actuating mechanism together and actuated simultaneously.

| Trial number | Stopping Distance |
|---|---|
| 1. | 3.3 |
| 2. | 3.5 |
| 3. | 3 |
| 4. | 3.2 |
| 5. | 3.5 |

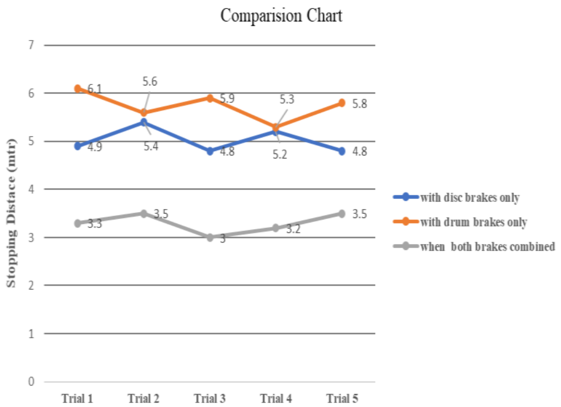


Figure 3: Comparison chart for stopping distance

## VI. RESULT AND DISCUSSION

1. The average stopping distance with drum brakes only = 5.7m
2. The average stopping distance with disc brakes only = 5.0m
3. The average stopping distance when both the brakes are combined = 3.3m

Above results indicates that hydraulic disc brakes are more effective than mechanical drum brakes. It contributes more efforts in the retardation of the vehicle.

## VII. CONCLUSION

1. We studied bunch of literatures related to braking system and design of braking system. We also gone through the analytical calculation part of design, which is a foundation for our design and evaluation.
2. We did sort of analytical calculations to decide some parameters for system design such as disc size, vehicle speed, stopping distance and brake force required.
3. Accordingly, we made an assembly of components to from a system and installed it on actual vehicle. We took no. of trials and tastings on vehicle to measure stopping distance.
4. Finally, results are collected together and represented in tabular form. based upon data that we have obtained we assigned disc brakes as primary and drum brakes as secondary brakes.

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