Design of Braking System for an Electric Golf-cart

Pawan Maske¹, Manas Agrawal² and Dr.Arvind Chel³
¹,²Department of Mechanical Engineering
³Associate Professor, MGM’s Jawaharlal Nehru Engg. College, Aurangabad

Abstract: Braking System is one of the most important systems in any vehicle used to retard the vehicle. For the safety of the driver and the passengers, it must work efficiently. This work deals with the design of a braking system for an electric golf cart, calculations and analysis for it along with design and analysis of Steering knuckle are performed. A hydraulic disc brake system is designed with four-disc rotors for each wheel in order to stop the vehicle in the shortest possible distance as per the driver requisite. This E-vehicle is six-seater; hence weight reduction is a major aspect that needs to be taken care of. Hence the steering knuckle is designed in such a way that it will sustain all the forces. Moreover, in this paper, the calculation of forces and the design of the steering knuckle is done. It was decided that bike rotor discs and calipers be used for all four wheels. Designing of Steering Knuckle is done on Creo 3.0 and the analysis is done with ANSYS 18.0.

IndexTerms - Electric vehicle, Brake System, Braking Calculations, Rotor Disc, Steering Knuckle, ANSYS.

I. INTRODUCTION

Electric vehicles are the need for the hour; hence they should also possess excellent brakes along with durable steering knuckle with minimum weight in order to attain high efficiency. Perfect functioning of brakes in all conditions is a necessity for the safety of passengers. There are various types of brakes available right from drum brakes to Pneumatic and Hydraulic brakes. Disc brakes are more efficient than drum brakes, with better heat dissipation but their cost is high.

The Braking system works on the principle of conservation of energy, i.e, the Kinetic Energy of the vehicle is converted to heat which is then dissipated to the surrounding. Also, these brakes are based on the principle of Pascal’s law which states, “The pressure exerted anywhere in a mass of confined liquid is transmitted undiminished in all directions throughout the liquid”. When the brake pedal is pressed the force is transferred to the master cylinder to the brake fluid and then to the pistons in the caliper, which in turn squeezes the brake pads against each other. Disc brakes have less number of sub-components which is one of the advantages over drum brakes.

The steering knuckle is a device which helps in directing the vehicle. The steering knuckle holds the wheel hub with help of the bearing and shaft. Also, it connects the steering tie-rod, the suspension arms, braking system, etc. Now considering the weight of this electric vehicle, the knuckle should have a minimum weight and maximum loading carrying capacity in order to reduce energy consumption.

Electric vehicles are eco-friendly, that is they do not use fossil fuels, and hence pollution caused by fossil fuel is absent in case of EVs’. For the brakes to work effectively, the brakes should work in proper synchronization with each other.

II. LITERATURE REVIEW:

Designing of brakes is a complicated process especially for a multi-seater electric vehicle, keeping the weight minimum results in an increase in overall efficiency, hence using motorcycle caliper in place of bulky hat type calipers have many advantages. In a similar work, numeric computations were done to obtain braking forces, braking torque, clamping forces at calipers, brake bias and other important parameters in a braking system. After a comparison of brake for the front wheel of the bike and front wheel of the car, it was thus observed that it is totally safe to use bike disc rotors and calipers in a formula car. A considerable amount of weight was reduced, without hampering the braking performances. [1]

A proper procedure was proposed for a project of an electric solar car to calculate the dependence of the wheel-braking force with the force applied by the driver on the brake pedal. Also, an actuator was installed on the rear spoiler for increasing the braking effort and reducing the stopping distance [2].

Instead of using conventional knuckle materials certain other materials such as aluminum are being used in electric vehicles to reduce the weight. In a word, it was found that stress was more in the case of ductile iron in comparison with Aluminium when loaded. The weight of Aluminium 7075-T6 is approximately 67% less than that of Iron and has nearly about 1.5 times more strength [3].
III. DESIGN OF DISC BRAKE:

III.I. Design considerations:
The design and fabrication of hydraulic disc brakes for our electric vehicle required some considerations which areas mentioned below.

1. **Feasibility**: The design and fabrication of the Electric vehicle should be feasible and easy, to ensure the easy and proper functioning of the brake system.
2. **Aesthetics**: To give aesthetic view to the vehicle, the hydraulic braking system is assembled with the chassis in such a way that it does not appear to the viewers but is easy for maintenance. The Fabrication and factor of safety will be highly emphasized in the design.
3. **Cost**: One of the main objectives of this project are to minimize the cost of the hydraulic braking system without compromising with the safety.
4. **Ergonomics**: The vehicle will be multi-seater hence the shape, size weight and materials used should be up to the mark.

III.II. Components:

Hydraulic disc brakes have various components right from the disc rotors to the brake pedal. The following are the major components:

A. **Disc Rotors**: The disc rotor is mounted on the wheel i.e it is bolted with the wheel and rotates along with it. The Electric Vehicle was to be designed with a low sitting posture due to which the diameter of wheel was to be reduced, which resulted in a reduction in the size of the rotor disc. For this vehicle, it was decided to use bike rotor discs of outer diameter 220mm and inner diameter 190mm with thickness 0.4mm to be selected.

B. **Caliper**: The Calliper is mounted on the Steering Knuckle which is a stationary part of the braking system. The double piston calipers were selected according to the suitability with the Rotor disc. The piston diameter was 26mm.

C. **Tandem master Cylinder**: Tandem Master Cylinder was used because of its ability to be operated by the single brake pedal and having two different hydraulic lines at the same time; which also reduces brake failure as diagonal split-connections were given. Dot4 Brake fluid oil is used.

D. **Brake pedal**: Brake pedal with a leverage ratio of 6:1 was used to decrease the effort and increase the output force.

III.III. Design Calculations:
The disc rotor design parameters have been evaluated and given in Table.1. The design calculations for pedal ratio, clamping force, rotor torque, total braking force were calculated based on following design calculations.

1) Pedal Ratio or leverage ratio= \( L_2/L_1 = 6:1 \)
   \( L_2 \) = distance from the brake pedal arm pivot to the brake pedal pad
   \( L_1 \) = distance from the brake pedal arm pivot to the output rod
   \( F_{bp} \) = Force Output of assembly = Pedal ratio x Applied Effort by the driver
   \[ F_{bp} = 6 \times 200 = 1200N \]

2) Diameter of master cylinder piston = \( D_{mc} = 0.01905 \text{ m} \)
   Area of master cylinder piston = \( A_{mc} = \pi/4 \times D_{mc}^2 \)
   \[ A_{mc} = 2.849 \times 10^{-4} \text{ m}^2 \]
   Pressure applied by Tandem Master Cylinder pressure= \( P_{tmc} = F_{bp}/A_{mc} \)
   \[ P_{tmc} = 4.21 \text{MPa} \]

3) Diameter of caliper piston = \( D_{cal} = 0.026 \text{ m} \)
   Area of caliper = \( A_{cal} = \pi/4 \times D_{cal}^2 = 5.3066 \times 10^{-4} \text{ m}^2 \)
   Mechanical force generated by Caliper = Area caliper x caliper pressure
   \[ = 4.21 \times 10^6 \times 5.3066 \times 10^{-4} = 2234.07N \]

4) Clamping Force of the caliper = 2 x Force generated by the Caliper
   \[ = 2 \times 2234.07 = 4468.15N \]

5) Force frictional = Coefficient of friction (Rotor and brake pads) x Clamping Force
   \[ = 4468.15 \times 0.4 = 1787.26N \]

6) Rotor Torque = Force frictional x Reflective = 1787.26 x 0.08 = 142.98N

7) All the tyres of the E-vehicle are of same size and dimensions with Rolling Radius of 0.237m.
Force on front tire = Rotor Torque/Radius of wheel = 142.98/0.237 = 603N

8) Total Breaking Force = Force on front tyre x 4=603 x 4

= 2413.18N

9) Retardation of the vehicle = Total Breaking force/Mass of vehicle

=2413.18/700=3.44m/s²

10) Breaking Distance of the vehicle =Velocity²/(2 x Retardation)

=6.94²/2 x 3.44=7m

11) Breaking time=(Velocity x Mass of Vehicle)/ Total Breaking Force =(6.94*700)/2413.18

= 2.01s

12) Distance between front axle and centre of gravity of the vehicle = C.Gf = 1 m
Distance between rear axle and centre of gravity of the vehicle= C.Gr = 0.7 m
Wheelbase = WB= 1.7 m
Height of centre of gravity =Hcg = 0.50 m
Total vertical force = Vt = 700 x 9.81 = 6867N

13) Rear Axle vertical force
C.Gr = (Vr x WB)/ Vt
Vr = 6867/0.7/1.7 = 4040N

14) Front Axle vertical force
C.Gf = (Vf x WB)/ Vt
Vf = 6867/1.7 = 4040N

15) Percentage of Front weight = Vf x100 / Vt = 58.8%
Percentage of Rear weight = Vr x100 / Vt = 41.16%

16) Weight Transfer = (av / g) x (Hcg / WB) x Vt = 708N

17) Vf,d = the front axle dynamic vertical force for a given Retardation
= Vf + WT =2827+708 = 3535N
Vr,d = the rear axle dynamic vertical force for a given Retardation
= Vr – WT = 4040-708 = 3332N

18) Weight transfer on tyre output
Ftyres front = μf x Vf = 0.7 x 2827 = 1979N
Ftyres, rear = μr x Vr = 0.7 x 4040 = 2828N

19) Maximum Braking force produced by Front axle= 0.7 x 3535 = 2475N
Maximum Braking force produced by Rear axle= 0.7 x 3332 = 2332N

<table>
<thead>
<tr>
<th>Table 1. Calculated Design Parameters</th>
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<tbody>
<tr>
<td><strong>Design Parameter</strong></td>
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<tr>
<td>Pedal Ratio</td>
</tr>
<tr>
<td>Clamping Force of the caliper</td>
</tr>
<tr>
<td>Rotor Torque</td>
</tr>
<tr>
<td>Total Breaking Force</td>
</tr>
</tbody>
</table>

III.IV Knuckle Design:

The energy produced by the engine must be utilized to the maximum extent; hence the suspension system must be of optimum ability to counter the energy loss problem. If a road was flat, with no bumps and drops, suspensions would be unnecessary. But roads are far from flat. Even the most maintained highways have defects that can disturb with the wheels of a car. The suspension system provides stability and assistance to the steering system. Considering our electric vehicle, it was designed for harsh terrain roads and was expected
that it should be able to work on the medium conditioned roads efficiently. The suspension system becomes an important factor to provide comfort to the passengers and the driver.

Bad roads provide the wheels with forces, which eventually results in force being applied on the wheel axle. As lighter vehicles generally accelerate quicker and require shorter stopping distances than heavier vehicles, hence a slight variation in the weight of the vehicle can affect the acceleration and stopping distance. It plays a crucial role in minimizing the vertical and roll motion of the vehicle body, which implies a poor passenger experience, when a vehicle is driven on a rough road.

III.IV.I. Design:
As per the design statistics received from the suspension team after the calculations of suspension system the knuckle was designed; And the results after the analysis on ANSYS software was done.

Fig.1 Design of steering knuckle

III.IV.II. Meshing:
The different mesh parameters like aspect ratio, skewness were considered to improve the mesh quality. Out of the different element types like hex dominant, sweep, etc. tetra elements capture the curvatures more accurately than in any other method. Proximity and curvature were used in order to ensure finer mesh along the curved regions and varying cross-section.

The Meshed model of a steering knuckle is subjected to mainly following three loads. Tensile and Compressive loads make up the axial loads and the third type of load is the inertia load. Bore diameter, seal groove, mounting, etc are decided and then the CAD modeling of the caliper was done using Creo. This model was analyzed.

Fig.2 Meshing of Steering Knuckle

III.IV.III Finite Element Analysis

After the numerical calculations all the parameters such as decided and then the CAD modeling of the caliper was done using solid works, By applying the forces and pressure. Static structural analysis of the CAD model was carried out in ANSYS 18.0.
IV. Result analysis:

After the numerical calculations all the parameters such as bore diameter, seal groove, mounting, etc decided and then the CAD modeling of the caliper was done using solid works. Static structural analysis of the CAD model was carried out in following material parameters was considered as given in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
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<tbody>
<tr>
<td>Density</td>
<td>2700 kg/m³</td>
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<tr>
<td>Young’s Modulus</td>
<td>72 GPa</td>
</tr>
<tr>
<td>Yield Tensile Strength</td>
<td>503 MPa</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>590 MPa</td>
</tr>
</tbody>
</table>

Table 2 Properties of Al 7075

The steering knuckle was designed to sustain 1800 N static load and the total deformation of steering knuckle is 0.08 mm as shown in Fig. 3. The equivalent von mises stresses induced are maximum 23.9 MPa as shown in Fig. 4.

V. Conclusion:

A theoretical and practical study of the braking system was performed. The procedure to calculate the braking forces, rotor torque, fluid pressure, etc along with all data, formulae and considerations are mentioned in this paper. Also, the selection of dimensions of braking system components was also briefly given. After the assembly of the braking system and installation, it was observed that the braking system works remarkably and provides a very effective braking operation.

Presented calculations for the braking system have been implemented for Multi seater Electric Vehicle, also using ABS in this vehicle can enhance the braking of Electric Vehicle. The results obtained indicate that the optimized geometry of the steering knuckle resists the applied forces and, therefore, it is viable for manufacture and use. As regards the magnitude of the applied forces and the safety
factors obtained, it can be concluded that the applied approach was conservative. One of the measures is to use bigger disc rotors to maximize net force on all the four wheels, which would then require larger diameter tires, and so on.

VI. References:


