Design and Analysis of a Novel Onboard Braking System Paddle Assembly

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ABSTRACT

Brakes are a mechanical device which helps in control and stopping of a vehicle by converting the Kinetic Energy of the vehicle into heat energy. While designing a race car, making it lightweight is one of the foremost priorities to increase its acceleration and top speed. Taking this into consideration, in- board brakes can be used in Spool drive vehicles (example- Formula student, Baja Off roading vehicles, Gokarts, some ATVs, etc). The in-board braking system is an automobile development where the disc brakes are directly mounted on the chassis of the vehicle (spool mounted), rather than on the wheel hubs. The inboard braking system has a various positives and differences compared to conventional disc braking system.

Keywords: *Brakes, Design, FEM Analysis, Automobile, In-Board Braking*

INTRODUCTION

Almost all Formula Student vehicles use Solid drilled rotors. However, there is not much research material available on the selection of disc material, the interaction of various Brake pad materials[1] on different materials of Brake rotor, and the design and FEA[2] of Pedal Assembly that uses class-1 lever mechanism.

Almost all Brake Rotor design and material selection involves study of the physical properties of the materials, however important properties like- coefficient of friction, wear of disc[3] and pad material,[4] etc. A part of our research will be focused on a comparative study of various Brake Disc[5] materials like- AISI 4130, SS202, Aluminium T6 6061, Cast Iron, etc with 'Wilwood Purple Brake Rotor' material.

Brake disc (rotor) and calipers are usually mounted on the wheel assembly (at the upright and hub), however, this adds to the Unsprung mass of the vehicle. Unsprung mass is the extra weight not handled by the car. The reduction in this factor can largely improve the car handling[6]. The unsprung mass factor is direclty related to shocks and vibrations over bumpy roads as lower its value lower is the distrubance. Lot of problems, if not all of them is caused by inertia.More mass means, more inertia and lesser speed and acceleration[7]. One solution to this issue could be the use of In-board Braking system. Preliminary calculations show that use of In-board braking system could help reduce upto 35-40% of the weight of the braking system.

The following are the methodologies by which we will be achieving the maximum possible 'Mass to Performance Ratio of the Rotor' without compromising it's safety.Design and develop in-board braking system for Formula Student race car, and to explore it's feasibility on commercial vehicles

1. Design and development of a Brake Rotor with FEA[8] analysis and Material selection
2. To select/develop the most appropriate material in order to get maximum performance
3. To reduce the mass of Braking system to the bare minimum for faster acceleration of the car and lower fuel consumption
4. Study and select the appropriate Brake Pad material to achieve highest coefficient of friction
5. Design the pedal assembly by a geometrical approach, for best actuation of the Brake Master Cylinder
6. Design a Class-1 lever Pedal Assembly for the specific Formula Student Racecar, by considering performance and Ergonomics.

The main objective of the project is to design a Braking system (Brake Pad and Rotor) with the maximum 'Mass to Performance Ratio' i.e to achieve the maximum braking performance by adding minimum weight to the vehicle.

The Outcome of the Project will be design and fabrication of an In-board braking system for a racecar by using sound engineering practice. The developed braking system will be at least 40% lighter, delivering maximum performance in braking.

The following are the goals to be accomplished-

- The rotors for the vehicle will be designed and fabricated with proper design validations, and to achieve the maximum 'Mass to Performance Ratio'.
- A study of various Brake pad material and their interaction with various Brake rotor materials will be made available.
- A complete design, analysis and fabrication of the entire Pedal assembly (using Class-1 lever mechanism), designed specifically to suit the needs of the Formula Student Racecar.

Design and Analysis

When all four wheels of the braking system can be locked a higher performance can be achieved from this system, this also keeps the weight and cost in check. The brakes system design includes on wheel brakes on front, and in board braking on rear to stop the vehicle. A brake is a mechanical device that inhibits motion by absorbing energy from a moving system and converting it to heat. The brakes are one of the most important safety systems on a vehicle. We are installing hydraulic actuated disc brakes to bring the vehicle to a quick and safe stop.

Table. 1 Data for Brakes

Type of brakes used	Hydraulic actuated Disc
Disc used	Custom made
Split Hydraulic system	Front/Rear Split
Caliper	GP200
Caliper Type	Fixed
Caliper piston bore	30mm (dual piston)
Total Brake Hose length	3.75 m
Brake Bias used	Balance Bar ; Larger Bore Master Cylinder on Front
Balance Bar	Tilton SKU 72-2X0
Master cylinder (Front)	Wilwood 260-6088
Master cylinder (Rear)	Wilwood 260-6087
Disc mounting on Front	Outboard
Disc mounting on Rear	Inboard (single disc)
Master cylinder bore	17.78 mm; 15.875 mm
Front Disc outer dia	190 mm
Rear Disc outer dia	220 mm

The pedal actuates the two master cylinders through a balance bar mechanism (cables are NOT being used). All brake lines are securely mounted with no part of it hanging below the frame of the vehicle. A Brake Over-Travel Switch is installed that will cut all the power circuits in case of any leakage and failure.

The Brake Pedal Design

The pedal assembly is designed and fabricated by LASER cutting Mild Steel plates. The Brake pedal is designed to be lightweight, withstand forces of upto 2000N and to actuate two master cylinders via the balance bar.

Fig.1 CAD model of clutch

Objective

The objective is to make light weight pedals for accelerator and clutch having high strength and stiffness. To make it possible, composite pedals with topology optimization method to get our required product is chosen.

Fig.2 Actual clutch and accelerator pedal

Topology Optimization

Firstly, the three major points of the pedals applied load area, pivot point and elastic support point is determined. With this three point, connection was made between them with cylindrical rod in all 3 axis to attach them and get the path shown in Fig.3

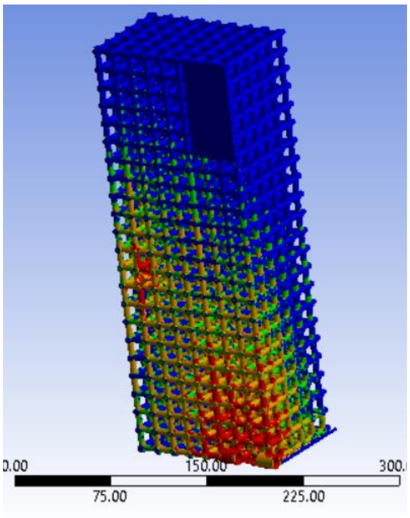

Fig.3 Topology Optimization

Fig. 4 Clutch pedal analysis

Fig. 5 Accelerator Pedal Analysis

Table 2. Values from Tire data-

Rate of Decceleration	15.429 m/s^2
Dynamic mass shift	63.516 kg
Normal Force on one Front tire (Fz)	845.4 N
Normal Force on one Rear tire (Fz)	390.6 N

The data represented in Fig. 4-5 and Table 2 validates the effectiveness of the braking system both computationally and experimentally. The data in Fig. 4-5 refers to pressure points used for analyzing the brake force and calculation of force on tires. The experimental values shown in Table.2 reiterate the computational results and establish the sync, which further suggests the validity of the design.

Conclusion:

The inboard braking system advantages over conventional disc brake system in the following ways

- Reduction of unsprung mass, which results in improvement of handling.
- Reduces the stopping distance.
- Protects the discs and callipers from the damage by outside environment like dust, oil/grease from bearings of the wheel etc.
- Steel brake lines can be used, using of flexible pipes is not necessary. Steel brake line increase the braking efficiency by reducing the pressure losses.
- Smaller discs can also be used, less torque is sufficient for stopping the vehicle.

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