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Design and Analysis of Brake Rotor for Formula Student Vehicle

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ABSTRACT

This project focuses on the design, analysis, and fabrication of a brake rotor for a Formula Student vehicle. The brake rotor is a critical component that must provide reliable and consistent stopping power while withstanding the high temperatures and stresses generated during racing. To achieve this, three different materials were considered: stainless steel 304, mild steel, and cast iron and it also considered different profiles like drilled, slotted, and drilled and slotted. Each material was evaluated based on its properties and performance characteristics, such as strength, corrosion resistance, thermal conductivity, profile, and cost. Using finite element analysis, the stress and deformation of each material under braking conditions were simulated to determine the most suitable option for the brake rotor. The results showed that stainless steel 304 with drilled and slotted offered the best overall performance and was therefore selected for fabrication. The brake rotor was then fabricated using Laser cut method, and its performance was tested on the Formula Student vehicle. The results demonstrated that the stainless steel 304 brake rotor provided excellent stopping power, durability, and consistency. Overall, this project highlights the importance of material selection and analysis in the design and fabrication of high-performance brake rotors for racing vehicles.

Keywords: Brake. Rotor,Simulation,Ansys,

Introduction

The brake system for an FSAE car typically includes various components such as brake discs, calipers, brake pads, master cylinders, brake lines, and brake fluid. Designing a brake system for an FSAE car requires careful consideration of the vehicle's weight, speed, and performance requirements. The system must be capable of providing consistent and responsive braking performance under varying conditions, including wet and dry surfaces, high and low temperatures, and different driving styles. A well-designed and maintained brake system can significantly enhance the performance and safety of the FSAE car, while a faulty or inadequate system can lead to disastrous consequences. Kinetic energy is a property of moving objects whose value is influenced by their mass and speed. Without the capacity to stop and slow down, we cannot maintain control of our vehicles, which would eventually lead to accidents. So, a braking system that will stop the vehicle is necessary to control a vehicle's kinetic energy or to slow it down. The braking system is what transforms the kinetic energy of the moving vehicle into heat energy through friction. As a driver applies the brakes, it is critical to dissipate the heat generated on the disc surface to retain braking effectiveness. A brake system's three primary purposes are to retain a vehicle when it is being parked, to reduce a vehicle's speed when necessary, and to maintain a vehicle's speed when travelling downhill. To do this, we must confirm the brake system's design using calculations. The torque created during braking must be larger than necessary; this is the primary factor considered when designing the brake system. The braking system is made up of five basic parts. When the driver applies force, it is instantly passed through the pedal assembly, which amplifies the force by employing simple leverage. The force generated is then divided using a bias or balancing bar, allowing for various amounts of force to be directed to the front and rear brakes. The master cylinders that regulate the front and rear brakes respectively are attached to the balancing bar at either end. As braking fluid is supplied into the master cylinders from a reservoir, they run under hydraulic pressure. The calipers at each of the four wheels physically grip the brake rotors by receiving the pressure generated in the master cylinder through hydraulic lines. Therefore, the system should be capable of locking all wheels in both static and dynamic conditions while providing maximum braking force with minimal effort from the driver. There are numerous factors to consider while correctly constructing a brake system, even though this system is closed and operates in a straightforward manner.

Literature Survey

Anshul Dhakar and Rishav Ranjan, "Force calculation in upright of a fsae race car". Volume 7, Issue 2, March-April 2016, pp. 168–176, Article ID: IJMET_07_02_018.The literature survey provides a comprehensive overview of the existing research on uprights in Formula SAE race cars, highlighting the importance of upright design and performance for achieving optimal racing performance.

Prof. Mit Patel, Mansi Raval, Jenish Patel, "Design of Disc Brake's Rotor", 2016 IJEDR | Volume 4, Issue 4. The literature survey provides a comprehensive overview of the existing research on disc brake rotor design and analysis, highlighting the importance of material selection, thermal behavior, and stress analysis in achieving optimal performance and reliability.

Akshay Naikwadi, Prof. C.S Wadageri, Prof. K.Y Bidari, "Design optimization of disc brake rotor". Volume: 04 Issue: 09 | Sep -2017. The literature survey provides a comprehensive overview of the existing research on the optimization of disc brake rotor design, highlighting the importance of material selection, shape optimization, and thermal analysis in achieving better performance and efficiency.

Yogesh H. Mishra, Prof. Vikas R. Deulgaonkar, Dr. P.A. Makasare, "Design and optimization of disc brake rotor (for two-wheelers)". International Engineering. Research Journal Page No 288-30. draft] 21.04.2021 | Adaptation of FSRules_2020_V1.1. Formula Bharat 2022 Rules Booklet. The literature survey provides a comprehensive overview of the existing research on the design and optimization of disc brake rotors for two-wheelers, highlighting the importance of material selection, shape optimization, and thermal analysis in achieving better performance and safety.

Praharsha Gurram,Shravan Anand Komakula, Design Of Disc Brake Rotor Using Static Structural And Thermal Performance Analysis,2019 JETIR April 2019, Volume 6, Issue 4 www.jetir.org (ISSN2349-5162) JETIR1904022 Journal of Emerging.The literature survey in this article provides a good understanding of the various factors that affect the design and performance of disc brake rotors, and the different approaches used in their analysis and optimization.

Technologies and Innovative Research (JETIR) 166. Anurag Parag Borse Design and Analysis of Brake Rotor (DISC International Research Journal of Engineering and Technology (IRJET) Volume: 06 Issue: 08. The studies mentioned suggest that there is ongoing research and development in the area of brake rotor design and materials, with a particular interest in improving performance and reducing weight.

Harshal Suresh Shinde Structural Analysis of Disc Brake Rotor for Different Materials International Research Journal of Engineering and Technology
(IRJET) Volume: 04 Issue: 07 | July -2017.
The literature survey provides a comprehensive overview of the existing research on the structural analysis of disc brake rotors made from different materials, highlighting the importance of material selection, analytical and computational techniques, and optimization techniques in achieving optimal performance and safety.

Prof. Swapneel D. Rawool Mr. Sumeet Satope Mr. Akshaykumar Bote Thermal Analysis of Disc Brake IJIRST –International Journal for Innovative Research in Science & Technology| Volume 3 | Issue 12 | May 2017. The article provides a comprehensive analysis of the thermal performance of a disc brake system and highlights the importance of optimizing the design for better heat transfer and improved braking performance.

Rahul Raosaheb Pind Prof. Swami M. C Kusekar S.K Design Analysis and Experimental Investigation of Brake Disc for Composite Materials Volume 4 Issue 5 January 2017 (carbon fiber). They also present their own design and analysis of a brake disc made from carbon fiber composite material, and report on the experimental results of their investigation.

Deekshith, Udaya Kiran, Vijaya Kumar "Design, Analysis and Manufacturing of Disc Brake Rotor" International Journal of Engineering Research and Development Volume 13, Issue 11 (November 2017) (SS321). The literature survey highlights the importance of material selection and finite element analysis for designing and manufacturing high-performance brake rotors. The study by Deekshith et al. demonstrates the suitability of SS321 material for brake rotor applications and provides a valuable insight into the design and analysis of automotive brake rotors.

Design and Analysis of Brake Rotor for Formula SAE Race Car" by B.Rathod, V. Prasad, and N. N. Thombare (2019) - This journal focuses on the design and analysis of brake rotor for FSAE race car. The study discusses the importance of the brake system and how the design of the rotor can affect the overall performance of the car. The study also includes a detailed analysis of the brake rotor, including stress analysis and thermal analysis.

"Brake Performance Testing and Evaluation for Formula SAE Race Car" by C. Lim, N. F. M. Zainal, and M. A. Abdul Aziz (2017) - This journal examines the brake performance testing and evaluation of FSAE race car using dynamometer testing. The study discusses the importance of brake testing and evaluation for ensuring the safety and performance of the car. The study also compares the performance of different brake pad materials, including metallic and ceramic composite.
"A Review on the Braking System of Formula Student Race Car" by P. B. Patil, A. V. Barhate, and N. B. Malve (2018) - This journal provides an overview of the braking system of FSAE race car, including the brake rotor. The study discusses the various design parameters of the rotor, including disc diameter and thickness, and how they affect the performance of the brake system. The study also provides recommendations for optimizing the design of the brake rotor.

"Optimization of Brake Rotor Design for Formula SAE Car" by P. Korjenevski, M. Gveric, and M. Blazic (2019) - This journal focuses on the optimization of the brake rotor design for FSAE car using a multi-objective optimization algorithm. The study considers several design parameters, including disc diameter, thickness, and material, and uses the optimization algorithm to find the optima.

Bayrakçeken, H. and Düzgün, M. (2005). Vehicles brake efficiency and braking distance analysis. Journal of Polytechnic. 8(2), 153-160. This study provides valuable insights into the design and performance of brake systems and can be useful for researchers and engineers working in this field.

Swapnil R. Abhang, D. P. Bhaskar "Design and Analysis of Disc Brake", International Journal of Engineering Trends and Technology Feb 2014. The article provides a comprehensive overview of the design and analysis of a disc brake system and its importance in the automotive industry.

Problem Statement

Our project's prime objective is to design a disc rotor for an FSAE car with an optimum size to achieve a balance between braking performance, weight, and cost. By carefully considering factors such as size, material, design, and complementary components, it is possible to design a disc rotor that meets the specific needs of an FSAE car and ensures maximum braking performance and driver safety.

Methodology

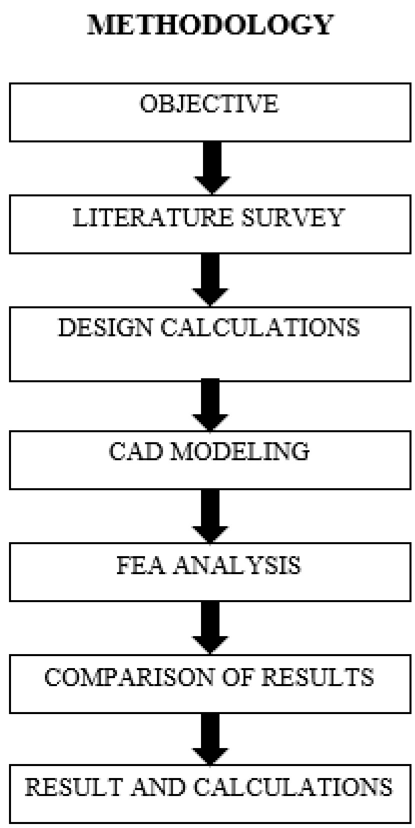

Fig 1. Methodology

Design Calculations

Relative CG (X) = H/L = 0.18064

Dynamic Axle Loads

i. Weight on the rear axle during braking $(W(r,b)) = W/L\ (\ Lr\ \ + H\ [a/g]\ ) = 1394.31$ N

ii. Weight on the front axle during braking $(W(f,b)) = W/L\ (\ Lr\ \ + H\ [a/g]\ ) = 1504.11$ N

Braking force before wheel lock

Braking force on rear axle (Fr) = W(r,b) * μ(t,r) = 2091.495 N
Braking force on front axle (Ff) = W(f,b) * μ(t,r) = 2028.705 N

Braking Torque

Force on the rear wheel while braking ($F_{(r,b)}$) = F_r / 2 = 1045.75 N

Required braking Torque for rear (T_r) = $F_{(r,b)}$ * R_t= 2.12*10^5 N mm

Force applied on master cylinder F_{MC} = F_{driver} * Leverage ratio = 35 * 4 * 9.81=1373.4 N
Pressure Developed by the Master Cylinder P_{MC} = F_{MC} / A_{MC} = 1373.40/197.96 = 6.94 N/mm^2
Clamping Force F_{cl} = P_{mc} * A_{cp}= 6.94 * 793.55= 5507.237 N
F_{cl} = 11014.5 N (As there are 2 pistons in each caliper)
Frictional Force F_f = F_{cl} * $\mu_{(p,r)}$= 11014.5 * 0.35 = 3855.075 N
Actual braking torque
Effective radius of rotor (R_{eff}) = (D+d)/4 = 75.38 mm
Braking Torque (T_b) = F_f * R_{eff} =2.91 * 10^5 N mm
Thus, the actual braking Torque produced by the braking components selected is greater than the required braking torque, thus the vehicle can be able to achieve its peak deceleration and reduce its speed in a short time.

CAD Modeling

For simulation, three different materials were assigned to brake rotor namely Stainless Steel, Cast Iron and Mild Steel. Three different disc configurations were assumed for the analysis namely drilled rotor, slotted rotor, and combination of drilled and slotted rotor.

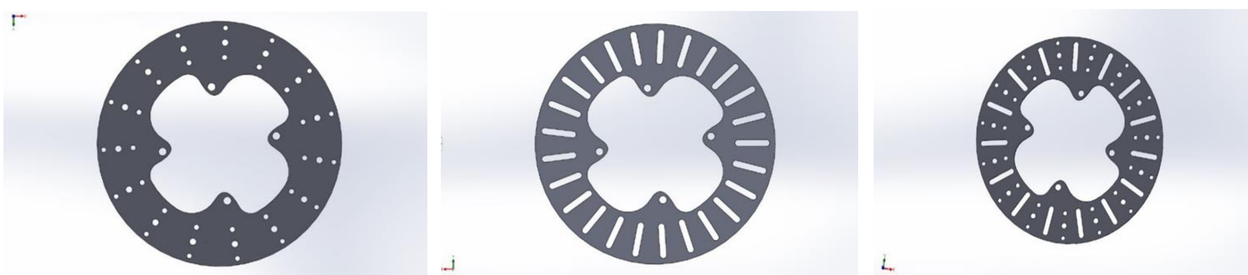

Fig.2 Drilled, Slotted and Drilled and Slotted Disc Rotor

FEA Simulation

The design and development of a disc rotor with an optimal size is essential for improving braking efficiency, efficient heat dissipation, and cost-effectiveness in braking systems. Considerations like stopping power, heat dissipation, weight, and cost can be made into the design of disc rotors in order to make them fit the needs of each application. The disc rotor is created considering all of these variables and using the ideal size of 183.5mm of outer diameter.

Tthree-disc profiles created with the desired dimensions that are drilled, slotted, and drilled & slotted. Static structural and Steady state thermal analysis was performed for stainless steel, mild steel and cast iron.

6.1 Drilled Rotor

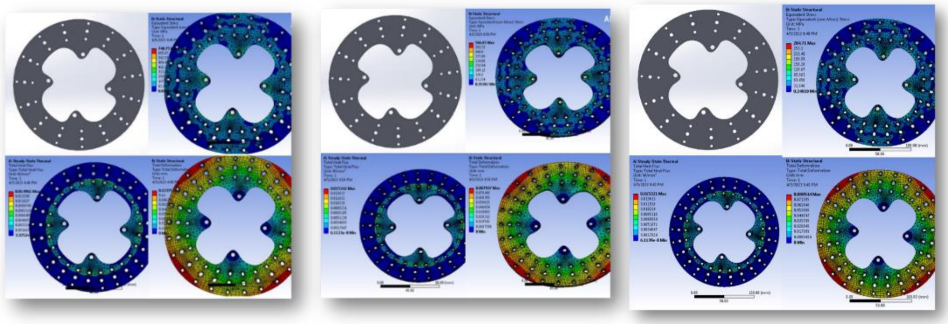

Fig 3. Drilled rotor with Stainless Steel, Mild Steel and Cast-Iron Material

6.2 Slotted Rotor

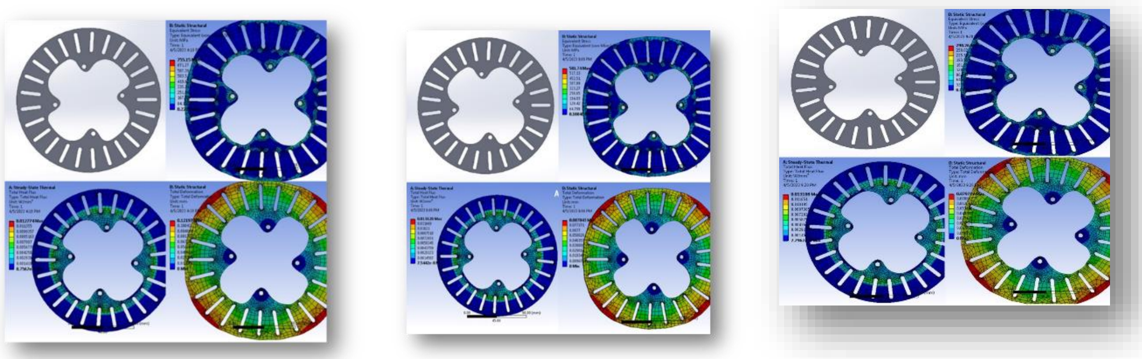

Fig 4. Slotted rotor with Stainless Steel, Mild Steel and Cast-Iron Material

6.3 Drilled and Slotted Rotor

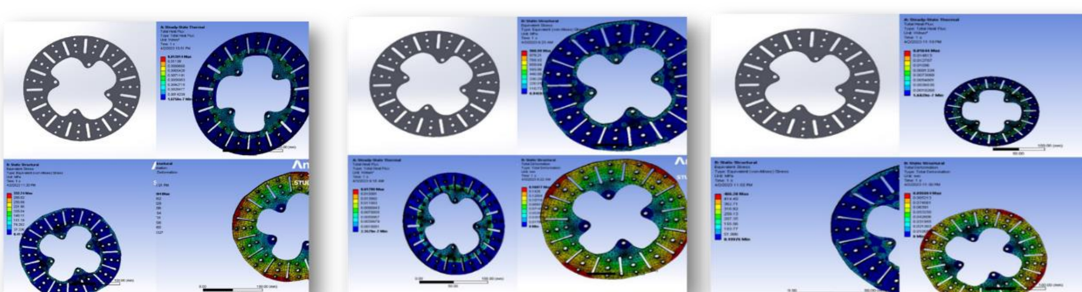

Fig 5. Drilled and Slotted rotor with Stainless Steel, Mild Steel and Cast-Iron Material

Result and Discussion

7.1 Drilled Disc Rotor

Material	**Total Heat Flux (W/mm^2)**	**Total Deformation (mm)**	**Equivalent Stress (MPa)**
Stainless Steel	0.014961	0.12375	748.75
Mild Steel	0.015342	0.087937	566.65
Cast Iron	0.015321	0.080544	284.71

7.2 Slotted Disc Rotor

Material	**Total Heat Flux (W/mm^2)**	**Total Deformation (mm)**	**Equivalent Stress (MPa)**
Stainless Steel	0.012814	0.075894	988.9
Mild Steel	0.01799	0.16077	466.28
Cast Iron	0.01644	0.095864	332.74

7.3 Drilled and Slotted Disc Rotor

Material	**Total Heat Flux (W/mm^2)**	**Total Deformation (mm)**	**Equivalent Stress (MPa)**
Stainless Steel	0.012774	0.12197	755.15
Mild Steel	0.013128	0.087043	581.74
Cast Iron	0.013108	0.079719	290.26

As a result, employing drilled and slotted stainless steel disc rotors for FSAE cars can have several advantages, such as greater heat dissipation, less brake fade, and better wet weather performance. Better braking efficiency and elevated track safety may result from these advantages. It is important to keep in mind that picking the ideal brake rotor design for an FSAE vehicle depends on a number of variables, including the precise vehicle design and track circumstances. Therefore, it is critical for FSAE teams to thoroughly consider their alternatives and select a brake rotor design that satisfies their unique needs and specifications.

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