Design and Analysis of FSAE Brake System using locally sourced Material

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***Abstract*— This work entails the design and analysis of a braking system based on FSAE application. Different Engineering software like SOLIDWORK and INVENTOR professionals, Mat lab and brake system calculator was utilized to determine the pedal ratio, master cylinders and caliper design, the number of rotors and their geometry. The guiding factors of the design process were maximum braking power, minimal weight and manageable temperatures while maintaining reliability. An approach drawn from Prof. Peter Wright concept was adopted. In this work, every progression of design was assessed and interpreted in details. Data acquired was also interpreted and related back to the assumptions used in the design analysis. The basic aim of this work is to achieve the required standards for brake design in FSAE and to scale through the technical inspection at the competition. For this to be actualized, the system must be able to lock up all the four wheels on pavement from acceleration run. Ergonomics and easy adjustability were also what was considered in this work. The project complied with all of the templates and envelopes required by the FSAE 2015 rules. The work serves as a guide to developing a high performance race car for the FSAE competition and will foster the ingenuity of designers by making the proposed indigenous car possible in view of the local content initiatives in Nigeria.**

***Index Terms*— Brake; Brake system; FSAE; Finite element analysis.**

I. INTRODUCTION

Formula Society of Automotive Engineers (FSAE) is an intercollegiate competition organized by the Society of Automotive Engineers (SAE) that challenges University students (Post graduate and undergraduates) around the globe and gives them the opportunity to design, build and compete with their own race car. High performances, durability and reliability must be the attributes of such race car. Cars are not just tested under dynamic racing conditions, but are tested based on their design, functionality, marketability and cost. However, these schools source for material, build and fund the project till a good race car is produced. In line with this, the design is targeted towards ensuring effective and efficient braking system.

A brake is a device by means of which artificial frictional resistance is applied to moving machine member, in order to stop the motion of a machine. In the process of performing this function, the brakes absorb either kinetic energy of the moving member or the potential energy given up by objects being lowered by hoists, elevators etc. The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in to the surrounding atmosphere to stop the vehicle, so the brake system should have the following requirements:

a. The brakes must be strong enough to stop the vehicle with in a minimum Distance in an emergency.
b. The driver must have proper control over the vehicle during braking and the vehicle must not skid.
c. The brakes must have good ant fade characteristics i.e. their effectiveness should not decrease with constant prolonged application.
d. The brakes should have good anti-wear properties.

Without brake system, the vehicle will put a passenger in unsafe position. Therefore, it is a must for all vehicles to have proper brake.

II. BRAKE SYSTEM OVERVIEW

Automobile Brakes

Modern automobile brakes evolved from the relatively crude brakes of horse-drawn vehicles. The earliest motor vehicle brakes were pads or blocks applied by levers and linkage to the outside of a solid tire on a wooden-spoked wheel. These brakes worked well with speeds of 10 mph to 20 mph and little traffic. Pneumatic tires used with this early brake were short-lived on automobiles. Owen, (2011). By the end of the first decade of the twentieth century, automobiles were using either external-contracting band brakes or internal-expanding drum brakes. A few internal expanding band brakes were tried on some early motor vehicles. External-contracting brakes have a band lined with friction material wrapped around a drum located on the driveline or on the wheels. The band is anchored at one end or at the center; levers and linkage tighten the band around the drum for braking force. Band brakes, either internal or external, lose their effectiveness when higher braking force is needed. It is very difficult to develop servo action with an internal band brake, and higher brake force is thus needed. Servo action on an external band brake tends to make the brake grab at high brake forces and high drum speed. Other problems associated with band brakes included dirt and water damage and loss of friction with external bands and the tendency of these brakes to lock if the drum is overheated and expanded too much. Internal band brakes also suffered from band and drum overheating and reduced braking force. As drum brakes evolved, internal-expanding shoe-and-drum brakes became the standard. External-contracting band brakes were used as parking brakes until the late 1950s, but their days as service brakes were over by the late 1920s.

Classification of Brake System

The brake s may be classified based on the following

1. On the Basis of Method of Actuation, brakes are classified as:

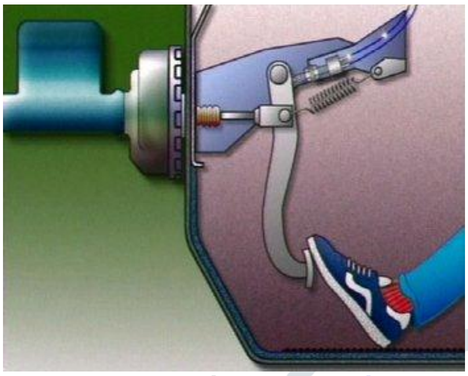


Fig. 1: Foot Brake (www.google.com)

Fig. 2: Hand Brake (www.google.com)

2. Based on mode of operation

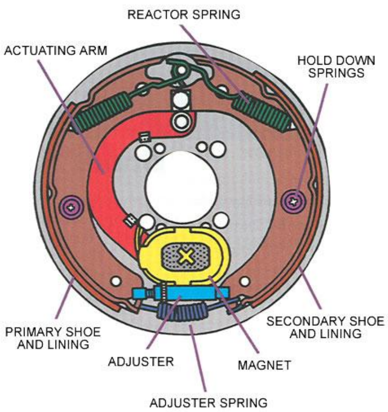


Fig. 4: Electric Brakes (www.google.com)

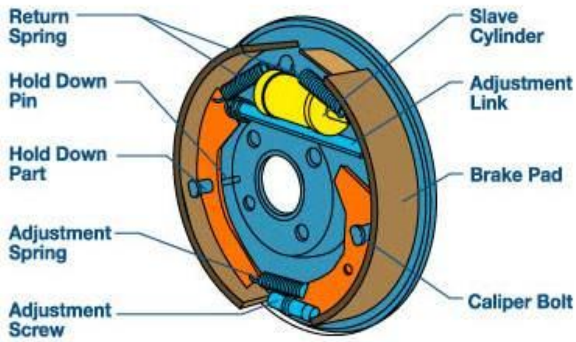


Fig. 5: Mechanical Brakes (www.google.com)

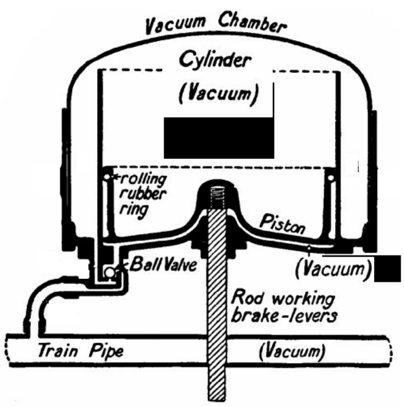


Fig. 6: Vacuum Brakes (www.google.com)

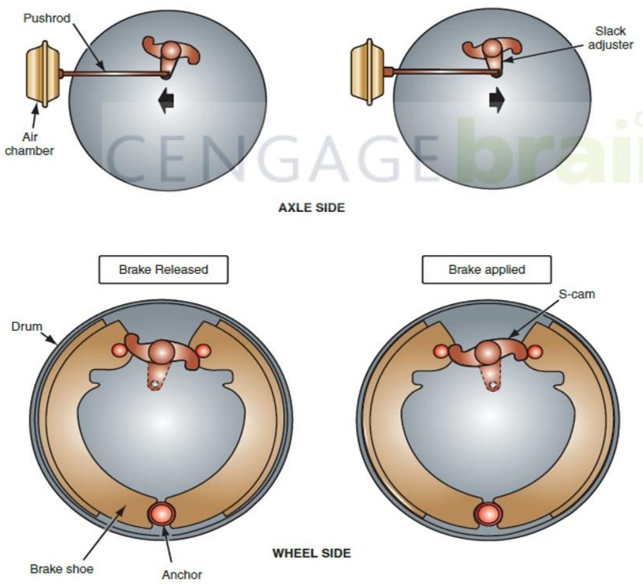


Fig. 8: Pneumatic Brakes (www.google.com)

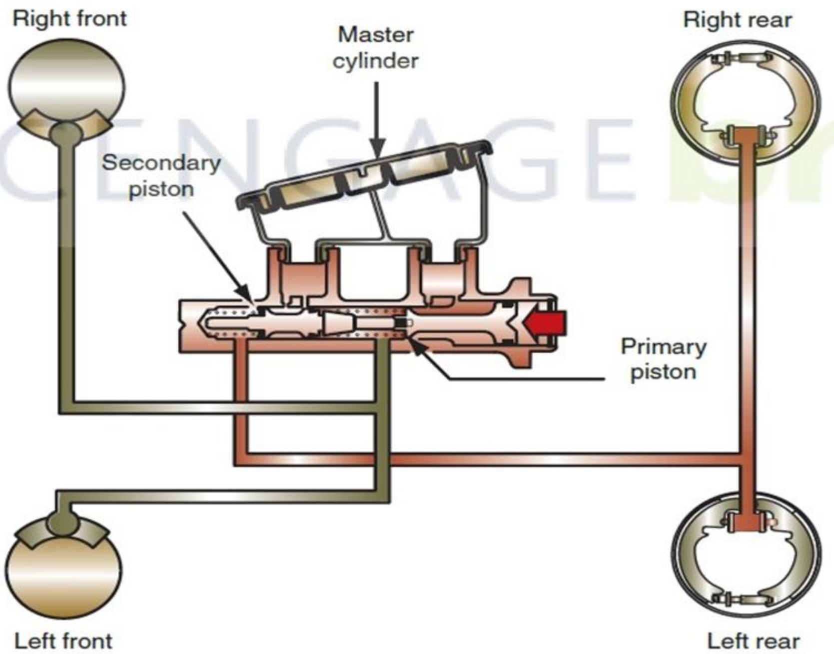


Fig. 9: Hydraulic Brakes (www.google.com)

FSAE Requirements

- The car must have four wheel brakes operated by a single control.
- It must have two independent hydraulic circuits with independent fluid reserves.
- The brake system must be capable of locking all four (4) wheels, and stopping the vehicle in a straight line.
- The braking systems must be protected with scatter shields from failure of the drive train.
- A brake pedal over-travel switch must be installed. This switch must kill the ignition and cut the power to any electrical fuel pumps.
- The car must be equipped with a red brake light that illuminates whenever the brakes are applied

III. Methodology

Design Goals

The design was done in such a way that it will meet these goals which included; Absolute reliability, Perform at High Speeds without failure, Maximum possible deceleration without locking, Consistent balance with changing temperatures.

Design Concept

The project will be achieved following the below processes that was adopted from the technology tree and system integration for a successful completion of a race car (F1 Technology by Peter Wright). *(See Fig. 10)*

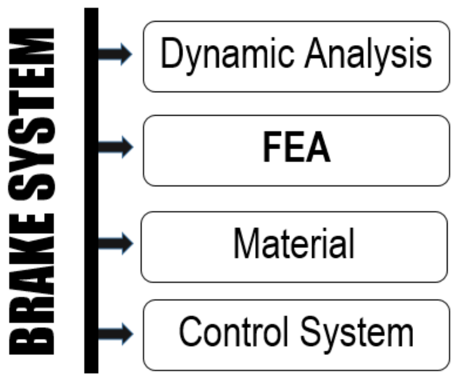


Fig. 10: Design concept adopted from Prof. Wright

Table 1: Brake System Components

Brake Type	**Hydraulics**
Brake Components includes;	
1.	Master Cylinders
2.	Brake Fluid
3.	Brake lines and Hoses
4.	Pressure Control Valves
5.	Wheel Cylinders and Caliper piston
6.	Brake Pad
7.	Brake Pedal
8.	Rotor (Brake Disc)

Design Guiding Factors

The guiding factors of the design process are:
- Maximum braking power;
- Minimal weight ; and
- Manageable temperatures while maintaining reliability

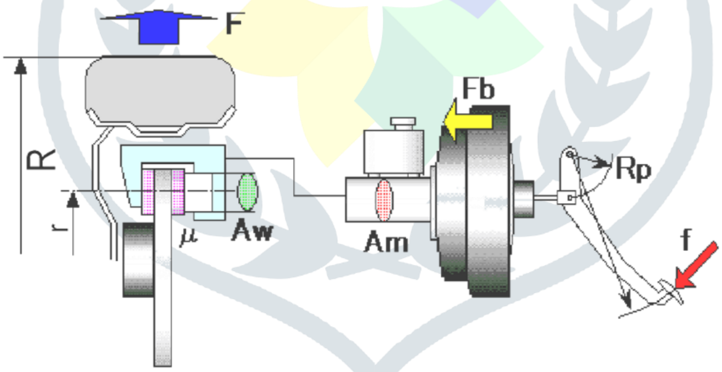
NB: Basic concepts as given below was employed in obtaining these

- The brake system converts the kinetic energy of vehicle motion into heat

  i.e. Kinetic energy = heat

- The brake system can only bring a moving vehicle to a stop, if only it could offer an opposing force that is equal (or greater than) than that propelling the vehicle in a different direction.

  i.e. Braking (Stopping) Force = F = ma



The braking force, $\boldsymbol{F_B}$, is given by:

$$F_B = \frac{r}{R} \times 2 \times \mu \times \frac{A_w}{A_m} \times (R_p \times f)$$

Computer Aided Engineering (CAE) Tool

SolidWorks CAD and Simulation software (hereafter refer as SolidWorks) is utilized for the design and analysis of the brake system components because of its exceptionally powerful capability in the field of design and analysis of engineering products. The one-stop package of comprehensive FEA and all-round design capability make it an ideal tool for the race team to be used to develop components of the race car and thus the chassis. As SolidWorks is also the exclusive tool for the race team to be used as and when it needs, this CAE tool is dominantly used for many projects of the race team, which also include this project.

IV. Results and Analysis

FEA on Brake Pedal (Objectives)

To create simulations of the pedal design that focus on the mass of the current design. It involves adding machined pockets on both sides of the pedals and validating the design change in the Stress Analysis Environment. *(See the Fig. and Tables below)*

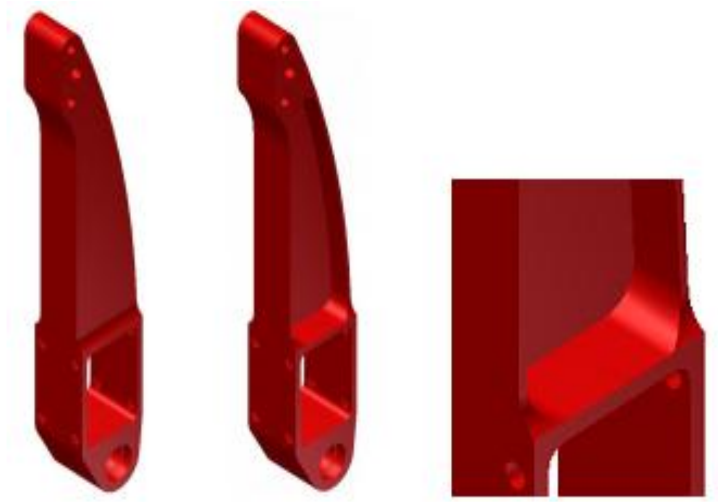


Fig. 11: Design concept of brake pedal

Table 2: Design Criteria

Stress	Displacement	Safety Factor
276 MPa	1.25mm	2.0

Table 3: Material Choice: Aluminum 6061 Alloy

Property	Value	Unit
Elastic Modulus	69000	N/mm^2
Poisson's Ratio	0.33	N/A
Shear Modulus	26000	N/mm^2
Mass Density	2700	Kg/mm^2
Tensile Strength	124.08	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	55.15	N/mm^2
Thermal Expansion Coefficient	2.4e^{-005}	/K
Thermal Conductivity	170	W/(m.K)
Specific Heat	1300	J/(Kg.K)
Material Damping Ratio		N/A

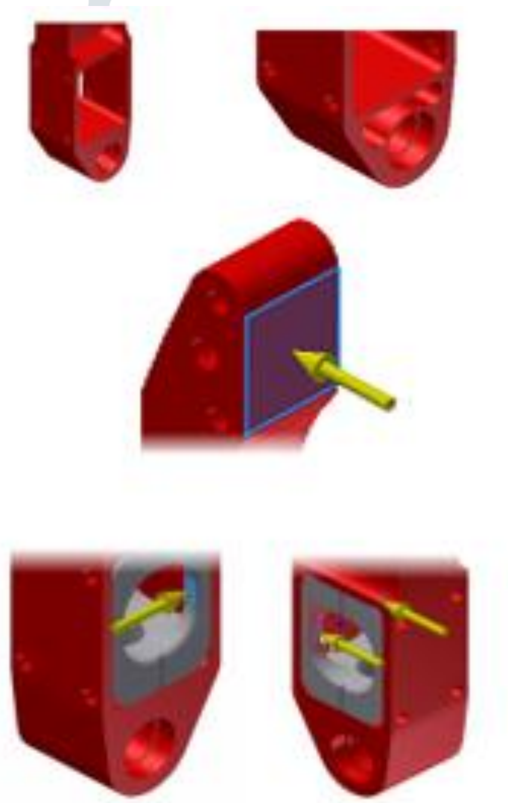
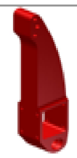
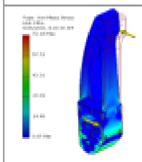
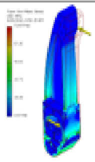


Fig. 12: Adding boundary condition to the model

The objective was to reduce the mass of the pedal and that has been achieved. The current design is 51%lighter than the original design. The overall dimensions of the brake assembly are controlled by 2 design criteria. *(See Table 4)*

Results of the FEA

Table 4: FEA results on brake pedal

Models	Von Mises Stress (MPa)		Displacement (mm)		FOS	Weight (Kg)
	Max.	Min.	Max	Min.		
	73.81	0.04	0.4493	0	3.73	0.311
	73.02	0.06	0.6154	0	3.77	0.165
	70.34	0.06	0.7225	0	3.91	0.151

FEA – Thermal Analysis on Disc Brake (Objectives)

To create a thermal simulations of the disc brake design that number of holes on the current design. It involves adding more holes on the surface of the disc brake and validating the design change in the Thermal Analysis environment. *(See fig. 13)*

Fig. 13: 3D model of Rotor

Table 5: Material Properties

Name	Gray Cast Iron
Model type	Linear Elastic Isotropic
Default failure	Unknown
Thermal	45 W/(m.K)
Conductivity	
Specific Heat	510 J/(Kg.K)
Mass Density	7200 Kg/m^3

Study Properties:

Analysis type – Thermal (Transient), Mesh type – Solid mesh, Solver type – FFEPlus and the solution type – Transient. The total time of the analysis is 3 seconds. *(See fig. 14)*

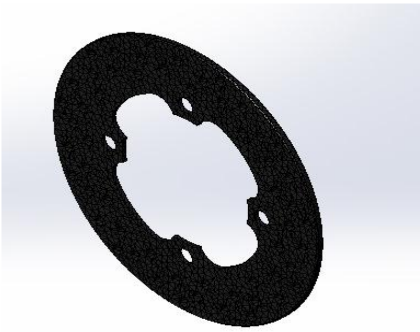


Fig. 14: 3D Mesh of rotor

Results of the FEA

Name	Type	Min	Max
Thermal1	TEMP: Temperature at Step No: 30(3 Seconds)	106.388 Kelvin Node: 1295	171.035 Kelvin Node: 1670

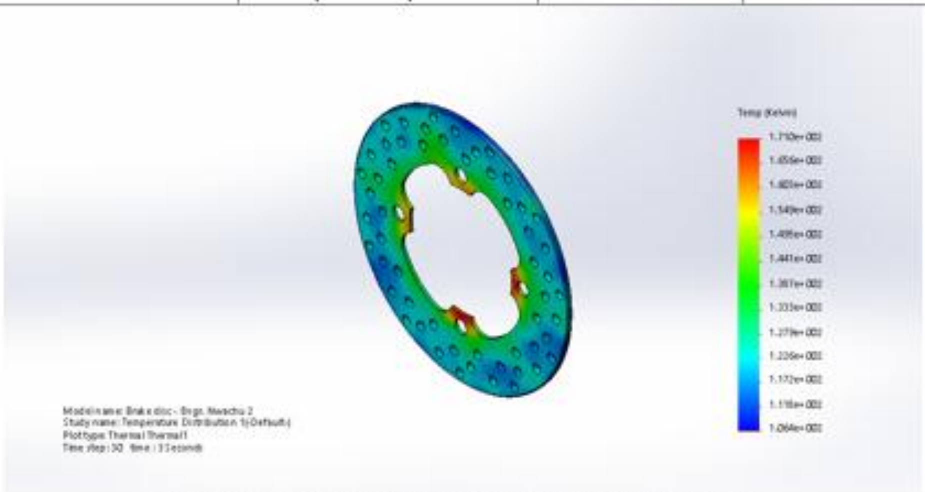


Fig. 30: Brake disc -Temperature Distribution 1-Thermal-Thermal1

Disc A

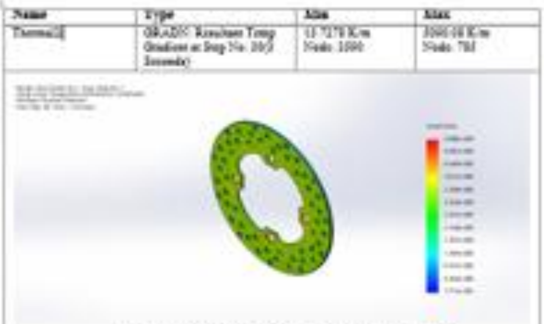


Fig. 31: Brake disc - Temperature Distribution 1-Thermal-Thermal2

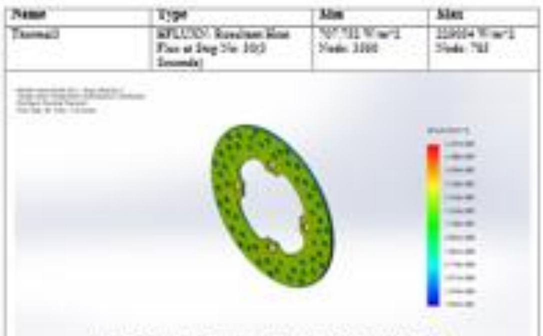


Fig. 32: Brake disc - Temperature Distribution 1-Thermal-Thermal3

Disc B

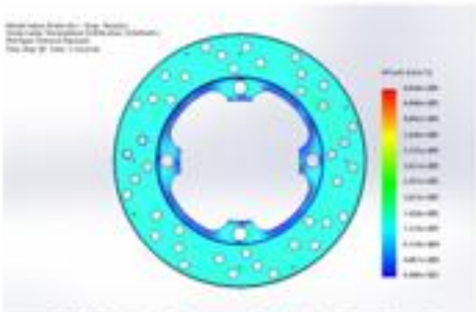


Fig. 35: Brake disc2 -Temperature Distribution 1-Thermal-Thermal2

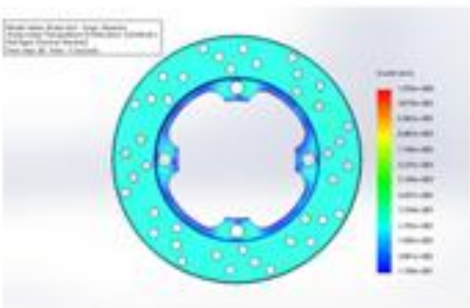


Fig. 36: Brake disc2 -Temperature Distribution 1-Thermal-Thermal3

Discussion

The heat flux produced from the friction between a disc and pad system leads to a high temperature which causes thermal stresses in the disc and after a number of repeated braking cycles, cracks might be initiated. The finite element analysis (FEA) is performed to determine the temperatures profile in the disc and to analyze the stresses for the repeated braking, which could be used to calculate the fatigue life of a disc.

Sequentially coupled approach is used for thermo-mechanical problem and the problem is divided into two parts, heat analysis and thermal stress analysis. The heat analysis is obtained by including frictional heat and adopting an Eulerian approach. The heat analysis is conducted by using SOLIDWORK software on two different disc with different number of perforations. The boundary conditions used was the same for every stage of the analysis.

V. CONCLUSION

In the project, the braking system of an FSAE single seater was developed with the aim of achieving the highest possible performance. The design was done to meet the international standard of the Society of Automotive Engineers requirement. The tasks of the project have been successfully completed. The development of the chassis follows a systematic process adopted from Prof. Peter Wrights Concept in his famous F1 Technology.

VI. ACKNOWLEDGMENT

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