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Design and Analysis of a Hydraulic Brake System of an Electric Formula Student Vehicle

Aarish Afsar[1], Arbab Karim[2], Fardeen Nayeem[3], Rounaque Noor[4], Shiraz Sajid Hashmi[5]

[1,2,3,4,5]*Student, Department of Mechanical Engineering, Faculty of Engineering & Technology, Jamia Millia Islamia, New Delhi, India*

Abstract - *Weight reduction is one of the prime concerns for a race vehicle; particularly electric vehicle. We aimed to design a braking system with the optimum size and feasibility while keeping the driver's safety in mind and the budget available. In this paper, the design choice of the braking mechanism has been discussed. Various calculation of braking force, braking torque and brake bias are presented. Likewise, the security of utilizing a self-planned brake plate is validated by estimations, calculations and thermal analysis.*

***Key Words*: Braking System, Thermal Analysis, Ansys, SolidWorks, Hydraulic Brake System**

1. INTRODUCTION

Brake System plays a vital role in the Formula Student vehicle. Our essential point was to come up with a braking mechanism that is straightforward and has an optimized size alongside being reliable. According to the rulebook of Formula Bharat 2021, the framework requires to comprise of two independently operated hydraulic circuits. Additionally, all four wheels should lock simultaneously and to achieve full safety, we needed to keep a brake over travel switch.

For the braking system, we have used disc brakes in all the four wheels. Each of the four wheels has a Wilwood caliper with self-designed brake disc to provide braking force. The vehicle has a brake pedal which actuates the master cylinder of the brake. Two hydraulic fluid lines are associated, one to the front wheels and one to the rear wheels. All the standards selected by us are predominantly to give a more secure and faster reaction of brakes. We have used Jr Dragster Caliper which has dual-piston, to provide enough clamp force. All the designs satisfy the rulebook of Formula Bharat 2021 and validated with the calculations and analysis.

2. SELECTION OF COMPONENTS

All the components are selected based on their reliability, feasibility and the budget. While keeping in mind that they satisfy the analysis reports and calculations.

2.1 BRAKE DISC AND CALIPER

The selection of brake disc depends on the size of the rim as well as on the braking torque. The brake torque remains constant so the larger the disc in diameter the least the force is required to stop the disc.

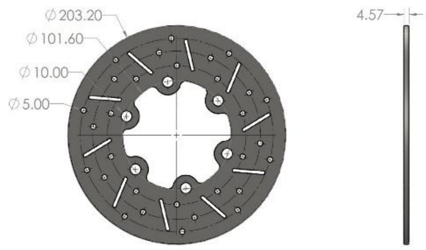

Fig: Brake Disc

Hence, a brake disc is designed on DS SolidWorks 2018 with a diameter of 203.2 mm was designed for a 13-inch wheel rim. The material finalized for the disc is AISI 1020. The thickness of the disc is 4.57mm and Wilwood's Jr. Dragster callipers with dual pistons were selected.

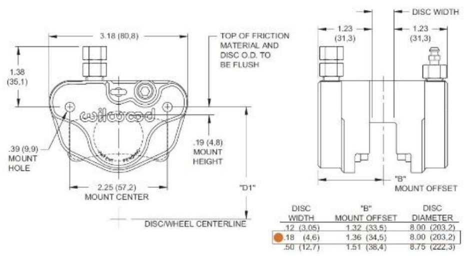

Fig: Brake Caliper

2.2 MASTER CYLINDER

A Tilton 76 series master cylinder was chosen with the goal that autonomous dual hydraulic circuits can be acquired and it very well may be gotten by a solitary control from the brake pedal. It contained DOT5 as brake oil. Two autonomous circuits were made, one associated with the front tires and the other associated with back tires so the vehicle keeps up strength if there should be an occurrence of the disappointment of one of the circuits. The circuit is comprised of rigid pipes followed by flexible brake lines.

Fig: Tilton 76 series

2.3 BRAKE PEDAL

The brake pedal was machined from a checkered Aluminum plate having thickness 5mm. It was intended to withstand a force of 2KN as the pedal input force with the pedal ratio of 7.192.

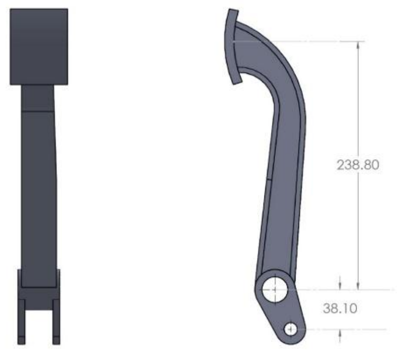

Fig: Brake Pedal

3. CALCULATIONS

Pedal ratio = L_2 / L_1 = 274/ 38.10 = 7.192

$F_o = F_d$ x (L_2 / L_1) = 250 x 7.192 = 1798 N

Where,

F_o = force output of the assembly

F_d = force applied to the pedal pad by the driver

L_1 = distance from the brake pedal arm pivot to the output rod clevis attachment

L_2 = distance from the brake pedal arm pivot to the brake pedal pad

3.1 MASTER CYLINDER

Diameter of master cylinder piston =Dmc = 0.0195m

= 19.05mm

Area of master cylinder piston = Amc = (π/4) x Dmc^2

= 2.85 x 10^{-4} m^2

Pressure generated by the master cylinder = Pmc = F_o / Amc = 1798 / 2.85 x 10^{-4}

= 6.3083 MPa

Where,

Pmc = hydraulic pressure generated by the master cylinder

Amc = effective area of the master cylinder hydraulic piston.

3.2 CALIPER

Diameter of caliper piston = Dcal = 25.4743 mm

= 0.0254743 m

Area of caliper piston = Acal = (π/4) x $Dcal^2$

= 5.0968 x 10^{-4} m^2

Pressure transmitted to calliper = Pcal = Pmc

= 6.3083 MPa

One sided linear mechanical force generated by the caliper will be equal to:

Fcal = Pcal x Acal = 6.3083 x 10^6 x 5.0968 x 10^{-4}

= 3215.1959 N

Where,

Acal = the effective area of the caliper

The clamping force will be equal to twice the linear mechanical force as follows:

F_{clamp} = 2 x Fcal = 2 x 3215.1959

= 6430.3918 N

3.3 BRAKE PAD

The frictional force is related to the caliper clamp force as follows:

$F_{friction} = F_{clamp}$ x μ_{bp} = 6430.3918 x 0.35

= 2250.6371N

Where,

μ_{bp} = the coefficient of friction between the brake pad and the rotor

3.4 DISC

The torque is related to the brake pad frictional force as follows:

$T_d = F_{friction} \times R_{eff} = 2250.6371 \times 0.08996$

$= 202.4673Nm$

Where,

T_d = torque generated by the disc

3.5 TYRE

The total force reacted between the tyres and the ground = 310 x 9.81 x 0.6

= 1824.66N

Force on front tyres = (1824.66 x 45)/100

= 821.097N

Force on an individual front tyre = 821.097/2

= 410.549N

Force on rear tyres = (1824.66 x 55)/100

= 1003.56N

Force on an individual rear tyre = 1003.56/2

= 501.782N

Weight Increment = (310 x 9.81 x 0.6 x 0.288)/1.727

= 304.286N

Weight increment on front tyres = (304.286 x 45)/100

= 136.93N

Weight increment on an individual front tyre = 136.93/2

= 68.46N

Total force acting between an individual front tyre and the ground = 410.549 + 68.46

= 479.009N

Torque on the tyre (T_t) = $479.009 \times R_{front} = 479.009 \times 0.25067$

= 120.07N

Now,

Since $T_t < T_d$

Therefore, the pedal force of 1798N would provide the sufficient braking torque to all wheels to lock.

3.6 DECELERATION OF VEHICLE IN MOTION

The deceleration of the vehicle will be equal to:

$A_V = \mu \times g = 0.6 \times 9.81 = 5.886\ m/s^2$

Where,

A_V = deceleration of vehicle

m_v = mass of the vehicle

3.7 BRAKING DISTANCE OF VEHICLE:

The theoretical braking distance of a vehicle in motion can be calculated as follows:

$d = v^2 / 2a_v = (16.67)^2 / (2 \times 5.886) = 23.605\ m$

Where,

v = velocity of vehicle

d = braking distance

3.8 THERMAL CALCULATIONS:

Kinetic Energy (KE) = $(1/2) \times mv^2 = (1/2) \times 310 \times (16.67)^2$

= 43072.7795 J

Where,

mv = mass of the vehicle

Vv = velocity of vehicle

For the braking kinetic energy is converted into thermal energy,

$KE = mb \times Cp \times \Delta Tb$

$\Delta Tb = (KE) / (mb \times Cp) = 43072.7795 / (0.846 \times 510.8)$

$= 99.674^0C$

Where,

mb = mass of braking system components which absorbs energy

Cp = specific heat of braking system components which absorbs energy

ΔTb = Temperature increases in the braking system components which absorbs energy.

We have calculated the heat flux for disc by the following equation in their work, assuming 70% energy on the front wheel and considering the energy of the one wheel, we get;

Heat Flux = (Heat Generated x 0.7)/ (2 x stopping time x area of rubbing) = (43072.7795 x 0.7) / (2 x 1.999 x 0.01459)

= 516895.625 W/m^2

Film Co-efficient:

Pr = (c_p x μ_v) / k= 0.8320 > 0.6

Where,

Cp= Specific heat of air at constant pressure

μv = Dynamic viscosity of air

k= Thermal Conductivity of air

= 0.024 W/m

Re = Vx/ν = (16.67 x 0.638)/ (3.212 x 10^{-5})

= 331309.31

Where,

V = Velocity of air = 60kmph = 16.67m/s

x = Distance travelled by air = 2πr

r = radius of disc = 101.6mm = 0.1016m

ν = kinematic viscosity = 2 x 10^{-5} m^2/s

The flow is Turbulent in nature.

The convective heat transfer coefficient h is of the form:

Film Coefficient = h = 0.04 x (k_a/D_o) x Re$^{0.8}$

= 187.724W/m^2

4. ANALYSIS

Steady state thermal analysis coupled with static structural analysis was performed on Ansys 17. The CAD model of rotor was created in DS SolidWorks 18 as per the adequate dimensions and calculations and then was exported for analysis.

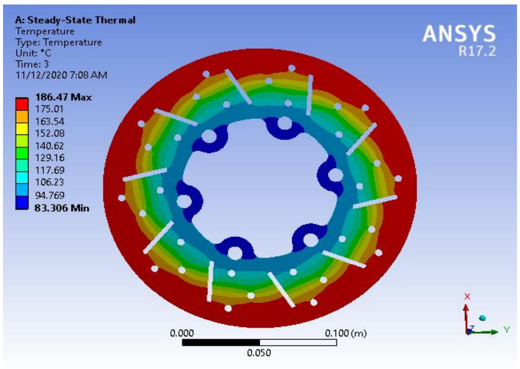

Fig: Temperature

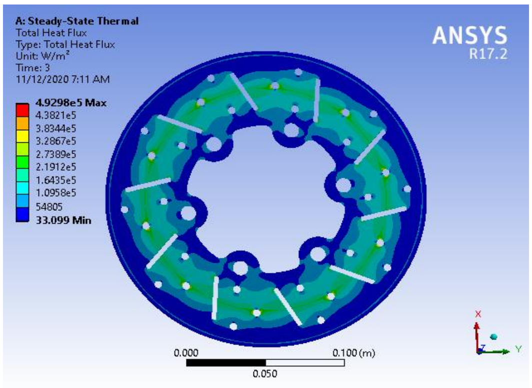

Fig: Total Heat Flux

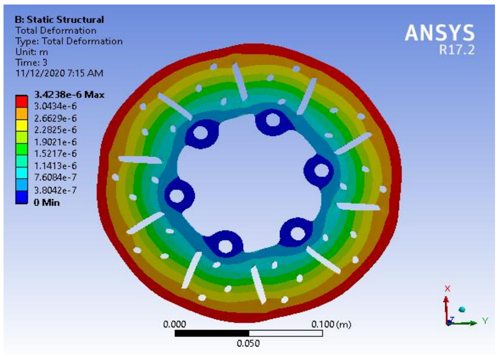

Fig: Total Deformation

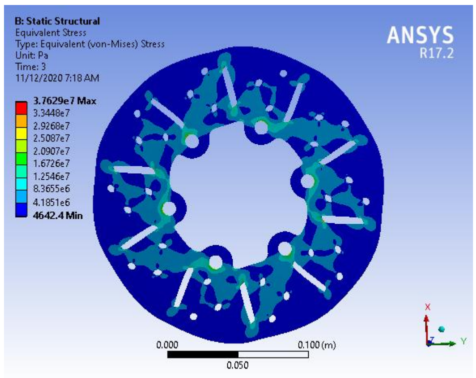

Fig: Equivalent Stress

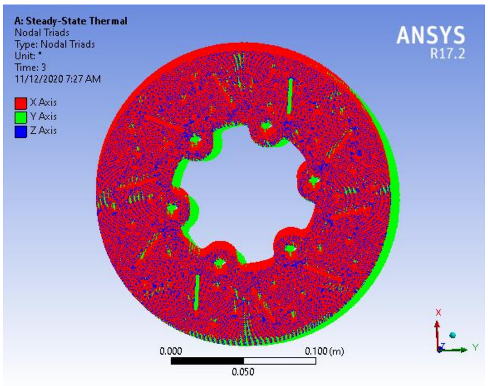

Fig: Nodal Triads

5. CONCLUSION

In this paper, numeric computations have been done to obtain braking forces, braking torque, clamping forces at calipers, brake bias and other important parameters in a braking system. Thermal Calculations for heat flux are done and the film coefficient is determined which helps in the thermal analysis. The results of coupled steady-state thermal and static structural analysis in Ansys have been shown. These results are quite satisfactory. This enforces that our Brake System is feasible, achievable and optimized according to the rulebook of Formula Bharat 2021 while keeping driver's safety as our priority.

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