

Design of Disc Brake's Rotor

¹Prof. Mit Patel, ²Mansi Raval, ³Jenish Patel

¹Assistant Professor, ²PG Student, ³PG Student

¹Mechanical Engineering Department,

¹Silveroak college of Engineering & Technology, Ahmedabad, India

Abstract— Consideration for optimization of technical aspects in automobile is very important and necessary as there are large numbers of vehicles running on road today, so that part or product will be durable, safe and affordable to the users. The brakes are very important aspects of a vehicle as it fulfils all the stopping functions and requirements. As brakes have to undergo through continuous use, many issues surround their heating characteristics when it comes to their development, including contact region properties, material choice, development of hot spots, associated physical geometry, and deformations. The main purpose of this study is to analysis the thermo-mechanical behaviour of the brake disc during the braking phase. The coupled thermal-structural analysis is used to determine the deformation and the Von Mises stress established in the disc to enhance performance of the rotor disc. A comparison between analytical and results obtained from FEA is done and all the values obtained from the analysis are less than their allowable values. Hence best suitable design, will be suggested based on the performance, strength and rigidity criteria.

Index Terms—Vehicle, Geometry, Stress, Performance.

I. INTRODUCTION

All manuscripts must be in English. These guidelines include complete descriptions of the fonts, spacing, and related information for producing your proceedings manuscripts. Please follow them. This template provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. 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. The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in to the surrounding atmosphere. A disc brake is a type of [brake](#) that uses [callipers](#) to squeeze pairs of [pads](#) against a [disc](#) in order to create [friction](#) that retards the rotation of a shaft, such as a [vehicle axle](#), either to reduce its rotational speed or to hold it stationary.



Figure 1- Disc Break

II. WORKING PRINCIPLE OF DISC BREAK

When a brake lever or pedal is pressed, the push rod which is connected to lever or pedal and master cylinder piston pushes the master cylinder piston. This movement allows the master cylinder piston to slide and push the return spring inside the bore of master cylinder, which generates pressure in reservoir tank. At this moment a primary seal allows the brake fluid of reservoir tank

to flow over it into the brake hosepipes. A secondary seal ensures that the brake fluid does not go other side. Then the fluid enters in to cylinder bore of caliper assembly via brake hosepipes and pushes the caliper piston or pistons. At this time the piston ring moves in rolling shape with piston. Then the caliper piston pushes brake pad. This movement causes brake pads to stick with brake disc which creates friction and stops the brake disc/rotor to rotate. This way disk brake system stops or slows down the vehicle.

Disc Brake Operation (floating caliper single piston)

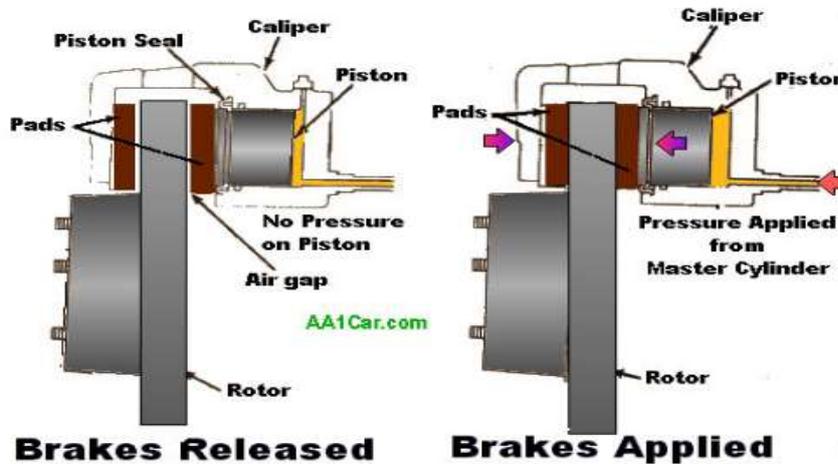


Figure 2- Working of Disc Break

When the brake lever or pedal is released the piston ring pushes the calliper piston back to cylinder bore of calliper till both, calliper piston and piston ring come into their original shape. At this time retraction spring pushes the brake pads to their original position. The return spring in master cylinder assembly pushes the master cylinder piston back into its original position and allows the fluid to flow back to reservoir via hosepipe and master cylinder bore.

III. LITERATURE REVIEW

A lot of research has been done in the area of modelling of components in closed mathematical/physical models. Commercial Computer Aided Engineering (CAE) software has been available since 1978. Over the years, the scope of such software has expanded beyond filling analysis to include analysis.

A. Belhocine, M. Bouchetara [1], The main purpose of this study is to analyse the thermo mechanical behaviour of the dry contact between the brake disc and pads during the braking phase. The simulation strategy is based on computer code ANSYS11. The modelling of transient temperature in the disc is actually used to identify the factor of geometric design of the disc to install the ventilation system in vehicles. The thermo-structural analysis is then used with coupling to determine the deformation established and the Von Mises stresses in the disc, the contact pressure distribution in pads. The results are satisfactory when compared to those found in previous studies.

Manjunath T. V, Dr Suresh P. M [2], The disc brake is a device for slowing or stopping the rotation of a wheel. Repetitive braking of the vehicle leads to heat generation during each braking event. Transient Thermal and Structural Analysis of the Rotor Disc of Disk Brake is aimed at evaluating the performance of disc brake rotor of a car under severe braking conditions and there by assist in disc rotor design and analysis.

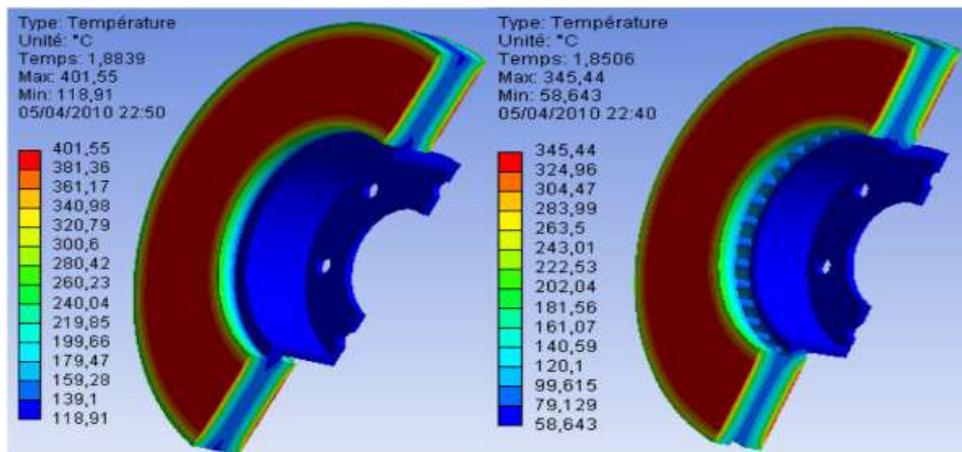


Figure 3- Temperature distribution of a full and ventilated disc of cast iron [2]

Disc brake model and analysis is done using ANSYS workbench 14.5. The main purpose of this study is to analysis the thermo mechanical behaviour of the dry contact of the brake disc during the braking phase. The coupled thermal-structural analysis is used to determine the deformation and the Von Mises stress established in the disc for the both solid and ventilated disc with two different materials to enhance performance of the rotor disc. A comparison between analytical and results obtained from FEM is done and all the values obtained from the analysis are less than their allowable values. Hence best suitable design, material and rotor disc is suggested based on the performance, strength and rigidity criteria. [2]

K.Sowjanya, S.Suresh[3], This paper deals with the analysis of Disc Brake. 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.

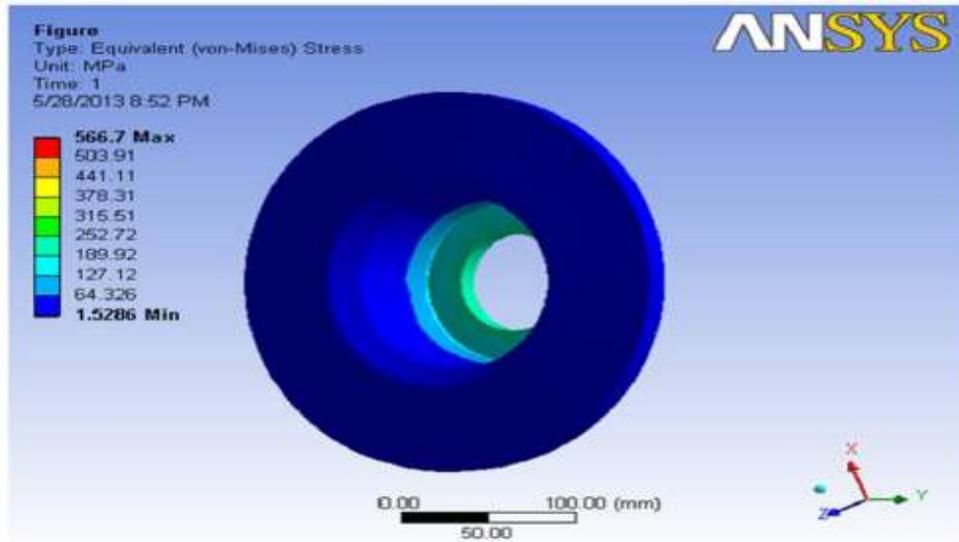


Figure 4- Equivalent stresses for disc [3]

Disc brake is usually made of Cast iron, so it is being selected for investigating the effect of strength variations on the predicted stress distributions. Aluminium Metal Matrix Composite materials are selected and analysed. The results are compared with existing disc rotor. The model of Disc brake is developed by using Solid modelling software Pro/E (Creo-Parametric 1.0).Further Static Analysis is done by using ANSYS Workbench. Structural Analysis is done to determine the Deflection, Normal Stress, Vonmises stress [3].

Viraj Parab, Kunal Naik, Prof A. D. Dhale [4], Disc (Rotor) brakes are exposed to large thermal stresses during routine braking and extraordinary thermal stresses during hard braking. The aim of the project is to design, model a disc. Modelling is done using catia. Structural and Thermal analysis is to be done on the disc brakes using three materials Stainless Steel and Cast iron & carbon-carbon composite. Structural analysis is done on the disc brake to validate the strength of the disc brake and thermal analysis is done to analyze the thermal properties. [4]

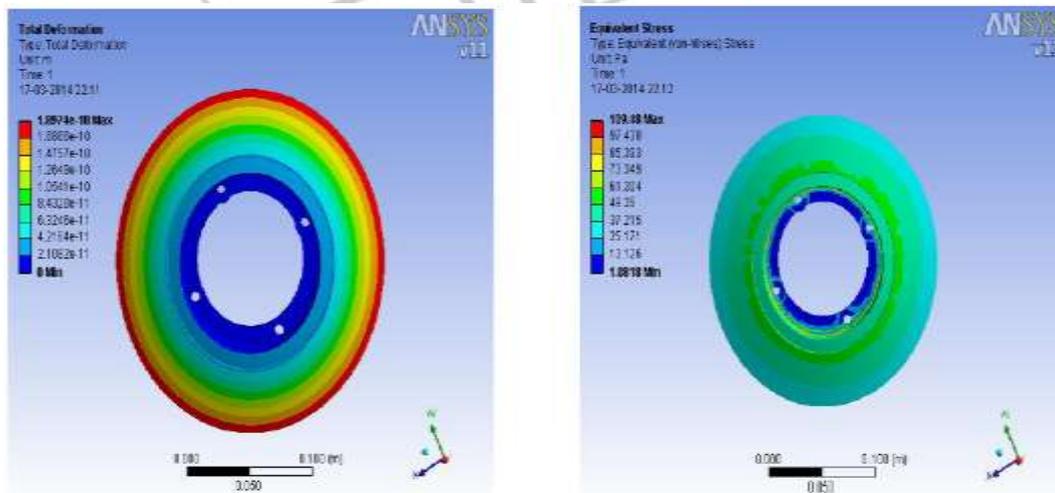


Figure 5- Equivalent stresses Temperature distribution [4]

Comparison can be done for deformation; stresses, temperature etc. form the three materials to check which material is best. Catia is a 3D modelling software widely used in the design process. ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements.

Guru Murthy Nathi, T N Charyulu, K.Gowtham, P Satish Reddy [5]. The motive of undertaking this project of “Coupled Structural / Thermal Analysis of Disc Brake” is to study and evaluate the performance under severe braking conditions and there by assist in disc rotor design and analysis. This study is of disc brake used for cars. ANSYS package is a dedicated finite element package used for determining the temperature distribution, variation of stresses and deformation across the disc brake profile. In this present work, an attempt has been made to investigate the effect of stiffness, strength and variations in disc brake rotor design on the predicted stress and temperature distributions. By identifying the true design features, the extended service life and long term stability is assured. A transient thermal analysis has been carried out to investigate the temperature variation across the disc using axisymmetric elements. Further structural analysis is also carried out by coupling thermal analysis. [5]

Swapnil R. Abhang, D. P. Bhaskar [6], Each single system has been studied and developed in order to meet safety requirement. Instead of having air bag, good suspension systems, good handling and safe cornering, there is one most critical system in the vehicle which is brake systems.

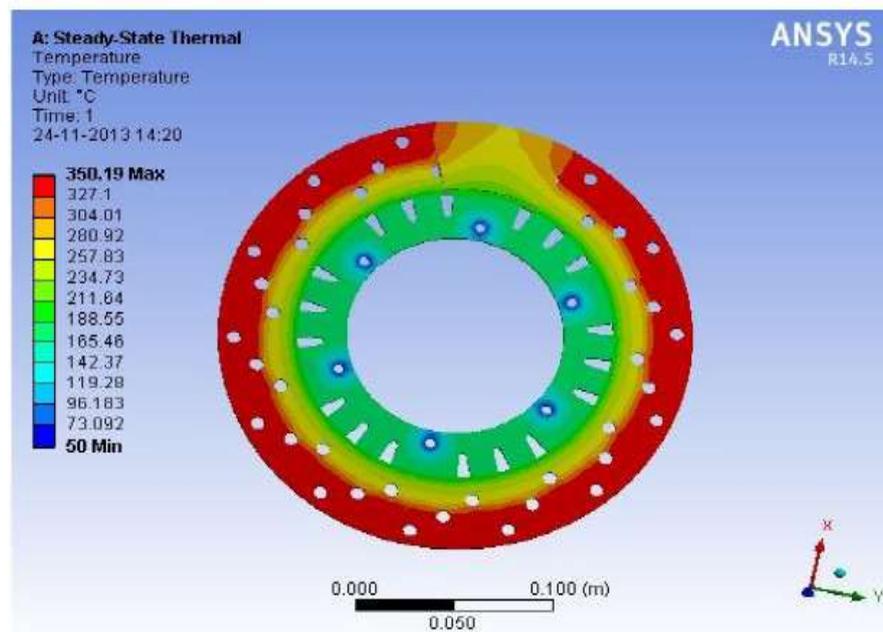


Figure 6- Temperature distribution [6]

Without brake system in the vehicle will put a passenger in unsafe position. Therefore, it is must for all vehicles to have proper brake system. In this paper carbon ceramic matrix disc brake material use for calculating normal force, shear force and piston force. And also calculating the brake distance of disc brake. The standard disc brake two wheelers model using in Ansys and done the Thermal analysis and Modal analysis also calculate the deflection and Heat flux, Temperature of disc brake model. This is important to understand action force and friction force on the disc brake new material, how disc brake works more efficiently, which can help to reduce the accident that may happen in each day.[6]

IV. DESIGN CALCULATION OF DISC BREAK ROTOR

Here, presenting the work for disc brake of MARUTI Company for stress reduction studies.

- Model No : ALTO 800 (Disc Brake)
- Type : Plain Brake
- Kerb weight : 695 kg (Vehicle)
- Max speed : 120 km/h (Vehicle)

<u>Parameter Name</u>	<u>Parameter Value (units)</u>
Mass of the vehicle (M)	1140 kg
Top speed	120 km/hr or 33.33 m/s
Wheel diameter	540 (mm)
Wheelbase	2360 (mm)
Rim diameter	304.8 (mm)
Body length, breadth & height	3495, 1475, 1460 (mm)

Table 1- Basic parameters of a vehicle

<u>Properties</u>	<u>Grey cast iron</u>
Density, ρ	7000 Kg/m ³
Yield tensile strength	142 MPa
Compression-to-Tensile Strength Ratio	4.05
Young modulus, E	100 GPa
Thermal conductivity, K	54 W/m.K
Specific heat, C_p	586 J/Kg.K
Passion's ratio, ν	0.28
Coefficient of expansion, α	$8.1 * 10^{-6}$ m/(m * K)

Table 2- Properties of grey cast iron

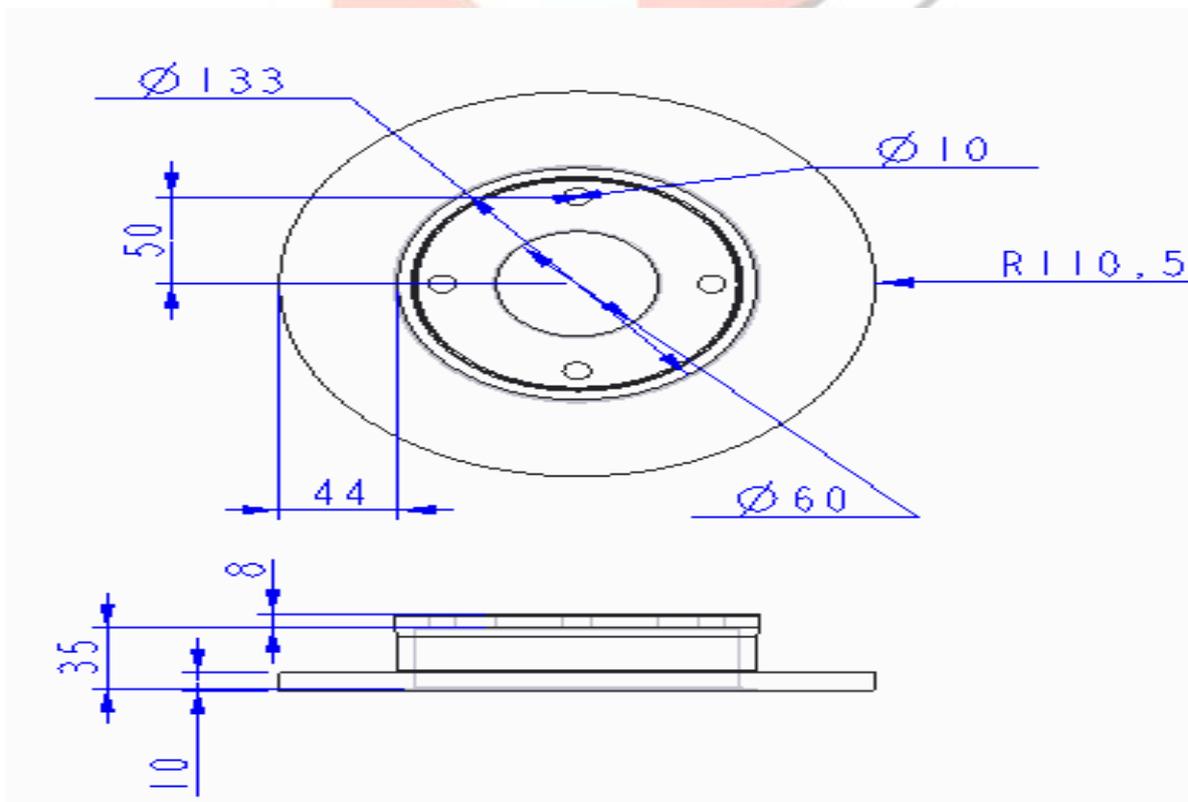


Figure 7- 2D diagram of rotor

<u>Parameter Name</u>	<u>Parameter Value</u>
Outer diameter of the rotor disc	221 mm
Inner diameter of rotor disc	133 mm
Hole diameter	60 mm
Thickness of rotor disc	10 mm
Calliper piston diameter	44 mm
Mass of disc	2.9 Kg

Table 3- Various parameters of disc rotor

(1) Kinetic Energy of Vehicle

$$\begin{aligned}
 \text{K.E} &= \frac{(M \times V^2)}{2} && \text{equ. (1)} \\
 &= \frac{(1140 \times 33.33^2)}{2} \\
 &= 633206.7 \text{ Joule}
 \end{aligned}$$

Where, K.E – kinetic Energy (J)
M – Mass of vehicle (Kg)
V – Linear velocity of vehicle $\left(\frac{m}{s}\right)$

(2) Stopping distance of vehicle

Braking distance of vehicle refers to the distance a vehicle will travel from the point when its brakes are fully applied to when it comes to a complete stop.

$$\begin{aligned}
 \text{The maximum friction force } F &= \mu * M * g && \text{equ. (2)} \\
 &= 0.7 * 1140 * 9.81 \\
 &= 7828.4 \text{ N}
 \end{aligned}$$

$$\begin{aligned}
 \text{Hence deceleration of the vehicle: } a &= F/M && \text{equ. (3)} \\
 &= 7828.4/1140 \\
 &= 6.9 \text{ m/s}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Time taken to stop the vehicle: } t &= V/a \\
 &= 33.33/6.9 \\
 &= 4.83 \text{ s} \\
 &\approx 5 \text{ s}
 \end{aligned}$$

Maximum speed of vehicle is 33.33 m/s

$$\begin{aligned}
 \text{So distance covered by vehicle in 5 second is} &= 33.33 \times 5 \\
 \text{Stopping distance (SD)} &= 166.65 \text{ m}
 \end{aligned}$$

Now, following is other equitation to calculate total stopping distance by considering reaction time of driver is

$$\begin{aligned}
 \text{Total Stopping distance (SD)} &= (V \times \text{reaction time}) + \frac{v^2}{2 * \mu * g} \\
 &= (33.33 \times 2.5) + \frac{33.33^2}{2 * 0.7 * 9.81} \\
 &= 164.21 \text{ m}
 \end{aligned}$$

Above answers are almost same so the calculations are right.

So by considering the average stopping distance is 165 m.

(3) Breaking force

Brake force, also known as Brake Power, is a measure of braking power of a vehicle. Here following process is given to calculate exact force required to stop vehicle within stopping distance or stopping time.

$$\begin{aligned} \text{Tangential braking force: } (BF)_t &= K.E / (S D) && \text{eq. (4)} \\ &= 633206.7 / 165 \\ &= 3837.61 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Tangential force on each wheel } F_t &= (BF)_t / 4 && \text{eq. (5)} \\ &= 3837.61 / 4 \\ &= 959.40 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Braking torque on wheel } T_w &= F_t \times R && \text{eq. (6)} \\ &= 959.40 \times 0.270 \\ &= 259.03 \text{ N.m} \end{aligned}$$

Where, R – Radius of the tyre (m)

$$\begin{aligned} \text{Effective rotor radius } R_e &= \left(\frac{\text{rotor diameter}}{2} \right) - \left(\frac{\text{caliper piston diameter}}{2} \right) \text{ eq. (7)} \\ &= \left(\frac{221}{2} \right) - \left(\frac{44}{2} \right) \\ &= 88.5 \text{ mm} \end{aligned}$$

Here, caliper piston diameter is 44 mm.

$$\begin{aligned} \text{Braking torque on disc } T_b &= T_w \times \frac{R}{r} && \text{eq. (8)} \\ &= 259.03 \times \frac{270}{110.5} \\ &= 633 \text{ N.m} \end{aligned}$$

$$\begin{aligned} \text{Clamping force } C &= \frac{T_b}{2 \times \mu \times R_e} && \text{eq. (9)} \\ &= \frac{633}{2 \times 0.5 \times 0.0885} \\ &= 7610 \text{ N} \end{aligned}$$

Here approximate 7610 N of force is acting on each side of rotor by calliper piston.

(4) Angular velocity of rotor

Maximum speed of vehicle is 120 km/hour or 33.33 m/s

$$\begin{aligned} \text{Velocity } V &= (\pi \times D \times N) \\ 33.33 &= (\pi \times 0.540 \times N) \\ N &= 19.65 \text{ rps (revolution per second)} \end{aligned}$$

$$\begin{aligned} \text{Angular velocity } w &= 2\pi N \\ &= 2 \times \pi \times 19.65 \\ &= 123.65 \text{ r/s} \\ &= 123.65 \times (180/\pi) \\ &= 7073.74 \text{ degree/second} \end{aligned}$$

(5) Heat Flux

In a braking system, the mechanical energy is transformed into a calorific energy. This energy is characterised by a total heating of the disc and pads during the braking phase. The energy dissipated in the form of heat can generate rises in temperature ranging from 300 °C to 800 °C. Generally, the thermal conductivity of material of the brake pads is smaller than that of the disc. We consider that the heat quantity produced will be completely absorbed by the brake disc. The heat flux emitted by this surface is equal to the energy generated by friction.

Heat generated when applying braking action on disc brake = kinetic energy

$$\begin{aligned} H_g &= K.E \\ &= 633206.7 \text{ Joule} \end{aligned}$$

Also, heat generation is $H_g = m_d \times C_p \times \Delta t$

$$\begin{aligned} 633206.7 &= 2.8 \times 586 \times \Delta t \\ \text{Therefore, } \Delta t &= 385.91 \text{ }^\circ\text{C} \end{aligned}$$

Where, m_d – Mass of disc (Kg)
 C_p – specific heat (J/Kg.K)
 Δt – temperature difference ($^\circ\text{C}$)

$$\begin{aligned} \text{Where, } \Delta t &= (t_f - t_i) \\ 385.91 &= (t_f - 25) \\ t_f &= 410.91 \text{ }^\circ\text{C} \end{aligned}$$

Therefore, consider as $t_f = 411 \text{ }^\circ\text{C}$.

As kinetic energy is entirely converted for 5 seconds the power produced will be

$$\begin{aligned} P &= \text{K.E}/t && \text{eq. (10)} \\ &= 633206.7/5 \\ &= 126.64 \text{ kW} \end{aligned}$$

Since only 60% of the mass of the vehicle will be on the front, the power is reduced.

$$\begin{aligned} &= (126.64 \times 0.60)/2 \\ &= 38 \text{ kW} \end{aligned}$$

$$\begin{aligned} \text{Now power on each front rotor is } P &= 38/2 \\ &= 19 \text{ kW} \end{aligned}$$

$$\begin{aligned} \text{Heat flux } H.F &= (P/t)/A && \text{eq. (11)} \\ &= \left(\frac{19}{5}\right)/0.0275 \\ &= 138.18 \text{ kW/m}^2 \end{aligned}$$

$$\begin{aligned} \text{Where } A &= 2 \times \text{contact area of piston of calliper} \\ &= 2 \times \frac{\pi}{4} \times [(\text{diameter of rotor})^2 - (\text{diameter of rotor} - \text{diameter of piston})^2] \\ &= 2 \times \frac{\pi}{4} \times [(0.221)^2 - (0.221 - 0.044)^2] \\ &= 0.0275 \text{ m}^2 \end{aligned}$$

V. CONCLUSION

- Literature study is done for disc brake as per problem statements.
- Design calculation of braking force acting on disc rotor and heat flux is calculated.

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