

# Design and Analysis of Bike Disc Brake Rotor

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**Abstract** - Braking is the most important system of an automobile and such a design where the smooth application of brakes within given braking distance and deceleration and thermal aspects are studied in this paper. Maximum Human effort is taken into consideration while designing the disc to ensure ease in braking. The objective of the paper is to design a brake disc and conduct static Structural analysis for deformation and Thermal analysis for temperature gradient and heat flux. Design is accomplished by using the software Solidworks while Siemens NX and Fusion 360 is used for analysis. The obtained results were found to be safe for the respective structure of the disc assuming normal operating conditions. There were no large deformations and hotspots observed on the disc.

**Key Words:** Disc brake, Static Analysis, Thermal analysis, Stress, Solidworks, Siemens NX, Fusion 360.

## 1. INTRODUCTION

The principle used by every brake is friction. Opposing any force is something friction does but we increase it using brakes. Friction uses kinetic energy to effectively bringing the car to a stop. Every time the brake will use friction to stop the car, one way or another. Brakes introduce a stationary element and put it in contact with a moving one thus causing friction. Friction converts kinetic energy into heat energy.

The braking system should fulfill the following requirements:

- Brakes must be strong and efficient to stop any vehicle within minimum distance during an emergency.
- Brakes must not wear out i.e., their effectiveness should not decrease with the prolonged application.
- Provide good control over the vehicle during emergency braking and the vehicle must not skid.

When the brake pedal is pressed, the high-pressure fluid from the master cylinder pushes the piston outward. The piston pushes the brake pad against the rotating disc. As the inner brake pad touches the rotor,

the fluid pressure exerts further force and the caliper moves inward and pulls the outward brake pad towards the rotating disc and it touches the disc. Now both the brake pads push the rotating disc, a large amount of friction is generated in between the pads and rotating disc and slows down

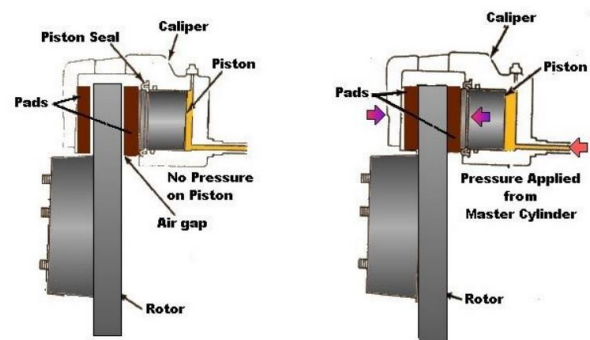


Fig -1: Schematic diagram of Front brake disc

the vehicle and finally stop it. When the brake pad is released, the piston moves outward, the brake pad moves away from the rotating disc and the vehicle again starts to move.

When brake pad comes in contact with the brake disc during brake application, due to friction kinetic energy is converted into heat. The surface of disc in contact with the pads gets heated and due to convection heat generated dissipates to the surrounding to maintain the system in thermal equilibrium. This causes deformation, stress in the disc.

## 2. LITERATURE REVIEW

Manjunath et al [5] studied Transient Thermal and Structural Analysis of the Rotor-Disc of Disc Brake and aimed at evaluating the performance of disc brake rotor of a car under severe braking conditions and thereby assist in disc rotor design and analysis. Disc brake model and analysis were done using ANSYS workbench 14.5. The main purpose of their study was to analyze the thermomechanical behavior of the dry contact of the brake disc during the braking phase. The coupled thermal-structural analysis was used to determine the deformation and the Von Mises stress established in the disc for both solid and ventilated

discs with two different materials to enhance the performance of the rotor disc.

Venkatramanan R et al [4] investigated and analyzed the temperature distribution of rotor disc during operation using Ansys. This was done to understand the pressure force and friction force on the disc brake material, which can help to reduce the accidents that may happen each day. In this research work design of a disc brake was proposed with copper liner, the heat transfer of existing and hybrid disc was calculated for finding the effectiveness of heat transfer and it was concluded that using a copper liner reduced the maximum temperature attained by the disc.

A. Belhocine et al [3] performed numerical simulation for the coupled transient thermal field and stress field was carried out sequentially with the thermal-structural coupled method, based on ANSYS software, to evaluate the stress fields of deformations that are established in the disc with the pressure of the pads. The results obtained by the simulation are satisfactorily compared with those of the specialized literature.

### 3. METHODOLOGY

For this study the disc brake CAD model of front brake disc (Fig -2 and Fig -4) and Rear brake disc (Fig -3 and Fig -5) were modelled using Solidworks, Static analysis is performed using NX Siemens and Thermal Analysis in Autodesk Fusion 360.

The rotor modelled has drilled holes and slots in order to maximize the heat dissipation while braking of the vehicles, also holes for bolts are provided.

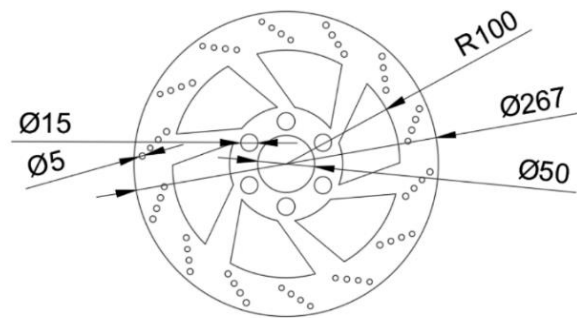
#### 3.1 Design Specifications

Specifications for the model and analysis are of Yamaha R15 bike, this bike was selected because of its popularity and affordability. The following table shows the specification of its braking system [7, 8]:

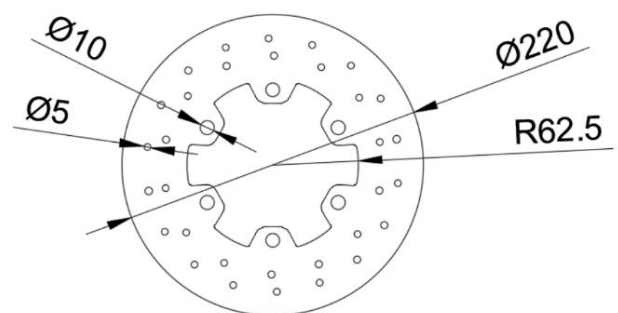
**Table - 1:** Specifications

Parts	Front	Rear
Master Cylinder Diameter	11 mm	12.70 mm
Piston Caliper Diameter	25.40 mm (Dual)	32 mm (Single)

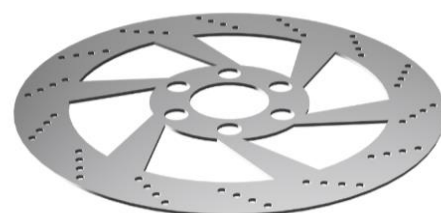
	Piston)	Piston)
Pedal Ratio	5:1	5:1
Tire Diameter	575.9 mm	613.79 mm
Disc Diameter	267 mm	220 mm
Disc Thickness	4 mm	4.50 mm
Brake Bias	72:28	
External Diameter of Rubbing Surface	265 mm	200 mm
Internal Diameter of Rubbing Surface	210 mm	138 mm
Friction Length of Pads	61.5 mm	59.2 mm
Ventilated discs	Yes	Yes
Number of pads	2	2
Caliper	1	1



**Fig -2:** Schematic diagram of Front disc



**Fig -3:** Schematic diagram of Rear disc



**Fig -4:** Front brake disc design



Fig -5: Rear brake disc design

### 3.2 Calculations

The governing calculations required to perform the analysis are given as follows:

External parameters required for the calculations are:

Initial Velocity = 120 kmph = 33.33 m/s<sup>2</sup>

Stopping Distance (s) = 100 m

Mass of vehicle along with driver = 200 kg

$v$  = Initial Velocity (m/s)

$u$  = Final Velocity (m/s)

$a$  = Acceleration (m/s<sup>2</sup>)

$t$  = Time (seconds)

$T_t$  = Total Time (seconds)

$K.E_1$  = Kinetic Energy Initial (J)

$K.E_2$  = Kinetic Energy Final (J)

$W$  = Work Done (J)

Using Newtons Laws of motion,

Calculating Deceleration ( $a$ ):

$$v^2 = u^2 + 2 \times a \times s$$

$$a = \frac{v^2 - u^2}{2s}$$

$$a = \frac{0 - 33.33^2}{2 \times 100}$$

$$a = 5.55 \text{ m/s}^2 \quad \dots (\text{deceleration})$$

Calculating stopping time taken ( $t$ ):

$$v = u + a \times t$$

$$0 = 33.33 - 5.55 \times t$$

$$t = 6 \text{ sec}$$

However, in real life the time taken is more due to human reflexes,

$T_i$  = Reaction time = 0.06s

$T_a$  = time required to apply brake = 0.18s

$T_b$  = time required to start deceleration = 0.95s

$T_t$  = Total time (seconds)

$$T_t = t + T_i + T_a + T_b$$

$$T_t = 7 \text{ sec}$$

**For Front Disc-**

Braking force ( $F_b$ ):

$$K.E_2 - K.E_1 = W \quad \dots (\text{Conservation of Energy})$$

$$\frac{1}{2} \times 0.72 \times M \times v^2 - 0 = F_b \times s \quad \dots (\text{Brake bias is 72:28})$$

$$F_b = 799.84 \text{ N}$$

Torque required to stop the wheel ( $T$ ):

$$T = F_b \times \text{radius of wheel}$$

$$T = 799.84 \times \frac{0.575}{2}$$

$$T = 229.954 \text{ Nm}$$

Force on Brake Disc ( $F_d$ ):

$$F_d = \frac{T}{\text{radius of disc} \times \mu} \quad \dots (\mu \text{ for pads} = 0.4)$$

$$F_d = 4306.25 \text{ N}$$

Pressure created by piston ( $P$ ):

$A$  = Area of 1 piston caliper

$$P = \frac{F}{2 \times A}$$

$$P = 4.249 \text{ MPa}$$

Force applied by master cylinder to get the required pressure ( $F_{cylinder}$ ):

$A$  = Area of master cylinder piston

$$F_{cylinder} = P \times A$$

$$F_{cylinder} = 403.8 \text{ N}$$

Since the pedal ratio is 5:1

The force applied by human ( $F_h$ ):

$$\frac{5}{1} = \frac{F_{cylinder}}{F_h}$$

$$F_h = \frac{403.8}{5}$$

$$F_h = 80.76 \text{ N}$$

Mean right hand brake force by human is 78.66 N [1].

**For Rear Disc-**

Braking force ( $F_b$ ):

$$K.E_2 - K.E_1 = W \quad \dots (\text{Conservation of Energy})$$

$$\left(\frac{1}{2}\right) \times 0.28M \times v_2 = F_b \times s \quad \dots (\text{Brake bias is 72:28})$$

$$F_b = 311.04 \text{ N}$$

Torque required to stop the wheel ( $T$ ):

$$T = F_b \times \text{radius of wheel}$$

$$T = 95.44 \text{ Nm}$$

Force on Brake Disc ( $F$ ):

$$F = \frac{T}{\text{radius of disc} \times \mu} \quad \dots (\mu \text{ for pads} = 0.4)$$

$$F = 2169.09 \text{ N}$$

Pressure created by piston ( $P$ ):

$A$  = Area of 1 piston caliper

$$P = \frac{F}{A}$$

$$P = 2.69 \text{ MPa}$$

Force applied by master cylinder to get the required pressure ( $F_c$ ):

A = Area of master cylinder piston

$$F_c = P \times A$$

$$F_c = 341.65 \text{ N}$$

Since the pedal ratio is 5:1

The force applied by human ( $F_h$ ):

$$F_h = \frac{341.65}{5}$$

$$F_h = 68.33 \text{ N}$$

The maximum leg force by human is 780 N [2].

### 3.3 Material

Material used for front and rear disc is Cast Iron it is characterized for good thermal conductivity and anti-vibration capacity. Following are the properties of Cast Iron [6]:

**Table -2:** Material properties

Material Properties	Values
Density	7.15E-06 kg/mm <sup>3</sup>
Young's Modulus	120500 MPa
Poisson's Ratio	0.3
Yield Strength	758 MPa
Ultimate Tensile Strength	884 MPa
Thermal Conductivity	0.021 W/(mm K)
Thermal Expansion Coefficient	1.2E-05 /K
Specific Heat	450 J/(kg K)

### 3.4 Operation Conditions

The operating parameters for the study are set according to the Table -3:

**Table -3:** Operation conditions

Temperature ambient	20 °C
Stopping time	7 seconds
Convection value (medium- air)	38 W/(m <sup>2</sup> K)
Acceleration Due to gravity	9.81 m/s <sup>2</sup>

## 4. ANALYSIS

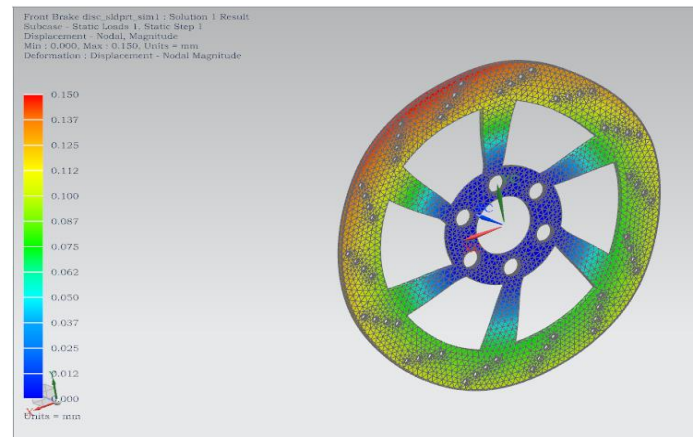
Static and thermal analysis were performed on the models of the brake discs using the calculated forces and pressure applied on the discs, material and operating conditions as given in Table -2 and Table -3.

### 4.1 Static structural analysis:

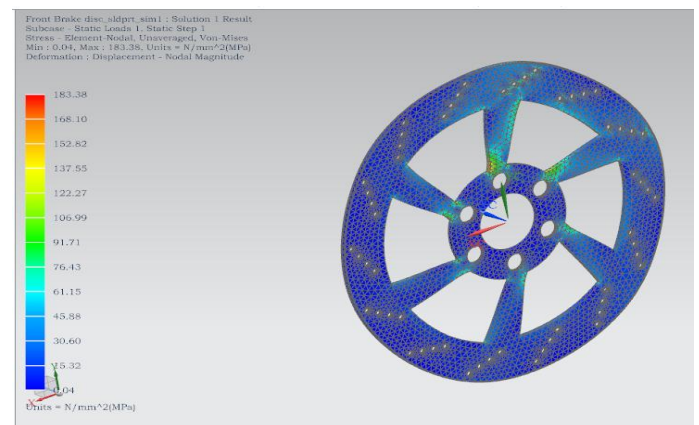
Static analysis is performed over a structure when the loads and boundary conditions remain stationary and do not change over time; it is assumed that the load or field conditions are applied gradually.

#### Solving Model

- Total Deformation given in Fig -6 and Fig - 8
- Von Mises Stress given in Fig -7 and Fig -9



**Fig -6:** Total deformation for front disc



**Fig -7:** Equivalent (von- Mises) stress for front disc

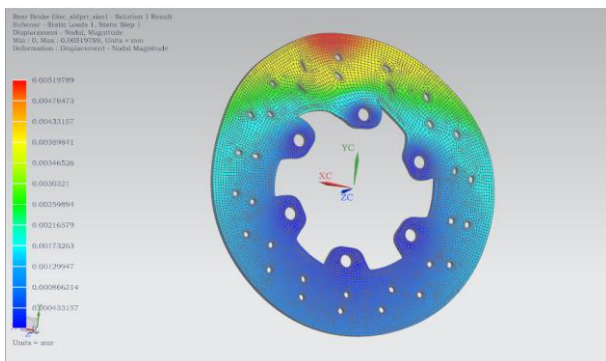


Fig -8: Total deformation for rear disc

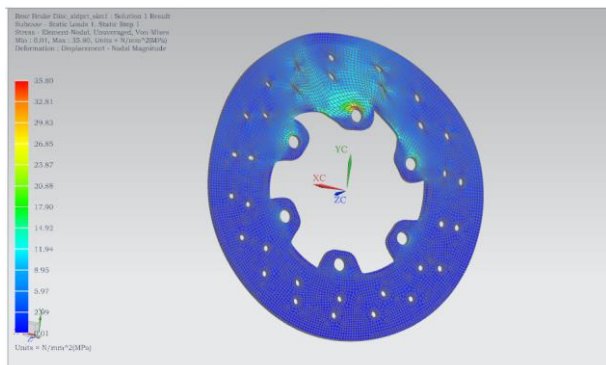


Fig -9: Equivalent (von- Mises) stress for rear disc

#### 4.2 Thermal analysis:

Steady state thermal analysis is performed to determine the effect of temperature by assigning surface temperature to the model and constraints.

#### Solving Model

- Temperature Change given in Fig -10 and Fig -12
- Heat Flux given in Fig -11 and Fig -13

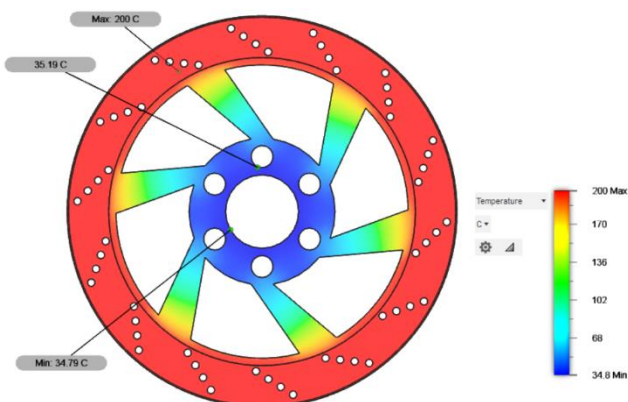


Fig -10: Temperature for front disc

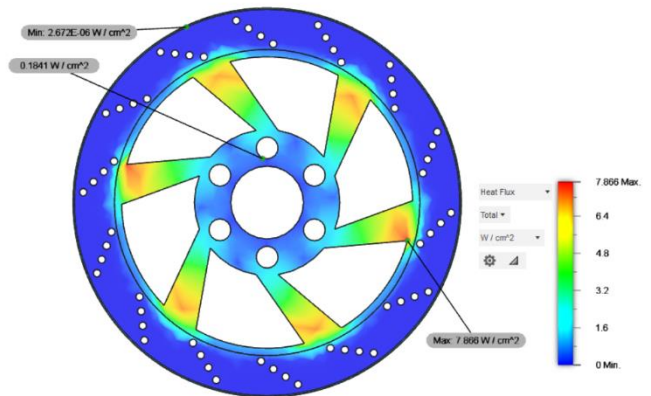


Fig -11: Total heat flux for front disc

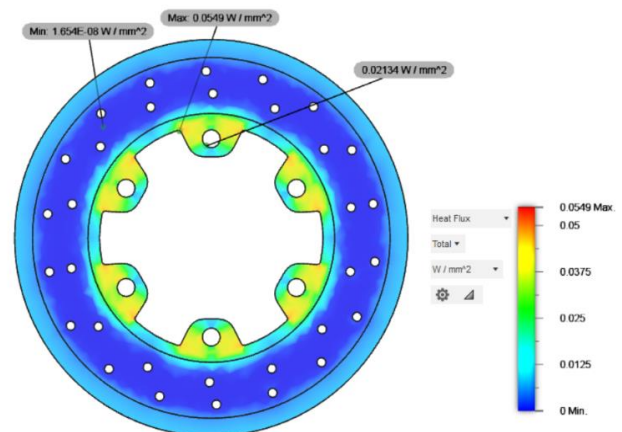


Fig -12: Temperature for rear disc

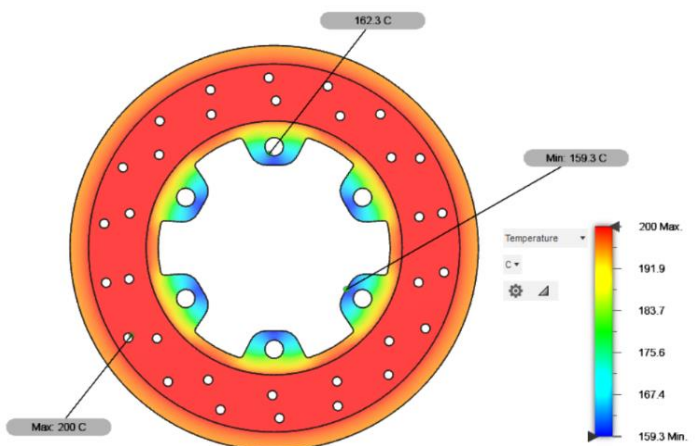


Fig -13: Total heat flux for rear disc

### 5. RESULTS AND DISCUSSION

As per the calculations vehicle moving at a speed of 120 kmph has the stopping distance of 100 meters takes 7 seconds to stop after an obstacle is visible.

To understand the deformation and stresses generation in the front and rear disc of the vehicle after applications of forces and pressure a static analysis was performed on the NX Siemens software. A force of 4306.25 N with pressure of 4.249 MPa was applied on the front brake disc model and force of 2169.09 N along with pressure equal to 2.69 MPa was applied on the rear disc model.

**Table -4:** Specifications for perimetric brake disc

Parameter	Front		Rear	
	Max	Min	Max	Min
Von Mises Stress	183.38 MPa	0.04 MPa	35.80 MPa	0.01 MPa
Temperature	200 °C	34.6 °C	200 °C	158 °C
Heat Flux	0.093 W/mm <sup>2</sup>	5.78E-08 W/mm <sup>2</sup>	0.545 W/mm <sup>2</sup>	5.86E-8 W/mm <sup>2</sup>
Thermal Gradient	4.44 °C/mm	2.75E-6 °C/mm	2.597 °C/mm	2.79E-6 °C/mm

## 6. CONCLUSIONS

This paper explains design of front and rear brake disc of a two-wheeler in Solidworks and the calculation of force applied by human on brake handle. Analysis results from Siemens NX and *Fusion 360* provides displacement and Von Misses Stress and Thermal analysis respectively.

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