Design and Analysis of Brake Rotor (DISC)

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Abstract - *A brake is a mechanical device that inhibits motion by absorbing energy from a moving system. It is used for slowing or stopping a moving vehicle, wheel, axle, or to prevent its motion, most often accomplished by means of friction. The brakes are very important aspects of a vehicle as it fulfils all the stopping functions and requirements. The following work is about the disc or rotor of disc brake analysis. A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc or "rotor"[1] to create friction. Hydraulically actuated disc brakes are the most commonly used form of brake for motor vehicles. Development of disc-type brakes began in England in the 1890s. Mass production began with the 1955 Citroën DS. The disc is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To slow down the wheel, friction material in the form of brake pads, mounted on the brake caliper, is forced mechanically, hydraulically, pneumatically, or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. The material of the disc used for study is Stainless Steel,. The main purpose of this study is to analysis the thermo-mechanical behavior of the brake disc during the braking phase on ansys. After obtaining the analyzed results the manufacturing of the rotor for the best results is carried out.*

Key Words: *- Disc Brake, Heat Generation, Friction, Analysis, Ansys.*

1. INTRODUCTION

The brake disc (or rotor) is the rotating part of a wheel's disc brake assembly, against which the brake pads are applied. The material is typically gray iron, a form of cast iron. The caliper having brake pads is mounted on the rotor. Some discs are simply solid, but others are hollowed out with fins or vanes joining together the disc's two contact surfaces. The weight and power of the vehicle determines the need for ventilated discs. Discs for motorcycles, bicycles, and many cars often have holes or slots cut through the disc. This is done for better heat dissipation, to aid surface-water dispersal, to reduce noise, to reduce mass, or for marketing cosmetics. The force applied on brake pads is generally in three ways such as hydraulic, pneumatic and mechanical. Slotted discs have shallow channels machined into the disc to aid in removing dust and gas. Slotting is the preferred method in most racing environments to remove gas and water and to deglaze brake pads. Disc brakes provide higher stopping performance.

A modern development, particularly on inverted ("upside down", or "USD") forks is the radially mounted caliper. Although these are fashionable, there is no evidence that they improve braking performance, nor do they add to the stiffness of the fork.

1.1 Working Principle of Brake

The disc brake system works based on Pascal's law which states that " Pressure exerted anywhere in a contained incompressible fluid is distributed equally in all direction throughout the fluid". When you apply the brake, the caliper will receive the high pressure hydraulic fluid from the brake master cylinder. The fluid will push the piston which makes the inner brake pad to squeeze against the disc rotor surface. As a result the fluid's backward force will push the caliper frame along the side pin which makes the outer brake pad to squeeze against the other side of the disc rotor.

1.2 Components of Disc Brake System

1.) Wheel Hub Assembly- It holds the wheel and the disc rotor and bearing inside it allows their smooth rotation.

2.) Disc Brake Rotor- It is the part to which the brakes pads squeeze against which retard the rotation of the wheel. It produces a lot of heat due to friction and the drilled holes provides ventilation to remove this heat.

3.) Brake Caliper Assembly- It uses the hydraulic forces from the brake pedal to squeeze the brake pads to the rotor surfaces, thus creating friction and decelerates the wheel. The caliper assembly consist of

- Caliper Bracket
- Slider Pins
- Dust boots/ Rubber Bellows
- Inner brake pads
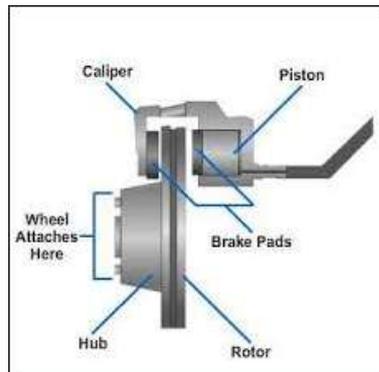- Outer Brake Pad
- Caliper Frame
- Piston

4.) Wheel

Fig-1 Disc Brake Assembly

1.3 Automotive Purpose

For automotive use, disc brake discs are commonly made of grey iron. The SAE maintains a specification for the manufacture of grey iron for various applications. For normal car and light-truck applications, SAE specification J431 G3000 (superseded to G10) dictates the correct range of hardness, chemical composition, tensile strength, and other properties necessary for the intended use. Some racing cars and airplanes use brakes with carbon fiber discs and carbon fiber pads to reduce weight.. The structural steel includes a broad variety of low carbon and manganese steels. Structural steels also include minor quantities of significant additions of other elements like Nb, V, Ti and Al.

1.4 Methodology

The braking system design includes the single disc at the front wheel to lock/stop the vehicle. Master cylinder is used at the front near the brake lever providing the occupant to easily accessible space.

2. Selection of Calipers:-

The dual piston calipers were selected due to their light weight easy availability and reliability. The disc of suitable to the caliper was used for Anaysis.

1. Diameter of the Disc: 180mm

2. Thickness of the Disc: 4.5mm

3. Effective disc radius: 56.25mm

2.1 Master Cylinder:-

The master cylinder with bore Diameter 22 mm proved to be best suited for the design. The single piston master cylinders were used.

A catia model of the rotor was designed having parameter assigned according to analysis procedure. Following figure represents the catia model of Disc.
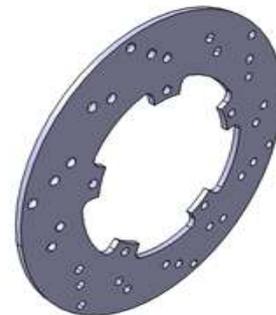

Fig 2 Catia Model of Disc

Table 1 Optimization chart

Parameters	Before optimization		After Optimization	
	Minimum	Maximum	Minimum	Maximum
Total Heat Flux	0	1.52E5 w/m^2	0	1.24E5 w/m^2
Temperature Effect	73.5C	180C	73.59 C	165C

From the above tabulated results of Brake Disc, It shows that the Total Heat Flux generated in optimized Brake Disc is less than the Total Heat Flux generated in Brake Disc before optimization, hence the chances of Heat generation in optimized brake disc during braking is very less which increases the braking efficiency.

Fig.3 Analysis of Disc on Ansys

2.2. Brake Fluids

We have decided to use DOT 3 Brake fluid

- Inexpensive.

- Easily available.

- Compatible.

Considering the Gross weight of bike as 280 KG

Gross Mass of bike: 280.

Front: Rear = 45:55

Type : Disc

Rear: OD – 190mm

Front: OD – 170mm

Master cylinder: 22 mm.

Caliper piston diameter:

Front: 34mm.

Rear: 34mm.

Brake pedal/lever ratio: 7:1.

Stopping distance: 3.6m.

$A_{mc} = 3.8013 * 10^{-4} m^2$

$A_{cal} = 1.0178 * 10^{-3} m^2$

2.3 Selection of Rotor

Calculations for rotor diameter and material selection for brake disc is as Stainless steel.

1) Torque required to stop the vehicle T_b – this torque depends upon dynamic weight transfer and the wheel dimensions. It plays a fair role in calculating the rotor diameter. The following expression gives the braking torque.[4]

$$T = \frac{Wt}{2} * \frac{Dw}{2} * g$$

Where, D_w =Diameter of tyre

W_t = Dynamic axial weight

When a vehicle is travelling with a certain speed is suddenly stop. The front suspension goes into jounce where as the rear spring experiences rebound the reason behind this is that a portion of rear axle weight get transferred to the front axle, this is known as dynamic weight transfer. The Dynamic weight transfer is given by the expression.

$$W_t = \frac{m*g}{b}$$

Where, W_t= Dynamic weight transfer.

h = height of CG from ground

m = Mass of vehicle in Kg.

b = Wheel base

The caliper pressure generated is 800 PSI

(According to karizma ZMR manufacturing catalogue)

$P_a = 5515200$ N/m²

h = 600mm= 0.6m

m =220 Kg

g = 9.81

b = wheel base => 1200mm\

$$W_t = \frac{0.6*220}{1.2} = 110 \text{ Kg}$$

Applying the above formula,

$$T_b = \frac{Wt}{2} * \frac{Dw}{2} * g$$

$$= \frac{110}{2} * \frac{0.558}{2} * 9.81$$

T_b =150.5344 N-m

Torque Generated by caliper on the rotor is given by

$$T = \frac{P*f*\pi*(D^2 - d^2)*d}{4}$$

Iterations were done to find the rotor diameter using this formula.

Sample calculations are below

Where, P_a=Pressure generated in caliper

The caliper pressure generated is 800 PSI according to Karizma ZMR manufacturing catalog.

Therefore, P_a = 5000000 N/m²

Pad Friction (f) =0.4

d= Inner diameter of rotor contact = 140 mm

D= Outer diameter of rotor contact = 180 mm

$$T = \frac{5000000 * 0.4 * \pi \left(0.180^2 - 0.140^2\right) * 0.140}{4}$$

T= 2814.867 N-m

The above relationship assumes that pad covers 360 degrees of disc on one side. However the pad covers only a fraction of disc. The pad fraction is the pad contact angle divided by 360 degrees.[13]

$$\text{Pad Fraction} = \frac{Pad contact angle}{360}$$

$$= 30/360$$

$$= 1/12$$

Actual T= T*pad fraction

$$= 2814.867 * \frac{1}{12}$$

T = 234.5722 N-m

$$\text{Factor of safety} = \frac{Torque generated}{Torque required}$$

$$= \frac{234.5722}{150.5344}$$

FOS = 1.558

Hence the design is safe.

3 Calculations for Stopping Distance

1. Kinetic energy of vehicle, $K.E = \frac{m \times v^2}{2}$

$$= \frac{220 \times 11.11^2}{2}$$

$$= 13580.24 \text{ Joules}$$

Where, m = mass of vehicle

     V= speed of the vehicle (m/s)

2. Stopping distance of vehicle

a) The maximum friction force, $F = \mu \times m \times g$

$$= 0.7 \times 220 \times 9.81$$

$$= 1510.74 \text{ N}$$

Where, H= friction coefficient

     m = mass of the vehicle

     g = acceleration due to gravity

b) Deceleration of the vehicle (a) = $\frac{F}{M}$

Where, F= maximum friction force

     M= mass of the vehicle

     a = 6.86 m/s^2

c) Time taken to stop the vehicle

$$t = \frac{V}{a} = \frac{11.11}{6.86} = 1.6195 \text{ sec}$$

d) Distance covered by vehicle in 5 sec in stopping distance

$$= V \times 5$$

$$= 11.11 \times 5$$

$$= 55.55$$

e) Total stopping distance = $V \times$ (reaction time) + $\frac{V^2}{2\mu g}$

$$= 11.11 \times (2.5) \times \frac{11.11^2}{2 \times 0.7 \times 9.81}$$

$$= 36.76 \text{ m}$$

3.1 Calculations for Brake Force and heat flux[10]

1) Tangential braking force (B.F) $_t$ = $\frac{Kinetic energy}{stopping distance}$

$$= \frac{13580.24}{36.76}$$

$$= 369.429 \text{ N}$$

2) Tangential force on each wheel, $F_t = \frac{(B.F)_t}{4}$

$$= 92.357 \text{ N}$$

3) Braking torque on wheel, $T_w = F_t \times R = 25.76$ N-m

     Where, R= radius of tire

4) Effective rotor radius,

$$R_e = \frac{rotor\,outer\,radius}{2} - \frac{rotor\,inner\,radius}{2}$$

= 77.5mm

5) Clamping force, $C = \frac{T_b}{2 \times \mu \times R_e}$ = 2312.288 N

6) Heat Flux

In braking system, the mechanical energy is transformed into a calorific energy.

Heat generated or disc brake = Kinetic energy

H_g = K.E

Where, $H_g = m_d \times C_p \times \Delta t$

   m_d = mass of the disc

   C_p = Specific heat

Δt = temperature difference

$H_g = 0.4 \times 460 \times \Delta t$

$\Delta t = \frac{13580.24}{0.4 \times 460}$

$\Delta t = 73.8056\,°C$

3. CONCLUSIONS

Hence with the help of the calculation procedure the disc was designed as per the assumed weight of the bike. The below table represents the result out of the calculation of the disc. The Thermal analysis was performed on the disc rotor with the help of the Ansys software.

Table no 2 Result Table

Sr. No	Parameters	Results
1	Material	Stainless Steel 321
2	Outer Diameter	180 mm
3	Inner Diameter	140 mm

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