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DESIGN AND ANALYSIS OF OUTBOARD BRAKING FOR ALL TERRAIN VEHICLES

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Abstract:

This project report on design and analysis of outboard braking in all terrine vehicles is to explain the brake function and its types. Along with this, the design and analysis of brake components such as disc plate, callipers, pedal, and disc material were done. It was done to avoid the problems faced by the brake assembly during dynamic and static conditions of a vehicle. The design and calculations of brake is done to attain a proper wheel locking under any condition i.e. the braking is possible in on-road and off-road setup. This paper involves the component description involved in the brake system, designing of customised brake disc, analysis of the disc on thermal conditions.

1. Introduction:

All-terrain vehicles (ATV's) have become very popular for both recreational and utility purposes. ATV's are off-road vehicles characterized by having four wheels (two front and two rear) with low pressure tires, handlebars connected to the front wheels for steering, a straddle-type seat designed for a single rider, laterally extending footrests on opposite sides of the vehicle, and an engine and transmission located generally beneath the straddle-type seat and substantially between the footrests. Typically ATV's are not wider than about 50 inches-most commonly about 44-48 inches in overall width. In many applications, it is desirable to have all four wheels driven by the engine. Four wheel drive ATV's typically have one drive train connecting the transmission to the rear wheels and a separate drive train connecting the transmission to the front wheels. ATV's desirably include a braking system capable of braking all four wheels. Typically the braking system includes a separate disc brake on each front wheel and a disc brake on the generally rigid axle carrying the rear wheels. A master cylinder, typically operated by a handlebar-mounted lever, is hydraulically connected to each of the disc brake callipers so that actuation of the lever simultaneously actuates all of the brake callipers, providing even braking of all of the ATV's wheels. A disc brake is a wheel brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of callipers. The brake disc is usually made of cast iron. This is connected to the wheel and the axle. To stop the wheel, friction material in the form of brake pads, mounted on a device called a brake calliper, is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade.

- Braking System: The braking system is designed to decelerate a vehicle. The systems used to rely on drum brakes and more lately upon disc-brakes. Some are air-brakes like on trucks or trains. Essentially when you press the brake-pedal you are forcing brake oil through a master cylinder and then through metal tubes that will in turn, push a disc-pad against a disc. An excellent braking system is the most important safety feature of any land vehicle. Competition regulations require at least two separate hydraulic braking systems, so that in the event of a failure of one, the other will continue to provide adequate braking power to the wheels.
- Function of Braking System: The main function of braking system is to decelerate or decrease the speed of moving automobile bikes, car, trucks, etc., Brakes have two functions in common. To decelerate or stop a moving vehicle and to send an electrical signal to the tail lamp there by informing other vehicles on the road about the braking.

Deceleration:

The main function of the brake system is to decelerate or decrease the speed of a vehicle. By stepping on the brake pedal, the brake pads compress against the rotor attached to the wheel, which then forces the vehicle to slow down due to friction.

Absorption:

A brake system absorbs the kinetic energy of the vehicle mechanically or electrically in order to decrease its speed. In mechanical brakes, friction converts the kinetic energy into heat. In electric brakes, an electric current forces a magnet to apply the brakes.

Types of Brake System:

Mechanical Brakes: These act by generating frictional forces as two surfaces rub against each other. There are two types of mechanical brakes:

Drum Brakes: The drum brake has a metal brake drum that encloses the brake assembly at each wheel. Two curved brake shoes expand outward to slow or stop the drum which rotates with the wheel.

Disc Brakes: A friction system using a wheel brake to slow the rotation of the automobiles wheels; brake pads are pushed against the brakes rotor with a set of callipers.

Hydraulic Brakes: These brakes which are operated by means of hydraulic pressure are called hydraulic brakes. These brakes are based on the principle of Pascal's law.

Single-Circuit Hydraulic Brakes: A master cylinder fed by a reservoir of hydraulic brake fluid and connected by a system of metal pipes and rubber fittings attached to wheel cylinders; each wheel has opposing pistons on band or drum brake; pressure is produced to push pistons apart and force brake pads into wheel cylinder.

Dual-Circuit Hydraulic Brakes: Brake system consists of a command circuit that activates when brakes are pressed, and a second circuit controlled by the cars computer that calculates applied force and applies it to the hydraulic pump system.

Brake Considerations:

Weight Transfer: The amount of load that converted as weight when the brake is applied that travels totally from the roll cage to the tire entirely at the point when the brake is applied to the vehicle stops that is known as weight transfer

Wheel Base: The distance from the front wheel to the back wheel is known as wheel base that is the total distance between the axils and for off road vehicle it is taken that from the steering axial.

Deceleration: This deceleration means the reduction of velocity while in braking actually. Because when the braking load is applied on the vehicle which moves with great velocity because of acceleration so this takes place mainly on application of braking load.

Frictional Force: Frictional Force refers to the force generated by two surfaces that contacts and slide against each other. These forces are mainly affected by the surface texture and amount of force impelling them together. The angle and position of the object affect the amount of frictional force.

Brake Torque: Brake torque is the force applied at the brake wheel to stop the motion of the moving equipment. Assuming the operating conditions for the equipment are constant, a brake having a retarding torque equal to the full load torque of the motor to which it is applied is usually satisfactory.

Braking Power: Only when the brake is applied (but rotating) is energy being dissipated in the brake system. Some of the stop energy is dissipated in the tyre as wheel slip. Managing the ideal wheel slip is the ultimate goal of ABS development but here assume 8%. The energy to each brake depend on the number of brakes and the proportion of braking on each axle..

2. Problem Identification:

Vehicle handling is the most important way that, vehicle performs transverse to their direction of motion, significantly during cornering and swerving. It also includes their directional stability when moving in steady state condition. While driving a vehicle, its handling comfort and braking performance are the most important aspects of a vehicle's "active" safety. The utmost lateral acceleration is sometimes discussed on individual basis as "road holding". (This discussion is directed at road vehicles with at least three wheels, however a number of it is going to apply to alternative ground vehicles.) Cars driven on public roads whose engineering requirements are handling over comfort as well as passengers space which has to be present in a sports car.

More Unsprung Mass:

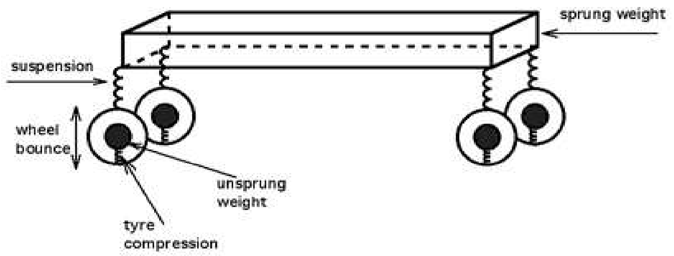

Figure 1: More Un Sprung Mass

All weight which is supported by the suspension, including portions of the weight of the suspension members are regarded as sprung weight. Un-sprung weight includes the suspension upright and all components attached to it; the brake calliper, brake disc, wheel, tire and a portion of suspension arms. Sprung weight is protected from the shocks and vibrations that the wheels experience as they travel over every bump and pothole. This makes for a more comfortable ride and protects the sprung components from destructive and life shortening shocks and vibrations. Conversely, unsprung weight must be designed to be tough enough to survive the constant shocks and vibrations, which can be difficult for complex parts such as wireless pressure sensors. In general, it’s best to have a high ratio of sprung to un-sprung weight. A higher proportion of sprung weight can then push down on the wheels and tires with more force, keeping them in contact with the pavement or whatever surface they are traveling across. Maintaining contact with the roadway improves handling and traction, and this becomes more of an issue for off-roading and traveling over rough roads. So as a rule, designers try to minimize un-sprung weight to improve handling and steering.

Complex Hub and Knuckle Design:

In rear side, the hub and knuckle design is more complex due to arrangement of disc and calliper inside the wheel setup and also there is a drive shaft arrangement in rear side. So, it has more complex to designing the outboard brake system within wheel setup.

Brake Bleeding Effort:

Bleeding problem takes place when the brake lining has hole or the hole is made during the manufacturing process that leads to bleeding of the fluid from the lining that leads to break failure

Twisting Force on Suspension Arm:

In normal brake system, the brake torque is generated on calliper and it is applied directly to the knuckle. Further it has been transferred to the suspension arm. So suspension arm must resist the twisting force applied by the brake.

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3. Disc Material:

Cast iron usually refers to grey cast iron, but identifies a large group of ferrous alloys, which solidify with a eutectic. Iron accounts for more than 95%, while the main alloying elements are carbon and silicon. The amount of carbon in cast iron is the range 2.1-4%, as ferrous alloys with less are denoted carbon steel by definition. Grey cast iron contains appreciable amounts of silicon. Normally 1-3%, and consequently these alloys should be considered ternary Fe-C-Si alloys. Graphite is present in the form of flakes. Disc brake disc are commonly manufactured out of a material called grey cast iron. Grey cast iron, a type of cast iron that has a graphite microstructure. It is named after the grey colour of the fracture it forms, which is due to the presence of graphite. It is the most common cast iron and the most widely used cast material based on weight.

Properties of Grey Cast Iron:

Structural	
Young's Modulus	1.1e+005 MPa
Poisson's Ratio	0.28
Density	7.2 e-006 kg/mm3
Thermal Expansion	1.2e-005 1/0C
Tensile Yield Strength	250 MPa
Compressive Yield Strength	250 MPa
Tensile Ultimate Strength	460 MPa

Table 1: Properties of grey cast iron

4. Brake Design Calculations:

Design Parameters:

Front Axle Static Load:

$$\text{Front axle static load } (W_1) = \frac{W * C_f}{L}$$

$$= \frac{2540.79 * 33.5}{58}$$

$$W_1 = 1467.52 \text{ N}$$

Where,

W = Total weight of the vehicle (N)

C_f = Longitudinal distance from front wheel base to CG point (inch)

L = Wheel base of the vehicle (inch)

Deceleration:

Maximum velocity of the vehicle (v) = 60 kmph = 16.66 m/s

Assumed stopping time (T) = 3 sec

$$\text{Decelaration}(a) = \frac{V}{T}$$

$$\text{Decelaration}(a) = \frac{16.667}{3}$$

$$a = 5.55 \text{ m/s}^2$$

Front Axle Dynamic Load:

$$\text{Front axle dynamic load } (W_{dL1}) = W_1 + \frac{aWH}{gL}$$

$$W_{dL1} = 1863.31 \text{ N}$$

Where, H = Centre of gravity height from ground level (inch)

g = Acceleration due to gravity (m/s^2)

Frictional Brake Torque Required to Lock the Front Wheels:

Brake torque on front wheels $(T_f) = \mu_T * R_f * W_{dL1}$

T_f =295.80 Nm

Where, μ_T = Co-efficient of friction of tyres (Assume μ_T =0.5)

R_f = Radius of the front wheel tyres (m)

Brake Force Required:

$$\text{Brake force } (B_f) = w_d * a * g$$

$$B_f = 1776 \text{ N}$$

Where, w_d = Weight of the vehicle in N (Assume driver's weight 60 kg)

Calculation for Selecting a Disc Rotor:

Total Brake Force:

$$\text{Total brake force } F = \frac{r * 2 * \mu_d * A_w * R_p * f}{R * A_m}$$

$$F = \frac{2 * 0.75 * 4 * 250 * r * A_w}{0.3175 * 3.14 * (0.015875)^2}$$

$$F = \frac{1500 * r * A_w}{0.0000628435}$$

Where, r = Disc plate outer radius (m)

μ_d = Co-effiecient of friction of disc plate (Assume μ_d = 0.75)
A_w= Area of calliper piston (m^2)
R_p = Pedal Ratio
f = Pedal force (N)
R = Radius of tyres (m)
A_m = Area of Master Cylinder piston (m^2)

Frictional Force:

$$F_{f1} = \mu_d * W_{dl1}$$

$$F_{f1} = 1397.48 \text{ N}$$

Where, F_{f1} = frictional force on front side (N)

Front Disc Selection:

$$2386.88 * 10^4 * r_f * A_w > 1397.48$$

Front calliper piston diameter = 0.030 m

$$2386.88 * 10^4 * r_f * \frac{\pi}{4} 0.030^2 > 1397.48$$

$$1.68 * 10^4 * r_f > 1397.48$$

$$r_f > \frac{1397.48}{1.68 * 10^4}$$

$$r_f > 0.082m$$

In front side, we choose Out Board brake system so there is two disc mounted on inside the wheel setup. For a safety purpose, radius of 0.09 m disc plate has been selected.

$$r_f = 0.09\text{m}$$

Where, r_f = Front disc plate radius

Total Braking Force:

$$\text{Brake force on front} = 2386.88 * 10^4 * r_f * A_w$$

$$= 2368.88 * 10^4 * 0.09 * \frac{\pi}{4} (0.030)^2$$

$$T_{Bf} = 1512 \text{ N}$$

Design Checking:

Total Braking Force:

$$\text{Total braking force applied } (T_{BF}) = T_{BF(f)} + T_{BF(r)}$$

$$= 1512 + 898.8$$

$$T_{BF} = 2410.8 \text{ N}$$

Required braking force < total braking force applied

1776 N < 2410.8 N

So design of disc plate is safe.

Brake Torque:

$$\text{Brake torque applied } (T_B) = T_{BF} * R$$

$$T_B = 765.429 \text{ Nm}$$

$$\text{Required brake torque } (T_{Br}) = T_f + T_r$$

$$= 295.80 + 107.54$$

$$T_{Br} = 403.34 \text{ N}$$

Required brake torque < brake torque applied

403.4 Nm < 765.424 Nm

So design of disc plate is safe.

Braking Performance:

Stopping Time:

$$\text{Stopping time } (T) = \frac{v}{a_{avg} * g}$$

$$a_{avg} = \frac{v}{\left(\frac{v}{a}\right) + 0.3g}$$

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'a' value is obtained by assumed stopping time (t) 3 sec = 5.55 m/s^2

$$a \text{ in g units} = \frac{5.55}{9.81}$$

= 0.565 g units

Maximum velocity of the vehicle (v) = 60 kmph = 16.66 m/s

$$T = \frac{16.66}{0.513 * 9.81}$$

$$\text{Stopping time (T)} = 3.33 \text{ sec}$$

Where, V = Maximum velocity of the vehicle (m/s)

a_{avg} = Average deceleration of the vehicle (m/s^2)

T = Time taken to the stop the vehicle (sec)

g = Acceleration due to gravity (m/s^2)

a = Deceleration obtained by assumed stopping time (m/s^2)

Stopping Distance:

In order to bring the vehicle to rest, the work done against friction must be equal to kinetic energy of the vehicle

$$T_{Bf} * X = K.E$$

$$K.E = \frac{1}{2} mv^2$$

$$K.E = 35986.61 \text{ J}$$

$$2410.8 * X = 35986.61$$

$$X = \frac{35986.61}{2410.8}$$

$$\text{Stopping distance (X)} = 12.8 \text{ m}$$

Where, K.E = Kinetic energy of the vehicle (J)

T_{Bf} = Total braking force (N)

Braking Efficiency:

$$\text{Braking Efficiency } (\eta) = \frac{\text{Total Braking force}}{\text{Total weight of the vehicle}} \times 100$$

$$= \frac{2410.8}{310 * 9.81} \times 100$$

$$\eta =$$

$$79.99\ \% \cong 80\ \%$$

Heat Load Calculation:

Stop Energy:

Stop Energy (E) = kinetic Energy (K.E) + Potential Energy (P.E) + Rotational Energy (R.E).

Kinetic Energy (K.E) = 35986.61 J

$$\text{Potential Energy (P.E)} = \frac{mgs}{\sqrt{1+s^2}}$$

$$P.E = \frac{259 * 9.81 * 16.62}{\sqrt{1+16.62^2}}$$

$$P.E = 10059.97 \text{ J}$$

Rotational Energy = assume 3% of Kinetic Energy

$$R.E = 0.03 * 35986.61$$

$$R.E = 1079.59 \text{ J}$$

Stop Energy (E) = 35986.61 + 10059.97 + 1079.59

E = 47126.17 J

Energy on front side (E_f) = E * 0.7

$$= 47126.17 * 0.7$$

$$\text{for single disc, } E_f = \frac{32988.31}{2}$$

$$E_f = 16494.15 \text{ J}$$

Energy on front side (E_r) = E * 0.3

$$= 47126.17 * 0.3$$

$$E_f = 14137.851 \text{ J}$$

Brake Power:

$$\text{Brake power (P)} = \frac{E}{T}$$

$$\text{Brake power on front side } (P_f) = \frac{E_f}{T}$$

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$$P_f = \frac{16494.15}{3.33}$$

$$\text{Brake power on front side } (P_f) = 4953.19 \text{ W}$$

Heat Flux on Disc:

$$\text{Heat Flux } (q) = \frac{4 * P}{\pi(D^2 - d^2)}$$

$$\text{Heat Flux on front side } (q_f) = \frac{4 * P_f}{\pi(D_f^2 - d_f^2)}$$

$$q_f = 40766.995 \text{ w/m}^2$$

Where,

D = Disc outside diameter (m)
d = Disc Inside diameter (m)

Maximum Temperature on Disc Plate:

$$\text{Maximum temperature } (T_{max}) = \frac{0.527 \times q\sqrt{T}}{\sqrt{(\rho * C * K)}} + T_{amb}$$

$$\text{Max. temperature on front disc} (T_{max\,1}) = \frac{0.527 \times q_f\sqrt{T}}{\sqrt{(\rho * C * K)}} + T_{amb}$$

$$T_{max\,1} = \frac{0.527 \times 407669.95 \times \sqrt{3.33}}{\sqrt{(7250 * 500 * 58)}} + 32$$

$$T_{max\,1} = 63.03°C$$

Where, ρ = Density of disc material (kg/m3) i.e for cast iron $\rho = 7250 \text{ kg/m}^3$
C = Specific heat capacity (J/kg/k) i.e. for cast iron $C = 500 \text{ J/kg/k}$
K = Thermal conductivity (W/m.K) i.e. for cast iron $K = 58$ W/ (m.K)
T_{amb} = Ambient temperature (°C)

5. Disc Brake Analysis Using Ansys:

Introduction to Ansys:

Ansys is an engineering simulation software provider founded by software engineer john Swanson. It develops general-purpose finite element analysis and computational fluid dynamics software. While Ansys has developed a range of computer-aided engineering (CAE) produce, it is perhaps best known for its ANSYS mechanical and Ansys multiphysis products. Ansys mechanical and Ansys multiphysics software are non-exportable analysis tools incorporating pre-processing modules in graphical user interface. These are general-purpose finite element modelling packages for numerically solving mechanical problems, including static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. Two types of analysis made on the dis rotor: structural analysis and thermal analysis

Structural Analysis:

A static analysis calculates the effect of steady loading condition on a structure, while ignoring inertia and damping effects, such as these caused by time varying loads. An analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads.

Transient Thermal Analysis:

The Ansys/Multi physics, Ansys/Mechanical, Ansys/Thermal, and Ansys/Flotran products support transient thermal analysis determines temperature and other thermal quantities that vary over time. Engineers commonly use temperature that a transient thermal analysis calculates as input to structural analyses for thermal stress evaluations. Many heat transfer applications- heat treatment problems, nozzles, engine blocks, piping systems, pressure vessels, etc., involve transient thermal analyses.

Finite Element Analysis Using Ansys:

Static Structural Analysis:

Mesh View of Front Disc Rotor:

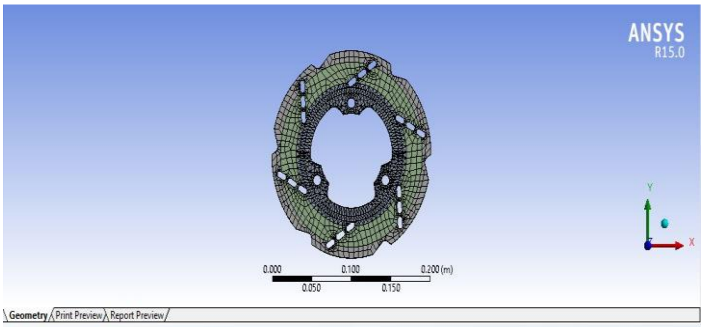

Figure 2: Mesh View of Front Disc Rotor

Total Deformation View of Front Disc Rotor:

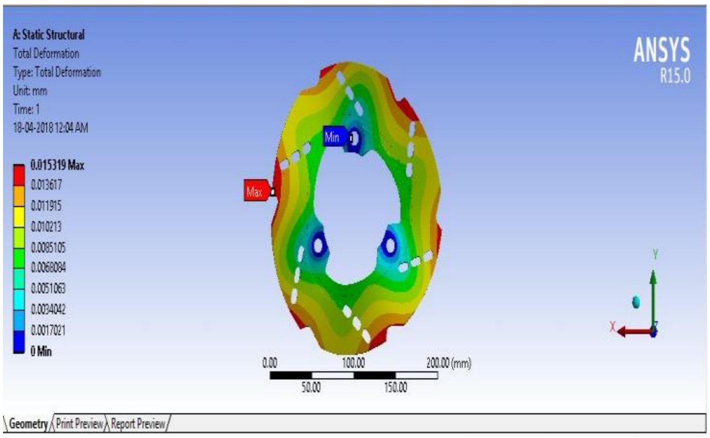

Figure 3: Total Deformation View of Front Disc Rotor

Equivalent Stress View of Front Disc Rotor:

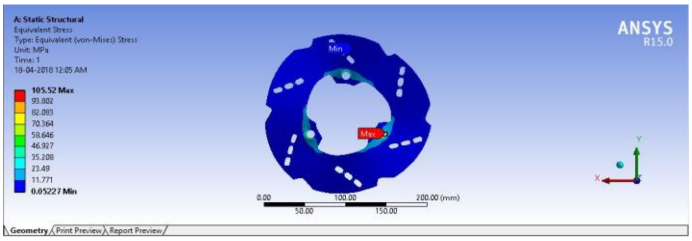

Figure 4: Equivalent Stress View of Front Disc Rotor

Steady State Thermal Analysis:

Temperature Distribution of Front Disc Rotor:

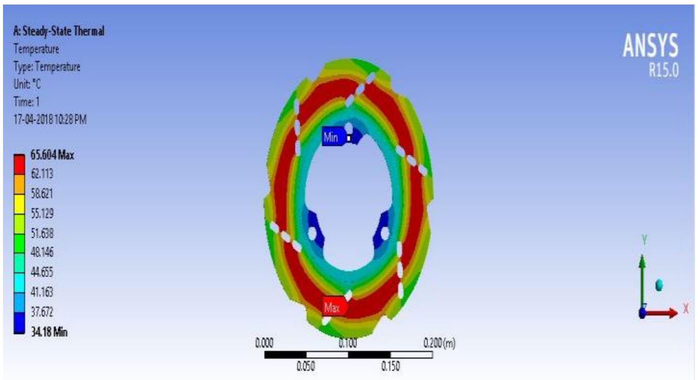

Figure 5: Temperature Distribution of Front Disc Rotor

Total Heat Flux of Front Disc Rotor:

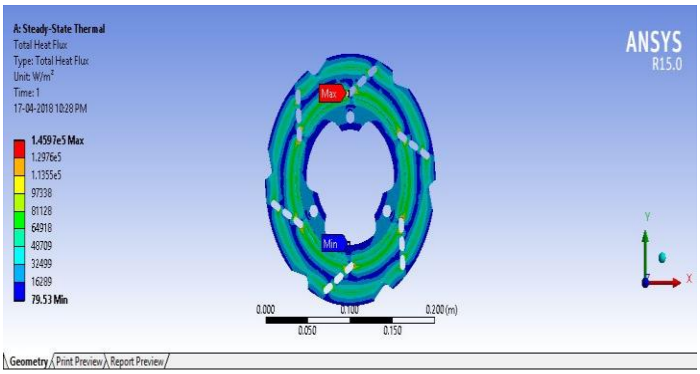

Figure 6: Total Heat Flux of Front Disc Rotor

6. Conclusion:

In this project, all design parameters of brake system has determined by theoretical calculation and also disc temperature and heat flux has determined by using numerical method. The disc rotor and caliper standard has selected by using design parameters and standard disc brake has designed using solid works and also this project presents thermal analysis and structural analysis of a standard disc brake model based on ATV vehicle specification. Regarding the calculation results, we can say that they are in agreement with those commonly found in the literature investigations. It is also concluded that inboard brake system is the best for the All Terrain Vehicle to obtain good performance. All the values obtained from the analysis are less than their allowable values. Hence the brake disc design is safe based on the strength and rigidity criteria.

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