International Journal of Mechanical and Industrial Technology (IJMIT)
Vol. 1, Issue 1, pp: (7-12), Month: October 2013-March 2014, Available at: www.researchpublish.com

Design and Analysis of Disc Brake Rotor for a Two Wheeler

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ABSTRACT: A transient analysis for the thermo elastic contact problem of the disk brakes with heat generation is performed using the finite element analysis. To analyze the thermo elastic phenomenon occurring in the disk brakes, the occupied heat conduction and elastic equations are solved with contact problems. The numerical simulation for the thermo elastic behavior of disk brake is obtained in the repeated brake condition. The computational results are presented for the distribution of heat flux and temperature on each friction surface between the contacting bodies. Also, thermo elastic instability (TIE) phenomenon (the unstable growth of contact pressure and temperature) is investigated in the present study, and the influence of the material properties on the thermo elastic behaviors (the maximum temperature on the friction surfaces) is investigated to facilitate the conceptual design of the disk brake system. Based on these numerical results, the thermo elastic behaviors of the carbon-carbon composites with excellent mechanical properties are also discussed.

1. INTRODUCTION

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 being lowered by hoists, elevators etc. The energy absorbed by brakes is dissipated in the form of heat. This heat is dissipated in the surrounding atmosphere to stop the vehicle, so the brake system should have following requirements:

- The brakes must be strong enough to stop the vehicle with in a minimum distance in an emergency.
- The driver must have proper control over the vehicle during braking and vehicle must not skid.
- The brakes must have well anti fade characteristics i.e. their effectiveness should not decrease with constant prolonged application.
- The brakes should have good anti wear properties.

CLASSIFICATION OF BRAKES

The mechanical brakes according to the direction of acting force may be divided into the following two groups:

- Radial Brake
- Axial Brake

Radial brakes:

In these brakes the force acting on the brakes drum is in radial direction. The radial brakes may be subdivided into external brakes and internal brakes.

Axial Brakes:

In these brakes the force acting on the brake drum is only in the axial direction. i.e. Disk brakes, Cone brakes.

DISK BRAKE

A disk brake consists of a cast iron disk bolted to the wheel hub and a stationary housing called caliper. The caliper is connected to some stationary part of the vehicle like the axle casing or the stub axle as is cast in two parts each part containing a piston. In between each piston and the disk there is a friction pad held in position by retaining pins,
spring plates etc. passages are drilled in the caliper for the fluid to enter or leave each housing. The passages are also connected to another one for bleeding. Each cylinder contains rubber-sealing ring between the cylinder and piston. A schematic diagram is shown in the figure 1.1.

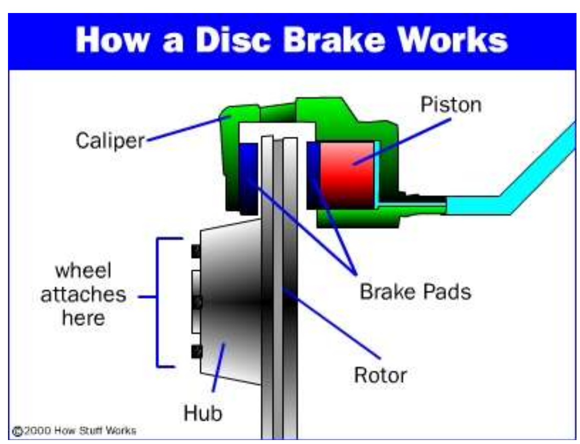

Fig. 1 Disk Brake

PROBLEMS IN DISK BRAKE

In the course of brake operation, frictional heat is dissipated mostly into pads and a disk, and an occasional uneven temperature distribution on the components could induce severe thermo elastic distortion of the disk. The thermal distortion of a normally flat surface into a highly deformed state, called thermo elastic transition. It sometimes occurs in a sequence of stable continuously related states s operating conditions change. At other times, however, the stable evolution behavior of the sliding system crosses a threshold whereupon a sudden change of contact conditions occurs as the result of instability. This invokes a feedback loop that comprises the localized elevation of frictional heating, the resultant localized bulging, a localized pressure increases as the result of bulging, and further elevation of frictional heating as the result of the pressure increase. When this process leads to an accelerated change of contact pressure distribution, the unexpected hot roughness of thermal distortion may grow unstably under some conditions, resulting in local hot spots and leaving thermal cracks on the disk. This is known as thermo elastic instability (TEI). The thermo elastic instability phenomenon occurs more easily as the rotating speed of the disk increases. This region where the contact load is concentrated reaches very high temperatures, which cause deterioration in braking performance. Moreover, in the course of their presence on the disk, the passage of thermally distorted hot spots moving under the brake pads causes low-frequency brake vibration.

OBJECTIVE OF THE PRESENT STUDY

The present investigation is aimed to study:

1. The given disk brake rotor of its stability and rigidity (for this Thermal analysis and coupled structural analysis is carried out on a given disk brake rotor).
2. Best combination of parameters of disk brake rotor like Flange width, Wall thickness and material there by a best combination is suggested.

2. FINITE ELEMENT ANALYSIS

The finite element method is numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. Because of its diversity and flexibility as an analysis tool, it is receiving much attention in almost every industry. In more and more engineering situations today, we find that it is necessary to obtain approximate solutions to problem rather than exact closed form solution. It is not possible to obtain analytical mathematical solutions for many engineering problems. The finite element method has become a powerful tool for the numerical solutions of a wide range of engineering problems. It has been developed simultaneously with the increasing use of the high- speed electronic digital computers and with the growing emphasis on numerical methods for engineering analysis. This method started as a generalization of the structural idea to some problems of elastic continuum problem, started in terms of different equations.

PROCEDURE FOR ANSYS ANALYSIS

Static analysis is used to determine the displacements stresses, stains and forces in structures or components due to loads that do not induce significant inertia and damping effects. Steady loading in response conditions are assumed. The kinds of loading that can be applied in a static analysis include externally applied forces and pressures, steady state inertial forces such as gravity or rotational velocity imposed (non-zero) displacements, temperatures (for thermal strain). A static analysis can be either linear or non linear. In our present work we consider linear static analysis. The procedure for static analysis consists of these main steps

- Building the model
- Obtaining the solution
- Reviewing the results.

Build the Model

In this step we specify the job name and analysis title use PREP7 to define the element types, element real constants, material properties and model geometry element type both linear and non- linear structural elements are allowed. The ANSYS elements library contains over 80 different element types. A unique number and prefix identify each element type. E.g. BEAM 94, PLANE 71, SOLID 96 and PIPE 16

Material Properties

Young's Modulus (EX) must be defined for a static analysis. If we plan to apply inertia loads (such as gravity) we define mass properties such as density (DENS). Similarly if we plan to apply thermal loads (temperatures) we define coefficient of thermal expansion (ALPX).

Geometrical definitions:

There are four different geometric entities in pre processor namely key points, lines, area and volumes. These entities can be used to obtain the geometric representation of the structure. All the entities are independent of other and have unique identification labels.

Model Generations:

Two different methods are used to generate a model:

- Direct generation.
- Solid modeling

With solid modeling we can describe the geometric boundaries of the model, establish controls over the size and desired shape of the elements and then instruct ANSYS program to generate all the nodes and elements automatically.

3. FINITE ELEMENT FORMULATION FOR HEAT CONDUCTION

The unsteady heat conduction equation of each body for an axis-Symmetric problem described in the cylindrical coordinate system is given as follows:

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r k_r \frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) \qquad (3.1)$$

With the boundary conditions and initial condition

$$T = T^{*} \quad on \ \Gamma_0 \qquad (3.2)$$

$$q_n = h(T - T_\infty) \ on \ \Gamma_1 \qquad (3.3)$$

$$q_n = q_n^{*} \quad on \ \Gamma_2 \qquad (3.4)$$

$$T = T_0 \quad at \ time = 0 \qquad (3.5)$$

Where ρ , c , k_r and k_z are the density, specific heat ant thermal conductivities in r and z direction of the material, respectively. Also, *T** is the prescribed temperature, h the heat transfer coefficient,q_n* the heat flux at each contact interface due to friction, T_∞ the ambient temperature, T_0 the initial temperature and Γ_0, Γ_1 and Γ_2 are the boundaries on which temperature, convection and heat flux are imposed, respectively.

$$C_T \dot{T} + KH_T T = R \qquad (3.6)$$

Where C_T is the capacity matrix, KH_T is the conductivity matrix. T and R and are the nodal temperature and heat source vector, respectively. The most commonly used method for solving Eq. (3.6) is the direct integration method based on the assumption that temperature *t* T at time t and temperature $T_{t+\Delta t}$ at time $t + \Delta t$ have the following relation:

$$T_{t+\Delta t} = T_t + \left[(1-\beta)\dot{T} + \beta \dot{T}_{t+\Delta t} \right] \Delta t \qquad (3.7)$$

Eq.(3.7) can be used to reduce the ordinary differential Eq.(3.6) to the following implicit algebraic equation:

$$(C_T + b_1 KH_T)T_{t+\Delta t} = (C_T - b_2 KH_T)T_t + b_2 R_t + b_1 R_{t+\Delta t} \qquad (3.8)$$

Where the variable b_1 and b_2 are given by

$$b_1 = \beta \Delta t \ , \quad b_2 = (1-\beta)\Delta t \qquad (3.9)$$

For different values of β , the well-known numerical integration scheme can be obtained [23].in this study, 0.5 ≤ β ≤1.0 was used, which is an unconditionally stable scheme.

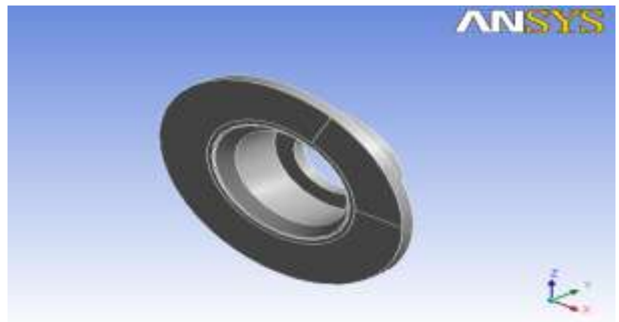

Fig. 3.1 Model of 12mm Disk brake

SOLID 90 ELEMENT GEOMETRY

The geometry, node locations, and the coordinate system for this element are shown in Fig. 3.1. The element is defined by 20-node points and the material properties. A prism shaped element may be formed by defining duplicate K, L, and S; A and B, and O, P, and W node numbers. A tetrahedral-shaped element and a pyramid-shaped element may also be formed as shown in Fig. 3.2

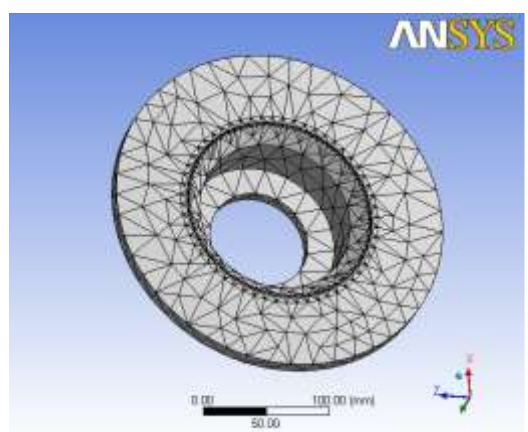

Fig. 3.2 3-D Meshed Model

APPLYING THE BOUNDARY CONDITIONS

In thermal and structural analysis of disk brake, we have to apply thermal and boundary conditions on 3-D disk model of disk brake.

THERMAL BOUNDARY CONDITIONS

As shown in Fig. 3.4 a model presents a three dimensional solid disk squeezed by two finite-width friction material called pads. The entire surface, S, of the disk has three different regions including S1 and S2. On S1 heat flux is specified due to the frictional heating between the pads and disk, and S2 is defined for the convection boundary. The rest of the region, except S1 U S2, is either temperature specified or assumed to be insulated: the inner and outer rim area of disk.

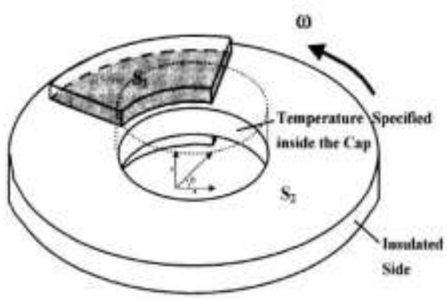

Fig. 3.3 Thermal model of Disk brake

$$q = \mu V P = \mu \omega r P \quad (3.10)$$

Where μ is the coefficient of friction, V the sliding speed, P the contact pressure, and ω is used for angular velocity.

STRUCTURAL BOUNDARY CONDITIONS

Since the axis-symmetric model is considered all the nodes on the hub radius are fixed. So the nodal displacements in the hub become zero i.e. in radial, axial and angular directions, as shown in Fig 3.4

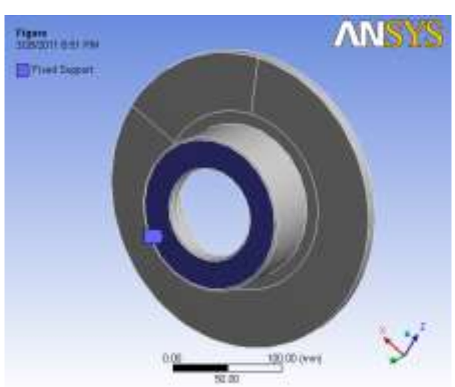

Fig. 3.4 Structural model of Disk brake

4. MATERIALS USED FOR DISC BRAKE

CAST IRON:

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. Cast irons contain appreciable amounts of silicon, normally 1-3%, and consequently these alloys should be considered ternary Fe-C-Si alloys. Here graphite is present in the form of flakes. Disc brake discs are commonly manufactured out of a material called grey cast iron.

Table 4.1 PROPERTIES OF MATERIALS USED

PROPERTIES	MATERIAL 1	MATERIAL 2	MATERIAL 3
DENSITY, ρ	7100 Kg/m^3	2765.2 Kg/m^3	2820.6 Kg/m^3
YOUNGS MODULUS,E	125 GPa	98.5 GPa	113.76 GPa
THERMAL CONDUCTIVITY, k	54 W/m.K	181.65 W/m.K	147.95 W/m.K
SPECIFIC HEAT. C_p	586 J/Kg.K	836.8 J/Kg.K	828.43 J/Kg.K
POSSION'S RATIO, υ	0.25	0.33	0.35
COEFFICIENT OF EXPANSION, α	$8.1*10^{-6}/^0K$	$17.5*10^{-6}/^0K$	$16.9*10^{-6}/^0K$

RESULTS AND DISCUSSION

5. VALIDATION OF RESULTS

First of all, to validate the present method, a comparison of transient results with the steady state solution of thermo elastic behaviours was performed for the operation condition of the constant hydraulic pressure *P* =1Mpa and angular velocity ù = 50 rad/s (Drag brake application) during 10 seconds. If the transient solution for this operation condition converges to the steady solution as time elapse, it can be regarded as validation of the applied transient scheme. The thermal boundary conditions used are adiabatic on the boundary of the inner and outer radius and the prescribed temperature condition T = 20° C on the both boundaries along the radius of the lower and upper pad by assumption of the cooling state. Step Δt =0005 sec. was used.

5.1 ANSYS

Table 5.1 Steady-State Thermal

Object Name	*Temperature*	*Total Heat Flux*	*Temperature 2*	*Total Heat Flux 2*
State	Solved			
Scope				
Geometry	All Bodies		1 Edge	
Definition				
Type	Temperature	Total Heat Flux	Temperature	Total Heat Flux
Display Time	End Time			
Results				
Minimum	111.4 °C	2.9106e-004 W/mm²	160.87 °C	0.12044 W/mm²
Maximum	176.92 °C	0.26901 W/mm²	161.09 °C	0.13937 W/mm²
Information				
Time	1. s			
Load Step	1			
Sub-step	1			
Iteration Number	1			

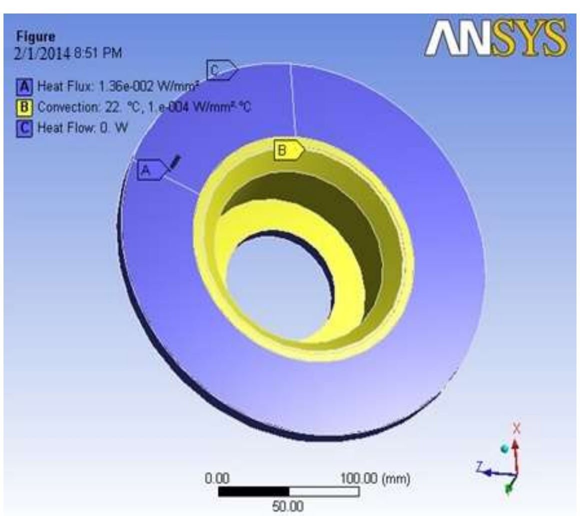

Fig. 5.1 Steady-State Thermal

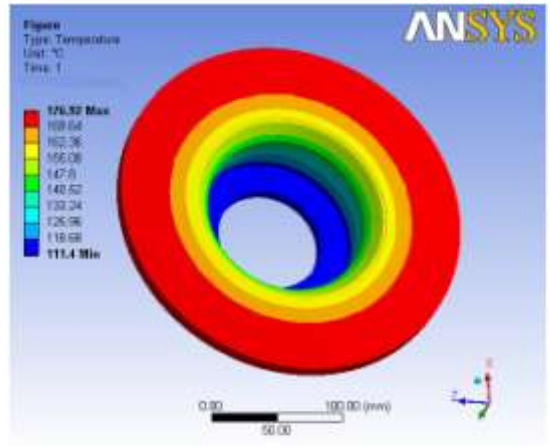

Fig. 5.2 Static Structural

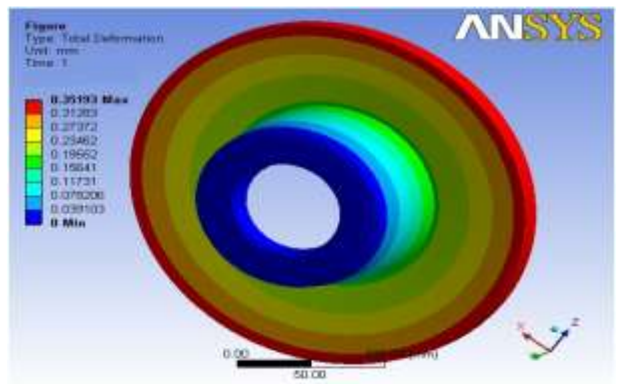

Fig. 5.3 Normal Stress

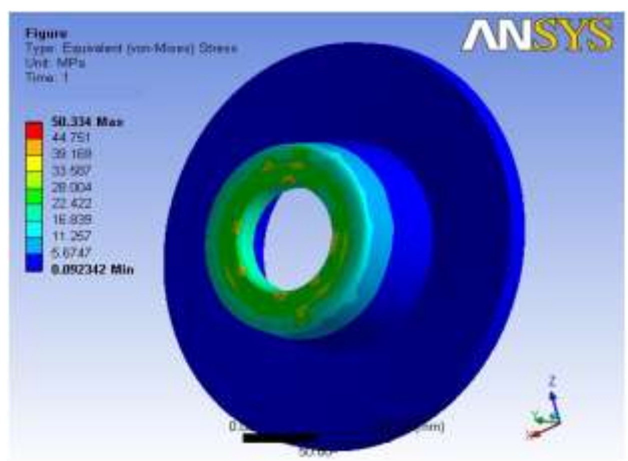

Fig. 5.4 Equivalent Stress

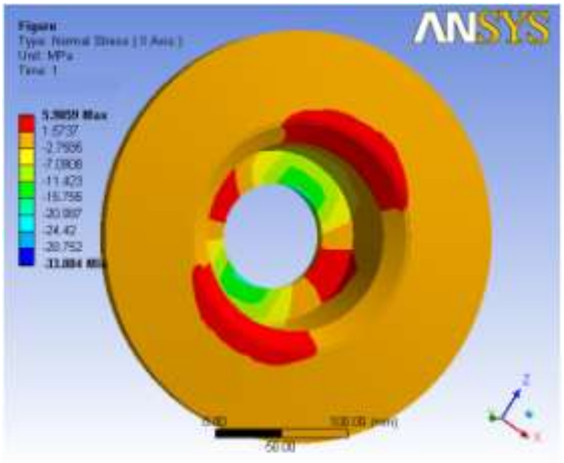

Fig. 5.5 Shear stress

Table 5.1 Comparision of all three materials

Material	Deflection mm	Normal Stress in x direction MPa	Total heat flux w/mm^2	Max temperature ^0c	Von Mises stress MPa
Grey cast iron (material 1)	**0.35193**	**5.9059**	**0.80704**	**486.76**	**50.334**
AL-MMC (material 2)	**0.35229**	**64.812**	**$4.3053e^{-002}$**	**29.232**	**211.98**
AL-MMC (material 3)	**0.36648**	**66.345**	**$6.1466e^{-002}$**	**30.307**	**586.7**

6. CONCLUSIONS

The following conclusions are drawn from the present work.
An Axis-symmetric analysis of disc brake has been carried out using **Plane 77** and **Plane 82** through **ANSYS R 10.0 (F.E.A)** software. A transient thermal analysis is carried out using the **direct time integration technique** for the application of braking force due to friction for time duration of **4.5 seconds.** The maximum temperature obtained in the brake disc for the Materials 1,2 and 3 were 486.76,29.232,30.307 respectively at the contact surface. Static structural analysis is carried out by coupling the Thermal solution to the structural analysis and the maximum Von Mises stress was observed to be 50.334 M Pa for Material 1, 211.98 M Pa for Material 2 and 586.7 M Pa for Material 3.Comparing the different results obtained from the analysis, it is concluded that Cast Iron is the Best possible combination for the present application.

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