Finite Element Analysis of Two Wheeler Disc Brake Rotor

Vijay Kumar B P¹, Pavan Kumar B K², Manjunatha E³, Mayur D Pawar⁴ & Shivaramakrishna A⁵
¹,²,³,⁴&⁵ Asst.Prof, Mechanical Department, Ballari Institute of Technology & Management, Ballari, Karnataka 583104

Abstract: This present paper is concerned with design of components using numerical tools (Finite Element methods) like Catia for modeling, Hypermesh for meshing and Ansys for analysis of various parameters like stress analysis, strain analysis, thermal analysis, vibration analysis, structural analysis etc. This process is shown by taking disc brake rotor of the motorbike as the component. The rotor of disc brake plays a very important part in braking action. A friction material rubs against the rotor which develops frictional force that brings the vehicle to rest. This happens with the absorption of kinetic energy of the bike which gets dissipated as heat. Hence component of various bikes of different brands is taken and analyzed and compared using FEM software.

Keywords: Finite Element Analysis, disc brake rotor, Catia, Hypermesh, Ansys

1. INTRODUCTION TO BRAKING SYSTEMS

The most important part of any engineering branch is the design of new components that is converting a problem into a physical component that solves the problem. In recent past designing a mechanical component was done using methods like manual drafting, model making, prototype design and then costly practical testing or analysis which never met the requirements completely. Automobiles are fitted with brakes to control the speed or to stop it either on horizontal or on inclined surfaces when and where desired by the application of force. Brakes are mechanical devices for increasing the frictional resistance that retards the turning motion of the vehicle wheel. It absorbs either kinetic energy or the potential energy or both while remaining in action and this absorbed energy is dissipated in the form of heat to the surrounding. The brakes must be capable of decelerating a vehicle at much faster rate then engine is capable of accelerating the vehicle. There are mainly two types of brakes, the

1 Drum brake:
In drum brake a friction material expands and grips the internal surface of the drum to retard the vehicle. Due to drawbacks like reduced braking effect due to increased wear of the friction material this brake is better replaced by disc brakes.

2 Disk brake:
It uses an exposed disc that is attached to the hub flange. The two friction pads are pressed on to this disc to provide braking action. The pads are actuated by hydraulic pistons placed in cylinders formed in a caliper, which is secured to a fixed part of the axle. Since the rotor plays a very important part in overall functioning our study is mainly related to rotor analysis using FEA tools.

2. Objective
The present study is on Finite Element Modeling for disk brake rotors of different bike manufacturers basically are to carryout Thermal Analysis, Coupled-Field Analysis and Modal Analysis.

The main objective is to predict
i. The temperature distribution throughout the disc rotor.
ii. The coupled-field analysis i.e., thermal to static structural analysis which gives thermal stresses and their corresponding displacements in the disc brake rotor due to the application of temperature.
iii. The natural frequencies and associated mode shapes.
iv. The better rotor based on comparison of above results and costs
3. ASSUMPTIONS AND CALCULATIONS

3.1 ASSUMPTIONS:

The following assumptions are made in the finite element analysis of the two wheelers disc brake rotors.

1) The kinetic energy produced by the vehicle is converted into heat by neglecting the losses.

2) Heat flux is constant throughout the disc rotor.

3) Material of the disc is isotropic.

4) 70% of the kinetic energy transferred to the front wheel and remaining 30% to the rear wheel.

5) The vehicle moves with a speed of 60 kmph.

6) The bike has two riders with an average weight of 65kg.

3.2 CALCULATIONS FOR HEAT FLUX AND KINETIC ENERGY

1) BIKE: FLAME (BRAND: TVS 125 CC)

Let, Initial Velocity, \( V_1 = 60 \text{kmph} = 16.67 \text{ m/sec} \).

Final Velocity, \( V_2 = 0 \text{ kmph} \).

Mass of the vehicle, \( m_1 = 123 \text{kg} \)

Mass of the driver, \( m_2 = 65 \text{ kg} \)

Total mass, \( m = m_1 + m_2 + m_3 \)

\( = 123 + 65 + 65 \)

\( = 253 \text{ kg} \).

Thermal conductivity of the disc material, \( K = 50e^{-3} \text{ W/mmK} \).

Density of the disc material, \( \rho = 7150e^{-9} \text{ kg/mm}^3 \).

Time for disc to come rest, \( t = 2.9 \text{ sec} \).

Temperature, \( T = 308 \text{ K} \).

Specific heat, \( C_p = 438 \text{ J/kg K} \).

Film co-efficient, \( h = 30e^{-6} \text{ W/mm}^2 \text{ K} \).

Braking distance \( = 24 \text{m} \).

\( = 24000 \text{ mm} \).

We know that,

Kinetic Energy \( = \frac{1}{2} m \left( v_1^2 - v_2^2 \right) * 0.7 \)

\( = \frac{1}{2} * 253 \left( (16.66)^2 - (0)^2 \right) * 0.7 \)

\( = 24577.54 \text{ m}^2 \text{kg/sec}^2 \).

\( = 24577.54 \text{J} \).

We know that,

Heat Flux, \( \Phi = \frac{Q}{A} \)

Where, \( Q \) = heat in joules

\( A = \text{effective area of gripping surface of the disc rotor in mm}^2 \).
3.3 TO FIND THE EFFECTIVE AREA OF GRIPPING SURFACE OF THE DISC ROTOR

Let

Outside diameter of the disc $d_1 = 240$ mm.

Inside diameter of the disc, $d_2 = 176$ mm.

Hole diameter, $d_3 = 8$ mm.

No. of holes, $n = 36$.

Area without holes, $A_1 = \frac{\pi}{4} \left( d_1^2 - d_2^2 \right) = \frac{\pi}{4} \left( 240^2 - 176^2 \right) = 41820.8 \text{ mm}^2$.

Area of all holes, $A_2 = \frac{\pi}{4} d_3^2 n = \frac{\pi}{4} \left( 8^2 \right) \times 36 \times 2 = 3619.1 \text{ mm}^2$.

Effective area, $A = A_1 - A_2 = 41820.8 - 3619.1 = 38201.76 \text{ mm}^2$.

Heat flux, $Q = \frac{\Phi}{A} = \frac{24577.54}{38201.76} = 0.6433 \text{ J/mm}^2$.

2. BIKE: Pulsar (BRAND: BAJAJ, 150CC)

Let,

Initial Velocity, $V_1 = 60$ kmph. = 16.67 m/sec.

Final Velocity, $V_2 = 0$ kmph.

Mass of the vehicle, $m_1 = 150$ kg

Mass of the driver, $m_2 = 65$ kg $m_3 = 65$ kg

Total mass, $m = m_1 + m_2 + m_3 = 150 + 65 + 65 = 280$ kg.

Thermal conductivity of the disc material, $K = 50e-3 \text{ W/mmK}$.

Density of the disc material, $\rho = 7150e-9 \text{ kg/mm}^3$.

Time for disc to come rest $t = 3.4$
Temperature, \( T = 308 \) K.
Specific heat, \( C_p = 438 \) J/kg K.
Film co-efficient, \( h = 30e-6 \) W/mm\(^2\) K.
Braking distance = 19.13 m.
\[ = 19130 \text{ mm.} \]

We know that,
\[
\text{Kinetic Energy} = \frac{1}{2}m\left(v_1^2 - v_2^2\right) \times 0.7
\]
\[ = \frac{1}{2} \times 280\left(16.66\right)^2 - (0)^2 \times 0.7 \]
\[ = 27200.44 \text{ kg m}^2/\text{sec}^2. \]
\[ = 27200.44\text{ J}. \]

We know that,
\[
\text{Heat Flux, } \varphi = \frac{Q}{A}
\]
Where, \( Q = \) heat in joules
\[ A = \text{effective area of gripping surface of the disc rotor in mm}^2. \]

3.4 TO FIND THE EFFECTIVE AREA OF GRIPPING SURFACE OF THE DISC ROTOR.

Let,

Outside diameter of the disc, \( d_1 = 240 \) mm.
Inside diameter of the disc, \( d_2 = 176 \) mm.
Hole diameter, \( d_3 = 8 \) mm.
No. of holes, \( n = 36. \)

Area without holes, \( A_1 = \frac{\varphi}{4} \left[ d_1^2 - d_2^2 \right] \times 2 \]
\[ = \frac{\varphi}{4} \left[ 240^2 - 176^2 \right] \times 2 \]
\[ = 41820.8 \text{ mm}^2. \]

Area of all holes, \( A_2 = \frac{\varphi}{4} d_3^2 n \times 2 \]
\[ = \frac{\varphi}{4} [8]^2 \times 36 \times 2 \]
\[ = 3619.1 \text{ mm}^2. \]
Effective area, \[ A = A_1 - A_2 \]
\[ = 41820.8 - 3619.1 \]
\[ = 38201.76 \text{ mm}^2. \]

Heat flux, \[ \varphi = \frac{Q}{A} \]
\[ = \frac{27200.44}{38201.76} \]
\[ = 0.71202 \text{ J/mm}^2. \]

5. FINITE ELEMENT MODELING
OVERVIEW
The ultimate purpose of a finite element modeling is to re-create mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. In the broadest sense, this model comprises all the nodes, elements, material properties, real constants, boundary conditions, and other features that are used to represent the physical system.

MODELLING TOOL:
The modeling tool used for the present work is HYPERMESH-7. Some features of the tool are as highlighted below;
Altair Hyper Mesh includes many enhancements that can help improve productivity. Major improvements have been made in importing CAD data, geometry cleanup and surface meshing. The performance of Hyper Mesh while handling large models has improved.

AUTOMATIC MESH GENERATION:
Hyper Mesh has a centralized plate and shell mesh generation tool called the auto-meshing module. Most of the element creation panels use this module, which supplies as much automated assistance as possible. One can adjust interactively a wide variety of parameters and choose from a suite of algorithms. Hyper Mesh responds with immediate feedback on the effects of the changes, until you are satisfied with the resulting mesh.

There are two approaches to the auto-meshing module, depending on whether or not you use surfaces as the basis for the operation.

The created mesh can be previewed, which allows you to evaluate it for element quality before choosing to store it in the Hyper Mesh database. While you are in the meshing module, you can use any of viewing tools on the permanent menu and the visual options menu to simplify the visualization of complex structures in your model. If you use surfaces, you can specify the mesh generation and visualization options to use on each individual surface. You may choose from several mesh generation algorithms. Mesh smoothing is also available and you may select the algorithm for that operation as well.

APPROACHES FOR FE MODELLING:
It is very much important to have proper approach for FE modeling
- 1 Planning can be broadly termed as number of decisions that determine how to simulate mathematically the physical system.
- 2 The objectives of the analysis
- 3 Will FE modeling involve all, or just a portion, of the physical system?
- 4 Types of elements to be used
- 5 Finite element mesh details
- 6 Balance computational expense (CPU time, etc.) against precision of results.
- 7 The decisions/proper planning at FE modeling stage will to larger extent govern the success or failure of the analysis.

Once a proper planning is done to approach the FE modeling of the model the next immediate concern will be to categorize the model as being 2-dimensional or 3-dimensional, and as being composed of point elements, line elements, area elements, or solid elements.
ELEMENT TYPES
Once the choice of the modeling type is done it is essential to look for the elements that will be used for the modeling type. For the present work solid elements are used.

SOLID ELEMENT
There are three types of solid elements commonly used they are brick, wedge and tetrahedron. Order of solid elements varies from linear, quadratic and cubic. For the 3D simulation of radial flow turbine the structural 3D solid 45 is used. Following are the characteristics of solid 45 elements.

SOLID 45 is used for the three-dimensional modeling of solid structures. Eight nodes having three degrees of freedom at each node define the element translations in the nodal x, y, and z directions.

MESH GENERATION
- Set the element attributes
- Set mesh controls
- Generate the mesh

MAPPED AREA MESHING
An area mapped mesh consists of either all quadrilateral elements or all triangular elements. For the present work 3D structural solid (Solid 45) is used for area mapped meshing.

Guidelines for meshing
- Either three or four lines must bind the area.
- The area must have equal numbers of element divisions specified on opposite sides.

MAPPED VOLUME MESHING
To mesh a volume with all hexahedron elements, the following conditions must be satisfied.
- The volume must take the shape of a brick (bounded by six areas), wedge or prism (five areas), or tetrahedron (four areas).
- The volume must have equal numbers of element divisions specified on opposite sides.
- The interfaces between metal and plastic surface element nodes are merged.

7. Conclusion:
A. The temperature distribution throughout the disc rotor is uniform.
B. The thermal to static structural analysis which gives thermal stresses and their corresponding displacements in the disc brake rotor due to the application of temperature.
C. The natural frequencies and associated mode shapes are within range.
D. The better rotor based on comparison of above results and costs.

8. References:
[12] Catia V5 for Engineers & Designers by Prof. Sham Tickoo.