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STEADY STATE THERMAL ANALYSIS OF DISC BRAKES

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Abstract

The disc brakes are used for stopping or deceleration the wheel's rotation.Braking is a process which helps in dissipation of kinetic energy in the form of heat by converting it to mechanical energy. A brake disc, connected to wheel or axle, is made up of composites of ceramics or cast iron. Brake pads that acts as friction material and mounted on brake calliper is forced hydraulically, pneumatically, mechanically or electromagnetically to stop the wheel. This research deals with the modelling and analysis of disc brakes using Solid-Works 2014 and Ansys-14. Pro-E is used for the preparation of FEA models and ANSYS is used for simulation, based on the finite element method (FEM). In this research Thermal analysis is carried out for the application of braking force because of friction on disc brakes (or Rotor).

Keywords: *Disc brakes, thermal analysis, FEA, Ansys, Solidworks, modelling, calliper, brake pads.*

1. Introduction

Brakes are classified as:
1. Mechanical
2. Electric
3. Hydraulic

Based on the acting force's direction the mechanical brakes are classified as:

1. Axial brakes.
   The force acting on brake drum is in the axial direction. For example Cone brakes and Disc brakes.
2. Radial brakes.
   The force acting on brake drum is in the radial direction.

Disc brakes:

Disc brake comprised of a stationary housing i.e. calliper and a disc of cast iron bolted to wheel hub. The calliper is cast in two parts with a piston each and connected to the stub axle or axle casing like stationary parts. There is a friction pad in between the disc and each piston, held in position by spring plates, retaining pins etc. For the fluid to enter or leave each housingpassages are drilled in the calliper. For bleeding these passages are connected to another one. A rubber-sealing ring is used between the cylinder and piston in each cylinder [1]. A schematic diagram is shown in the figure 1.

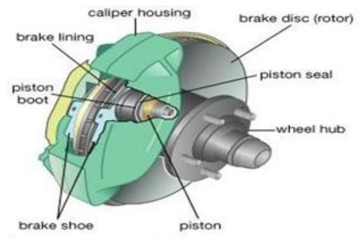


Figure 1: Disc Brake

The purpose of braking system is to decrease the vehicle's speed by converting kinetic energy to mechanical and then to some other form. Using dry friction effects thermal energy is generated form kinetic energy and that is dissipated to surroundings [2]. The braking technologies have developed for a few decades at intervals raised in many sectors: space, petro chemistry, nuclear power, automotive, aeronautics and so forth [3].

In 2002, Nakatsuji [4] did a study on the initiation of hair-like cracks which formed around small holes in the flange of one-piece discs during overloading conditions. The study showed that thermally induced cyclic stress strongly affects the crack initiation in the brake discs. In order to show the crack initiation mechanism, the temperature distribution at the flange had to be measured. Using the finite element method, the temperature distribution under overloading was analysed. 3D unsteady heat transfer analyses were conducted using ANSYS. A 1/8 of the one piece disc was divided into finite elements, and the model had a half thickness due to symmetry in the thickness direction. In 2000, Valvano & Lee [5] did a study of the technique to determine the thermal distortion of a brake rotor.In 1997, Hudson & Ruhl [6] did a study of the air flow through the passage of a Chrysler LH platform ventilated brake rotor. Modifications to the production rotor's vent inlet geometry are prototyped and measured in addition to the production rotor. Vent passage air flow is compared to existing correlations. With the aid of Chrysler Corporation, investigation of ventilated brake rotor vane air flow is undertaken.

2. Process Methodology

Steps:

1. Use of modelling software to prepare the models.
2. Finite element modelling of the disc brakes.
3. Analysis using ANSYS 14.
    i. Selection of elements
    ii. Generation of mesh
    iii. Applying forces, constraints

3.Material of Rotor Disc of Disc Brake

Grey Cast Iron is the common material for discs. It is primarily composed of Iron 95%, Carbon 2-5%, Silicon 1-3%, with small percentages ofPhosphorus, Manganese and Sulphur. It has thermal conductivity and high specific heat capacitymaking it suitable for making of rotor disc.The material properties are:

4.Modelling of rotor disc

Solidworks 2014 is used as modelling software.

Density	*7200 kg/m^3*
Young's modulus	125 Gpa
Poisson's ratio	0.25
Specific heat	447 J/kg ^{0}C
Thermal conductivity	52 W/m ^{0}C

The assumptions taken are as follows:

1. The problem domain - axis-symmetric The rotor

Table 1: Material properties of rotor disc

2. disc material - homogeneous and isotropic
3. Inertia effects are negligible
4. Rotor disc is ventilated
5. Thermal conductivity of the material is constant
6. Before the application of brakes there is no stress in rotor
7. Brakes are applied on all the wheels
8. Specific heat of rotor disc material is constant and does not change with temperature
9. Only ambient air cooling is considered

5. Thermal analysis

It's been done for temperature distribution and thermal quantities in brake disk, such as:

1. Thermal fluxes
2. Temperature distribution
3. Heat loss or gained

Types of thermal analysis:

1. Transient thermal analysis for temperature distribution and quantities under time varying conditions.
2. Steady state thermal analysis for temperature distribution and quantities under steady state loading conditions i.e. where heat storage effects over a time varying condition is ignored.

6.Finite element analysis

It is a numerical analysis technique to obtain approximate solutions to a variety of engineering problems, rather than exact closed form solution [7].

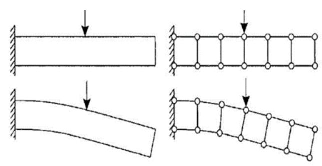


Fig 2: A cantilever beam and its FEM model

It has been developed simultaneously with the growing emphasis for engineering analysisand increasing use of the electronic computers. Most of problem areas include heat transfer, mass transport, structural analysis, fluid flow etc. It subdivides a large problem into smaller parts called finite elements to solve the problem.

7. Procedure for thermal analysis

STATIC ANALYSIS

For calculating effects of steady loading conditions on a structure a static analysis is done. Inertia effects and damping effects caused by time varying loads are ignored. Time varying loads approximated to static equivalent loads and steady inertia loads like rotational velocity and gravity are considered in static analysis [8].

Table 2: Flow Chart for Thermal Analysis

Start Ansys 14.0
↓
Model import from Solidworks
↓
Model geometry checking
↓
Select problem domain (Thermal)
↓
Solve
↓
Check temperature
↓
Generate Graphs and Report

Static analysis is used to determine stresses, displacement and strains in components and structures caused by loads that do not induce damping or inertia effects. The structure's response and the loadis assumed to vary with respect to time slowly. The kinds of loading applied in a static analysis is as follows:

1. Temperatures (for thermal strain)
2. Steady- state inertial forces (such as gravity and rotational velocity)
3. Externally applied forces and pressures
4. Imposed (non-zero) displacements

Linear static analysis is considered in this work. Steps included in procedure are:

1. Model building
2. Obtaining the solution
3. Reviewing the results

8.Heat flux entering the disc

The heat distribution between the friction pads and disc brake is mostly dependent on characteristics of mateial, like density ρ (d, p) [kg/m^3], thermal conductivity k (d, p) [W/mK] and specific heat C (d, p) [J/kgK] of the disc (d) and braking pad (p) materials respectively. Q (d) and Q (p) [J] are the heat quantities, expressed in the following manner [9].

$$\frac{Q_d}{Q_p} = \frac{\sqrt{\rho_d k_d c_d}}{\sqrt{\rho_p k_p c_p}} \qquad (1)$$

The initial heat flux q_0 entering the disc is given by:

$$q_0 = \frac{1-\emptyset}{2} \times \frac{mgv_o z}{2A_d \epsilon_p} \qquad (2)$$

Where

m = mass of the vehicle in kg

z = a/g: braking effectiveness

a = deceleration of the vehicle in ms^{-2}

g = acceleration of gravity in ms^{-2}

Ø = rate distribution of the braking forces between the front and rear axle

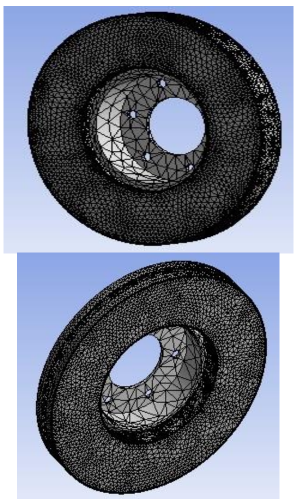
ϵ_p= factor load distribution on the surface of the disc in m

A_d = disc surface swept by the brake pad in m^2

ν_0= initial speed of the vehicle in ms^{-1}
ϵ_p= factor load distribution on the surface of the disc in m
m = mass of the vehicle in kg
Ø = rate distribution of the braking forces between the front and rear axle

9. Meshing of the disc

Geometry clean-up is done before meshing. Tetrahedral 3-D elements with 10 nodes (isoperimetric) are the elements used for the mesh of the full and ventilated disc.



(a) (b)

Fig 3: Meshing of Disc
a) Full disc (2467653 nodes – 1478997elements)
b) Ventilated disc (2137949 nodes – 1383770 elements)

10.Initial and boundary conditions

Bydefining the physical properties of materials and by choosing the mode of first simulation of the all (transitory or permanent), the boundary conditions are introduced into ANSYS. These conditions constitute the initial conditions of our simulation.

1. Materials: Grey Cast iron
2. Initial Temperature of the disc = 22 °C
3. Total time of simulation = 20 s
4. Increment of initial time = 1 s
5. Increment of minimal initial time = .5 s
6. Increment of maximal initial time = 1.5s
7. Mass of the disc = 9.2953 kg
8.

11.Topology Optimization

Due to the revolution of the high speed computing and software development many optimization methods, types and tools are available nowadays. There are four disciplines:

1. Topology optimization: it gives the optimum material layout according to the loading case and design space.
2. Shape optimization: for optimum outer dimensions and optimum fillets
3. Topography: an advanced form of shape optimization, a design region is defined and reinforcement is generated by a pattern of shape variable.
4. Size optimization: it is to obtain component's optimal thickness.

Finite element method used for mostly linear and nonlinear analysis, fatigue analysis etc. Genetic Algorithms is used for generation of shape optimization. It is applied to Computational Fluid Dynamics especially aerodynamics and mechanical engineering, for example: a cantilever beam, strain gauge load cell etc. [10].

12.CAD Iteration and Design Check

Stage 1:
Portions having relative density less than 0.3 were removed, to reduce the weight of the model as well as maintaining the strength and rigidity of the model. To test the modified CAD assembly the design check was carried out. Targeting percentage mass reduction from Topology optimization material, if any, was removed.Modified CAD model (with same material) was subjected to same loading condition as mentioned in linear static analysis. Further iteration if required was carried out to confirm any scope for further optimization. The main idea is to carry out the process until regions of negligible material removal as a scenario is reached. Results of Design Check were satisfactory.

Stage 2:
To reduce the stresses in model based on the results obtained from shape optimization,CAD model was modified. Design check was carried

to test the modified CAD assembly. The modified CAD model (with same material) was subjected to same loading condition as mentioned in linear static analysis. Results of Design Check were excellent and the model was finalized.

13.Conclusion

Conclusions drawn:

1. Time duration for the application of braking force: 4 s
2. The maximum temperature obtained is at rubbing surface: 172^{0}C
3. Based on stability and strength criteria the grey cast iron rotor disc is safe
4. Resultof thermal analysis was validated using fracture analysis and digital logic methods.

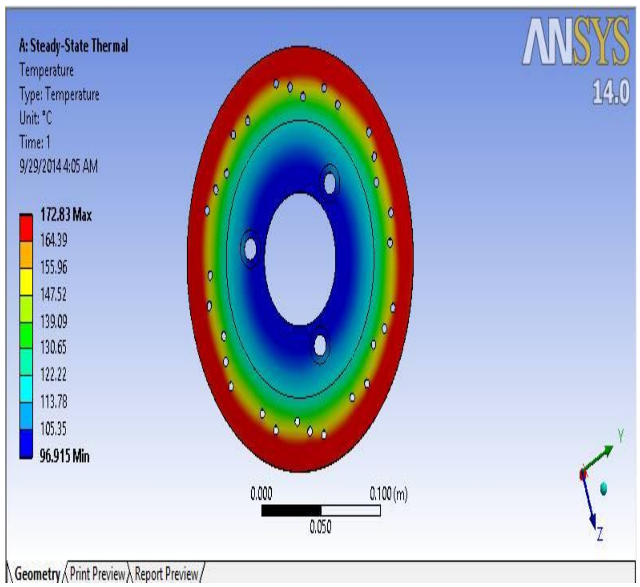


Fig 4: Thermally analysed disc brake

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