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Structural and Thermal Analysis of Honda CB Unicorn Disc Brake Using Solid Works and Ansys

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Abstract:
Brakes has been an essential part of today's modern automotive system. Brake are mechanical device that stops or retards the motion of moving member by absorbing kinetic energy and converting it heat energy. In the case of automobile this moving member is wheel. Brakes are not only important for stopping the vehicle but also for controlling it. Many different types of brakes are available in the market. Mostly disc brakes are preferred in two wheelers, because in disc brakes it gets enough time and space to disperse the heat produced during braking. Disc brake consists of brake pad, caliper, disc, hub and piston. Hub is attached to the wheels it rotates along with the wheels. Disc is attached to the hub and brake pad are mounted on disc on both side with the help of caliper. This caliper is operated by piston. When brakes are applied piston forces the caliper to move towards each other, thus forcing the brakes pads to rub against the rotating disc. And thus the speed of vehicle reduces and which eventually result in stopping of vehicle. In this paper we are modelling and analyzing the disc brake system of Honda CB Unicorn 150.

Keywords: ANSYS, Disc Brake, Finite Element Analysis, SolidWorks, Honda

1. Introduction

Brakes has been an essential part of today's modern automotive system. Brake are mechanical device that stops or retards the motion of moving member by absorbing kinetic energy and converting it heat energy [1]. In the case of automobile this moving member is wheel. Brakes are not only important for stopping the vehicle but also for controlling it. Many different types of brakes are available in the market. Mostly disc brakes are preferred in two wheelers, because in disc brakes it gets enough time and space to disperse the heat produced during braking [2].

Disc brake consists of brake pad, caliper, disc, hub and piston. Hub is attached to the wheels it rotates along with the wheels. Disc is attached to the hub and brake pad are mounted on disc on both side with the help of caliper. This caliper is operated by piston. When brakes are applied piston forces the caliper to move towards each other, thus forcing the brakes pads to rub against the rotating disc. And thus the speed of vehicle reduces and which eventually result in stopping of vehicle [2].

During the stopping process there is friction at the interface of disc and brake pad. Due to the friction huge amount of heat is generated. Because of this temperature at interface increases up to 300^{o} C [3] which result in deformation of disc and brake pad. Disc which is usually made of cast iron or ceramic composite which include silica, Kevlar, or carbon [4]. This heat generation leads to coning, cracking and scaring of disc [5]. Coning refers to axial distortion of disc because of which it takes the shape of cone. Due to which pressure distribution is not uniform which results in decreased lifetime and performance of disc. While the problem of cracking becomes more severe in case of two wheelers because there the disc are vented. Since the input heat energy at interface is more than the output heat energy by convection [5]. It result in developing crakes near the edges of drilled holes on the disc[6]. There others problems like this which affect the performance of disc brake. While scaring occurs when brake pads are not changed promptly [6].

Considering all this facts proper design of design of disc brake becomes very much vital. So in paper we are doing detailed analysis and design of disc brake of Honda CB Unicorn 150. Design of disc brake is done with the SolidWorks 2016 while the analysis part is done Ansys R15.

2. Literature Review

Lee and Yee [7] established that the uneven distribution of temperature on frictional pad surfaces is the cause for thermal distortion commonly known as coning and this is the major cause for the judder effect and disc thickness variation.

A Disc brake is subjected to mainly three types of Mechanical stress, viz,

- Traction force which occurs when wheel is rotating and no brake force is applied to the disc. It is caused due to centrifugal effect
- Compressive force exerted by pressing the pad perpendicular onto the surface of the disc when the brake is applied due to action of the force
- Due to braking action, acting in opposite direction of the disc rotation, caused by rubbing on the brake pad against the surface of the disc.

Dufreny and Weichert [8] proved the existence of radial tensile stress on disc surface by calculating with hole drilling strain gauge method. The outcome of the pressure distribution plays a vital role. Uniform pressure distribution between pad and the rotor causes uniform pad wear and even the friction coefficient. Alternatively, non-uniform pressure distribution may causes uneven wear and its called disc brake squeal. [9] Frictional heat produced by two sliding bodies is liable for thermo-elastic deformation which ultimately changes the contact pressure distribution. In order to estimate the temperature distribution, much research had been carried out on heat generation phenomenon between contact surfaces in brake. Due to the distinctive pressure sliding speed, coefficient of viscosity this process is very intricate. Finite element analysis is used to solve it. [10].

From investigational setup it has been found out that coefficient of viscosity generally decreases with increase in applied load and sliding speed but increases with rising disc temperature of 230 degree and then decreases with above disc temperature. Moreover, specific wear rate was found to increase with increase in sliding speed and disc temperature.[11]

Furthermore, if the sliding speed is high, it may result in instability in thermo-mechanical. Also, it leads to non-uniform contact distribution, which creates hotspots. This is complemented with high local stress that can result in material degradation. [12] Due to continuous repetitive braking, temperature of ventilated disc can upsurge relatively faster than solid disc [13]. Ventilated disc is light in weight, has convective heat transfer and can regulate the temperature rise, and thus the effect of thermal problem. Yet, in ventilated discs, due to uneven temperature around the disc, there may be increase in judder problem. [14]

Valvano and Lee presented a study on the technique to estimate the thermal distortion of brake rotor. Due to the critical thermal distortion of brake, it can affect the system response and brake judder propensity. Accurate estimation of the thermal distortion improves the design of disc brake[15].

In the braking segment, temperatures and thermal gradient are very high. It can cause stresses and deformation which is designated by its appearance, cracks on the disc [16].

3. Objective

The objective of this paper is to design a Disc brake using the software SolidWorks 2016 and perform a Finite Element Analysis (FEA) on the designed model of disc brake using ANSYS R15. Thus, we can obtain the values of total deformation, shear stress and the temperature distribution on disc brake.

4. Calculation & Design

In braking system, mechanical energy is converted into thermal energy. This energy is considered by the total heating of the disc and pads during the braking stage. The energy dissipated in form of heat can produce temperature ranging from 300°C to 800°C. Typically, thermal conductivity of brake pad material is lower than that of the disc material. We will consider that the quantity of heat produced will be totally absorbed by brake disc. The heat flux displaced of this surface is equal to the friction due to pads. Initially, heat flux entering the disc is calculated by the following formula [17]:

$$q = \frac{1-\varphi}{2} \times \frac{mgvz}{2A_p\varepsilon}$$

Vehicle Model: Honda CB Unicorn 150

Item	Values
Disc Diameter	240 mm
Disc Thickness	5 mm
Centre Diameter	123 mm
Size of pad, A_p	2800 mm^2
Top Speed of Automobile v	101 km/hr = 28 m/s
Mass of Vehicle, m	145 kg
Mass of the disc	500 g
Size of front tyre	2.75-18
Radius of front tyre, r_t	500 mm
Deceleration, α	8 m/s^2

Data assumed [18]:

Properties	Values
Specific heat, C_p	450 J/kgK
Acceleration due to gravity,	9.81 m/s^2
Hydraulic pressure between Brake pad & disc	1 MPa
Factor of charge distribution of the disc, ε	0.5
Rate distribution of the braking forces, Φ	20%

Stopping distance: $\frac{v^2}{2a} = \frac{28^2}{2\times 8} = 49\ \text{m}$

Rotational speed, ω: $\frac{v}{r_t} = \frac{28}{0.5} = 56\ \text{rad/s}$

Heat flux entering disc, q = 170694 W/m^2

5. Material Property

The disc material is gray cast iron (FG) with high carbon content, with good thermophysical characteristics. The brake pad has an isotropic elastic behavior which thermomechanical characteristics adopted in this simulation in the transient analysis of the two parts are summarized in table below.

Density	7200 kg/m^3
Thermal Conductivity	52 W/mK
Young Modulus	138 GPa
Poisson Ratio	0.28
Specific Heat, C_p	447 J/kgK
Coefficient of Friction, μ	0.2

6. Methodology

6.1 Meshing of the disc

For this analysis, disc brake model of Honda CB Unicorn was meshed using triangular surface mesher. As a result, 81234 nodes and 43608 elements were generated. The meshed model is analyzed to get the result of contact zone (disc-pad). This is important because in this zone the temperature increases considerably.

For this analysis, disc brake model of Honda CB Unicorn was meshed using triangular surface mesher. As a result, 72401 nodes and 39841 elements were generated. Hence, the model is meshed and then analyzed to get the details and the correct result of the stress on the contact surface.

6.2 Loading and Boundary Condition

For the thermal analysis, the temperature distribution is a function of heat flux entering the disc and heat transfer coefficient of the disc. For this analysis, the initial and final boundary conditions are introduced in the transient thermal module of ANSYS Workbench.

For the structural analysis, the temperature and its corresponding stress in disc brake differ under the freeway driving conditions. For this analysis, the initial and final boundary condition are introduced in the static structural module of ANSYS Workbench. The conditions used are as follow:

Initial temperature of disc	65 °C
Pressure applied on both surface	1 MPa
Rotational speed of disc	56 rad/s

6.3 Finite Element Analysis

FEA is a numerical technique for getting the approximate solutions to the boundary value problems for partial differential equations. It subdivides the whole problem domain into simpler parts, called as finite elements and solves the problem by diminishing an associated error function. Sub-dividing the whole domain has several advantages:

1. An accurate representation of complex geometry.
2. Insertion of dissimilar material property.
3. Simple representation of the solution.

Thus, it divides a domain into a group of sub-domains and every sub-domain is characterized by a set of element equations of the actual domain.

7. Analysis

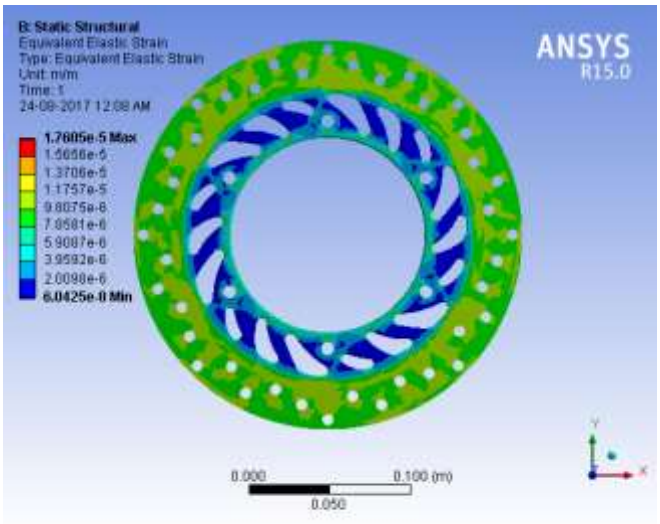

Figure 1: Equivalent Elastic Strain

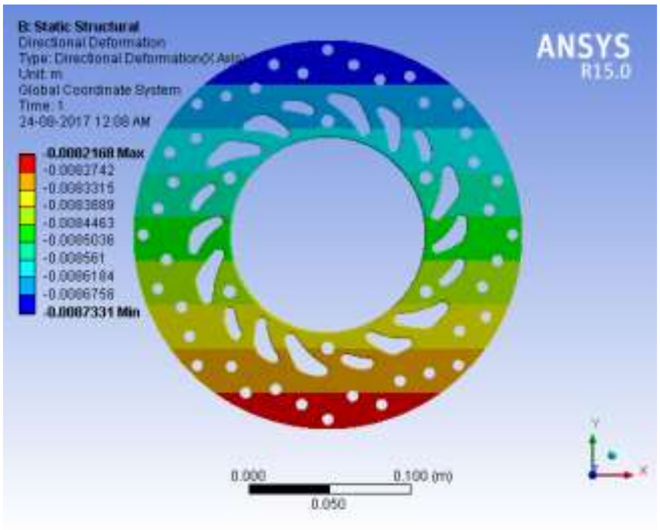

Figure 2:Directional Deformation

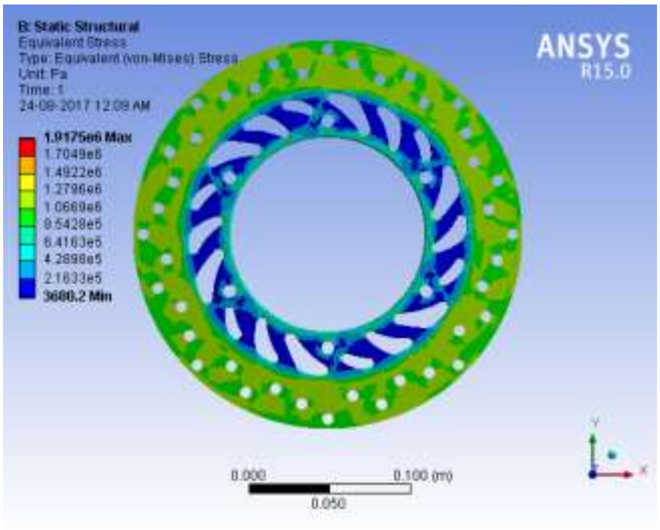

Figure 3: von Mises Stress

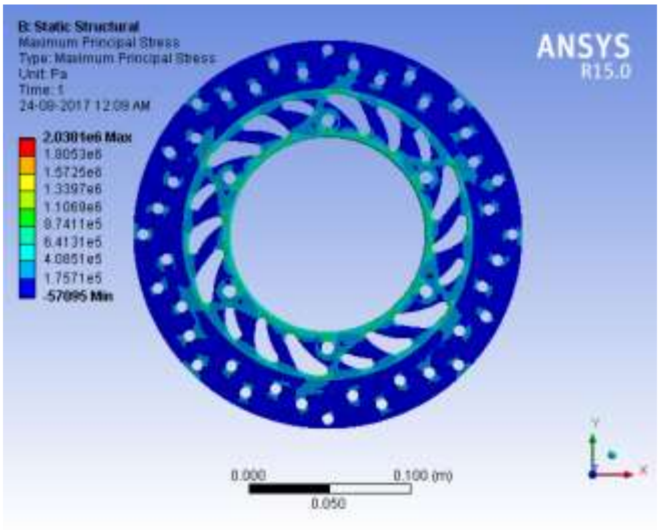

Figure 4: Maximum Principal Stress

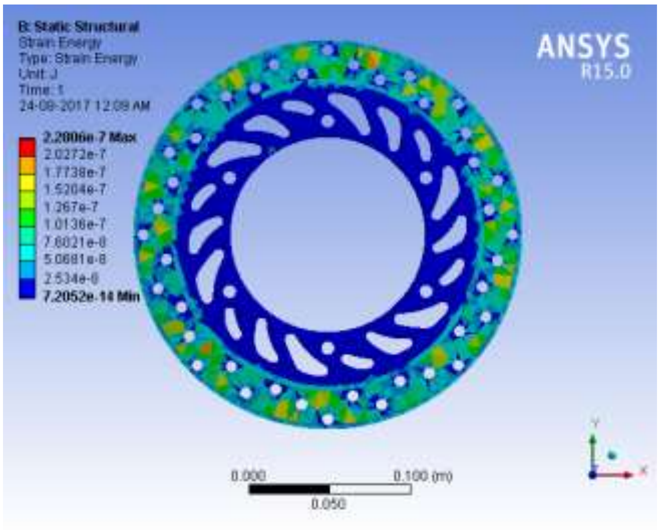

Figure 5: Strain Energy

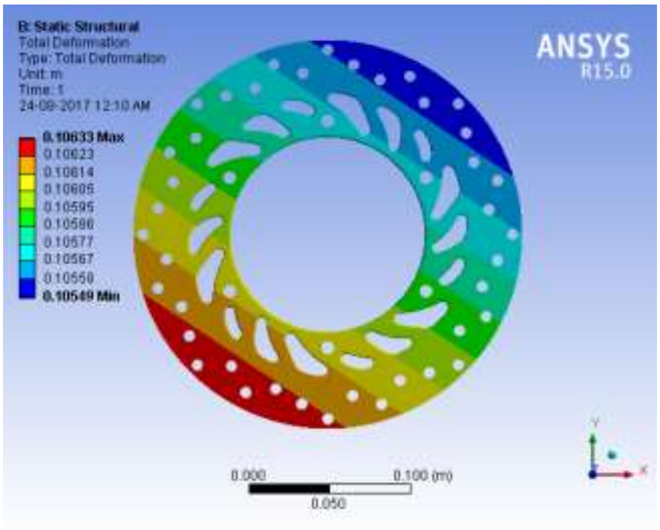

Figure 6: Total Deformation

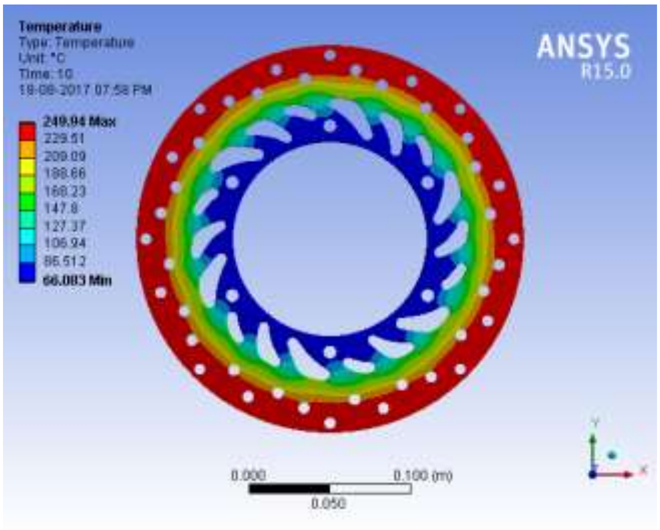

Figure 7: Temperature Distribution

8. Result

Parameter	Max Value	Min Value
Equivalent Elastic Strain	1.76e-5 m/m	6.042-8 m/m
Directional Deformation	-8.2e-3 m	-8.7e-3 m
Von Mises Stress	1.917e6 Pa	3680 Pa
Maximum Principal Stress	2.038e6 Pa	-57095 Pa
Strain Energy	2.28e-7 J	7.2e-14 J
Total Deformation	0.01063 m	0.10549 m
Temperature	66.083 °C	249.94 °C

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