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Transient Thermal Analysis of Automotive Disc Brake

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Abstract: *Vehicle deceleration is achieved by braking. For proper selection of material for braking application it becomes necessary to analyze the disc brake subjected to dynamic condition. The dynamic condition incorporates braking of vehicle considering effects of air on cooling characteristics of brake. CAD model of disc brake is developed in CREO 2 design package and analyzed in ANSYS mechanical software .The model is subjected to low speed and high speed testing using ANSYS CFX solver. On the basis of heat flux and maximum temperature obtained best material suitable for this application is determined. The results obtained from software is validated using experimental testing with lathe machine*

Keywords: *Disc brake, thermal analysis, CFD, ANSYS, Transient thermal*

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I. Introduction

Brake is a device for slowing or stopping a moving vehicle, typically by applying pressure to the wheels. The aim of braking system is to transform mechanical energy of moving vehicle into the some other form, which results by decreasing of the vehicle speed. The kinetic energy is transformed into the thermal energy, by using the dry friction effects and, after that, dissipated into the surroundings. Because high temperatures can lead to overheating of the brake fluid, seals and other components, the stopping capability of a brake increases with the rate at which heat is dissipated due to forced convection and thermal capacity of the system. In this study, we will present a numerical modeling in three dimensions to analyze the thermo mechanical behavior of the full and ventilated disc brake .The strategy calculation based on the finite element method will be carried out using code ANSYS 14.0 The study aims in watching the heat dissipation rate for low as well as high speed vehicles. The velocity of 2 m/s is taken for analyzing the heat dissipation in low speed vehicle and a velocity of 8 m/s is taken for high speed vehicle.

Finite element optimization techniques are used to design a single alloy disc brake rotor that is lighter and performs as well as existing single alloy rotors. The scope of this paper is to investigate rotor design using topological optimization for a single alloy disc brake rotor. All finite element analysis and optimization is done on a linear finite element solver. Under normal braking, the rotor should remain in its elastic region. Otherwise the rotor would deform after each use.

II. Methodology

The disc brake is analyzed at steady state conditions using ANSYS thermal module. Temperature plot and heat transfer coefficient value is determined. The method used for this analysis is F.E.M which stands for Finite Element Method which is based on discretization of solid model to finite element model known as meshing, formulation of element stiffness matrices, assembly of global stiffness matrices and calculation of variables at nodes and interpolation of results along entire element edge length.

On the basis of results obtained in steady state thermal analysis CFD simulation of disc brake is performed in ANSYS CFX solver. ANSYS CFX is more than just a powerful CFD code. Integration into the ANSYS workbench platform provides superior bi-directional connections to all major CAD systems, powerful geometry modification and creation tools with ANSYS Design modeler, advanced meshing technologies in ANSYS meshing, and easy drag and drop transfer of data and results to share between applications The method used for analysis is F.V.M which stands for Finite Volume Method. Governing equation of CFD is Navier's Stokes equation and based on conservation of mass, momentum and energy. The Navier-Stokes equations are vector equations, meaning that there is a separate equation for each of the coordinate directions. There are thus three different momentum equations that together comprise the Navier-Stokes Equations

A. Continuity Equation:

$$\int_{cs} \rho V dA + \frac{\partial}{\partial t} \int_{cv} \rho dA = 0$$

B. Momentum Equation:

C. ***Energyequation****:*

$$\rho\frac{\partial u}{\partial t}+\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}+\rho w\frac{\partial u}{\partial z}=\rho g_x-\frac{\partial p}{\partial x}+\mu\frac{\partial^2 u}{\partial x^2}+\mu\frac{\partial^2 u}{\partial y^2}+\mu\frac{\partial^2 u}{\partial z^2}$$

$$\rho\frac{\partial v}{\partial t}+\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}+\rho w\frac{\partial v}{\partial z}=\rho g_y-\frac{\partial p}{\partial y}+\mu\frac{\partial^2 v}{\partial x^2}+\mu\frac{\partial^2 v}{\partial y^2}+\mu\frac{\partial^2 v}{\partial z^2}$$

$$\rho\frac{\partial w}{\partial t}+\rho u\frac{\partial w}{\partial x}+\rho v\frac{\partial w}{\partial y}+\rho w\frac{\partial w}{\partial z}=\rho g_z-\frac{\partial p}{\partial z}+\mu\frac{\partial^2 w}{\partial x^2}+\mu\frac{\partial^2 w}{\partial y^2}+\mu\frac{\partial^2 w}{\partial z^2}$$

III. CAD Modeling OF Disc Brake

The CAD model of disc brake is developed using CREO 2.0 . Creo is a sketch beased, feature based parametric 3d modeling software which is parametric and has the properties of parent child relationship and bi-directional associativity. The model is prepared using sketch , extrude and followed by pattern about an axis .The CAD model developed is assembled with brake shoe . This is assembled with experimental set up CAD model of axle and wheel.

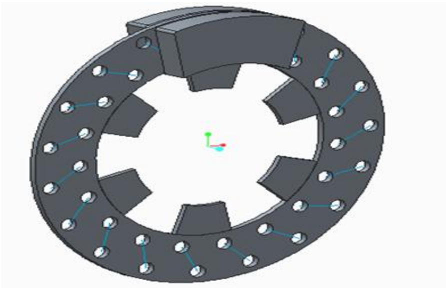

Fig1.CAD model of disk brake

Fig2. CAD model of disk brake setup

IV. Experimental Setup And Calculations

The actual experiment is performed inside the workshop where the wheel is turned through chuck center of a lathe machine and the braking is applied mechanically at the desired rpm which are taken through a tachometer also the heat flux and convection are calculated using the temperature sensors as shown in fig 4. Once the static heat transfer analysis is being finalized we have now done a second analysis for the time based transient thermal analysis using the same model but different boundary conditions. From the heat transfer equation we can see that the heat flux is directly proportional to the time and so we have analyzed the transient thermal performance of the disc brake for low and high velocities and to see the heat dissipation rate relation with respect to time as under

Fig3. Experimental setup of lathe machine and disk brake

Rotation Speed is taken as 200 Rpm which gives the angular velocity as 20.94 rad/ Sec
As we know that energy cannot be destroyed it can only converted from one form to other so same in case of braking when we apply brake and if the vehicle stops then we can say that the kinetic energy at that instance will be going to change into the thermal energy and will be given as:
Kinetic Energy = Thermal Energy = ½ I $\square^2$
Braking time = 0.8 second
Again we know that the braking power is given as:
Braking Power = Thermal Energy / Time
Braking Power = 15.81 J
Area Of Rubbing Surface = .041 m^2
Heat Flux= Braking Power / Area Of Rubbing Surface = 385.67 W/M^2

V. Simulation

The CAD model is imported in ANSYS workbench and meshed with tetra elements The meshing is based on the concept of discretization of domain which means converting solid models to finite element models that is converting it into nodes and elements of appropriate mesh density and size. If mesh density is too fine it will take high computational time and mesh density is too low would result in compromise of accuracy level of solution.Heat flux boundary conditions are applied with value of 385.67 W/m^2 and convection value of 7.9W/m^2 for cast iron to air, 11.3W/m^2 from steel to air, 90 W/m^2 from Al-MMC to air. Ambient temperature is set to 28^0C. For CFD simulation the same model is imported in ANSYS CFX. Enclosure surrounding CAD model is generated with dimensions of .1m*.1m*.1m. Boolean operation is done where disc brake volume is subtracted from enclosure volume. The fluid domain type is taken for analysis with inlet boundary of air at 2.5 m/sec for low speed and 10 m/sec for high speed is taken. The turbulence model taken is k-epsilon which is easier to simulate and can handle complex models. The outlet boundary condition is set to zero relative pressure condition. The energy model taken for analysis is thermal energy which takes into account of change in temperature. Convergence criteria set for analysis is RMS residuals to 1e-4.

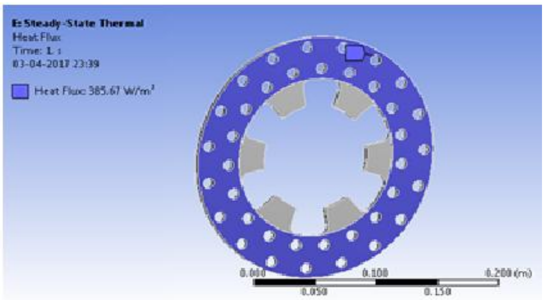

Fig4.Thermal flux boundary condition

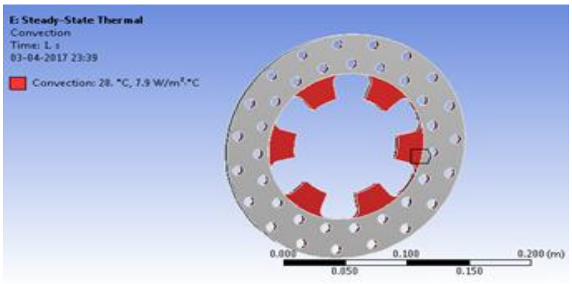

Fig5. Heat transfer boundary condition

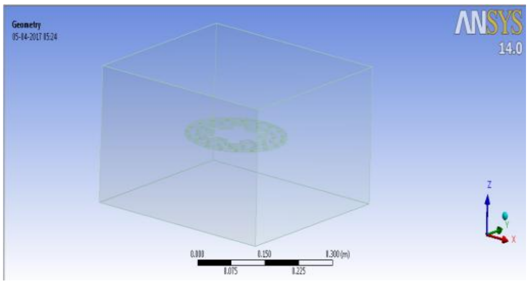

Fig6. Enclosure modeling in CFX

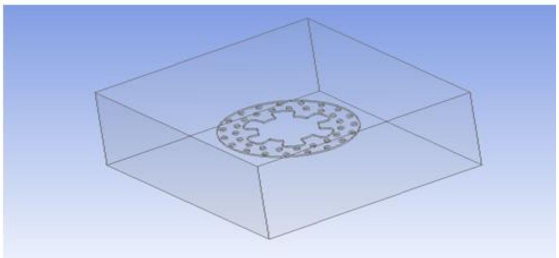

Fig7.Boolean operation in CFX

VI. Results And Discussion

The CAD model of disc brake is analyzed and contour plot of temperature, heat flux is plotted for steady state thermal analysis. The temperature contour of cast iron at steady state thermal analysis Fig no. , steel Fig no and Al-MMC fig no. . All the contour plots shows maximum temperature at outer portion of disc brake where heat flux is applied. The temperature decreases as we move towards center of disk brake where temperature is lowering and heat is dissipated by convection.

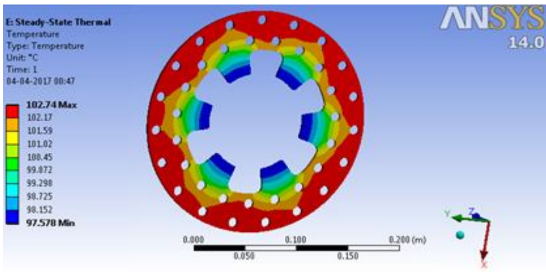

Fig8. Temperature distribution of cast iron

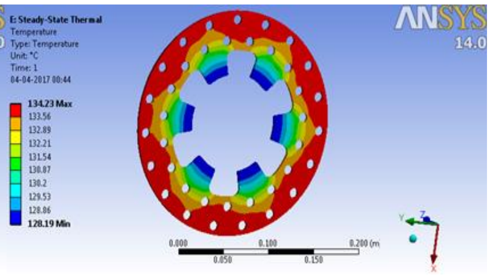

Fig9. Temperature distribution of steel

Fig10. Temperature distribution of Al-MMC

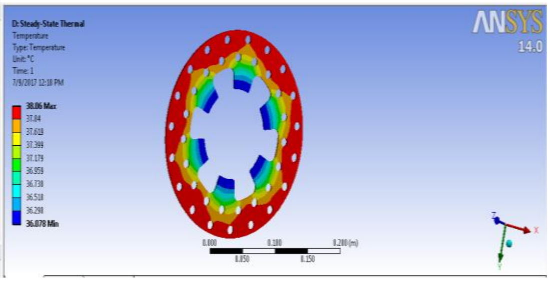

Fig11. Temperature distribution of cast iron in CFX

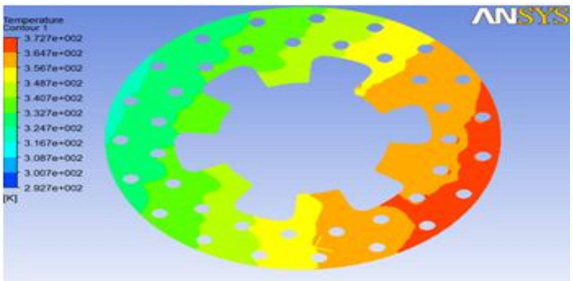

Fig12. Heat flux distribution of cast iron in CFX

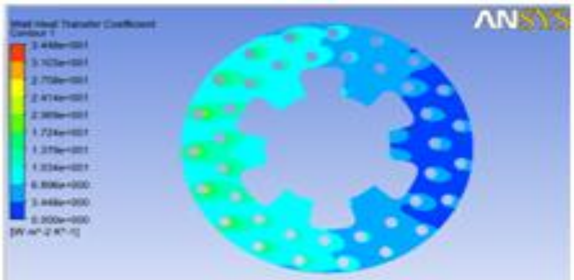

Fig13. Temperature distribution of steel in CFX

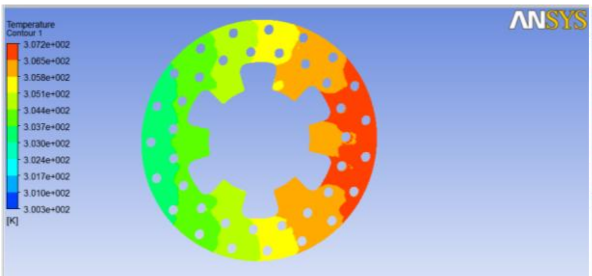

Fig14. Temperature distribution of steel in CFX

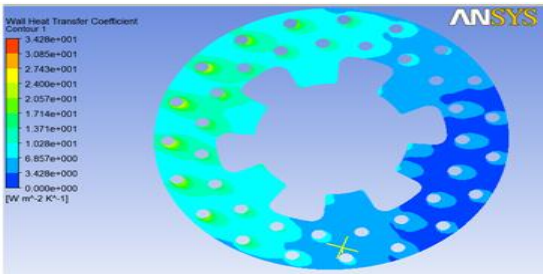

Fig15. Temperature distribution of Al-MMC in CFX

The CFD analysis at both low speeds and high speeds shows that maximum temperature of disc brake is observed to be at right end of disc brake and minimum temperature is observed to be at left end of disc brake. This is due to high rate of heat transfer at the regions near inlet and low rate of heat transfer at regions distant from air inlet. Figure 1,2 and 3 shows temperature distribution at steady state analysis and figure 12,13,14,15 shows temperature distribution at dynamic state in CFX

Table 1: Steady state temperature distribution for different materials

S. NO	Temperature (Steel Material) in ^{0}C	Temperature (Cast Iron) in ^{0}C	Temperature (Al-MMC) in ^{0}C
1	134.23	102.74	34.5

Table 2: Transient state temperature distribution for different materials at low speed test

Time in seconds	CAST IRON TEMP(K)	STEEL TEMP(K)	Al-MMC TEMP(K)
.1	348.13	366.22	305.18
.2	318.77	323.85	302.74
.3	300.12	298.61	301.06
.4	296.57	294.54	300.66

Table 3: Transient state temperature distribution for different materials at high speed test

Time in seconds	CAST IRON TEMP(K)	STEEL TEMP(K)	Al-MMC TEMP(K)
0.1	314.91	319.60	302.45
0.2	295.63	295.63	300.74
0.3	298.17	298.17	300.85
0.4	300.83	300.83	300.01

VII. Conclusion

[1] For any material the time taken to dissipate a large amount of heat in transient thermal analysis is approximately 0.4 seconds for low speed i.e, up to 2.5 m/s and is approximately 0.2 seconds for high speed vehicles i.e, up to 10 m/s

[2] The heat transfer coefficient is also suddenly increases after application of brake for the first 04 seconds and become again steady as required.

[3] From the result table it can be concluded that the material can play very important role in case of heat transfer coefficient but is

[4] A computer aided model of disc brake can be simulated using Ansys software and will best match the results obtained experimentically.

[5] The temperature distribution for Al-MMC material is compatible for disc brake application with comparison to stainless steel and cast iron material for both static and transient thermal analysis.

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