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Transient & thermal analysis of automotive disc brakes using CFD software

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ABSTRACT

Braking is one of the important functions of a vehicle. It is very important to design the braking system in such a way that the vehicle remains safe at the braking conditions. The disc brakes are commonly used in most vehicles. When the brakes are applied high amount of energy is dissipated from the disc brakes. The efficiency of the dissipation of the brakes defines the safety of the braking system. This depends on various parameters like the material, ambient temperature, braking power, heat transfer coefficient of the air on the surface of the disc brake. A computational fluid analysis (CFD) and thermal analysis is performed on the disc brake to study the heat dissipation characteristics of the designed disc brake. The surface heat transfer coefficient of the disc brake, velocity is studied in the ANSYS FLUENT solver and the structural-thermal analysis is performed in the ANSYS Workbench in which deformation and final temperature are calculated.

Keywords: CFD, FLUENT, Heat Transfer Coefficient, Steady State Thermal, Static Structural

1. INTRODUCTION

The braking system is a vital part of a vehicle. The brakes are used to inhibit the motion of the vehicle and also to control the speed of the vehicle. The braking system depends on the frictional force to stop or control or the motion of the vehicle. The brakes can be mechanical, hydraulic or pneumatic type. The Hydraulic brakes use an enclosed fluid to stop the vehicle by using the fluid for transmitting pedal force. The friction between the rotating disc and the stationary brake pads are used to stop the vehicle by squeezing action of the pads. The brakes used can be drum or disc type. The braking system of the vehicle depends on the various factors like the mass of the vehicle, the braking force, torque required. The Master cylinder with required dimensions is used to generate appropriate pressure in the brake circuit. Brake pedal with an optimum pedal ratio should be used to apply force to the master cylinder. [1]

During a braking event, kinetic energy is transformed into heat by means of the friction brakes. This heat is generated within the contact surface between the brake disc and pad. In the following section, some general modeling approaches for this contact surface are discussed. Generally, the contact between the disc and pad can be modeled as a perfect or an imperfect contact. The perfect contact postulation assumes that the disc and the pad have identical surface temperatures. The imperfect contact postulation assumes a temperature discrepancy between both parts.

All brake systems can be divided into four basic subsystems like:

1. Energy source: This includes the components of a brake system that produce, store, And make available the energy required for braking. The energy source subsystem ends where driver controlled modulation of the energy supply begins. The fundamental component for that category is the master cylinder.
2. Apply system: This includes all components that are used to modulate the level of braking. The apply subsystem ends where the energy required for applying the brakes enters the energy transmission system. More Specifically Pedals and the leverage parts are includes.
3. Energy transmission system: This includes all components through which the energy required for applying the brakes travels from the apply system to the wheel brakes. Brake rubes required for carrying hydraulic or air medium are part of the energy transmission system. Metallic rigid brake tubes commonly are called brake fines, whereas flexible tubes are called brake hoses.
4. Actuation System: These are the components where the forces are produced which oppose the existing or intended vehicle motion. mostly this system includes the calipers wheel cylinders, disc rotors. [3]

1.1 Disc Brake

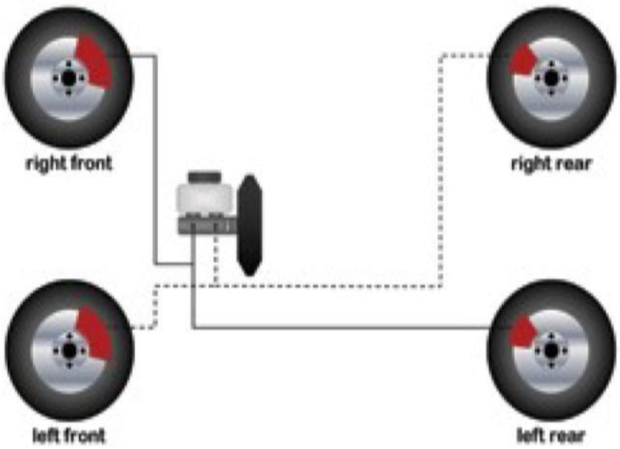


Fig. 1: X –Split braking Circuit

The Disc brake is the most commonly used type of brake which works by creating the friction between the brake pad and disc on the application of brakes. The disc brakes are one of the types of hydraulic brakes. The disc brake is mounted on the wheel hub. And between the caliper. On the application of brakes, the squeezing action takes place on which vehicle stops immediately. Generally, the disc brakes are more often used for front wheels. The X-split braking circuit is used for the vehicle in which the front and rear wheels are shown in the following figure.

1.2 Advantages of Disc Brake

1. Good Braking Performance
2. Good Heat Dissipation
3. Requires less effort to brake
4. Easy maintenance
5. Don't wear out of the rim

1.3 Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics is the powerful tool used to predict the fluid flow, heat and mass transfer of the fluid. It works based on the Conservation of Energy, Mass and momentum. Based on these equations temperature, velocity, pressure, density etc. are calculated.

There are many CFD solvers like Fluent, CFX, ABAQUS etc. Here, ANSYS Fluent solver is used to perform CFD analysis of the disc brake. The heat transfer coefficient of the disc is calculated in the Fluent solver.

The thermal analysis of the disc brake is performed in the CFD analysis. These processes analyse the thermal efficiency of the disc brake.

2. MATERIAL USED

The material used for the disc brake is Stainless Steel. Generally, the disc brakes are made of Grey Cast Iron, composites etc. The stainless steel is used in spite of its high cost because of its high corrosion resistance, less wear, good strength, good coefficient of friction and good thermal efficiency. The following are the properties of the Stainless
Steel

Table 1: Properties of Stainless Steel

S no.	Parameter	Value
1	Density	7.85 g/cc
2	Ultimate Tensile Strength	1470 MPa
3	Ultimate Yield Strength	1008 MPa
4	Thermal Conductivity	25 W/m-K
5	Coefficient of thermal expansion	9.9 μm/m/°C
6	Specific Heat capacity	460 J/ Kg-k

3. DESIGN OF DISC BRAKE

The disc brake is designed and analyzed considering the various parameters of the vehicle. The disc brake design depends on the mass of the vehicle, braking force, Dynamic Weight transfer. acceleration, the assembly of the disc brake to the wheel hub etc. [6]

3.1 CAD Model of the disc brake

The CAD model of the disc brake is designed in CATIA v5 software. The disc brake is designed based on the thermal, structural analysis and the wheel assembly components. This type of disc brake is also called as slotted disc brake as slots are provided for the good heat transfer and the weight reduction. The similar design is used for both the front and rear wheels of the vehicle. The dimensions of the disc brake are considered based on the optimum heat transfer and minimum weight of the disc brake the following are the final dimensions of the disc brake.

Outer Diameter - 190 mm Inner Diameter - 120 mm Thickness - 4 mm

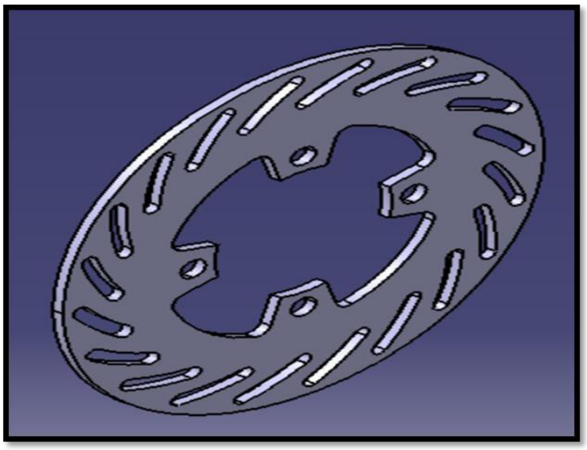


Fig. 2: CAD Model of disc brake

3.2 Design Parameters

The following are the design parameters considered for the design and analysis of the vehicle.

Table 2: Design Parameters

	Design Parameters		
S no.	**Parameter**	**Value**	**Symbol**
1	Mass of the vehicle	300 kg	m
2	Dynamic Weight Transfer to rear side	0.5	ρ
3	Acceleration of the Vehicle	8 m/s2	a
4	Velocity of the Vehicle	12 m/s	v
5	Outer Diameter of the Disc	190 mm	D0
6	Inner Diameter of the Disc	120 mm	Di
7	Disc Swept Area	0.0217 m 2	A
8	Effectiveness of Brake (a/g)	0.8	Z
9	Factor of charge distribution of the disc	0.5	ϵ

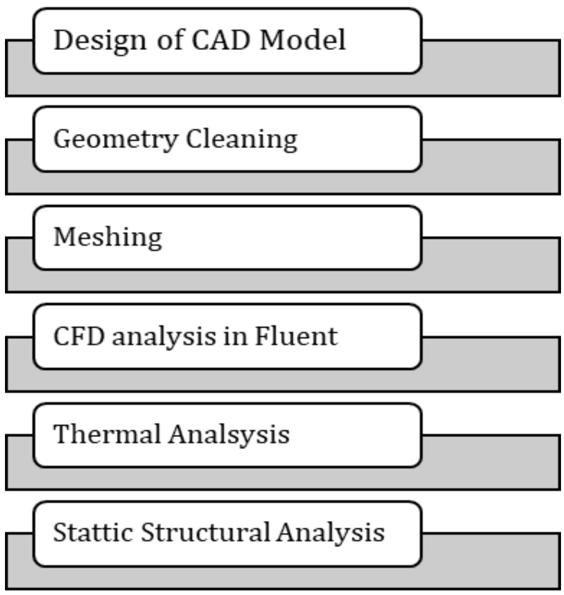


Fig. 3: Analysis Procedure

4. CALCULATION OF SURFACE HEAT TRANSFER COEFFICIENT

The surface heat transfer coefficient of the disc surface is calculated using ANSYS Fluent Solver. When the brakes are applied at running conditions the heat is generated in the disc and it is dissipated to the surroundings. The heat convection takes place by dissipating the heat to the air from the disc. The rate of convection depends on the heat transfer coefficient which again depends on the type of material used inlet conditions of air like temperature, velocity etc. The surface heat transfer coefficient can also be calculated analytical procedures like by calculating Nusselt numbers, Reynolds number etc. But the accurate results are obtained by simulating the exact conditions in the ANSYS fluent solver. [2] The heat transfer coefficient is calculated in the following steps

4.1 Creation of Domain

The air domain should be created around the disc in the ANSYS Design Modeler. There is a great significance for this air domain. As we are calculating the heat transfer coefficient through the air flow around the rotor. The air should be created virtually in the solver. The enclosures are used to create the air domain around the rotor. There are different types of enclosures available in ANSYS like Box, Cylinder and spherical type. The custom enclosures can also be created around the design based on the complexity and conditions of the problem. Here the box type of enclosure domain is created considering the disc in static condition. The dimensions of the enclosure is as follows:

Length - 300 mm
Breadth - 300 mm
Height - 300 mm

The above dimensions are determined iteratively based on the design of the disc. If the enclosure size is small there will be backflow of the fluid (air) before outlet region. If the enclosure size is very big it will increase the size of the problem which increases the time for solving the problem. The boundary conditions for this domain is created in the ANSYS Mechanical. The following pictures shows the air domain, inlet and outlet conditions of the analysis.

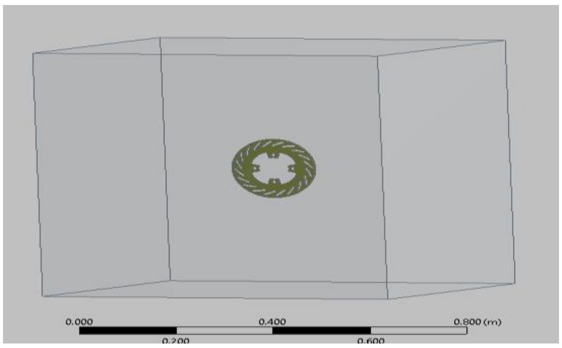


Fig. 4: Box Domain

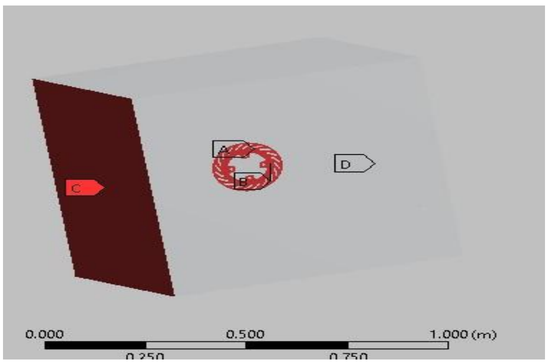


Fig. 5: Inlet of air

4.2 Meshing

Meshing is generated on the ANSYS Mechanical. The element size of the model is considered as 3mm of tetrahedrons type. The number of elements and nodes generated are 54537, 291612 respectively. It is very important to have good quality of mesh for obtaining accurate results. The fine mesh quality is generated by adopting proximity and curvature functions. [4]

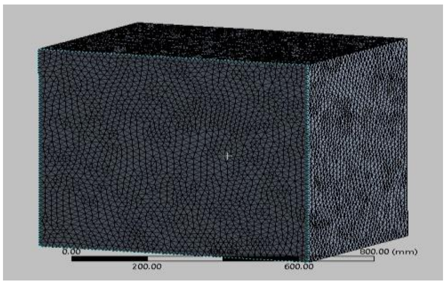


Fig. 6: Meshing

4.3 Boundary Conditions

The boundary conditions define the boundaries of the problem in order to converge at a point. These are assumed and calculated based on the problem statement and the objectives to perform the experiment. The boundary conditions are determined in the ANSYS Mechanical. The properties of the air

Table 3: Boundary Conditions

S no.	Parameter	Value
1	Inlet Velocity of the air	17 m/s
2	Heat Flux Entering the Disc	90000 W/m2
3	Pressure Outlet of the air	1 atm
4	Inlet Temperature of the air	30 ℃
5	Ambient Temperature	22 ℃
6	Viscous Model	k- ϵ model

The following formula is used to calculate the initial heat flux entering the disc brake

$$q = \frac{1-\rho}{2} X \frac{mxgxvxz}{2xAx\epsilon}$$

4.4 Assumptions

In order to reduce the complexity of the problem the following assumptions are made in performing CFD analysis

1. The air flow around the disc brake is turbulent, hence kepsilon turbulent model is adopted.
2. The inlet velocity of the air remains 12 m/s around the brake.
3. The heat flux entering the disc is uniform across the surface.
4. There are no losses in heat dissipation.
5. The properties of the air remains same at the given temperature.
6. Air flow is steady.

5. STRUCTURAL – THERMAL ANALYSIS

Structural-Thermal analysis is the process of analyzing the static structural and thermal behavior of a model by coupling static structural and Steady state thermal analysis. This is performed in ANSYS 18.1 software. This method is used to obtain the maximum temperature of the disc brake and the deformation caused due to the thermal load. [5]

5. 1 Analysis Procedure

The CAD model of the disc brake is imported in the ANSYS Design Modeler. The surface of the disc brake is divided into different parts based on the application of forces. The CAD model is meshed in the ANSYS Mechanical with the element size of 3 mm of tetrahedrons type. The number of nodes and elements are respectively.

The heat energy input for the disc brake is given in the form of heat flux entering the disc brake and the initial temperature on the surface of the disc brake. The surface heat transfer is obtained from the results obtained through CFD analysis which is given as input for the convection. These boundary conditions are used to calculate the heat transfer and final temperature of the disc brake. The following figures describes the boundary conditions and results obtained from the Steady Thermal Analysis. The solution obtained in the Steady State Thermal Analysis is exported to the static structural analysis package. The final temperatures imported are used as thermal load in order to perform the static structural analysis. The fixed supports for the disc brake are given and the analysis is performed. The deformation of the disc brake at these conditions and the factor of the safety is determined in this process.

6. RESULTS

The following results are obtained from the CFD and the thermal analysis. These are the final results obtained from the ANSYS Fluent and ANSYS Mechanical. The solution in CFD is converged after 1000 iterations.

Table 4: Table of Results

Results			
S no.	**Parameter**	**Value**	**Units**
1	Heat Transfer Coefficient	357	W/m^2-K
2	Maximum Final Temperature	91	C
3	Deformation	0.005	cm
4	Stress developed	216	MPa
5	Thermal strain	0.0008	cm/cm
6	Factor of safety	1.1517	

The following figures shows output obtained from solver

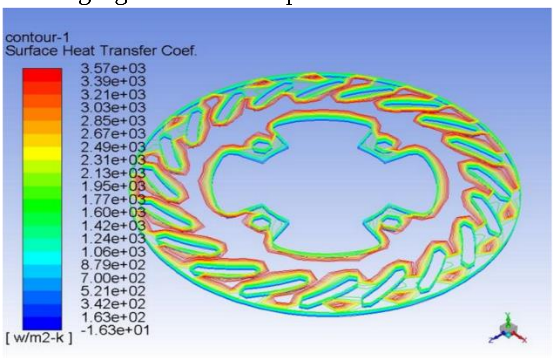


Fig. 7: surface heat transfer coefficient

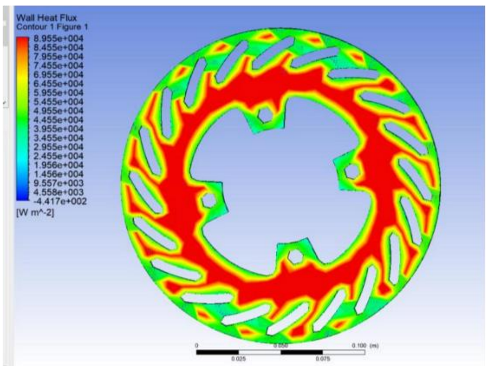


Fig. 8: Wall heat flux distribution around the dis

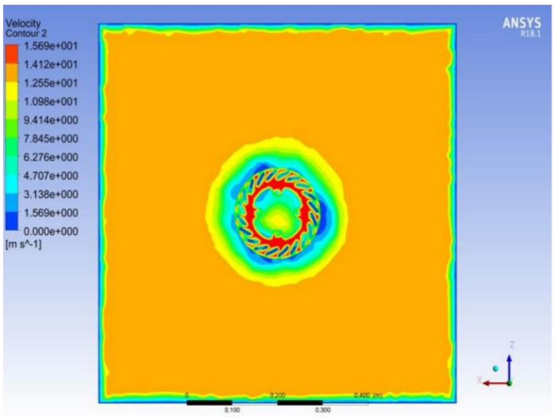
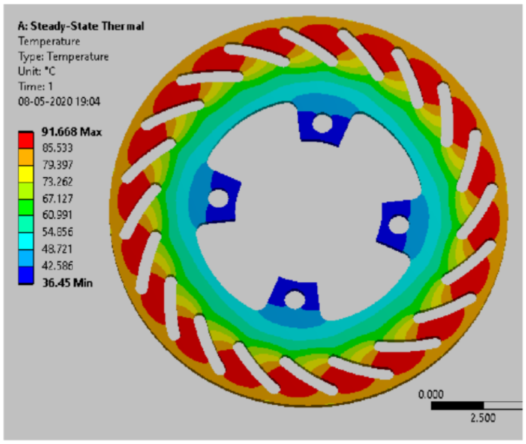
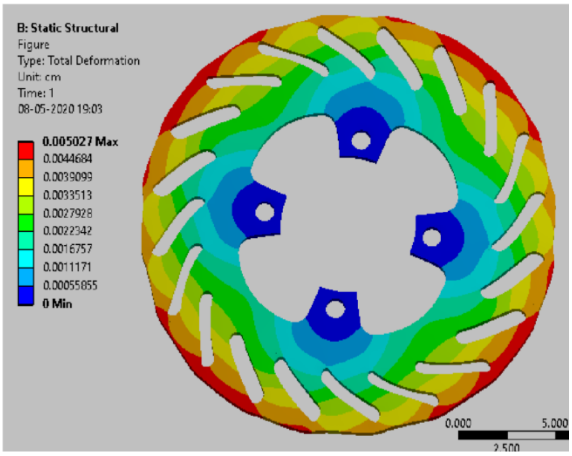


Fig. 9: Velocity of air around the disc



Fir. 10: Temperature



Fir. 11: Total deformation

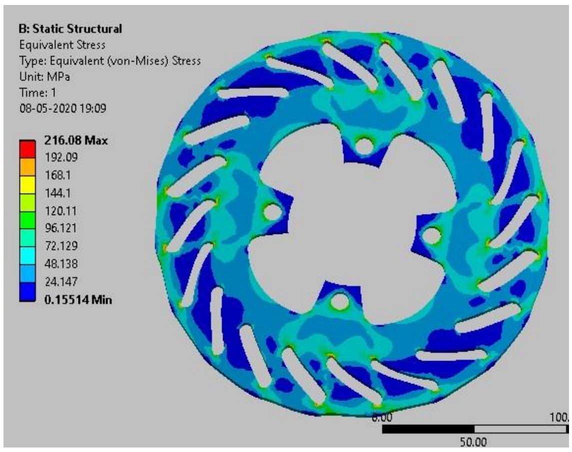


Fig. 12: Equivalent Stress

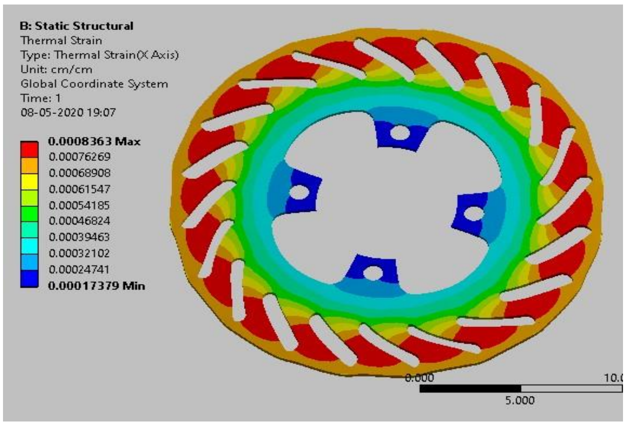


Fig. 13: Thermal Strain

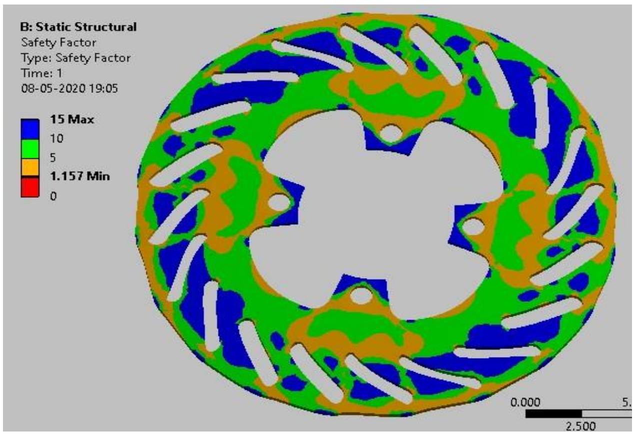


Fig. 14: Safety Factor

7. CONCLUSION

The CFD and thermal analysis is performed on the disc brake using ANSYS Fluent and ANSYS Workbench. The surface heat transfer coefficient is obtained from the ANSYS and with the output from the CFD analysis thermal analysis is performed in the ANSYS Mechanical. The temperature distribution of the disc brake is studied in the ANSYS. The results obtained from the solver prove can be conclude that that the disc brake is good to use in the vehicle of the corresponding parameters.

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