

Cooling Performance Analysis in Disc Brake System by ANSYS

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ABSTRACT: Disc brake systems play a vital role in automobile field like in two wheelers to stop the heavy and high speed vehicle in less time. In applying the brakes the generation of heat in brake system and its dissipation happens regularly. To improve the efficiency of brake it is necessary to cool the brake system naturally. The ventilated disc brake rotor with vane passages formed between braking surfaces; acts as a centrifugal fan and facilitates the required air flow for cooling. Geometrical configuration of brake plays a key role in brake system. Hence it is necessary to make modifications in the existing rotor geometry vane passages and which will consequently contribute for better flow development. In this project, an attempt is made to analyse the disc brake system by increasing the number of vanes and the vane material in the disc which improves the cooling rate and overall performance of disc. Here a brake system with 18 number of vanes and 32 number of vanes are considered and made analysis using ANSYS simulation and compared the results of both conditions. Aluminium alloy material is considered for analysis and the number of vanes is increased from 18 to 32 in count. By considered the obtained simulated results it is concluded that the directional heat flux and the total heat flux varied rapidly, but the temperature difference is very negligible at the minimum level and remains same at maximum level.

KEYWORDS: Disc Brake, Vanes, Air Ventilation, Aluminium Alloy, ANSYS Simulation.

I. INTRODUCTION

The modern automotive brake system has been refined for over 100 years and has become extremely dependable and efficient. A brake is a device for slowing or stopping the motion of a machine or vehicle, or alternatively a device to restrain it from starting to move again. Brakes of some description are fitted to most wheeled vehicles, including automobiles of all kinds, trucks, trains, motorcycles, and bicycles. Friction brakes on cars store the heat in the rotating part (drum brake or disc brake) during the brake application and release it to the air gradually. The kinetic energy lost by the moving part is usually translated to heat by friction. Alternatively, in regenerative braking, much of the energy is recovered and stored in a flywheel, capacitor or turned into alternating current by an alternator, then rectified and stored in a battery for later use. Kinetic energy increases with the square of the velocity ($e = (mv^2)/2$). This means that if the speed of vehicle doubles, it has four times much energy. The brakes must therefore dissipate four times of energy to stop it and consequently the braking distance is four times as long. When the brake pedal is depressed, the vehicle's braking system transmits the force from pedal foot to its brakes through a fluid. Since the actual brakes require a much greater force than the leg could apply with, vehicle must also multiply the force of foot. It does this in two ways; mechanical advantage (leverage) and hydraulic force multiplication. The brakes transmit the force to the tires using

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friction. The typical brake system consists of disk brakes in front and either disk or drum brakes in the rear connected by a system of tubes and hoses that link the brake at each wheel to the master cylinder. Other systems that are connected with the brake system include the parking brakes, power brake booster and the anti-lock system.

II. LITERATURE REVIEW

Y. Yildiz et al ., [1] have studied on a stress analysis of three different ventilated brake discs using the finite Element method., the cross drilled disc, the cross-slotted disc, and the cross-slotted with a side groove disc, were manufactured, and their braking force performances were investigated experimentally together with a solid disc. Analyses results showed that the maximum stress generations were formed on the ventilated discs in comparison to the solid disc. However, these comparisons indicate that the application of varying force distributions along brake pads reduces the stresses on ventilated discs by 8.8% to 19.1%.

Mesut Duzgun et al., [2] has studied Investigation of thermo-structural behaviours of different ventilation applications on brake discs. In this study, the thermal behaviours of ventilated brake discs using three different configurations were investigated at continuous brake conditions in terms of heat generation and thermal stresses with finite element analysis. The results were compared with a solid disc. Heat generation on solid brake discs reduced to a maximum of 24% with ventilation applications. The experimental study indicated finite element temperature analysis results in the range between 1.13% and 10.87%.

M. Pevec et al.,[3] have studied the common method that is used for predicting the temperatures in the brake disc during braking is numerical simulation analysis. With the help of Computational Fluid Dynamics, the flow through a vehicle ventilated brake disc of known geometry was determined, and the wall heat transfer coefficients for all vehicle speeds and brake disc temperatures were calculated. The results were then imported into a thermal numerical simulation of a sequential braking vehicle test. The results showed that the consideration of cooling factors has a significant impact on temperature courses.

Sung Pil Jung et al ., [4] have studied Thermal Characteristic Analysis and Shape Optimization of a Ventilating Disc. The mathematical analysis is done to obtain braking power generation, and by applying the thermal energy the heat flux is calculated, from 130 km/h to 0 km/h with deceleration of 0.4 g. The shape of the cross section of the disc is optimized according to the response surface analysis method in order to minimize the temperature rise and thermal deformation.

Pyung Hwang et al., [5] have studied on 3D thermo-mechanical coupling model of temperature and thermal stress in ventilated disc brake based. In this study, the temperature and thermal stress in the ventilated disc-pad brake during single brake is investigated. The brake disc is decelerated at the initial speed with constant acceleration, until the disc comes to a stop. The ventilated pad-disc brake assembly is built by a 3D model with a thermo-mechanical coupling boundary condition and multi-body model technique.

Ali Belhocine et al., [6] have studied Thermal analysis of a solid brake disc. The objective of this study is to analyze the thermal behavior of the full and ventilated brake discs of the vehicles using computing code ANSYS. The modeling of the temperature distribution in the disc brake is used to identify such as the type of braking, the geometric design of the disc and the material used. The results obtained by the simulation are satisfactory compared with those of the specialized literature.

Jaeyoung Kang et al., [7] has studied Squeal analysis of gyroscopic disc brake system based on finite element method. The dynamic instability of a car brake system with a rotating disc in contact with two stationary pads is studied. For actual geometric approximation, the disc is modelled as a hat-disc shape structure by the finite element method.. The corresponding gyroscopic matrix of the disc is constructed by introducing the uniform planar-mesh method. The dynamic instability of a gyroscopic non conservative brake system is numerically predicted with respect to system parameters. The results show that the squeal propensity for rotation speed depends on the vibration modes participating in squeal modes. Moreover, it is highlighted that the negative slope of friction coefficient takes an important role in generating squeal in the in-plane torsion mode of the disc.

Sung Pil Jung et al., [8] have studied Thermo Mechanical Finite Element Analysis of Hot Judder Phenomenon of a Ventilating Disc Brake System. In this paper hot judder characteristics of a ventilated disc brake system are discussed. Three dimensional finite element models of the ventilated disc, pads and pistons are created, and a fully coupled thermo mechanical analysis of the hot judder phenomenon of the disc brake system is performed using

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SAMCEF. The brake dynamo test is carried out according to the high speed judder test mode. The evolution of the temperature distribution on the disc surface is described, and the hot spot generation process is investigated. The simulation results such as the maximum disc temperature, BTV are compared to the data from the dynamo test, and the reliabilities of the analysis technique and simulation model presented in this paper are verified.

Sung-Soo Kang et al., [9] have studied Thermal deformation and stress analysis of disk brakes by finite element method. The thermal characteristics of disk brakes, thermal deformation analysis and thermal stress analysis due to heat transfer were carried out through the finite element analysis for ventilated disk and solid disk. By comparing the maximum temperature in the braking process, the ventilated disk showed a lower temperature than the solid disk and effect of temperature increase and decrease, depending on the vent area generated in the flange part of the disk. The thermal deformation in ventilated disk type occurs in all directions by 0.1162 mm, thermal distribution in the circumferential direction showed large deviation, about 0.017 mm due to the vents.

Byeong- Choon Goo et al., [10] have studied Thermal fatigue of cast iron brake disk materials. In this paper to develop cast-iron brake disks with high heat resistance to thermal shock loading, three candidate materials were developed. The main components were Fe, C, Si, Mn, Ni, Cr, Mo, Cu and Al. The mechanical and thermal properties of the candidates were measured. After the literature survey it is decided that dissertation work is to develop for weight optimization of disc and to increase cooling effect with compared to the existing disc.

Rajendra Pohane, R. G. Choudhari et al., [11] FEM model is prepared for contact analysis. A three dimensional finite element model of the brake pad and the disc is developed to calculate static structural analysis, and transient state analysis. The comparison is made between the solid and ventilated disc keeping the same material properties and constraints and using general purpose finite element analysis. This paper discusses how general purpose finite element analysis software can be used to analyse the equivalent (von-misses) stresses & the thermal stresses at disc to pad interface.

Masayuki and Mikio et al., [12] studied the effect of contact angle on the squeal using beam on disc system with variable angle of the rod. Their results showed that when the rod angle is in the same direction with the disc rotation, rubbing and squeal occurs and the vibration increases with increasing the rod angle.

III. FINITE ELEMENT METHOD

Finite Element Method is a powerful numerical tool used to find out stress analysis and deformations occurred in beams, trusses, planes and in automotive machine components. If component is felt difficulty in analysing then it is considered as small parts called elements. Then these element are joined with the help of nodes .By providing a serial numbers these all elements are joined to make a global system of component .Finally the boundary conditions are applied and we solve the equations and find out the unknown quantities. But these solutions give the approximate values but not exact solution. To solve the bigger matrices we depend on the software packages that solves the problems easily like as ANSYS. The various steps involved in Finite element analysis are in three stages .They are Pre-processing, Processing and Post processing.

i) **Pre-processing:** It involves selection of element, providing element shape, thermal conductivity, and density of material, nodes, and boundary conditions etc., which are treated as the initial information to solve the problem.

ii) **Processing:** In this the problem is solved using the above given shape, size and values of boundary conditions to the appropriate level of solution.

iii) **Post processing:** It provides the file output that is deformations, mode shapes, thermal distribution, etc., and list out the magnitudes of various processes.

IV. ASSUMPTIONS AND MATERIAL PROPERTIES CONSIDERED FOR ANALYSIS

4.1 The following assumptions are made to do an analysis where the behaviour of material is assumed to be Isotropic and the thermal conductivity of the material is uniform in all directions of the material. They assumptions are as follows

- Brakes are applied on Two and Four wheels.
- Thickness of 5mm is considered for all the models.
- The disc brake model used is of Ventilating Type.

- The thermal conductivity of the material is uniform throughout.
- The kinetic energy of the vehicle is lost through disc brakes i.e. there is no heat loss between the tire and the road side.

4.2 The Aluminium properties considered for analysis are as follows,

Density = 2770 kg/m³
Coefficient of Thermal Conductivity = 2.3 X 10⁻⁵ / °C
Specific Heat = 875 J/kg/°C

V. METHODOLOGY OF PRO-E CREO PARAMETRIC

A CAD designed model is prepared in 3D for the test equipment as a model of the brake test with some variations and assumptions. The measurement fan in the funnel inlet is neglected. The surrounding temperature and pressure are considered as negligible where inlet and outlet pressures very less. For the analysis purpose the Aluminium alloy material is selected and the number of vanes are varied and taken as 18 and 32 vanes for analysis and the results of the both analysis which was done in Ansys Multi physics was compared and the results are plotted in graphs.

5.1 **Disc brake of 18 Vanes:** The interior vanes of the design model of disc brake (18 vanes) are modelled with a Aluminium alloy material which is shown in below Fig 5.1.(a) and it describes the side view design of the model done in Creo Parametric.

Similarly , Fig 5.1(b), shows the Isometric view of the same disc brake meshed with tetra shaped elements and source of heat is provided on one side of the brake with initial temperature conditions as ambient temperature of 22⁰C. The same ambient temperature is taken referred as the initial temperature of the brake material and after solving the brake model in Ansys Multi physics simulation, it shows the maximum temperature of 70⁰ C.

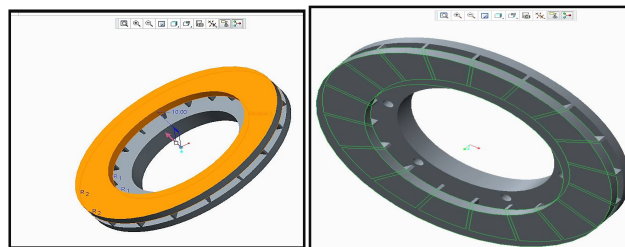


Fig : 5.1.(a) Disc brake (side view) Fig: 5.1.(b) Disc brake (Isometric view)

Fig 5.1: Model of the Disc Brake with 18 vanes made Aluminium alloy

5.2 **Disc brake of 32 Vanes:** In this second case of analysis the number of count of vanes is changed from 18 to 32. The design model of this disc brake is also modelled in Creo with same material as Aluminium alloy which is shown in below Fig 5.2.(a) and it describes the side view of the brake. Similarly , Fig 5.2 (b), shows the Isometric view of the same disc brake which is meshed with tetra shaped elements and heat is provided with initial temperature conditions of surrounding temperature of 22⁰C. After simulation it also shows the maximum temperature of 70⁰ C.

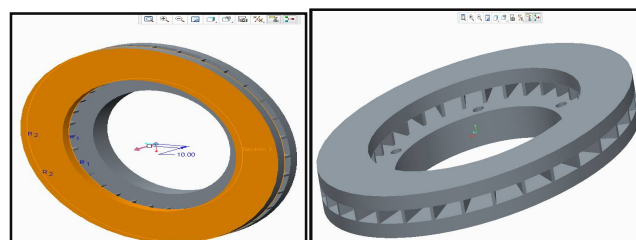


Fig : 5.2.(a) Disc brake (side view) Fig: 5.2.(b) Disc brake (Isometric view)

Fig 5.2: Model of the Disc Brake with 32 vanes made of Aluminium Alloy

VI. ANSYS METHODOLOGY

The ANSYS computer program is a large scale multipurpose finite element program that may be used for solving several classes of engineering analysis. The analysis capabilities of ANSYS include the ability to solve static and dynamic structural analysis, steady state and transient heat transfer problems, mode frequency and buckling Eigen value problems, static or more time varying magnetic analysis, and various types of field and coupled field applications.

In this program the ANSYS Multiphysics APDL 14.0 version is used to make the analysis by modelling the 3D model designed in Creo parametric 2.0 version and importing the object into ANSYS. For analysis the number of vanes are varied or changed to analyse the cooling performance of disc brake. Here in this work, an attempt is made with 18 and 32 vanes made of Cast Iron and Structural Steel materials are considered.

A. RESULTS OF 18 VANES DISC BRAKE:

By analysing the brake with steady state thermal condition, the disc brake results with given material and with given condition of ambient temperature it shows the following results shown in below figures from Fig 6.1(a) to Fig:6.1(c).

The results shows that the directional heat flux varies from -733.61 W/m^2 to 737.33 W/m^2 (Fig: 6.1.1) and total heat flux was changed from 1.496 w / m^2 to 980.22 W/ m^2 (Fig: 6.1.2), and lastly the temperature has attained o to a maximum of 70° C (Fig: 6.1.3) with a minimum starting at 69.902°C .

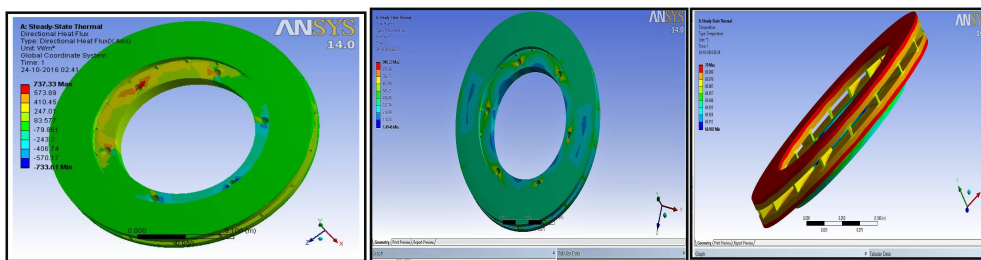


Fig:6.1.(a) Steady State Thermal (Directional Heat Flux)

Fig:6.1.(b) Steady State Thermal (Total Heat Flux)

Fig 6.1.(c) : Steady State Thermal (Temperature Gradient)

B. RESULTS OF 32 VANES DISC BRAKE:

These are first modelled in Creo parametric and imported to Ansys and made the simulation analysis. The vane count has been changed to 32 for analysis and it shows the following results shown from Fig 6.2(a) to Fig 6.2(c).

The results shows that the directional heat flux varies from -751.16 W/m^2 to 740.24 W/ m^2 (Fig: 6.2.(a)) and total heat flux was changed from 2.0041 w / m^2 to 1073.4 W/ m^2 (Fig:6.2.(b)), and lastly the temperature has attained to a maximum of 70° C (Fig:6.2.(c))with a minimum starting at 69.901°C .

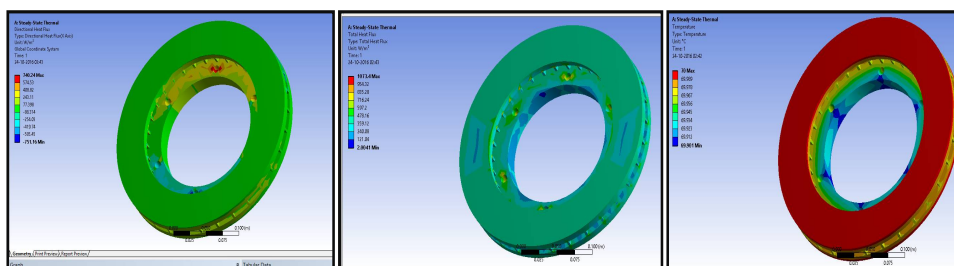


Fig:6.2.(a) Steady State Thermal (Directional Heat Flux)

Fig:6.2.(b) Steady State Thermal (Total Heat Flux)

Fig 6.2.(c) : Steady State Thermal (Temperature Gradient)

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VII. RESULTS AND CONCLUSIONS

A. RESULTS:

After conducting the analysis of disc brake has been done in Ansys Multi physics simulation by importing the model from Creo, the following results and conclusions has been finded out.

- The total temperature on the disc plate was reduced when compared to cast iron to structural steel.
- Compare to Cast Iron physical and mechanical properties, Structural steel is a better grade in ductile property, so that we concluded structural steel is the better material for disc.
- Heat flux is reduced and heat transfer rate is increased with number of vanes increased.
- By giving number of vanes air ventilation is increased radically compared to 18 vanes by doing the observation of early cooling of disc brake happened by incremental of vanes.
- The analysis results showed that, temperature field and stress filed in the process of braking phase were fully coupled.
- Static structural analysis is carried out by coupling the thermal solution to the structural analysis.
- All the values obtained from the analysis are less than their allowable values. Hence the brake disc design is safe, based on the strength and rigidity criteria.
- Comparing the different results obtained from analysis, it is concluded that more vanes ventilated type disc brake is the best possible for the present application.

B. CONCLUSIONS:

The various conclusions which can be made by observing the table (Table 7.3.1) are as follows:

- The structural disc brake made of 18 vanes shows the less total heat flux (980.22 W / m^2) when compared to disc made of 32 vanes (1073.40 W / m^2) due to increase in surface area of through vanes which acts as a fin which transfers more heat from source.
- The temperature in both the conditions of vanes (in 18 and 32 vanes) remains same as 70°C of maximum.
- The directional heat flux also varied with a small variation reached a maximum level up to 737.33 and 740.24 w/m^2 in 18 and 32 vaned disc brakes but started with negative condition in both models.

C. RESULTS COMPARISON TABLE OF 18 AND 32 VANES :

The comparison table (Table 7.3.1) shown below announces that the temperature values are same for both the vanes variation but the total heat flux has been changed from 980.22 W / m^2 for 18 vanes to 1073.4 W / m^2 for 32 vanes, and the Directional Heat flux also varied from -733.61 W/m^2 to 737.33 W/m^2 (for 18 vanes) to that of -751.16 W/m^2 to 740.24 W/m^2 (for 32 vanes).

Table: 7.3.1 Table showing the comparison of results of 18 and 32 vanes disc brakes

SLNO	ITEM DESCRIPTION	18 VANES DISC		32 VANE DISC	
		Min	Max	Min	Max
1	Total Heat Flux (W / m^2)	1.4946	980.22	2.0041	1073.40
2	Directional Heat Flux (W / m^2)	-733.61	737.33	-751.16	740.24
3	Temperature ($^\circ\text{C}$)	69.902	70°C	69.901	70°C

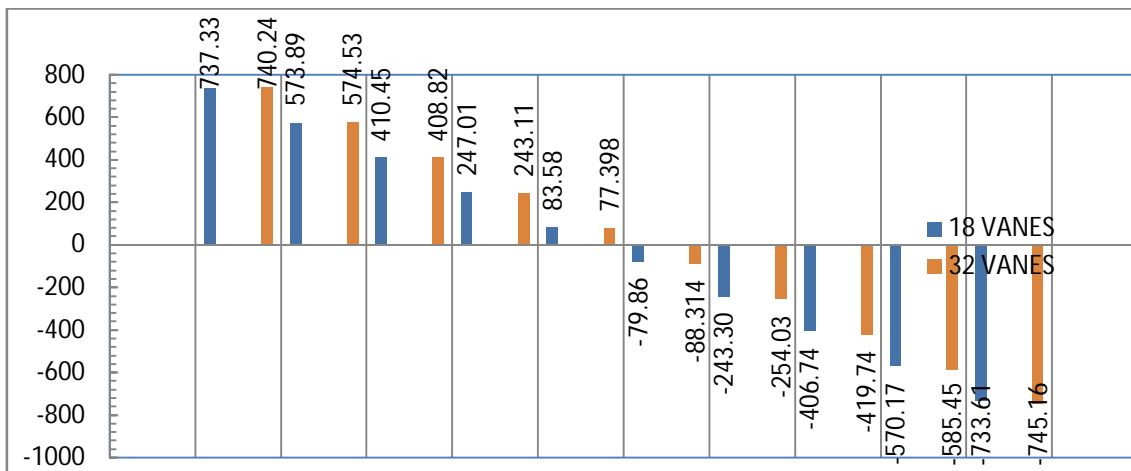
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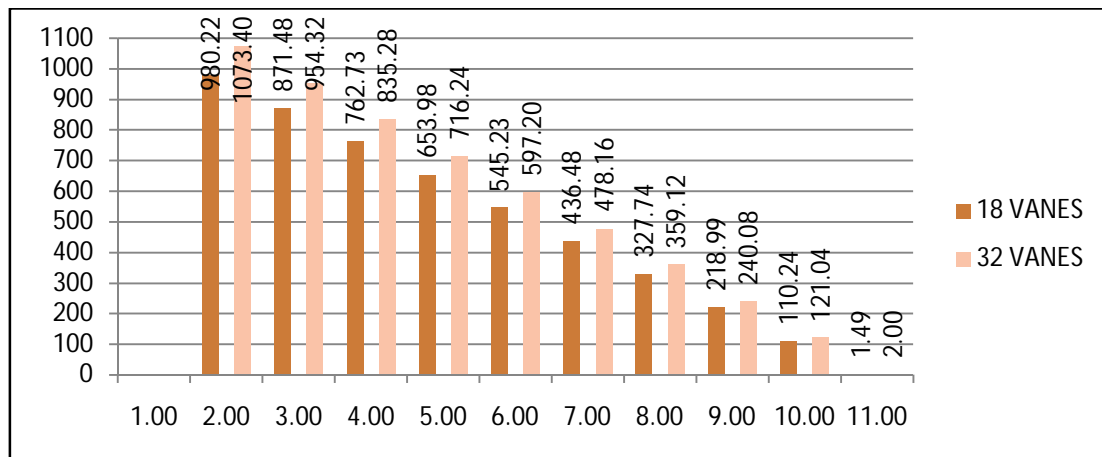
D. COMPARISON GRAPHS OF 18 AND 32 VANES:

The graphs are drawn between simulation values obtained for 18 and 32 vanes for directional heat flux in W/m^2 and total heat flux in W/m^2 which varies rapidly in both the vanes. The comparison graph is shown in below Graph 7.4.1 for Directional heat Flux in W/m^2 and this graph explains that the directional heat flux is more for 32 vanned brake disc compared to 18 vanned disc, which indicated that by increasing the number of vanes the heat can be dissipated in better way.



Graph: 7.4.1 Comparison graph showing the Directional heat flux in 18 and 32 vanes of disc brake

The graph 7.4.2 shows the differences between total heat flux occurred between 18 and 32 vanes where it is more in 32 vanes compared to 18 vanes.



Graph: 7.4.2 Comparison graph showing the Total heat flux of 18 and 32 vanes of disc brake

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