Review Paper on Thermal Analysis of Ventilated Disc Brake by Varying Design Parameters

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Abstract

Safety aspect in automotive engineering has been considered as a number one priority in development of new vehicle. Brakes convert friction to heat, but if the brakes get too hot, they will cease to work because they cannot dissipate enough heat. Ventilated disc brake is the state of the art technology in automobile brake system .In this study FEA approach has been conducted in order to identify the temperature distributions and behavior of disc brake rotor in transient state. This paper reviews work of previous investigators on transient thermal analysis on the vented disk rotor and rotor designs to evaluate and compare their performance. Time varying temperature load is applied on the rotors and the temperature distribution was analyzed considering cooling parameters (convection and radiation). The main of aim of this review work is to study various researches done in past to improve heat transfer rate of disc brake (ventilated) by changing vane geometry and material.

Keywords: Thermal analysis, ANSYS, FEA, Ventilated disc brake, Heat Transfer coefficient, Dry contact, Heat flux.

1. Introduction

The disc brake is of two type solid full and ventilated. The disc brake is a device for slowing or stopping the rotation of a wheel. A brake disc (or rotor) usually made of cast iron or ceramic composites (including carbon, Kevlar and silica), is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads (mounted on a device called a brake caliper) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. These brakes offer better stopping performance than comparable drum brakes, including resistance to "brake fade" caused by the overheating of brake components, and are able to recover quickly from immersion (wet brakes are less effective). Discs have now become the more common form in most passenger vehicles, although many (particularly light weight vehicles) use drum brakes on the rear wheels to keep costs and weight down as well as to simplify the provisions for a parking brake. As the front brakes perform most of the braking effort, this can be a reasonable compromise.

Friction brakes act by generating frictional forces as two or more surfaces rub against each other. The stopping power or capacity of a friction brake depends on the area in contact and coefficient of friction of the working surfaces as well as on the actuation pressure applied. Wear occurs on the working surfaces, and the durability of a given brake (or service life between maintenance) depends on the type of friction material used for the replaceable

surfaces of the brake. If drake disc are in solid body the Heat transfer rate is low. Time taken for cooling the disc is low. If brake disc are in solid body, the area of contact between Disc and Pads are more, so efficiency of brake is high.

We introduced variation in vanes pattern on the disc in ventilated disc brake. The Heat transfer rate is increase. Time taken for cooling the disc is high. It has been seen that the generation of huge amount of temperature on disc surface during braking needed to be dissipated as efficiently and soon as possible. It's observed that many factors are responsible which restricts heat dissipation, ultimately leading to brake failure due to situation like brake fade and judder. Factors such as Vehicle speed, type of braking (Emergency braking or repetitive breaking), rotor geometry and dimension, disc or pad materials (Cast iron, Aluminium metal matrix composite, ceramics etc), contact pressure distribution etc are some certain factors which can be varied to achieve a satisfactory heat dispersion. Primarily a vented disc rotor have been choose for study and with design modification of fins (forward angled and reversed angled with alternate short length fins) and also with two different materials (GCI an AlMMC) a FEA approach based on transient response is to be studied for thermal analysis of disc rotor. By comparing the output one can have deep insight of the heat transfer in the solid ventilated disc.

2. Literature review

TING-LONG HO Et al. (1974), Investigated on the effect of frictional heating on brake material (Aircraft) **[1]**. In this paper simplified analysis is conducted to determine most significant factors which affect surface temperature. Where there are size and weight restrictions the specific heat and maintaining the contact area appear a criterion is suggested for determining the number and thickness of brake disks, within the limited space available in a wheel. Frictional variations at high temperature could result from three different phenomenons: softening of the material, formation of oxides and surface melting. Metallographic study approach is been used here. It was found that minimum surface temperature would result under material with minimum value of (1/ρc) and (1/kρc), when there is maximum contact area and by using higher load-lower friction system.

Masahiro Kubota et al. (2000), presented paper on development of a lightweight brake disc rotor: a design approach for achieving an optimum thermal, vibration and weight balance **[2]**. This paper presents a parametric study that was conducted on the basis of an analysis of airflow through the ventilation holes as well as a thermal stress analysis and a vibration analysis during braking. Based on the relationships obtained between rotor weight, shape and each performance requirement, a method is presented for designing a lightweight disc rotor. Computational fluid dynamics (CFD) analysis approach is used to visualize the actual process. Short and gourd shaped fins arrangement had been used and the results verified that anti-squeal performance was improved, and also a substantial weight reduction was achieved compared with the baseline rotor shape without causing cooling performance and heat resistance to deteriorate.

Choi and Lee, (2004) presented a paper on Finite element analysis of transient thermo elastic behaviors in disk brakes **[3]**. A transient analysis for thermo elastic contact problem of disk brakes with frictional heat generation is performed using the finite element method. To analyze the thermo elastic phenomenon occurring in disk brakes, the coupled heat conduction and elastic equations (cylindrical coordinates) are solved with contact problem. Material used is carbon-carbon composite and wear is assumed negligible. The numerical simulation for the thermo elastic behavior of disk brake is obtained in the repeated brake condition. The computational results are presented for the distributions of pressure and temperature on each friction surface between the contacting bodies. It is observed that the orthotropic disc brakes can provide better brake performance than the isotropic one because of uniform and mild pressure distribution.

JIANG LAN et al. (2011), presented paper on thermal analysis for brake disk of Sci/6061 Al. Alloy co-continuous composite for CRH3 during emergency braking considering air flow cooling **[4]**. The thermal and stress analyses of SiCn/Al brake disk during emergency braking at a speed of 300 km/h considering airflow cooling were investigated using finite element (FE) and computational fluid dynamics (CFD)

methods. All three modes of heat transfer were analyzed. The highest temperature after emergency braking was 461 °C and 359 °C without and with considering airflow cooling, respectively. The equivalent stress could reach 269 MPa and 164 MPa without and with considering airflow cooling, respectively. The airflow through and around the brake disk was analyzed using the Solidwork2012 simulation software package. The results suggested that the higher convection coefficients achieved with airflow cooling will not only reduce the maximum temperature in the braking but also reduce the thermal gradients, since heat will be removed faster from hotter parts of the disk.

Oder G. et al. (2009), worked on thermal and stress analysis of brake discs in railway vehicles **[5]**. Performed analysis deals with two cases of braking; the first case considers braking to a standstill; the second case considers braking on a hill and maintaining a constant speed. In both cases the main boundary condition is the heat flux on the braking surfaces and the holding force of the brake calipers. In addition the centrifugal load is considered. Finite element method (FEM) approach is been used, 3D model has been modeled for analysis. Brake disc material is rounded graphite; two types of disc considered for studies one without wear and one with 7mm wear on both sides. Maximum speed is 250 km/hr and the ambient and initial disc and surrounding temperature is 50 C Temperatures and stress in discs under different loads is very high. Although they are fulfilling the buyer's requirements for safety, this investigation not considered shearing forces, residual stress and the cyclic loads during brake discs lifespan. The results need to be compared with experimental results.

Talati and Jalalifar (2009), presented a paper on Analysis of heat conduction in a disk brake system **[6]**. In this paper, the governing heat equations for the disk and the pad are extracted in the form of transient heat equations with heat generation that is dependant to time and space. In the derivation of the heat equations, parameters such as the duration of braking, vehicle velocity, geometries and the dimensions of the brake components, materials of the disk brake rotor and the pad and contact pressure distribution have been taken into account. The problem is solved analytically using Green's function approach. It is concluded that the heat generated due to friction between the disk and the pad should be ideally dissipated to the environment to avoid decreasing the friction coefficient between the disk and the pad and to avoid the temperature rise of various brake components and break fluid vaporization due to excessive heating.

Zaid, *et al.* (2009) presented a paper on an investigation of disc brake rotor by Finite element analysis. In this paper, the author has conducted a study on ventilated disc brake rotor of normal passenger vehicle with full load of capacity **[7]**. The study is more likely concern of heat and temperature distribution on disc brake rotor. In this study, finite element analysis approached has been conducted in order to identify the temperature distributions and behaviors of disc brake rotor in transient response. Modeling is done in CATIA & ABAQUS/CAE has been used as finite elements software to perform the thermal analysis on transient response. Material used is Grey cast iron, with maximum permissible temperature 550 C. For load analysis 10 cycles of breaking and 10 cycles without breaking (idle) operation is considered total of 350 seconds. Result provided during 1^{st} , 5^{th} and during 10^{th} cycle. Thus, this sure study provide better understanding on the thermal characteristic of disc brake rotor and assist the automotive industry in developing optimum and effective disc brake rotor.

Piotr Grzes & Adam Adamowicz (2011), presented paper on analysis of disc brake temperature distribution during single braking under non-axisymmetric load **[8]**. First step of the analysis based on the previously developed model where the intensity of heat flux was assumed to be uniformly distributed on the friction surface of disc during braking process, and the heat is transferred exclusively in axial direction, whereas during the second, the three-dimensional rotor is subjected to the non-ax symmetric thermal load to simulate realistic thermal behaviour of the brake action. Operation conditions, thermo-physical properties of materials and dimensions of the brake system were adopted from the real representation of the braking process of the passenger vehicle. Arbitrarily selected four values of the velocities at the moment of brake engagement were applied to the models so as to investigate theirs influence on the obtained solutions of the temperature evolutions on the contact surface of the disc volume referring to two separated finite element analysis. Two- and

three-dimensional FE modeling techniques is used considering FEA approach. Finite element analysis and Fast Fourier transform been used to reduce computational time. Radiation heat transfer had been neglected and wear on the contact surface is negligible. We can conclude that the large amount of heat generated at the pad/disc interface during emergency braking indisputably evokes non-uniform temperature distributions in the domain of the rotor, whereas the pad element is constantly heated during mutual sliding.

Ali Belchocine & Mostefa Bouchetara (2012), presented paper on thermal analysis of a solid brake disc **[9]**. 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. In this analysis approach is to create the model CFD which contains the fields to be studied in Ansys Workbench. Three different grade of cast iron is chosen (FG 25 AL, FG20, and FG15). The numerical simulation shows that radial ventilation plays a very significant role in cooling of the disc in the braking phase. The variation in temperature between a full and ventilated disc having same material is about 60 degree at the moment1.8839 s from application of brake The obtained results are very useful for the study of the thermo mechanical behavior of the disc brake (stress, deformations, efficiency and wear).

Haripal Singh and Harshdeep Shergill (2012), presented paper on thermal Analysis of Disc Brake Using Comsol **[10]**, in these paper Finite element analysis techniques is used to predict the temperature distribution and identify the critical temperature of brake disc. Considering all three modes of heat transfer (conduction, convection and radiation) for three different materials of rotor disc are been used (cast iron, aluminium and ceramics). It is concluded that cast iron can be used in brake disc which will give moderate cooling at low temperature as compared to other. Ceramics has good cooling characteristics but it is costly, can be used in racing cars where high temperature is produced.

Zhang Jiang& Xia Changgao (2012), research of the transient temperature field and friction properties on disc brakes **[11]**. The 3D transient and cyclic symmetry finite element model of the temperature field of the ventilation caliper disc brake in a long downhill braking condition was established in this paper. The finite element modeling for three-dimensional transient cyclic symmetry during the long downhill braking is established. The variation of the friction factor combined with the temperature characteristics of the friction factor during the braking are analyzed. Analysis is done by using finite element software ANSYS. During the braking, the temperature of the brake rises increasingly and reaches the top temperature of 316.04℃ at the end of braking process; the high temperature section concentrates in the far area of the friction surface. The maximum rate of recession is 8.16%, friction coefficient is always stable within a reasonable range, and the obvious thermal recession is not happened.

K. Sowjanya & S.Suresh (2013), presented paper on Structural analysis of disk brake rotor **[12]**. Disc brake is usually made of Cast iron, so it is being selected for investigating the effect of strength variations on the predicted stress distributions. Aluminum Metal Matrix Composite materials are selected and analyzed. The domain is considered as axis-symmetric, inertia and body force effects are negligible during the analysis. The model of Disc brake is developed by using Solid modeling software Pro/E (Cero-Parametric 1.0).Further Static Analysis is done by using ANSYS Workbench. Thermal solution to the structural analysis and the maximum Von Misses stress was observed to be 50.334 M Pa for CI, 211.98 M Pa for AlMMC1, and 566.7 M Pa for AlMMC2, the Brake disc design is safe based on the Strength and Rigidity Criteria.

K. M. Muniswamy et al. (2013), heat transfer enhancement on ventilated brake disk with blade inclination angle variation **[13]**. The objective of the current study is to investigate the potential heat transfer enhancements in ventilated brake disk by varying the geometrical parameters of the blades inside the flow passage. The thickness remains constant and only the length can be changed to fit the inner and outer radius. The computational model constructed in GAMBIT. The models are solved using ANSYS-FLUENT proprietary software package. The results show a tremendous increase in the heat transfer rate with blade inclination angle configurations as compared to conventional straight blade. The Nusselt number is found to be in a power-law relationship with the Reynolds number. Distinct relationship between laminar and turbulent condition is predicted. An improvement in total

convective heat transfer coefficient of 51% was achieved with blade inclination angle of 40 C tilting towards clockwise direction and also recirculation was also eliminated completely in 30 degree blade designs with heat dissipation 32%.

3. Conclusion

Disc brake design plays as an important role in heat transfer as other variable like plate & vane thickness, fin material and flow pattern. There is a scope of improvement in heat transfer in ventilated disc brake if vane is angled and of alternate length other than straight radial vane. Contact time between air flow and vanes (time between air inlet and outlet flow through vanes) is also important factor in heat transfer from Disc rotor. There is also scope of research in improvement of heat transfer of rotor by increasing the contact time between vanes and air flow by design modification of vanes in such a way that fulfills the requirement.

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