



Review on Thermal Analysis of Different Disc Brake Rotor with Ventilated Flow Passage Configuration Using Finite Element Method (FEM)

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Abstract:

A new vehicle's safety features are given top consideration throughout development. A running vehicle needs a braking system to be controlled and stopped. The brakes become excessively hot when kinetic energy is converted into thermal energy. They may stop functioning if they are unable to sufficiently discharge this heat. The heat produced while braking is held in the brake disc rotor and is mostly released into the environment via forced convection. Optimal designs of vented disc brake rotors can promote cooling, which is necessary for effective braking function. The flow routes for the braking discs include radial vanes and pillared vanes, among others. Considerable temperatures have been discovered to be the cause of disc brake thermal failure, but it has also been observed that big temperature gradients cause high thermal stress to build within rotor channels. High thermal strains result from the radial vane rotor temperature dispersion throughout the vane's irregular passage. Pillared rotors are a better option to radial vane rotors because they have a more consistent temperature distribution across the rotor passageways. Even though pillared rotors have a lower mass flow rate than radial type rotors, their heat transfer rates are nearly same. The primary focus of this study is on comprehending the airflow and heat transfer properties of a few radial and pillared rotors with various designs. Further results were compared to find best and most effective design of ventilated disc brake rotor.

Keywords: Thermal stress, straight radial vane, tapered radial vane, rotor, circular pillared.

1. Introduction:

The important control system of an automobile is braking system. Brakes are used to slow down or stop a moving vehicle as per requirement. Earlier vehicle was fitted with either band brakes or drum brakes. Brake fade and water fade are the main disadvantages of these types of brake. Now in modern age high speed vehicles are in use. Therefore, modern automobile requires high speed braking system, especially passenger and racing cars. Drum brakes are inadequate to meet the braking requirements in these conditions. Further in order to reduce un-sprung mass it is necessary to design brakes in smaller size with higher amount of kinetic energy absorption. This heat absorption has increased the area available for heat dissipation is reduced. In result, high temperature in brake disc leads to thermal failures due to cracks and hot spots. In recent years, the stopping capacity of brakes need to be design more accurate and efficient for increasing level of duty requirements. The stopping capacity of brake increases by the heat dissipation rate due to forced convection and thermal capacity of the braking system. In early age of automobile history drum brakes got used for many years but now in modern high speed vehicles disc brake comes with better efficiency and performance. Drum brakes are not much effective to use in this condition to meet braking requirements. Fig. 1 shows the disc brake rotor, pad, and caliper assembly of an automobile. The rotor's temperature may reach very high while braking application. Therefore, the disc brake rotor must be able to dissipate heat as fast as possible to perform efficiently with ensuring the life expectancy of the whole braking system.



Figure 1 Disc brake rotor, pad and caliper assembly

The disc brakes rotors are solid and ventilated type. Modern high-speed vehicles have fitted with ventilated type disc brakes. The ventilated disc rotors are mainly used to enhance cooling performance and its operation seems to be similar as centrifugal impeller. Ventilating disc rotors have more surface area and less mass over solid disc rotors so that ventilated discs are recommended to use in automobiles. The mass flow and heat dissipation rate of disc brake rotors depend upon various parameters such as geometry of rotor and flow passages, air flow rate through ventilated passages, air turbulence etc. The brake rotors are mainly differentiated into radial type and pillared type brake rotors. Radial type disc brakes are easy to be manufactured as compared to pillared rotors but after that it has more thermal and structural advantages over the radial brake rotors. The material distribution is more uniform in pillared rotors over the radial rotors which provide resistance to crack propagation. In case of straight radial vane rotor passages the pressure, velocity and temperature distributions is not uniform which leads to high thermal stresses. [2] These parameters and heat transfer rate from the rotor passages is symmetrical in case of pillared rotors. That is why ventilated pillared rotors may be more appropriate as compared to straight vane rotors for modern high-speed vehicle.

2. Literature Review:

Limpert, Rudolf [2022] compared the cooling performance of solid and ventilated disc brake rotor. They found that solid rotors exhibit larger convective heat transfer coefficient than that produced by ventilated rotors. Approximately one third cooling from the vanes and two third from the friction surface exposed to the ambient air consist in total convective heat transfer coefficient. At high speed of rotor almost 50-60 percent contribution of total cooling belongs to internal cooling. The larger surface area of ventilated disc rotor is the major factor for reduced temperature.[1]

Chandra Sarthok et. al. (2022) Nowadays, manufacturers fight to develop flashy cars without compromising safety. The most important aspect of high-speed vehicles lies in their braking system. As a result, several types of research are being conducted to enhance the disc brake quality. Brake discs often use gray cast iron because of its high friction properties and low cost of production, despite its low level of corrosion and wear resistance. In order to solve this issue, several investigations are being undertaken on brake discs for different materials. A steady-state thermal analysis of a disc brake made of carbon-carbon composites and aluminum silicon carbide metal matrix composites has been carried out. The materials are selected to dissipate heat at a very rapid rate. For improving brake stability, optimization of heat transfer rate is a major issue. In this analysis, the temperature fields of the disc are evaluated for one second of braking time using a steady state thermal analysis. Hence, there is no dissidence that a carbon-carbon composite rotor is more suitable for braking application.[2]

Budi Sethiyana et.al. (2022) Brakes are used to slow down or stop a moving object. The temperature of the disc brake will rise as a result of the conversion of kinetic energy from vehicle speed into thermal energy during the braking operation. To prevent harm to the disc brake or other components, the heat generated by this disc brake must then be released into the environment. Therefore, it is crucial to provide effective heat dissipation to the environment. Increasing the surface area where heat is dissipated into the environment is one potential solution. In this study, the variation of the drill hole angles and groove hole angles is proposed as a geometry modification to encourage greater heat dissipation in disc brakes. In addition, the thermal performance of disc brakes made from various types of materials is assessed using finite element analysis. [3] <http://dx.doi.org/10.1016/j.rineng.2022.100844>.

Yaseen Tabbai et.al. (2022) There is a large amount of thermal energy wasted during the driving cycle of all kinds of vehicles. In this paper, a pyroelectric harvester system, based on temperature change, is designed for low-powered sensors for a reliable Electronic/Electric architecture development of autonomous vehicles. For this proposed approach, three main elements are required: Pyroelectric energy harvest module, energy conversion module and power storage module. The energy harvest module includes a pyroelectric material, which captures the temperature of the braking system, and harvests the wasted heat energy during the contact process. In the energy conversion module, the temperature variation through the pyroelectric material generates electricity, given the cooling phenomena with the ambient air.[4] <http://dx.doi.org/10.1051/epjap/2022220093>.

Welteji Bena et.al. (2022) This paper deals with the coupled thermal structural analysis developed in Volvo heavy truck disc brake as a function of disc thickness and braking time. A ventilated type of disc brake was employed by having vents (holes) on its surface, which needs a cooling system. When the brake pedal is applied, the friction between the disc and pad tremendously increases due to the heat generated in this system. This heat was partitioned into two contacting bodies (disc rotor and pad). Both analytical and numerical approaches were used to carry out the analysis. Analytically, the transient

temperature obtained by the partial solution approach and the stress field were evaluated by the elastic von Mises criterion. In the numerical approach, temperature and stress response were analyzed by the explicit standard ABAQUS. From both results, high thermal gradient and von Mises stress distribution were observed at the sharp edges of the disc, which causes a decrement in braking efficiency and an overall drop in braking performance.[5] <http://dx.doi.org/10.1155/2022/7945264>.

Filip et.al. (2022) For road safety, braking system performance has become a very important requirement for car vehicle manufacturers and passengers. To this end, vehicle designers must understand the characteristics of tribological behavior and the causes of their variation in properties. This paper analyzes the tribological behavior (at friction and wear) of the most recent material couples of the braking disk-pad system affected by their structural change through the implications on the braking system stability, reliability, and suitable characterizations. Obtaining information to design a very efficient braking system and assessing the influence of the material's structural changes on its stability has become a necessity. This has been made possible by using several methods of testing a brake disk-pad couple on various devices intended for this purpose. The materials of the contact surface disk-brake pad with their tribological performance (friction, wear), especially the friction coefficient, present particular importance.[6] <http://dx.doi.org/10.3390/ma15144745>.

Dr. Swastik Pradhan et.al. (2022) An important part of a car's safety system is the brakes. Brakes are easily worn, leading to unpredictable disasters. To avoid this, ventilated disc brakes are used, which helps the brakes to work well in stressful conditions and high temperatures. The materials used play an important role in determining performance. The main objective of this research work is to analyze the current design and conduct a suitable brake rotor analysis to improve its performance. Existing brake disc designs are modeled in Creo and analyzed with software. The material grades used in this study were performed on stainless steel, grey cast iron, structural steel, and titanium alloy brake discs using the same brake disc design to determine the best grade.[7] <https://doi.org/10.22214/ijraset.2022.43959>.

R.A. Garcia et.al. (2021) In the braking system, the heat dissipation generated by the friction between the disc and pad should be evacuated as quickly as possible. In this work, five common different automotive disc brakes were studied through mathematical theories of heat transfer and numerical methods using the ANSYS software. In addition, a direct comparison between experimental, theoretical, and simulation values found in the open literature was performed to propose a disc brake with an improved geometry in terms of dissipation of heat transfer. The numerical results were considered to propose two possible solutions of disc brake geometries using N-38 ventilation blades used in aeronautic engineering. An improvement in temperature dissipation was achieved by approximately 23.8% compared to the five geometries analyzed with a simple type N-38 ventilation blade. The heat dissipation in the brakes strongly depends on the geometry of the disc, the geometry of the blades, the material from which it is manufactured, the material of the pad, the weight of the vehicle, and the operating conditions, as can be verified with mathematical calculations and experiments. The results obtained demonstrate that the discs can be used effectively in extreme working conditions (80 km/h and 33°C), without affecting the safety of the occupants and the braking system.[8] <https://doi.org/10.3390/fluids6040160>.

3. Proposed Methodology:

In order to increase brake efficiency, thermal behaviour of disc brake rotor studied on different parameters. Different flow passage vane configurations were considered for analysis of disc brake. A particular disc brake design was used in simulation to describe a method for calculating the rate of mass flow and the rate of heat dissipation of rotor at different speeds. The heat transfer coefficient was determined using FEM, temperature distributions and rate of mass flow in the flow field of the rotor passage. FEM results were compared with previous experimental work for validation. The previous experimental results of different researchers however provide a relative idea of actual performance and give it as a critical validation tool for numerical analysis. Principles of Finite Element Method. The basic idea of FEM is to discretize the domain of interest, where the PDE is defined, in order to obtain an approximate solution of the PDE by a linear combination of basic functions defined within each subdomain.

4. Conclusion:

The paper describes the design and analysis of the disc brake. The analysis has been done for various types of materials to find its static structural analysis which consists of strain, stress, shear stress, total deformation, thermal analysis temperatures, and total heat flux. From the above static structural results, we can conclude that structural steel has less strain compared to the remaining materials followed by stainless steel, grey cast iron, titanium, copper, and aluminium alloy. But were in stress aluminium alloy has less stress and then followed by grey cast iron and stainless steel. In shear stress, copper has less value. Even though in different conditions different material holds different values stainless steel and grey cast iron have maintained their average values in every analysis output. But stainless steel has higher corrosion properties.

5. References:

- [1] Limpert, Rudolf Types of Braking System in Automobile - Mechanical Booster." system.html#Need_of_a_Braking_System (accessed Jan. 17, 2022).
- [2] Chandra Sarthok "Automotive Brakes, Safety, and Control Systems Explained." <https://gomechanic.in/blog/automotive-brakes-explained/> (accessed Jan. 19, 2022).
- [3] Budi Sethiyana Drum Brakes Brakes for Automobiles Product Products and Technologies Akebono Brake Industry Co., Ltd." (accessed Jan. 19, 2022).

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- [4] Yaseen Tabbai Disc Brakes Brakes for Automobiles Product Products and Technologies |Akebono Brake Industry Co., Ltd.” (accessed Jan. 21, 2022).
- [5] Welteji Bena changed brake pads, but when you press the brakes, it is soft? - Page 2 - Xoutpost.com.” (Accessed Jan. 22, 2022).
- [6] Filip et.al. What Causes Brake Rotors to Warp? - Brake Experts.” (Accessed Feb. 02, 2022).
- [7] Dr. Swastik Pradhan⁴, Santhosh M1, Palepu Rithvik², Katkam Ravi Teja³ Modelling and analysis of ventilated disc Brakes using Creo and FEA software (IJRASET) ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538 Volume 10 Issue VI June 2022.
- [8] R.A. Garcia-Leon, E. Florez-solana, Dynamic analysis of three auto ventilated disc brakes, *Ingenieria e investigation* 37, 102–114.
- Ameer Fareed Basha Shaik, Ch. Lakshmi Srinivas, structural and thermal analysis of disc brake with and without cross drilled rotar of race car, *international Journal of Advanced Engineering Research and Studies*
- [9] S. M. Kim, A study on thermal analysis in ventilated brake by FEM, *Journal of the Korean Society of Machine Tool Engineers*, 18 (5) (2009) 544-549
- [10] P. Grzes, Maximum temperature of the disc during repeated braking applications, *Adv. Mech. Eng.*
- [11] Anil Babu Seelam, Nabil Ahmed Zakir Hussain, Sachidananda Hassan Krishanmurthy and design and analysis of disc brake system in high-speed vehicles, *Int. J. Simul. Multidisci. Des. Optim.* 12 19 (2021)
- [12] Mithlesh, S. & Tantray, Zubair & Bansal, Mohit & Kumar, Kotte & Kurakula, Varun & Singh, Manpreet. (2021). Improvement in performance of vented disc brake by geometrical modification of rotor. *Materials Today: Proceedings*. 47. 10.1016/j.matpr.2021.05.006.
- [13] R. Limpert, “Cooling analysis of disc brake rotors,” *SAE Tech. Pap.*, 1975, doi: 10.4271/751014.
- [14] R. Krüsemann and G. Schmidt, “Analysis and optimization of disk brake cooling via computational fluid dynamics,” *SAE Tech. Pap.*, vol. 104, no. 1995, pp. 1475–1481, 1995, doi: 10.4271/950791.