International Journal of Research in Engineering, Science and Management
Volume-1, Issue-7, July 2018
www.ijresm.com
ISSN (Online): 2581-5782

Significance of Modifications on Disc Brake Vane in the Enhancement of Heat Transfer - A Review

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***Abstract*: The conventional design of disc brakes has its limitations when it comes to the flow alignment and heat transfer. Ventilated brake discs are used in high speed vehicles. The brake disc is an important component in the braking system which is expected to withstand and dissipate the heat generated during the braking event. The main limitations are flow misalignment or formation of high pressure and low pressure regions within the vane channel and the air inflow angle. The flow misalignment and inflow angle plays an important role in mass flow rate and heat transfer within the disc brakes. The flow misalignment factor is controlled by curved vane and its modifications. The results prove to improve both the mass flow rate and HTC compared to that of the straight radial vanes. In the present work, an attempt is made to study the effect of vane-shape on the flow-field and heat transfer characteristics for different configurations of vanes like Straight Curved, circular, diamond shape, airfoil etc.**

Key Words: CFD analysis, Cast iron

1. Introduction

Braking is the foremost important safety feature in an automobile which enables the driver not only to stop the vehicle when and where required but also to decelerate and reduce the speed during transit. Braking is also an energy conversion process in which the kinetic energy of the vehicle is converted to heat energy by the application of friction which makes it a thermo mechanical problem too. The temperature of the disc brake during braking is so high and inadequate cooling of the brake can cause formation of Micro hotspots. Brake disc rotate with high rpms in the air so that the cooling of the disc brake comes under forced convection. The study also shows the formation of recirculation zone within the vane. This recirculation zone results in flow separation at the tip of the leading vane side. The study also revealed that the formation of the low pressure region reduces flow velocity and thereby creates the chance for laminar boundary layer formation which in effect reduces the heat transfer to the air.

Braking system is mainly used to decelerate vehicles from an initial speed to a given speed. Friction based braking systems are the common device to convert kinetic energy into thermal energy through friction between the brake pads and the rotor faces. The modernization of multi-lane facilities paves the way for high-speed driving of vehicles. The passenger and racing cars require high speed braking system which could not be met with drum braking systems. Excessive thermal loading can result in surface cracking, judder, and high wear of the rubbing surfaces. High temperatures can also lead to overheating of brake fluid, seals and other components. The stopping capability of brake increases by the rate at which heat is dissipated due to forced convection and the thermal capacity of the system.

2. Theory

In braking operation, the kinetic energy of the vehicle is converted to thermal energy and this induced high temperature in the discs. The temperature rise occurs in the disc brake due to two kind of braking operations. Stop braking is the braking process which causes constant retardation of the vehicle and consequently stopping of the vehicle. This operation occurs in a small amount of time and releases huge amount of energy and it comes under the transient mode of heat transfer. Hold braking is used by a driver when the vehicle going on a decent and to prevent the vehicle from accelerating. This braking helps the driver to hold the vehicle in a constant safe speed in the gradient. The temperature produced is comparatively low compared to stop braking but for a long duration can cause TEI and Hotspot formations. This kind of braking therefore comes under the steady state heat transfer problem.

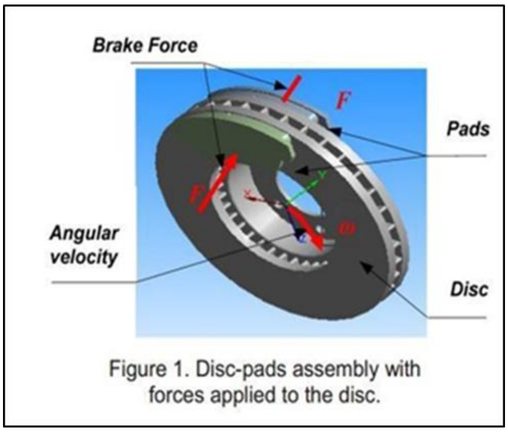

Figure 1. Disc-pads assembly with forces applied to the disc.

Fig. 1. Disc-pads assembly with forces applied to the disc

The heat is produced in the interface of brake pad and brake disc is due to the thermo mechanical conversion of the kinetic energy. The thermal energy is shared by both disc and the pads, the brake pads used in the disc brake operations are generally insulating materials such as asbestos and polymers which does not take much part of the thermal energy so that it is assumed that the conducting metallic disc absorbs and dissipates all the thermal energy produced in the process. There are three mode of heat transfer namely conduction, convection and radiation. The radiation heat transfer occurs without a medium, thermal energy is emitted as quanta of energy in the form of infrared and ultraviolet radiations. The radiation heat transfer is however predominant above 500◦C.the temperature range for the safe operation of the disc brake is below 500◦C, so radiation heat transfer is neglected. Second mode of the heat transfer is the conduction; conduction is the mode of heat transfer within the solids .the thermal energy produced at the friction surface is carried to the other portion of the material .the conduction within the disc materials helps the transfer of the heat from high temperature region of the disc surface to the inner channel region. The conduction within the metal is governed by Fourier equation. The conduction heat transfer plays important role in transient stop braking operations. Third and important mode of heat transfer is by convection heat transfer in transfer of heat from one medium to other occurs by the transport of the fluid medium.

The heat transfer coefficient and Nusslet number is dependent on the Reynolds number of the flow which is dependent on the flow velocity of air , thermal boundary layer formation and turbulence characteristics of the internal flow . the internal flow of the air is produced due to the rotation of the disc .the centrifugal action creates the flow of the air in the radial direction creates suction pressure at the inlet portion of the disc brake and thereby increases the mass flow rate through the channel. The rotation of the brake disc at constant rpm causes fresh air to enter into the channel and also flow above the braking surface and thereby ensures maximum heat transfer and helps reduce the operating temperature of the disc.

3. Review Based on Available Data and Information’s

A. Heat Transfer Analysis on Straight Vanes

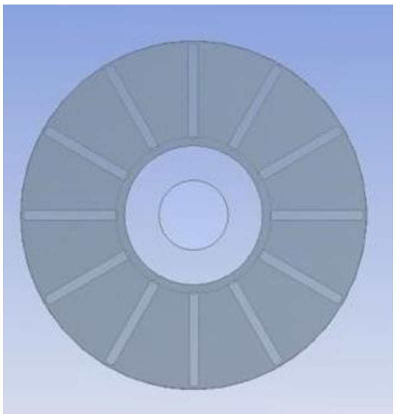

Fig. 2. Disc brake with straight vanes

Ali Belhocine, et al presented a numerical simulation of the thermal behavior of a full and ventilated disc in transient state .By means the computer code ANSYS 11 was able to study the thermal behavior of three types of cast iron (AL FG 25, FG 20, FG 15) for a determined braking mode. In addition to the influence of the ventilation of the disc, we also studied the influence of the braking mode on the thermal behavior of the discs brake. The numerical simulation shows that radial ventilation plays a very significant role in cooling of the disc in the braking phase. The obtained results are very useful for the study of the thermo mechanical behavior of the disc brake (stress, deformations, efficiency and wear). Through the numerical simulation, we could note that the quality of the results concerning the temperature field is influenced by several parameters such as:

- Technological parameters illustrated by the design,
- Numerical parameters represented by the number of element and the step of time.
- Physical parameters expressed by the type of materials.

A.D. McPhee, et al characterized the convective heat transfer for a brake rotor, transient experiments were conducted over a range of rotor speeds. The temperature profiles for each of the nominal speeds conformed to the anticipated exponential decay. Using exponential curve fits generated from blocked rotor testing, the external heat transfer coefficients for 342, 684, and 1025 [rpm] were determined to be 27.4, 40.8, 53.3 [Wm−1 K−1], respectively. Using the external convection terms and results from open rotor testing, the internal convection heat transfer coefficients for 342, 684, and 1025 [rpm] were determined to be 27.0, 52.7, and 78.3 [Wm−1 K−1], respectively. Although based on a small sample population, it was inferred that for the range of speeds tested, the internal convection increases linearly with speed.

While internal and external convective heat transfer coefficients were comparable at 342 [rpm], the internal coefficient increased much more rapidly with increasing speed. This result illustrates the importance of vented rotors for operation at moderate speeds. In terms of the total convective heat transfer, internal convection contributed 45.5% at 342 [rpm], increasing to 55.4% at 1025 [rpm].

Ventilated Brake Disk Air Streamlining Using Curved Vane is done by (K.M. Munisamy et al.2013) Flow misalignment was identified in the conventional ventilated disk brake design. The conventional ventilated disk brake has straight bi-directional blade design. The misalignment was quantified using CFD as design tool. In the effort of re-aligning the flow angle helical lines fitted onto the conventional inner and outer diameter disk brakes yielded two different design innovations.

Thermal Analysis of both Ventilated and Full Disc Brake Rotors with Frictional Heat Generation by, (M. Aslani et al 2011) studies, model of the thermal behavior of a dry contact between the discs of brake pads during the braking phase; the strategy of calculation is based on the software ANSYS 11. This last is comprehensive mainly for the resolution of the complex physical problems. As a current study of the problem, ANSYS simulations with less assumption and less program restrictions have been performed for the thermo-mechanical case. A temperature distribution obtained by the transient thermal analysis is used in the calculations of stresses on the disc surface. In this part, the maps of total and directional heat flux as well as the temperature distribution in the full and ventilated discs of cast iron FG 15 for each braking phase are presented.

The temperature distribution of the disc at the beginning of the braking (t = 0.25 s) is in homogenous. According to experimental tests, the braking often begins with the formation from hot circles relatively on the uniform surfaces of the disc in the circumferential direction, moving radically and then transforming into hot points (hot spot). The appearance of the phenomenon of the hot points is due to the non-uniform dissipation of the heat flux.

B. Heat Transfer Analysis on Curved Vanes

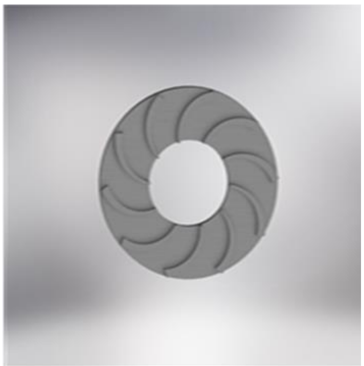

Fig. 3. Disc brake with curved vanes

Thermal Analysis and Optimization of a Ventilated Disk Brake Rotor Using CFD Techniques by (M. Bouchetara et al.2012) aims in the investigation is to achieve thermal optimization of a Ventilated Disc Brake Rotor (VDBR) by the use of Computational Fluid Dynamics (CFD) techniques. The analysis of an existing VDBR model is first presented. Literature suggests that the prime cause of failure is overheating and large thermal stress which arises due to ineffective heat transfer. In this paper, we present a comparative study to optimize the heat transfer rate by simple modifications. These simple modifications are considered due to their ease of manufacturing. It was found that a considerable enhancement in the heat transfer rate can be attained when the proposed modifications are incorporated in the design.

Increasing the curvature to 3 mm for a 36 vane rotor yields an increase of 8.76% in the heat transfer rate in comparison with the non-modified rotor. Curving the vane with 53 vanes at a center offset of 3 mm increases the heat transfer by 11.03 % in comparison with the non-modified rotor. In the current analysis, largest heat transfer was observed for this configuration. Further investigation of this configuration with regards to structural stability needs to be undertaken.

C. Heat Transfer Analysis on Pillar Vanes

Role of Cross-Drilled Holes in Enhanced Cooling of Ventilated Brake Discs by (Y B.Han et al. 2015) as constructive guidance for brake design engineers to improve brake disc cooling, understanding of thermo-fluidic behaviors associated with ventilated brake discs has attracted much attention. In this study, a systematic comparison of the thermo-fluidic characteristics between standard and cross-drilled ventilated brake discs incorporating radial vanes is carried out using numerical simulations. Mechanisms for heat transfer enhancement by the cross-drilled holes are clarified. To validate the numerical model, a series of experiments are also conducted. The gradient of axial pressure is found to drive the cooling air into the ventilated channel through cross-drilled holes.

Pressure difference drives cooling air into the ventilated channel through cross-drilled holes, causing accelerated boundary layer flow over the rubbing surface. As a result, within the radial spans of the cross-drilled holes, substantially enhanced local heat transfer is achieved. Therefore, further increase of pressure difference is expected to increase the mass flow rate of cooling air through the cross-drilled holes. Correspondingly, local heat transfer on both rubbing surface and surface of holes can be further improved.

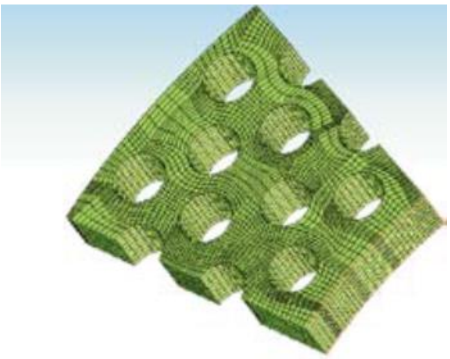

Fig. 4. Disc brake with circular pillar vanes

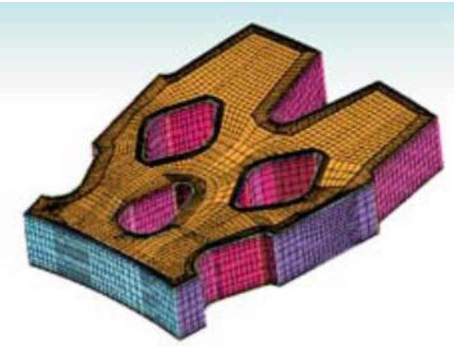

Fig. 5. Disc brake with diamond pillar vanes

Numerical Investigation of Fluid Flow and Heat Transfer Characteristics on the Aerodynamics of Ventilated Disc Brake Rotor Using CFD analysis by (F. Talati et al.2008) revealed that Ventilated brake discs are used in high speed vehicles. The brake disc is an important component in the braking system which is expected to withstand and dissipate the heat generated during the braking event. In the present work, an attempt is made to study the effect of vane-shape on the flow-field and heat transfer characteristics for different configurations of vanes and at different speeds numerically. Three types of rotor configurations circular pillared, modified taper radial and diamond pillar vanes were considered for the numerical analysis. In this present work, heat transfer characteristics of circular pillar, modified taper radial vane and diamond pillar vanes are analyzed. The following conclusions are drawn. Mass flow rate is considerably higher in modified taper radial vane compared to circular pillar rotor vanes. Heat dissipation in diamond pillared vane is around 25% higher as that of circular pillar and modified taper radial vanes. Circular pillar rotor vanes have more uniform pressure and velocity distribution which results in more uniform temperature drop around the vanes. This will ensure uniform and even cooling of rotor vanes. It would avoid the thermal failure of rotor vanes due to large thermal gradients between the rotor vanes as expected for MTRV and DP vanes. Due to these advantages, circular pillared vanes are preferred than modified taper radial vanes and diamond pillar vanes.

It is found that the velocity and pressure distribution is uniform even when the diameter is reduced to 6 mm from 8 mm and this trend becomes less uniform when it is decreased further to 5 mm diameter. The 6 mm diameter with 17 circular pillared vanes has around 20% better mass flow rate and around 4% better heat dissipation characteristics compared to 8 mm diameter and 12 circular vane rotor brake discs.

D. Heat Transfer Analysis on Airfoil Vanes

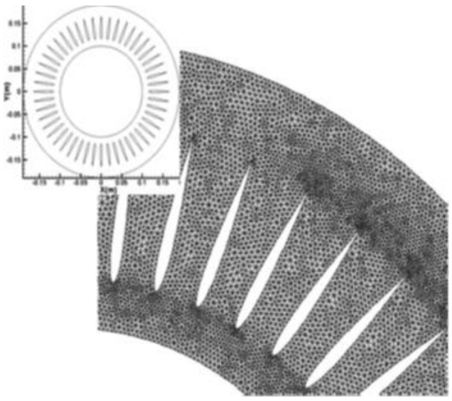

Fig. 6. Disc brake with airfoil pillar vanes

Heat Transfer Enhancement in Ventilated Brake Disk Using Double Airfoil Vanes by A. Nejat *et al* aims that the research is to enhance the heat transfer of ventilated brake disks using modified vanes. The investigated braking scenario is a hold braking deceleration during a downhill drive. A simple model for computing the steady state vane's temperature is presented. The heat transfer coefficient (HTC) of the brake disk's ventilation is estimated by means of a verified CFD computation. A novel design for the vanes is proposed using an airfoil profile to improve the air pumping efficiency increasing the flow velocity between vanes.

A simple approach for modeling of the steady state braking scenario was presented. The verification of the numerical simulation of such braking scenario for the heat transfer coefficient, HTC, of the straight vanes was conducted against both theoretical empirical data as well as another numerical simulation. The flow fields of the various air passage topologies were modeled via CFD simulation. Some detailed analysis was performed by studying the velocity and temperature distribution around vanes. The result showed that the increasing the flow momentum and limiting the flow separation region especially close to the leading edge of the vanes are the key factors in overall HTC improvement. A novel design was introduced by means of two airfoils as primary and secondary vanes improving the air pumping efficiency noticeably. The overall HTC was enhanced 17% to 29% for different angular velocities using the new design. It is worth mentioning that the manufacturability and the final price of such a product, i.e., a brake disk with airfoil vanes, need to be investigated separately, and is beyond the scope of current study. As a future work we intend to optimize the gap size between vanes, the location and the shape of the secondary vane to achieve the optimal HTC for a double vane disk brake.

Heat Transfer Enhancement in Ventilated Brake Disc Using Airfoil Vanes was studied by (M. Aslani et al. 2011) this research, the curved vane brake rotors are studied via a detailed numerical simulation. To increase the air pumping efficiency a novel design is used by means of the airfoils. In order to enhance the ventilating capacity, the airfoil geometry, the arrangement and its installation angle are studied to find a maximum cooling performance. A steady state scenario for braking is investigated using CFD and the corresponding heat dissipation rate is computed for different velocities. Some specific recommendations are made to achieve better thermal efficiency for the brake system.

To reveal the best quality of this design, the contours of the temperature are shown. Since the air flow is accelerated, it has assisted cooling down the vanes especially in areas where the single airfoil design failed to cool down appropriately. Also the regions with high temperature are eliminated in the new design in comparison with straight vanes. The result showed that increasing the flow momentum and limiting the flow separation region especially close to leading edge of the vanes are the key factors in overall HTC improvement. Improving the air pumping efficiency noticeably using a novel design was introduced by means of two airfoils as primary and secondary vanes. The overall HTC was enhanced between 18 to 30 percent for different angular velocities using the new design. As a future work we intend to optimize the location and the shape of the secondary vane to achieve the optimal HTC for a double vane brake disc. The ventilated brake rotors are mainly classified into radial type and pillared type brake rotor. The radial type brake rotors are easy to manufacture as compared to pillared type rotors. To improve the performance of a vented brake rotor, an understanding of air flow and heat transfer phenomena is very important. The flow through passages of the ventilated disc brake rotor is highly complex in nature and it can be better understood by using computational fluid dynamics (CFD).

E. Heat Transfer Analysis Depends On number of Vanes

Disc Brake and Its Effective Air Cooling System Analysis by Computational Fluid Dynamics (Rupert 1983) the potential of victimization procedure fluid dynamics could be a check to work out its viability for determinative its performance parameters. The target this paper is to research the warmth transfer and flow characteristics of brake disc with various number of straight vanes.

The results of twenty four vanes show that non uniform variation heat transfer over its surface. whereas perceptive the results of thirty two vanes the utmost worth 122.27 W/m^2 K that is considerably not up to worth of sixteen vanes (130.138 W/m^2 K).The results show that when ten seconds the disc (without vanes) is cooled all the way down to a minimum temperature of 294.05°C. Within the case of sixteen vanes the temperature is 293.643°C. The minimum temperature earned is 294.101°C for disc with eight and twenty four vanes whereas for thirty two vanes the temperature is reduced to 294.336°C. Whereas considering the results show that when forty sec the disc (without vanes) is cooled all the way down to a minimum temperature of 277.601°C. Within the case of sixteen vanes the temperature is 276.705°C. The minimum temperature earned is 278.399°C for disc with eight vanes and it's 277.594°C for twenty-four vanes whereas for thirty two vanes the temperature is reduced to 279.414°C.

4. Conclusion

In this present work, heat transfer characteristics of straight, curved, circular pillar, modified taper radial vane and diamond pillar vanes, Airfoil pillar vanes are analyzed. The following conclusions are drawn. Mass flow rate is considerably higher in modified taper radial vane compared to circular pillar rotor vanes. Heat dissipation in diamond pillared vane is around 25% higher as that of circular pillar and modified taper radial vanes. Circular pillar rotor vanes have more uniform pressure and velocity distribution which results in more uniform temperature drop around the vanes. This will ensure uniform and even cooling of rotor vanes. It would avoid the thermal failure of rotor vanes due to large thermal gradients between the rotor vanes as expected for MTRV and DP vanes. Due to these advantages, circular pillared vanes are preferred than modified taper radial vanes and diamond pillar vanes. The diameter and number of pillars in circular pillar vanes are modified for better mass flow rate and heat dissipation characteristics. It is found that the velocity and pressure distribution is uniform even when the diameter is reduced to 6mmfrom 8mmand this trend becomes less uniform when it is decreased further to 5 mm diameter. The 6 mm diameter with 17 circular pillared vanes has around 20% better mass flow rate and around 4% better heat dissipation characteristics compared to 8mmdiameter and 12 circular vane rotor brake discs.

A novel design was introduced by means of Airfoils as primary and secondary vanes improving the air pumping efficiency noticeably. The overall HTC was enhanced 17% to 29% for different angular velocities using the new design. The result showed that the increasing the flow momentum and limiting the flow separation region especially close to the leading edge of the vanes are the key factors in overall HTC improvement.

The analysis results shown significant improvement in the parameters such as heat transfer coefficient, mass flow rate etc. Of the models analysis the temperature distribution, velocity distribution and pressure contour which gives exact idea of the flow of the air within and outside the disc. The geometrical modifications helps improve the existing problems such as inflow angle and flow misalignment and improves the heat transfer rate. The flow misalignment problem that is discussed in the literature is solved by the model and thereby helps cool the disc .The comparison of the contours created by the curved vane and new type vane shows the improvement in the flow pattern and internal flow velocity.A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

References

[1] R. Limpert, The thermal performance of automotive disc brakes, vol. 750873, 1975.
[2] H.B. Yan, Q.C. Zhang, T.J. Lu, T. Kim, A lightweight X-type metallic lattice for single-phase forced convection, Int. J. Heat Mass Transfer, submitted for publication (manuscript No. HMT-D14-00833).
[3] L. Wallis, E. Leonardi, B. Milton, P. Joseph, Air flow and heat transfer in ventilated disc brake rotors with diamond and tear-drop pillars, Numer. Heat Transfer A Appl. 41 (6–7) (2002) 643–655.
[4] F.talati and S.Jalalifar,"Investigation of heat transfer phenomenon in a ventilated disc brake rotor with straight radial rounded vanes.journal of applied sciences 8(20) 3538-3592,2008
[5] McPhee. A and D. Johnson, Experimental heat transfer and flow analysis of a ventilated brake rotor, vol. 47, pp. 458-467, 2008.
[6] H.B. Yan, Q.C. Zhang, T.J. Lu, T. Kim,"Role of cross-drilled holes in enhanced cooling of ventilated brake Discs" Applied Thermal Engineering 91 (2015) 318-333
[7] Rajagopal, T. K. R., Ramachandran, R., James, M.,Gatlewar, S. Ch., Numerical investigation of fluid flow and heat transfer characteristics on the aerodynamics of ventilated disc brake rotor using CFD, Thermal Science 18 (2) 2014 667–675.
[8] A.Belhocine, M. Bouchetara, Thermal analysis of a solid brake disc, Appl.Therm. Eng. 32 (2012), 59-67.