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Investigation for Thermal Performance of Ventilated Disc Brake Rotor using CFD

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ABSTRACT

The kinetic energy of vehicle gets converted into heat energy by the friction between disc brake and the brake pad. It is then dissipated to the atmosphere. Poor heat dissipation results into high temperature gradients, hot spots, judder, brake fluid vaporization and even cracking of brake rotor. Convective heat transfer plays an important role for heat dissipation through the rotor. The ventilated disc brake rotor will increase both surface area and heat transfer coefficient of rotor by forcing the air through internal flow passages. Different rotor vane configurations viz. Straight Radial Vane (SRV), Taper Radial Vane (TRV) & Alternate Long and Short Vane (ALSV) were analyzed by using Fluent and ICEM CFD software. Experimental analysis has performed on existing TRV rotor to understand the heat dissipation characteristics of the rotor. TRV rotor gives better rate of heat dissipation than ALSV and SRV rotor. ALSV rotor shows less heat dissipation compared with TRV rotor but it has more uniform temperature distribution inside the flow passages. Hence, for modern high speed vehicles ALSV rotor may be more appropriate.

Keywords— **heat dissipation, ventilated disc, vane configuration, forced convection.**

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I. INTRODUCTION

The main purpose of a braking system is to slow down a vehicle or to stop it completely within a certain distance. Any moving vehicle contains kinetic energy by virtue of its motion and is proportional to the square of its velocity. Brake converts this energy into heat by virtue of friction. If this heat is not dissipated from brakes it will result in warping, cracking, hot judder, brake fading, brake fluid vaporisation and overheating of seals and other components. Solid brake rotors have good heat absorbing capacity but they are poor in heat dissipation. Today’s high speed vehicles demand more heat dissipation and the stability of fast moving vehicle do not allow air to pass beneath the vehicle and hence over the brakes. In order to increase the heat dissipation from brakes, internal vanes are provided to maximize the heat dissipation. Brakes are classified as drum brakes and disc brakes. Disc brakes are more reliable than drum brakes because of their high heat dissipation capacity and better performance when brakes are wet. In the present work different vane configurations are analyzed for fluid flow and heat dissipation.

II. EXPERIMENTAL WORK

In this experiment a 36 vane TRV brake rotor was used. The rotor material is cast iron with a mass of 8.31 kg and specific heat of 566 J/kg K. In order to measure the mass flow through the rotor a test rig is used as shown in figure 1, appendix I. Anemometer was used to measure velocity of air at exit. A custom test bench was fabricated to facilitate the rotation of the brake rotor to analyze the thermal behavior of rotor as shown in figure 2, appendix I. The rotor was heated nearly to the temperature of 85 oC. A maximum temperature of 85 oC was selected to minimize heat loss by radiation and conduction. For heating purpose, a customized 1.0 kW surface heater was used, ensuring a spatially uniform temperature distribution. Upon reaching the desired temperature, the heat source was removed and the brake rotor accelerated to a constant speed of 500 rpm. The rotor was driven by a 2 hp three phase induction motor, with speed controlled by variable frequency drive. The power is transmitted from motor to rotor via torque limiter and bearing assembly connected to hub. Torque limiter is provided to avoid motor stall conditions while extreme breaking. The resulting setup best simulated the performance of an unobstructed brake rotor open to the atmosphere. The temperature decay of the brake rotor was monitored and subsequently used to determine the heat transfer coefficients for a given speed. Measurement of brake rotor temperature was accomplished using infra red pyrometer. Assumption made during experiment are,1. Rotor speed is constant (500 rpm).2. Rotor temperature is uniform.3. Velocity at exit of duct is uniform.4. Instruments used gives measurement within accepted accuracy.5.Experimental procedure has been verified from the literature survey. Observations from experimental procedure

Table 01. Temperature drop of rotor in each 300 sec.

Sr. No	**Speed** rpm	**Time** sec	**Initial Disc Temp** ^0C	**Final Disc Temp** ^0C	**Temp Diff** ^0C
1	524	300	85	60.8	24.2
2	530	300	60.8	50.6	10.2
3	525	300	50.6	47	3.6

The graph shows the trend of temperature decay with time for TRV rotor .the behavior of curve can be given by lagrangian interpolation technique and it is found to be

y = 4 x 10-5 x2 – 0.083x + 45.6

y is temperature difference and x is time

dy/dx = 8 x 10-5 x – 0.083

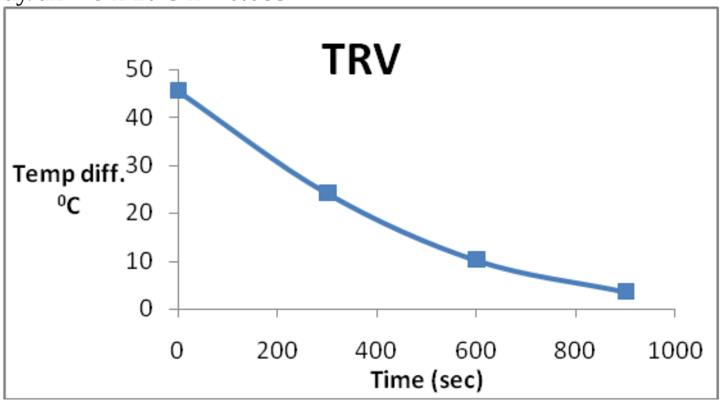


Figure01. Graph of temperature vs. Time

In order to calculate instantaneous HTC at 85 oC let us draw a tangent at time equal to 0.

the equation of curve is given by

y = s x + c

where s is slope of line and c is constant

at x=0

s= -0.083

now apply the energy conservation law

Amount of heat lost by rotor = amount of heat carried by air

m cp dT/dt = h A (T_D –T_{atm})

8.31 x 566 x 0.083 = h 0.09972 (85- 27)

h = 67.497 W/ m^2 ^{0}k

III. CFD ANALYSIS

Validation and grid independence study

The numerical approach adopted in this work was applied to TRV rotor. The predicted results were compared with

Type of rotor	HTC for 350k Temperature		HTC for 375k Temperature		HTC for 400k Temperature	
	Speed		Speed		Speed	
	500 rpm	700 rpm	500 rpm	700 rpm	500 rpm	700rpm
TRV	65.20	94.46	77.78	103.01	78.709	104.8
ALSV	50.99	82.019	57.68	91.108	59.10	94.41
SRV	42.72	52.54	47.450	56.89	49.036	60.71

experimental results for validation of CFD code used in this work. The grid independence study was carried out for these results with grid sizes of 300000, 350000,375000, 400000,425000 and 450000 elements for TRV rotor. The elements were varied for TRV rotor which shows the unchanged results at approximately 4, 25,000 elements and at 450000 elements as shown in graph. Meshing the geometry with 425000 elements shows a good agreement between predicted and experimental values. Hence it was decided to use 425000 elements for all the configurations.

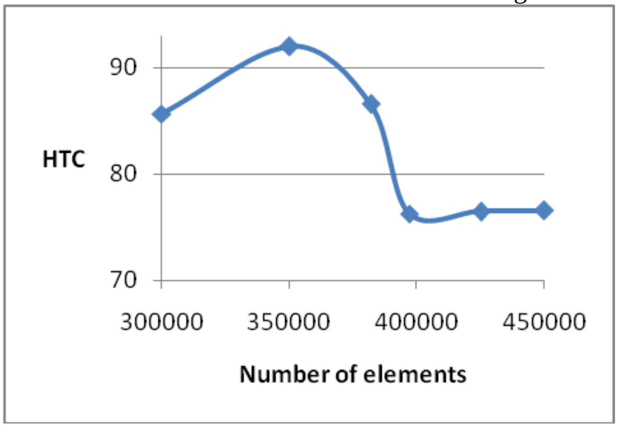


Figure02. HTC vs. No of elements for grid independence test

The value of HTC obtained from simulation is 75 W/m2 k

The % difference between Experimental and CFD value is

% error = 67.5-75/67.5

= 11.4%

The assumptions made in experimental work may clarify the error which has occurred in the results. Maximum 30% error is allowed in numerical and experimental results. (Brake design and safety Limpert page 88)

Rotors are compared based on heat dissipation characteristics and temperature distribution within rotor i.e. uniformity of temperature inside the rotor. The below table gives the performance of TRV, SRV and ALSV rotor within defined scope i.e. temperature range of 350to 400 k and at speed 500 rpm and 700rpm.

Table 03. Rotor HTC at given speed and temperature.

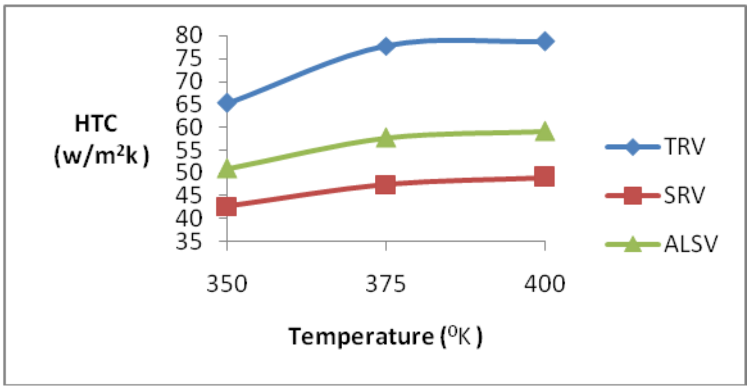
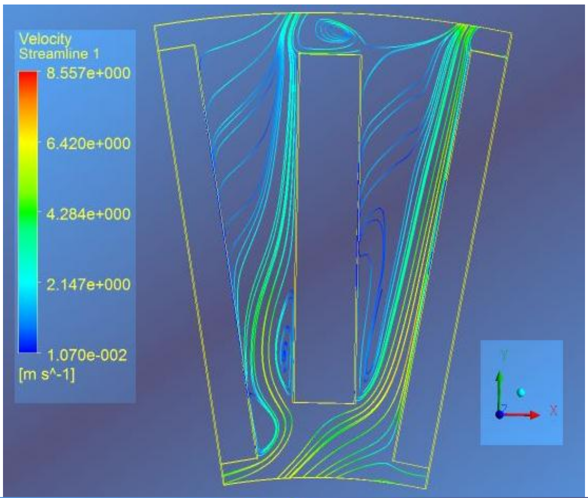
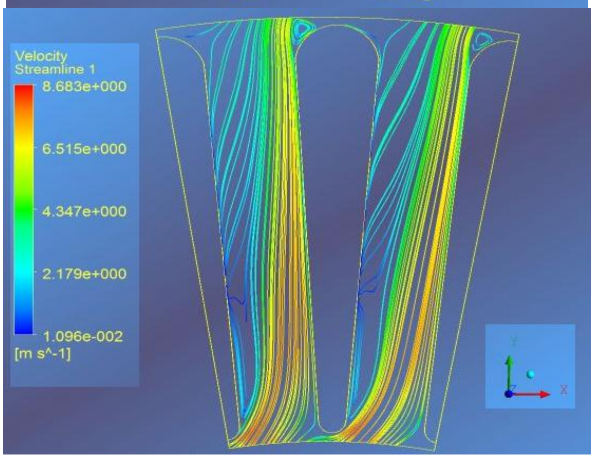


Figure 03 . Graph of HTC vs. temperature at 500 rpm

It is clear from the table that the TRV rotor gives better HTC than other two rotors at all speed and temperature range. the heat dissipated is also highest for TRV rotor than other two. The below figure gives the comparison of rotors based on streamlines





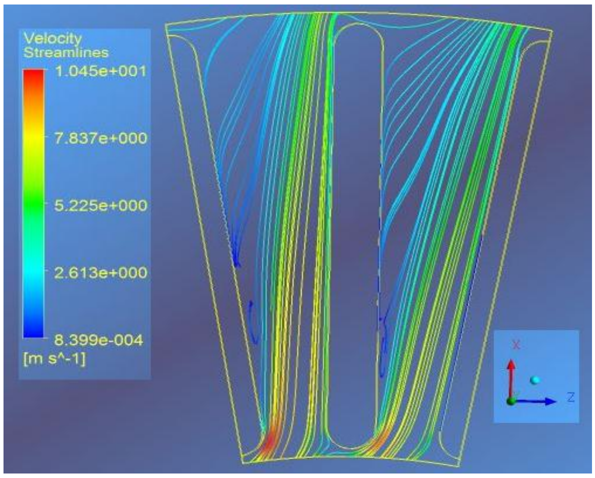
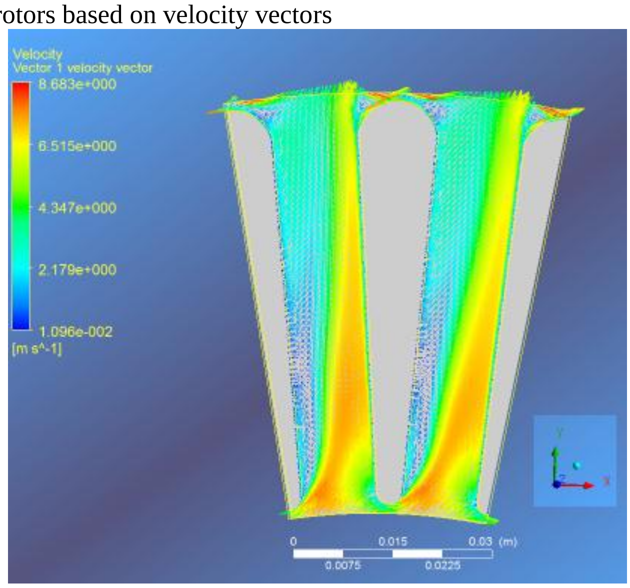


Figure 04. Streamlines of ALSV, TRV and SRV

The streamlines gives the development of flow within the rotor passages. It is observed from streamline pattern that formed separation zone are symmetric in nature for SRV and TRV rotor. Because of more entry to flow at inlet in case of ALSV rotor it is observed that air makes contact on both sides of vanes which help in maintaining more uniform temperature within fluid passage. The uniform flow passage of TRV rotor gives better attachment of flow with the boundary resulting in improved heat dissipation from the rotor. SRV rotor gives reduced heat dissipation characteristics because of separation of the flow from the boundary and formation of recirculation zone. The increase in mass flow rates increases with increase in speed of rotor. At 500 rpm, the mass flow rate through SRV rotor is about 78 % more compared to TRV rotor , 75% and 83% more compared to ALSV rotor. It is seen from the rotor configurations that the lowest air movement is found in the ALSV rotor. The below figure gives the comparison of rotors based on velocity vectors



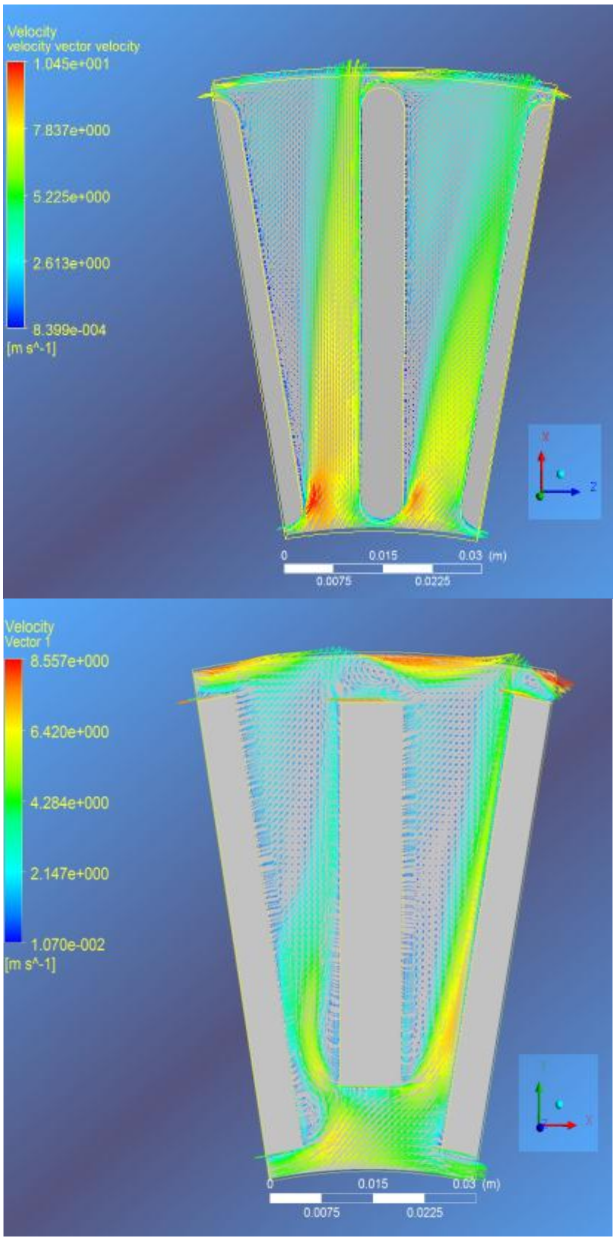


Figure 05 .velocity vectors of ALSV, TRV and SRV

The CFD results have conformity with experimental results. The maximum mass flow is observed for TRV followed by SRV and least for ALSV rotor. The mass flow through the rotor has superior effect on heat dissipation but the mass flow alone cannot decide the choice of rotor. Below figures shows the temperature distribution within flow passages of rotor.

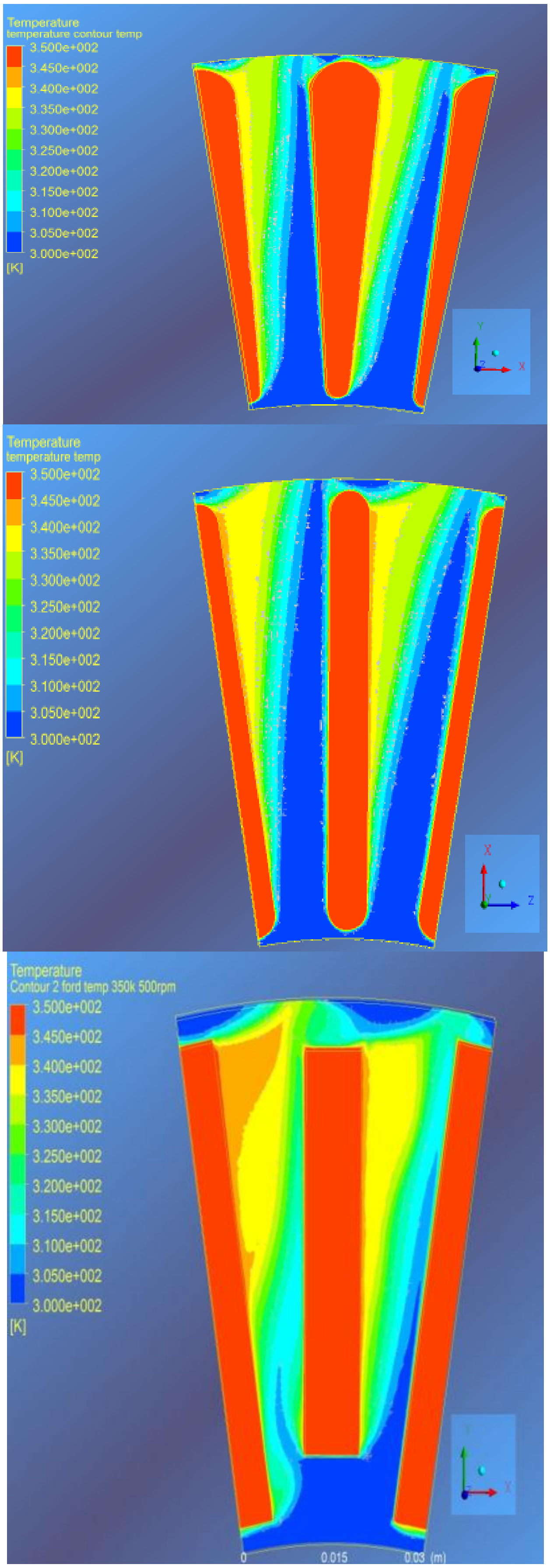


Figure 06. Temperature contours of ALSV, TRV and SRV

The ALSV rotor has more uniform temperature distribution within flow passage as compared to other two rotors. Most of air in the passage of SRV and TRV remains unaffected ie at inlet temperature so it may result in formation of temperature gradient in the rotor. HTC is good for TRV rotor as compared to ALSV but the better temperature distribution within flow passage is advantage for ALSV rotor.

IV. CONCLUSION

In this analysis, the thermal behaviors of different ventilated disc brake rotor configurations have been studied experimentally as well as using CFD software and the following conclusions are drawn.

1. Disc brake rotor with taper radial vanes (TRV) results in better rate of heat dissipation than the Alternate Long and Short (ALSV) rotor by about 21.8% at 500rpm and 13% at 700 rpm with steady temperature of 350k.
2. Rotor with tapered radial vanes (TRV) gives better heat transfer of about 39.7% more than SRV at 350k temperature and 500 rpm speed.
3. At higher temperature of 400k the HTC for TRV shows 24.9% and 9.9% higher value at 500 rpm and 700 rpm respectively.
4. TRV rotor gives improved heat dissipation at all speed and at all given temperature conditions compared to all rotor configurations.
5. Alternate Long and Short vane rotor (ALSV) has not as much of heat dissipation as of TRV rotor but the ALSV has advantage of better temperature distribution inside the flow passage.
6. It may be concluded that the design of the disc brake rotor should not be selected by considering only the rate of heat transfer achieved but it should also consider the uniform heat dissipation from the rotor.

Hence, for modern vehicles, Alternate Long and Short vane rotor may be more appropriate.

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