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Comparison of Cooling Performance Between Straight Vane with Cross Drill Disc Brake and Curve Vane Disc Brake

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ABSTRACT: *The disc brake is used in most automobile industries. The disc brake function is to reduce the force motion object to stationary. The frictional heat will produce from the brake pad and disc during the braking process. It will transfer to the disc brake which will cause the temperature of the disc brake to increase and causing brake pads to fade faster. Thus, in this research, two different modified disc brakes have been designed to increase the cooling performance of the disc brake. The same boundary condition has been assigned to the disc brakes and comparison of their cooling performance is compared. Simulation at two different speeds which are 1500 RPM and 2000 RPM have been set to compare the cooling rate at a different speed. The results from the simulation are compared with theoretical data to validate the results and the percentage error of the simulation. The graph is plotted from the simulation data to compare the cooling performance of the disc brake.*

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I. INTRODUCTION

High temperature in braking system of a vehicle will cause the brake pad and caliper to wear. It will decrease the life span of disc brake and increase the rate of corrosion. Braking system is the most important control system in vehicle. All modern cars have disc brakes on the front wheel and some of the cars have disc brakes on all four wheels.

The disc brake consists of disc rotor which will rotate together with the wheel and has a stationary brake caliper assembled with brake pad. When the vehicle moves, the disc rotor will move and when braking is applied, the brake pads are forced to push against both sides of the disc brake. The friction force occurs and coverts kinetic energy to heat and this causes the rotation of the rotor and the wheel to become slower and finally stop if continuous braking is applied. There are a few types of disc rotor used in car. This research will focus on straight vane and curve vane types, including the modified design of these two types of disc brakes.

Simulation by using Computational Fluid Dynamics (CFD) software is done to get the cooling performance of the two types of disc brakes. Basically, disc brake comprises of these two elements: rotating axisymmetric disc and immovable non-axisymmetric pad.

The disc brake is a device for slowing or stopping the rotation of wheels. Brake pads work as a friction material which forced mechanically against both side of the disc and will cause the vehicles to slow and stop. When brake pedal is pressed, the caliper presses on the disc thus causes it to heat up while slowing the vehicle down. This action causes heat to occur due to friction. If the brakes are used continuously over a certain period of time, the brake pads become worn faster. It is crucial to ensure that the cooling rate of disc brake is at its maximum to prevent brake malfunction.

This malfunction of the brake system is called brake fade. In every brake pad there is the friction material which is held together with some sort of resin. Once brake pad starts to get too hot, the resin holding the pad material together starts to vaporize or forming gas. That gas cannot stay between the pad and the disc, so it forms a thin layer between the brake pad and rotor trying to escape. The pads lose contact with the disc, thus reducing the amount of friction. Other than brake fade, disc rotor also undergoes cracking, coning, thermal judder, brake shudder, because of poor design, inappropriate materials and uneven stress and thermal distribution during braking [3]. In the braking phase, temperatures and thermal gradients are very high. This generates stresses and deformations whose consequences are manifested by the appearance and the accentuation of cracks [4].

The objective of this research is to compare the cooling performance between current design of straight vane and curve vane disc brakes and modified design of straight vane and curve vane disc brakes using CFD software. The research mainly focuses on the simulation of cooling performance of current design and the modified design of the two types of disc brakes at two different speeds. The material of the disc brakes used in this research is grey cast iron.

This paper has four sections which are the introduction, methodology, results and discussion, and conclusion. The introduction describes disc brakes, braking system and problem statement that leads to the objectives of the project. The methodology section explains the process flow of the research. The results and discussion section analyses the results obtained from the simulation. The conclusion section clarifies the objectives of the research based on the analysis.

II. METHODOLOGY

This section explains the process flow of the research. The same process will be repeated to analyze four types of discs; The four types of discs consist of current design of straight vane disc brake, current design of curve vane disc brake, modified straight vane disc brake and modified design of curve vane disc brake at two different speeds which are 1500 RPM and 2000 RPM [9, 11]. The simulation results will show the temperature drop on the discs and finally the cooling performance will be analyzed and compared.

A. Design Modeling

Figure 1 shows the process flowchart. The process started with exporting CAD files to ANSYS R15 for further simulation process. The meshing detail and boundary condition were set up before the simulation began. The temperature difference is compared with theoretical analysis and form a percentage error table to check the accuracy.

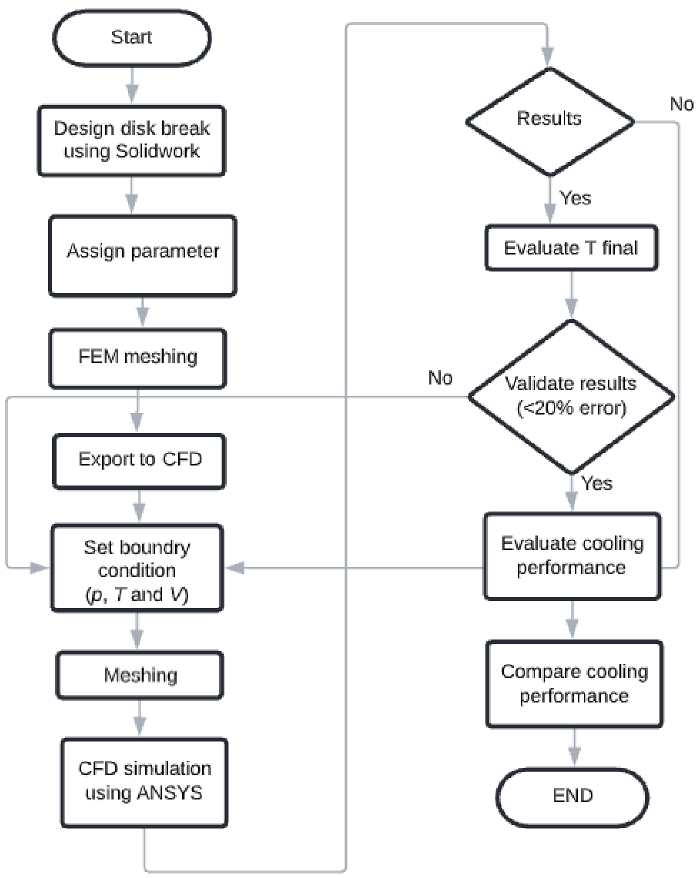

Fig. 1 Flow chart of the research project

Figure 2 until Figure 5 represent the dimension of current and modified curve vane disc brake and straight vane disc brake designs using SolidWorks software. The modified straight vane disc brake has cross-drilled holes on the disc meanwhile the modified curve vane disc brake has slanted curve vanes with angle of 19.36 degrees [6, 10]. These modifications give more surface area to the discs thus will increase the rate of heat transfer during the cooling process.

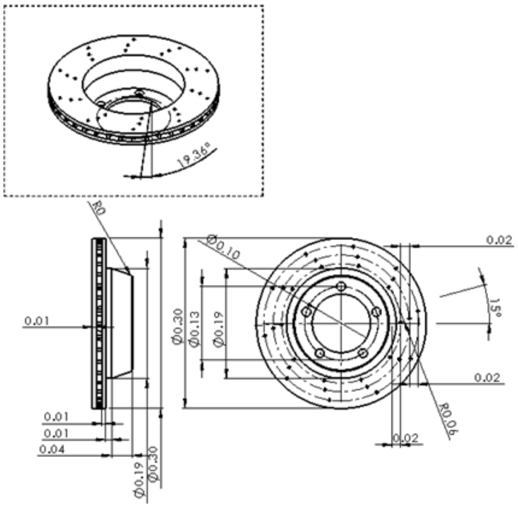

Fig. 2 Current design of straight vane disc brake

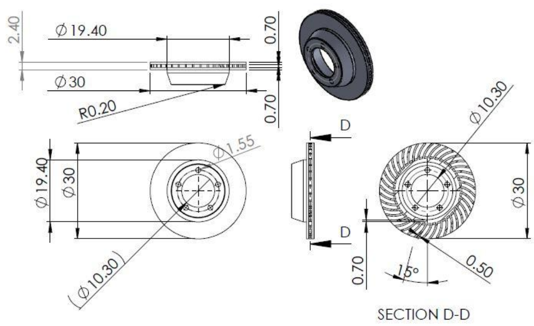

Fig. 3 Current design of curve vane disc brake

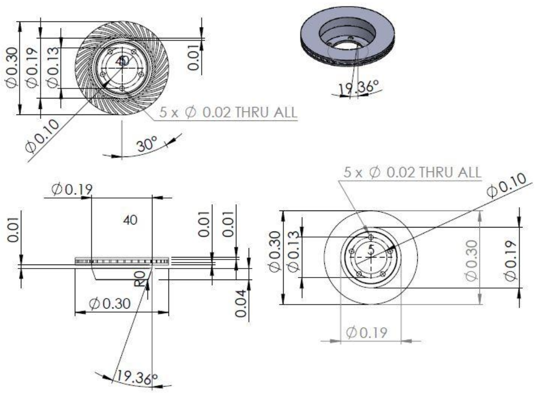

Fig. 4 Modified straight vane disc brake

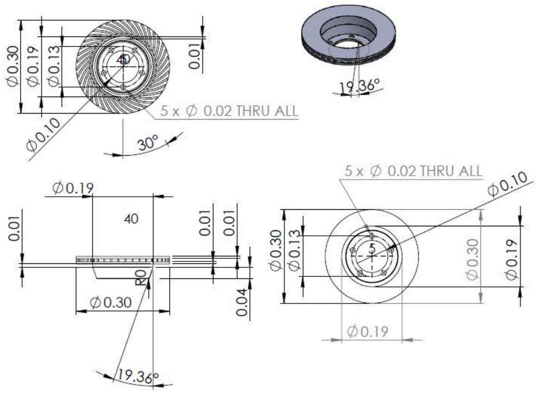

Fig. 5 Modified curve vane disc brake

B. Material Selection

The material should have certain criteria and requirements based on the product model. In this research, grey cast iron material is chosen for all disc brakes. The grey cast iron is a common material for automobile brake discs. Table 1 shows the properties of grey cast iron.

Table 1 Grey cast iron properties [5]

Material Properties	Disc
Thermal conductivity, (W/m°C)	57
Density, (kg/m^3)	7250
Specific heat, (J/kg°C)	460
Poisson's ratio	0.28
Thermal expansion, (10^{-6}/K)	10.8
	5
Elastic modulus, (GPa)	138
Heat Transfer Coefficient, (W/m^2K)	16

C. Heat Transfer Coefficient

Heat transfer occurs in the disc when braking is applied. It happens when the brake pads grip on the disc, causing heat due to the friction of the metal. Heat dissipates from the brake discs by three modes of heat transfer which are conduction, convection and radiation [1]. The flow aspect of the simulation involved the determination of the velocity field through the internal passages formed by the radial fins [8].

Convection is one of the heat transfer modes where the physical behaviour of heat transfer is by a medium that consists of moving fluid that transport heat energy from one place to another [2]. Equation 1 shows the convection equation.

$$\dot{Q}\text{ conv } = hA(T_i - T_f) \quad (1)$$

$$h_c = \frac{\dot{Q}conv}{A_c(T_{initial} - T_{final})}$$

$$\dot{Q}\text{ conv} = \dot{m}\, c_p\, (T_{initial} - T_{final})$$

Where:

q = heat transferred per unit time,	h = heat transfer coefficient
T_f = final temperature,	T_i = initial temperature
A_c = surface area,	$\dot{m}$ = mass flow rate

The basis of the lumped capacitance method is that the temperature of the solid is spatially uniform at any given instant during a transient process. The key point of this assumption implies that temperature gradients within the solid are negligible. The second major assumption of the lumped capacitance method is that resistance to conduction within the solid is small compared to the resistance to heat transfer between the solid and its surroundings [7]. Equation 2 shows the lumped capacitance method equation. This formula is essentially used to find the final temperature of the brake disc.

$$T_{final} = (T_i - T_\infty) \exp [-(\frac{h_c A_c}{\rho V c})t] + T_\infty \quad (2)$$

Where*:*

- h_c = Convection or radiation coefficient,
- L_c = Characteristic of the length of the solid,
- t = Time,
- A_c = surface area,
- v_c = volume of the solid
- k = Thermal conductivity of the solid
- T_∞ = Ambient temperature
- ρ = Density
- $\dot{m}$ = mass flow rate

D. Biot Number

Biot Number is a dimensionless group named after J. B. Biot who, in 1804, analyzed the interaction between conduction in a solid and convection at its surface. The numerical value of the Biot Number (Bi) is a criterion which gives a direct indication of the relative importance of conduction and convection in determining the temperature history of a body being heated or cooled by convection at its surface. Bi should always be enumerated at the outset to identify transient conduction problems which may be treated simply as lumped parameter problems, for which Bi < 0.1 and for which it is seldom necessary to solve the conduction equation, i.e., convection is the rate controlling process. Equation 3 shows the Biot number equation.

$$Bi \equiv \frac{h\, L_c}{k} \quad (3)$$

Altogether, there are eight simulations done. The results obtained from the simulations were then verified with analytical calculations. A small error between the simulation results with analytical values give higher accuracy of the simulation. The error can be calculated by using Equation 4 below.

$$\%\, Error = \frac{Tanalytical - T\ simulation}{T\ analytical}\ x\ 100\% \quad (4)$$

Only results with an error less than 20 percent are acceptable. Any error that is more than 20 percent is considered as too big thus the simulation needs to be redone by making changes in the boundary conditions. The analysis is then continued with analysis of cooling performance of the brake discs and comparison is made to determine the best cooling performance.

III. RESULTS AND DISCUSSION

The CFD simulation of current design and modified design of straight vane disc brake and curve vane disc brake has been generated. Each disc brake run at 1500 RPM and 2000 RPM. The initial temperature of the disc is set to be evenly distributed at 300^{o}C. The results from the simulation can be seen in Figure 6 until 13 below.

A. Current Design of Straight Vane

The temperature drop varies according to the location of surface on the disc from the surrounding through convection heat transfer. The duration taken for the simulation is 120 seconds at 1500 RPM and 2000 RPM. The iteration applied for the simulation is 1 iteration per time steps. The current design of straight vane disc brake is set to an initial temperature at 300°C. The temperature drop of current design of straight vane disc is recorded. Figure 6 below shows the temperature drop at 1500 RPM and the value of the temperature is 261°C.

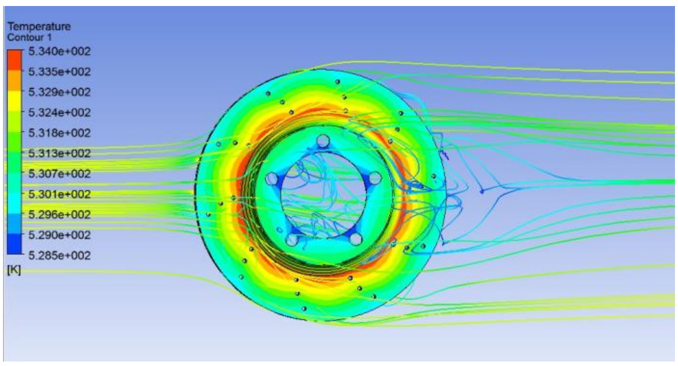

Fig. 6 The temperature distribution for current design of straight vane design disc brake at 1500 RPM

Figure 7 shows the temperature reduction after 120 seconds of simulation at 2000 RPM. The value of the temperature is 218°C. It can be seen that the higher the speed, the higher the temperature drop.

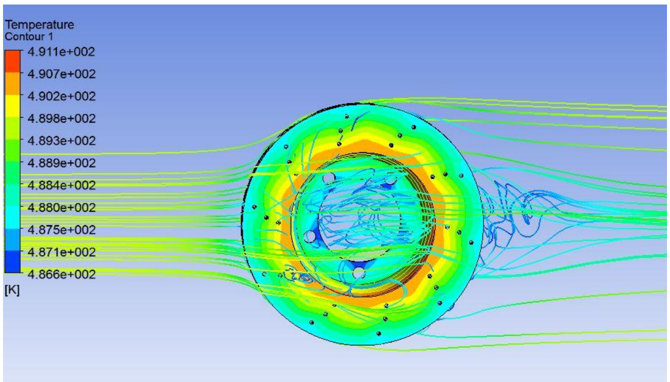

Fig. 7 The temperature distribution for current design of straight vane design disc brake at 2000 RPM

B. Modified Straight Vane

The temperature of drop varies accordingly to the location of surface on the disc from the surrounding through convection heat transfer. The duration taken for the simulation is 120 seconds at 1500 RPM and 2000 RPM. The iteration applied for the simulation is 1 iteration per time steps. The modified straight vane disc brake is set to an initial temperature at 300°C. The temperature drop of modified straight vane disc is recorded. Figure 8 below shows the temperature drop at 1500 RPM and the value of temperature is 239°C.

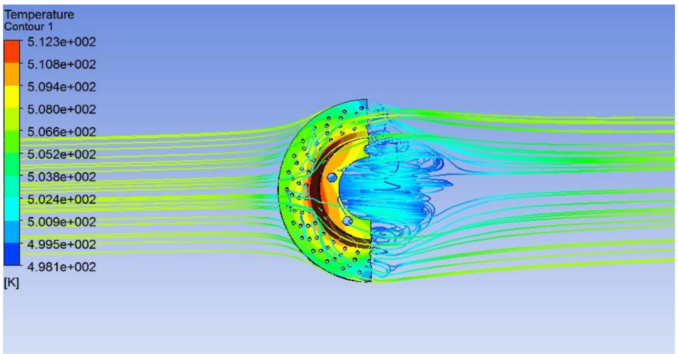

Fig. 8 The temperature distribution for modified straight vane design disc brake at 1500 RPM

Figure 9 shows the temperature reduction for modified straight vane design at 2000 RPM. The lowest temperature recorded after 120 seconds is 192°C. It can be seen that the higher the speed, the higher the temperature drop.

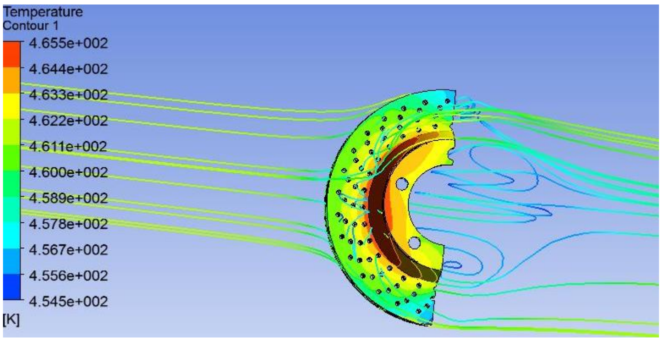

Fig. 9 The temperature distribution for modified straight vane design disc brake at 2000 RPM

C. Current Design of Curve Vane

The temperature distribution varies according to the location of surface on the disc from the surrounding through convection heat transfer. The duration taken for the simulation is 120 seconds at 1500 RPM and 2000 RPM. The iteration applied for the simulation is 1 iteration per time steps. The current design of curve vane disc brake is set to an initial temperature at 300°C. The temperature drop of the curve vane disc brake is recorded. Figure 10 shows the temperature reduction after 120 seconds simulation at 1500 RPM and the value of the temperature is 263°C.

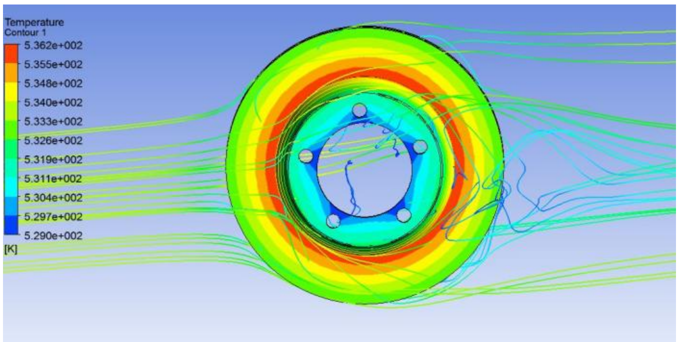

Fig. 10 The temperature distribution for current design of curve vane design disc brake at 1500 RPM

Figure 11 shows the temperature reduction after 120 seconds simulation at 2000 RPM and the temperature is 246°C. It can be seen that the higher the speed, the higher the temperature drop.

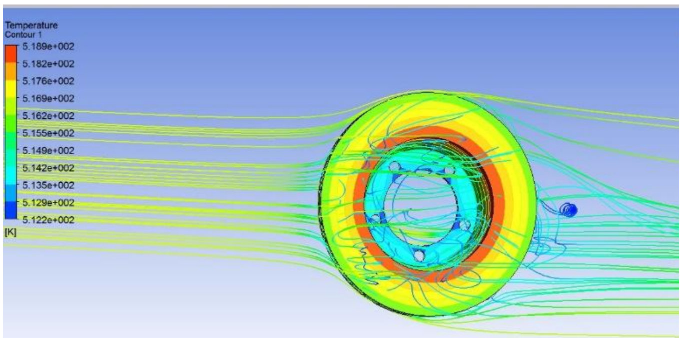

Fig. 11 The temperature distribution for current design of curve vane design disc brake at 2000 RPM

D. Modified Curve Vane

Figure 12 below shows the temperature reduction after 120 seconds simulation at 1500 RPM and the temperature is 217°C.

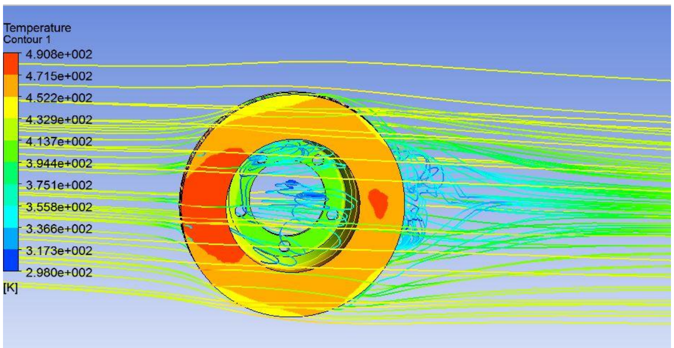

Fig. 12 The temperature distribution for modified curve vane design disc brake at 1500 RPM

Figure 13 shows the temperature drop for modified curve vane design at 2000 RPM. The temperature reduction after 120 seconds is 198°C. It can be seen that the higher the speed, the higher the temperature drop.

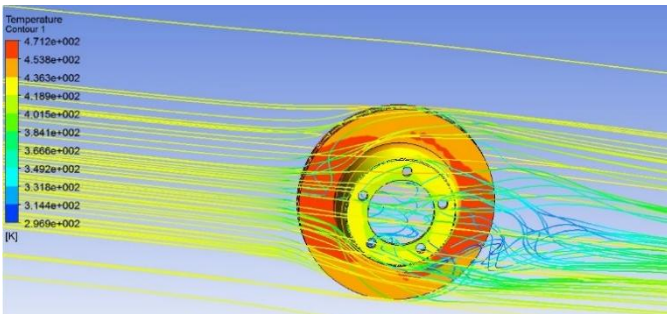

Fig. 13 The temperature distribution for modified curve vane design disc brake at 2000 RPM

E. Percentage Error

Percentage error is tabulated to determine the accuracy of the simulation results. A percentage error is done by comparing the final temperature from simulation data and theoretical data. The lesser the percentage error, the higher the accuracy of the result. Table 2 below shows the percentage error between the simulation and theoretical analysis.

Table 2 Percentage error between all the disc brake

Disc types	Speed of the disc (rpm)	Simulation T_{final} °C	Theoretical T_{final} °C	Percentage Error (%)
Current straight vane	1500	261	253	3.2
	2000	218	249	12.4
Modified straight vane	1500	239	241	0.8
	2000	220	238	7.6
Current curve vane	1500	263	258	1.9
	2000	246	254	3.1
Modified curve vane	1500	217	238	8.8
	2000	198	220	10.0

The graphs have been plotted to analyze the overall cooling performance of the disc brake. The graphs in Figures 14 and 15 showed the modified curve vane has more cooling performance compared to the modified straight vane disc brake at 1500 R.P.M, meanwhile, at 2000 R.P.M there is no significant change.

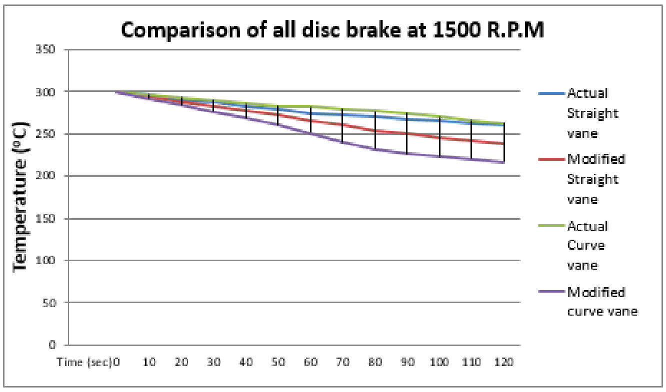

Fig. 14 Comparison of temperature drop in all disc brakes at 1500 RPM

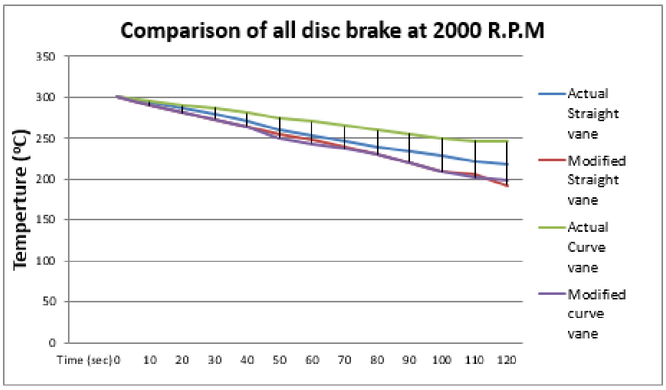

Fig. 15 Comparison of temperature drop in all disc brakes at 2000 RPM

IV. CONCLUSION

From the simulation, a few conclusions can be made based on the analysis that has been done. The modified straight vane disc has been designed with 90 drilled holes while the actual straight vane disc brake has only 30 drilled holes. The cooling performance of the modified straight vane disc brake has increased vigorously with the amount of area added to the surface from the drilled holes. In conclusion, the modified straight vane design disc brake can dissipate heat faster than the disc brake without holes due to the added surface area from the drilled holes. The bigger the surface area, the more the cooling performance of the disc brake. Meanwhile, the angle of the disc brake is also an important aspect when comes to cooling. The result from the simulation shows that the current design of the curve vane disc brake has 15 degrees of angle for its curved vanes meanwhile the modified disc brake has 30 degrees of angle for its curved vanes. The modified curve vane disc cooled faster when adjustment of the angle made to the design.

V. RECOMMENDATION

Based on this project, some recommendations can be made to further performing research on the cooling performance of disc brake. The recommendations are as follows:

1. The disc brake should be fabricated and the disc brake cooling performance should be done experimentally
2. The structural analysis on the disc brake should be one to determine the strength of the modified disc brake.

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