Experimental Analysis of Ventilated Brake Disc with Different Blade Configuration

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Abstract: Most modern cars on the road using brake disc as the braking system to slow down and stop the car. Because of the better breaking performance, simpler design and easy to service, car manufacturer prefer disc brake rather than drum brake. During braking, the kinetic energy of a car is dissipated through frictional energy and greatly as heat energy. The excessive heat needs to be cooled faster otherwise the braking performance of the car will decrease. The heat removal has a close correlation with mass flow through the ventilated brake disc. From literature, there is no stationary test rig ever developed to study the mass flow through the ventilated brake disc. There is a lot on wheel testing, yet with other influence like rims, suspension system, coil spring and others. Thus an experimental rig to study the mass flow and differential pressure was developed in Department of Mechanical Engineering, University Tenaga Nasional. The experimental rig is design to cater for any configuration of ventilated brake disc blade design. This paper will present the effect of mass flow and differential pressure for a few blade design configurations.
Keywords: Brake Disc; Blade Design; Test Rig.

1. Introduction

Brakes are the most important mechanism on any vehicle because the safety and lives of those riding in the vehicle depend on proper operation of the brake system. In the early stage, drum brakes were used to slow down a vehicle. Disc brakes were then introduced as an option in the braking system as the technology of the automotive developed.

Most modern cars have disc brake on the front wheel, and some have disc brakes on all four wheels. A disc brake operates by squeezing brake pads on both sides of the rotor or disc that is attached to the wheel. Friction between the pads and the discs slows the disc down. A moving car has a certain amount of kinetic energy, and the brakes have to remove this energy from the car in order to stop it.

The kinetic energy of a car is dissipated through frictional energy and greatly as heat energy during the braking. Because of the short duration of the braking process, the heat generated will increase the temperature of the disc brakes very quickly.

Invention of ventilated disc brake is a state of the art in braking technology since the design has a significant effect on cooling of extreme heat on the disc brakes. Early analytical work by Limpert [1] stated that the convective heat transfer coefficient of a vented disc brake is approximately twice that of solid disc.

Simulation and analysis of the cooling of the brake disc done by Polansky and Kovarik [2] reveal that a shorter cooling time could be reached by increasing the mass flow rate or increasing the heat exchange surface. The pattern of the blades will affect the cooling time strongly.

Study on current trend of ventilated brake disc for commercial cars in Malaysia by Mahmod and Munisamy [3] shows several existing brake disc pattern in term of brake disc size and blade design.

An experimental rig was developed to study the effect of different blade configuration. The rig was developed with the aim to measure the mass flow rate and pressure different at different rotational speed. This paper will describe the experimental rig and the analysis on the effect of different blade configurations.

2. Test Rig Descriptions

1) Components

The test rig consists of motor, controller box, magnetic-pickup, ducting system and shaft with two bearings. 3-phase 415V motor was used to rotate the specimen (brake disc). Variable speed controller will control the rotational speed of the specimen. The speed will be read by the magnetic-pickup and adjusted to desired values using the variable speed controller. Two bearings were needed to connect the motor to the specimen by shaft. The ducting system is build around the specimen in such a way to separate between the inlet and outlet air flow with teflon sealing at inlet. Pressure tapings were located at the inlet and outlet ducting to measure the pressure.

2) Specimens

The specimens are manufactured according to the actual size of the brake disc used in commercial car in Malaysia (use by Proton Perdana). Aluminum is used as the material for the specimen instead of cast iron to avoid corrosion and to have lighter specimen. In order to study the effectiveness of the blade design, all specimens will have the same diameter and thickness. Only the blade design will be different for each specimen. Fig. 1 shows the general view of the ventilated brake disc used for the experiment.

Figure 1: Ventilated brake disc (specimen with straight and rounded blade).

The outer diameter of the solid disc is maintained at 255mm while the inner diameter is 147mm as shown in Fig. 2 below. For any blade design, the distance of the blades from inner and outer diameter will be maintained. The blades will be 7mm from the inner diameter and 5mm from the outer diameter. The height (10mm) and thickness (4mm) of the blade is also maintained for any blade design.

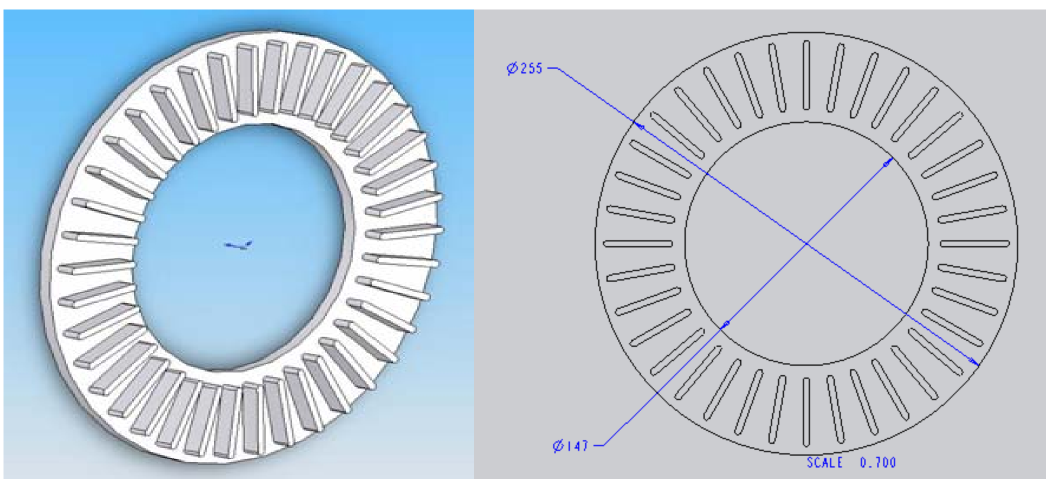


Figure 2: Drawing of the specimen (only the blade part).

3. Measurements

The test rig will give three types of reading at any time of experiment. The measurements are rotational speed, pressure at inlet and outlet and air outlet velocity.

1) Rotational Speed

The rotational speed of the specimen is measured using the magnetic-pickup in revolution per minute (rpm). An indicator was placed at the shaft and will be detected by magnetic-pickup every cycle the shaft rotates. The variable speed controller will be adjusted until the magnetic-pickup shows the desired valued before the pressure reading and air velocity reading are taken.

2) Mass Flow Rate

The mass flow rate of the air flow will not be measured directly from the test rig. The mass flow rate would be calculated using the air velocity reading, which is measured by air velocity meter. The reading is taken at the outlet ducting. Inlet mass flow rate is assumed to be the same as the outlet. The mass flow rate calculation is shown in the result analysis part.

3) Pressure Different

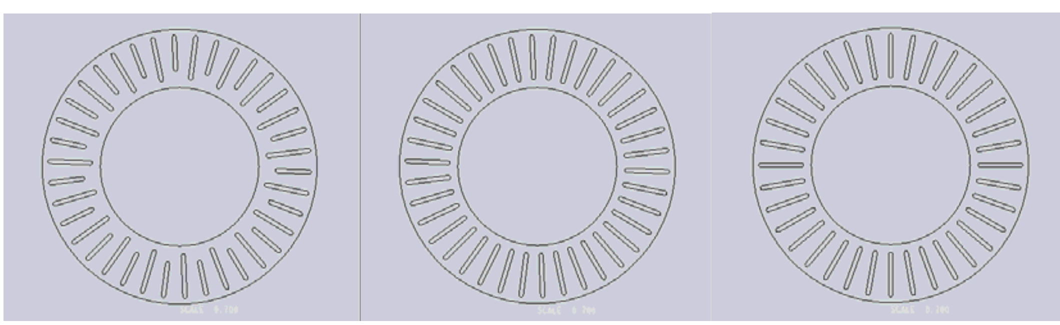
The pressure readings would be taken at two different part of the ducting. The reading will be measured using inclined manometer. Four pressure tapings were placed at the ducting just before the specimen to measure the inlet pressure. Another four pressure tapings were placed just after the specimen to measure the outlet pressure. Four pressure tapings were used for each part to give an average pressure value inside the cylindrical shape ducting.

4. Blade Design

As mention earlier, the size and thickness of the ventilated brake disc is maintained for every specimen. Only the blade design is different. The differences can be in term of number of blades, shape of the blade (rectangle or rounded) and inclination of the blade.

In this paper, three blade designs would be studied. The blade design of each specimen is shown in Fig. 3. The details for the designs are:

- Design A - 38 straight, rounded and offset blades.
- Design B - 38 straight and rounded blades.
- Design C - 36 straight and rounded blades.



Design A **Design B** **Design C**

Figure 3: Blade design of the three specimens

Experimental data for all three specimens would be compiled and calculated to find the mass flow rate and pressure different. Comparison would be made to see the effect of the different blade configuration.

5. Result Analysis

All readings will be recorded inside the standard result sheet. The result sheet will be used for all specimens. Data obtained from the result sheet will be used to calculate the pressure different and air mass flow rate at all speed. The formula used for the calculations are:

- Pressure Different, $\Delta P = \rho_w \, g \, \Delta h$ (1)

  Where Δh = Vertical separation of liquid level in manometer
  $= (x_1 - x_2) \cos \theta$ (2)

  θ = Inclination of manometer

- Mass Flow Rate $= \rho_a \, A \, V \times 10^3$ (3)

  Where ρ_a = Air density
  A = Outlet cross section area
  V = Air velocity

Table 1, 2 and 3 show the experimental data and calculations obtained for all three specimens. The result will then use to analyze the pattern of the pressure different and mass flow rate with respect to the speed.

Table 1: Data and calculation result from experiment (Design A).

Speed		Pressure Different ΔP		Air Velocity V	Mass Flow Rate
rpm	km/h	[* 0.1 kPa]	[Pa]	[m/s]	[g/s]
643	80	0.170	17.0	6.50	26.0182
804	100	0.260	26.0	8.20	32.8229
965	120	0.370	37.0	10.00	40.0280
1125	140	0.500	50.0	11.75	47.0329
1286	160	0.640	64.0	13.40	53.6375
1447	180	0.810	81.0	15.20	60.8425
1608	200	0.995	99.5	16.90	67.6473

Table 2: Data and calculation result from experiment (Design B).

Speed		Pressure Different ΔP		Air Velocity V	Mass Flow Rate
rpm	km/h	[* 0.1 kPa]	[Pa]	[m/s]	[g/s]
643	80	0.170	17.0	6.50	26.0182
804	100	0.260	26.0	8.15	32.6228
965	120	0.370	37.0	9.90	39.6277
1125	140	0.500	50.0	11.60	46.4325
1286	160	0.645	64.5	13.30	53.2372
1447	180	0.810	81.0	15.10	60.4422
1608	200	0.990	99.0	16.90	67.6473

Table 3: Data and calculation result from experiment (Design C).

Speed		Pressure Different ΔP		Air Velocity V	Mass Flow Rate
rpm	km/h	[* 0.1 kPa]	[Pa]	[m/s]	[g/s]
643	80	0.190	19.0	6.55	26.2183
804	100	0.280	28.0	8.25	33.0231
965	120	0.390	39.0	10.05	40.2281
1125	140	0.520	52.0	11.75	47.0329
1286	160	0.670	67.0	13.45	53.8376
1447	180	0.840	84.0	15.30	61.2428
1608	200	1.030	103.0	17.00	68.0476

The tables above were expressed in graphical form. Four graphs were drawn to show the graphical output of the result. Fig. 4 shows the pressure different distribution for all specimens with respect to speed (rad/s). The mass flow rate distribution (g/s) with respect to speed (rad/s) is plotted in Fig. 5. Fig. 6 and Fig. 7 illustrates the effect of pressure different and mass flow rate at certain speed for all different specimens.

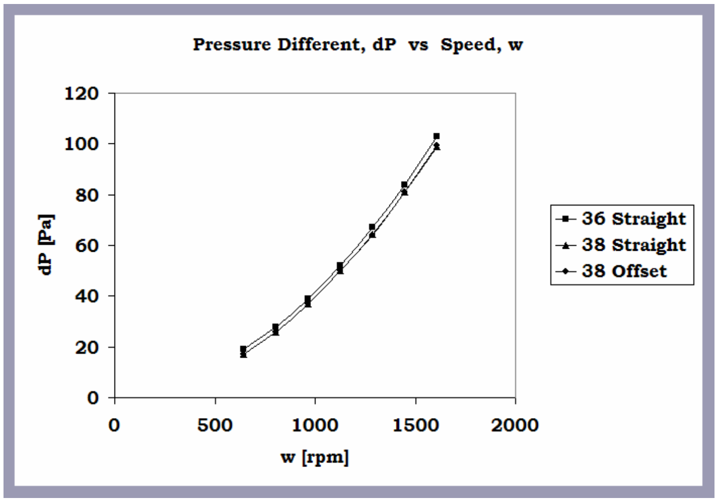


Figure 4: Graph of pressure different against speed.

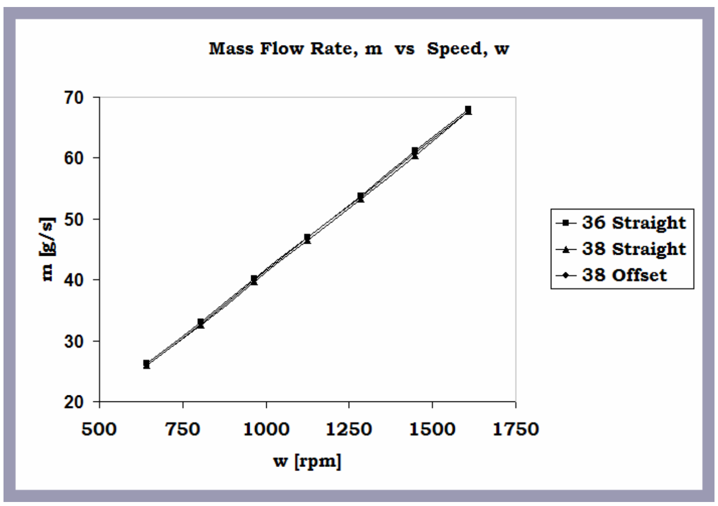


Figure 5: Graph of mass flow rate against speed.

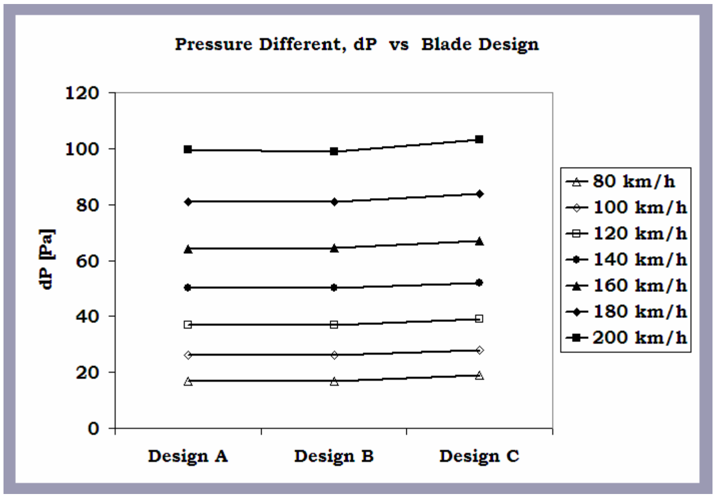


Figure 6: Graph of pressure different against blade design.

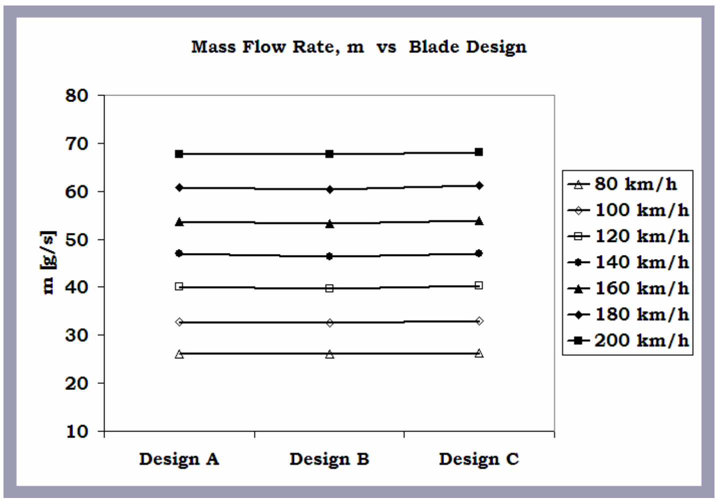


Figure 7: Graph of mass flow rate against blade design.

6. Discussion

Fig. 4 shows that the pressure different between the inlet and outlet of the ducting increases as the rotational speed rise. The rise in pressure different will affect the air flow through the blades (vanes). The higher the pressure different, higher volume of air will be forced through the blade. The effect can be seen in Fig. 5, where the mass flow rate increases with the speed in conjunction with the increase in pressure different between the inlet and outlet.

The results for all three specimens were found to be almost the same particularly for design A (38 blades) and B (38 blades offset). The result for design C (36 blades) is slightly better in terms of pressure different and mass flow rate compare to the other two designs. As shown in Fig. 6 and Fig. 7, design C give slightly higher values for pressure different and mass flow rate at all the speed.

Shorter cooling time could be reached by increasing the mass flow rate. By only considering this factor, design C can be said as a better design compare to the other two designs.

7. Conclusions

Experimental analysis on the pressure difference and mass flow rate at a few rotational speeds was successfully studied for 3 different ventilated brake disc designs. The result shows the pressure difference and mass flow rate are proportional to the rotational speed. As the speed increases, the pressure difference and mass flow rate would increase as well. The result also shown that the pressure different and the mass flow rate are proportional to each other. Higher mass flow rate will be obtained as the pressure different between the inlet and outlet of the flow passage increase. This will definitely enhance the cooling process of the brake disc.

The results for all 3 specimens were found to be almost similar. However, the value for the 36 blades disc (design C) is slightly higher. The experimental analysis need to be carried out with more specimens for blade design optimization.

Nomenclature

A	=	Outlet cross section area [m^2]
g	=	Gravitational acceleration [m/s^2]
ρ_a	=	Air density [kg/m^3]
ρ_w	=	Water density [kg/m^3]
V	=	Air velocity [m/s]
Δh	=	Vertical separation of liquid level in manometer [m]
ΔP	=	Pressure Different [Pa]
θ	=	Inclination of manometer [degree]

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