Braking Torque Analysis On Electromagnetic Braking Study Using Eddy Current For Brake Disc Of Al6061 And Al7075

Article *in* Applied Mechanics and Materials · January 2011

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Braking Torque Analysis On Electromagnetic Braking Study Using Eddy Current For Brake Disc Of Al6061 And Al7075

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Keywords: Electromagnetic, Eddy Current, Al6061, Al7075, Braking Torque.

Abstract. Two different series of Aluminium which are Al6061 and Al7075 has been studied as the brake disc material for this electromagnetic braking system using eddy current. Both series been studied experimentally by varying a few parameters such as current induced to the electromagnet, air-gap, brake disc thickness, number of turns and voltage supplied for the DC motor. PULSE analyzer been used to capture the speed (rpm) and time (s). This paper also addressed the calculation for the braking torque that been generated during the process by using previous study equation. From this research, it can be concluded that thicker disc performs better with electromagnetic braking and smaller air-gap produced high braking torque in order to stop the disc rotation. Besides that Al6061 have greater performance than Al7075 for electromagnetic braking purposes as the brake disc material.

Introduction

An environmental friendly braking system is an essential need today parallel to the advanced in automotive technology and towards green technology. When we do braking in conventional braking system using brake pad, we are actually polluting our environment. Brake pad is producing wear debris during braking which is obviously contained potential hazard to environment [1]. These hazardous elements may interact with DNA of living organisms and cause carcinogenesis [2]. It also been founded that copper from brake pad wear find its way into stormwater and tributaries feeding into San Francisco Bay, which killed invertebrates and algae and harming fish [3].

Electromagnetic braking using eddy current is a contactless braking that could lead to overcome this problem. As vehicle speed increases, a more powerful brake system is required to ensure vehicle safety and its reliability [4]. An eddy current is induced around the pole area when magnetic flux goes through a rotating conductive disc [4]. It produced a retarding braking force which come from the interaction occurred between the eddy current and magnetic flux.

Experiment setup

Fig. 1 shows the test rig for this research in 3D view which drawn using Solidworks while Fig. 2 is the real view of test rig for this research. A few modifications been made from the experiments conducted by Gonzalez about eddy current [5]. This experiment use an optical tachometer connected to PULSE analyzer to record the angular speed (rpm) and time instead of using the digital tachometer and stopwatch. Current induced to the electromagnet from 0-10A DC power supply and another power supply of 0-30V been used to rotate the DC motor.

Table 1 shows the design parameters for this experiment. Two series of aluminium been chosen as the material after the first stage of this research which compared three types of materials which are aluminium, copper and zink [6]. Al6061 is an aluminium alloy which has good mechanical properties and weldability. It has been used for aircraft structures construction, wheel spacers in automotive and yacht construction [7]. Al7075 is also an aluminium alloy which is strong and has good fatigue strength with average machinability, but has low resistance to corrosion compared to many other alloys. It is been used in transport applications such as in marine, aviation or automotive applications due to their high strength-to-density ratio [8].

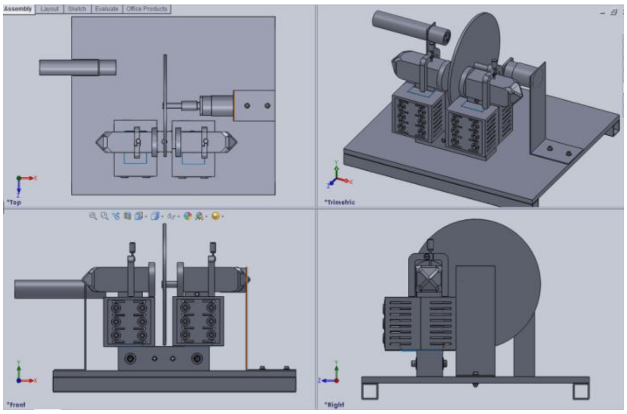

Fig. 1 : 3D view for the electromagnetic braking using eddy current study

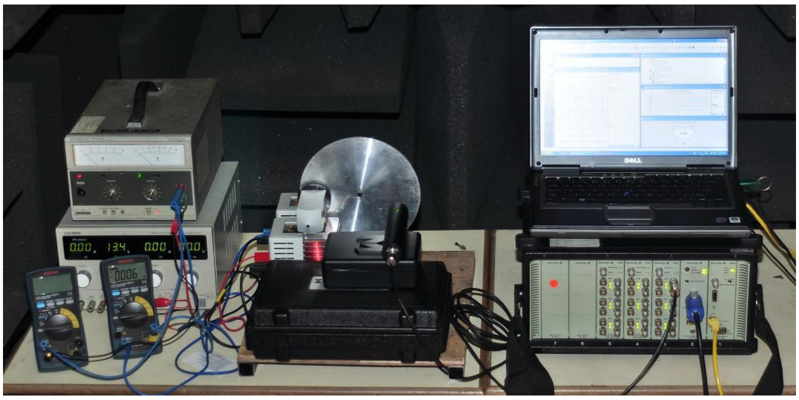

Fig. 2 : Full view for the experimental setup in semi-anechoic chamber for electromagnetic braking using eddy current

Table 1
Design parameters for the experiment setup

Aluminium disc radius, r	190 [mm]
Air gap, l_g	1, 3, 5 [mm]
Number of electromagnet turns, n	250
Disc thickness, d	4, 5 [mm]
Pole diameter	60 [mm]
Distance between center of disc and center of pole, R	70 [mm]
Pole area, S	$S = \pi(0.03)^2 = 2.828 \times 10^{-3}$ [m^2]

Braking Torque Analysis

For the braking torque analysis, we've followed the analysis that been done by Lee. The iron core shape use in this study was a round shape in diameter of 60 mm. For this analysis, n, i, l_g, *and* μ_o represent the number of electromagnet turns, applied current, air-gap and permeability of air, respectively. Here, the μ_o been taken as 12.568 x 10^{-7} N.A^{-2} . For the electrical conductivity, it was 2.73 x 10^{7} Ω.m^{-1} and 1.92 x 10^{7} Ω.m^{-1} for Al6061 and Al7075, respectively [9]. In Eq. 1, the magnetic flux density [4] can be expressed in the form of

$$B = \frac{\mu_o n i}{l_g} \tag{1}$$

While the current density, J that been induced at center of the pole [10] as Eq. 2 as

$$J = \sigma(R\,\dot{\theta} \times B) \tag{2}$$

where σ and $\dot{\theta}$ are the electrical conductivity and angular velocity of the brake disc. If all the power dissipated by the eddy current, P_d which is the power dissipation assumed to be converted to generate braking torque T_b [10], which can be expressed as Eq. 3

$$T_b = \left(\frac{P_d}{\dot{\theta}}\right) \tag{3}$$

The total power dissipation, P_d can be described [4] as Eq. 4

$$P_d = \rho J^2 \times \text{Volume} = \sigma R^2 S d \dot{\theta}^2 B^2 \tag{4}$$

Here, ρ indicates the disc resistivity. For the braking torque calculation as in Eq. 5, S, R *and* $\dot{\theta}$ represent the pole area, distance between centre of the disc and pole centre, and angular speed, respectively. The braking torque [4] can be expressed in the form of

$$T_b = \sigma R^2 S d \dot{\theta} \left(\frac{\mu_o n}{l_g}\right)^2 i^2 \tag{5}$$

Result and discussion

Fig. 3 show the speed (rpm) versus time (s) for disc in 4 mm and 5 mm thickness of Al6061 while Fig. 4 show the speed (rpm) versus time (s) for disc of 4mm and 5 mm thickness for Al7075. Both test use air-gap of 1 mm, voltage supplied of 11V for the DC motor with 250 turns of electromagnet. Torque produced on the disc is proportional with the disc thickness. From Fig. 3 and Fig. 4, we can see that disc with 5 mm of thickness has higher negative slope compared to 4 mm disc. It means that the thicker the disc is, the better the braking performance because tork produced on thicker disc will generate high torque which will approach near the motor torque in order to stop the disc rotation.

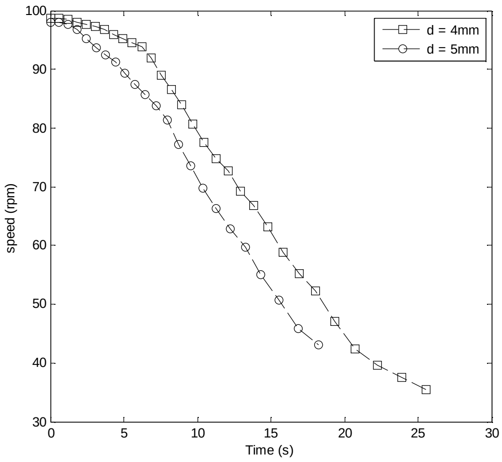

Fig. 3 : Speed (rpm) vs time for Al6061 with N(250), l_g(1mm) and V(11V)

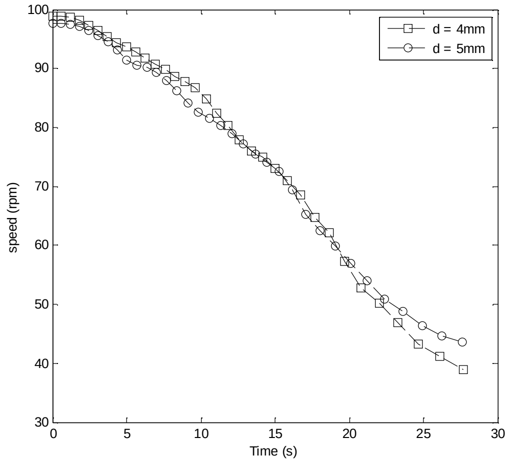

Fig. 4 : Speed (rpm) vs time for Al7075 with N(250), l_g (1mm) and V(11V)

Fig. 5 presents the braking torque versus current for Al6061 with air-gap of 1 mm, Fig. 6 for air-gap of 2mm and Fig. 7 with 3 mm of air-gap. Disc thickness fixed at 5 mm with 250 turns of electromagnet. Voltage supplied for DC motor varied at 11V, 13V and 15V. Braking torque value increased when we decreased the air-gap. It’s because the magnetic flux induced in large air-gap is lower than the small air-gap. Therefore, higher braking torque been produced in small air-gap. As we can see from the three graphs, 1A of induced current could produced about 2 N.m amount of torque for 1mm air-gap, compared to less than 0.5 N.m produced by air-gap of 2 mm and 3 mm, respectively. Hence, it can be concluded here that smaller air-gap will produced higher braking torque for the electromagnetic braking.

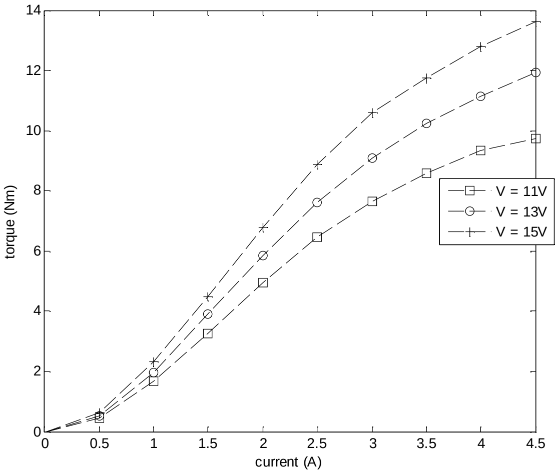

Fig. 5 : Braking torque vs current for Al6061 with *N*(250), l_g(1mm) and *d*(5mm)

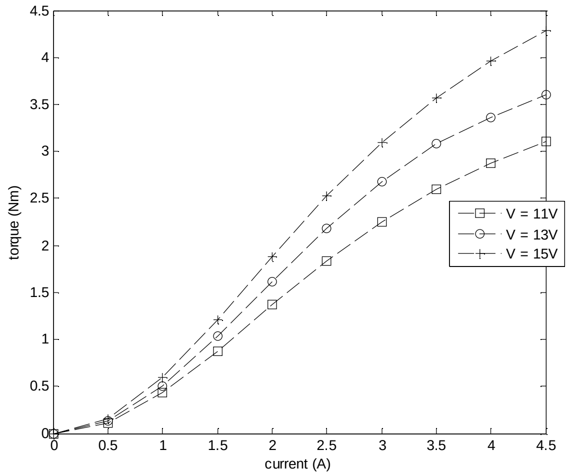

Fig. 6 : Braking torque vs current for Al6061 with *N*(250), l_g(2mm) and *d*(5mm)

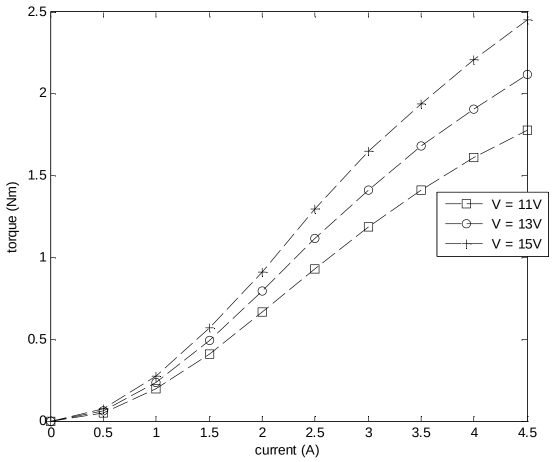

Fig. 7 : Braking torque vs current for Al6061 with *N*(250), l_g (3mm) and *d*(5mm)

Fig. 8 shows the braking torque versus current with air-gap of 1 mm, 4 mm disc thickness and 250 turns of electromagnet for Al6061 and Fig. 9 for Al7075 with the same parameters. Fig. 10 represent for Al6061 with the same air-gap and electromagnet turns as Fig. 8, but using 5 mm disc thickness while Fig. 11 represent for Al7075 also using 5 mm disc thickness. As shown in Fig. 8 and Fig. 10, Al6061 has produced around 10 N.m to 15 N.m, compared to Al7075 in Fig. 9 and Fig. 11 which just produced around 10 N.m to 12 N.m only. This condition shows that Al6061 has produced higher braking torque compared to Al7075. Al6061 give better performance for the electromagnetic braking using eddy current. Al6061 has higher electrical conductivity of 2.73 x 10^7 Ωm^{-1} compared to 1.92 x $10^7 \Omega m^{-1}$ for Al7075. This will influenced of greater generation of braking torque. Besides that, one of the main component of Al7075 is zinc, which has low electrical conductivity. Materials with higher electrical conductivity will generate high torque to agains the motor torque itself in order to stop the disc.

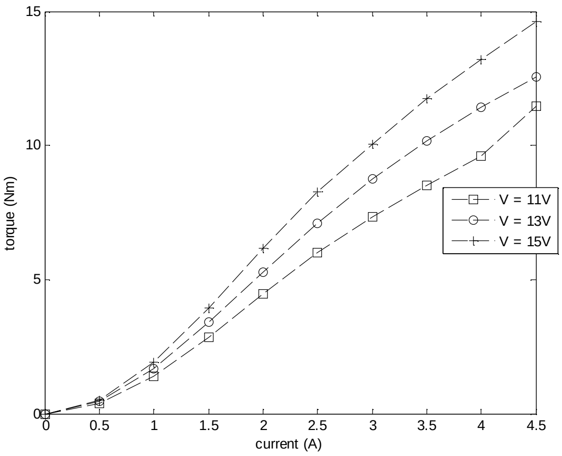

Fig. 8 : Braking torque vs current for Al6061 with N(250), l_g(1mm) and d(4mm)

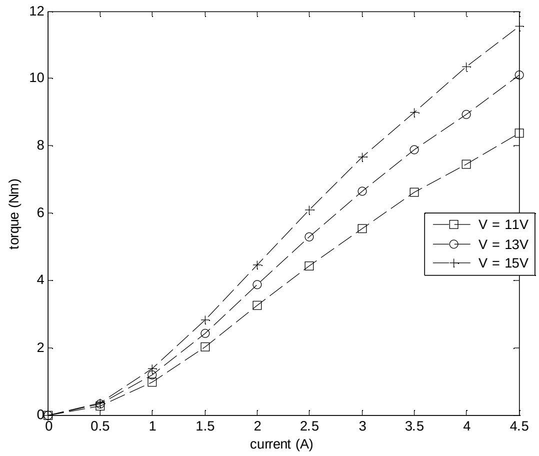

Fig. 9 : Braking torque vs current for Al7075 with N(250), l_g (1mm) and d(4mm)

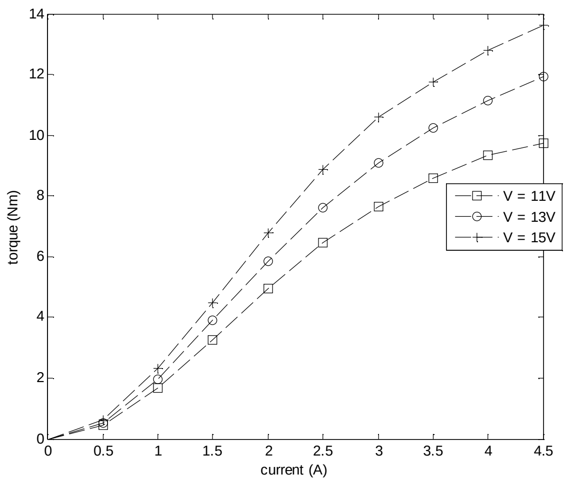

Fig. 10 : Braking torque vs current for Al6061 with N(250), l_g(1mm) and d(5mm)

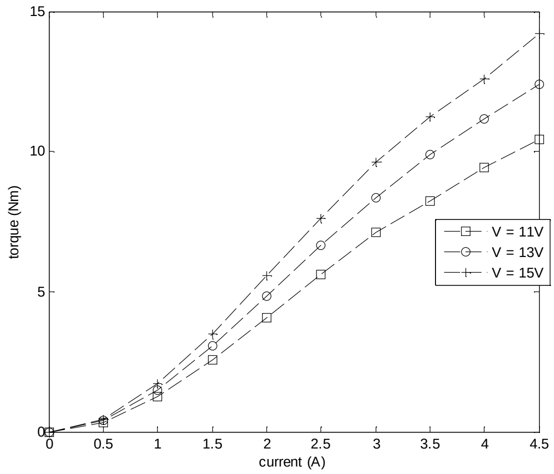

Fig. 11 : Braking torque vs current for Al7075 with N(250), l_g(1mm) and d(5mm)

Conclusion

From this study, it can be concluded that thicker disc will generate high torque which will approach the motor torque in order to stop the disc rotation which in this study disc of 5 mm is better than 4 mm of thickness. Smaller air-gap will produce high braking torque and give better performance to the electromagnetic braking which air-gap of 1 mm shows the best result compared to 3 mm and 5 mm gap. Al6061 which has higher electrical conductivity than Al7075 shows great performance of braking torque produced in this study. Therefore, findings of mentioned parameters from this study are parallel with the theory and will be the guidance to extend this project for any potential application.

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