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Original Article

Effect of Materials and their Geometry on Performance of Electromagnetic Braking System

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Abstract - *A Conventional or mechanical braking system involves applying pedal force on the brake shoe, which comes in contact with the brake drum and stops the vehicle due to enough friction force by opposing the wheel's rotational motion. This results in a lot of heat generation and frequent worn out of brake shoes. Also, it is prone to accidents unless timely replacement and maintenance are carried out properly. On the other hand, the non-contact nature of magnetic and electromagnetic brakes leads to effective performance of braking action. Of course, it requires detailed analysis and implementation of various parameters like magnetic field generation, number of magnets, air gap, material selection, and understanding properties like conductivity, electromagnetic intensity, and various geometrical parameters. It has been observed from the literature that a number of attempts have been made by researchers on the analysis of magnetic brakes by considering these parameters, except that they have focused on the effect of material selection and geometry on the braking system's effectiveness. Theoretical analysis involves the principle of Lenz's law. A more concrete understanding is feasible through experiments for validating the theoretical results. In order to validate the results, a prototype model to carry out experiments has been developed. In this work, an attempt has been made to investigate the effect of materials selection and geometrical parameters of disc-like width, Radius of magnetic core, and Radius of disc, etc, on effective braking system performance and its validation.*

Keywords - *Electromagnetic braking system, Magnetic field intensity, Conductive materials, Lenz's law, Torque.*

1. Introduction

A manually operated braking system involves the application of force on the brake drum through the brake shoe, which comes in contact with the brake drum and stops the vehicle due to enough friction force by opposing the rotational motion of the wheel. This is not effective unless the components of the system are made of effective materials. Hence, the material selection plays a greater role apart from the design and analysis of various braking system components. Even though there may be chances to generate a lot of heat and frequent worn out of components involve relative contact. In order to avoid any malfunctioning and accidents due to failure of such braking systems, a replacement with a non-contact nature of magnetic and electromagnetic brakes is highly required, which leads to effective performance of braking action. Of course, it requires detailed analysis and implementation of various parameters like magnetic field generation, number of magnets, air gap, material selection, and understanding properties like conductivity, electromagnetic intensity, and various geometrical parameters. A number of researchers have carried out analyses in this direction, but a more rigorous analysis is highly required on materials selection and their geometry for various components of the braking system. So the selection of materials for various components and their geometry, combined with experimental verification, is important for the effective performance of the braking system. Magnetic and electromagnetic brakes provide a magnetic field that generates eddy currents to oppose the Torque of the wheel in motion. These are more effective due to the absence of wear and tear components of the braking system.

2. Literature Review

An investigation on the effectiveness of braking systems using permanent magnets by analyzing different parameters like number of magnets, air gap, Torque, etc is carried out, another study made on effectiveness of electromagnetic braking system on similar parameters which needs continuous supply of electrical energy for operating the brakes. In another work, a prototype testing was carried out by selecting the metallic strip of infinite dimensions used between two rectangular magnetic poles by varying different parameters [1]. The braking system's effectiveness was investigated through generated eddy currents and its effect on providing opposing Torque on the rotating disc. In this study, the distance between the magnets for the eddy current generation was also studied [2]. The shape of the pole and geometry are influenced by the required eddy current produced for effective braking torque. Analytical methods cannot be generalized for this purpose. An approach for analyzing the eddy currents in different aspects of a rotary disc for variable time domain was presented by Kapjin Lee et al [3]. Braking torque and distributed density analysis are demonstrated for a disk in rotation with a limited Radius.

These are based on the law of Coulomb's, but the radial length and other boundary conditions are specified with the help of image and mapping method concepts. The distributed density of eddy currents when a strip is positioned in the middle of rectangular magnetic poles is evaluated by Herald [4]. This author estimated electric field intensity based on Coulomb's law by formulating the pole's projected area surface charging density in the pole edge projection area. Shrivastava S. et al [5] carried out an analysis on Eddy current braking for magnetic brakes. This is a parametric analyzation and which involved Automobiles as well as Locomotives by applying SIMULINK. A concised analytical approach on ab initio field theory of A. G. Ganz was narrated by Li in his approach, the base for which is from saturated iron eddy current theories correlations of McConnell, H.M. [6]. The effect of eddy currents is appropriately considered into account in this method.

The advent of precise magnetic amplifiers seriously required a proper approach for accounting for eddy currents generated through magnetic materials. Hollowell et al [7] investigated an eddy current brake and the effect of an eddy current motor. The author considered the effect of stator spacing and the geometry of magnets on the effectiveness of brakes. Kapjin Lee et al [8] demonstrated that the eddy currents generated depend solely on geometrical parameters. So, there is no general approach to arrive at an analytical model. Analysis carried out by considering an invariant domain. The author proved that the braking Torque calculated using the Lorentz law matches the experiments well. Jun Liu et al [9] carried out an analysis on linear eddy current brakes.

The author developed an equivalent circuit method for analysing eddy currents in this work. The author also emphasised the importance of geometry parameters through the analytical method. A comparison of results on accuracy and efficiency obtained from the equivalent circuit method has been made with that of the finite element method. Ye-Ji Park et al [10] demonstrated how a force generated from the magnetic effect counteracts the force corresponding to the input torque. The author elaborated that for varying load conditions, the magnitude of the stopping force required is taken care of by the magnets. The author validated this by fabricating a prototype model for a permanent magnet brake, and experiments have been performed. Ahmed M. Salman et al [11] analysed the influence of materials on the efficiency of the eddy current braking system using permanent magnets. The author proved that the effectiveness of the eddy current braking system in different environmental conditions is far better than that of the traditional braking system. The author demonstrated the efficiency of the permanent magnetic eddy current braking system in terms of force production, energy dissipation, and overall performance. M. R. A Putra et al [12] reviewed the literature and investigated the potential eddy current braking systems on heat generation. The authors studied the exceptionality of the eddy current braking system and found that the proper cooling system provides good support for the effectiveness and efficiency of the eddy current braking system. It can be concluded from the literature that the main focus of existing work on electromagnetic braking systems is that it included different parameters, but more elaborate and effective work on the effect of material selection and geometry on the performance of braking systems has not been carried out theoretically and experimentally together for its validation. Hence, this work is an attempt to validate the effect of material selection and geometry experimentally, with a theoretical analysis

2.1. Theory of Magnetic Brakes

Based on the control and generation of magnetic fields, two basic categories of magnetic brakes are available.

- Electromagnetic brakes
- Permanent Magnet brakes

For variable magnetic field generation and control, the influence of various parameters can be effectively controlled using Electromagnetic brakes. These brakes operated through the supply of electrical energy to produce a magnetic field to generate eddy currents. These brakes require continuous availability of an electrical supply for proper functioning.

Functioning will be disturbed when the supply of power is not maintained continuously. But the use of permanent magnets can be operated without a supply of any power, but controlling the operation can not be achieved effectively.

2.1.1. Advantages of Magnetic and Electromagnetic Braking Systems

- Non-contact Braking system.
- Preventable wear and tear.
- Reliability and long life of the brake.
- In Numerous kinds of applications, the usage of these brakes is feasible.

In this study, an attempt has been made to correlate the effectiveness of material selection, geometry of disc and magnets, which are basically conductive materials, on the performance of brakes as it is clear that conventional braking system replacement required due to its wear and tear which are so frequent due to contact of surfaces while applying the brake. Reliable and efficient in operation due to the non-contact nature of magnetic brakes, which improves their performance. Opposing Torque due to magnetic force, which is provided to stop the vehicle, is the basic idea of the magnetic braking system. A regular power supply is required to generate and control the magnetic field, which leads to the generation of eddy currents for inducing Torque. This study involves the effect of material and its geometry on the performance of the braking system while using both permanent and electromagnets to generate a magnetic field. This braking system is found in various applications due to its long life and lower maintenance cost than traditional or mechanical brakes.

3. Electromagnetic Induction: Theory and Principle

Similar to a conventional brake, a magnetic brake dissipates kinetic energy as heat in order to control a moving object. Nevertheless, in contrast to electric friction brakes, which use friction between two squeezed surfaces to create the drag force needed to control the moving object. The electromagnetic force created by induced eddy currents from the conductor by electromagnetic induction between a magnet and a nearby conductive object in associated motion is known as the drag force in a magnetic brake.

4. Methodology

In order to move on with the process of designing and developing a magnetic braking system, a thorough analysis of current systems and proven theories is needed. The project entitled Designing and developing a concept validated prototype. In order to validate the theoretical results, this work involves the development of an experimental setup to confirm and guarantee the accuracy of the concept utilizing force-generating materials and components of the same conceptual relevance but differing in material selection, with variable magnitudes of geometrical parameters and also parameters of electromagnets. The following are the primary guidelines for the prototype's design:

- The substance that generates a magnetic field.
- The conducting material is subjected to a continuous magnetic field, aluminium and copper disk effects.
- Force to keep the electromagnet and conducting material moving in a continuous relative motion using the 1000 rpm DC motor.
- Geometrical variables include the effective Radius, the width of the disc, the diameter of the magnetic core, and the number of magnets.
- Batteries are capable of powering DC forms of electromagnets. Electromagnets are used over permanent magnets because they operate more quickly and with fewer losses than mechanical actuation.

The design of the braking system heavily relies on the conducting material, and two different materials, ie copper and aluminium discs, are used to carry out the experiment and theoretical calculations.

4.1. Selection of Materials and Geometry Details

Copper and aluminium discs, each with a diameter of 200 mm. Thickness: 2 mm, DC motor, 2500 rpm, electromagnets with a diameter of core t = 12mm and number of magnets n = 4. The force required to keep the disc and magnets moving relative to one another has been provided by a high rpm motor. The objective of the experiment was to observe how the speed of the rotating disc dropped when magnets were brought closer to it. The angular velocity of the disc significantly decreased as the magnets got closer. Also, to measure the time to stop the vehicle and the distance travelled with and without engaging the brakes. The disc was attached to the motor following an assessment of the concept of the electromagnetic braking system. Thus, it was determined how much Torque was needed to stop the wheel at different speeds and corresponding times and distances travelled before stopping the vehicle. The Torque needed is determined by a number of factors, including the following. Wheel initial velocity (u) (m/sec) Wheel final velocity (v) (m/sec) Time of stop (t) (sec) Wheel deceleration (a) (m/sec2), stopping force (F) (N) Mass of vehicle (m) in kilograms disc radius (R) (m) and width of the disc(d)(m). The wheel would come to rest with a final velocity equal to zero. Deceleration is determined by the following equation, which depends on the stopping time:

The following formula, shown in Equation (1), determines the force needed to stop the wheel:

$$F = \text{m} \times \text{a} \tag{1}$$

The Torque needed to stop the wheel is finally determined by the following formula given in Equation (2).

$$\boldsymbol{T} = \mathbf{F} \times \mathbf{R\omega} \tag{2}$$

The disc's initial linear velocity is transformed into an angular velocity using the relation given in Equation (3).

$$v = \text{r} \times \omega \tag{3}$$

Where v is linear velocity (m/sec), r is the disc radius (m), ω is the angular velocity (radian/sec), and N is the rpm of the disc.

4.2. Relation among Torque and Magnetic Field [9]

The design of an electromagnetic braking system was finalized after the Torque needed for different speed ranges was calculated. The following formulas of Equations (4), Equation (5) and Equation (6) are used to determine the Torque needed for a magnetic braking system.

$$T = \text{n} \times \text{A} \times \sigma \times \text{d} \times \text{B}^2 \times \text{R}^2 \times \omega \tag{4}$$

Where Torque=T (Nm); magnets number 'n'; surface area of magnet A (m^2); specific conductivity of the material σ (S/m); width of the disc 'd' (m); magnetic field intensity 'B"(Tesla); effective radius 'R'(m); angular velocity 'ω' (radian/sec), so that

$$A = \frac{\pi t^2}{4} \tag{5}$$

$$B = \frac{N \times u_0 \times i}{4 i_g} \tag{6}$$

Where the diameter of the magnet core 't' (m), number of turns', permeability constant 'uo'; current 'i (amps); air gap 'ig'(m) between the magnets. The Torque resulting from electromagnetic contact is provided by this equation. This equation shows that the Torque produced is dependent on the number of magnets utilized, their surface area, the material-specific conductivity, the disc width, the strength of the magnetic field, the effective Radius, and the angular velocity. The distance between the disc and the magnet centre is known as the effective Radius. The dimensions selected for each material of the disc are given oin Table 1.

Table 1. Dimensions selected for each material of the disc

S. No.	Variable Selection	Copper	Aluminum
1	Radius of the Disc(mm)	100	100
2	Thickness of the disc(mm)	2	2
3	Number of magnets	4	4
4	Specific conductivity(S/m)	$5.8\text{x}10^7$	$3.54\text{x}10^7$
5	Magnetic field intensity(Tesla)	0.4398	0.336
6	Wheel radius(mm)	300	300
7	Diameter of magnetic core(mm)	12	12

5. Results and Discussion

Table 2 represents the Braking Torque variation with the number of magnets. Braking torque is more for the number of magnets. As the number of magnets increases, the cumulative magnetic field intensity increases, which increases the electromagnetic force generation, leading to powerful eddy currents. Obviously, the braking torque capacity to stop the wheel is increased accordingly. For the same number of magnets, braking torque is more in the case of copper disc due to its high conductivity value than aluminum, so copper is more effective in generating eddy currents. A similar trend is also reflected in Figure 1. It has been observed that for a specific number of magnets, the Torque generated from eddy currents is almost 3 times more in copper than .In aluminum material discs.

Also, in copper, the torque generation with the increment of two magnets each time becomes double the value of the Torque without the given increment in the number of magnets. But in the case of aluminum, for each time increment of two magnets starting from four magnets, the torque value is less than 50% of the value without increment in the number of magnets. The change of Torque is more with the change of Radius of the disc, as data reflecting in Table 3 and also shown in Figure 2. Since the Torque is proportional to the square of the Radius of the disc, effect of increment of Radius on increment of Torque is more as compared to the effect of Torque on increasing the number of magnets. Also, it can be observed that the torque magnitude rises faster in the case of the copper disc due to its more conductive nature than the aluminum disc. The overall observation has also been made that whether the number of magnets or the effective Radius of the disc becomes too large, the increment in torque value is not much appreciable. Similarly, from Table 4 and Figure 3, it has been observed that the Torque in the beginning, when the diameter of the magnetic core increases from 6mm to 12mm, the increment in the Torque becomes four times from its previous value.

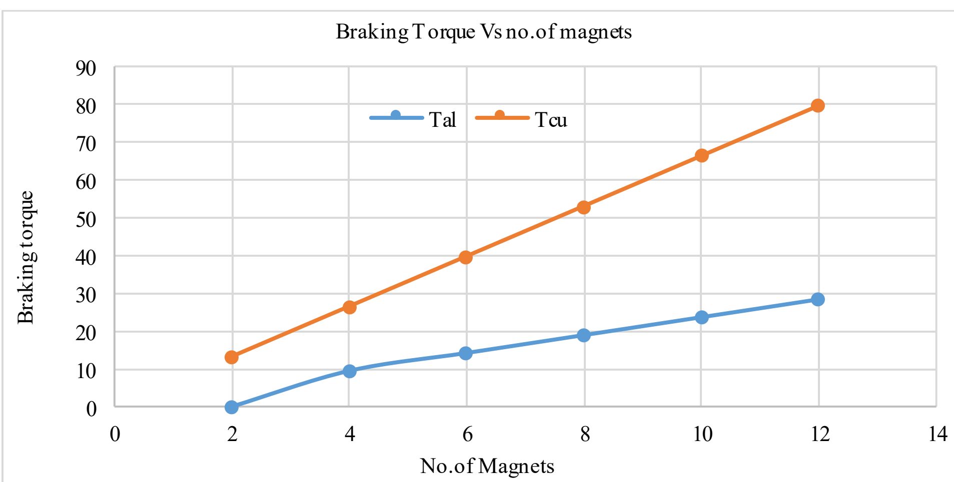

Fig. 1 Number of magnets vs. Braking torque variation

Table 2. Number of magnets vs. Braking torque variation

S. No	No. of Magnets	Torque Nm(AL)	Torque Nm(CU)
1	2	4.7285	13.2733
2	4	9.457	26.5466
3	6	14.1855	39.8199
4	8	18.914	53.0932
5	10	23.6424	66.3665
6	12	28.3709	79.6398

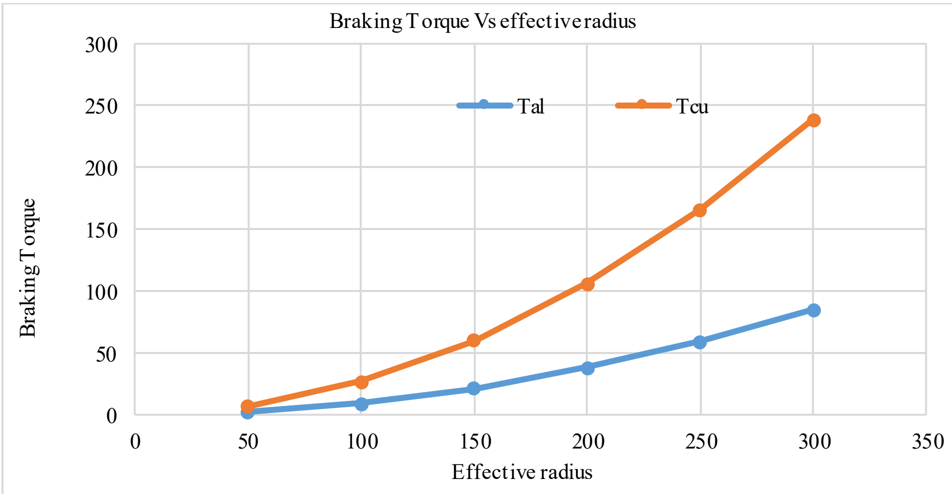

Fig. 2 Braking torque vs Effective radius

Table 3. Braking torque vs Effective radius

S.No	Effective Radius (mm)	Torque Nm (AL)	Torque Nm (CU)
1	50	2.3642	6.6367
2	100	9.457	26.546
3	150	21.2782	59.729
4	200	37.8279	106.186
5	250	59.1061	165.916
6	300	85.1128	238.919

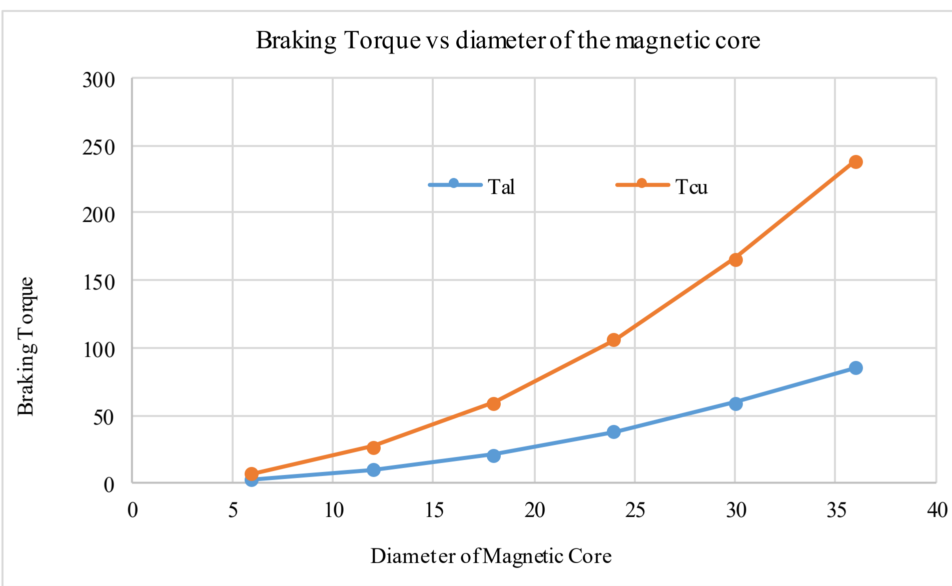

Fig. 3 Torque vs Diameter of magnetic core

Table 4. Torque vs Diameter of magnetic core

S.No	Diameter of Magnetic Core (mm)	Torque Nm (AL)	Torque Nm (CU)
1	6	2.3642	6.6367
2	12	9.457	26.546
3	18	21.2782	59.7299
4	24	37.8279	106.1864
5	30	59.1061	165.9163
6	36	85.1128	238.9194

But the more and more value of the diameter of magnetic core, there is a decreasing trend in the improvement of Torque and at higher values of magnetic core diameter, improvement in Torque becomes further slower, and the variation is similar to the case of the effect of Radius of disc on change of Torque. Also, the observation from Table 5 and Figure 4 is that at lower values of disc width, the increment of Torque with the increment of disc width becomes double, but as the disc width further increases, the disc width improves Torque at a slower rate. This effect is similar to the effect of the number of magnets on Torque. So the trends observed in the case of increasing disc width are similar to the effect of the number of magnets on Torque. Also, the effect of core diameter on Torque is similar to the effect of Radius of the disc on the Torque change.

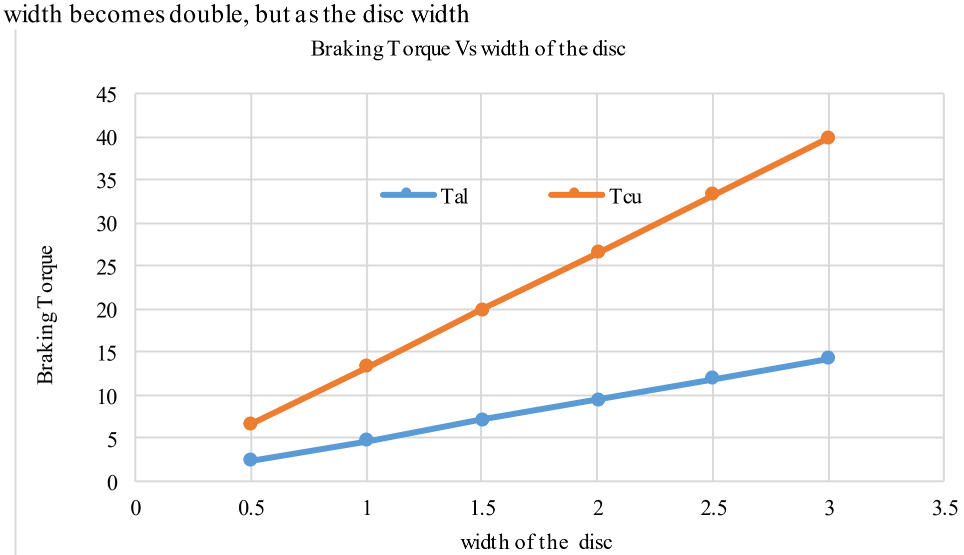

Fig. 4 Torque vs Disc width

Table 5. Torque vs Disc width

S.No	Width of the disc (mm)	Torque Nm (AL)	Torque Nm (CU)
1	0.5	2.3642	6.6367
2	1	4.7285	13.2733
3	1.5	7.0927	19.91
4	2	9.457	26.5466
5	2.5	11.8212	33.1833
6	3	14.1855	39.8199

6. Development of a Prototype for Testing

In order to retard or stop the motion of the vehicle electromagnet set is brought close to the rotating conductor disc which in turn attached to the wheel of the vehicle. Due to the generation of a magnetic field by electromagnets, the formation of eddy currents in the conductor results. The setup is made such that these eddy currents produce Torque in the reverse direction to the rotation of the wheel of the vehicle. This involves the principle of Lenz's law. The required arrangements of various elements have been shown in the prototype model, which uses copper and aluminum discs as given in Figures 5 and 6, respectively. So, the fabrication involves two main components: the disc and rotational arrangement, which use a motor and speed controllers.

6.1. Prototype Preparation

- Thorough analysis for the selection of electromagnets.
- Selection of various elements for assembling, like a belt to connect the motor to the shaft, bearings, a speed control switch, etc.

- Conducting the disc material selection and procuring all the parts.
- Preparing the final prototype by assembling these parts.

Fig. 5 Electromagnetic braking system with copper

Fig. 6 Electromagnetic braking system with Aluminum

6.2. Principle and Working

Power supply is provided to the system. The motor is rotated with a selected speed by regulating the paddle so that the disc can be rotated at the required speed using a belt connection between them. Then the motor is disengaged from the disc to engage electromagnets because of the eddy current generated by the electromagnetic field from magnets, which opposes the rotation of the wheel. So the vehicle stops after some period of time. Eddy currents generated in the disc can be varied by changing the magnet's position from the disc for the required braking action. Torque is tabulated at various speeds of disc rotation, and corresponding force and deceleration values are evaluated. Based on torque requirements, variables like current, airgap, and number of magnets were considered for the carrying experiment with each disc material. For copper and aluminium disc materials, experiments have been conducted at various speeds. By keeping the stopping time the same value, the distance travelled by the vehicle at different speeds has been tabulated for both copper and aluminium discs. The experimental setup for both copper and aluminium disc cases has been shown in Figures 5 and 6, respectively. Theoretical and experimental values for these stopping distances are also shown in these tables. The stopping distance evaluated for various speed levels of the vehicle, as shown in Tables 6 and 7, is greater in the case of practical situations. The reason for this may be the estimation of the required Torque in theoretical calculations. This is because of the difficulty in adjusting current and voltage simultaneously while supplying power to the magnets, and also, a practically continuous regulated power supply may not be appropriate. Also, the variation of stopping distance is not so high, it is 10 to 12%

6.3. Variation of Braking Torque with Distance Covered

It has been observed from Tables 6, 7, and Figures 7 and 8 that the stopping distance is greater in the case of the aluminium disc due to its lower weight and inertia and less magnetic field intensity compared to the copper disc.

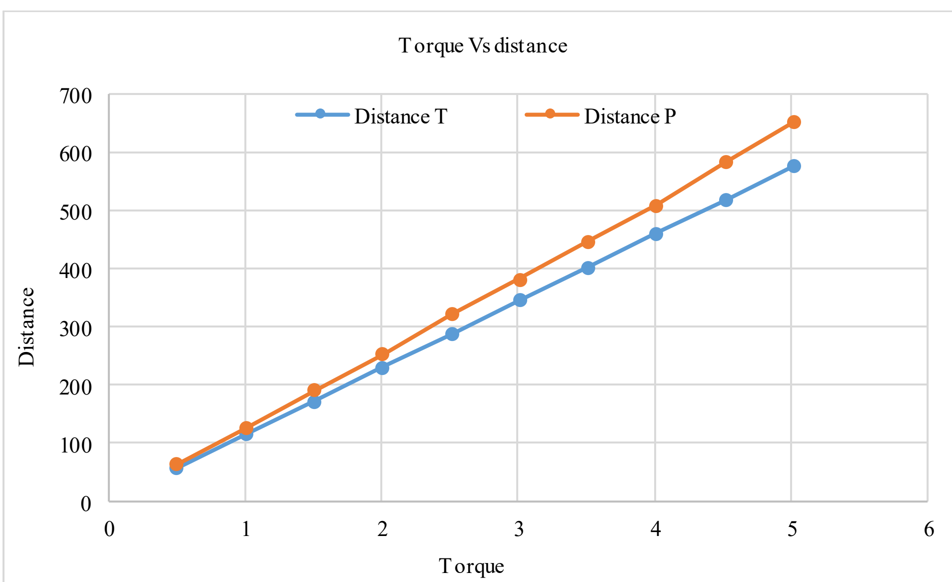

Fig. 7 Torque vs Distance travelled (aluminium disc)

Table 6. Torque vs Distance travelled (aluminium disc)

S.No	Torque AL Nm	Distance (m) Theoretical (T)	Distance (m) Practical (P)
1	0.502	57.63	64
2	1.004	115.27	126
3	1.506	172.91	191
4	2.008	230.55	253
5	2.51	288.19	322
6	3.012	345.83	382
7	3.514	403.47	447
8	4.016	461.11	509
9	4.518	518.75	583
10	5.02	576.39	652

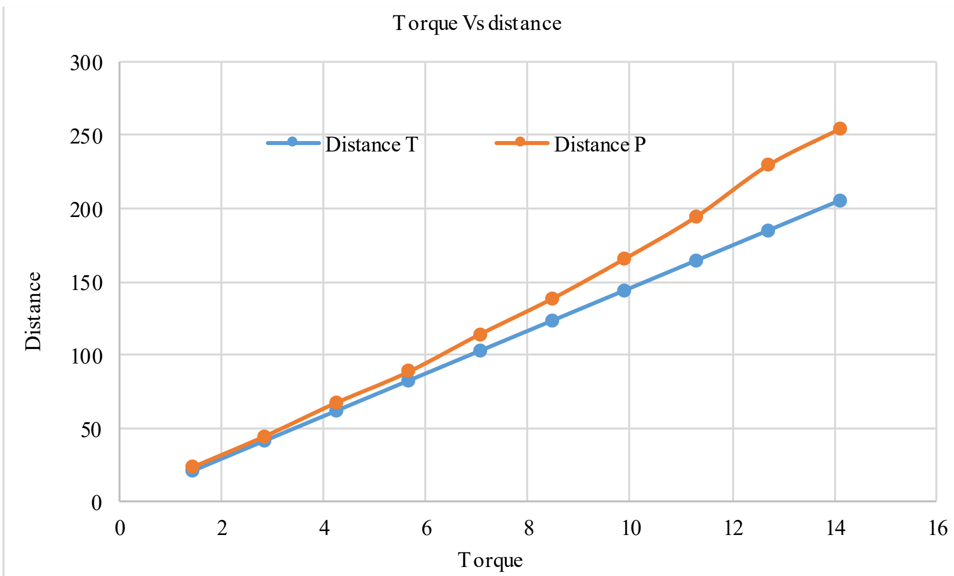

Fig. 8 Torque vs Distance travelled (copper disc)

Table 7. Torque vs Distance travelled (copper disc)

S.No	Torque Nm (CU)	Distance (m) T	Distance (m) P
1	1.41	20.5	23
2	2.82	41.04	44
3	4.23	61.56	67
4	5.64	82.08	88
5	7.05	102.6	113.8
6	8.46	123.12	138
7	9.87	143.64	165
8	11.28	164.17	193.84
9	12.69	184.69	229
10	14.1	205.21	254

6.4. Variation of Torque with Speed

From Table 8 and Figure 9, it has been observed that for the same speed, the opposing Torque due to eddy currents generated is less in the aluminium disc. The variation of Torque with speed exhibits a similar trend for theoretical calculations as well. Also, similar trends for theoretical and practical values of Torque as well as stopping distance for copper and aluminium disc brakes have been verified.

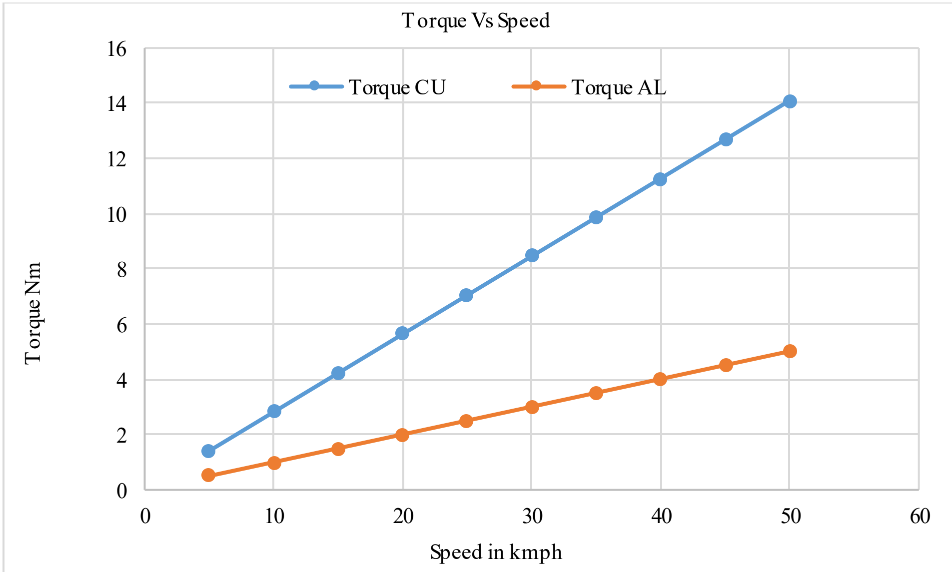

Fig. 9 Torque vs speed

Table 8. Torque vs speed

S.No	Speed m/sec	Torque (Nm) (AL)	Torque (Nm) (CU)
1	5	0.502	1.41
2	10	1.004	2.82
3	15	1.506	4.23
4	20	2.008	5.64
5	25	2.51	7.05
6	30	3.012	8.46
7	35	3.514	9.87
8	40	4.016	11.28
9	45	4.518	12.69
10	50	5.02	14.1

7. Conclusions

- The electromagnetic braking system is power-controlled, which needs a continuous supply of power to generate eddy current, which in turn exerts opposing Torque on the disc to stop the wheel. It is cost-effective and has lower maintenance costs as frequent replacement of parts is not needed due to the absence of direct contact.
- The life of the braking system's components is limited due to the absence of friction.
- The stopping distance increases with increasing Torque at higher speeds due to difficulty in controlling the power supply, as it requires a continuous variable supply.
- The theoretical stopping distance is less than the practical stopping distance due to the difficulty in supplying uninterrupted variable power.
- The effect of variation of the Radius of the disc on Torque is similar to that of the core diameter of magnets.
- The effect of variation of the number of magnets on the braking system is similar to the effect of the width of the disc.
- The stopping distance is always greater at any speed for the aluminum disc than the copper disc brake due to the lower weight and lower magnetic field intensity, and conductivity for aluminum.
- From the experiments, it has been observed that the vehicle cannot be stopped suddenly with the application of the brake, as opposing Torque is always more in the case of theoretical calculations than in practical possibility for generating the same.

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References

[1] H.D. Wiederick et al., "Magnetic Braking: Simple Theory and Experiment," *American Journal of Physics*, vol. 55, no. 6, pp. 500-503, 1987. [CrossRef] [Google Scholar] [Publisher Link]

[2] Scott B. Hughes, "*Magnetic Braking: Finding the Effective Length Over which the Eddy Currents*," Junior Independent Study Thesis, Physics Department, The College of Wooster, Ohio 44691, 2000. [Google Scholar] [Publisher Link]

[3] Kapjin Lee, and Kyihwan Park, "Modelling Eddy Currents with Boundary Conditions by Using Coulomb's Law and the Method of Images," *IEEE Transactions on Magnetics*, vol. 38, no. 2, pp. 1333-3140, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[4] Mark A. Heald, "Magnetic Braking: Improved Theory," *American Journal of Physics*, vol. 56, no. 6, pp. 521-522, 1988. [CrossRef] [Google Scholar] [Publisher Link]

[5] Er. Shivanshu Shrivastava, "A Parametric Analysis of Magnetic Braking - The Eddy Current Brakes - For High Speed and Power Automobiles and Locomotives Using SIMULINK," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 3, no. 8, pp. 11131-11138, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] H.M. McConnell, "Eddy-Current Phenomena in Ferromagnetic Material," *Transactions of the American Institute of Electrical Engineers, Part I: Communication and Electronics*, vol. 73, no. 3, pp. 226-235, 1954. [CrossRef] [Google Scholar] [Publisher Link]

[7] Thomas Hollowell et al., "*Eddy Current Brake Design for Operation with Extreme Back-Drivable Eddy Current Motor*," University of Michigan Library, 2010. [Google Scholar] [Publisher Link]

[8] Kapjin Lee, and Kyihwan Park, "Analysis of an Eddy-Current Brake Considering Finite Radius and Induced Magnetic Flux," *Journal of Applied Physics*, vol. 92, no. 9, pp. 5532-5538, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[9] Jun Liu et al., "Analysis of Linear Eddy Current Brakes for Maglev Train Using an Equivalent Circuit Method," *IET Electrical Systems in Transportation*, vol.11, no. 3, pp. 218-226, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] Ye-Ji Park et al., "A Study on the Design of a Variable Power Electromagnetic Brake for Industrial Applications," *Machines*, vol. 13, no. 3, pp. 1-12, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[11] Lennart Guckes et al., "Evaluation of an Electromagnetically Actuated Drum Brake Concept," *Automotive and Engine Technology*, vol. 8, no. 2, pp. 127-140, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[12] M.R.A Putra et al., "Heat Generation Problem in the Eddy Current Brake: A Mini-Review," *Cogent Engineering*, vol. 11, no. 1, pp. 1-20, 2024. [CrossRef] [Google Scholar] [Publisher Link]