Experimental Analysis on Effective Electro Magnetic Braking System

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Abstract. A traditional breaking system involves conversion of mechanical energy in to the heat energy leads to reduction in effectiveness of breaking due to thermal effects. This results improper functioning and may fail ultimately. It has been found in the literature that the development of magnetic breaking system which is an improved version of traditional braking system to enhance its effectiveness and durability. Even though this magnetic braking system is better than traditional braking system, it has drawbacks in generating required amount of magnetic field, inducing directional torque, adjustment of air gap, selection of motor for driving and stopping the system. Hence present work Electromagnetic braking assembly has been designed, fabricated and partially validated for improvement of performance of braking system by analyzing similar parameters such as braking torque, speed, current, arrangement of number of magnets, magnetic field, air gap. A small scale prototype has been fabricated for testing and verification. Therefore more effective braking system is suggested than magnetic braking system. Implementation of this braking system is environment friendly in a sense pollution free, easy to operate and simple to fabricate. Hence this kind of system sustains for long life.

Keywords: electromagnetic, braking system, braking torque, eddy currents, copper disc

1 Introduction

Braking system plays a prominent role in any automotive sector to control the motion of the vehicle and to stop if required. Malfunction of braking system results moderate to severe effect to the people concerned. To prevent such events frequent maintenance is very important for the braking system to its smooth functioning.

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In electromagnetic brakes electrical energy is used to generate magnetic field to induce eddy currents. Improper functioning of magnetic brakes possible only when electrical energy supply is continuous and invariable. But in the case of using permanent magnets there will not be any problems as the electrical energy is not required to supply so it works most efficiently in variety of working environmental conditions.

Magnetic braking system uses permanent magnets for generating eddy currents which induce opposing torque to control or retard the motion of the vehicle. The magnetic braking system is better than conventional braking system to produce the varying amount of opposing torque through the variation of parameters like speed, current, arrangement of number of magnets, magnetic field, air gap, disc thickness, width and effective radius of the disc and material of the disc as well as magnets. The draw back in permanent magnets is the constant magnetic field intensity which cannot be varied to generate eddy currents and induce the torque that means it is not fully controlled braking system.

On the other hand Electromagnetic braking system can be able to produce variable magnetic field intensity to control the braking torque apart from varying other geometric parameters. So that there is an improvement in performance of braking system. Literature survey reveals using electromagnetic braking system, it is very easy to control the motion of the vehicle and stop the vehicle. Hence electro magnetic braking system is more reliable than conventional system.

Practically determined measurements of metal strip in terms of disc diameter, thickness, effective radius and relationship between them on the basis of change any of these quantities are given[1]. It reveals some understanding on magnetic brakes. It involves conduction of experiment using larger length metal strip made of aluminum used in between magnetic poles of rectangular shape. Effectiveness of brakes are based on the eddy currents generated in disc moving in rotary path which is kept in midway of magnets. This paper described these aspects[2].

Configuration of conductive strip and the pole influence the generation of eddy currents. Kapiin Lee et al[3] given an approach to analyse eddy currents in time-invariant rotary disc as a particular study. In this study distribution of density as well as torque when brake is applied are evaluated in case of disc in rotary motion with finite diameter. Base of it is Coulomb’s Princple, but finited diametric length was considered using image method approach. Density of eddy currents generated for the strip, which is in mid position of magnetic poles of rectangular shape is obtained by Heald[4]. Heald formulated and estimated electric field effect near the edge of the pole geometry area and also evaluated field effect of electricity by Coulomb’s law. McConnell, H.M[6] has established connectivity among all theories of eddy currents relevancy for magnet metals for eddy current generation. The significance of various magnetic materials and approach for generating eddy currents are in urdent need at present scenario of technological progress.

H. D. Wiederick et al [7] presented a simple model contains important physical features illustrated Lorentz force law but the approach does not allow to decide the effect of neglecting the fringing on the resistance ratio. Kapjin Lee and Kyihwan Park[8] presented an approach on analysis of the eddy current for a disc with rotary motion in a constant time condition. Principle of Coulomb's law is followed in this approach and the method of images used to for boundary conditions consideration. So a comparison was given for estimated braking torque and the experimental torque for its validation. Mark A Heald[9] demonstrated the magnetic braking experiment of Wiederick *et al.*, by considering the fringing streamlines appeared in generation of eddy currents for a rectangular ‘‘footprint’’ of the magnetic field. Jaw-Kuen Shiau[10] enunciated the relative motion of a permanent magnet moving along a finite dimensional conducting plate results the magnetic drag force.

Srinivasa Gupta et al[11] devised an experimental demonstration on a concept on magnetic braking system, which is based on Lenz's law. An aluminium disc is used to fit into the wheel of a bicycle and the influence of different parameters on braking torque have been studied analytically as well as experimentally.

2 Theory and principle

There is a similarity in control the motion of the object in magnetic and conventional brakes while release kinetic energy in the form of heat. But in electric brakes the regulating agency is drag force
Which generates the friction through compressed surfaces. This drag force in case of electromagnetic brakes is a force in between magnet and a conductive object when they bring close each other in related motion. This drag force is result of eddy currents induced in conductor by electromagnetic induction.

3 Methodology

Design and manufacturing of electromagnetic braking assembly needs thorough understanding of current status of research and enormous effort for its fabrication. This work involves design and fabrication of prototype to validate appropriateness of its functioning. This requires use of proper parts and responsive materials for preparing with necessary geometry.

The important variables for development of practical model on design are:

- Selection of materials to generate magnetic field
- Conducting material for effective magnetic field
- 1000 rpm DC Motor to manage force and relative motion among electromagnet and conducting material
- Electro magnets for electrical actuation
- Conductivity is the most significant property of material for design of braking unit.

Various factors considered for selection are:

For disc material copper is selected with 200 mm diameter, 3 mm thick, 1000 rpm speed motor force to maintain relative motion of disc with respect to magnets. This step is to bring magnets or move towards rotating disc, then drop in angular velocity of disc is to be observed. After confirmed with electromagnetic field connect the disc with the system. In this way the torque variation with respect to speed and time can be calculated.

Other parameters effect the torque requirement are:

Initial and final wheel velocity (u and v respectively in m/sec), time required to stop(t), deceleration(a), force to stop the wheel(F), radius etc.

The deceleration and disc stopping are related and given by $v = u + a\,t$
Force for bringing the wheel in to rest can be written as $F = m\,a$
And Torque for bringing the wheel into rest can be given as $T = F\,r$.
We know that $v = r\,\omega$ where ω is angular velocity in rad/sec and is given by $2\,\Pi\,N / 60$, N is the speed of disc in rpm

3.1 Torque and Magnetic Field Relation:

After calculating the torque required for various speed ranges, it was decided to design electromagnetic braking system. Effect of different variables on Torque is given by the following equation using which Torque can be calculated.

Where T= Torque (Nm); n = magnets number; A= magnet surface area (m^2);

$$T = n \times A \times \sigma \times d \times B^2 \times R^2 \times \omega$$

σ = material specific conductivity (S/m); d = disc width (m); B = field intensity of magnet (Tesla); R = disc radius (m); ω = rotational velocity (rads/sec), so that
Where t= diameter of magnet core (m); N=number of turns; u_0=permeability constant ; i=current (amps); i_g= air gap between the magnets (m)

$$A = \frac{\pi \times t^2}{4} \qquad B = \frac{N \times u_0 \times i}{i_g}$$

Above equation Indicates the torque by electromagnetic effect. This reveals the factors which contribute directly or indirectly on torque are number, surface area of magnets, material conductivity, disc width, intensity of magnetic field, disc diameter, and rotational velocity

4 Results and analysis

4.1 Variation of Torque With Velocity of The Disc

Table1 is representing time taken for generating torque at different initial velocities of vehicle. It has been observed from the figure 4.1 that the torque is gradually decreasing when stopping time is keep on increasing at constant uniform velocity of the vehicle.

Table 1. Braking torque Vs time for different initial velocities

Initial velocity (u) (Km/hr)	Velocity Initial (u) (m/sec)	Velocity Final (V) (m/sec)	Time (sec)	Acceleration (m/sec^2)	Force (N)	Torque (Nm)
10	2.778	0	1	2.7778	138.89	13.889
10	2.778	0	5	0.5556	27.778	2.7778
10	2.778	0	10	0.2778	13.889	1.3889
10	2.778	0	15	0.1852	9.2593	0.9259
20	5.5556	0	1	5.556	277.778	27.778
20	5.5556	0	5	1.111	55.5556	5.5556
20	5.5556	0	10	0.556	27.7778	2.7778
20	5.5556	0	15	0.37	18.5185	1.851
30	8.3333	0	1	8.333	416.667	41.667
30	8.3333	0	5	1.667	83.3333	8.3333
30	8.3333	0	10	0.833	41.6667	4.1667
30	8.3333	0	15	0.556	27.7778	2.7778
60	16.667	0	1	16.667	833.333	83.333
60	16.667	0	5	3.3333	166.667	16.667
60	16.667	0	10	1.6667	83.3333	8.3333
60	16.667	0	15	1.1111	55.5556	5.5556

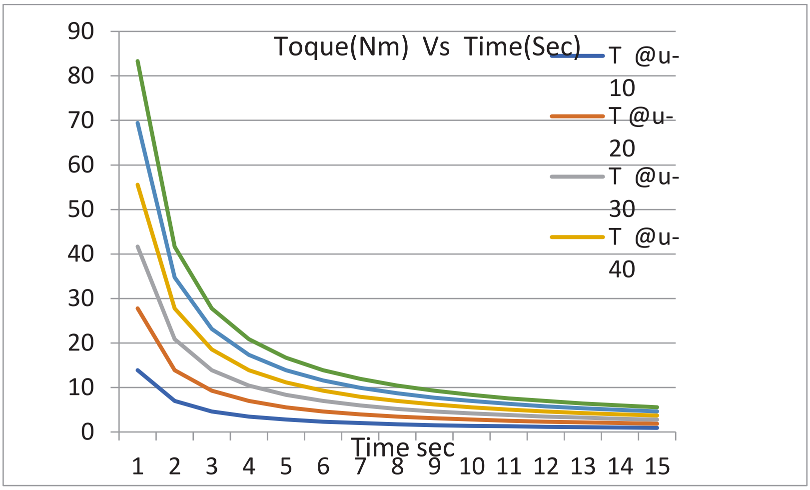

Fig. 1. Torque vs Time for various initial velocity values

4.2 Variation of Torque With Number of Magnets:

By keeping all other parameters constant except number of magnets obviously torque generated will be increasing with number of magnets increased. We can also carryout experiments by varying multiple variables simultaneously and observe the variation of torque based on the relationship of these variable with respect to other variables resulted the generated torque as given in the Table 2 as well as corresponding figure 2

n = Variable; σ = 5.8×107 S/m; d= 3 (mm); B=0.4398 (Tesla); R=100 (mm);
ω =261.7 (rads/sec); t= 12 (mm); N= 2100; u_0=4×10-7; i=1 (amps); i_g= 6 (mm)

Table 2. Change in torque with number of magnets

Number of magnets	Torque (Nm)
2	19.9225
4	39.8449
6	59.7674
8	79.6899
10	99.2247

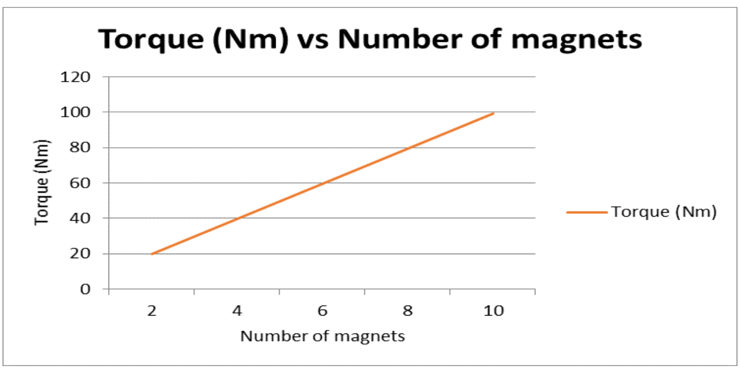

Fig. 2. Torque vs Number of magnets

4.3 Torque variation with magnetic field

Field intensity of Magnet(B) increase when the magnets distance decreases and also current supply increases. Variation of magnetic field intensity, torque verses air gap is studied from table 3. and the variation of Torque with change of air gap is depicted in figure 3.

So by fixing all the other parameters in the torque equation a table is made and variation of torque is observed and graphs are plotted.

The following values are assigned for parameters and considered in developing the table

n = 2 ; $\sigma = 5.8\times10^{7}$ S/m; d= 3 (mm); B= Variable (Tesla); R=100 (mm); ω =261.7 (rads/sec); t = 12 (mm) ; N= 2100; $u_0=4\times10^{-7}$; i=1 (amps); i_g= Variable (mm)

Table 3. Change in torque with magnetic field and air gap for two and four magnets

Air Gap(mm)	Magnetic field(Tesla)	Toque2 (Nm)	Toque 4 (Nm)	Air Gap(mm)	Magnetic field(Tesla)	Toque 2 (Nm)	Toque 4 (Nm)
1	2.6389	717.28	1434.56	10.5	0.2513	68.312	136.625
1.5	1.7593	478.19	956.373	11	0.2399	65.207	130.415
2	1.3195	358.64	717.28	11.5	0.2295	62.372	124.744
2.5	1.0556	286.91	573.824	12	0.2199	59.773	119.547
3	0.8796	239.09	478.187	12.5	0.2111	57.382	114.765
3.5	0.754	204.94	409.874	13	0.203	55.175	110.351
4	0.6597	179.32	358.64	13.5	0.1955	53.132	106.264
4.5	0.5864	159.4	318.791	14	0.1885	51.234	102.469
5	0.5278	143.46	286.912	14.5	0.182	49.468	98.9352
5.5	0.4798	130.41	260.829	15	0.1759	47.819	95.6373
6	0.4398	119.55	239.093	15.5	0.1703	46.276	92.5522
6.5	0.406	110.35	220.702	16	0.1649	44.83	89.66
7	0.377	102.47	204.937	16.5	0.1599	43.472	86.943
7.5	0.3519	95.637	191.275	17	0.1552	42.193	84.3859
8	0.3299	89.66	179.32	17.5	0.1508	40.987	81.9748
8.5	0.3105	84.386	168.772	18	0.1466	39.849	79.6978
9	0.2932	79.698	159.396	18.5	0.1426	38.772	77.5438
9.5	0.2778	75.503	151.006	19	0.1389	37.752	75.5031
10	0.2639	71.728	143.456	19.5	0.1353	36.784	73.5672
				20	0.1319	35.864	71.728

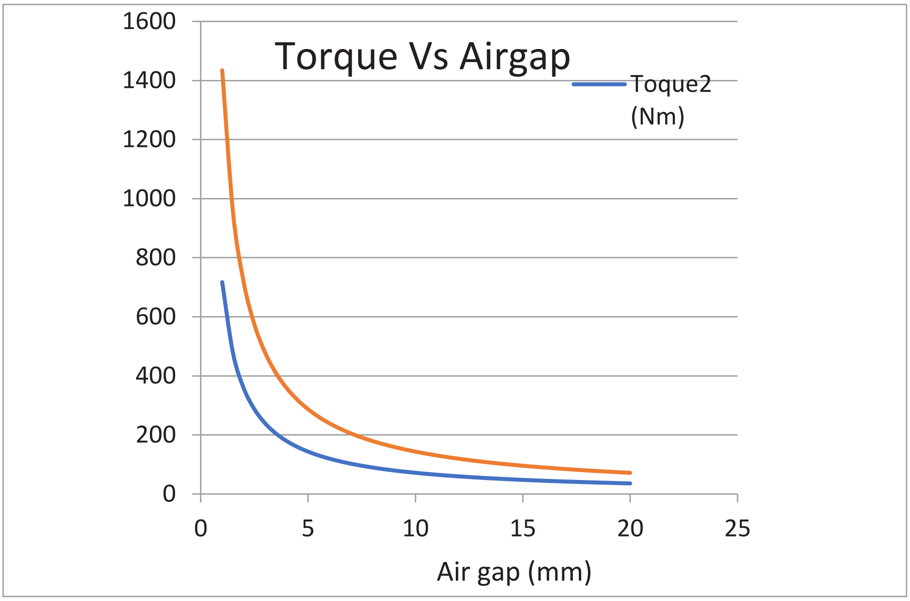

Fig. 3. Torque Vs Air gap

5 Prototype development

Lenz's law describes the effect of eddy current generation when electro magnet is moved near to the material of conductivity. These eddy currents slows down or stops the motion. Based on this concept procurement of electro magnets and conductive materials have been chosen.

The model development is involved two stages: Disc selection and fabrication. Copper disc with 200 mm diameter and 3mm thick is seleted. Screwed joint is used to assemble the disc. This prevents the relative motion of disc with respect to shaft.

Electric motor is a unit which changes electrical energy in the form of mechanical energy. It has an armature placed in between the centre of a permanent magnet.
When the current is passed through the armature, the armature produces field of magnetic nature. The magnetic field of permanent magnets is in the opposite direction of the field of magnesity produced by the armature. The interaction between the two magnetic fields resulting the armature starts rotating continuously. In this project, we used electromagnet to stop the disc. It is made by copper winding around the cylindrical soft iron for producing an amount of strength required

5.1 Sequence of Steps in Fabrication

- Study the problem on the fabrication of electromagnetic braking assembly.
- Designing the required components.
- Selection of required materials.
- Purchasing the materials.
- Fabrication of electromagnets.

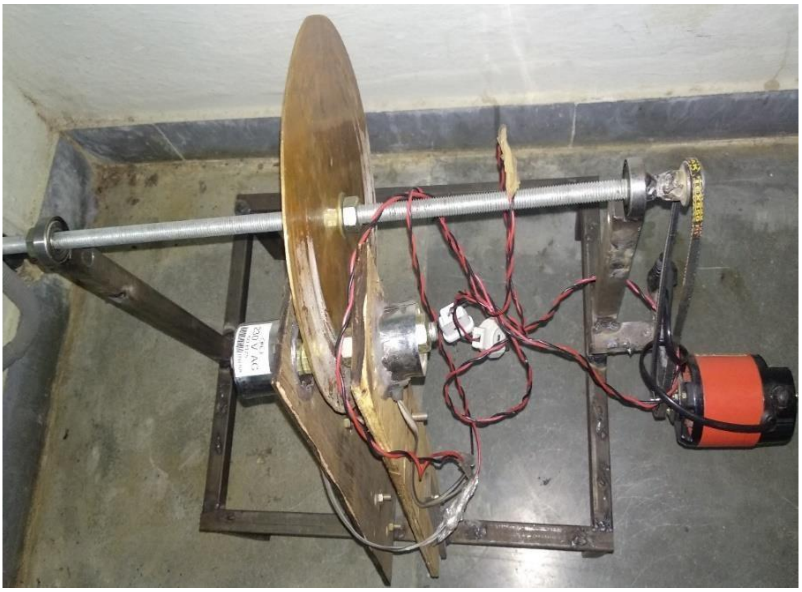

Fig. 4. Electromagnetic braking system

5.2 Working Principle

Overall system is provided with electrical supply. With the help of the motor speed regulator paddle the disc is made to rotate at desirable rotation per minute. The speed from motor to disc is transmitted by belt driven mechanism. When the required speed is obtained the motor speed regulator paddle is disengaged and the electromagnets are engaged. Magnetic field generated from electromagnets causes disc to stop rotating after certain time.

Based on the relative distance between magnets and disc eddy currents can vary and disc can be slowed down or stopped. The readings are tabulated as and when the magnets are in active and power supply of motor is kept off mode.

Experimental set up for two magnets has been shown in Figure 4. In this experiment the disc is made to rotate with different speeds using the motor(type) by controlling voltage. The magnetic field generated is varied by using two magnets through different field currents. Theoritical calculation have been compared with experimental values as given in Table 4. Air gap between magnets and disc has been adjusted accordingly. Speed of rotation of disc is made varying by belt converter from the motor to shaft of the disc (connecting motor pully with pully on shaft through belt)

Table 4. Speed Vs. time for engagement and disengagement of brakes

Sr No	Rotating Speed(Rpm)	Stopping time when brakes are not engaged(Sec)	Stopping time when brakes are engaged(Sec)
1	500	7.1	5.5
2	1000	10.1	7.8
3	1500	12.2	9.3
4	1700	13.5	10.8
5	2000	14.5	11.5

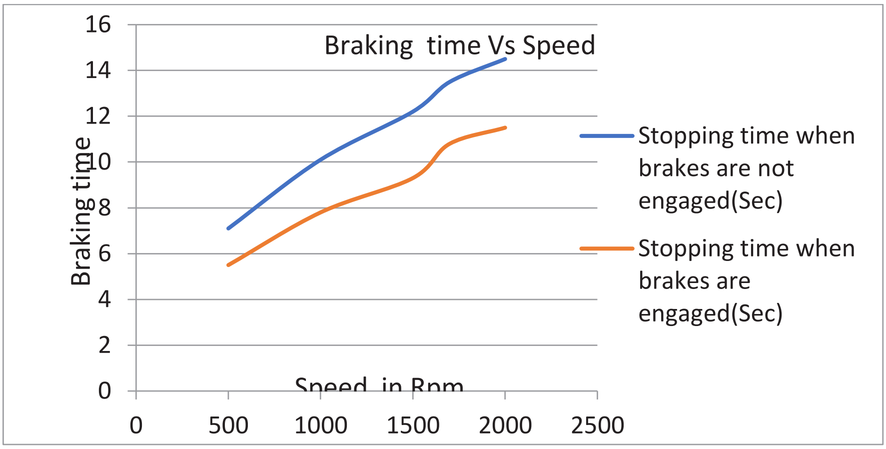

Fig. 5. Braking time Vs. speed

6 Conclusions

1. 1. In order to avoid difficulties like fading, over maintenance cost, slipping, short life, special requirements of servo system, heaviness, frequent failures etc these electro magnetic brakes are used as accessory with conventional brakes.
2. installing cost is also less so that these can be used in automobiles.
3. Durability of eddy current brakes is higher as no friction in operation.
4. Torque generation can be increased with increasing magnetic field intensity. For instance magnetic field at 1 amp is 0.43 T increases to 1.34T at 3 amps.
5. After experiment we had observed that disc slow down but cannot stop instantaneously.
6. The electromagnetic system become an environment friendly as it is free from pollution, easy to operate and simple to fabricate.

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