# Current trends in Electro-magnetic Braking System: A review paper of the current scenario of the magnetic braking system

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*Abstract*— Current paper contains three reviewed research papers on the electro-magnetic braking. Electro-magnetic braking is now taking a good pace in the applications on the day to day stuffs like cars, machine stopper and as motion retarder as well. Rather than a conventional contact friction braking, this system are more efficient, quick in the response and has no wear so it has good durability. So three different papers are reviewed and summarized here to know the principles, applicability and future scope of electro-magnetic braking system.

***Key words:*** electro-magnetic braking, Permanent magnet; Magnetic braking, FEM of electromagnetic braking, mathematical modeling of electromagnetic braking

## I. INTRODUCTION

The present paper is a review paper of the ‘magnetic braking’ system. The first attempt of making a braking system using electro magnets was done by Thomas A. Edison and he got the patent for that back in October, 1881. It was just a proposed theoretical model only, he did not make any actual system having electromagnets but he received the patent for the basic principle that is used to create electromagnetic brakes. The topic of magnetic braking has dramatically increased in popularity in recent years. Since1987, numerous articles about magnetic braking were published. These articles describe both experiments dealing with magnetic braking, as well as the theory behind the phenomenon. Magnetic braking works because of induced currents and Lenz’s law. If you attach a metal plate to the end of a pendulum and let it swing, its speed will greatly decrease when it passes between the poles of a magnet. When the plate enters the magnetic field, an electric field is induced in metal and circulating eddy currents are generated. These currents act to oppose the change in flux through the plate, in accordance with Lenz’s Law. The currents in turn heat the plate, thereby reducing its kinetic energy. The practical uses for magnetic braking are numerous and commonly found in industry today. This phenomenon can be used to damp unwanted notations in satellites, to eliminate vibration in space crafts, and to separate nonmagnetic metals from solid waste.

## II. REVIEWED PAPERS

[1] The first paper we have reviewed is ‘Modeling and control of electromagnetic brakes for enhanced braking capabilities or automated highway systems’ by M. Qian, and P. Kachroo, University of Nevada, *LasVegas*, IEEE Conference on Intelligent Transportation Systems, pp. 391-396, January, 1997.

A modified mathematical model is developed for electromagnetic brakes, is proposed to describe their static characteristics i.e. angular speed versus brake torque. This paper describes electromagnetic brakes as a supplementary system for regular friction brakes. This system provides better response time for emergency situations, and in general keeps the friction brake working longer and safer.

To control the brakes, a robust sliding mode controller is designed to maintain the wheel slip at a given value. Simulations show that the controller designed is capable of controlling the vehicle with parameter deviations and disturbances.

There are three models proposed in the literature on eddy current brakes.

### A. *Smythe's approach*

Smythe's approach [2] is to treat the rotating part as a disc of finite radius and obtain a closed-form solution by means of a reflection procedure specifically suited to the geometry of the problem. The first step is to calculate the magnetic induction, B, produced by the eddy currents induced in a rotating disk by a long right circular cylinder. After deriving the stream function, which is the current flowing through any cross section of the rotating disk from a point to its edge, the torque can be calculated by integrating the product of the radial component of the current by the magnetic induction and by the lever arm and integrating over the area of the pole piece. Since there is a demagnetizing effect such that permeable pole pieces of an electromagnet short-circuit the flux of the eddy current, the total flux in motion would be

$$\phi = \phi_0 - \frac{\beta^2\gamma^2\omega^2\,\phi}{R} = \frac{R\,\phi_0}{R + \beta^2\gamma^2\omega^2}$$

where $\phi_0$ is the flux penetrating the rotating disk at rest, and $\beta^2\gamma^2\omega^2\phi/R$ represents the demagnetizing flux attained through dividing the demagnetizing magnetomotive force by the reluctance of the electromagnet. The final integration result of the brake torque is:

$$T = \omega\gamma\phi^2 D = \frac{\omega\gamma R^2 {\phi_0}^2 D}{(R + \beta^2\gamma^2\omega^2)^2}$$

T = brake torque
$\omega$ = angular velocity
$\phi_0$ = flux penetrating the rotating disk at rest
D = constant coefficient, depending on pole arrangement
R = reluctance of the electromagnet
$\beta$ = constant coefficient
$\gamma$ = 10-9 /$\rho$, where $\rho$ is the volume resistivity of the disk

This model is good at low speed but decreases too fast in high speed compared with the experimental curve. The asymptotic behavior shows a fall-off of the torque more rapid than $\omega^{-1}$ the high speed region, which is in contradiction with experimental results. Smythe pointed out that this behavior could be due to other conditions, such as the degree of saturation of the iron in the magnet which will upset the assumed relations between magnetomotive force and flux.

### *B. Schieber' approach*

Schieber adapted a general method of solution to a rotating system which is different from
Smythe's approach. The result is for low-

$$T=\frac{1}{2}\sigma\delta\omega\pi R^2m^2B_Z^2[1-\frac{(R/a)^2}{[1-(m/a)^2]^2}]$$

σ = electrical conductivity
δ = sheet thickness
ω = angular velocity
π = coefficient
R = radius of electromagnet
m = distance of disc axis from pole-face centre
a = disk radius
$B_z$ = z component of magnetic flux density

### *C. Wouterse approach*

Based on the works of Schieber and Smythe, Wouterse tried to find the global solution for the high-speed region as well as the low-speed region. Wouterse proposed the following expression for low speed:

$$Fe=\frac{1}{4}\frac{\pi}{\rho}D^2dB_0^2cv$$

$$c=\frac{1}{2}[1-\frac{1}{4}\frac{1}{(1+\frac{R}{A})^2)(\frac{A-R}{D})^2}]$$

where,
Fe is the braking force and v is the speed.

The other variables are parameters that can be evaluated based on different types of eddy current brakes. The formula completely agrees with Smythe's result in the low-speed region.

Wouterse's study on the air gap magnetic field at different speeds produced three remarkable phenomena:

- At very low speeds, the field differs only slightly from the field at zero speed.
- At the speed at which the maximum dragging force is exerted, the mean induction under the pole is already significantly less than B
- At higher speeds, the magnetic induction tends to further decrease.

Based on this observation, Wouterse proposed the following solution at the high speed region:

$$Fe(v)=\hat{Fe}\frac{2}{\frac{v_k}{v}+\frac{v}{v_k}} \quad \text{with}$$

$$\hat{Fe}=\frac{1}{\mu_0}\sqrt{(\frac{c}{\xi})\frac{\pi}{4}D^2B_0^2}\sqrt{(\frac{x}{D})}$$

$$v_k=\frac{2}{\mu_0}\sqrt{(\frac{1}{c\xi})\frac{\rho}{d}}\sqrt{\frac{x}{D}}$$

where
ρ = specific resistance of disc material
d = disc thickness
D = diameter of soft iron pole, for noncircular pole shape D denotes the diameter of the circle with the same area as pole face
ξ = ratio of zone width, in asymptotic current distribution around poles, to air gap
c = ratio of total contour resistance to resistance of contour part under pole
v = tangential speed, measured at center of pole
$v_K$ = critical speed
$B_0$ = air gap induction at zero speed
x = air gap between pole faces including disc thickness or coordinate perpendicular to air gap
R = distance from center of disc to center of pole

[2] The second paper we have reviewed is 'Innovative Electro Magnetic Braking System' by Sevvel P, Nirmal Kannan V, Mars Mukesh S published in *International Journal of Innovative Research in Science, Engineering and Technology, Volume 3, Special Issue 2, April 2014.*

In this paper, the conventional braking systems have been analyzed i.e. different friction brakes, hydraulic brakes along with their effects and difficulties which include Brake fading effect, Brake fluid leakage, brake fluid vaporization and brake fluid freezing. Next is the description of the working principle of electromagnetism using the known Oersted experiment, magnetic effect of the flow of current in a conductor and the factors affecting the strength of electromagnet are discussed.

### *A. Electromagnetic brakes*

Electromagnetic brakes operate electrically, but transmit torque mechanically. This is why they used to be referred to as electro-mechanical brakes. Over the years, EM brakes became known as electromagnetic, referring to their actuation method. The variety of applications and brake designs has increased dramatically, but the basic operation remains the same. Single face electromagnetic brakes make up approximately 80% of all of the power applied brake applications.

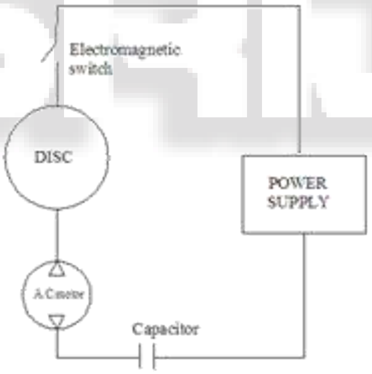


Fig. 1: Working of Electro Magnetic Disc Brake, Courtesy: Innovative Electro Magnetic Braking System'International Journal of Innovative Research in Science, Engineering and Technology, Volume 3, Special Issue 2, April 2014

### *B. Thermal Dynamics*

Thermal stability of the electromagnetic brakes is achieved by means of the convection and radiation of the heat energy at high temperature. The value of the energy dissipated by the fan can be calculated by the following expression:
$QMC_p = D_q$
where M = Mass of air circulated;
$C_p$ = Calorific value of air;
$D_q$ = Difference in temperature between the air entering and the air leaving the fan;

### *C. Working Of Electromagnetic Disc Brake:*

The electromagnet is energized by the AC supply where the magnetic field produced is used to provide the braking mechanism. When the electromagnet is not energized, the rotation of the disc is free and accelerates uniformly under the action of weight to which the shaft is connected. When the electromagnet is energized, magnetic field is produced thereby applying brake by retarding the rotation of the disc and the energy absorbed is appeared as heating of the disc. So when the armature is attracted to the field the stopping torque is transferred into the field housing and into the machine frame decelerating the load. The AC motor makes the disc to rotate through the shaft by means of pulleys connected to the shaft.

One can conclude this paper as follows:

- With all the advantages of electromagnetic brakes over friction brakes, they have been widely used on heavy vehicles where the 'brake fading' problem exists. The same concept is being developed for application on lighter vehicles. The concept designed by them is just a prototype and needs to be developed more because of the above mentioned disadvantages. These electromagnetic brakes can be used as an auxiliary braking system along with the friction braking system to avoid overheating and brake failure. ABS usage can be neglected by simply using a micro controlled electromagnetic disk brake system .These find vast applications in heavy vehicles where high heat dissipation is required.

[3] Third reviewed paper is 'Design of a magnetic braking system', by Min Joua,Jaw-Kuen Shiaub, Chi-Chian Suna, *Journal of Magnetism and Magnetic Materials 304 (2006) e234–e236*

A model has been developed to demonstrate the working principles of the magnetism.

In current experiment, an upright magnetic braking system was designed (Fig. 2) using permanent magnet which can be used in elevators as one of the safety features, particularly, for skyscrapers. The guiding track is designed as the conducting plate which is easy to construct with building or join with existed elevators. Two pairs of permanent magnets (NdFeB-35) are mounted with the loading table in both front and rear side.

Their objectives of this study were:

(1) To develop a FEM to analyze the magnetic field for calculation of the braking force; and
(2) To obtain the effect of track materials and air gap on the magnetic flux density.

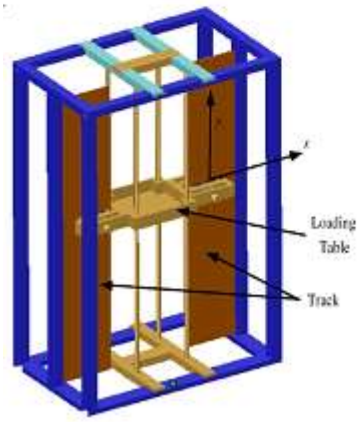


Fig. 2: Structure of magnetic braking system, Courtesy: M. Jou et al. / Journal of Magnetism and Magnetic Materials 304 (2006) e234–e236

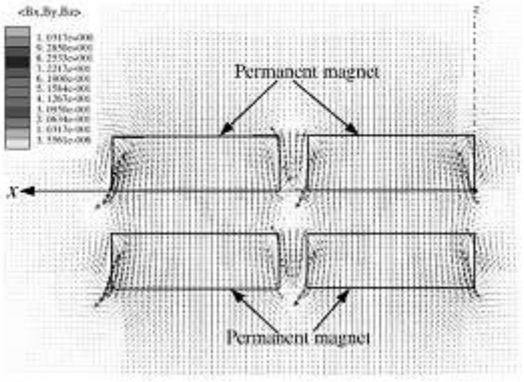


Fig. 3: Magnetic flux density for 1mm air gap. Courtesy: M. Jou et al. / Journal of Magnetism and Magnetic Materials 304 (2006) e234–e236

The approaches to design the magnetic braking system are based on the principle of design for manufacturing and design for assemble.

Therefore the considerations and their corresponding assumptions are as followings:

(1) Rectangular magnets are used in this study. This will reduce the model from 3D to 2D.
(2) The magnets are mounted in symmetry in order to reduce the vibrations due to unbalance of forces.

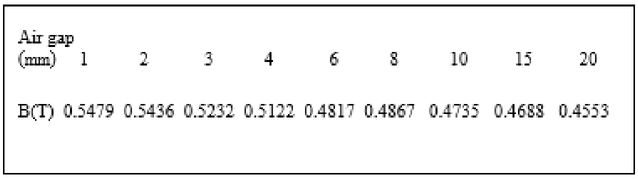
Thus, the analysis can be treated as 2D and symmetric problem.

The distance between front magnet and rear magnet is equal to two times of the air gap plus the thickness of track.

The simulation of magnetic flux density is shown in Fig. 3.

In this study, the magnetic flux for nine different air-gaps is analyzed and its average value is listed.

The results indicate that increasing air gap will decrease the average value of magnetic flux density. The verification shows the predicted magnetic flux is within 5% difference with the measured value. Therefore, the magnetic flux density computed by the developed FEM model can be applied during the design stage of magnetic braking systems.



| Air gap (mm) | 1 | 2 | 3 | 4 | 6 | 8 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| B(T) | 0.5479 | 0.5436 | 0.5232 | 0.5122 | 0.4817 | 0.4867 | 0.4735 | 0.4688 | 0.4553 |

## III. CONCLUSION

The first reviewed paper summarizes that the capability of the braking system can be increased using electromagnetic brakes, and sliding mode controller can be used for satisfactory results for electromagnetic brake control.

In second reviewed paper the authors have attempted to make practical electro-magnetic brakes and it is proposed to use the electro-magnetic braking system along with the conventional braking to avoid overheating and brake failure. These electromagnetic brakes can be used in wet conditions which eliminate the anti-skidding equipment, and cost of these brake are cheaper than the other types.

Third paper represents a FEM model of magnetic braking. The model analyzes and computes the magnetic flux density at an early level of braking system design. This project demonstrated that the air gap has a significant effect on the magnetic flux density from FEM model.

## REFERENCES

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[3] Design of a magnetic braking system, Min Joua,Jaw-Kuen Shiaub, Chi-Chian Suna, Journal of Magnetism and Magnetic Materials 304 (2006) e234–e236