A Comprehensive Study on Frictionless or Electromagnetic Braking System

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Abstract: ***Breaking system is widely used in automobiles to ensure the safety and comfort of the passengers. It directly affects the traffic safety for the safe driving of the vehicle. Various brake testing standards are used and followed to assure this safety. An electromagnetic braking system (EM braking system) is a new and revolutionary concept. Irrespective of hydraulic fluid in disc and drum brakes, EM brakes use magnetic power to engage the brake. Therefore, electromagnetic brakes work on electric and magnetic power. Unlike the conventional braking system which is often referred to as bulky, EM braking system is compact and offers high degree of safety. These brakes have various names like electromechanical brakes, eddy current brakes, frictionless brakes, non-contact brakes and many more. This system works under the principle of electromagnetism. This braking system is frictionless, hence there is no wear and tear of the system parts. This phenomenon is governed by Faraday's Law of Electromagnetic induction and Lenz' Law. Eddy current is generated by the relative motion between a metal, an alloy conductor, and a magnet. Now when the magnetic flux passes through and perpendicular to the rotating wheel, eddy current flows opposite to the rotating wheel/ rotor direction. This eddy current tries to stop the rotating wheel/rotor. Therefore, the rotating wheel/rotor comes to rest position. This type of braking system is generally used in trains and trams. EM braking system is better in performance and also has low maintenance as compared to conventional braking system.***

Keywords: Conventional braking system, Eddy current, Electromagnetism, Magnetic flux, Non-contact braking, Torque

1. Introduction

Electromagnetic brakes were invented by an African-American self-taught engineer known as Granville Tailor Woods. They were originally called as electro-mechanical brakes, but as time passed by, people were used to call it electromagnetic brakes. These EM brakes are used widely in locomotive industries especially in trains and trams. These trains and trams EM brakes for safe and efficient travel on tracks. They are also used as emergency braking system when electronic brakes fail to function.

Types of EM brakes:-

- Single-face brakes
- Particle brakes
- Multiple disc brakes
- Power off brakes
- Hysteresis brakes

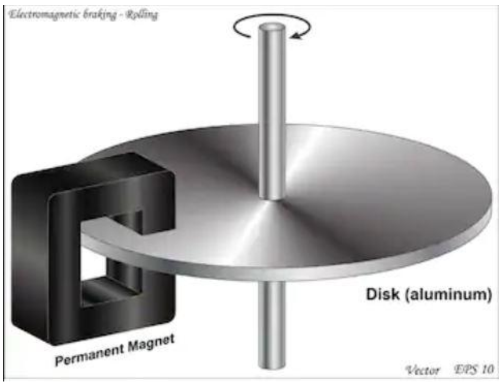

Figure 1: Pictorial representation of EM brake

In a study, it was found that these EM brakes develops a negative power, which constitutes about twice the maximum power output of a typical engine, and at least three times the braking power of an exhaust break (Reverdin 1994).

The working principle of the EM brake is based in formation of magnetic field within a mutual disc rotating between two electromagnets. This sets up a force opposing the rotation of the disc. As mentioned earlier, both Faraday's Law and Lenz' Law govern this phenomenon.

Faraday's Law of electromagnetic induction states that "the induced voltage in a circuit is directly proportional to the rate of change of time of the magnetic flux throughout the circuit".

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

ε = induced voltage

N = number of loops

$\Delta\Phi$ = change in magnetic flux

Δt = change in time

Negative sign indicates that the induced emf opposes the change in magnetic flux.

Lenz' Law states that "the current induced in a circuit due to change in magnetic field is directed to oppose the change in magnetic flux and to exert a mechanical force which opposes the motion.

$$\epsilon = -N\frac{\partial\Phi_B}{\partial t}$$

ϵ = induced emf

N = number of turns in coil

$\partial\Phi_B$ = change in magnetic flux

∂t = change in time

2. Literature Review

The calculation of brake torque is generally a difficult task as they engage a complex electromagnetic and thermal phenomenon. These calculations must be precise. There are three models proposed on EM brakes:

1) W.R.Smythe's model
2) D.Schieber's model
3) J.H.Wouterse's model

W.R.Smythe's model:
This approach treats the problem as a disc of finite radius and obtained a closed form solution of torque calculation by means of a reflection procedure specifically suited to the geometry of the problem.

D.Schieber's model:
This formula is for low speed only. He found out that his results were very close to Smythe's result at low speed and that it is valid for a linearly moving strip as well as a rotating disc.

J.H.Wouterse's model:
He tried to find the global solution for the torque in the high speed region as well as in low speed regions.

3. Methodology

Initially, the base for the electromagnets and the stand for fitting the wheel are constructed. Then, a wheel is made and attached to the stand by the help of bearings.

An electromagnet is made by winding the copper wire with the cylinder body and attached to its base. Then, an U shaped metal rod is welded with a L shaped metal bar forming a brake shoe and then its ends are rested inside the electromagnet. Also a fan is attached to the motor, and then it is attached to the base. So the electromagnet and the motors of the wheel and the fan are circuited to an external battery. And by turning it on, they work respectively.

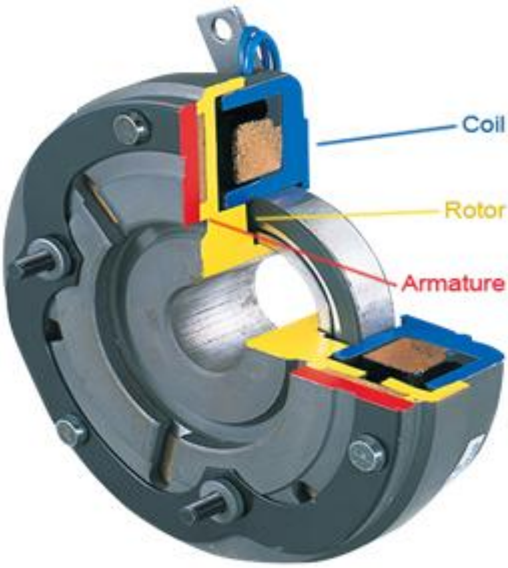

Figure 2: (structure of EM brake)

4. Theoretical/ Conceptual Framework

It mainly consists for three parts. Driving unit, Braking unit, and other miscellaneous parts.

1) Driving unit

- Electric motor:
  It is an electrical device that converts electrical energy to mechanical energy. To generate force within the motor, electric motor operates by interaction between an electric motor's magnetic field and winding currents.
- Power control:
  It consists of power to supply the whole system and separate power control system to control the motion.
- Wheel:
  It gets in motion with the help of running motor. Here, both the motor and the wheel is connected with the help of connecting chain and chain ring.

2) Braking unit

- Electromagnet:
  In this type of magnets, the magnetic fields are produced by electric current. When the electric current is turned off, the magnetic field disappears. This electromagnets generally consist of insulated wire wounded into a coil. When the current is turned on, the current through the line produces a magnetic field which is concentrated in the hole in the coil's centre. The wire turns are often wound around a magnetic core.
- Brake shoe:
  It is the part that is used to stop the main wheel when the electromagnet is turned on.

3) Miscellaneous parts

- Spring:
  A coil spring also known as a helical spring is a mechanical device which is typically used to store energy and then release it. This is done to absorb shock or to maintain a force between the contacting surfaces.
- Bearings:
  The general purpose of these bearings is to reduce the rotational friction and support radial and axial loads.

5. Working

The key components of EM brakes are field coil, armature, and the hub. EM brakes operate via an electric actuation but produce torque mechanically. When voltage or current is applied to the brake, the coil becomes an electromagnet and produces magnetic lines of flux. This magnetic flux travels through the small air gap between the field coil and the armature, magnetically pulling the armature against the hub and creating a holding force.

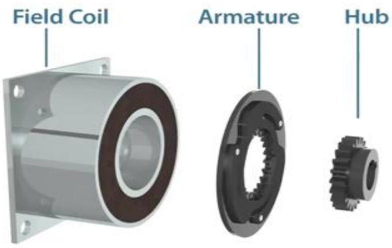

Figure 3: Main parts of EM brakes

When the brake is fully engaged, torque transfer is 100% efficient as there is no relative slip. When the current or voltage is removed from the brake, springs hold the armature away from the hub surface creating a small air gap. In most mobile or outdoor applications, friction material is not used. However in industrial applications, the friction material is used to help slow down the wear in a clutch or the brake. The friction material is flushed with the steel holes. The single friction plate design allows for a very fast response. So the brakes are very well suited for high cycle applications.

Importance of Voltage/ Current

A constant power supply is very important for accurate and maximum torque from the brake. If non-regulated power supply is been used, the magnetic flux will degrade as the resistance of the coil increases. In short, hotter the coil gets, lower will be the torque generated.

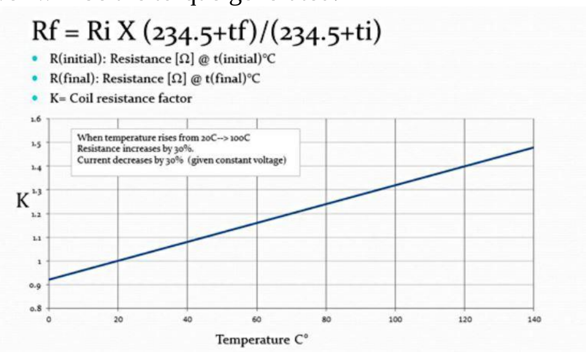

Figure 4: (graph plotted between resistance factor of the coil vs its temperature)

The resistance factor of the coil is reduced by an average of 8% for every 20^0 increase in temperature. To reduce the cost of the power supply, slightly oversizing the brake can be done instead of magnetic flux degradation. This is done by maintaining the temperature constantly.

$$R_f = R_i x (234.5 + t_f) / (234.5 + t_i)$$

R_f= final resistance

R_i = initial resistance

234.5 = temperature coefficient of resistance of copper wire

T_f = final temperature

T_i = initial temperature

Torque Required – Burnishing:

Burnishing is the wearing in or mating of the opposite surfaces. When the armature and the brake faces are produced, the faces are machined as flat as possible. Burnishing is the process of cycling the brake to wear down the initial peaks on the surface of steel so that there is more surface contact between the mating faces. This process involves cycling the brake a number of times at lower inertia, lower speed, or combination of both. This process can require 20 to over 100 cycles depending upon the size of the brake and the amount of initial torque required.

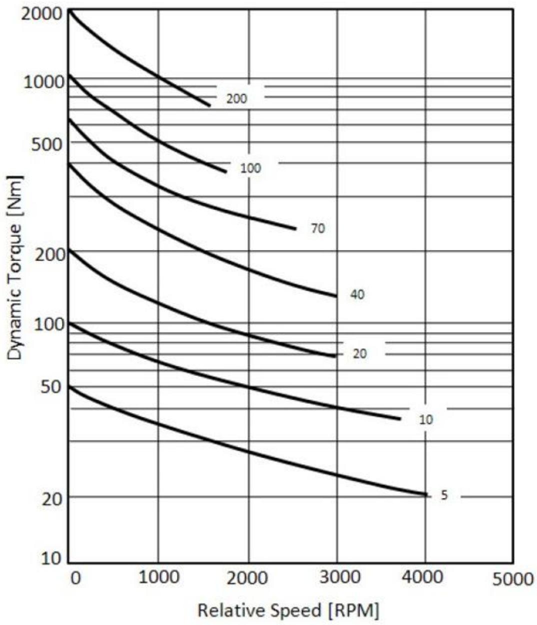

Figure 5: Graph plotted between dynamic torque vs the relative speed

Burnishing can affect the initial torque of the brake. But there are also several other factors that affect the torque performance of the brake.

Formula Required

The calculations used in electromagnetic brakes are:

Magnetic force produced:-

$$B = \mu IN$$

Since there are two electromagnets used;

$$B' = 2 \times B$$

Total force produced:-

$$F = B^2A / \mu G^2$$

Resistance of the wire:-

$$R = \rho L / A$$

Heat produced:-

$$H = I^2RT$$

- B = magnetic force produced
- μ = magnetic flux density
- N = number of turns
- I = current induced
- F = total force produced
- A = crossectional area of the wire
- G = gap between magnet and the iron
- R = resistivity of the wire
- ρ = resistivity of the copper wire
- L = length of the copper wire
- H = heat produced
- T = time taken in sec

6. Significance and Limitations of EM Brakes

Significance

1) EM brake component's price is fairly low, henceforth these brakes are cheap
2) As these EM brakes are termed as frictional brakes, they have better heat dissipation capability to reduce maintenance cost.
3) As these brakes are completely contactless and only function under magnetic fields, they emit negligible noise.
4) The efficiency of these EM brakes are very high, hence making its degree of safety high.
5) These EM brakes have minimalistic components and are simple in design.

Limitations

1) Usage of electric power is high for braking purposes
2) Due to lack of space between gearbox and the rear axle, it is arduous to install an EM brake.
3) EM brakes are better at slowing down, not completely stopping them. Hence they are less effective under low velocities.
4) If not properly governed, there is a high chance of electromagnetic coil failure.

7. Conclusion

Electromagnetic or frictionless braking is a non-contact braking system and hence there is no friction and minimum wear and tear. Therefore, the maintenance cost of this braking system is low. EM braking system gives superior controllability to the driver. These brakes have been used as supplementary retardation equipment in addition to regular frictional brakes. Hence, these brakes help in avoiding and minimizing traffic accidents. EM brakes are also reliable and eco-friendly. ABS usage can be neglected and wheel skidding is eliminated. These brakes consume small space and hence installation is pretty easy. It can not only be used in field of automobiles, but also in aeronautics field. Hence, EM braking system can be better technology revolution in the future.

References

[1] AkashSawant, Myron Pereira, Roger Pereira, YogeshIngavale "FRICTIONLESS BRAKING SYSTEM" - IRJET Volume: 07 Issue: 07, July 2020

[2] Prof. N.B.Totala, PriyaBhosle, SeemaJarhad, SoniyaJadhav, KamleshKuchekar "Electromagnetic Braking System" - National Conference on Innovations in Mechanical Engineering, Engineering, 6-8 April 2015, Organized by Department of Mechanical Engineering, MIT Academy of Engineering, Alandi, Pune 412105, India

[3] Sudarshan T A, Sefeej, Swathin,Nikith T, Nidhin "DESIGN AND FABRICATION OF ELECTROMAGNETIC BRAKING SYSTEM" - JETIR June 2018, Volume 5, Issue 6

[4] Hiralpatel, Sanketpatel, Aakashbhavsar, Gosaipratikgir, Mehulsorthiyas "A Review Paper On Contactless Braking System" - International Journal of Advance Engineering and Research Development, Special Issue SIEICON-2017,April -2017

[5] Peijiang Chen "The Testing and Data Analyzing of Automobile Braking Performance" - International Conference on Computational Science and Engineering (ICCSE 2015)

[6] Varun Kumar Reddy Malipeddi , RamcharanVuyyala , PremsagarPenumala "A Role of Electromagnetic Braking System inan Automobile" - International Journal of Innovative Research in Science, Engineering and Technology Vol. 7, Issue 10, October 2018

[7] Akshaykumar.S.Puttewar, Nagnath. U. Kakde.,Huzaifa.A. Fidvi, BhushanNandeshwar, Dr.BabashahebAmbedkar College of Engineering& Research, Wanadongri, Nagpur, " Enhancement of Braking System in Automobile using Electromagnets"

[8] Nitesh Kumar Yadav, PosanSah, SamipTimilsina, SujanShrestha, SumanThapa"STUDY AND FABRICATION OF ELCTROMAGNETIC BRAKING SYSTEM" - Kathmandu University, School of Engineering, Department of mechanical engineering

[9] Journal of Magnetism and Magnetic Materials, 304(2006) c234-c236. A.Aravind, V.R.Akilesh, S.Gunaseelan, S.Ganesh "Eddy current embedded conventional braking system" - IJIRSET Volume 5, Special Issue 7, April 2016

[10] "Innovative Electro Magnetic Braking System" by Sevvel, NirmalKannan& Mars Mukesh, Dept. of MechEngg, Magna College of Engineering,Chennai, Tamilnadu, India on 2nd April 2014.

[11] William Gaskey, SandipMistry, Duy Nguyen, JeeYoon; ELET4308/12652, University of Houston College of Technology – Fall2006,"ElectromagneticBraking System"

[12] "Eddy Current Braking Study for Brake Disc of Aluminium, Copper and Zink" by M.Z.Baharom, M.Z.Nuawi, G.Priyandoko, S.M.Harris, L.M.Siow, Department of Mechanical and Material Engineering UniversitiKebangsaan, Malaysia in October 2011.

[13] "Innovative Electro Magnetic Braking System" by Sevvel, NirmalKannan& Mars Mukesh, Dept. of MechEngg, Magna College of Engineering,Chennai, Tamilnadu, India on 2nd April 2014.

[14] Design of Machine Elements by V.B. Bhandari, 2014 Edition