CONTACTLESS EDDY BRAKING SYSTEM

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ABSTRACT

Electromagnetic braking systems use electronic and magnetic power to apply wheel brakes. Our system utilizes the concept of electromagnetism in order to achieve braking without friction. Eddy braking improves the reliability & life of brakes since they do not wear out over time due to friction. This needs comparatively very less maintenance and no oiling. This leads to very low maintenance cost due to no friction and no oiling. Also traditional braking systems are prone to slipping while this one is guaranteed to apply brakes to the vehicle. So without friction or need of lubrication this technology is a preferred replacement for traditional braking. Also it is quite smaller in size compared to the traditional braking system.

KEYWORDS

1. Electromagnets
2. DC Motor
3. Battery
4. Supporting Frame
5. Wheel.

INTRODUCTION

When electromagnets are used, control of the braking action is made possible by varying the strength of the magnetic field. A braking force is possible when electric current passed through the electromagnets. The movement of the metal through the magnetic field of the electromagnets creates eddy currents in the discs. These eddy currents generate an opposing magnetic field, which then resists the rotation of the discs, providing braking force. The net result is to convert the motion of the rotors into heat in the rotors.

EDDY CURRENTS

A metal sheet moving to right under a magnet, illustrating how linear eddy current brake work. In the drawing the magnet is drawn spaced apart from the sheet to reveal the vectors; in an eddy current brake the magnet is normally located as close to the sheet as possible.
Eddy currents (I, red) induced in a conductive metal plate (C) as it moves to right under a magnet (N). The magnetic field (B, green) is directed down through the plate. The increasing field at the leading edge of the magnet (left) induces a counterclockwise current, which by Lenz’s law creates its own magnetic field (left blue arrow) directed up, which opposes the magnet’s field, producing a retarding force. Similarly, at the trailing edge of the magnet (right), a clockwise current and downward counter field is created (right blue arrow) also producing a retarding force.

**BRAKE STRUCTURE**

The braking force of an eddy current brake is exactly proportional to the velocity V, so it acts similar to **viscous friction** in a liquid. The braking force decreases as the velocity decreases. When the conductive sheet is stationary, the magnetic field through each part of it is constant, not changing with time, so no eddy currents are induced, and there is no force between the magnet and the conductor. Thus an eddy current brake has no holding force. There are two types of eddy braking system, they are Linear and Circular Eddy Current brakes.

**LITERATURE REVIEW**

N. Paudel, S. Paul, and J. Z. Bird in his paper general 2-D analytic based transient formulation for a magnetic source
moving above a conductive plate has been derived. The formulation is written in a general forms of magnetic source can be utilized. The derived field and force equations need to be computed by evaluating a single integral. The conductive region was solved for the vector potential whereas the air region was solved for the magnetic scalar potential. The inverse Laplace transform of the vector potential was obtained by using the Heaviside expansion theorem. The transient solution for the normal and tangential forces along the surface of the conductive plate were obtained by using Maxwell’s stress tensor and Parseval’s theorem. The use of Parseval’s theorem circumvented the need for inverse Fourier transforming. The derived equations were validated by comparing them with two different 2-D FEA transient models.

Authors: Virendra Kumar Maurya, Rituraj Jalan, H. P. Agarwal, S. H. Abdi, Dharmendra Pal, G. Tripathi and S. Jagan Raj. With all the advantages of electromagnetic brakes over friction brakes, they have been widely used on heavy vehicles where the “brake fading” problem is serious. The same concept is being developed for application on lighter vehicles. A Halbach magnetized mover was applied to a high-speed eddy current braking system. Based on analytical 2-D field solutions considering dynamic end effect, the magnetic field, eddy current distribution, and forces according to the secondary relative permeability and conductivity were presented. It was observed that the air-gap flux density has a non-uniform distribution for the high speed. Comparisons between numerical simulations and experimental data were also presented.

Authors: Andrew H. C. Gosline, Student Member, IEEE, and Vincent Hayward, Fellow, IEEE The pertinent background to dissipative actuation and passivity control of haptic interfaces were first discussed to familiarize the reader with the focus of this paper. Basic eddy current brake physics were presented, the design of an ECB damper for the Pantograph haptic interface was described, and results from an experimental optimization of damping hardware were discussed. A prior existing time domain passivity control methodology was adapted for the use of physical damping, rather than virtual. The physically damped passivity controller was shown to improve stability of virtual stiff wall. The authors would like to note that virtual walls rendered using the physical dampers do not have the characteristic “sticky” feel that is
typical of walls increases considerably. There are also limitations to the use of physical dampers for passivity control. First, as this method is dependent on additional hardware, a haptic interface would have to be equipped with programmable physical dampers to make use of this method. Second, the dampers actuate slower than the motors, the system energy could be in the active region longer than if virtual damping was used.

Authors:- Kapjin Lee, Kyihwan Park In order to solve the problems of the conventional hydraulic systems such as time delay response due to pressure build-up, brake pad wear due to contact movement, bulky size, and low braking performance in a high speed region, an eddy current brake system is developed and its performance is investigated by using a scaled model. Braking torque analysis is performed by using an approximate theoretical model and the braking torque is experimentally compensated. Optimal torque control which can shorten the braking distance is achieved by maintaining a desired slip ratio which gives the maximum braking force coefficient. A sliding mode controller is used for the optimal torque controller. From simulation and experimental results, it is observed that the eddy current brake (ECB) provides a fast braking response because it is capable of fast anti-lock braking.

Baoquan Kou et al [2015] [2], in this paper, a novel hybrid excitation linear eddy current brake was presented. The hybrid excitation linear eddy current brake has the advantages of high force density and low excitation loss compared to the electric excitation linear eddy current brakes. The validity of the analytical model was verified by the FEM and experimental tests, therefore the analytical model can be used in the preliminary design of eddy current brakes. Parametric analysis was performed to explore the influence of the design parameters on the eddy current brake performance. Moreover, the experimental results show that the eddy current brake can generate objective braking force using the controller proposed in this paper. It has been found that the proposed eddy current brake system can be used in road and rail vehicles. Effect of parameters on the performance of ECBS has also been discussed. Experimental results show very good slip regulation in a braking event on the low friction coefficient surface when compared with the non-ABS braking condition. The results show that the proposed ABS controller provided a smooth ABS stop as evident from the vehicle speed plots.
MAIN COMPONENTS OF THE CONTACTLESS EDDY BRAKES

The main components that are used in the fabrication of our project is listed in below,

1. Electromagnets
2. Rotor Disc
3. DC Motor
4. Battery
5. V-Belt.

ELECTROMAGNETS

Electromagnets are DC type that can be powered by battery. Electromagnets are selected instead of permanent magnet as electrical actuation is faster than mechanical actuation with lower losses.

ROTOR DISC

The figure for disc is given in below. This disc is the main component which supports the whole blade arrangement which is made up of mild steel. It is used for breaking purpose and generating the Eddy current. A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc in order to create friction that retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. The energy of motion is converted into waste heat which must be dispersed.

DC MOTOR

12V DC Series motor is used in this experiment, which converts electrical energy into mechanical energy. Its location is based on the principal that when a current carrying Conductor is placed in the magnetic field, it experiences a mechanical force whose direction is given by Fleming’s left hand rule.

BATTERY

Despite having a very low energy-to-weight ratio and a low energy to volume ratio, their ability to supply high surge currents means that the cells maintain a relatively large power to weight ratio. 12V Lead acid battery are used which are connected in series. They could deliver 4Amps.

V-BELT

V belts solved the slippage and alignment problem. They provide the best combination of traction, speed of movement, load of the bearings, and long service life. The V shape
of the belt tracks in a mating groove in the pulley, the belt cannot slip off. The belt also tends to wedge into the groove as the load increases the greater the load, the greater the wedging action improving torque transmission and making the V-belt an effective solution, needing less width and tension than flat belts. Optimal speed range is 300–2,130 m/min.

**DESIGN PARAMETER:**

The design of an eddy current brake reduced to five optimization problems which are discussed in the proceeding sections.

1. **ROTOR MATERIAL**
   
The material of the rotor disc must also be optimized in order to minimize the time constant, $\tau$ and minimize the disc’s moment of inertia, $I$. There are two strong candidates in our selection of material which are copper and aluminum.

$$\tau = \frac{I}{b} = \frac{2\rho R^2}{\pi \sigma D^2 B^2}$$

<table>
<thead>
<tr>
<th>Material</th>
<th>Density [Kg/m³]</th>
<th>Specific conductivity [S/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper</td>
<td>8.9</td>
<td>58.0</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2.7</td>
<td>38.5</td>
</tr>
</tbody>
</table>

2. **ROTOR DISC THICKNESS**

The thickness of the rotor disc, $d$, must also be optimized in order to minimize the time constant, $\tau$ and minimize the disc’s moment of inertia, $I$. The inertia of the disc is linearly proportional to the thickness, so minimizing the disk radius minimizes the disk inertia. The time constant does not depend on the disc thickness. Thus, the optimization problem reduces to minimizing disc thickness while maintaining structural rigidity.

$$I = \frac{1}{2} \rho d \pi R^4$$

$$\tau = \frac{I}{b} = \frac{2\rho R^2}{\sigma D^2 B^2}$$

3. **ROTOR DISC RADIUS**

The radius of the rotor disc, $R$, must also be optimized in order to minimize the time constant, $\tau$ and minimize the disc’s moment of inertia, $I$. The inertia of the disc is proportional to the radius to the fourth power, so minimizing the disk radius minimizes the disk inertia.

$$I = \frac{1}{2} \rho d \pi R^4$$

$$\tau = \frac{I}{b} = \frac{2\rho R^2}{\sigma D^2 B^2 n}$$

$$\phi(R) = BD(R)n(R)$$
CALCULATION OF POWER DISSIPATION BY CONTACTLESS EDDY CURRENT BRAKES:

Under certain assumptions (uniform material, uniform magnetic field, no skin effect, etc.) the power lost due to eddy currents per unit mass for a thin sheet or wire can be calculated from the following equation

\[
P = \frac{\pi^2 B_p^2 d^2 f^2}{6k \rho D}
\]

Where:

- \( P \) is the power lost per unit mass (W/kg),
- \( B \) is the peak magnetic field (T),
- \( d \) is the thickness of the sheet or diameter of the wire (m),
- \( f \) is the frequency (Hz),
- \( k \) is a constant equal to 1 for a thin sheet and 2 for a thin wire,
- \( \rho \) is the resistivity of the material (m),
- \( D \) is the density of the material (kg/m³).

CALCULATION OF BRAKING TORQUE:

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

Where, the electrical conductivity of the rotating disk and sheet thickness rotating disk should be known, \( r \) = radius of electromagnet, \( m \) = distance of disc axis from pole-face center, \( B_Z \) = Magnetic flux density, \( a \) = disk radius

CALCULATION OF TORQUE GENERATED IN DISC:

\[
\tau_{diss} = n \frac{\pi \sigma}{4} D^2 d B^2 R^2 \theta
\]

The magnitude of the braking torque, \( \tau d \) [N m] can be theoretically derived to be a function of the number of magnets around the wheel, the specific conductivity of the material, \( \sigma \) [Ω -1 m-1], the diameter of the magnet core \( D \), the thickness of the disk \( d \), the magnetic field \( B \), the effective radius \( R \), and the instantaneous angular velocity \( \theta \).

However, the equation shown above is given under the assumption that the primary magnetic field is sufficiently greater than the induced magnetic field.
WORKING OF CONTACTLESS EDDY BRAKING SYSTEM

When the vehicle is moving, the rotor disc of eddy current brake which is coupled to the wheels of the vehicle rotates, in close proximity to stationary magnetic poles. When we want to brake the vehicle, a control switch is put on which is placed on the steering column in a position for easy operation.

When the control switch is operated, current flows from a battery to the field winding, thus energizing the magnet. Then the rotating disc will cut the magnetic field. When the disc cuts the magnetic field, flux changes occur in the disc which is proportional to the strength of the magnetic field. The current will flow back to the zero field areas of the metal plate and thus create a closed current loop like a whirl or eddy. A flow of current always means there is a magnetic field as well. Due to Lenz’s law, the magnetic field produced by the eddy currents, work against the movement direction. Thus instead of mechanical friction, a magnetic friction is created. In consequence, the disc will experience a “drag” or the braking effect, and thus the disc stops rotation. The wheels of the vehicle, which is directly coupled to the disc, also stop rotation. Faster the wheels are spinning, stronger the effect, meaning that as the vehicle slows, the braking force is reduced producing a smooth stopping action. The magnetic field of this eddy current produces a breaking force or torque in the opposite direction of rotation disc. This kinetic energy of rotor is converted as heat energy and dissipated from rotating disc to surrounding atmosphere. Current in the field can change by changing the position of the controls switch. Thus we can change the strength of the braking force.

CONCLUSION

The use of eddy current braking system we can reduce the wear, maintenance cost, increased durability is achieved. Hence, due to all these factors, overall cost is reduced. Eddy current braking system is used for dynamic braking. Due to its various applications as discussed earlier, it can use as a secondary braking system.
REFERENCES


