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A Study about Eddy Current Brakes

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Abstract-- Many of today's popular brakes work through mechanical blocking to stop the vehicle. This results in vehicle skidding and wear and tear. And, if the vehicle's speed is very high, the brake would be unable to provide too much high braking power, causing problems. The eddy current brake, a simple and efficient braking device, can overcome these disadvantages of ordinary brakes. It is an abrasion-free braking system for vehicles and trains. It makes use of the eddy current's opposing tendency. The swirling current generated in a conductor when the magnetic field changes are known as eddy current. Eddy currents waste energy because they appear to contradict each other. Eddy currents, more precisely, convert more useful sources of energy like kinetic energy into heat, which is much less useful. The loss of usable energy is not especially desirable in many applications. However, there are several implementations in the real world. The eddy current brake is one such application..

History-- François Arago (1786–1853), the 25th Prime Minister of France and a mathematician, physicist, and astronomer, was the first to note eddy currents. In 1824, he discovered rotatory magnetism and the ability to magnetize most conductive bodies; Michael Faraday (1791–1867) completed and clarified these findings.

Heinrich Lenz established Lenz's law in 1834, which states that the direction of induced current flow in an entity is such that its magnetic field opposes the change in magnetic flux that produced the current flow. Eddy currents generate a secondary field that cancels out a portion of the external field and allows some external flux to bypass the conductor.

Eddy currents are said to have been discovered by French physicist Léon Foucault (1819–1868). In September 1855, he discovered that when a copper disc is rotated with its rim between the poles of a magnet, the force needed for rotation increases, and the disc becomes heated as a result of the eddy current produced in the metal. In 1879, David E. Hughes used eddy current to perform metallurgical sorting experiments, which was the first time it was used for non-destructive testing.

I. INTRODUCTION

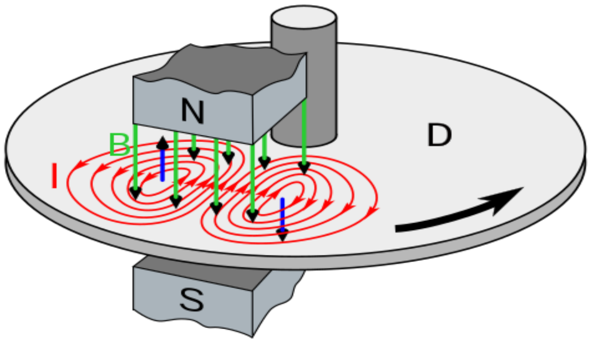
An eddy current brake, also known as an induction brake, electric brake, or electric retarder, is a mechanism that uses heat to slow or stop a moving object. Unlike friction brakes, which use friction between two surfaces pressed together to stop a moving object, an eddy current brake uses an electromagnetic force between a magnet and a nearby conductive object in relative motion to stop the moving object, due to induced eddy currents in the conductor by electromagnetic induction.

As explained by Faraday's law of induction, a conductive surface moving past a stationary magnet will have circular electric currents called eddy currents induced in it by the magnetic field. According to Lenz's law, circulating currents generate their own magnetic field, which opposes the magnet's field. As a result, the magnet will exert a drag force on the moving conductor. It's in motion, and its speed is proportional to it. The heat generated by the current flowing through the electrical resistance of the conductor dissipates the kinetic energy of the moving object. In an eddy current brake, the magnetic field may be created by a permanent magnet or by a permanent magnet. By changing the electric current in the electromagnet's windings, the braking force can be switched on and off or varied. Another benefit is that, unlike friction brakes, there are no brake shoe surfaces to wear out and need replacement, as there are with friction brakes. There is no brake on the vehicle. Retaining power Eddy current brakes are used to slow high-speed trains and rollercoaster’s, as a supplement for friction brakes in semi-trailer trucks to help prevent brake wear and overheating, to quickly stop powered tools when power is turned off, and in electric meters in electric utilities.

II. PRINCIPLE OF OPERATION

Faraday's law of Lenz electromagnetic induction governs the use of an eddy current brake. When a conductor cuts magnetic lines of force, an emf is induced in the conductor, the magnitude of which is proportional to the strength of the magnetic field and the speed of the conductor. If the conductor is a disc, circulatory currents, or eddy currents, will be induced in the disc. The current is guided in such a way that it opposes the cause, i.e. disc movement, according.

Eddy current brakes are made up of two parts: a stationary magnetic field mechanism and a solid rotating component with a metal disc. The metal disc is subjected to a magnetic field from an electromagnet during braking, which generates eddy currents in the disc. to Lenz's rule. The spinning disc is slowed by the magnetic interaction between the applied field and the eddy currents. Since the wheels are directly attached to the disc of the eddy current brake, the vehicle's wheels slow down as well, resulting in a smooth stopping motion.



III. THEORETICAL FOUNDATION

Induced currents appear when electrical conductors undergo conditions of variable magnetic flux. In particular, we talk about eddy currents when bulk conductor pieces instead of wires are involved. There are two basic procedures to achieve such conditions:

• exerting a time-varying magnetic field on a static piece;

• exerting a steady magnetic field on a moving one.

We'll look at an example of the latter category. It is made up of a spinning metallic disc that is subjected to the magnetic field generated by an electromagnet's gap. Inside the disc, eddy currents emerge and stop the rotation. The electromagnetic braking systems used by heavy vehicles such as trains, buses, and lorries are built on this basis. The pattern of eddy currents is complex even in such a geometrically simple case. However, an approximate expression for the power dissipated by eddy currents is simple to obtain. The induced electric field in each point of the disc is given by E = v B, where v is the velocity of that point [4], because the magnetic field B is constant. Rather than calculating B directly, we'll use the excitation current Iex in the electromagnet coil, which is easily observable. For the time being, we'll say B is proportional to Iex (the validity of the hypothesis).

This theory will be explored later, since it is not valid for magnetic media). Then there was the

The following proportionality rule applies:

$E \propto \omega Iex$

Where ω is the angular speed of the disc. This means that for any loop of eddy current the induced electromotive force, being the line integral of the induced field, is also proportional to ωIex . Finally, the basic laws of electric current state that the power dissipated in that particular loop are proportional to the square of the electromotive force and to the inverse of the electrical resistivity of the disc. The same holds for the power dissipated in the whole disc: Pe = K ω2/2

IV. CONSTRUCTION AND WORKING

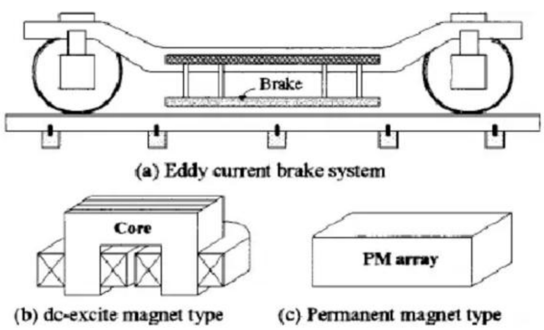
Eddy current brakes are made up of two parts: a stationary magnetic field system and a solid rotary member usually made of mild steel, which is referred to as the secondary because it is where the eddy currents are induced. Two members are separated by a small air distance, and there is no interaction between them for torque transmission purposes. As a result, unlike a friction brake, there is no wears in friction brake

Pole heart, pole shoe, and field winding make up a stator. The pole centre is wounded by the field winding. Pole cores and pole shoes are made of east steel laminations and are screwed or bolted to the state of the frames. The winding material is made of copper and aluminum.

1. Stator
2. Rotor

The rotor disc of an eddy current brake, which is attached to the vehicle's wheels, rotates in near proximity to stationary magnetic poles while the vehicle is moving. When we want to stop the car, we turn on a control switch that is mounted on the steering column in a convenient location.

When the control switch is pressed, current is directed from a battery to the field winding, thus energising the magnet. The magnetic field would then be cut by the spinning disc. When the disc cuts the magnetic field, it causes flux shifts in the disc that are proportional to the magnetic field's power. The current would flow back to the metal plate's zero field regions, forming a closed current loop similar to a whirl or eddy. A magnetic field is still present when there is a current flow. The magnetic field created by eddy currents works against the movement direction due to Lenz's law.



As a result, magnetic friction is produced instead of mechanical friction. As a result, the disc will experience a "drag" or braking effect, and the disc will come to a halt. The vehicle's wheels, which are directly coupled to the disc, often come to a halt. The greater the speed at which the wheels rotate, the greater the impact, which means that as the vehicle slows, the braking force is decreased, resulting in a smooth stop.

The control switch can be placed in a variety of positions to control the excitation current to a variety of preset values in order to regulate the magnetic flux and, as a result, the magnitude of the braking force. i.e., if the vehicle's speed is lpw, only a small amount of braking force is needed to bring it to a stop. As a result, the control switch is set to the lowest location, supplying a low current to the field winding. The magnetic field generated will then be of low strength, resulting in the necessary low braking force.

V. TYPES OF EDDY CURRENT BREAKS

A. Disk Type:

When the power is switched off, disc electromagnetic brakes are used on vehicles such as trains and power tools such as circular saws to rapidly stop the blade. A disc eddy current brake is made up of a conductive non-ferromagnetic metal disc (rotor) fixed to the axle of the vehicle's wheel and an electromagnet with poles on both sides of the disc, allowing the magnetic field to move through it. The braking force can be varied thanks to the electromagnet. There is no braking force as no current is passing through the electromagnet's winding. Current is transmitted through the electromagnet windings as the driver presses the brake pedal, producing a magnetic field. The stronger the braking force, the stronger the eddy currents and the greater the current in the winding. Permanent magnets are used in power tool brakes, and when the power is switched off, a connection moves them adjacent to the disc. The kinetic energy of the vehicle's motion is dissipated in Joule heating by eddy currents moving through the disk's resistance, causing the disc to become hot, much like traditional friction disc brakes. Since the metal of the disc moves through the magnetic field repeatedly, unlike the linear brake below, disc eddy current brakes get hotter than linear eddy current brakes.

B. Linear Type

Linear eddy current brakes are used on some rail vehicles, such as trains. They are used on roller coasters, to stop cars smoothly at the end of the ride. The linear eddy current brake consists of a magnetic yoke with electrical coils positioned along the rail, which are being magnetized alternating as south and north magnetic poles. This magnet does not touch the rail, but is held at a constant small distance from the rail of approximately 7 mm (the eddy current brake should not be confused with another device, the magnetic brake, which exerts its braking force by friction of a brake shoe with the rail).It operates similarly to a disc eddy current brake in that it induces closed loops of eddy current in the conductive track, which produce counter magnetic fields that oppose train motion.

Figure: Linear Eddy current breaks in roller coasters

The eddy current flowing through the electrical resistance of the rail converts the kinetic energy of the moving vehicle into heat, causing the rail to warm. Since each section of rail passes only once through the magnetic field of the brake, as opposed to the disc brake, which passes each section of the disc through the brake several times, the rail does not get as hot as a disc, allowing the linear brake to dissipate more energy and have a higher power rating.

The eddy current brake has no mechanical contact with the rail, so it does not wear out, and it makes no noise or odour. The eddy current brake is ineffective at low speeds, but it can be used for emergency and service braking at high speeds.[1]

According to the EU's TSI (Technical Specifications for Interoperability) for trans-European high-speed rail, all newly constructed high-speed lines should be able to use the eddy current brake.

This method of braking is used on modern roller coasters. They use permanent magnets instead of electromagnets to avoid the possibility of power outages, and therefore do not need a power supply. This application does not have the same ease of adjustment of braking power as electromagnets.

VI. EDDY CURRENT BREAKS IN TRAINS

The part of the train where the eddy current is caused is the track. An electromagnet is formed by wrapping the brake shoe in a coil. Eddy currents are caused in the rail by electromagnetic induction when the magnet is energized, reslting in braking action

Figure: Eddy current Breaking system used in trains

VII. AIR COOLED EDDY CURRENT BREAKS

The Dynamatic® Air-Cooled, Adjustable Torque Eddy-Current Brakes are made up of a rotating disc that is cooled by air. A stationary brake coil and a member (rotor) keyed to a straight-through double extension shaft. At variable speeds, the brake applies regulated deceleration. Between rotating and stationary members, there is no physical contact. This results in a smooth response, which eliminates shock loading and extends the life of the equipment.

An externally mounted tachometer generator can be added to these brakes to provide a feedback signal to the brake controller. The brake coil receives DC excitation from the controller. To provide reliable, smooth, regulated braking or constant speed during the time of excitation, the feedback signal from the tachometer generator is compared against a reference signal within the controller. With highly precise torque changes, constant torque can be achieved. The controllers for the brakes are described in the Product Catalog.

VIII. LIQUID COOLED EDDY CURRENTS BREAKS

A rotating member (rotor) keyed to a straight through double extension shaft, a stationary brake coil, and an automatic water piping flow through cooling system make up liquid cooled eddy-current brakes. At variable speeds, the Eddy-Current brake applies regulated deceleration. There is no physical interaction between the input and stationary members by using the Eddy-Current torque transmission theory. This results in a smooth response, which eliminates shock loading and extends the life of the equipment.

An optional tachometer generator mounted internally in Eddy-Current brakes can provide a feedback signal to the brake controller. The DC excitation is given by the controller. The tachometer generator's feedback signal is compared to a reference signal inside the controller. Provide precise, smooth, regulated braking or maintain a constant speed for the duration of the trip excitement with highly precise torque changes, constant torque can be achieved.

There are two types of eddy current brakes according to the method of excitation.

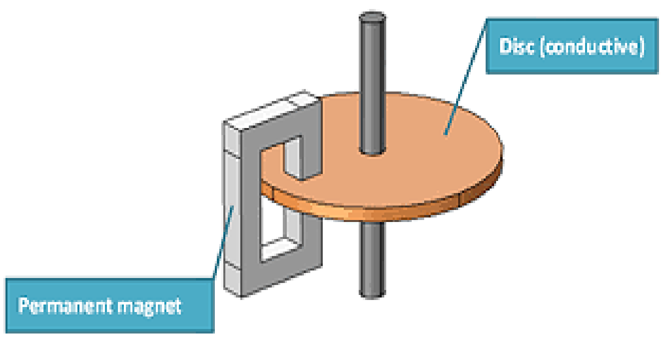
1. Electrically excited eddy current brake:

Electrically excited eddy current brakes are a no-abruption braking system. They are a good alternative to the mechanical rail brakes that are currently used in high-speed trains

The brake comes into contact with the rail during braking, and the magnetic poles of the brakes are energized by a supplied winding. Brake magnetic poles are energized by a winding that receives current from the battery. The magnetic flux is then dispersed through the rail. In the rail, eddy currents are produced, resulting in an electromagnetic braking force. If the electrical power supply fails, this form of braking requires an external safety power supply.

2. Permanent magnet eddy current brake:

For subways, trams, and local trains, permanent magnet eddy current brakes have been created. To switch the magnets on and off, these brakes require a mechanical actuator. The primary benefit of this form of brake is its protection. To energies the magnet, it does not require an electric supply.



IX. MODELING EDDY CURRENT BREAKS

Assume you're building an eddy current brake and want to know how big the permanent magnet needs to be to provide enough torque to slow down the vehicle (train, roller coaster, car...) in a reasonable amount of time. In this case, we're assuming that the induced current distribution does not travel with the spinning disc, but rather remains stationary near the magnet. When modeling electromagnetic with moving magnetic sources or where the moving domain is of bounded extent in the same direction as the motion or differs in this direction, the induced Lorentz current density term often causes confusion. Magnetic flux produced by these types of moving sources is not included in the Lorentz definition. To be sure, the induced current distribution in our case is stationary, not moving with the disc. Assume you have a copper disc that is 1 centimeter thick, has a radius of 10 centimeters, and rotates at 1,000 revolutions per minute. The 1 T permanent magnets is attached by an iron yoke, and the disc will spin in a 1.5 cm gap of air. As shown in the figure's 1, 2

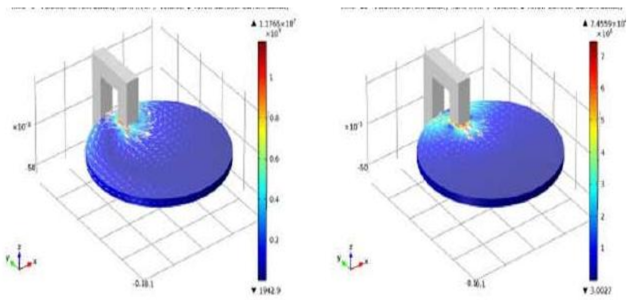


Figure: 3D model showing eddy current density and directionatt=0s and 3D model showing Eddy current densityatthe=25s

You can calculate how much torque your brake system would have using COMSOL Multiphysics and the AC/DC Module. It's worth noting that you can use the device's rotation without using a moving mesh. A dynamic equation (which describes the rotation of the disc) is combined with the finite element approach in the magnetic brake model (this defines the torque). This will allow you to figure out how long it will take to fully stop the machine.

In your magnetic brake system, we can also plot the time evolution of angular velocity, braking torque, and dissipated power. As shown in the below graph 1,2,3

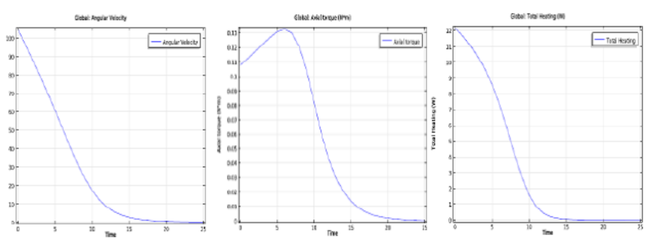


Figure: Graph 1: Time evolution of angular velocity, Graph 2: Time evolution of dissipated power, Graph 3: Time evolution of breaking torque

X. BREAKING POWER CALCULATIONS

For the design of eddy current brakes, sophisticated measurement methods for determining braking forces are critical. The drag or braking force on a thin non-magnetic disc, such as copper, for a simple eddy current brake where H denotes the frequency of the magnetic field in Webers. A = Area of the pole force in cm2. V = Velocity of the disc's mean radius under the poles in cm/sec. T stands for disc thickness in centimetres.ρ = micro ohms/cm3 specific resistance of disc material at operating temperature. F * R Nm = Torque Where R denotes the average pole radius in metres. P = 2 πNT/60 watts of power

XI. EDDY CURRENT BREAK REQUIREMENTS

An eddy current brake is an energy converter that converts a vehicle's kinetic energy into heat and dissipates it at a rate that keeps the unit's temperature within acceptable limits during maximum and sustained braking. The energy consumed by the brake is converted to heat by the currents generated in the motor, and this heat is then dissipated in the surrounding air by the medium of appropriately shaped fins on the rotating member.In mountainous areas, where continuous braking force is needed for an extended period of time (say, half an hour), eddy current braking is more suitable for operation without overheating. The application of these retarders is not restricted to mountainous terrain. On city roads with few stops, they can be usefully used on public transportation buses. However, in this braking scheme, the vehicle is at rest without any braking force. As a result, the eddy current brake is used as a heavy-duty auxiliary retarder. The use of an auxiliary retarder ensures very smooth retardation and reduces the likelihood of skidding on slick road surfacesSince the brake is used as an auxiliary heavy-duty retarder, smooth braking operation reduces tier were. The use of an auxiliary retarder ensures very smooth retardation and reduces the likelihood of skidding on slick road surfaces. Since traditional brakes are relieved of heavy duty and are only needed to bring vehicles to a stop, smooth braking operation reduces tier were..

XII. MOUNTING AND INSTALLATION

A standard eddy current brake mounting consists of two pole salient style discs supported between the frame numbers of a vehicle chassis. The rotor is connected to the vehicle's wheels through a shaft that runs between the gearbox and the propeller shaft, while the stator is attached to the vehicle's frame. The driver, who can choose between one and four excitation settings depending on the breaking effect needed, instals a control switch on the steering column in a convenient location.

The switch's operative positions 1, 2, 3, and 4 contractors are energised to supply current to the retarder's excitation windings. When the retarder is turned on, a warning lamp illuminates on the instrument panel. This protects the driver from accidentally turning on the unit when the vehicle is stopped.

XIII. ADVANTAGES AND DISADVANTAGES

Eddy-current brakes, on the other hand, are silent, frictionless, and wear-free, and they need little or no maintenance. Unlike friction brakes, which can release toxic "particulates" (microscopic bits of dust and metallic fragments) into the atmosphere, they emit no odour or emissions. All of this makes them much more appealing than noisy friction brakes, which need routine maintenance and sometimes wear out. Switching an electric train from friction brakes to eddy-current brakes is expected to cut the cost of brake operation and maintenance in half over the course of its lifetime.

The edyy current brake's biggest drawback is that it needs electric power to operate. Researchers are working to solve this problem by making the brake regenerative that is, transforming the vehicle's kinetic energy into electric energy and storing it in the battery. The disadvantages of eddy current brakes stem from our lack of experience with them in real-world situations. The electromagnetic parts of eddy current brakes have occasionally caused problems by interfering with train signaling equipment, as Jennifer Schakowsky noted in an excellent review of the technology for Railway Gazette in 2008. While heat dissipation in rails should not be an issue in theory, high-speed trains' brakes must be extremely strong, so the heating effect may be important. If there is a busy section of track where several trains brake in rapid succession (such as the approach to a station), rail heating and expansion could be a concern, reducing the effectiveness of the brakes or causing structural problems in the tracks.

Another important question is whether eddy-current braking would ever be widely used, considering the increasing interest in regenerative brakes, which absorb and store energy from moving vehicles for later use (a much more energy-efficient approach than turning energy into useless heat with eddy currents). Regenerative brakes are used on some of the most recent Shinkansen trains (series E5), whereas earlier versions used eddy-current technology. It's possible to say that the two technologies are diametrically opposed: eddy current brakes waste energy while regenerative brakes save it. Both types of braking can add considerable weight to a vehicle (an eddy current train brake can weigh almost a tonne), which reduces fuel economy and efficiency, but at least regenerative brakes

XIV. APPLICATION

Eddy current breaks are mainly used for increased protection on long decants in mountainous areas for high-speed passenger and cargo vehicles

Because of their jerk-free operation, eddy current brakes are excellent replacements for conventional brakes, which are now used in both road vehicles and trains. Eddy current braking is very useful for working without overheating in mountain areas where continuous braking force is needed for a long time. Eddy new brakes are extremely useful for high-speed travelers and high-quality automobiles. It can also be used to slow down quicker roller coaster trolleys.

CONCLUSION

Where the highest levels of reliability and safety are needed, eddy current brakes are the best option. They work even in the harshest of environments. Even a lightning strike would not result in a loss of braking power. The eddy current braking mechanism is no longer widely used. However, we hope that the eddy current braking system, which is simpler and more reliable, will eventually replace the conventional braking system, and that it will be the standard in a few years.

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