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DESIGN AND OPTIMIZATION OF AN ELECTROMAGNETIC FRICTIONLESS BRAKING SYSTEM FOR AUTOMOTIVE APPLICATIONS

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Abstract
Rolling wheels of any kind has some form of braking system by which it can decelerate and stop as and when necessary. When the mass of the stock and speed of the wheel increases, the braking system needs to be more robust and powerful. A braking system that can stop the vehicle or reduce the vehicle speed as quickly as possible is always desirable. The conventional braking system which is predominantly used works on the basic principle of friction to stop the moving wheel. An electromagnetic (EM) braking system is an alternate method of braking which is frictionless, less maintenance and works on the basic principle of eddy currents and electromagnetism. Here, an attempt has been made to fabricate a prototype model of an EM braking system for use in automobiles and the responses are recorded for varied load conditions. The results show that the EM braking systems will be a potent braking system in automotive industry and will warrant further explorations.

Keywords: *electromagnetic braking, eddy currents, magnets, friction, electromagnetic flux,*

I. Introduction

The automotive industry has been a significant sector since the 19th century and the braking system remains one of the most crucial components of vehicle safety whose efficiency is expected to be high so as to avoid fatalities. The brakes are important components that stop or slow down the movement of a moving object. In the conventional braking system, as the driver presses the brake pedal, the brake shoes are pushed against the drum of the wheel and this causes braking due to friction. The brake shoes require time to time maintenance due to its wear and tear and hence increased maintenance costs. To address this challenge an electromagnetic braking system could be used. This is basically a contactless system that operates by inducing eddy currents opposing the wheel’s rotation and eventually leading to braking and slowing or stopping down the movement. Ayush Gupta, et al, discusses Electromagnetic braking has several advantages over other braking systems. One of the main advantages of electromagnetic braking is that it can provide smooth and precise braking control [4]. Alumona. L. O, et al, observed the EM braking system could generate high braking forces without causing wear and tear to the braking components [2]. Additionally, it is less prone to failure than other types of braking systems, as there are no mechanical parts that can wear out or break. In general, electromagnetic braking is a dependable and effective braking technique that has been widely adopted in a variety of industrial applications [4].

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II. PRINCIPLE

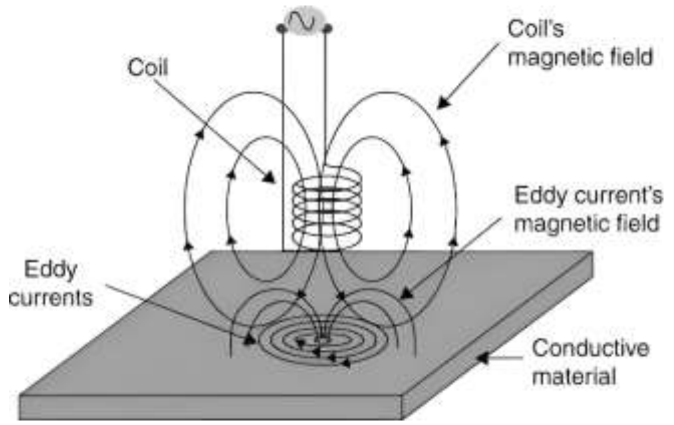

Figure 1. [Courtesy: P. Rizzo, in Sensor Technologies for Civil Infrastructures]

The principle of electromagnetic braking is based on the interaction between a magnetic field and an electric current. When a magnetic field is applied to a conductor carrying an electric current, the two interact and generate a force perpendicular to both the current and the magnetic field[9, 24]. In electromagnetic braking, this force is used to slow down or stop a moving object.
The braking system consists of a magnetic field and a conductor, usually a metal disc or drum, that rotates around an axis. When the brakes are applied, say when the magnetic field is activated, creating a force that opposes the rotation of the conductor[15]. This force slows down the conductor and the object it is attached to, bringing it to a stop.
In short, eddy current brakes use the electromagnetic induction principle to create a magnetic field that acts as a braking force[4]. Eddy currents are produced when conductive materials, like a metal discs, move through a magnetic field. These eddy currents produce their own magnetic field, which opposes the motion of the primary magnetic field and produces a braking force that slows or stops the moving object [3]

III. ELECTROMAGNETIC BRAKES & EDDY CURRENT BRAKES

There are significant parallels between electromagnetic brakes and eddy current brakes. In order to create a magnetic field that interacts with the conductive material in the brake rotor and produces a braking force that slows or stops the rotor, both types of brakes rely on the electromagnetism principle. Both kinds of brakes can be modified to meet the requirements of a specific application and offer fine control over the braking force. Although eddy current brakes are a particular kind of electromagnetic brake, it's crucial to understand that not all electromagnetic brakes rely on eddy currents.
A common type of electromagnetic brake uses a magnetic field generated by an electromagnet to create a force that opposes the motion of a moving object. When the brake is applied, the magnetic field exerts a frictional force on the brake's stationary and moving parts, converting the energy into thermal energy in the process of slowing it down or bringing it to a stop, thus producing heat, the strength of the magnetic field, the speed and mass of the moving component, the length and frequency of the braking cycle, and other variables all affect how much heat is produced by an electromagnetic brake [15].
In an eddy current electromagnetic brake, the electromagnet is energized when the brake is applied. This produces a magnetic field that pulls on a metal disc or plate attached to the object being braked, slowing or stopping it. Eddy current brakes and other electromagnetic brakes are used in a range of

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applications, such as industrial machinery, roller coasters, and railroads, where traditional friction brakes would not be effective [4].

One of the main advantages of electromagnetic brakes is their high braking force, which makes them well-suited for heavy-duty applications. However, they can be prone to wear and tear and require regular maintenance to ensure they continue to function properly. Eddy's current brakes, on the other hand, are generally more reliable and require less maintenance, but they may not provide as much stopping power as electromagnetic brakes in certain applications [12].
In summary, both electromagnetic brakes and eddy current brakes are effective braking systems that use the principles of electromagnetism to bring a moving object to a rest. The choice between the two depends on the specific application and the required level of braking force, with electromagnetic brakes being better suited for heavy-duty applications and eddy current brakes being more appropriate for high-speed applications [12].

IV. ELECTROMAGNETIC FLUX

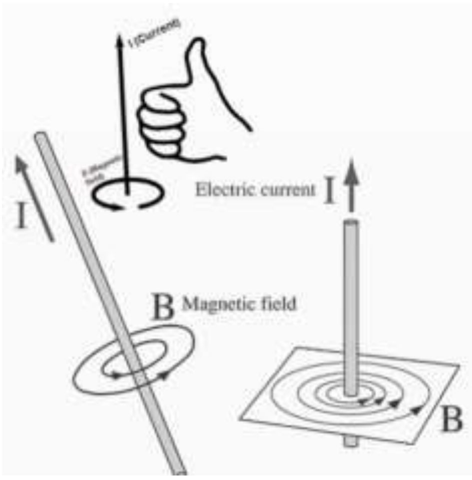


Figure 2. Magnetic flux

The V-1 Right-hand thumb rule: If a piece of copper wire was wound around the nail and then connected to a battery, it would create an electromagnet. The magnetic field that is generated in the wire, from the current, is known as the "right-hand thumb rule"[3]. (V-1) The strength of the magnetic field can be changed by changing both wire size and the amount of wire (turns). EM clutches are similar; they use a copper wire coil (sometimes aluminium) to create a magnetic field. The fields of EM brakes can be made to operate at almost any DC voltage and as long as the appropriate operating voltage and current are employed with the appropriate brake, the torque generated by the brake will remain constant. If a 90-volt brake had 48 volts applied to it, this would get about half of the torque output of that brake but it is only true if the voltage/current relationship is almost linear, which is not necessarily true for all brake designs. This is because voltage/current is almost linear to torque in DC electromagnetic brakes. A constant current power supply is ideal for accurate and maximum torque from a brake. If a non-regulated power supply is used the magnetic flux will degrade as the resistance of the coil goes up. Basically, the hotter the coil gets the lower the torque will be produced by about an average of 8% for every 20°C but can vary depending on the design. If the temperature is fairly constant, and there is a question of enough service factor in the design for minor temperature fluctuation, by slightly oversizing the brake can compensate for degradation in some cases. This will allow the use of a rectified power supply, which is far less expensive than a constant current supply.

V. LITERATURE SURVEY

Ayush Gupta, et al (2023), observed the electromagnetic braking system is an important area of research in the field of automotive engineering, with significant potential to overcome the limitations of conventional braking systems [4].

Lei Li, et al (2023) applied EM braking technology to artillery, conducting prototype tests and analyzed the dynamic mechanical characteristics of NdFeB and found the results more suitable..Numerical simulations confirm NdFeB's suitability, with damage value distribution provided as a reference for future EMB use and maintenance [9].

Prashant Sinha, et al, (2023) observed through FEM and experimental studies with multiple electromagnets and multidisc brakes, improve the performance and torque of MR brakes and minimizing power loss [17].

CaoTan, et al, (2022) observed that the braking-by-wire system based on electromagnetic direct drive valves solves existing problems such as complex hydraulic pipelines and insufficient response speed. [6].

Vishwjeet V. Ambade, et al, (2022) compared electromagnetic braking with traditional exhaust brakes and found that EM brakes prevent accidental harm [22].

Ashutosh Kumar, et al (2021), Stated that EM braking systems are cheaper, reliable and more resistant to failure compared to oil or air braking systems which has the possibility of leakage [3].

Dr. A. H. Ingle, et al (2021) [7] observed that the automatic EM braking system could be used as a secondary braking system and cannot replace regular brakes.

Faizal Mohamed, et al, (2021) observed that EM brakes are non-contact, low maintenance, superior control, reduce accidents, reliable, eco-friendly, easy installation, and versatile in automobiles and aeronautics [8].

Yash Gandhi, et al, (2021) verified that Combining electromagnetic and magnetic brakes can overcome the drawbacks of each system [23].

Lokhande B E, et al (2020) confirmed that a four-disc electromagnetic brake system with individual coils and firing circuits on each wheel ensures redundancy in case of coil failure. Prevents accidents [10].

Momin GG, et al (2020) Observed that EM braking system offers hope for energy scavenging in terms of automotive braking energy waste. [13].

M. Sampathkumar, et al (2019) [11] studied and developed an EM brake system for brakes that work with equipment, autos, and movers. Suitable for 10-380mm drums, with a range of torque and AC/DC power.

Sudarshan. T. A, et al, (2018) observed EM brakes make up 80% of power-applied brake applications, providing effective braking, accident prevention, reduced heat-related risks, and cost savings [21].

Mahadeo Gurav, et al, (2017) experimented Eddy's current braking system is a very great innovation on its own and is specially made for the purpose to stop the wheel in minimum time. [12].

Alumona. L. O, et al, (2016) This paper studied Eddy current braking using a rotating magnetic field and found it to be effective at low vehicular speeds [2].

Oscar Rodrigues, et al (2016) [15] compared theoretical and practical braking time to establish an air gap limit for the effective performance of electromagnetic brakes. Results showed a 23.97% reduction in braking time.

Rhythm Dhoot, et al (2016) studied aluminium & copper brake discs in an electromagnetic braking system. Aimed to determine the best material & current for Eddy's current project [19].

Romin Patel, (2016) Observed EM braking system can be used as an auxiliary brake in heavy vehicles, and with further improvements, it has the potential to be incorporated into future automobiles [20].

Mr. Parag Satish Kulkarni, (2015) observed an emergency brake is a mechanical backup system used for parking or emergencies. Regular checks are necessary for the proper functioning of conventional braking [14].
Akshay Kumar S. Puttewar, et al (2014), observed that EM braking system is reliable with individual components on each wheel, reducing the risk of complete brake failure due to coil failure [1].
Parag G Shewane, et al (2014) Observed that Neodymium (NdFeB) magnets can potentially be used to generate energy without fuel with a magnetic turbine [16].
Ren He, et al (2014) This paper introduces electromagnetic braking technology and the innovative hybrid brake with the double disc. Bench testing verified the feasible design with an electromagnetic braking torque of 198N·m [18].

VI. METHODOLOGY

Initially, a model was constructed with a motor, central shaft, 100 cc bike brake disc, 8 Kg lifting solenoid electromagnets and belt and pulley mechanism arranged in a frame assembly. It was observed that the presence of holes in the disc lessened the braking effect. To provide better results a plain MS disc of 240mm diameter and 4mm thickness was replaced with bike brake disc with a chain drive mechanism which would reduce friction was used. It was observed that there was some improvement in the braking effect but it was not appreciable. Due to the motors' incompetence to pull a higher load with proportional speed was substituted with a motor that's able to achieve a speed of 6500 r.p.m and 8 kg lifting solenoid electromagnets were replaced with 10 kg lifting AC-powered electromagnets and improved braking was observed but desired result was not attained. To deliver improved results further study into the electromagnetic brake system revealed that metals that are non-ferrous and good conductors of electricity could yield better results, therefore MS disc was swapped for an aluminium disc of 300mm diameter and 5 mm thickness to provide more surface area to assist more eddy current formation on the disc. Further to strengthen the braking force of the model 10kg lifting AC-powered electromagnets were replaced with a neodymium magnet of grade 35 with dimensions of 50*50*25mm and a dimmer is used in this instance to determine the effectiveness of this brake system at various speeds. This combination carried out the braking with the desired results. Overall, this project featured a step-by-step methodology that enabled the discovery of flaws and potential for improvement, all of which contributed to the accomplishment of the desired outcome.

VII. DESIGN & DEVELOPMENT

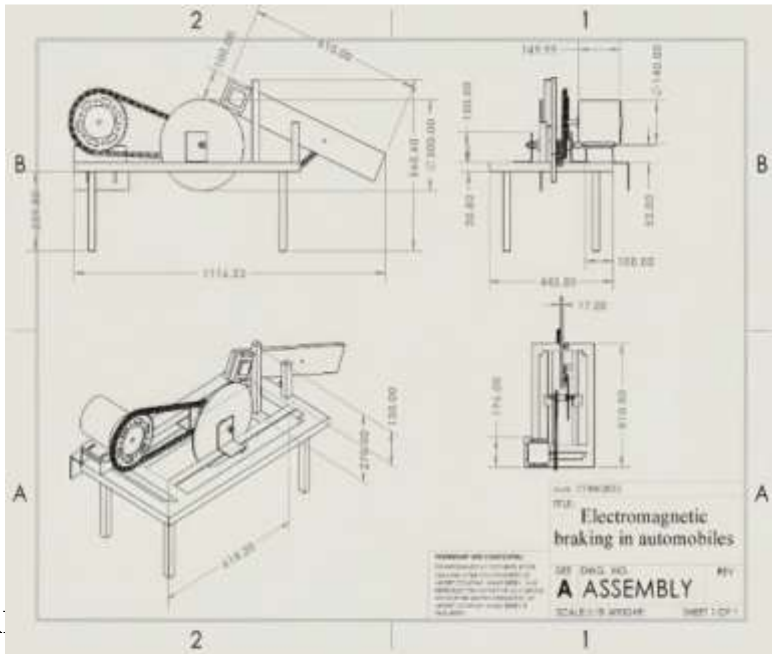
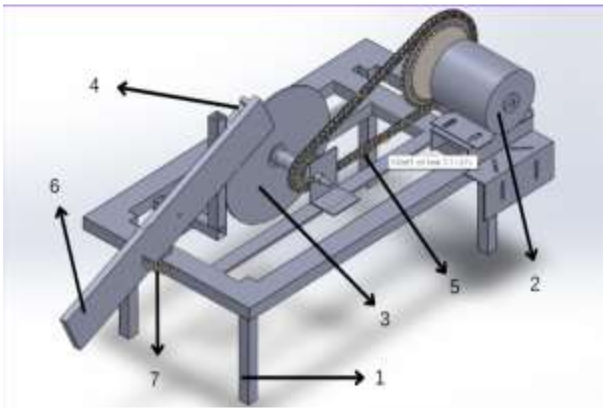


Figure 3. 2D diagram

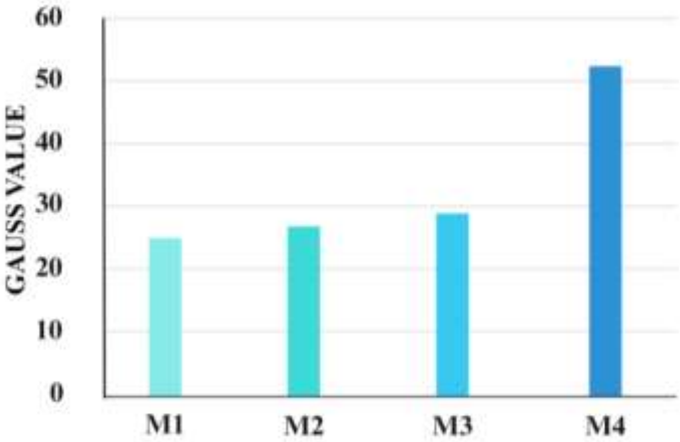
Materials used



1.Frame:MS Rectangular tube(30.2*50*2mm)
& MS square tube(26 mm)
2.Motor: Speed-6500 RPM, Voltage - 220-240
Volts(AC)
3.Disc: Aluminium, Thickness - 5mm, Dia-300 mm
4. Magnet: Electromagnet
5. Drive train: Chain Drive
6. Wooden Lever
7. Coil Spring

VIII. PROTOTYPE MODEL

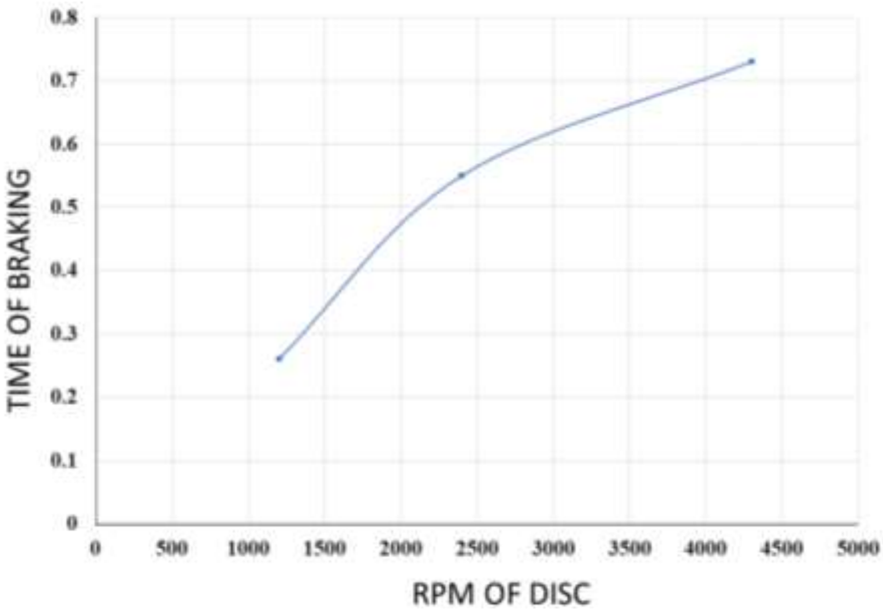
IX. MAGNETIC FIELD INTENSITY



M1 – 8kg lifting solenoid DC electromagnet
M2 – 10kg lifting permanent magnet
M3 – 10kg lifting AC electromagnet
M4 – Neodymium magnet (grade 35)

X. RESULTS AND DISCUSSION

Testing was done at the maximum rotational speed of the motor and by using a neodymium magnet without causing any disruption to the motor's operation, the rotating disc quickly came to a complete halt in 0.73 seconds at 4300 r.p.m, 0.55 seconds at 2400 r.p.m, and 0.26 seconds at 1200 r.p.m. This shows the neodymium magnet's is effective in stopping the disc at high speeds.



Conventional braking uses friction for stopping a motion and wears the brake, eventually the component in this braking system deteriorates and for the brakes to work flawlessly the components should be changed and for light motor vehicles, most manufacturers instructs that brake pads should be replaced for every 20000 km and brake disc or brake rotor should be changed for every 80000 km and frequent high-speed braking reduce these statistics hugely. Hence, this Electromagnetic braking system for automobiles can be considered as a potential alternative braking method as against the conventional braking system. The design and deployment of systems that demands wear lessbraking operations could be significantly achieved by the Electromagnetic braking system.

XI. Conclusion

The fabricated EM braking system model using a neodymium magnet developed the needed braking force and the results proved the effectiveness of this braking system. Also, electromagnets of equal or more power than that of neodymium magnet can yield better results in automotive braking and can be considered an alternative mode of braking for the conventional braking system. Further studies could be done to incorporate EM brakes in future E-vehicles with less effort to make it a viable braking system.

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