Design and Fabrication of Efficient Electromagnetic Braking System for Bangladesh Railway: A Prototype Approach

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Abstract
Electromagnetic brake is a new and revolutionary concept. Electromagnetic braking system is a modern technology braking system used in light motor & heavy motor vehicles. The purpose of this research work is to develop a concept of designing and fabricating an electromagnetic braking system for Bangladesh railway which can be used in lieu of existing frictional braking system. The methodology is based on creating a magnetic field on the heads of E-shape core through electricity and attaching circular ferromagnetic material parts under every train carriages. This created magnetic field penetrates train wheels and circular ferromagnetic parts to steadily reduce train motion. This research work finds the proposed electromagnetic braking system reliable and efficacious. The proposed electromagnetic braking system is found to be efficacious for both high and low speed train. This paper presents the implementation of electromagnetic braking system through a prototype.

Keywords
Electromagnetic braking, E-shape core, Circular ferromagnetic parts, Reliable, Prototype

1.0 Introduction:
With the technological enhancement, a lot of new technologies are arriving in the world. The braking system of high-speed and low speed trains, which is one of the most important technologies of trains, is very important to operation reliance and security of trains. But Bangladesh, at the current situation, is completely detached from using advanced braking system technology. Therefore, the current conventional braking system of train is completely dependent on frictional braking system. The braking methods that are used by developed countries for high and low speed trains at the present time are mainly regenerative braking system and disc braking system. It is very important to explore new braking methods in Bangladesh which can be applied either for high or low speed trains. This paper approaches to develop a new technique for Bangladesh railway by introducing electromagnetic braking system both for high and low velocity trains of Bangladesh. This proposed prototype of braking method will not only reduce energy consumption, but also facilitate better economic benefits and technical features.

1.1 Objectives:
Some severe problems faced through the conventional frictional braking system are given below:
- Braking shoe need to rub on the train wheels to slow the train. This mechanism can lead damage to the breaking shoe within a short period of time
- Due to the generation of corrosion, wheel needs to go through frequent maintenance operation and replacement.
- For having heavy weight, train creates huge kinetic energy. Therefore, sometimes it is not possible to control the train in short period of time which may lead to accident frequently.
- Braking system needs to be activated when train speed is too low.

The main purpose and objective of the work was to design and fabricate an electromagnetic braking system which could overcome the drawbacks of current frictional braking system of Bangladesh railway.

2.0 Literature review:

Many research papers discussed braking system policy of train and proposed different ways and sectors to improve the braking system. In one research (Zhang, 2009), a detailed study was carried out on the design and fabrication policy of high speed train. Eddy current brake, which can be compared as an electromagnetic force between magnet and conductive elements, has been proposed in the braking system of trains by many researchers to overcome the consequences of frictional braking system. Eddy current brake, alternatively known as electric brake, induction brake, is usually used to slow down or stop a moving object by dispersing it's kinetic energy in form of heat (Kunz, 2005; Yazdanpanah and Mirsalim, 2014; Li et al., 2011). Kunz (2005), in his research, discussed the technical views and operating experience of eddy current brake in ICE3 high speed train. Yazdanpanah and Mirsalim (2014) and Li et al. (2014) completely focused on illustrating the design and performance analysis of hybrid electromagnetic braking system in their research paper.

Many other researchers like (Liudvinavičius and Lingaitis, 2007; Puttewar, 2014) focused on using electromagnetic braking system for the betterment of transport system. Another research (Floegel-Delor et al., 2019) focused on evaluating technique of magnetic levitation train, alternately known as Maglev train.

3.0 Methodology

3.1 Construction and installation location:

There are two parts in an electromagnetic brake: E- shape electromagnet and Circular ferromagnetic material part. The Circular ferromagnetic material part is bolted in a frame that is placed between front and back wheels. E-shape electromagnets are buried between two tracks. There is an air gap between Circular ferromagnetic material part and electromagnet.

3.2 Working Principle:

The working principle of the electromagnetic brake is based on 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 Electro magnet. The magnetic field that is generated in the wire, from the current, is known as the "right hand thumb rule".

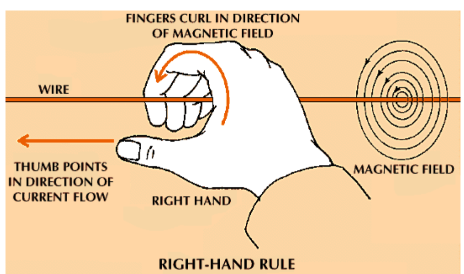

Figure 1: Relationship between current/voltage and magnetic field

The strength of the magnetic field can be changed by changing both wire size and the amount of wire (turns). The fields of EM brakes can be made to operate at almost any DC voltage and the torque produced by the brake will be the same as long as the correct operating voltage. 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. If the temperature is fairly constant, and there is a question of enough service factor in the design for minor temperature fluctuation, by slightly over sizing the brake can compensate for degradation. This will allow the use of a rectified power supply, which is far less expensive than a constant current supply.

Based on $V = I \times R$, as resistance increases available current falls. An increase in resistance, often results from rising temperature as the coil heats up, according to:

$R_f = R_i \times \{1 + \alpha Cu \times (T_f - T_i)\}$ (Puttewar et al., 2014)

Where Rf = final resistance, Ri = initial resistance, αCu = copper wire's temperature coefficient of resistance, 0.0039 °C-1, Tf = final temperature, and Ti = initial temperature.

Magnetic Power, $Pmag = B^2/2\mu$ Pascal (Floegel-Delor et al., 2019)

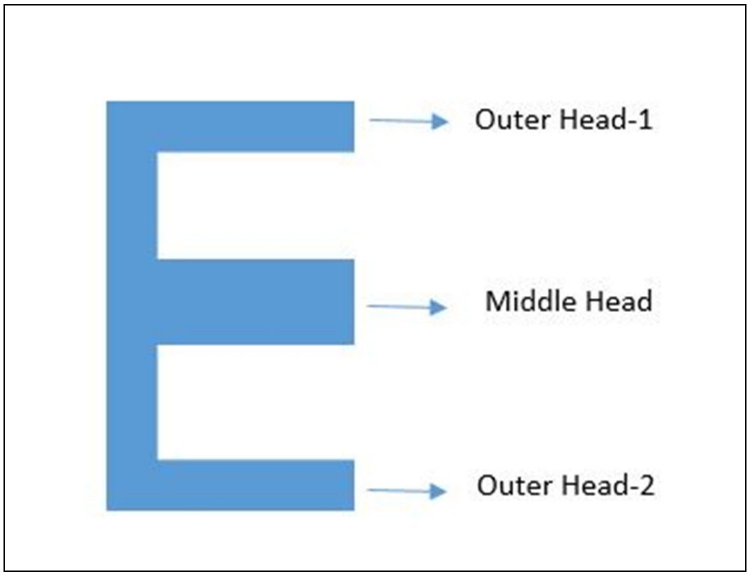

Figure 2: Different heads of E- Shaped core

The main mechanism behind designing the electro-magnetic braking system in this research work lies in E-shape core. The figure 2 shows that there are three main head in E shape core, calling outer head-1, Middle head and outer head-2 respectively. Copper wire needs to be turned into middle head. If current is flown through turned Copper wire, Middle Head turns into North Pole and outer heads become South Pole, vice versa. As a result magnetic flux will be generated on one surface. Electromagnet will be placed under the train tracks while tracks will be placed on outer head-1 and outer head-2 respectively and Middle Head will be situated between two tracks. As tracks will be created with ferromagnetic material and connected with magnet; so, whenever current will be flown through the copper wire, tracks will also be magnetized. Therefore, whenever train wheels will come into magnetic track, magnetic flux will pass through train wheels (train wheels will also be created by ferromagnetic material). As a result, magnetic flux will resist angular motion of the train wheels. At the same time, magnetic flux of the middle head of the E shape electromagnet will pass through circular ferromagnetic material parts (which will be placed under train carriage) and will resist the kinetic energy of train. That is to say, all three heads of the E-shape electromagnet will work simultaneously and resist train motion continuously. If an amount of energy which will be equivalent to the kinetic energy of train can be applied into train wheels and circular ferromagnetic material parts in a form of magnetic flux, the train will stop at end of the time. In this research approach, there could be two ways to control the train. For each way of controlling, the kinetic energy of train needs to be measured. In One option of controlling, circular ferromagnetic materials parts will be fixed under the train carriage and maintain minimal air gap with middle head of electromagnet. Magnetic power will need to be controlled according to the kinetic energy of the train. In second option of controlling, magnetic power will be fixed. Circular ferromagnetic materials part will be assembled by servo motor or hydraulic mechanism or gear or so on. As these parts can move up and down, air gap between these parts and middle head of the electromagnet can be changed to maintain the amount of cutting flux according to the kinetic energy of train.

3.3 Details of components used:

Braking coil: An electromagnetic coil (or simply a "coil") is formed when a conductor (usually an insulated solid copper wire) is wound around a core or form to create an inductor or electromagnet. When electricity is passed through a coil, it generates a magnetic field. One loop of wire is usually referred to as a turn or a winding, and a coil consists of one or more turns.

E- Shaped Electro-magnet: An electromagnet is a type of magnet in which the magnetic field is produced by the flow of electric current. An electric current flowing in a wire creates a magnetic field around the wire. To produce the E-shape electro magnet, wire is turned into a coil around the middle of the E-shape core with many turns of wire lying side by side. The direction of the magnetic field through a coil of wire can be found from the right-hand rule. The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be rapidly manipulated over a wide range by controlling the amount of electric current. Figure 3 and figure 4 illustrate front and top view of the E-shape electro magnet respectively.

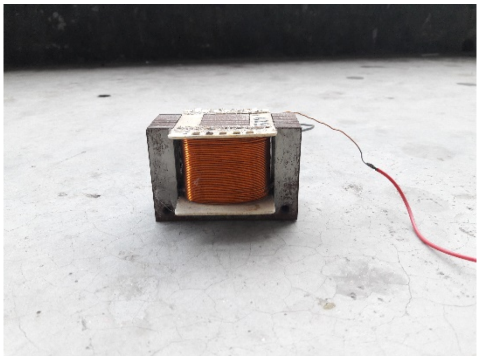

Figure 3: Front view of magnet

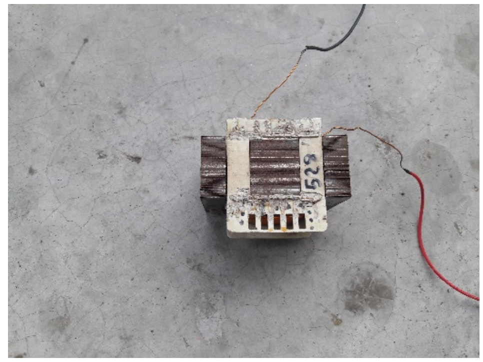

Figure 4: Top view of magnet

Circular ferromagnetic material: For magnetic attraction, circular ferromagnetic material parts were produced and these circular parts were welded with bolt. These parts will need to be assembled with frame. Either by using servo motor or using hydraulic mechanism, this ferromagnetic material parts can be moved up and down to control magnetic attraction or the air gap between magnet and the Circular ferromagnetic material parts can be increased or decreased. Due to some technical limitations, the distance between E-shaped electromagnet and ferromagnetic parts was fixed. Figure 5 presents several circular ferromagnetic material parts. In this research work, cast iron was used to make circular ferromagnetic material parts where the diameter of each part was 34 mm.

Figure 5 Circular ferromagnetic material parts

Frame: Figure 6 demonstrates frame which **is** non-ferromagnetic and was made of stainless steel. Several holes were produced in the frame body for the purpose of attaching circular ferromagnetic material with the frame through the help of nut.

Figure 6: Frame

Power supply: In this research, silicon control rectifier (SCR) was used for electro-magnetic braking system. This SCR provides high current to our electro-magnetic braking system and attracts the iron plate towards itself. Figure 7 represents AC to DC conversion.

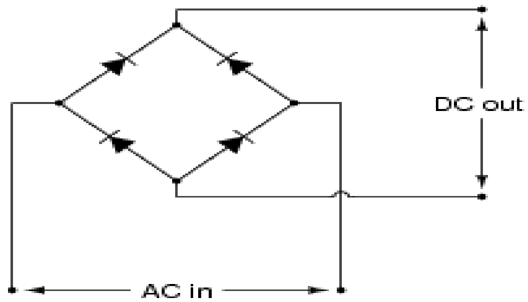

Figure 7: AC to DC converter

3.4 Fabrication of model:

The fabrication of the prototype model was completed through several stages. At first, to make electromagnet, "E" shaped sheet was produced. The thickness of this sheet was 0.5 mm. each core was built with 73 sheet. Since all sheets were insulated from each other, the induced circulated current in the core is negligible. Figure 8 and 9 is presented to depict E-shaped sheet and E-shaped core respectively.

Figure 8: "E" shaped sheet

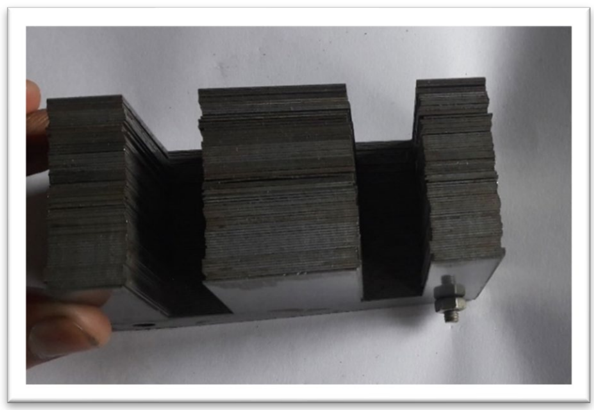

Figure 9: "E" shaped core

After this, cu wire was used for winding the core with 550 turns. Here the wire size was 18 which has maximum current capacity of 6 amp. Then, E-shaped electromagnet was installed upon a rigid slot which was designed both for cooling purpose and the firm attachment of the E-shaped electromagnet. The slot was made of stainless steel. Train tracks of this research work was made of ferromagnetic material and a distance of 74 mm was maintained between two tracks. Figure 10 and figure 11 is represented to depict slot and tracks respectively.

Figure 10: Slot

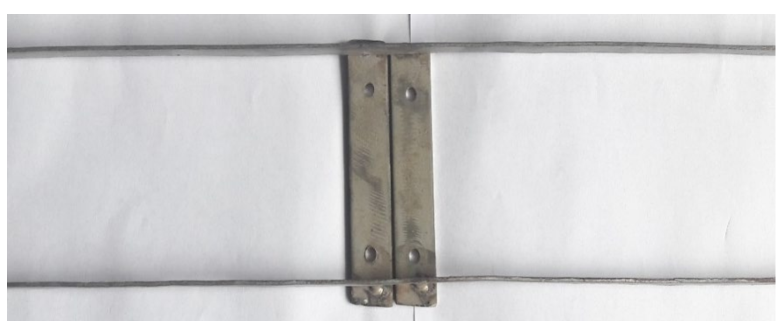

Figure 11:Track

In each of the slot, E-shaped electromagnet was placed and firmed with nut and bolt to ensure a tight attachment.

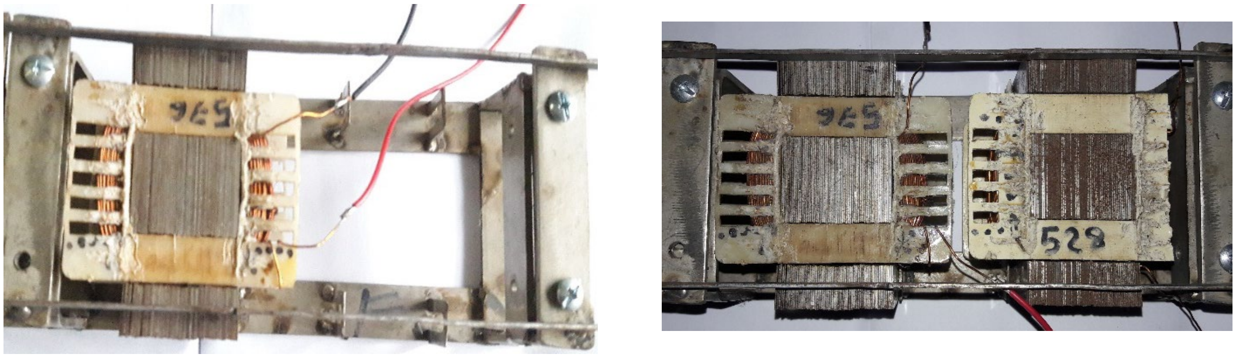

Figure 12: “E” – shaped electromagnet in the slot.

Then circular ferromagnetic material parts were assembled into the frame. While performing this function, it was ensured that the frame has the property of hardness so that it will not be deformed in the braking time. Figure 13 illustrates an assembly body of frame and circular ferromagnetic material.

Figure 13: Assemble body of frame and circular ferromagnetic material parts

After that, set of wheels were made with ferromagnetic materials which is presented in figure 14. Four wheels were used to make each set.

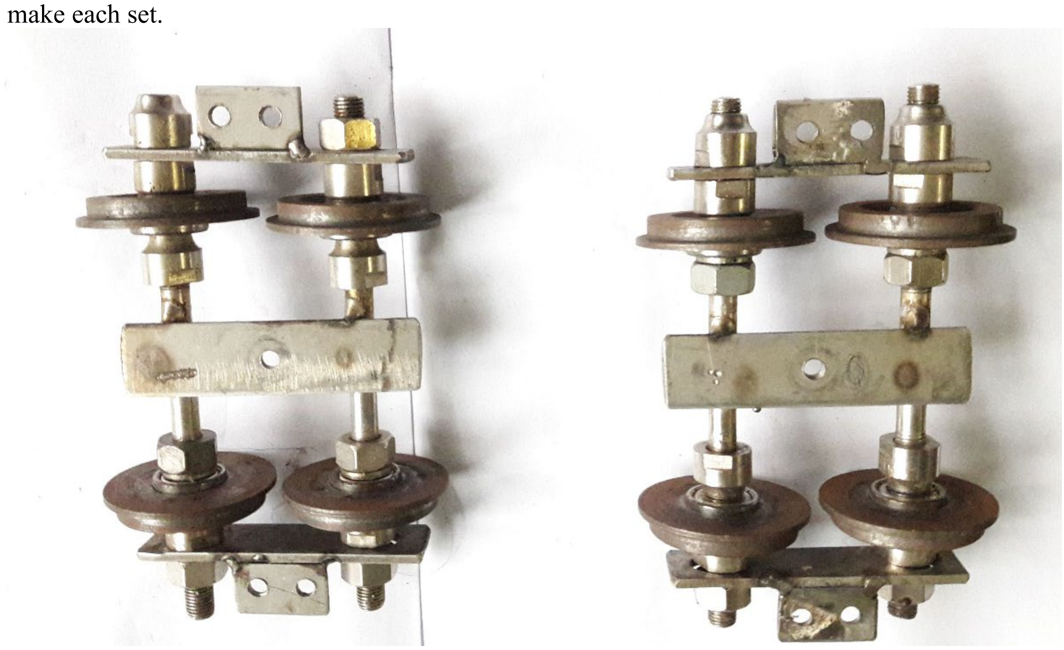

Figure 14: Two sets of train wheel

Next, the assemble body consisting of frame and circular ferromagnetic material parts was installed between two sets of wheels. This installment was conducted using bearing mechanism so that the assemble body can rotate in the time of train turning. This set up is represented in figure 15.

Figure 15: Installation of frame and circular ferromagnetic material parts between wheel sets

Figure 16 and figure 17 illustrate the front view and top view of the train track. The train tracks need to be placed over the assemble body of slot and E-shaped electromagnet in such a way so that the two outer sides of the E-shaped can be aligned with the track.

Figure 16: front view of track design

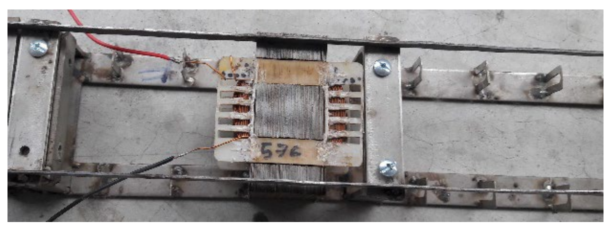

Figure 17: Top View of track design

After that, a train body was placed over the installed body part which was obtained from figure 14 with bearing mechanism. Figure 18 represents the top view of train.

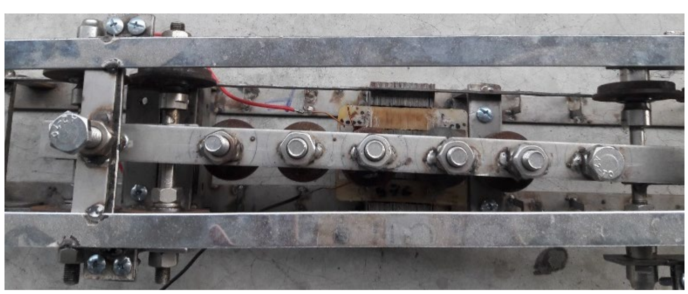

Figure 18: Top view of train

Finally, control circuit box with battery was assembled and connected to the limit switches. Thus the final assembly was obtained. Figure 19 depicts a scenario of the electromagnetic braking system.

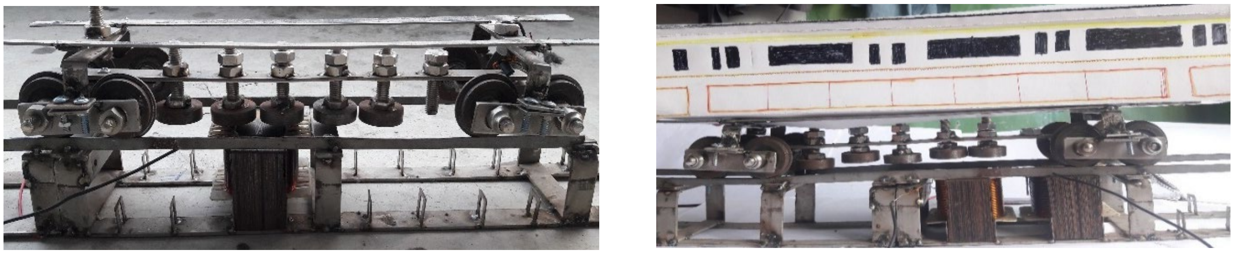

Figure 19: Final prototype of electromagnetic braking system

4.0 Results and discussion:

In Bangladesh, Baud gauge train wheel size is 1676 mm, and distance between two tracks are 1016 mm according to the survey result. But, due to paucity of funding opportunities, we considered our prototype train to have wheel diameter and track distance of 30.5 mm and 74 mm respectively. Table 1 was drawn to illustrate and compare the features of Baud gauge train and the prototype train.

Table 1: Features of wheel size and track distance of Baud gauge and prototype train

No.	Features	Baud gauge train	Prototype train
1.	Distance Between two TRACK	1676mm	74mm
2.	Wheel Diameter	1016mm	30.5mm

The final prototype which was designed and fabricated with an aim of introducing a new technique in Bangladesh railway to overcome the consequences of frictional braking system covered an estimated cost of 15500 Bangladeshi Taka. Table 2 was drawn to depict the cost calculation of the prototype train.

Table 2: Cost calculation of prototype train

NO.	Component	Number of component	Cost
1.	Circular ferromagnetic material part	6	1000
2.	Frame	1	500
3.	Electromagnet	2	1500
4.	Power supply	1	12,000
5.	Rectifier	1	500
		Total Cost	15,500

In this prototype, an efficient electromagnetic braking system was designed and fabricated where this braking system was found to be less costly and easy to install. Through the prototype experiment, this braking system found to be more efficient and reliable than the frictional braking system. It was found while operating the prototype that either high or low speed train could be stopped efficiently at desired distance by using the braking system. Also, through the prototype experiment, this braking system found to be a solution to avoid frequent damage of braking shoe and frequent maintenance of train wheel. Hence, this type of braking concept will hopefully bring a revolutionary change in train communication of Bangladesh railway.

5.0 Conclusion:

The complete idea and research work of designing and fabricating of electromagnetic train braking system was carried out considering the existing drawbacks of conventional frictional braking system of Bangladesh railway. Though many developed countries are moving forward with the advanced technology in train braking system, Bangladesh railway completely rely on outdated braking system policy. This research work will hopefully be a guidelines to improve the existing braking system of Bangladesh train. The purpose in this research work was to generate and apply an amount of magnetic force in a form of magnetic flux into train wheels and circular ferromagnetic material parts which will be sufficient to resist the kinetic energy of train and eventually stop the train. This purpose can be proceeded either by controlling current flow directly or by maintaining air gap between circular ferromagnetic material parts and middle head of E-shaped electromagnet. Due to some technical limitations, this research work of designing and fabricating electro-magnetic braking system followed the procedure of controlling current flow directly to vary magnetic flux according to the kinetic energy of train. The other method of maintaining air gap for the design of electro-magnetic braking system can be implemented in the further future.

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Biographies

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