High Speed Electromagnetic Propulsion System

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***Abstract*— An electromagnetic launcher is a technologically advanced electromagnetic device designed to accelerate projectiles to high velocities using magnetic forces. This concept utilizes the principles of electromagnetic induction and Lorentz force to propel objects without the need for traditional chemical propellants. The electromagnetic launcher consists of several key components, including a series of coils or rails arranged along a pathway, a power source capable of delivering high currents in a short duration, and a projectile designed to interact with the electromagnetic fields generated by the coils or rails. Electromagnetic launchers offer several advantages over traditional propulsion methods. They eliminate the need for bulky propellants, reducing the overall weight of the system and increasing efficiency. Additionally, they produce less heat and fewer emissions, resulting in a cleaner and more environmentally friendly form of propulsion. Research and development in electromagnetic launcher technology continue to explore ways to optimize efficiency, increase projectile velocities, and address technical limitations. Practically electromagnetic launchers are still primarily in experimental and prototype stages.**

***Index Terms*—Electromagnetic propulsion, Projectile, Copper wound coils, Converter, Coil Gun.**

1. Introduction

An electromagnetic launcher, often referred to as a coilgun or railgun, is a remarkable device that harnesses the power of electromagnetism to accelerate projectiles to staggering velocities. This innovative technology has captured the imagination of scientists, engineers, and enthusiasts alike due to its potential applications in fields ranging from space exploration to military weaponry. By exploiting the fundamental principles of electromagnetism, electromagnetic launchers have emerged as a symbol of cutting-edge engineering and physics, demonstrating the remarkable ability of magnetic fields to propel objects at extraordinary speeds.

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In this exploration, we delve into the captivating world of electromagnetic launchers, uncovering their underlying physics, practical implementations, and the exciting prospects they hold for the future of transportation, defense, and space exploration. A coil gun is a kind of mass driver made up of one or more coils that operate as electromagnets in the form of a linear motor to quickly accelerate a conducting or ferromagnetic projectile. The coils and the gun barrel are positioned along the same axis in nearly all coil gun setups.

A coil gun is often made up of one or more coils positioned along a barrel, with the projectile's course speeding down the coils' central axis. By properly timing the on and off of the coils, magnetic forces propel the bullet along the barrel at a rapid pace. An electromagnet, or coil of wire, with a ferromagnetic projectile positioned at one of its ends, can be used to create a single-stage coil gun for ferromagnetic projectiles. This particular kind of coil gun is designed to function similarly to an electromechanical relay's solenoid, which is a current-carrying coil that draws a ferromagnetic item through its centre.

The projectile is drawn to the centre of the coil when a powerful magnetic field is created by pulsating a significant amount of electricity through the wire coil. To keep the projectile from becoming stopped at the magnets core, the electromagnet must be turned off as soon as it approaches this point. The projectile is then gradually accelerated by repeating this procedure with more electromagnets in a multistage configuration.

Power is supplied to the electromagnet from some sort of fast discharge storage device, typically a battery, or capacitors (one per electromagnet), designed for fast energy discharge. A diode is used to guard against damage from reversed polarity of the voltage when the coil is turned off, which could harm polarity-sensitive components like electrolytic capacitors or semiconductors.

2. Comparison With Other Launchers

The majority of conventional weapons work by propelling a bullet quickly out of a barrel through the action of expanding gases. These devices are propelled by the detonation of gunpowder, which results in an explosion behind a projectile that is placed inside a barrel with a closed breech. Gunpowder-operated systems are very noisy, leave residue in the barrel and action, are difficult to maintain, and require a lot of cleaning in order to function.

Electromagnetic coil guns substitute electromagnetic (EM) propulsion for gunpowder with nearly equivalent results in speed and kinetic energy. This offers several benefits over conventional gunpowder or rocket fuel, which is both inherently dangerous and expensive. Electromagnetic launchers have been a growing topic of interest in both the civilian and military sectors because of the precise control that is possible over acceleration profiles and the attainable projectile speeds that can be significantly higher than those of a conventional cannon and at a small fraction of the cost of rockets. These characteristics also make electromagnetic launchers the perfect substitute for missiles and shipboard cannons, providing a quicker and less expensive option without compromising firepower.

A. Basic Working Principle

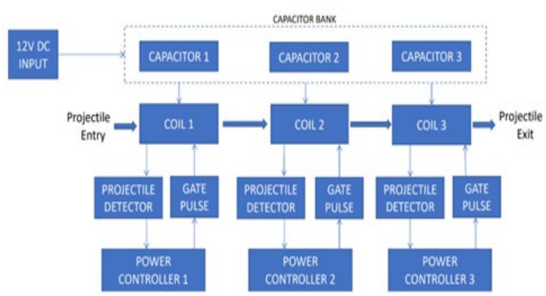

Fig.1. Block diagram of Electromagnetic Propulsion System

The proposed system uses 3 segments of copper wound coil. A 12v DC supply is fed into the capacitor bank which consists of the same number of capacitors as that of the coils. When the coils are charged, a magnetic field is developed in the coil which will be same on both sides of the coil. Initially when the propulsion is initiated, the projectile will be attracted by the magnetic field present on the right side of the coil. When the projectile tries to move out, it will be attracted backwards by the magnetic field present on the right side. Due to this, an effect known as suckback effect can be seen where the coil shows a tendency to oscillate and eventually comes to rest exactly at the center of the coil.

To avoid this, a projectile detection system is used which is placed before every coil to detect whether the projectile has entered or not. Projectile detection system consists of an IR sensor and phototransistor which detects and sends signal to thyristor which acts as switch turning off the supply. Due to this the magnetic field on the right side of the coil is eliminated. By increasing the coil segments, the speed and the distance travelled by the projectile can be increased.

B. Connection Diagram

The updated circuit diagram represents a sophisticated 3-coil propulsion system, essential for the efficient launch of projectiles. These coils, designated as L1, L2, and L3, serve as the backbone of the propulsion mechanism, each strategically positioned to contribute to the propulsion process. Powering this system is a 12V input derived from a

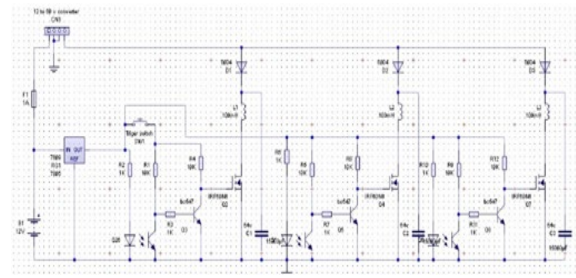

Fig.2. Circuit diagram of Electromagnetic Propulsion System

reliable UPS battery source. This input voltage undergoes a transformation process facilitated by a 12-60V converter and a 7805 voltage regulator IC. The regulator's crucial role lies in its ability to step down the voltage to a stable 5V DC output, ensuring consistent and reliable power delivery throughout the system. A notable aspect of this setup is the integration of a projectile detection system, a pivotal component for the precise initiation of the propulsion sequence. Comprising infrared sensors and NPN transistors, this detection system operates seamlessly within the circuit. When a projectile is detected, the infrared sensor triggers an output high signal, activating an NPN transistor acting as a swift switch. This transistor then facilitates the transmission of a low current to the relay's control mechanism. The relay, in turn, plays a crucial role in orchestrating the propulsion process. When activated, it enables a higher current flow from the capacitors, which have been precharged through diodes D1, D2, and D3. This surge of current effectively magnetizes the corresponding copper coil, initiating the propulsion of the projectile. Crucially, the momentum of the projectile is augmented with each passage through a coil, ensuring a progressive increase in velocity. Fine-tuning the propulsion force is made possible through the careful adjustment of the number of coils engaged in the system, allowing for precise control over the launch dynamics.

3. Hardware

A. SEGMENT 1

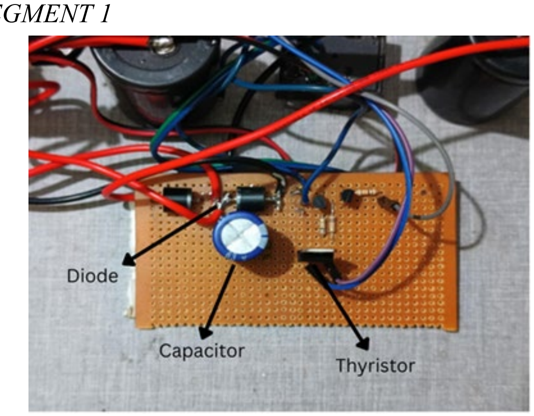

Fig.3. Segment 1

The primary function of this segment is to step down the supply voltage from 12V to 5V DC, serving as the common supply for all IR sensor modules. This is achieved using a 7805 regulator IC, which efficiently converts the input voltage to the desired output. In addition to voltage regulation, diodes are employed to prevent the discharge of capacitor energy back into the supply, effectively acting as back EMF arrestors. This feature ensures the stability and integrity of the power supply. Furthermore, a filter capacitor is integrated into the circuit to suppress harmonics and absorb unwanted signals, thus serving as a signal conditioning unit. This capacitor helps maintain a clean and stable power supply, essential for the proper functioning of electronic components. A 15000µF, 63V capacitor is utilized for rapid charge and discharge operations. This capacitor plays a crucial role in energizing the coil winding, facilitating efficient and reliable operation of the propulsion system. Its high capacitance and voltage rating make it well-suited for handling the demands of fast charge and discharge cycles, ensuring optimal performance of the coil winding.

B. SEGMENT 2

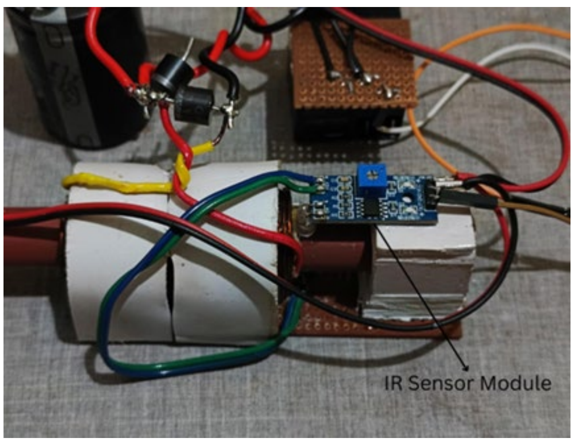

Fig.4. Segment 2

This segment primarily features an IR sensor, which serves as a pivotal component within the projectile detection system. The IR sensor module's key function is to detect whether the projectile has entered the coil or not, thereby initiating subsequent actions within the system. The IR sensor module typically comprises three pins: VCC, GND, and OUT. The VCC pin is connected to the output of Segment 1, ensuring a stable power supply to the IR sensor module. The GND pin is grounded to establish a reference point for electrical potential. Of significant importance is the OUT pin, which plays a critical role in the detection process. This pin outputs a signal based on the presence or absence of the projectile within the coil. The signal from the OUT pin is then fed into a relay, which acts as a switch to control the supply to the coil. When the IR sensor detects the projectile's presence, it generates a signal that triggers the relay, interrupting the supply to the coil. This action effectively halts the propulsion mechanism, preventing further acceleration of the projectile. In summary, this segment serves as the interface between the IR sensor module and the propulsion system, facilitating the accurate detection of the projectile and enabling timely control of the coil's energization.

C. FINAL HARDWARE

The final hardware incorporating together all the hardware segments is shown below.

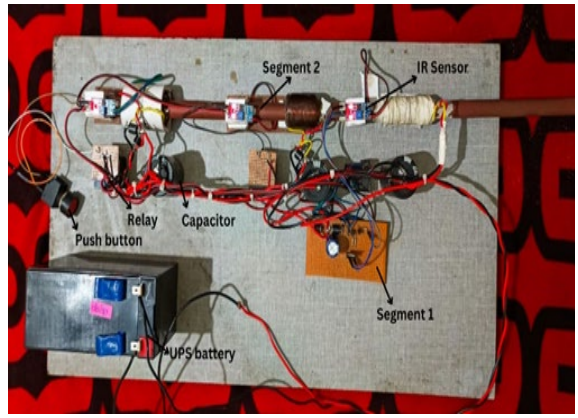

Fig.5. Top view

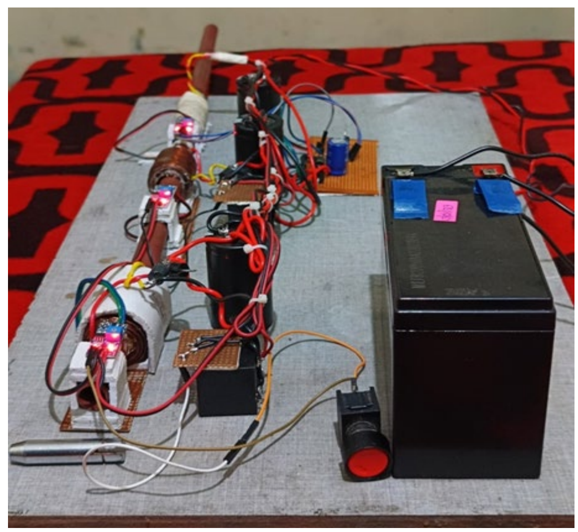

Fig.6. Front view

4. Results And Discussion

The performance of the propulsion system was evaluated using various materials, including cast iron and soft iron. During testing, the propulsion system was positioned at an elevation height of 75cm, and experiments were conducted. Notably, the second coil unit remained unfixed, allowing for the variation of its position and consequently adjusting the distance between the coil and the IR sensor module. As the coil's distance from the module increased, the projectile speed and range also increased. This phenomenon occurred because greater distance allowed more time for the signal to reach the relay, resulting in timely interruption of the coil's supply and preventing the "suckback" effect. Initially, tests were

Table.1.
Result obtained when tested with Cast Iron

Distance between IR module and coil (cm)	Distance travelled by projectile (cm)
5	160
4	155
3	140
2	137
1	90

conducted using cast iron. At a separation distance of 5cm between the coil and IR module, the observed projectile range was 160cm. The corresponding ranges for other separation distances are provided in the table below. However, after three rounds of testing, it was noted that the cast iron material became magnetized. This magnetization led to a severe braking effect, significantly delaying the experimentation.

Table.2.
Result obtained when tested with Soft Iron

Distance between IR module and coil (cm)	Distance travelled by projectile (cm)
5	210
4	190
3	155
2	142.5
1	92.5

process and impacting the reliability of the results. In the experimentation with soft iron, its favorable characteristics of high magnetic permeability and immediate demagnetization after the current supply cut resulted in the absence of any braking effect. At a separation distance of 5cm between the second coil and the IR sensor module, the observed projectile range extended to 210cm.

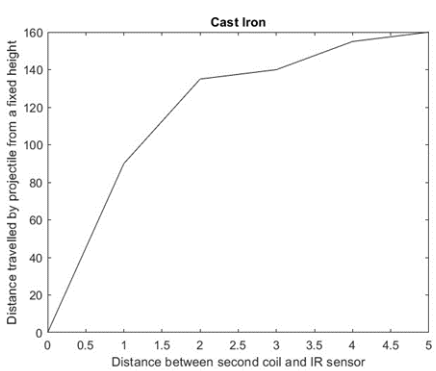

Fig.7. Cast iron plot

Below is a graph illustrating the relationship between the distance between the second coil and the IR sensor module (x-axis) and the range of the projectile (y-axis): The data points plotted on the graph demonstrate how varying the separation distance between the coil and the IR sensor module influences the projectile's range.

As the distance increases, allowing more time for the signal to reach the relay and interrupt the coil's supply, the projectile range proportionally increases. This graph serves to visualize the direct correlation between the separation distance and the projectile range, highlighting the effectiveness of soft iron in maintaining consistent propulsion system performance without encountering.

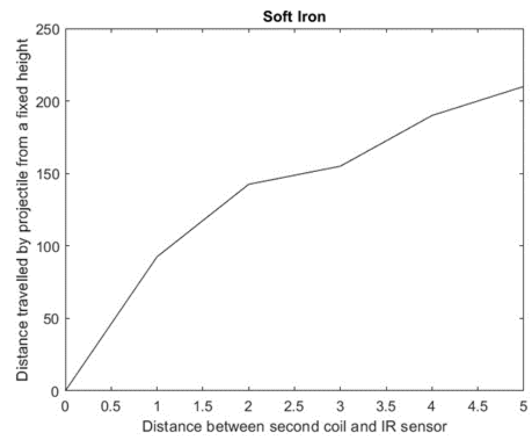

Fig.8. Soft iron plot

braking effects. Overall, these findings underscore the importance of material selection in propulsion system design and highlight the need for materials that can maintain their properties over extended testing periods to ensure consistent and reliable performance.

5. Conclusion

In the proposed system, we have implemented an electromagnetic launcher harnesses the principles of electromagnetism to propel objects at high speeds. EM launchers typically consist of electromagnetic coils, a power source, control electronics, and a barrel. These components work together to create a magnetic field and propel a projectile. The performance of the propulsion system was evaluated using various materials, including cast iron and soft iron. In the future, Electromagnetic (EM) propulsion holds promise for revolutionizing transportation with efficient electric vehicles and high-speed trains, while also offering potential advancements in space exploration. Continued research and development are key to enhancing the efficiency and scalability of EM propulsion systems for widespread adoption in a sustainable and interconnected world.

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