DESIGN, FABRICATION, INSTRUMENTATION AND CONTROL OF ELECTROMAGNETIC PROPULSION DEVICE

A Final Year Project Report

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Bachelor of Mechanical Engineering

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by

Malik Muhammad Hamza Farooq

Muhammad Talha

Huzaifa Tahir

Hamza Bashir

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EXAMINATION COMMITTEE

We hereby recommend that the final year project report prepared under our supervision by:

Muhammad Talha	285859.
Malik Muhammad Hamza Farooq	291362
Huzaifa Tahir .	294402
Hamza Bashir .	282956

Titled: "Design, Fabrication, Instrumentation and Control of Electromagnetic Propulsion Device" be accepted in partial fulfillment of the requirements for the award of Mechanical Engineering degree with grade ___

Supervisor: Dr Syed Hussain Imran	______________ Dated:
Committee Member:	______________ Dated:
Committee Member:	______________ Dated:

______________________ ____________

(Head of Department) (Date)

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Dated: _______________ ________________________

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ABSTRACT

This thesis presents the design, fabrication, instrumentation, and control of an electromagnetic propulsion device in the form of a railgun. The electromagnetic propulsion device is designed to achieve a muzzle velocity of 100 m/s. The device is primarily composed of two parallel rails, a projectile, a power supply, and an injector system. The projectile is accelerated along the rails via the Lorentz force resulting from the interaction between the magnetic field generated by the rails and the electric current passing through the projectile. The fabrication of the railgun involved the use of high-grade materials, including copper and aluminum, to ensure optimal performance and durability. To ensure accurate measurement of the device performance, instrumentation was implemented to measure the speed of the projectile.

Two different models are designed and manufactured. Maximum 70 m/s muzzle velocity is attained. The efficiency is low, and the target muzzle velocity is not achieved due to the low time constant of capacitor bank. The time constant has to be increased in such a way that it ensures the efficient energy transfer and at the same time guarantees maximum current input to device.

Keywords:

Electromagnetic, Muzzle velocity, Projectile, Capacitor Bank, Time Constant

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Lastly, we would like to thank the participants who volunteered their time for the experiments and provided valuable data for the analysis. Without their participation, this project would not have been possible. Thank you all for your support and encouragement, which has helped me to complete this project successfully.

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CHAPTER 1: INTRODUCTION

For many years, research has been ongoing on the creation of electromagnetic railguns. Railguns launch objects at high speeds with outstanding accuracy and efficiency by using the Lorentz force to accelerate a projectile down two parallel rails. Railguns are particularly appealing for military applications because of their high-velocity launch capabilities, which is essential for long-range precision aiming. Additionally, railguns have a number of benefits over traditional guns, including less barrel wear, fewer maintenance costs, and less logistical support.

Motivation:

Designing, making, equipping, and controlling an electromagnetic railgun with a muzzle velocity of 100 m/s is the driving force behind this project. The main goal of this research is to show that it is feasible to construct an accurate and efficient railgun that meets these performance criteria. This weapon could find use in the military, aerospace, and industrial sectors, among other areas.

Problem Statement:

The goal of this project is to solve the different technical issues that arise during the design and construction of an effective railgun. These difficulties include attaining an ideal power source, choosing appropriate materials, engineering an appropriate railgun geometry, and putting in place precise instrumentation systems to track the railgun's performance while it is in use. These objectives must be accomplished through a comprehensive strategy that combines cutting-edge design, production, and measurement and control approaches.

Objectives:

The following are the project's goals:

- To develop and create an effective electromagnetic railgun with a 100 m/s muzzle velocity. Appropriate materials, ideal geometry, and effective power supply systems must all be incorporated into the design.
- To create a precise and dependable instrumentation system for gauging the muzzle velocity of projectile. Data on the railgun's performance while it is in use must be provided by the instrumentation system to enable the examination of various performance metrics.
- To develop and put into use a control system that will regulate the power supply of the railgun and guarantee its safe and effective operation. Several safety measures, including short-circuit and overcurrent protection, must be included in the control system.
- To assess the railgun's performance through data analysis and experimental testing. In the experimental testing, a projectile is fired at various speeds while its speed and temperature are recorded.

CHAPTER 2: LITERATURE REVIEW

History of Electromagnetic Rail Guns:

The fascinating history of electromagnetic rail guns may be traced to the early 20th century. Although the idea of projectile launch utilising electromagnetic forces was initially considered in the 1800s, development on railgun technology didn't start until the early 1900s.

German scientists created the first electromagnetic launchers for artillery and anti-tank guns in the 1930s. These early railguns propelled their projectiles at great speeds by combining electromagnetic and chemical propulsion. Germany and the United States both advanced railgun technology for military uses during World War II, but because of the expensive expense of research and development, development slowed down after the war. Research on electromagnetic railguns restarted in the 1960s and 1970s, with an emphasis on creating more effective and potent railgun systems. The creation of the plasma armature railgun, which used plasma armature to lower electrical resistance and improve launching efficiency, was one of the key developments during this time. This technology paved the way for the development of more advanced railgun systems that could launch projectiles at higher velocities and with greater precision.

Since then, electromagnet railgun design and research have advanced significantly. The United States Navy started investing in railgun technology for military uses in the 1980s, and a lot of work was done on creating railguns that could fire projectiles at hypersonic speeds. In recent years, railgun technology has been investigated for potential uses in interstellar travel, orbital launch of payloads, and perhaps space propulsion.

Fundamental Principal:

The fundamental principle behind electromagnetic railguns is the Lorentz force [1], which is generated when an electric current passes through a magnetic field. This force is a result of the interaction between the magnetic field and the electric current. The Lorentz force is defined by the following equation:

$$F = q\,(E + v \times B)$$

Where F is the force, q is the charge of the object, E is the electric field, v is the velocity of the object, and B is the magnetic field.

Governing Laws:

The Lorentz force is derived from several fundamental laws of electromagnetics [1], including Faraday's law, Biot-Savart law, Ampere’s Law, and the Flemming’s right-hand rule.

Faraday's Law of electromagnetic Induction:

Faraday's law states that a changing magnetic field induces an electric field, and vice versa. This law is represented by the equation:

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

where $\nabla \times E$ is the curl of the electric field and $\partial B/\partial t$ is the time rate of change of the magnetic field. This law implies that a changing magnetic field can induce a voltage in a conductor.

Biot-Savart law:

The Biot-Savart law describes the relationship between a magnetic field and an electric current. This law is represented by the equation:

$$B = \frac{\mu}{4\pi} \int \frac{\mathrm{Idl\ x\ r}}{r^3}$$

where B is the magnetic field, μ is the permeability of free space, I is the electric current, dl is the length of the current element, r is the distance between the current element and the point at which the magnetic field is measured. This law implies that a current-carrying conductor generates a magnetic field.

Ampere's Law:

The integral form of Ampere's law can be stated as follows:

The integral of the magnetic field (B) around a closed loop is equal to the product of the permeability constant (μ_0) and the net electric current (I) passing through the area enclosed by the loop.

Mathematically, this is represented as:

$$\oint B \cdot dl = \mu_0 I$$

Where:

B is the magnetic field.

dl is an infinitesimal vector element of the closed path.

μ_0 is the permeability constant of free space,

I is the current passing through the surface enclosed by the path.

Flemming's Right Hand Rule:

The direction of force and the current is governed by Fleming's right-hand rule. According to this rule, force/motion of conductor, current passing through conductor I and Magnetic Field B. Vectors are orthogonal to each other which can be demonstrated by a right hand. If forefinger indicates the direction of magnetic field B, middle finger indicates the direction of current I then thumb would represent the direction of force and movement of conductor.

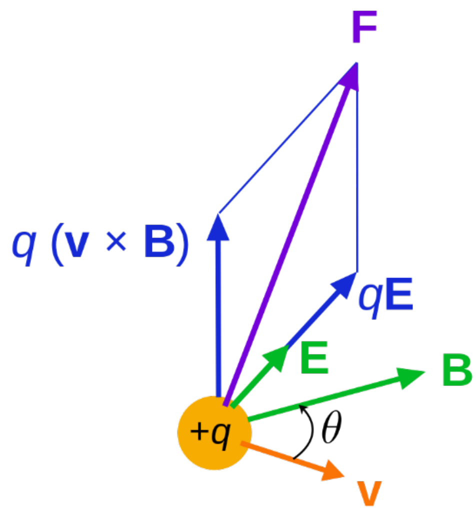


Figure 1 Flemming Right Hand Rule

Electromagnetic Railgun Schematics:

In the case of an electromagnetic railgun, two parallel rails made of conductive material are connected to a high-current power supply. A projectile is placed between the rails and is in contact with both rails. When a high current passes through the rails, a magnetic field is generated perpendicular to the rails. This magnetic field interacts with the electric current flowing through the projectile, generating a Lorentz force that propels the projectile along the rails.

The fundamental principle of an electromagnetic railgun is based on the interaction between the magnetic field and the electric current, which is described by the Biot-Savart law and Faraday's law. The Lorentz force generated by this interaction provides the propulsive force that accelerates the projectile to high velocities.

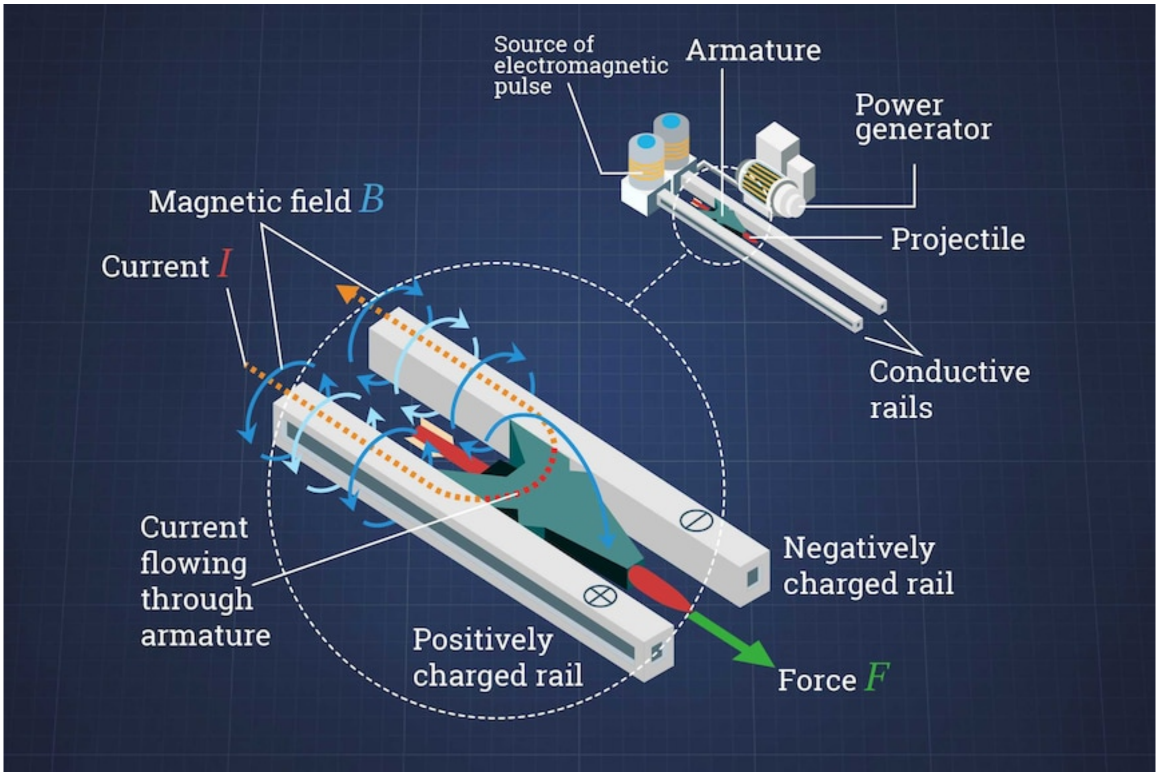


Figure 2 Basic Schematics and Principle [2]

Main Components:

An electromagnetic railgun consists of several main components that work together to generate and accelerate a projectile to high velocities. These components include:

Power supply:

The railgun's power source supplies the required electrical power. To generate the magnetic field required to drive the projectile, the power source must be able to produce a high current for a brief amount of time. The usual power source for railguns is a capacitor bank.

Rails:

The rails are parallel to one another and constructed of conductive materials like copper or aluminum. In order to create the magnetic field, a large current is transmitted through the rails. The rails must be built to resist the tremendous pressure and temperature produced when the railgun is in use.

Projectile:

The thing that the railgun accelerates is the projectile. Usually constructed of copper or aluminum, the projectile is formed of conductive material and is made to fit tightly between the rails. The projectile's size, shape, composition of materials, and surface quality are all important factors in how effectively it performs.

Barrel:

The object that houses the rails and directs the projectile along its course is the barrel. The barrel must be smooth to reduce friction between the projectile and the barrel and built to resist the high temperatures and pressures produced during operation.

Triggering mechanism:

The capacitor bank is discharged by the triggering mechanism, producing the high current required to produce the magnetic field. Typically, an electronic switch that receives a signal from a computer or other control system serves as the triggering mechanism.

Instrumentation:

The voltage and current given to the rails, the projectile's acceleration, and the temperature are all variables that are measured using equipment while the railgun is in use.

Materials:

The materials [3] used for the rails, projectile, and barrel of an electromagnetic railgun are critical to the performance and durability of the weapon system.

Rails:

The rails in an electromagnetic railgun are typically made of materials having high electrical conductivity and high resistance to wear and deformation. This is necessary to withstand large current pulses and mechanical stresses involved in the operation of the weapon. Common materials used for rails include copper, aluminum, and tungsten-copper alloys. Copper and aluminum are lightweight and highly conductive, making them ideal for railgun applications. However, these materials are prone to wear and deformation due to the high currents involved. Tungsten-copper alloys, on the other hand, are more durable and resistant to wear and deformation, but are also heavier and less conductive than copper and aluminum.

Table 1 (Material selection of rail)

Rail Material					
Material	Resistivity	Strength (MPa)	Cost	Available	Machining
Copper	58 MS/m	210	Medium	✓	Easy
Silver Alloys	63 MS/m	140	Very High	×	Easy
Tungsten Alloys	18 MS/m	170	High	×	Hard
Tantalum alloys	8 MS/m	900	Very High	×	Hard

Projectile:

The projectile in an electromagnetic railgun is typically made of a conductive material that can withstand the high magnetic forces generated during the launch process. Common materials used for railgun projectiles include aluminum, copper, and tungsten.

Aluminum is lightweight and relatively cheap but is prone to deformation due to the high magnetic forces involved. Copper is also lightweight and highly conductive but can be expensive and difficult to machine. Tungsten is heavier than aluminum and copper, but is extremely durable and resistant to deformation, making it an ideal material for high-velocity railgun projectiles.

Barrel:

The barrel of an electromagnetic railgun is typically made of a high-strength material that can withstand the high impulsive forces, mechanical stresses and thermal stresses involved in the launch process. Common materials used for railgun barrels include steel and titanium. Steel is a strong and durable material that is relatively inexpensive but is also heavy and can be prone to corrosion. Titanium, on the other hand, is lighter than steel and highly resistant to corrosion, but can be more expensive and difficult to machine.

In summary, the materials used for the rails, projectile, and barrel of an electromagnetic railgun are chosen based on their properties of conductivity, durability, strength, and resistance to deformation, wear, and corrosion. Copper, aluminum, tungsten-copper alloys, aluminum, copper, and tungsten are commonly used for the rails and projectile, while steel and titanium are used for the barrel.

The purpose of the inner barrel is to insulate (electrically and thermally) and seal copper rails from external containment whereas outer barrel constitutes the external structure of railgun assembly which requires strength, toughness and stability.

Non-metals include high strength plastics such as Polytetrafluoroethylene (PTFE, Teflon) and Polyamide (Nylon). Teflon is a thermoplastic polymer with melting point as high as 327 °C. It has a strength of 23 MPa and thermal expansion ranging from $112–125\times10^{-6}$ K^{-1} which makes it an ideal candidate for inner barrel materials in railgun prototypes operating at 10 to 20 kilojoules energy. Teflon exhibits high thermal stability before melting point and strength enough to sustain impulsive forces. [4]

Nylon is also a thermoplastic polymer with a melting point of 220°C. It is known for resistance to abrasion and wear and is more useful for the outer barrel. Nylon like Teflon is practical in prototype materials.

Mathematical relations:

There is a set of complex physics and mathematical formulas and relations [5] to approximate the performance of electromagnetic propulsion device.

For approximating muzzle velocity following projectile motion relations can be used:

$$h = \frac{v_i^2 \sin^2 \theta_i}{2g}$$

$$R = \frac{v_i^2 \sin 2\theta_i}{g}$$

And the inductance gradient could be found by:

$$L' = \frac{\mu_o}{\pi} \ln \left[\frac{2W_A + W_R}{W_R} \right]$$

The inductance gradient and muzzle velocity can be related by:

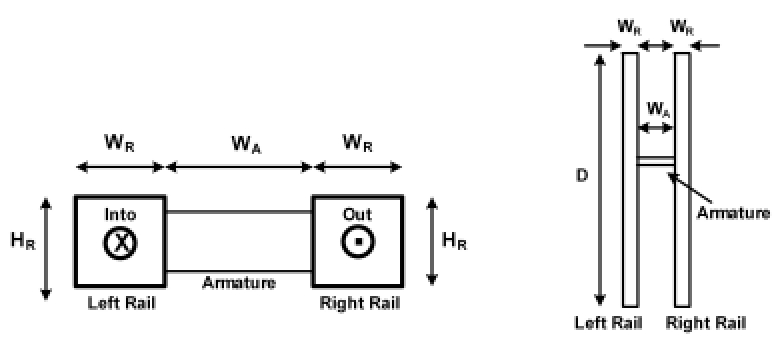
$$\frac{dy}{dt} = \frac{L' I^2}{2m} \times t$$

$$t_b = \sqrt{\frac{4 \times m \times D}{L' \times I^2}}$$

These formulas [6] can be used to find the unknown current required which will lead to required capacitance and voltage through this formula:

$$C = \frac{100 L' I^2}{V^2}$$

The unknown in these formulas are shown in figure:



Problems Expected:

Here are some of the major problems [7] associated with railguns:

Gouging:

Gouging occurs when the cross-sectional area or shape of the bore varies from one end to another end of the barrel. This can be attributed to the rails placement which may not be perfectly parallel. This can cause a decreased area at the exit. Projectile erodes the rail surfaces when launched. The erosion of metal surfaces also depends upon the levels of friction and heat generated between the rails and the projectile during the launch process. Gouging can cause damage to the rails, resulting in decreased performance and shortened rail life. Gouging can be mitigated by using the right combination of materials in rails and projectile.

Arcing:

Arcing is another major problem in railguns. It occurs when contact is poor between rails and projectile or there is a small gap leading to an electric arc forming between the rails and the projectile. This can cause damage to the rails and reduce the overall efficiency of the weapon system. Arcing is difficult to eliminate because even if contact between rails and projectile is perfect, material loss due to friction and other shortcomings causes poor contact conditions towards the muzzle end of the gun.

Velocity Skin Effect:

The velocity skin effect is a phenomenon where the electrical resistance of the rails increases as the velocity of the projectile increases. This is due to the concentration of the current at the back of the projectile at high speeds and not enough time to diffuse to entire surface area of contact. This can cause significant heating of the rails quickly and fusion of armature at the point of contact where current is concentrated. Since this is a large deviation from idealized model, this is the major factor to reduce the efficiency of the weapon system. Velocity skin effect can be minimized by optimizing the shape of projectile.

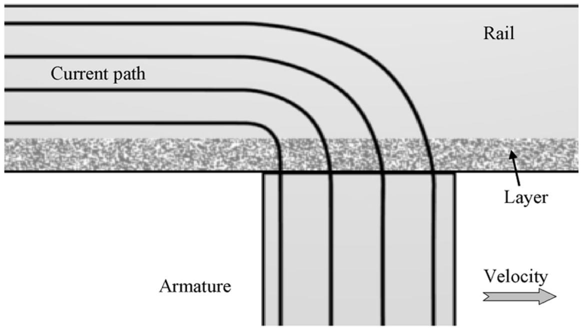


Figure 3 Low velocity current flow [7]

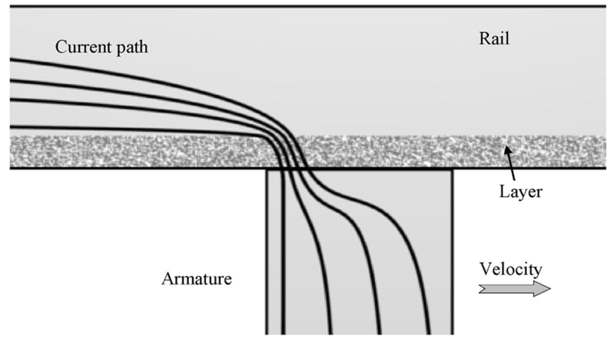


Figure 4 High Velocity current flow [7]

Deposition:

Deposition of projectile material occurs on rail surfaces because of high friction and huge current concentration at the rear projectile-rail contact interface at high speeds (Velocity Skin Effect, VSEC). The molten conductive material between rails and projectile acts as lubricant however after solidification, it turns out to be a rough and porous deposit of unequal thickness. This makes the firing of multiple projectiles impractical since precision is required. Even the perfect contact between rails and armature obtained by precise machining cannot mitigate the shortcomings like arcing and velocity skin effect less alone a rough and irregular rail surface, which will add only to the deterioration of performance.

Mechanical Stress:

Railguns are subjected to significant mechanical stress during the launch process. This can cause deformation of the rails and other components, which can result in decreased performance and shortened rail life. Especially, the projectile sustains severe damage which can be analyzed after launch.

Power Supply:

The power supply for a railgun is a crucial component, and it can be a major source of problems. High-power capacitor banks or pulsed power supplies are required to generate the high currents necessary to launch the projectile, and these can be expensive and difficult to maintain. A practical US Navy railgun requires 10 to 60 megajoules of energy which will require warship engines to deviate their power from propulsion to the charging of capacitor banks or pulse formation networks.

Projectile Design:

The design of the projectile is also an important consideration. The projectile must be strong enough to withstand the high magnetic forces generated during the launch process, and it must be shaped and sized properly to minimize the effects of air resistance and other external factors.

Heating Effect of Current:

The heating effect of current [6] in railguns is a serious problem that can affect the system's performance and dependability. Due to the rails' resistance, when a high current is transmitted through them, a lot of heat is produced. Several issues can be brought on by this heat, including:

Rail melting:

If the current is too high or the rails are not properly cooled, the heat generated by the current can cause the rails to melt. This can result in damage to the railgun and decreased performance.

Rail deformation:

The heat generated by the current can also cause the rails to deform, which can affect the trajectory of the projectile and decrease the accuracy of the system.

Reduced efficiency:

The heat generated by the current can reduce the overall efficiency of the system, as it can cause energy to be lost to the surroundings rather than being used to propel the projectile.

Railguns are often built with cooling systems to dissipate the heat produced by the current in order to overcome these problems. These cooling systems can circulate coolant through the rails to remove heat produced by the current, or they can use liquid or gas. Using high-conductivity materials for the rails is another way to lessen the heating effect of electricity. As a result, the quantity of heat produced by the current may be reduced by lowering the rails' resistance.

Additionally, the size and geometry of the rails can have an impact on how well current heats things up. For a given current, rails with a lower cross-sectional area will have more resistance and produce more heat than rails with a larger cross-sectional area.

CHAPTER 3: METHODOLOGY

This chapter focuses on the design and fabrication of prototype of electromagnetic propulsion device. It discussed how the design originated and how it is improved to achieve the optimum final design. Moreover, it also explains that manufacturing steps and approach. On the basis of shape and geometry of rails, there are two types of protypes fabricated. They can be classified as:

1. Initial Design Prototype
2. C-type Rails Prototype

The main component in which design improvement has taken place is the conducting barrel and injector system. In conducting barrels, rails and barrel design is the main consideration. Moreover, the instrumentation system of muzzle velocity measurement is also discussed, and some simulation approaches are described in this chapter.

Initial Design Prototype:

This is the very simple and basic design to perform electromagnetic propulsion of 7g aluminum projectile. The CAD model of this design is shown in figure.

CAD Model:

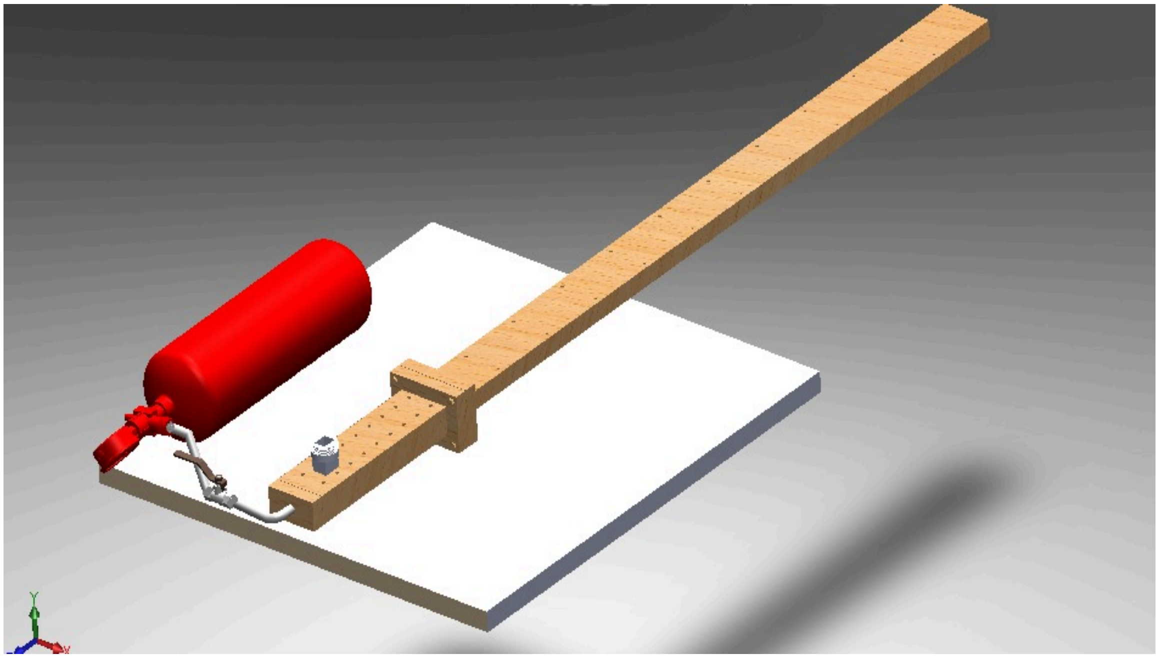


Figure 5 CAD model of initial prototype

The CAD mode shown in figure 5 depicts the outer structure of electromagnetic propulsion device. The tank is used for storing pressurized air. Then, there is a control valve and non-conducting barrel to give initial velocity to projectile. Afterwards, there is a conducting barrel that propels the projectile with the help of Lorentz or electromagnetic force. To determine the internal structure or geometry of conducting barrel, the figure shows the front view of barrel.

Now, let's discuss the design of each component in detail:

Rail design and fabrication:

The material selected for the rails is copper. Copper bars up to 90% purity are used. This is because of the high conductivity and low resistivity of copper. This decreases the resistance and increases the amount of current to flow but at the same time decreases the time constant of capacitor bank. The length of the bars is 650cm. The cross section is rectangular with dimensions of 2.4 by 1 cm. This required dimension is obtained through milling process. The details are shown in figure 6.

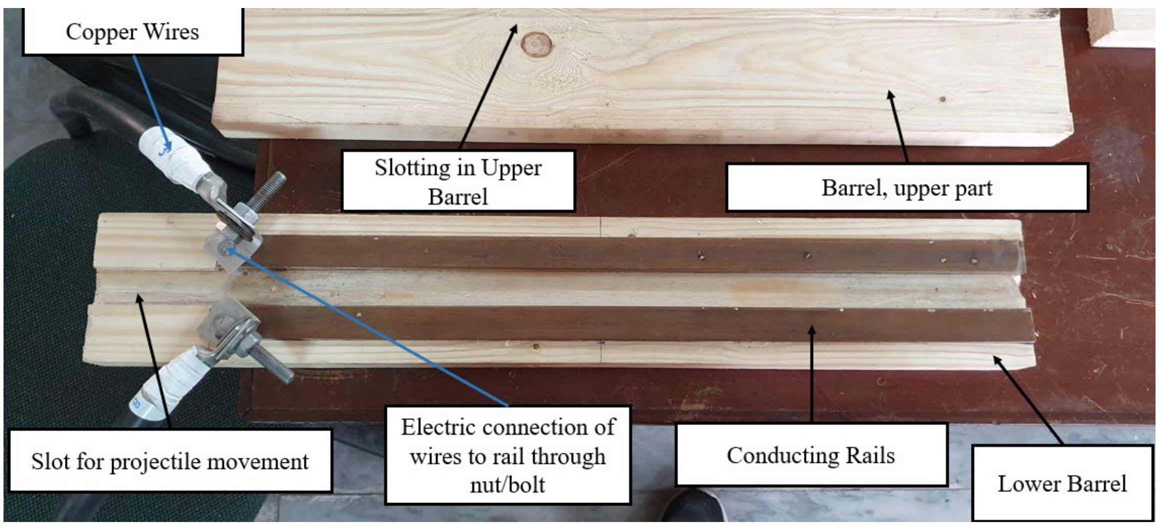


Figure 6 Rails and Barrel of intial prototype

Design and fabrication of conducting barrel:

The figure also shows the wooden barrel holding the rails and providing supportive structure to electromagnetic propulsion device. Wood is used because it is a testing model and wood is cheap and easily available. This also makes the barrel lightweight. The upper and lower barrel is held tight during firing by using C-clamps. The word conducting barrel is used because this is the barrel which propels the projectile using electromagnetic force. The barrel has dimensions as 104 × 32 × 800 mm.

Injector system:

As discussed in chapter 2, the injector system is the system that provides initial push or velocity to projectile to avoid spot welding in conducting barrel. In this initial design prototype, the injector system comprises of compressor, pressurized tank, manual valve, PVC pipe for providing inertia and a manual projectile loader. It is designed so that it attains the speed of 40m/s with input of 60-70 psi pressure. Figure 7 shows the system with labelled components. This is the pneumatic system. Initially, mechanical systems were developed using spring mechanisms, but they were not capable of providing enough inertia to projectile. One of these mechanical systems is shown in figure 8.

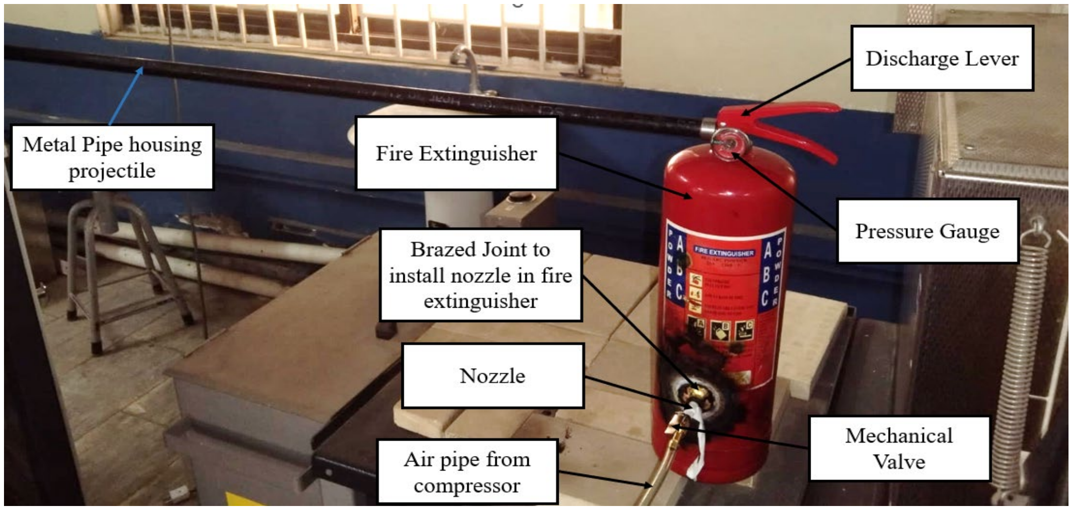


Figure 7 Pneumatic Injector System

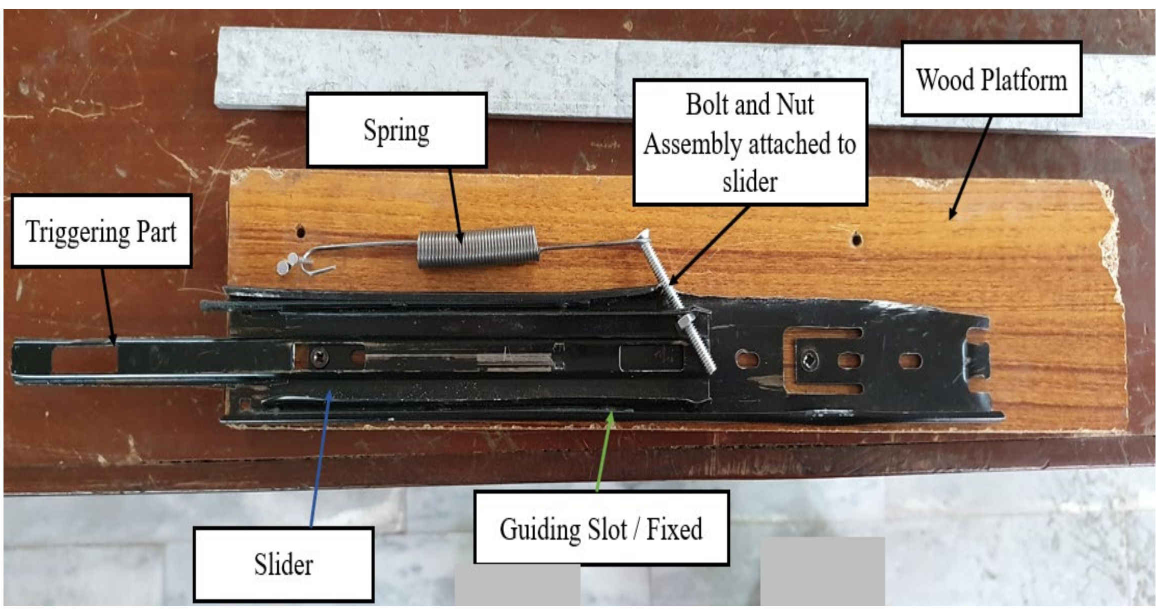


Figure 8 Mechanical Injector System

The loading mechanism for projectile is made by using PVC joints and cap as shown in figure 9.

Figure 9 Projectile Loader

Design of projectile:

Deciding the shape and impact of projectile would have severe impact on device performance. The maximum current through projectile has to be obtained but at the same time the friction between rails and projectile should be kept minimum. Figure 10 shows the rectangular shape of the projectile. It offers maximum friction, which makes it unfavorable. The projectile in figure 11 shows the projectile with a slightly aerodynamic shape with a curve at behind. This curve helps in developing electromagnetic arc more effectively. The projectile in figure 12 is the latest shape that makes only line contact and offers minimum aerodynamic resistance. This shape is further used in all experiments.

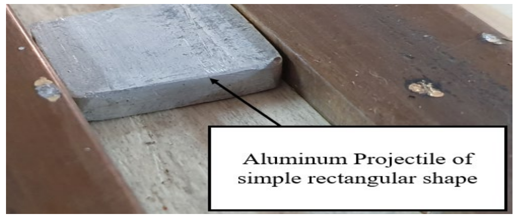


Figure 10 Rectangular Projectile

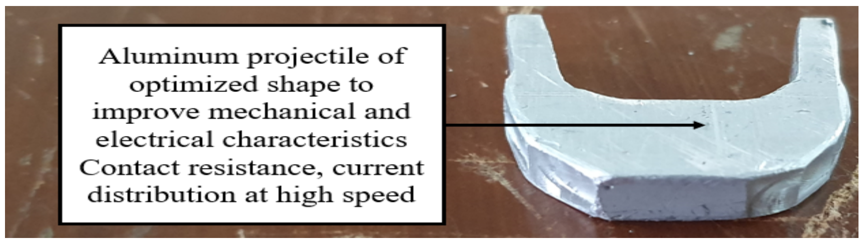


Figure 11 Optimized shape

Figure 12 Bullet Shape Projectile

Assembled Initial Prototype:

The following figure 13 shows a completely fabricated first prototype.

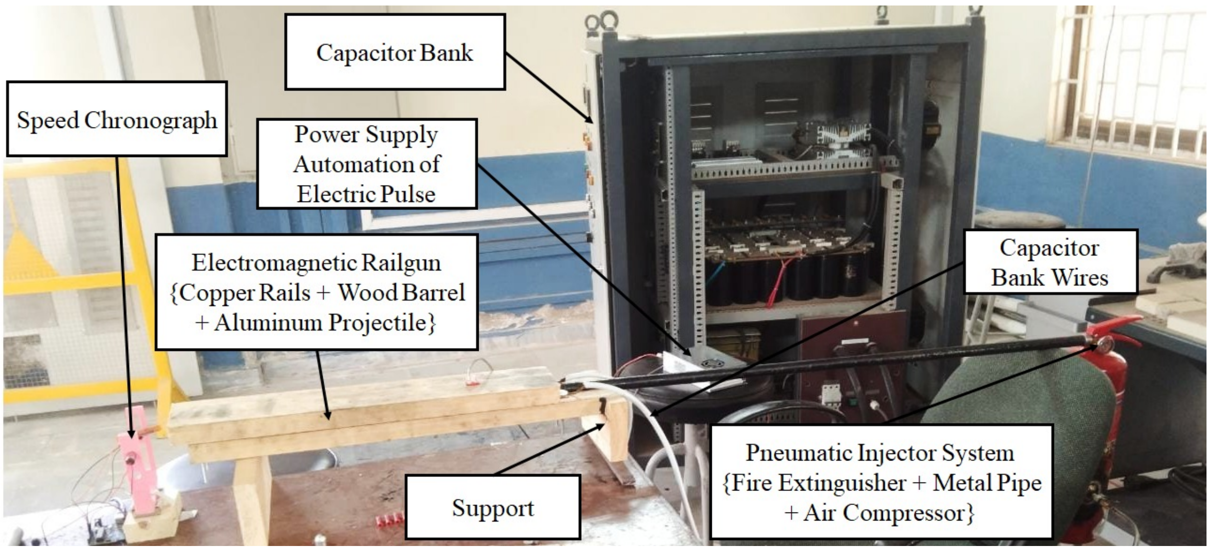


Figure 13 Assembled Initial Prototype

This design has been achieved through constant improvement. The power supply is capacitor bank with 11.8KJ power. It has capacitance of 22mF and maximum voltage of 1000V.

C-type Rails Prototype:

This model of electromagnetic propulsion device is characterized by the shape of its rails. They are uniquely C type shape.

Objective of this design.

The initial prototype design offers more friction with wood and wood surface also gets worn out after repeated firing. This is due to high friction between projectile and wood. The second big issue is that projectile also get disconnected from rail because rails are only at two sides of projectile. Slight error in dimensioning disturbs the contact of both which leads to arcing and gouging problem.

CAD model:

The detailed internal view of this new design is shown in figure 14 and overall geometry is also shown in figure 15. The design can be better understood by the front cross section of the conducting barrel. This cross-section is shown in figure 16. This new design provides more accuracy and stability to the device. Let's discuss the design and fabrication of each component in detail.

Rails Design and Fabrication:

There are three rectangular cross section rails which combine to form one C shape rail as shown in figure 16. The projectile travels between these two C shape rails. The bottom two

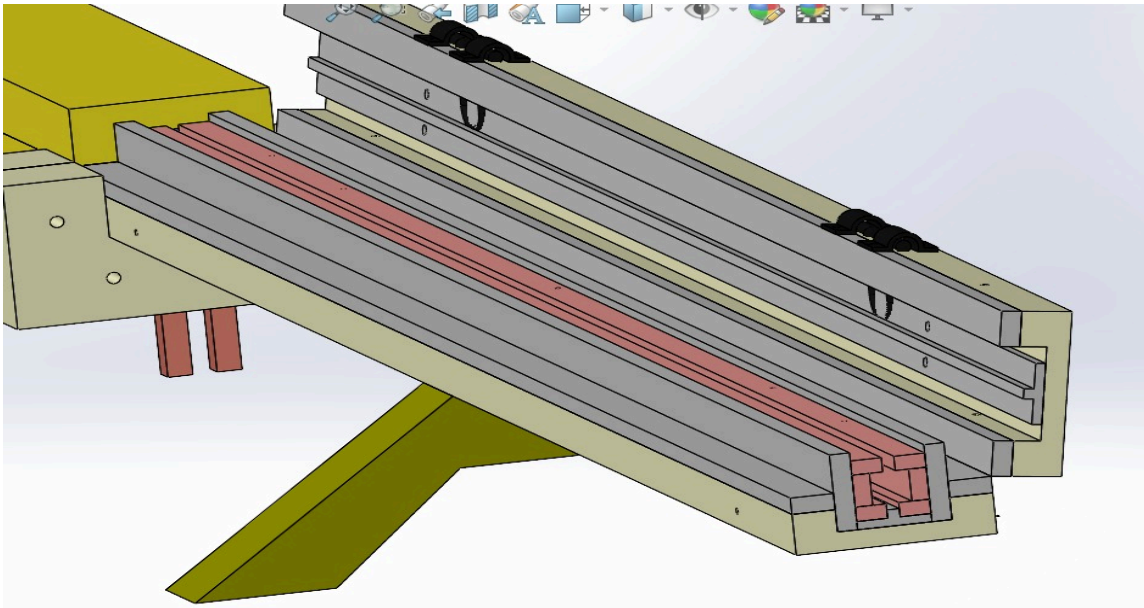


Figure 14 Detailed view of C-type rail design

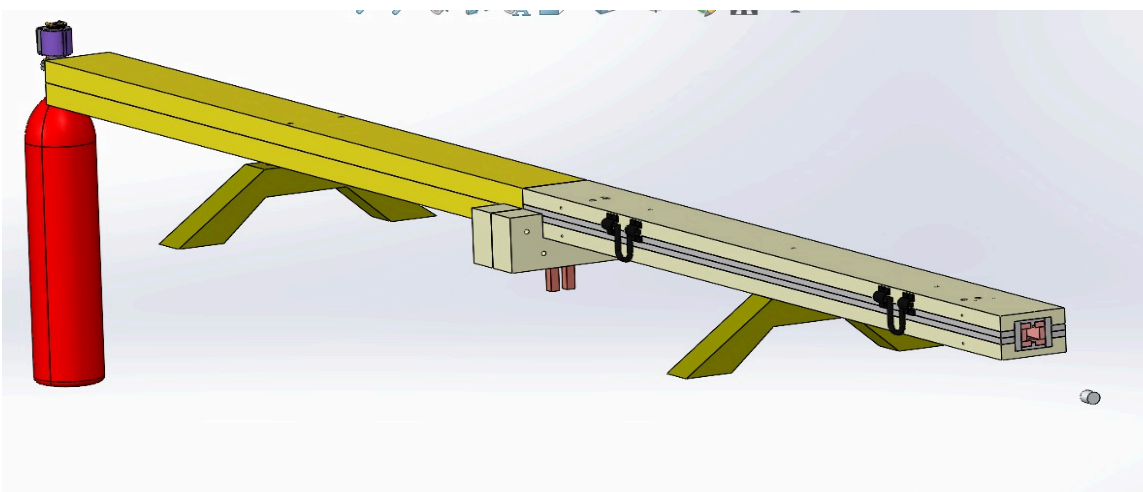


Figure 15 Overall view of C-type rail design

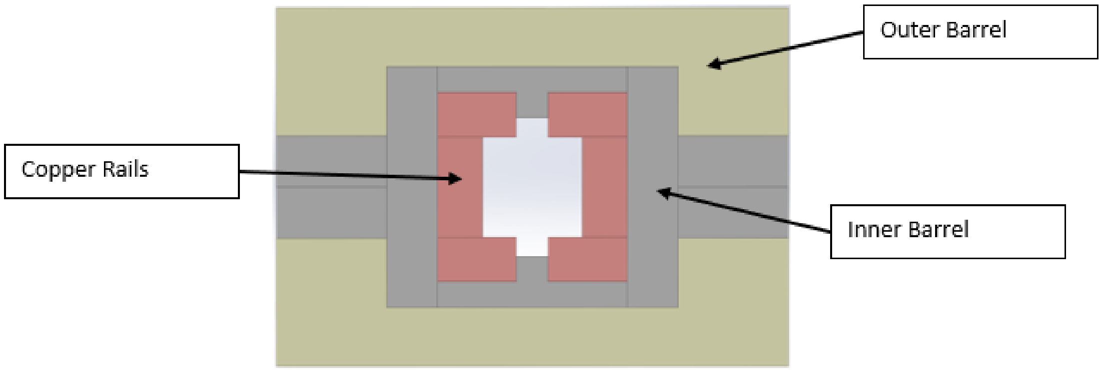


Figure 16 Rails and barrel schematic

rails in L shape configuration are fixed in lower barrel using M5 screws while the straight single above rail is mounted in upper barrel using M5 screws. When these two barrels combine using latches, they force both rails over one another, thus making a complete connection. The material is the same as the initial design model, but the length is increased to 1m. The bottom L shape rails are combined using gas welding.

Barrel Design and Fabrication:

In this model, conducting barrel consists of mainly two materials, Nylon and Teflon. Teflon is a gray colored material surrounding the rails and acting as an insulator between two rails. It is used so because of its high melting point. In this way, it is not destroyed due to heating up of rails. The outer covering of both lower and upper barrel is made by Nylon because it is lightweight and easily machinable, but it has less melting point. That is why it is not used directly in contact with rails.

The insulated barrel also has an upper and lower part, both made up of Nylon. It holds the PVC pipe which is part of the injection system. This provides initial inertia or velocity to projectile.

Injector System:

In this C type rails prototype, the injection system is same as previous prototype except that it is automated and controlled using Solenoid volve. This valve operates directly on 220V and has high pressure rating. The solenoid valve used is shown in figure 10. This also increased the safety of the system.

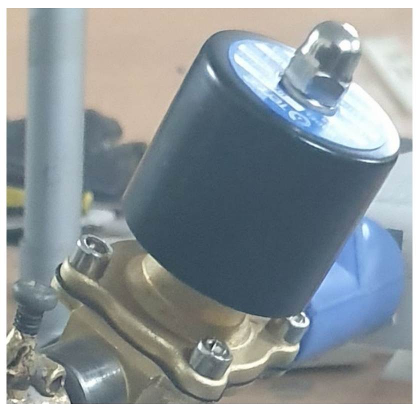


Figure 17 Solenoid valve

Assembled Product:

The completely assembled C type rails prototype is shown in figure 18.

Figure 18 Assembled Product

Instrumentation (Speed Measurement):

The device generally used to measure muzzle velocity is known as chronograph. There are two types of chronographs used.

1. Beta Chrony
2. New Design

Beta Chrony:

It is made by a famous company, Chrony. It is its beta version. It has optical sensors that operate using infrared radiation. It is shown in figure 14.

Figure 19 Beta Chrony

New Design:

The need for this design arose due to the limitations of beta Chrony. The beta Chrony requires high light intensity around to function properly and it is also required to be held at 1m distance which is not possible in our lab environment.

For this, the new design is made as shown in figure 15. It has two points where projectile is detected using wire brushes. The brushes holders are 3D printed with PLA material. The distance between both holders is fixed and muzzle velocity is computed in a program through simple distance, time and speed relation. As soon as the projectile completes the contact between these brushes, the signal is completed and conveyed to Arduino which through its program measures muzzle velocity. The program is written in appendix II.

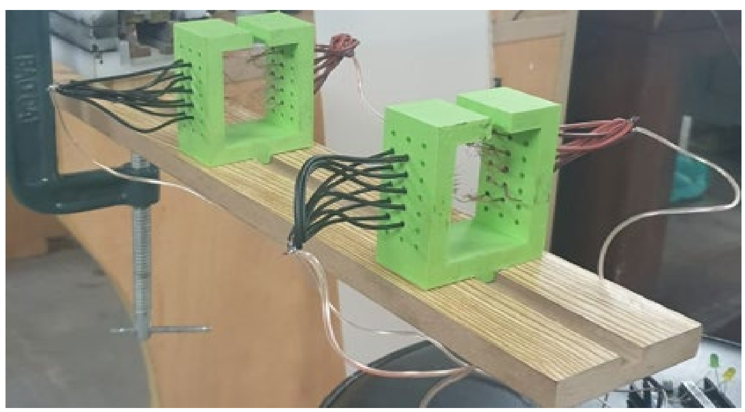


Figure 20 New Design Chronograph

Capacitor Bank:

The capacitor bank that powers the electromagnetic propulsion mechanism has a total energy storage capacity of 10.8 kilojoules. The capacitor bank is made up of 30 separate capacitors that are wired together using both parallel and series circuits. The bank can reach a total capacitance of 22 millifarads thanks to this combination. A capacitor's capacitance is a gauge of how much charge it can hold per unit of voltage. By storing a large quantity of electrical charge in your bank, which can then be swiftly released to power the railgun, you can store a lot of electrical charge by having a bank with a high total capacitance.

The capacitor bank operates between 50 and 1000 volts of voltage. The quantity of energy that the capacitors can store increases with the voltage at which they are charged. The wide voltage range allows for adjustable energy production. The capacitors can hold a maximum of 10.8 kilojoules at higher voltages while storing less energy at lower levels.

Making ensuring that the capacitors can be charged and discharged safely and effectively is the key problem with such a system. Capacitors that have been overcharged may eventually fail, which could create a dangerous circumstance.

CHAPTER 4: RESULTS AND DISCUSSIONS

Experimentation results:

1. It is found that if no initial velocity is given, the projectile gets spot welded with rails. It only projects out if input power is too high and material melting point is high enough not to be melted.
2. The line contact improves muzzle velocity of projectile as compared to surface contact.
3. The shape of projectile also creates a significant impact on muzzle velocity. The shape which offers good current density arc at back of projectile will have more muzzle velocity.
4. The effective length of rails is small because of the low capacitance of the power bank. Due to this low capacitance, current got discharged early without full power transmission.

Tabulated Results:

Effect of Voltage:

Table 2 (For initial prototype design)

Sr No	Input Voltage (V)	Muzzle Velocity (m/s)
1	0	28

2	380	50
3	500	57
4	850	67

Table 3 (For C-type Rails design)

Sr No	Input Voltage (V)	Muzzle Velocity Experimental (m/s)	Muzzle Velocity Theoretical (m/s)
1	0	35	40
2	380	62	120
3	500	70	140
4	850	70	210

The sample calculation sheet is shown in appendix I. These calculations are done using formulas in chapter 2.

Graph:

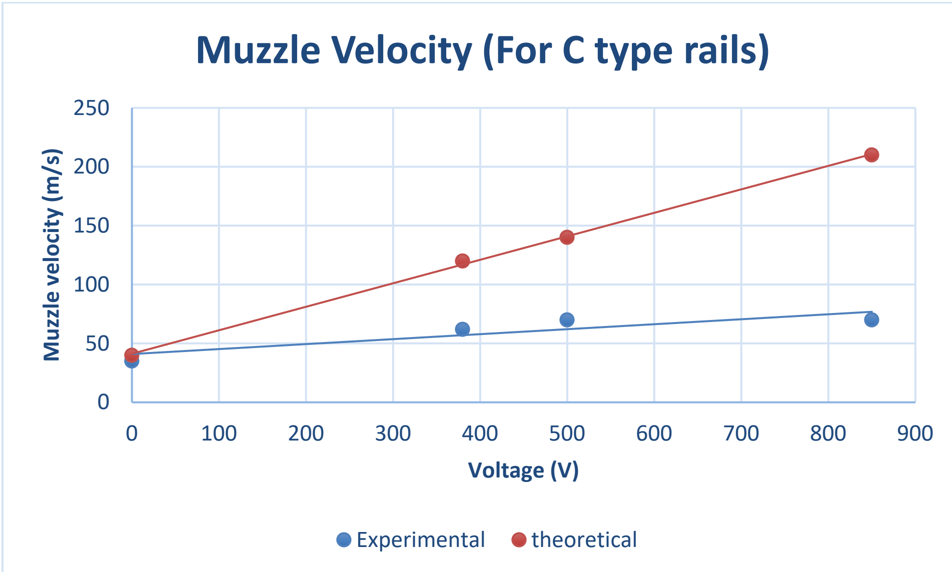


Figure 21 Muzzle Velocity Plot

The efficiency comes out at maximum achieved velocity experimentally is 1.5%.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The railgun was designed to achieve a muzzle velocity of 100m/s. The design approach included the use of an injector system for initial velocity, a pneumatic type of injector, and a chronograph for speed measurement. Throughout the course of the project, various challenges were encountered and addressed, including issues related to the rail materials, projectile materials, and the heating effect of current in the rails. Despite these challenges, the project was ultimately successful in achieving its objectives, demonstrating the feasibility and potential of electromagnetic railgun technology. With further development and refinement, this technology has the potential to be applied in a variety of fields, including military and industrial applications.

From figure 20, it can be seen that experimental velocity has no effect after an increase in voltage over 500V. This is because an increase in voltage cause ionization of air around projectile and energy got wasted there. That is why there is no substantial increase at high voltage. Instead, it reduces the muzzle velocity by creating an electric arc explosion around the projectile which disturbs its path.

It is required to increase the time constant of capacitor bank. It will provide constant and larger energy to projectile. Currently, its time constant is very low, equal to 0.04ms. It can be increased by increasing resistance of current path, but it will reduce the amount of current passing and the Lorentz force also. Another way to increase time constant is to increase the value of capacitance. This is the best and optimum way to increase device efficiency and output muzzle velocity.

The current efficiency is very low about 1-2 %. It is because of the very low time constant of capacitor bank. This low time constant initiates instant spark instead of arc of energy that would propel projectile with high muzzle velocities. The impurities in materials are also a source of very low efficiency.

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APPENDIX I: SAMPLE CALCULATIONS SHEET

Enter range(m)	75						
Enter vertical height fall (m)	1.2	The muzzle velocity is:(m/s)	170				
between two rails(m)	0.018	Inductance gradient is:	6.10423E-07				
Enter width of rail from top view(m)	0.01			Force on projectile is:(N)	72.25	Capacitance required is:(F)	0.02
Enter rail length(m)	1	Current in rail is:(A)	15385.74922	Time of projectile inside rail is:(s)	0.011765		
Enter projectile mass(kg)	0.005	Specify voltage V	850				

APPENDIX II: CHRONOGRAPH CODE

```
unsigned long Time1=0;
unsigned long Time2=0;
boolean stop1=true;
boolean stop2=true;
int distance=200;
int Final_time;
int Speed;
void setup() {
  pinMode(8,INPUT_PULLUP);
  pinMode(9,INPUT_PULLUP);
  pinMode(11,OUTPUT);
  pinMode(10,OUTPUT);
  Serial.begin(9600);
}
void loop() {
  if(digitalRead(8)==LOW && stop1==true){
    digitalWrite(10,HIGH);
    Time1=millis();
    Serial.print("Time 1: ");
    Serial.println(Time1);
   // stop1=false;
  }
  if(millis()>=(Time1+3000)){
    Time1=millis();
    digitalWrite(10,LOW);
    //stop1=true;
  }
if(digitalRead(9)==LOW && stop2==true){
  digitalWrite(11,HIGH);
  Time2=millis();
  Serial.print("Time 2: ");
  Serial.println(Time2);
  //stop2=false;
}
  if(millis()>=(Time2+3000)){
    Time2=millis();
    digitalWrite(11,LOW);
   // stop2=true;
  }
```

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