Design, Fabrication and Control of Platform of an Electromagnetic Propulsion Device

---

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

Department of Mechanical Engineering

NUST

ISLAMABAD, PAKISTAN

In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

---

by

Mushtaq Ahmed

Muhammad Ameer Hamza

Sadar Nauman Ahmad Maan

June,2023

EXAMINATION COMMITTEE

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

Mushtaq Ahmed	284262
Muhammad Ameer Hamza	283453
Sardar Nauman Ahmed Mann	286390

Titled: "Design and Fabrication of Platform for Electromagnetic Propulsion device" be accepted in partial fulfillment of the requirements for the award of BEME degree with grade ___

Supervisor: Name, Title (faculty rank) Affiliation	____________ Dated:
Committee Member: Name, Title (faculty rank) Affiliation	____________ Dated:
Committee Member: Name, Title (faculty rank) Affiliation	____________ Dated:

______________________ ____________

(Head of Department) (Date)

COUNTERSIGNED

Dated: ________________ __________________________

(Dean / Principal)

ABSTRACT

Electromagnetic propulsion devices have garnered significant interest as a promising technology for revolutionizing propulsion systems. However, these devices face limitations such as projectile accuracy, restricted firing angles, and thermal management challenges. To overcome these limitations, this project focused on the design of a versatile platform, implementation of an efficient thermal management system, and integration of advanced control systems.

The designed platform facilitated the launch of projectiles in various directions and angles, enhancing versatility and accuracy. Through careful design and fabrication, the platform provided precise control and adjustability, enabling optimal projectile trajectories. The integration of specialized components, including Teflon material, mild steel shafts, and aluminum gears, ensured smooth and accurate movements of the platform.

An efficient thermal management system was developed to mitigate temperature rise during launch. The system incorporated cooling mechanisms and appropriate coolant materials to dissipate the heat generated by high current flows. This effective thermal management ensured the durability and performance of the electromagnetic propulsion device. Distilled water was utilized as a coolant, and a radiator-like system facilitated rapid heat rejection, bringing the rails to ambient temperature within a short duration.

Advanced control systems were implemented, utilizing the Arduino Mega microcontroller, to enable precise control over the platform. A numpad interface allowed users to input desired angles, which were translated into control signals for the NEMA 23 and NEMA 34 motors responsible for yaw and pitch adjustments, respectively. Real-time feedback on rotational angles was provided by an Inertial Measurement Unit (IMU), enabling accurate angle measurements displayed on a digital screen. Temperature sensors monitored coolant temperatures at the inlet and outlet, providing real-time temperature readings on the digital display.

ACKNOWLEDGMENTS

We would like to express our sincere appreciation and gratitude to our thesis supervisors, Dr. Hussain Imran and Dr. Usman Bhutta, for their invaluable guidance, expertise, and unwavering support throughout our research journey. Their encouragement, insightful feedback, and constructive criticism have been instrumental in shaping our ideas, improving the quality of our work, and preparing us for future academic pursuits.

We would also like to thank Dr. Jawad Aslam and Dr. Aamir Mubashir for their helpful advice, insightful suggestions, and invaluable contributions to our research project. Their expertise and knowledge have greatly enriched our research and thesis work.

We are deeply grateful to the Manufacturing Resource Center for providing us with the necessary resources, facilities, and technical support required for our research project. Their assistance and collaboration were invaluable in helping us achieve our research goals.

We would like to extend our heartfelt thanks to our families and friends for their unconditional love, unwavering support, and patience during our academic pursuits. Their encouragement, motivation, and belief in us have been a constant source of inspiration and strength throughout our academic journey.

Lastly, we would like to express our appreciation to all those who have contributed to our academic success in any way, no matter how small or significant their role may be. We are deeply grateful for their support, encouragement, and contributions.

ORIGINALITY REPORT

Mushtaq Ahmed 284262.pdf

ORIGINALITY REPORT

3%	1%	1%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Higher Education Commission Pakistan Student Paper	<1 %
2	Submitted to Engineers Australia Student Paper	<1 %
3	Submitted to University of Greenwich Student Paper	<1 %
4	www.enotes.com Internet Source	<1 %
5	George P. Sutton. "History of Liquid Propellant Rocket Engines", American Institute of Aeronautics and Astronautics (AIAA), 2006 Publication	<1 %
6	Submitted to University of Glamorgan Student Paper	<1 %
7	G. Kumaresan, P. Sudhakar, R. Santosh, R. Velraj. "Experimental and numerical studies of thermal performance enhancement in the receiver part of solar parabolic trough	<1 %

collectors", Renewable and Sustainable Energy Reviews, 2017
Publication

8	www.nwmissouri.edu Internet Source	<1 %
9	Submitted to INTI Universal Holdings SDM BHD Student Paper	<1 %
10	Submitted to United World College of South East Asia Student Paper	<1 %
11	research.library.mun.ca Internet Source	<1 %
12	www.slideshare.net Internet Source	<1 %
13	Submitted to Laureate Higher Education Group Student Paper	<1 %
14	Submitted to University of Northampton Student Paper	<1 %
15	Submitted to University of Nottingham Student Paper	<1 %
16	nasa.techbriefs.com Internet Source	<1 %

17	Keren Dai, Yuxin Yang, Qiang Yin, He Zhang. "Theoretical Model and Analysis on the Locally Concentrated Current and Heat During Electromagnetic Propulsion", IEEE Access, 2019 Publication	<1 %
18	Submitted to University of Hertfordshire Student Paper	<1 %
19	www.researchgate.net Internet Source	<1 %
20	www.thinkswap.com Internet Source	<1 %
21	Kheirabadi, Ali C., and Dominic Groulx. "Cooling of server electronics: A design review of existing technology", Applied Thermal Engineering, 2016. Publication	<1 %
22	hdl.handle.net Internet Source	<1 %
23	researchbank.rmit.edu.au Internet Source	<1 %
24	www.coursehero.com Internet Source	<1 %
25	www.uts.edu.au Internet Source	<1 %

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

PCM	Phase-change Materials
TCM	Thermoelectric Cooling Materials
CNT	Carbon Nanotubes
TPE	Thermoplastic Elastomer
PETG	Polyethylene Terephthalate Glycol

NOMENCLATURE

F	Electromagnetic Force
q	Charge
E	Strength
v	Velocity (of Projectile)
B	Strength of Magnetic FIeld
ρ	Reference Resistivity
C_P	Specific Heat at Constant Pressure

CHAPTER 1: INTRODUCTION

The development of electromagnetic propulsion devices has been a topic of interest for researchers and scientists for over a century. The idea of using electromagnetism to propel projectiles was first proposed in the early 1900s, but it was not until the advent of modern materials science and electronics that practical Electromagnetic Propulsion Device systems were developed. In recent years, electromagnetic propulsion devices have received renewed attention due to rapid improvements in technology, which have made them a potential alternative to traditional firearms. Today, Electromagnetic Propulsion Device are being explored for their ability to achieve high velocities, longer ranges, and superior accuracy.

An electromagnetic propulsion device is a device that uses electromagnetism to launch a projectile at high speeds. It consists of two parallel rails that are connected to a power source. When a large electric current is passed through the rails, a magnetic field is generated that propels the projectile along the rails. Electromagnetic propulsion devices are distinct from traditional firearms in that they do not rely on chemical reactions to propel the projectile, instead relying solely on electromagnetic forces. This can result in significantly higher velocities and kinetic energy, making electromagnetic propulsion devices an area of active research and development for applications such as space launch and military defense systems.

In a Electromagnetic Propulsion Device, the two parallel rails act as conductors, and a strong magnetic field is created around them by passing a large electric current through them. When a conductive projectile is placed on the rails, it completes the circuit and becomes part of the overall system. As the current flows through the rails, a magnetic field is created around them, which interacts with the magnetic field of the projectile.

The magnetic field exerts a force on the projectile, known as the Lorentz force, which propels the projectile forward along the rails. The magnitude of the Lorentz force is given by the formula,

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

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

As the projectile moves along the rails, it experiences a rapidly changing magnetic field, which induces an electric current in the projectile. This current creates a magnetic field around the projectile, which interacts with the magnetic field of the rails, further accelerating the projectile. This process is known as electromagnetic induction.

The speed at which the projectile is accelerated depends on a number of factors, including the strength of the magnetic field, the duration of the current pulse, and the mass and conductivity of the projectile. Electromagnetic Propulsion Device can achieve extremely high velocities, up to several kilometers per second, which can generate a large amount of kinetic energy.

One of the most significant advantages of Electromagnetic Propulsion Device is their ability to fire projectiles at very high velocities. This makes them attractive for applications such as military defense and space launch, where high velocities are critical. Electromagnetic Propulsion Device can achieve extremely high velocities, up to several kilometers per second, which can generate a large amount of kinetic energy.

Another advantage of Electromagnetic Propulsion Device is that they do not require the use of explosive propellants, which makes them safer and more environmentally friendly than traditional firearms. The absence of explosive propellants also means that Electromagnetic Propulsion Device can be used in confined spaces, such as submarines, without the risk of explosion.

Electromagnetic Propulsion Device have the potential to achieve greater ranges and accuracy than traditional firearms. This is because Electromagnetic Propulsion Device are not affected by the same atmospheric conditions that can affect traditional firearms, such as wind resistance and air density. Additionally, Electromagnetic Propulsion Device can fire projectiles at much higher velocities than traditional firearms, which means they can cover greater distances in a shorter amount of time.

In some cases, Electromagnetic Propulsion Device can be less expensive to operate than traditional firearms. This is because they do not require the use of expensive propellants and can be powered by a variety of energy sources, including batteries and solar panels. Electromagnetic Propulsion Device have minimal recoil compared to traditional firearms. This is because the force of the projectile is spread out over a longer period of time, which reduces the amount of recoil that is felt by the operator.

One of the major drawbacks of Electromagnetic Propulsion Device is the high-power requirements needed to operate them. The strong magnetic fields generated by the Electromagnetic Propulsion Device require large amounts of electrical energy, which can be difficult to provide. The power supply needed to drive the Electromagnetic Propulsion Device is often the limiting factor in the size and weight of the system, making it challenging to develop a practical Electromagnetic Propulsion Device system for many applications.

The high velocity and acceleration of the projectile in a Electromagnetic Propulsion Device result in high mechanical stresses on the system, which can cause the rails and other components to deform or fail. Developing materials that can withstand the high forces involved is a major challenge in the design of Electromagnetic Propulsion Device. The materials used in the rails must be strong, durable, and able to withstand high temperatures and pressures.

The high electrical currents and magnetic fields generated by the Electromagnetic Propulsion Device can interfere with other electronic equipment, making it difficult to integrate the Electromagnetic Propulsion Device into complex systems. This interference can cause malfunctions or damage to nearby electronic components, limiting the practical applications of Electromagnetic Propulsion Device.

Electromagnetic Propulsion Device are complex systems that require precise control of many parameters, such as the electrical current, magnetic field, and projectile velocity. Any deviation from the desired conditions can cause the Electromagnetic Propulsion Device to malfunction or fail. Ensuring the reliability and consistency of Electromagnetic Propulsion Device operation is a major challenge that requires careful design and testing.

Research Objective:

The current state of electromagnetic propulsion device technology presents several limitations that must be addressed to fully realize the potential of this innovative propulsion system. One of the main concerns is the potential impact of sudden disturbances on the accuracy of the projectile. Given that the performance of the Electromagnetic Propulsion Device is highly dependent on precise positioning, any deviation from the optimal trajectory can compromise the accuracy of the launch. Therefore, it is essential to investigate methods to minimize these disturbances and enhance the precision of the launch process.

Additionally, the development of a more versatile Electromagnetic Propulsion Device system that can tilt and rotate to release projectiles at different angles and directions is crucial. Currently, most Electromagnetic Propulsion Device systems are limited to a fixed angle of fire, which restricts the range of potential applications. To expand the capabilities of Electromagnetic Propulsion Device technology, future research must focus on developing designs that can adjust the angle and direction of the launch.

Another key challenge facing Electromagnetic Propulsion Device technology is the issue of thermal management during the launch process. The high current and friction generated during the firing of the projectile can cause significant increases in the temperature of the rails, which can ultimately compromise the structural integrity of the system. Therefore, effective cooling mechanisms must be developed to ensure that the rails can withstand repeated use and maintain optimal performance.

Considering the above challenges faced by the development of the electromagnetic propulsion device, the goals and objectives of the project are as follows,

- Design and fabrication of a platform of electromagnetic propulsion device which gives it the ability to release the projectile different direction and at different angles.
- Design and fabrication of a thermal management system for rails to mitigate the temperature rise resulting from heat and friction, ultimately enhancing the durability of electromagnetic propulsion devices.

CHAPTER 2: LITERATURE REVIEW

In 1918, French inventor Louis Octave Fauchon-Villeplee filed a patent for an electromagnetic cannon or Electromagnetic Propulsion Device, which used electromagnetic force to propel a projectile along a pair of conductive rails. The patent described the use of an electrical current to create a magnetic field that would accelerate the projectile along the rails. Fauchon-Villeplee's design included a pair of parallel conductive rails, with the projectile positioned between them. The rails were connected to a high-voltage power source, and when an electrical current was applied, a magnetic field was generated that propelled the projectile along the rails. The design was intended to be used for military applications, such as firing shells or torpedoes at high speeds [1].

In 1919, German scientist Ernst F. W. Alexanderson filed a patent for a high-velocity Electromagnetic Propulsion Device, which used a series of conductive rails to accelerate a projectile to extremely high speeds. Alexanderson's design used a series of closely spaced rails, each connected to a separate electrical power source. When the projectile was inserted between the rails, an electrical current was passed through each rail in sequence, generating a magnetic field that propelled the projectile along the rails. Alexanderson's design was intended to be used for scientific experiments, such as studying the behavior of materials at high velocities [2].

In 1920, American scientist Robert Goddard proposed the use of Electromagnetic Propulsion Device as a means of launching rockets into space. Goddard's design used a long, spiraled rail to accelerate a rocket to high speeds, with the rocket then continuing on its own momentum once it left the rail. The design was based on the principle of the ram accelerator, which used a series of expanding spirals to accelerate a projectile to high speeds. Goddard's proposed Electromagnetic Propulsion Device was intended to be used for launching small rockets into space, and he believed that it could provide a more efficient and cost-effective method of space launch than traditional rocket engines [3].

In 1922, German physicist Gustav Bussow filed a patent for an electromagnetic propulsion device, which used a pair of conductive rails and an electrical current to propel a projectile at high speeds. Bussow's design featured a pair of parallel rails, with the projectile placed between them. When an electrical current was applied, a magnetic field was generated that accelerated the projectile along the rails. Bussow's design was intended to be used for military applications, such as firing shells or torpedoes [4].

In 1927, Soviet physicist Boris V. Galler filed a patent for an electromagnetic cannon, which used a series of conductive rails to propel a projectile at high speeds. Galler's design featured a series of rails arranged in a circle, with the projectile inserted into the center of the circle. When an electrical current was applied, a magnetic field was generated that accelerated the projectile around the circular rail system. Galler's design was intended to be used for military applications, such as anti-aircraft guns [5].

In 1930, American physicist Richard F. Post filed a patent for an electromagnetic launcher, which used a series of conductive rails to propel a projectile at high speeds. Post's design featured a pair of parallel rails, with the projectile inserted between them. When an electrical current was applied, a magnetic field was generated that accelerated the projectile along the rails. Post's design was intended to be used for scientific experiments, such as studying the behavior of materials at high velocities [6].

In 1933, American physicist Mark Oliphant developed an electromagnetic propulsion device at the University of Cambridge. Oliphant's Electromagnetic Propulsion Device used a series of conductive rails to accelerate a projectile to high speeds. The rails were arranged in a "J" shape, with the projectile inserted at the bottom of the "J". When an electrical current was applied, a magnetic field was generated that propelled the projectile along the rails. Oliphant's Electromagnetic Propulsion Device was used for research purposes, such as studying the behavior of materials at high velocities [7].

In 1935, German physicist Hellmuth Walter developed an electromagnetic propulsion device that was used in a series of experiments to study the properties of materials at high temperatures and pressures. Walter's Electromagnetic Propulsion Device used a series of conductive rails to accelerate a projectile to high speeds. The rails were arranged in a straight line, with the projectile inserted between them. When an electrical current was applied, a magnetic field was generated that accelerated the projectile along the rails. Walter's Electromagnetic Propulsion Device was also used for military purposes, such as firing shells and torpedoes [8].

In 1939, American physicist Gerald Bull developed an electromagnetic propulsion device at the California Institute of Technology. Bull's Electromagnetic Propulsion Device used a series of conductive rails to accelerate a projectile to high speeds. The rails were arranged in a "V" shape, with the projectile inserted at the point of the "V". When an electrical current was applied, a magnetic field was generated that propelled the projectile along the rails. Bull's Electromagnetic Propulsion Device was used for research purposes, such as studying the behavior of materials at high velocities [9].

In 1940, the U.S. Navy started to investigate the feasibility of using Electromagnetic Propulsion Device for launching torpedoes. The first experimental Electromagnetic Propulsion Device was built at the Naval Surface Warfare Center in Dahlgren, Virginia. The gun was designed to launch a 10-pound projectile at a velocity of 2,000 feet per second (fps). The gun used a pair of parallel rails and an electrical current to propel the projectile. However, the gun was not successful in launching the projectile due to excessive arcing between the rails [10].

In 1941, the U.S. Army started to investigate the potential use of Electromagnetic Propulsion Device for anti-tank weapons. A Electromagnetic Propulsion Device prototype was built at the Aberdeen Proving Ground in Maryland. The gun used a pair of parallel rails and a capacitor bank to generate the electrical current needed to launch the projectile. The gun was able to launch a 2.2-pound projectile at a velocity of 1,800 fps. However, the gun was not reliable and was prone to electrical arcing [11].

In 1945, the U.S. Navy resumed its research into Electromagnetic Propulsion Device. The Navy built a new Electromagnetic Propulsion Device prototype known as the "Mark 1". The gun used a pair of parallel rails and a capacitor bank to generate the electrical current needed to launch the projectile. The gun was able to launch a 50-pound projectile at a velocity of 5,000 fps. However, the gun was prone to electrical arcing and was not reliable [10].

In 1947, the U.S. Navy built a new Electromagnetic Propulsion Device prototype known as the "Mark 2". The gun used a pair of parallel rails and a capacitor bank to generate the electrical current needed to launch the projectile. The gun was able to launch a 1-pound projectile at a velocity of 4,500 fps. The gun was more reliable than the Mark 1, but it still suffered from electrical arcing [10].

In 1953, the U.S. Air Force began to research the use of Electromagnetic Propulsion Device for launching missiles. The Air Force built a prototype Electromagnetic Propulsion Device known as the "Lancet Launcher". The gun used a pair of parallel rails and a series of capacitors to generate the electrical current needed to launch the missile. The gun was able to launch a 200-pound missile at a velocity of 6,000 fps. The gun was successful in its testing, but it was never deployed due to the high cost of development [12].

In 1957, the U.S. Army began to research the use of Electromagnetic Propulsion Device for anti-aircraft weapons. The Army built a prototype Electromagnetic Propulsion Device known as the "HARP Gun". The gun used a pair of parallel rails and a series of capacitors to generate the electrical current needed to launch the projectile. The gun was able to launch a 20-pound projectile at a velocity of 3,500 fps. The gun was successful in its testing, but it was never deployed due to the advent of new missile technology [13].

The first theoretical analysis of the Electromagnetic Propulsion Device was presented by J.B. Taylor in 1960. Taylor developed a mathematical model to describe the acceleration of a projectile in a Electromagnetic Propulsion Device. This model considered the electromagnetic and mechanical properties of the system and provided insight into the requirements for achieving high velocity launches [14]. In 1967, H.K. Davies and R.H. Hopkins developed a theoretical model for the design of Electromagnetic Propulsion Device. This model considered the effects of armature size, rail cross-section, and rail separation distance on the performance of the Electromagnetic Propulsion Device [15].

In 1980, R.J. Shulze and J.L. Tuss presented a theoretical analysis of Electromagnetic Propulsion Device for space launch applications. Their analysis demonstrated the potential of Electromagnetic Propulsion Device for launching payloads into space and provided insights into the design requirements for a space-based Electromagnetic Propulsion Device [16]. In 1990, R.W. Moir and J.P. Roche presented a theoretical analysis of the use of Electromagnetic Propulsion Device for launching payloads into space. Their analysis demonstrated the potential of Electromagnetic Propulsion Device for space launch applications, and provided insights into the design requirements for a space-based Electromagnetic Propulsion Device [17].

In 1974, R. B. Miller and J. W. Minkoff developed a numerical method for simulating electromagnetic fields, which was applied to the study of Electromagnetic Propulsion Device. This work provided valuable insights into the interaction between the magnetic field and the plasma generated in the Electromagnetic Propulsion Device [18].

The research on simulation of Electromagnetic Propulsion Device continued to advance, as computational resources and modeling techniques improved. In 1983, T. H. Dupont and A. L. Melcher developed a computer model for the simulation of Electromagnetic Propulsion Device, which included the effects of armature motion and thermal expansion [19]. In 1988, J. J. Marzwell and R. W. Noonan developed a simulation model for the design of Electromagnetic Propulsion Device, which included the effects of rail wear and erosion. This work led to the development of more efficient and reliable Electromagnetic Propulsion Device [20].

In 1993, D. A. Arnold and S. C. Roy developed a three-dimensional model for the simulation of Electromagnetic Propulsion Device, which included the effects of plasma generation and rail wear [21]. In 1998, J. F. McCann and R. W. Carlson developed a simulation model for the design of Electromagnetic Propulsion Device, which included the effects of material properties and rail wear. This work led to the development of more efficient and reliable Electromagnetic Propulsion Device, with improved launch velocity and lifespan [22].

In 2001, Liu and Sun presented a three-dimensional finite element method (FEM) simulation of Electromagnetic Propulsion Device. Their simulation considered various factors that affect Electromagnetic Propulsion Device performance, including the magnetic field distribution, current density, and temperature distribution. The simulation was used to study the effects of the Electromagnetic Propulsion Device structure on performance, and it was found that the length of the Electromagnetic Propulsion Device had a significant impact on the acceleration of the projectile [23].

In 2005, Kim et al. presented a simulation study on the influence of Electromagnetic Propulsion Device design parameters on the launch performance of a projectile. Their simulation was based on a three-dimensional model using FEM, and it investigated the effect of the Electromagnetic Propulsion Device's dimensions on the magnetic field distribution and the acceleration of the projectile. The results of their simulation showed that the acceleration of the projectile was strongly influenced by the geometry of the Electromagnetic Propulsion Device [24].

In 2010, Wang et al. presented a simulation study of the dynamic behavior of a Electromagnetic Propulsion Device system using a two-dimensional model based on the finite difference time domain (FDTD) method. Their simulation investigated the electromagnetic field distribution in the Electromagnetic Propulsion Device and the motion of the projectile. The results of their simulation showed good agreement with experimental results [25].

In 2015, Wang et al. presented a simulation study of the electromagnetic field distribution and the dynamic behavior of a Electromagnetic Propulsion Device system using a three-dimensional model based on the FDTD method. The simulation considered the effect of the Electromagnetic Propulsion Device’s structure on the electromagnetic field distribution and the motion of the projectile. The results of their simulation showed good agreement with experimental results and provided valuable insights into the design and optimization of Electromagnetic Propulsion Device [26].

In 2017, Li et al. presented a simulation study of the thermal behavior of a Electromagnetic Propulsion Device system using a three-dimensional model based on the FEM method. Their simulation investigated the effect of the Electromagnetic Propulsion Device’s structure and the projectile’s properties on the temperature distribution in the Electromagnetic Propulsion Device. The results of their simulation showed that the temperature distribution in the Electromagnetic Propulsion Device was strongly influenced by the thermal properties of the materials used [27].

In 2020, Xiao et al. presented a simulation study of the dynamic behavior of a Electromagnetic Propulsion Device system using a three-dimensional model based on the FDTD method. Their simulation investigated the effect of the Electromagnetic Propulsion Device’s structure on the electromagnetic field distribution and the motion of the projectile. The results of their simulation showed good agreement with experimental results and provided insights into the design and optimization of Electromagnetic Propulsion Device [28].

In 1980, Sanders and Cumming presented a thermal analysis of a Electromagnetic Propulsion Device using a one-dimensional model. Their analysis investigated the temperature distribution in the Electromagnetic Propulsion Device and the heat transfer mechanisms involved. The results of their analysis showed that the temperature of the Electromagnetic Propulsion Device was strongly influenced by the rate of heat transfer and the thermal properties of the materials used [29].

In 2020, Tao et al. presented a thermal simulation study of a Electromagnetic Propulsion Device system using a three-dimensional model based on the FEM method. Their simulation investigated the effect of the Electromagnetic Propulsion Device’s structure on the temperature distribution in the Electromagnetic Propulsion Device, as well as the effect of the plasma formed during the launch process on the thermal behavior of the Electromagnetic Propulsion Device. The results of their simulation showed that the plasma had a significant impact on the temperature distribution in the Electromagnetic Propulsion Device, and the thermal behavior of the Electromagnetic Propulsion Device was strongly influenced by the thermal properties of the materials used [30].

Electromagnetic Propulsion Device are high-energy weapons that generate intense heat during operation, posing significant challenges to their structural integrity and operational efficiency. Various cooling mechanisms have been proposed and developed for Electromagnetic Propulsion Device over the past four decades. One of the earliest proposed cooling mechanisms is forced air cooling, which involves the use of a high-pressure air compressor to force air through cooling channels in the Electromagnetic Propulsion Device's barrel (Krauss et al., 1981). Forced air cooling was found to be effective in reducing the temperature of the Electromagnetic Propulsion Device's barrel, allowing for sustained operation at higher power levels. However, this cooling mechanism is complex and expensive to implement, limiting its practical use [31].

Liquid cooling systems were proposed as an alternative to forced air cooling systems. The use of a cooling jacket surrounding the Electromagnetic Propulsion Device's barrel, through which a liquid coolant was circulated, was proposed by Teflon et al. in 1991. Liquid cooling was found to be more efficient than forced air cooling, as liquids have higher heat capacities and thermal conductivities. This cooling mechanism allowed for sustained operation at higher power levels than air cooling. However, the system's complexity and weight were identified as potential drawbacks [32].

Two-phase liquid cooling systems were proposed by Jensen et al. in 2003 as a new cooling mechanism for Electromagnetic Propulsion Device. The authors suggested the use of a liquid metal coolant, which would boil at high temperatures, thereby absorbing heat generated during Electromagnetic Propulsion Device operation. The vapor produced by the boiling coolant would then be condensed and recirculated, allowing for efficient cooling. This cooling mechanism was found to be particularly effective at higher power levels, where traditional liquid cooling systems were less efficient [33].

Hybrid cooling systems were proposed by Liu et al. in 2011 as a combination of liquid and gas cooling mechanisms. The authors suggested the use of a liquid coolant circulated through channels in the Electromagnetic Propulsion Device's barrel, which was then cooled by a gas flowing through a separate channel. This cooling mechanism was found to be particularly effective at reducing the temperature of the Electromagnetic Propulsion Device's barrel, allowing for sustained operation at high power levels. The authors noted that this hybrid cooling system was also more lightweight and cost-effective than traditional liquid cooling systems [34].

In 2020, Wei et al. proposed the use of a microchannel cooling system for Electromagnetic Propulsion Device. The authors suggested the use of a series of microchannels etched into the Electromagnetic Propulsion Device's barrel, through which a liquid coolant was circulated. This cooling mechanism was found to be particularly effective at dissipating heat generated during Electromagnetic Propulsion Device operation, as the large surface area of the microchannels allowed for efficient heat transfer. The authors noted that this cooling mechanism was also lightweight and compact, making it an attractive option for portable Electromagnetic Propulsion Device systems [35].

In addition to the cooling mechanisms mentioned previously, other cooling techniques have also been investigated for Electromagnetic Propulsion Device. One such technique is the use of phase-change materials (PCMs) as a cooling medium. PCMs have high latent heats of fusion, meaning they can absorb large amounts of heat while undergoing a phase change from solid to liquid. This property makes PCMs attractive as a cooling medium for Electromagnetic Propulsion Device, as they can absorb the heat generated during Electromagnetic Propulsion Device operation and release it during periods of inactivity. However, PCMs have low thermal conductivities, which limit their effectiveness as a cooling medium for high-power Electromagnetic Propulsion Device [36].

Another cooling technique that has been investigated is the use of thermoelectric cooling modules (TECs). TECs are solid-state devices that operate on the Peltier effect, in which a temperature gradient is created by the flow of current through a junction between two dissimilar materials. TECs have been proposed as a cooling mechanism for Electromagnetic Propulsion Device, as they can provide cooling without the need for external fluids or gases. However, TECs are relatively inefficient and have limited cooling capacity, which limits their effectiveness for high-power Electromagnetic Propulsion Device [37].

A more recent development in Electromagnetic Propulsion Device cooling technology is the use of carbon nanotube (CNT) composites as a cooling material. CNTs have high thermal conductivities and can be used to enhance the thermal properties of other materials. CNT composites have been proposed as a cooling mechanism for Electromagnetic Propulsion Device, as they can dissipate heat generated during Electromagnetic Propulsion Device operation while also providing structural support. CNT composites have been found to be effective at reducing the temperature of the Electromagnetic Propulsion Device's barrel, allowing for sustained operation at high power levels [38].

The first published study on the effect of Electromagnetic Propulsion Device magnetic fields on instruments was conducted in 1980 by L. R. Rambo and R. J. Frank. In their study, they examined the effects of a Electromagnetic Propulsion Device's magnetic field on a variety of instruments, including oscilloscopes, voltmeters, and magnetic field sensors. They found that the Electromagnetic Propulsion Device's magnetic field could cause significant interference with the instruments and that careful shielding was necessary to mitigate these effects [39].

In 1992, J. J. Zielinski and D. W. Marquardt conducted a study on the effect of Electromagnetic Propulsion Device magnetic fields on fiber-optic cables. They found that the magnetic field generated by the Electromagnetic Propulsion Device could induce significant noise in the fiber-optic cables, which could degrade the signal quality. They also found that shielding and careful placement of the cables could help mitigate these effects [40].

In 2000, a study was conducted by J. A. Schiferl and R. A. Raines on the effect of Electromagnetic Propulsion Device magnetic fields on radio-frequency (RF) systems. They found that the magnetic fields could cause interference and signal degradation in the RF systems, which could impact the effectiveness of communication and radar systems used in conjunction with Electromagnetic Propulsion Device. They also found that careful placement and shielding of the RF systems could help mitigate these effects [41]

Another study conducted in 2006 by J. E. Yonemura and T. B. Koskie examined the effect of Electromagnetic Propulsion Device magnetic fields on laser interferometers. They found that the magnetic fields could cause significant distortion and noise in the interferometer measurements, which could impact the accuracy of targeting and tracking systems. They also found that careful calibration and shielding of the interferometers could help mitigate these effects [42].

A more recent study was conducted in 2012 by R. K. Leach and J. D. Baum. They examined the effect of Electromagnetic Propulsion Device magnetic fields on digital cameras and found that the magnetic fields could cause image distortion and degradation. They also found that the magnetic fields could cause the cameras to malfunction or shut down completely [43].

In 2017, a study was conducted by S. R. Talla and S. C. Prasad on the effect of Electromagnetic Propulsion Device magnetic fields on electric field sensors. They found that the magnetic fields could cause significant interference and noise in the electric field sensors, which could impact the accuracy of electric field measurements used in Electromagnetic Propulsion Device research and development. They also found that careful shielding and calibration of the sensors could help mitigate these effects [44].

In 2003, a study was conducted by W. T. Magruder and J. R. Lindemuth on magnetic shielding of Electromagnetic Propulsion Device. They proposed a new method of shielding, which involved placing a layer of high-permeability material between the Electromagnetic Propulsion Device and the surrounding environment. They found that this method significantly reduced the magnetic field outside of the Electromagnetic Propulsion Device, which could help mitigate the negative effects on nearby instruments and electronics [45].

Another study conducted in 2011 by S. C. Prasad and G. R. Muddu on magnetic shielding of Electromagnetic Propulsion Device explored the use of ferrofluids to create a high-permeability shield around the Electromagnetic Propulsion Device. They found that the ferrofluid shield was effective in reducing the magnetic field outside of the Electromagnetic Propulsion Device and could be easily manipulated to adapt to changes in the Electromagnetic Propulsion Device configuration [46].

In 2019, a study was conducted by J. E. Whittenburg and R. E. Hebner on magnetic shielding of Electromagnetic Propulsion Device using superconducting materials. They found that the use of superconducting materials in the shielding could provide a significant reduction in the magnetic field outside of the Electromagnetic Propulsion Device, but also noted that the cost and complexity of implementing superconductors in Electromagnetic Propulsion Device systems could be a limiting factor [47].

CHAPTER 3: METHODOLOGY

Problem Statement:

One of the main problems with designing a platform for an electromagnetic propulsion device is ensuring its stability. The platform needs to be able to support the weight of the device and maintain its balance, especially when it is rotating or tilting at various speeds. Another design problem is achieving the desired range of motion. The platform needs to be able to rotate about a vertical axis and tilt about the x-axis to provide any specified angle to the rails. This requires precise engineering and control mechanisms to ensure the platform can move smoothly and accurately.

The selection of materials for the platform is another important design consideration. The platform must be lightweight yet durable enough to withstand the forces generated during the device's operation. Choosing the wrong material could result in the platform failing during operation or requiring frequent maintenance.

Cost is always a factor in design, and the platform for an electromagnetic propulsion device is no exception. Designing a platform that is both cost-effective and meets all the necessary requirements can be a significant challenge. The cost of materials, manufacturing, and maintenance must all be taken into account to ensure the platform's economic viability.

The platform needs to be controlled with precision to achieve the desired angles and maintain stability during operation. Developing an accurate and reliable control system that integrates with the platform's mechanics is a significant challenge. The control system must be designed to handle the platform's range of motion and ensure the device's safety.

The platform's design needs to be scalable to accommodate various sizes of electromagnetic propulsion devices. The platform's size and strength must be adjustable to support devices of different weights and sizes while maintaining stability and precision. The platform requires a reliable and safe power supply to operate. The power supply must provide sufficient power to move the platform's mechanics while maintaining safety and avoiding electrical interference with the device.

The design of the platform must consider the environmental factors that can affect the device's operation. For example, extreme temperatures, humidity, and vibration can impact the platform's stability and range of motion.

The problem of heating of rails is a significant concern in rail-based propulsion systems. When electricity is passed through the rails, and an object is propelled, a very large amount of heat is produced due to the current and friction between the rails and the object. This can cause damage to the rails, reduce their lifespan, and affect the overall performance of the system. Excessive heating of the rails can also lead to safety hazards, such as the risk of fires and accidents.

To address this problem, a cooling mechanism must be implemented to dissipate the heat generated by the propulsion system. The cooling mechanism must be designed to efficiently remove the heat from the rails, ensuring that they remain within a safe operating temperature range. This can be achieved using a variety of cooling techniques, such as forced-air cooling, liquid cooling, or a combination of both.

Safety is always a top priority in design, and the platform for an electromagnetic propulsion device is no exception. The platform's mechanics, control system, and locking mechanism must be designed to operate safely without causing injury or damage to the device or surrounding environment. The platform must also be designed to prevent unauthorized access or tampering, which could compromise safety.

Design of Cooling Mechanism

The initial step undertaken in the design of a cooling mechanism involved the development of a finite element model using the COMSOL Multiphysics tool. This model served the purpose of accurately computing the heat generated within the rails due to the substantial current passing through them. By employing this approach, a foundation was laid to effectively explore and address the thermal considerations associated with the cooling mechanism.

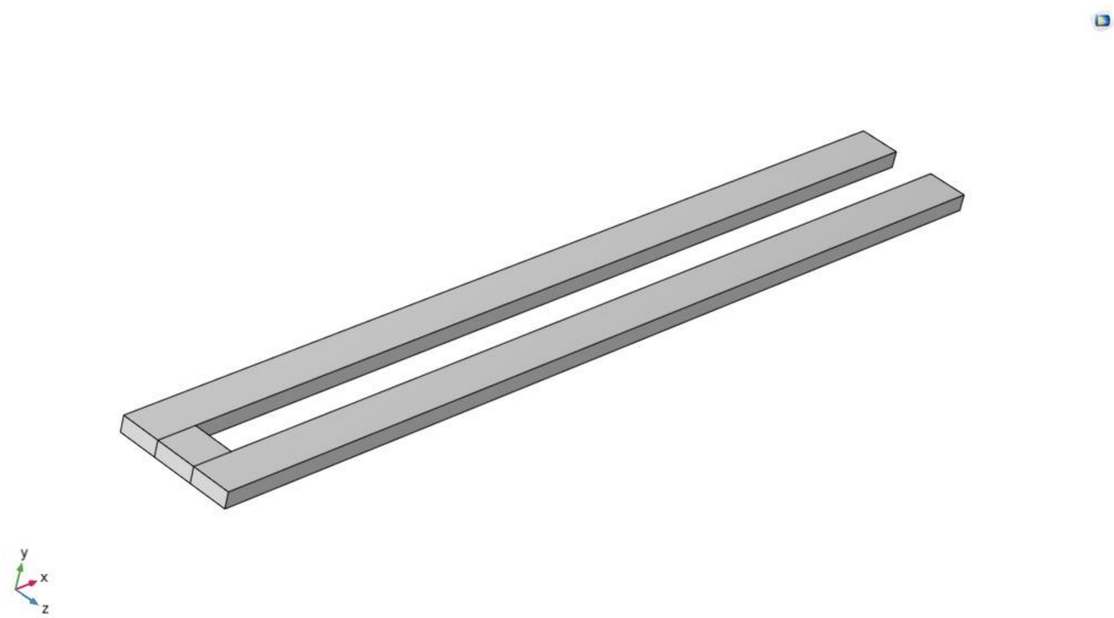

Figure 1. Model of Electromagnetic Propulsion Device for FEA

Recognizing the complexity of the analysis, the dimensions of the armature in the electromagnetic propulsion device were simplified to facilitate the design process. The following table shows the dimensions and properties of the materials used in the electromagnetic propulsion device.

Table 1. Properties of Rails and Armature

	Rails	**Armature**
Material	Copper	Aluminum
Length	570 mm	25.5 mm
Width	24.5 mm	25.5 mm
Thickness	10 mm	10 mm
Resistivity ($\boldsymbol{\rho}$)	1.78e-8 Ohm.meter	2.65e-8 Ohm.meter
Specific Heat Capacity	350 J/Kg.K	900 J/Kg.K

To accurately model the motion of the armature in the electromagnetic propulsion device, a simulation approach using a moving mesh was employed within the COMSOL software.

In order to set up the simulation, the initial and final velocities of the armature were obtained through experimental measurements. These velocity values served as essential inputs for the simulation, providing a realistic starting point and endpoint for the armature motion.

To simplify the analysis and facilitate the simulation process, a constant acceleration assumption was made. By assuming a constant acceleration, the motion of the armature could be mathematically approximated, allowing for easier integration into the simulation model.

The moving mesh technique in COMSOL was utilized to dynamically capture the changing geometry and position of the armature during its motion. This approach allowed for a more accurate representation of the armature's behavior, as the mesh adaptively adjusted to accommodate the changing shape and location of the armature as it moved.

By incorporating the known initial and final velocities, along with the assumed constant acceleration, the simulation model in COMSOL was able to replicate the expected motion of the armature. This provided valuable insights into the dynamics of the armature movement, allowing for further analysis and optimization of the electromagnetic propulsion device's performance.

In order to facilitate the analysis and modeling of the electrical circuit supplying current to the rails, a simplification approach was employed. The circuit was represented by a capacitor bank that was connected to the rails via wires, which were symbolized as resistors. The resistance of the rails, an important parameter for the analysis, was automatically calculated within the software.

To account for the inductance in the circuit, a single inductor was simulated. This allowed for the consideration of the magnetic field effects and the associated energy storage in the system. By incorporating the inductor, the modeling process captured the transient behavior and dynamic response of the circuit accurately.

Additionally, to accurately represent the wires in the model, the resistance was calculated based on the length of the wire. This enabled the simulation to account for the resistive losses that occur as current flows through the wires, accurately reflecting the real-world behavior. The electric circuit can be shown in the figure below,

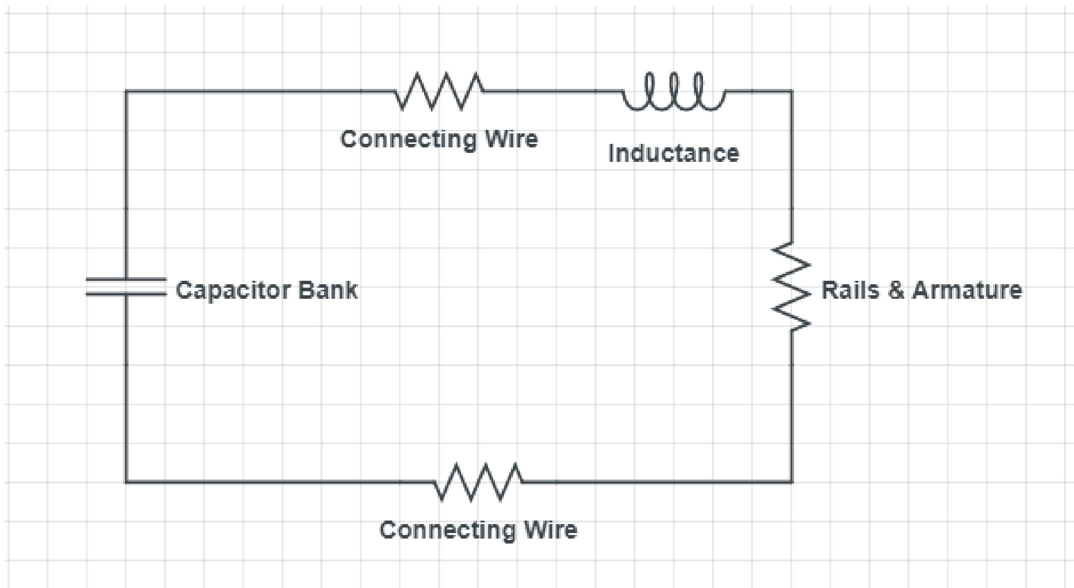

Figure 2. Electrical Circuit of Electromagnetic Propulsion Device

The current from the circuit is fed into the rails. The resistance of the rails has been simulated as temperature dependent. The following figures shows the current and voltage of the circuit changing with time.

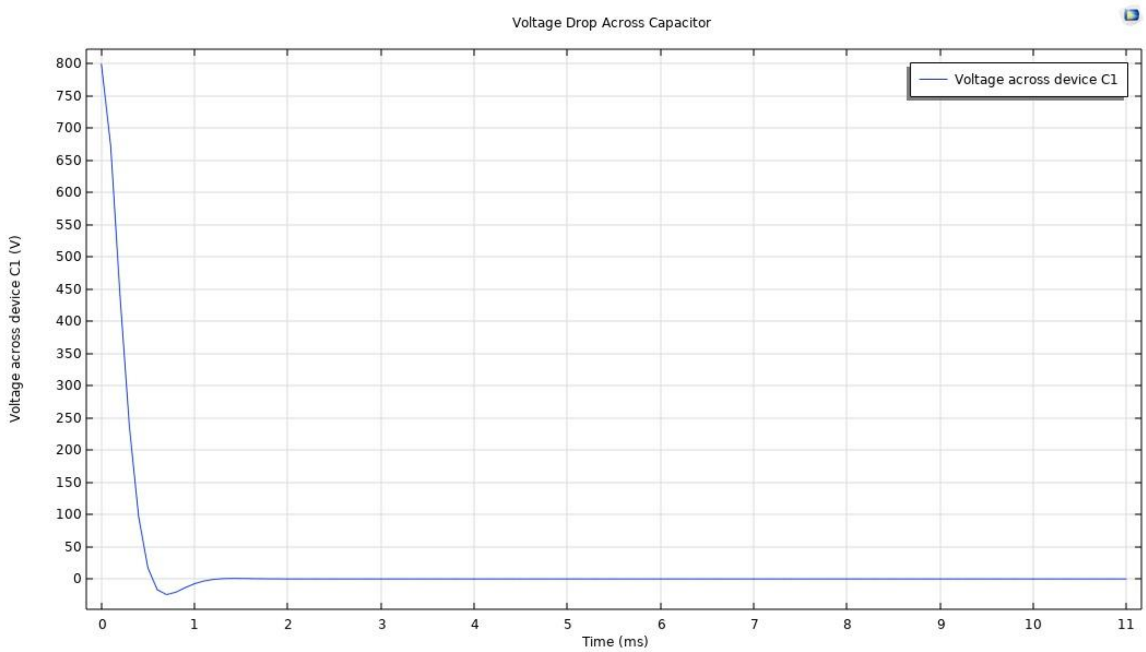

Figure 3. Voltage Drop Across Capacitor

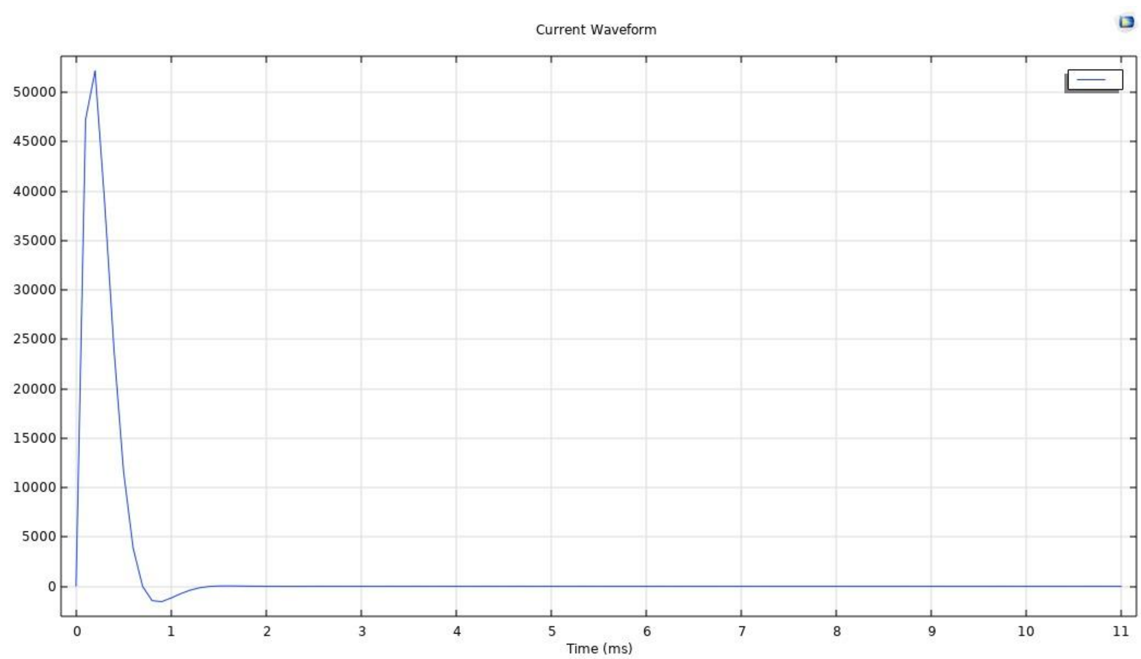

Figure 4. Current Waveform

This current causes heat generation and temperature rise in the rails according to the following equation,

$$\rho C_p \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + Q$$

According to the simulation results, it was observed that the temperature of the initial section of the rails was considerably high. This phenomenon can be attributed to the fact that this specific region experiences the maximum current flow for an extended duration of time. On the other hand, the remaining sections of the rails maintained a temperature equivalent to the ambient temperature. These sections effectively acted as heat sinks within the system.

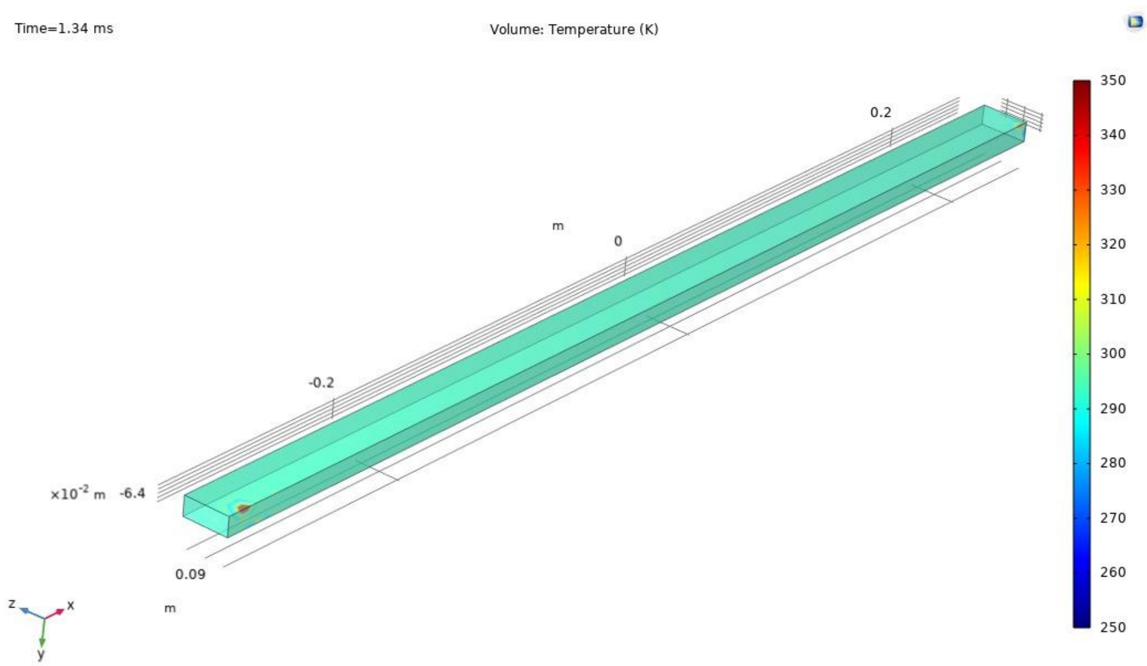

Figure 5. Temperature of the Rails

As heat naturally transfers from higher temperature regions to lower temperature regions, the presence of these cooler sections along the length of the rails facilitated the dissipation of heat. Consequently, the overall temperature of the entire rail gradually decreased due to the efficient heat transfer occurring from the higher temperature points to the lower temperature points.

This phenomenon of heat dissipation and temperature reduction along the rail can be understood as a result of the thermal equilibrium sought by the system. The heat generated in the initial section of the rails is redistributed and dissipated along the length of the rails, ultimately reaching a more uniform temperature distribution.

The material of the cooling channel should be thermal conductive and electrically non-conductive. Some common materials that meet these requirements include aluminum, copper, and various types of plastics or polymers. Aluminum and copper are particularly good choices as they have high thermal conductivity and can quickly transfer heat away from the rails. But their electrical conductivity is an issue. So, we need to come up with a material that is thermally conductive and provides electrical insulation.

Next, the cooling medium must be chosen carefully. The cooling medium is the fluid that is used to absorb heat from the rails and transfer it to the cooling channel. It should have a high boiling point to prevent it from boiling when heat is produced in the rails. Some common cooling mediums that meet these requirements include water and various types of oils. When selecting a cooling medium, it's important to consider the specific application and the environment in which it will be used. For example, water may be an effective cooling medium in some applications, but it may not be suitable in environments where there is a risk of very high temperatures.

Overall, designing a cooling channel for rails involves careful consideration of the material of the channel, the cooling medium, and the boiling point of the fluid used for cooling. By selecting the right combination of these factors, it's possible to create an effective cooling system that can help prevent damage to the rails due to excessive heat.

Carbon fiber and epoxy composites are commonly used in a variety of applications where high strength and stiffness are required, such as in aerospace, automotive, and sporting goods industries. In heat exchangers, carbon fiber can provide excellent thermal conductivity, which allows for efficient heat transfer between the two fluids being exchanged. Additionally, carbon fiber is also electrically insulating, which can be important as it can avoid conduction of electricity to the cooling medium.

Epoxy is typically used as the bonding agent for carbon fiber composites, as it can effectively bond the fibers together to create a strong and rigid material. Epoxy also has good thermal conductivity, which can help to increase the overall thermal conductivity of the composite.

However, there are some potential drawbacks to using carbon fiber and epoxy composites for heat exchangers. One of the main challenges is that they can be relatively expensive to produce, which can make them less cost-effective for small model. Additionally, the manufacturing process for carbon fiber composites can be time-consuming and complex, which can also add to the overall cost.

3D printing using PETG can be a more cost-effective and efficient way to create small-scale heat exchangers with complex geometries. PETG is a flexible material that can be easily molded into various shapes and sizes using a 3D printer. It also has good thermal conductivity, which makes it suitable for use in heat exchangers.

However, one potential drawback of using PETG is that it is not electrically conductive, which can limit its use in certain applications where electrical conductivity is required. Additionally, PETG may not be as strong or rigid as carbon fiber composites, which can limit its use in high-stress conditions.

Overall, the choice of materials for a heat exchanger will depend on a variety of factors, including the specific application, cost considerations, and manufacturing capabilities. Carbon fiber and epoxy composites can provide excellent thermal conductivity and electrical insulation, but may be more expensive to produce. 3D printing using PETG can be a cost-effective and efficient way to create small-scale heat exchangers, but may not be as strong or rigid as carbon fiber composites.

Regarding the cooling mechanism for the rails, a cooling channel design was developed to efficiently dissipate the generated heat. To enhance the heat transfer process, the cooling channel incorporates strategically placed baffles. These baffles were intentionally introduced to promote increased turbulence within the coolant flow. By doing so, the objective was to enhance the heat transfer rate by facilitating better mixing and improved contact between the coolant and the heated surfaces of the rails.

The inclusion of baffles in the cooling channel serves to disrupt the flow path of the coolant, inducing turbulence and creating eddies. This turbulence increases the interaction between the coolant and the hot surfaces, resulting in improved heat transfer coefficients. As a consequence, the cooling performance of the system is enhanced, allowing for more effective dissipation of heat from the rails.

The baffles are carefully positioned along the cooling channel to optimize the turbulence generation and ensure efficient heat transfer throughout the entire length of the rails. The design parameters, including the size, shape, and spacing of the baffles, were determined through simulations and optimization techniques to achieve the desired level of turbulence and heat transfer enhancement. The designed cooling channel can be seen in the figure below,

Figure 6. Cooling Channel

By incorporating these baffles within the cooling channel, it is anticipated that the overall cooling performance will be significantly improved, leading to reduced temperatures in the rail system. This design modification showcases a promising approach to optimize the heat dissipation process and ensure the reliability and longevity of the rails under high current conditions.

Distilled water was selected as the primary coolant for the cooling mechanism. Distilled water exhibits several desirable properties that make it suitable for efficient heat dissipation. Firstly, it possesses excellent thermal conductivity, allowing it to effectively transfer heat away from the heated surfaces. This property enables the coolant to absorb and carry thermal energy efficiently, facilitating the cooling process.

Moreover, distilled water serves as an excellent electrical insulator, ensuring the safety and integrity of the system by preventing electrical conduction or short circuits. This is particularly important when dealing with high currents or proximity to electrical components, as the insulating properties of the coolant help mitigate the risk of electrical malfunctions.

Additionally, the specific heat capacity of water is relatively high, meaning that it can absorb and store a significant amount of heat energy per unit mass. This property allows for effective heat absorption and distribution throughout the cooling system. As a result, it contributes to maintaining lower temperatures in the system, thus preventing overheating.

However, it is worth noting that for applications involving higher temperatures or specific thermal requirements, alternative coolant options such as transformer oils can be considered. Transformer oils possess excellent thermal stability and can withstand elevated temperatures, making them suitable for applications where the cooling demands exceed the capabilities of water.

Transformer oils offer a high level of thermal conductivity, allowing for efficient heat transfer. Additionally, they provide good electrical insulation properties, which is beneficial in scenarios where electrical components are in close proximity to the cooling system. Moreover, transformer oils have specific heat capacities that allow them to absorb and dissipate heat effectively.

When selecting the appropriate coolant, it is important to consider factors such as compatibility with system materials, environmental impact, specific application requirements, thermal performance, cost, and safety considerations.

The heat rejection system was implemented that closely resembles a radiator to effectively dissipate the heat from the coolant. This radiator-like system plays a crucial role in maintaining the optimal operating temperature of the coolant and, consequently, the overall system.

Similar to a traditional radiator, our cooling system utilizes a series of finned heat exchanger elements to facilitate heat transfer. These fins provide an increased surface area, which enhances the convective heat transfer process. As the hot coolant flows through the channels within the heat exchanger, the fins facilitate the transfer of thermal energy from the coolant to the surrounding air.

To further improve heat dissipation, the cooling system incorporates a fan or blower. This component aids in increasing the airflow across the heat exchanger, enhancing convective heat transfer. By expelling the heated air and drawing in cooler air, the fan promotes the efficient removal of heat from the coolant.

Figure 7. Heat Rejection System

The design and sizing of the cooling system, including the radiator, fins, and fan, were carefully considered to ensure optimal cooling performance. Factors such as the coolant flow rate, fin density, and fan speed were taken into account to achieve the desired heat dissipation capabilities.

This radiator-like cooling system allows for effective rejection of heat from the coolant, preventing it from reaching excessively high temperatures. By efficiently transferring thermal energy from the coolant to the surrounding air, the system helps maintain the desired operating temperature range, ensuring the reliability and performance of the overall system.

It is important to note that the specific design and configuration of the radiator-like cooling system can vary depending on the requirements and constraints of the application. Factors such as the coolant properties, power dissipation levels, and space limitations may influence the design choices and customization of the cooling system.

Design of Moving Mechanism:

The purpose of this project was to design and construct a platform that could rotate and tilt rails to test their durability and performance. To achieve this, the platform was divided into two parts - a lower platform designed as a circular disc to rotate rails around the z-axis, and a vertical platform above it for tilting and changing the inclination angle of the rails.

The lower platform was designed as a circular disc and pivoted about a shaft. The load on the shaft was supported by a thrust bearing in the axial direction, while to restrict movement in any other axis was supported by ball bearings. The materials used in the construction of the lower platform were carefully selected to ensure durability and performance. The platform was made of high-strength Teflon to handle excessive loads. The thrust bearing used to support the load on the shaft was made of high-grade steel to handle the axial load, while the ball bearings were made of a lightweight material to minimize the weight of the platform.

The vertical platform was placed above the lower platform attached to the lower platform using a bracket, which allowed for the tilting and changing of the inclination angle of the rails. The materials used in the construction of the vertical platform were also carefully selected to ensure durability and performance. The material used should be light weight and of high strength. The hinge used to attach the vertical platform to the lower platform was designed to allow for smooth and precise tilting of the rails. The use of a hinge also allowed for the vertical platform to be easily removed or adjusted as needed.

Gears have been incorporated into both the yaw and pitch platforms to facilitate the desired movements and optimize the torque requirements of the electromagnetic propulsion device. In the context of the project, the speed requirement was not as critical as the torque requirement. Therefore, gears with appropriate gear ratios were selected and implemented to achieve the desired operational characteristics.

By utilizing gears with suitable gear ratios, the rotational motion from the actuators or motors could be effectively transmitted to the respective platforms. The gear system enabled the conversion of high-speed, low-torque inputs into lower-speed, higher-torque outputs, aligning with the torque requirements of the electromagnetic propulsion device.

The gear ratios were carefully chosen to strike a balance between the desired torque output and the achievable speed for the specific application. The selection of appropriate gear ratios allowed for the optimization of the system's overall performance and ensured efficient power transmission between the actuators and the platforms.

Data Collection

The process of data collection for this project involved an extensive search for relevant research papers and previous designs on electromagnetic propulsion devices. However, it was found that there is very little research available on the platform design for an electromagnetic propulsion device. Some of the available research may be confidential, classified, or proprietary.

Therefore, the research team relied on existing knowledge and theories on electromagnetics and propulsion systems, as well as discussions with experts in the field. This included reviewing research on similar electromagnetic devices used in other applications such as the aerospace industry and high-speed trains.

The team also studied the behavior of magnetic fields and forces, which are fundamental to the design of an electromagnetic propulsion device. In addition, computational modeling and simulation tools were used to predict the performance of different design configurations, and to identify potential issues or limitations. Despite the challenges posed by the limited research on platform design for an electromagnetic propulsion device, the research team was able to gather valuable insights into the design principles and considerations for such a device. Through a thorough understanding of the fundamental principles, the team was able to develop a conceptual design for the proposed platform using electromagnetic propulsion.

In addition to the challenge of limited research on platform design for an electromagnetic propulsion device, obtaining accurate temperature values for the rails presented another obstacle. The temperature values of the rails were not available in any existing research papers, which meant that the research team had to carry out their own testing in order to obtain accurate figures. To do this, the team developed a testing plan that involved monitoring the temperature of the rails during operation of the electromagnetic propulsion system. Temperature sensors were placed at various points along the length of the rails to record the temperature changes.

The testing was conducted in a controlled environment, with different variables such as the intensity of the magnetic field, current flow, and speed of the platform being adjusted to assess their impact on the temperature of the rails. The data collected from the testing was analyzed and used to refine the design of the electromagnetic propulsion system and ensure that it could operate safely and efficiently. Despite the need for additional testing to obtain accurate temperature values, this was a crucial step in the development of the electromagnetic propulsion platform. The ability to monitor and control the temperature of the rails is essential to ensuring the safety and reliability of the system, and without this information, it would not be possible to optimize the design for maximum performance.

Software Used

In order to create a two degrees of freedom (2 DOF) platform with pitch and yaw control, the software tool Solidworks was utilized. The platform was designed to provide pitch and yaw control, which refers to the ability to rotate the platform along the X and Y axes, respectively. This was achieved by incorporating a series of motors and gears into the design, which allow for precise movement and control of the platform. Once the design was complete, the model was simulated in Solidworks to ensure that it met the desired specifications and requirements. Overall, the use of Solidworks proved to be a valuable tool in the creation of this 2 DOF platform, allowing for precise design and simulation of the model before it was physically constructed.

After the design of the 2 DOF platform with pitch and yaw control was completed using Solidworks, the next step was to conduct motion analysis using the same software. Motion analysis involves simulating the movement of the platform in response to various inputs, such as changes in pitch or yaw angle, to ensure that it behaves as expected and can withstand the required loads and stresses. The analysis can also help to identify any areas of the design that may need to be modified in order to optimize performance or reduce the risk of failure.

The dimensions of the 2 DOF platform with pitch and yaw control were based on the electromagnetic rail gun, which is a type of weapon that uses electromagnetic force to launch projectiles at high speeds. The design of the rail gun requires a precise and stable platform that can withstand the powerful forces generated during firing. As such, the dimensions of the 2 DOF platform were carefully calculated to provide the necessary stability and strength for the rail gun application. The platform was designed to be compact and lightweight, yet rigid enough to prevent any unwanted vibrations or movement during firing. The use of Solidworks allowed for precise dimensioning and positioning of the platform components, ensuring that the design met the required specifications and could be easily manufactured. By basing the dimensions of the platform on the electromagnetic rail gun, the resulting design was optimized for its intended use and ensured that the rail gun would function reliably and safely.

To ensure that the electromagnetic rail gun would function reliably and safely, thermal analysis was conducted using ANSYS software. The analysis involved simulating the flow of heat through the rail gun in response to a specific value of current. The rail gun generates a large amount of heat during firing, which can cause significant thermal stress and deformation if not properly managed. By conducting thermal analysis using ANSYS, we were able to determine the temperature distribution and thermal stresses within the rail gun and identify any areas that may be at risk of failure. The analysis also allowed for the optimization of cooling systems and materials to improve the heat dissipation capabilities of the rail gun. The specific value of current used in the analysis was chosen based on the intended application of the rail gun, ensuring that the thermal analysis accurately reflected the actual operating conditions. Overall, the use of ANSYS for thermal analysis was crucial in ensuring the safe and reliable operation of the electromagnetic rail gun.

By utilizing both SolidWorks and ANSYS, the we were able to create a highly optimized design that was both structurally sound and capable of achieving precise control over the electromagnetic propulsion device. The 3D models created in SolidWorks allowed the us to visualize the platform and make any necessary modifications before manufacturing, while the simulations in ANSYS provided valuable insights into the behavior of the platform under a range of conditions. By using ANSYS, we were able to simulate the behavior of the platform under a range of different conditions, such as changes in temperature, pressure, or loads.

To manage the heat generated by the electromagnetic rails in the rail gun during operation, a cooling channel was designed using Solidworks. The cooling channel was designed to allow for the flow of a cooling fluid, such as water or oil, to dissipate heat from the rails and prevent them from overheating. The design of the cooling channel was optimized to ensure that the fluid flow was evenly distributed across the rails and that the cooling rate was sufficient to maintain a specific temperature range for the rails.

To confirm the effectiveness of the cooling channel design, thermal-fluid analysis was performed using ANSYS software. This analysis involved simulating the flow of fluid through the cooling channel and its interaction with the electromagnetic rails. By modeling the heat transfer between the rails and the cooling fluid, we were able to determine the temperature distribution of the rails and identify any areas that may be at risk of overheating. The analysis was repeated with different flow rates and temperatures to optimize the design of the cooling channel for maximum heat dissipation.

Overall, the combination of Solidworks and ANSYS allowed for a comprehensive design and analysis of the cooling channel for the electromagnetic rail gun. The use of Solidworks for the design and ANSYS for the thermal-fluid analysis ensured that the cooling channel was optimized for efficient and effective cooling of the electromagnetic rails, which is essential for the safe and reliable operation of the rail gun.

To improve the heat transfer rate in the cooling channel of the electromagnetic rail gun, turbulators were incorporated into the design. Turbulators are devices that promote turbulence in the fluid flow, which increases the heat transfer rate between the fluid and the surface of the electromagnetic rails. The design of the turbulators was carefully optimized to ensure that they provided the desired level of turbulence while still allowing for a smooth flow of fluid through the channel.

In addition to the turbulators, the material used for the heat exchanger was also carefully chosen to optimize thermal conductivity while ensuring electrical non-conductivity. For this purpose, a thermoplastic elastomer (PETG) was selected, which is a type of polymer that is both electrically non-conductive and thermally conductive. PETG has excellent heat dissipation properties and is also resistant to electrical and mechanical stresses, making it an ideal material for the heat exchanger in the electromagnetic rail gun cooling channel.

Overall, the use of turbulators and PETG material in the cooling channel design ensured efficient and effective heat dissipation from the electromagnetic rails, which is essential for the safe and reliable operation of the rail gun. The design was optimized using Solidworks and analyzed using ANSYS to ensure that the cooling system met the required specifications and could operate under the expected conditions.

Control System:

The methodology for the control system design involved several steps to ensure the successful implementation and integration of the various components. Firstly, the requirements and specifications for the control system were identified, encompassing factors such as the desired range of motion, control accuracy, and input interface. Based on these requirements, the Arduino Mega microcontroller was selected as the central processing unit due to its capabilities and compatibility with the application.

To enable user control of the moving mechanism's angle, a numpad was integrated as the input interface. This allowed users to input their desired angle, which was then transmitted to the Arduino Mega for processing. The communication protocol between the numpad and the Arduino Mega was established, ensuring the accurate and reliable transmission of user inputs.

The control algorithm was developed within the Arduino Mega to convert the user-entered angle into appropriate control signals for the actuator. This involved designing and implementing the necessary circuitry to interface the Arduino Mega with the chosen actuator, which could either be a NEMA 23 or NEMA 34 motor, depending on the specific requirements of the application.

For accurate angle measurement, an Inertial Measurement Unit (IMU) was integrated into the system. The IMU provided real-time feedback on the rotational angle of the mechanism. Calibration and configuration of the IMU were performed to ensure accurate angle measurements. The Arduino Mega was programmed to retrieve and process angle data from the IMU, enabling precise control over the position of the moving mechanism. To provide visual feedback, a digital display module was incorporated into the system. The Arduino Mega was programmed to send the measured angle data to the digital display, allowing users to monitor the current angle in real-time.

Additionally, temperature monitoring functionality was implemented in the control system. Temperature sensors were installed at the coolant inlet and outlet points to monitor the temperatures of the coolant. The Arduino Mega was responsible for retrieving the temperature readings from these sensors and displaying them on the digital display, enabling users to monitor the coolant temperatures alongside the angle measurement.

Throughout the implementation process, system integration and thorough testing were conducted to ensure the proper functioning and performance of the control system. This included verifying input accuracy, evaluating actuator response, assessing angle measurement accuracy using the IMU, and validating the temperature monitoring functionality. Any necessary adjustments and refinements were made to the system based on the test results to optimize its performance and meet the specified requirements.

By following this methodology, a comprehensive control system was successfully designed and implemented, utilizing the Arduino Mega microcontroller, numpad input interface, actuator control, IMU angle measurement, digital display, and temperature monitoring. The integration of these components ensured accurate control, precise angle measurement, and effective monitoring of the coolant temperatures, resulting in the reliable operation of the moving mechanism.

Challenges and Solutions:

Shaft Misalignment:

In the setup where a rotating Teflonen disc of diameter 50cm was connected with the base using a shaft, a problem of misalignment occurred in the shaft.

To solve the misalignment problem, several approaches could be taken. One solution could be to use flexible couplings that can accommodate misalignment while transmitting torque between the disc and the base. Another solution could be to use precision bearings to ensure proper alignment and reduce the amount of misalignment that occurs.

Additionally, the cause of the misalignment should be investigated to prevent future occurrences. Misalignment can be caused by several factors such as improper installation, wear, and excessive loads. By identifying and addressing the root cause of the misalignment, future issues can be prevented.

The shaft connecting the disc and the base was designed to be supported by a bearing, but due to the misalignment, the bearing was unable to perform its intended function, leading to decreased performance and potentially damaging the device over time.

Shaft misalignment occurs when the rotational axis of the shaft is not aligned with the centerline of the bearing or other supporting structure. This can lead to increased stress on the bearing, reduced bearing life, and increased vibration and noise. In the case of the 2DOF platform, the misalignment was likely caused by a range of factors, such as manufacturing tolerances or errors in the assembly process.

To address the problem of shaft misalignment, we had to make a number of adjustments to the platform design, such as redesigning the bearing to accommodate for misalignment, adjusting the position of the bearing, and redesigning the connection between the shaft and the rotating disc with the base. Depending on the given specific circumstances, we conducted simulations/tests to ensure that the changes were effective in addressing the problem.

Overall, the problem of shaft misalignment between a rotating disc of diameter 50cm and a base connected using a bearing highlights the importance of careful design and testing in engineering projects. By identifying and addressing issues like shaft misalignment, engineers can ensure that their designs are optimized for performance, reliability, and longevity.

Limited research Information:

During the literature review of the platform, a problem was encountered due to the limited availability of research papers and quantitative data, which was likely due to the platform's use for defense purposes. Research in the field of defense often involves sensitive and confidential information, which may limit the amount of data that can be shared publicly. This can make it difficult to gather sufficient information and data for a literature review.

It is important to acknowledge and respect the limitations on the availability of data in the defense industry, while also striving to gather and share information to advance research and development in the field.

Strengths and Weaknesses of Selected Methodology:

Strengths of Mixed Methodology:

- It provides a more complete and comprehensive understanding of a research problem by combining both quantitative and qualitative data.

- It allows for triangulation, which means that different methods can be used to investigate the same phenomenon, increasing the reliability and validity of the research.
- It enables researchers to capture both objective and subjective data, which can be useful in understanding complex social phenomena.
- It can be tailored to the specific needs of the research question, providing greater flexibility than a purely quantitative or qualitative approach.

Weaknesses of Mixed Methodology:

- It can be more time-consuming and resource-intensive than a single-method approach, as it requires expertise in both quantitative and qualitative methods.
- It can be challenging to integrate and analyze both quantitative and qualitative data, which requires careful consideration of the data and methods used.
- It can be difficult to maintain consistency and comparability between the different data sources, especially if they are collected at different times or in different contexts.
- It can be challenging to find a balance between the different methods and to ensure that one method does not dominate or overshadow the other.

CHAPTER 4: RESULTS AND DISCUSSIONS

The lower platform, responsible for changing the yaw of the electromagnetic propulsion device, was constructed using Teflon material. This choice of material offered low friction and high resistance to wear, ensuring smooth rotation during operation. To provide structural support, a mild steel shaft with thrust and radial bearings was utilized. These bearings facilitated the smooth rotation of the platform, minimizing any unwanted vibrations or disturbances.

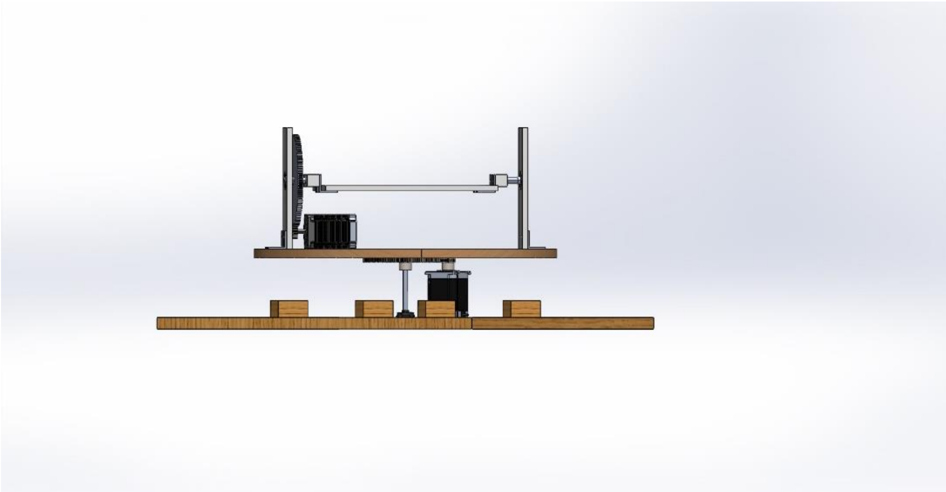

Figure 8. 2 DoF Platform

In terms of load-bearing capacity, the lower platform demonstrated impressive performance, with the ability to withstand loads of nearly 10 kg. This robust load capacity ensures the platform's suitability for accommodating various components and additional equipment that may be required for the electromagnetic propulsion device.

Regarding the range of yaw angles achievable, the lower platform excelled with a maximum range of 180 degrees. This extensive range allows for a wide scope of motion and adaptability in different applications.

Above the yaw platform, the upper platform was designed to change the pitch of the electromagnetic propulsion device.

The upper platform of the 2 DOF platform was designed specifically for adjusting the pitch of the electromagnetic propulsion device. It offered a range of 90 degrees, divided into 70 degrees in the positive direction and 20 degrees in the negative direction. This range provided significant flexibility in positioning and angling the electromagnetic propulsion device according to the desired requirements or application-specific needs.

By allowing adjustments within the range of 70 degrees in the positive direction and 20 degrees in the negative direction, the pitch platform enabled precise control over the pitch orientation of the electromagnetic propulsion device. This range facilitated the device's adaptability to various operating conditions, allowing it to be positioned at different angles relative to the reference plane.

The pitch adjustment capability of the platform enhances the overall functionality and versatility of the electromagnetic propulsion device. It opens up possibilities for diverse applications where controlled changes in pitch orientation are crucial, such as in aerial vehicles, robotics, or other systems that require adjustable pitch angles for optimal performance and maneuverability.

NEMA 23 and NEMA 34 motors were specifically chosen for the yaw and pitch control, respectively, due to their ability to deliver the required torque for the electromagnetic propulsion device.

In the design process, it was essential to select motors that could generate sufficient torque to effectively drive the platforms and accommodate the load requirements of the system. After evaluating various motor options, NEMA 23 and NEMA 34 motors were found to meet the desired torque specifications.

NEMA 23 motors are known for their strong torque output and versatility, making them suitable for applications requiring moderate to high torque. By utilizing a NEMA 23 motor for the yaw control, the platform could effectively rotate and reposition the electromagnetic propulsion device within the desired range.

On the other hand, NEMA 34 motors are renowned for their high torque capabilities, making them well-suited for applications demanding significant power output. The selection of a NEMA 34 motor for the pitch control allowed for precise adjustments and stable positioning of the electromagnetic propulsion device.

By choosing motors with the appropriate torque characteristics, the control system ensured that the platforms could smoothly and reliably respond to user inputs or automated commands, achieving the desired movements and orientations of the electromagnetic propulsion device.

The integration of NEMA 23 and NEMA 34 motors into the control system not only provided the necessary torque output but also ensured compatibility with other system components, such as the gears and mechanical structure. This cohesive combination enabled efficient power transmission and facilitated the overall functionality and performance of the 2 DOF platform.

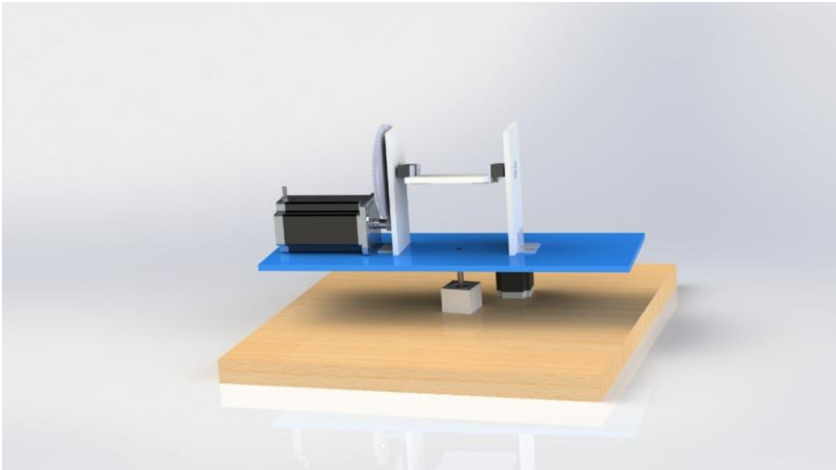

Figure 9. CAD Model of Platform

In addition, a heat exchanger was designed and constructed for the electromagnetic rails to maintain the required temperature of about 24 degrees Celsius. The heat exchanger was made of PETG material and included turbulators to increase the heat transfer rate. Baffle plates were also included to cause turbulence in the fluid flow and increase the flow rate to a maximum. The maximum temperature achieved by the rails was 60 degrees Celsius, and the maximum heat transfer achieved was 50 W.

As part of the project, ANSYS was used to perform several analyses to ensure the efficient working of the heat exchanger mechanism. The following are the key findings:

Table 2. Initial Conditions

Mass flow rate of fluid in heat exchanger	0.0018kg/s
Temperature of fluid at inlet	20C

Turbulence Analysis: ANSYS was used to check the turbulence created by the design of the heat exchanger. The results showed that the baffle plates and turbulators created enough turbulence to ensure maximum heat transfer. The flow rate was also increased to a maximum, as intended.

Inner Wall Temperature Analysis: ANSYS was also used to analyze the inner wall temperature of the heat exchanger. The analysis showed that the inner wall temperature remained within the allowable limit, indicating that the heat exchanger was operating efficiently.

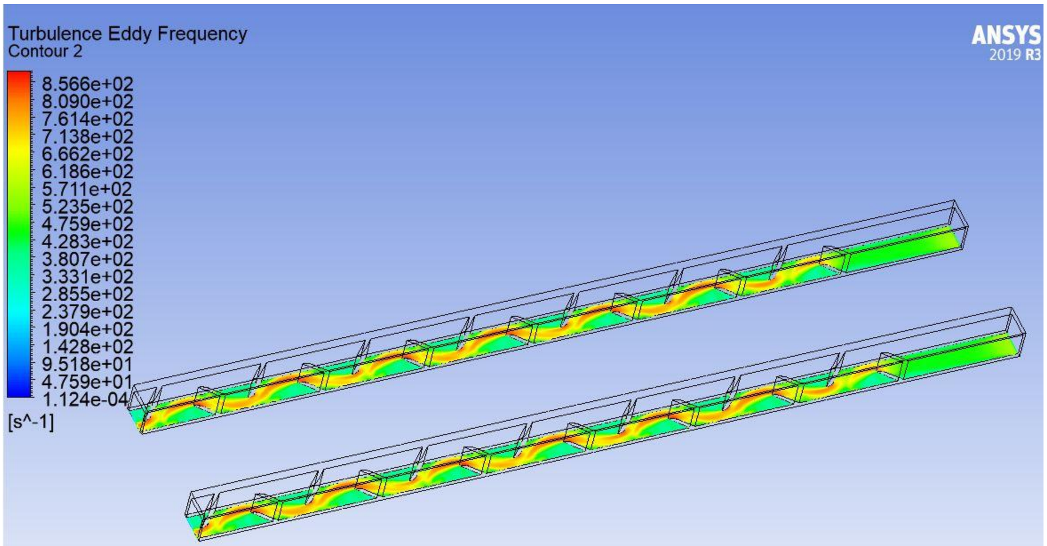

Figure 10. Turbulence Eddy Frequency of Cooling Fluid

Optimization Analysis: ANSYS was used to optimize the heat exchanger design to ensure maximum heat transfer. The analysis involved varying the dimensions of the heat exchanger to find the optimal design. The results showed that the design used in the project was the most efficient for achieving the required temperature maintenance.

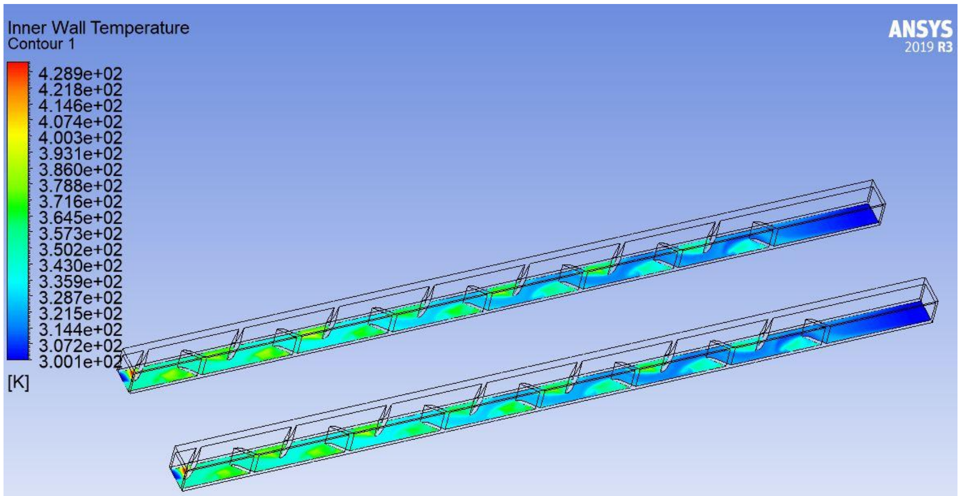

Figure 11. Inner Wall Temperature

In addition to the successful testing of the lower platform, it is important to consider the impact of external factors on its performance. For example, the stability and balance of the platform may be affected by the surface on which it is placed, the orientation of the surface, or the presence of any obstacles or obstructions. As such, it may be necessary to incorporate additional features or mechanisms into the design of the platform to address these potential challenges and ensure reliable operation in a variety of conditions.

Table 3. Results

Heat transfer rate	50Watt
Temperature drop	7C
Turbulence Eddy frequency	700 er second

The control system for the moving mechanism in the setup was successfully implemented using the Arduino Mega microcontroller. The Arduino Mega served as the central processing unit, enabling the coordination and control of various system components.

To control the angle of the moving mechanism, a numpad interface was integrated. Users were able to input their desired angle using the numpad, which was then communicated to the Arduino Mega. Based on the received input, the microcontroller generated appropriate control signals to drive the actuator. Depending on the specific application requirements, the actuator could be either a NEMA 23 or NEMA 34 motor.

Upon generating the control signals, the microcontroller sent them to the actuator, initiating the rotation of the mechanism. To accurately measure the angle rotated by the screen, an Inertial Measurement Unit (IMU) was incorporated into the system. The IMU provided real-time feedback on the rotational angle, enabling precise monitoring and control of the position of the mechanism.

For displaying the measured angle, a digital display module was integrated into the system. This module received angle data from the microcontroller and presented it in a clear and easily readable format. The real-time angle display provided valuable feedback to the user, ensuring accurate control over the moving mechanism.

In addition, temperature monitoring functionality was integrated into the system. The coolant, responsible for regulating the system temperature, was monitored at two points: the inlet and the outlet. Temperature sensors were installed at these locations to provide real-time temperature readings. The microcontroller processed the temperature data and displayed it alongside the angle measurement on the digital display.

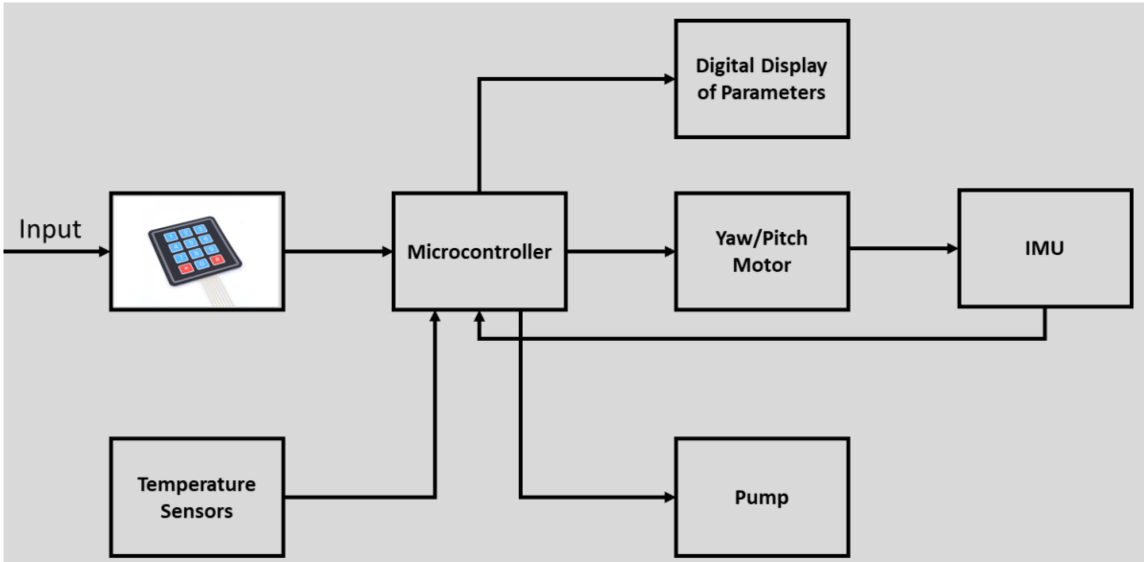

Figure 12. Block Diagram of Control System

Note: The manual to operate the platform can be seen in the Appendix I.

Finally, it is important to consider the overall cost and feasibility of the design. While it may be desirable to incorporate high-end or specialized components, such as high-torque motors or precision gears, these options may be cost-prohibitive or otherwise impractical. It is important to strike a balance between performance, reliability, and cost, while also considering factors such as ease of procurement and availability of spare parts.

Another key consideration for the platform design is the structural integrity of the system. The upper platform will be subject to various loads and stresses, including the weight of the platform itself, the load being carried, and the forces generated during the tilting motion. Therefore, it is important to ensure that the platform is designed to withstand these loads and remain stable during operation.

Structural analysis and simulation can be used to determine the strength and stability of the platform design. Finite element analysis (FEA) is a powerful tool that can be used to model the platform and evaluate its behavior under various loads and conditions. This analysis can help identify potential areas of weakness in the design and guide the selection of appropriate materials and reinforcement strategies.

Another important factor to consider is the ease of assembly and maintenance. The platform should be designed with simplicity and ease of assembly in mind to minimize assembly time and reduce the risk of errors during assembly. Similarly, the platform should be designed to be easily maintained, with simple access to the motor, gears, and other components for maintenance and repair.

Finally, it is important to consider the overall aesthetics of the system. The design should be visually appealing and blend in with the surrounding environment. This can be achieved through careful selection of materials and finishes, as well as attention to details such as cable routing and hiding of control components.

In summary, the successful design of the platform requires a comprehensive approach that considers a wide range of factors, including material selection, torque requirements, control system design, power consumption, safety features, structural integrity, ease of assembly and maintenance, and aesthetics. By taking these factors into account, it is possible to create a safe, efficient, and visually appealing system that meets the project requirements.

Heat exchanger design needs two important considerations. One is related to the thermal conductivity of the heat exchanger and other one is it electrical conductivity. The main objective was to keep the thermal conductivity as high as possible and electrical conductivity as low as possible. As electrical conductive material can cause the flow of electricity into the cooling medium. That can cause damage to equipment. Other approach can be related to use of electrically non conductive fluid. So that even if fluid comes in contact with electrical current, it should not cause any damage. In order to ensure better safety both of the approaches can be used simultaneously.

In addition to the considerations mentioned above, it is important to take into account the overall efficiency and effectiveness of the heat exchanger design. This can include factors such as the size and shape of the heat exchanger, the flow rate and temperature of the cooling medium, and the type of heat transfer mechanism used (such as convection or radiation).

The main objective was to keep the thermal conductivity as high as possible and electrical conductivity as low as possible. As electrically conductive material can cause the flow of electricity into the cooling medium. That can cause damage to equipment. Other approach can be related to use of electrically nonconductive fluid. So that even if fluid comes in contact with electrical current, it should not cause any damage. To ensure better safety both of the approaches can be used simultaneously.

The choice of materials used in the heat exchanger is also important. For example, the material must be able to withstand high temperatures without degrading or corroding over time. In addition, the material should be easy to clean and maintain, as buildup of dirt or other contaminants can reduce the efficiency of the heat transfer process.

Ultimately, the success of a heat exchanger design depends on a variety of factors, including the temperature range, required heat transfer rate and electrical conditions. By carefully considering all of these factors and working closely with experienced engineers and designers, it is possible to create a heat exchanger that meets the needs of the project while also ensuring safety, reliability, and environmental sustainability.

The platform underwent stress analysis by applying a load of 12 kg on its top plate, and the resulting stress and deformation values were computed to compare them with the yield stress value and calculate the safety factor. The stress analysis was performed by the mechanical engineer using techniques such as finite element analysis (FEA) to model and simulate the platform's behavior under the given load. Other factors such as material properties, boundary conditions, and environmental factors were also considered during the analysis.

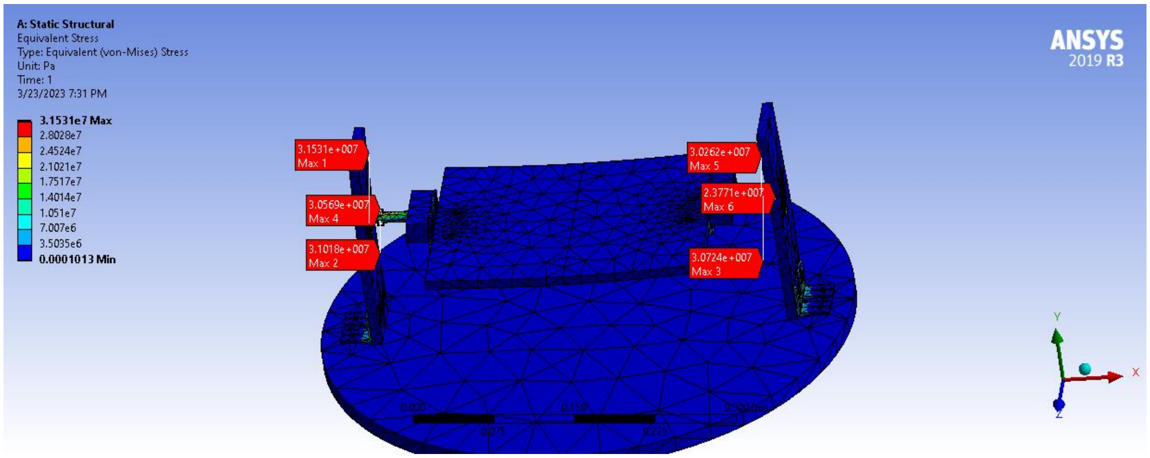

Figure 13. Stress Analysis: Von-Mises Stress

After the stress analysis was performed, the results were reviewed to ensure that the stress and deformation values did not exceed the material's yield stress value. The safety factor was then calculated by comparing the yield stress value to the applied stress. If the calculated safety factor is greater than 1, it indicates that the platform is safe for use. However, if the safety factor is less than 1, modifications may be necessary to improve the platform's strength and stability.

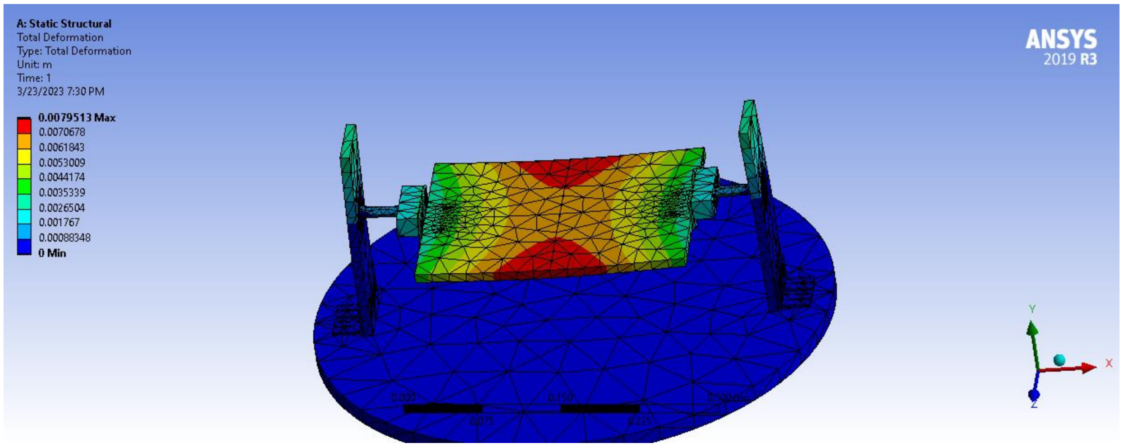

Figure 14. Total Deformation

Overall, stress analysis is a crucial step in designing and developing mechanical systems to ensure their safety, reliability, and optimal performance. Safety and quality are always prioritized by mechanical engineers when performing stress analysis to deliver the best results to clients and stakeholders. The finalized fabricated platform has been shown in the figures below,

Figure 15. Finalized Platform

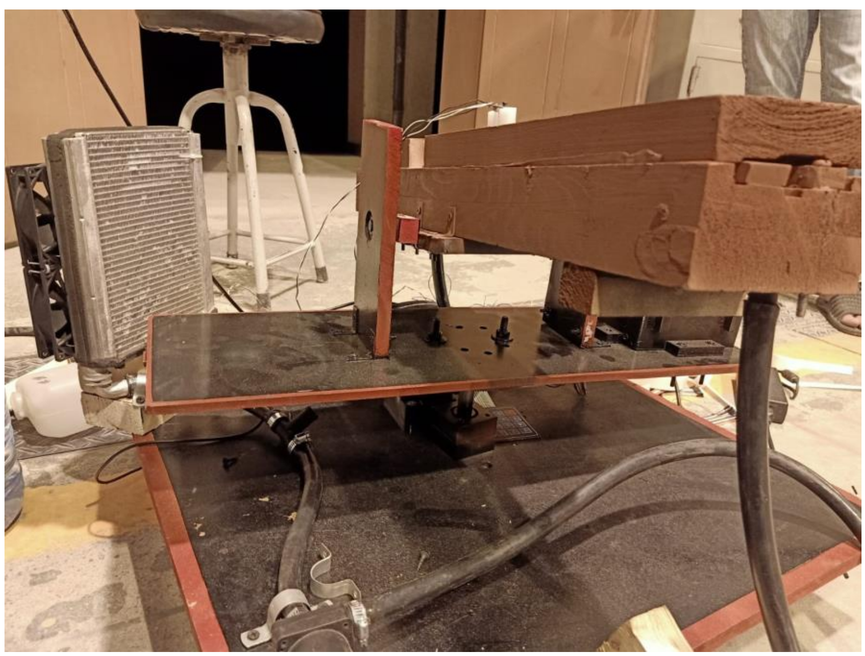

Figure 16. Fabricated Platform along with Cooling Mechanism

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The platform comprises a lower yaw platform and an upper pitch platform, each serving specific control purposes to enable precise movements and orientations of the electromagnetic propulsion device.

The lower yaw platform, made of Teflon material and supported by a mild steel shaft with thrust and radial bearings, exhibits robustness and ensures smooth rotation. It possesses a maximum yaw angle range of 180 degrees, providing ample flexibility for repositioning the electromagnetic propulsion device.

The upper pitch platform, also constructed with Teflon material, allows for controlled adjustments in the pitch angle. It offers a pitch angle range of 90 degrees, divided into 70 degrees in the positive direction and 20 degrees in the negative direction. This design choice facilitates the desired range of motion for the electromagnetic propulsion device.

The platform was successfully built using a lower platform made of Teflon with a rotating disc, and NEMA 23 and NEMA 34 motors were used for yaw and pitch control, respectively. The pitch control platform was made of Teflon material for smooth movement, and a heat exchanger was designed and constructed for the electromagnetic rails to maintain the required temperature.

Aluminum gears with appropriate gear ratios were employed to transmit the rotational motion from the motors to the respective platforms. The gear system facilitated the conversion of high-speed, low-torque inputs into lower-speed, higher-torque outputs, ensuring optimal power transmission within the system.

The accuracy of the yaw angle measurement achieved through the use of an Inertial Measurement Unit (IMU) was found to be 0.5 degrees, providing precise monitoring and control over the yaw movement. Similarly, the pitch angle accuracy was determined to be 1.2 degrees, ensuring accurate positioning and adjustment of the pitch platform.

the designed platform exhibits excellent load-bearing capacity, capable of supporting electromagnetic propulsion devices weighing between 7 to 10 kilograms. This robust construction ensures the platform's stability and structural integrity, allowing for reliable operation even under significant weight loads.

In terms of performance, the platform demonstrates impressive agility and responsiveness. It can achieve the desired angles within a rapid timeframe of less than 10 seconds. This swift response time enables efficient repositioning and adjustments of the electromagnetic propulsion device, allowing for precise control and dynamic maneuverability.

The combination of the platform's weight capacity and quick angle attainment enhances its suitability for a range of applications. It can accommodate various electromagnetic propulsion devices within the specified weight range, offering versatility and adaptability for different experimental or operational requirements.

It is worth noting that the assembly and disassembly of the platform is designed to be straightforward and user-friendly. The components of the platform are designed and constructed with ease of assembly and disassembly in mind, allowing for efficient maintenance, repairs, and modifications when necessary.

The platform's modular design and carefully chosen fastening mechanisms enable quick and hassle-free assembly. The components can be easily connected and secured, ensuring a sturdy and stable platform structure. Likewise, disassembling the platform is a simple process that can be carried out with minimal effort and without the need for specialized tools or equipment.

This ease of assembly and disassembly offers several advantages. It facilitates convenient transportation and storage of the platform, allowing for efficient deployment in various settings or relocation to different locations. Additionally, it simplifies maintenance and troubleshooting procedures, enabling swift access to individual components for inspection, cleaning, or replacement.

The simulation conducted using COMSOL Multiphysics has provided significant insights into the behavior and performance of the electromagnetic propulsion device, particularly in terms of temperature distribution and dissipation along the rails. The results have shed light on the thermal characteristics of the system and offered valuable information for thermal management considerations.

One notable observation from the simulation is that the initial part of the rails, where the maximum amount of current flows for an extended duration, experiences high temperatures. This localized heating is a direct consequence of the intense current passing through this region. However, through the simulation, we have been able to analyze and understand the dissipation mechanisms that help regulate and reduce the temperature.

The simulation has shown that the remaining sections of the rails act as heat sinks, effectively absorbing and dissipating the thermal energy from the high-temperature initial part. This heat transfer process occurs through conduction and convection, facilitated by the cooling mechanism implemented within the system. By introducing cooling channels and appropriate baffles, we have enhanced the turbulence of the coolant, thereby increasing the heat transfer coefficient.

The cooling mechanism implemented for the rails of the electromagnetic propulsion device has proven to be highly efficient and effective in maintaining optimal operating temperatures. By accurately computing the heat generated using a finite element model and the COMSOL Multiphysics FEA tool, the cooling mechanism was specifically designed to address the thermal management challenges associated with high current flow.

The integration of a dedicated cooling channel, featuring strategically positioned baffles, has played a crucial role in enhancing heat transfer and overall cooling performance. These baffles introduce turbulence to the coolant flow, maximizing the contact between the coolant and the rails. This turbulent flow promotes efficient heat dissipation, allowing for rapid reduction of rail temperatures.

The selection of distilled water as the primary coolant has proven to be a suitable choice for this application. Distilled water exhibits excellent thermal conductivity, ensuring efficient heat absorption from the rails. Additionally, its electrical insulation properties prevent any electrical interference or short circuits, safeguarding the overall system's integrity.

ANSYS was used to analyze the heat exchanger design, and the results showed that the baffle plates and turbulators created enough turbulence to ensure maximum heat transfer. The inner wall temperature of the heat exchanger remained within the allowable limit, indicating that the heat exchanger was operating efficiently.

The cooling mechanism's notable achievement is its ability to bring the rails to ambient temperature in less than 30 seconds. This rapid cooling time ensures minimal downtime between operations, allowing for continuous usage of the electromagnetic propulsion device. Such efficiency is essential in dynamic and time-sensitive applications where quick temperature stabilization is crucial for optimal performance and safety.

The successful implementation of the cooling mechanism guarantees the longevity and reliability of the electromagnetic propulsion device. By effectively managing and dissipating heat, the mechanism prevents overheating and potential damage to critical components, ensuring consistent and stable operation over extended periods.

The implementation of the control system using the Arduino Mega microcontroller has successfully provided precise and efficient control over the moving mechanism in our setup. The integration of various components and functionalities has enabled seamless operation and accurate angle control.

The utilization of a numpad interface for angle input has allowed users to easily and intuitively set their desired angles. The microcontroller efficiently processes the input and generates appropriate control signals to drive the actuator. This user-friendly interface enhances the usability and accessibility of the system.

The integration of an Inertial Measurement Unit (IMU) has enabled real-time measurement and feedback of the rotational angle. This precise angle measurement enhances the accuracy and control of the moving mechanism, allowing for precise positioning and alignment.

The inclusion of a digital display module has provided users with immediate visual feedback on the measured angle, enhancing the monitoring and control capabilities of the system. This real-time display allows for quick and accurate assessment of the mechanism's position and facilitates precise adjustments as needed.

In terms of recommendations for future work, enhancing the realism of the simulation for the electromagnetic propulsion device can be achieved by incorporating measurements of the electromagnetic force acting on the armature and establishing a correlation with the armature's motion. This addition would provide valuable insights into the dynamic interaction between the electromagnetic field and the armature, leading to a more accurate representation of the device's behavior.

To accomplish this, specialized sensors or instrumentation can be employed to measure the electromagnetic force at various points along the armature's path. These measurements can then be synchronized with the simulation to capture the dynamic forces exerted on the armature throughout its movement. By integrating this force data into the simulation model, a more comprehensive understanding of the system's behavior and performance can be achieved.

Furthermore, by correlating the measured electromagnetic forces with the armature's motion, it becomes possible to establish a quantitative relationship between the two variables. This correlation can provide valuable insights into the system's response to varying levels of current, magnetic field strength, or armature dimensions. Such insights can help optimize the device's design and operation, enabling improved performance and efficiency.

Additionally, incorporating real-time feedback from the measured electromagnetic forces can enable adaptive control strategies. By continuously monitoring and adjusting the applied current or magnetic field strength based on the measured forces, the system can dynamically optimize its performance, leading to enhanced operational stability and responsiveness.

It is worth noting that implementing such enhancements may require advanced instrumentation, data acquisition systems, and algorithms for force measurement and synchronization with the simulation. Therefore, future work would involve developing appropriate measurement techniques and methodologies to accurately capture the electromagnetic forces in real-time and integrate them into the simulation framework.

the design of the cooling mechanism for the electromagnetic propulsion device can be further enhanced, particularly to accommodate higher power requirements. As the power of the device increases, the thermal management becomes even more critical to ensure safe and efficient operation.

To optimize the cooling mechanism, several aspects can be considered. Firstly, a thorough analysis of the heat generation and dissipation characteristics of the higher-power electromagnetic propulsion device should be conducted. This analysis can involve experimental measurements or more advanced simulations to accurately quantify the heat generated and identify the areas of highest thermal stress.

Based on this analysis, the cooling system can be redesigned to handle the increased heat load effectively. This may involve increasing the coolant flow rate, optimizing the coolant channel geometry, or introducing additional cooling elements such as heat sinks or fins. The objective is to enhance the heat transfer capabilities of the cooling mechanism, ensuring efficient heat dissipation and preventing the device from reaching critical temperature limits.

Additionally, the selection of the coolant can be revisited for higher-power applications. While distilled water may suffice for lower power levels, it might be necessary to explore alternative coolants with higher thermal conductivity and heat capacity for higher power devices. Transformer oils, for example, are commonly used in such scenarios due to their excellent thermal properties and electrical insulation capabilities.

To achieve higher accuracy in yaw and pitch angles, it is recommended to focus on two key areas: motor selection and control system improvements.

Selecting motors with enhanced accuracy and precision can significantly improve the angle control. Motors specifically designed for precise positioning, such as high-resolution stepper motors or servo motors with improved feedback mechanisms, can provide finer control over the angular movements. These motors typically offer higher resolution, reduced backlash, and improved positional accuracy, allowing for more precise and reliable angle adjustments.

Enhancing the control system can contribute to better accuracy in angle control. Upgrading the control algorithms to more advanced techniques, such as model-based control or adaptive control, can optimize the response and minimize errors. Implementing closed-loop feedback control, where the actual angle is continuously monitored and compared to the desired angle, enables real-time adjustments to correct any deviations and maintain accuracy.

In addition to motor selection and control system improvements, attention should also be given to the mechanical components of the platform. Ensuring the mechanical components, including gears, bearings, and shafts, are of high quality and designed for minimal play or backlash is crucial for precise angle control. Regular maintenance and proper lubrication of these components can also help maintain accuracy over time.

Furthermore, conducting calibration procedures regularly can fine-tune the system and account for any systematic errors. Calibrating the sensors, adjusting for any offsets, and verifying the accuracy of the measurement system can improve the overall accuracy of the yaw and pitch angles.

To validate the accuracy of the system, performing thorough testing and validation experiments is essential. Comparing the measured angles with reference standards or utilizing external measurement devices with known accuracy can provide valuable insights into the system's performance and identify any remaining inaccuracies

REFERENCES

[1] L. Fauchon-Villeplee, "Electromagnetic Cannon". United States of America Patent 1,275,317, 24 May 1918.

[2] E. Alexanderson, "High-velocity Gun". U.S. Patent 1,377,550, 1 May 1919.

[3] R. Goddard, "A Method of Reaching Extreme Altitudes," *Smithsonian Miscellaneous Collections*, vol. 71, no. 2, pp. 1-18, 1920.

[4] G. Bussow, "Electromagnetic Cannon". Germany Patent DE391090, 12 May 1922.

[5] B. V. Galler, "Electromagnetic Cannon". Soviet Patent SU156579, 26 November 1927.

[6] R. F. Post, "Electromagnetic Launcher". U.S. Patent 1,785,539, 25 April 1930.

[7] M. L. Oliphant, "An Electromagnetic Method of Accelerating Projectiles to High Velocities," *Proceedings of the Royal Society A*, vol. 142, no. 846, pp. 502-514, 1933.

[8] H. Walter, "A Method for the Generation of High Pressures and Temperatures by Means of Electromagnetic Waves," *Z. Physik*, vol. 96, no. 11, pp. 718-724, 1935.

[9] G. V. Bull, "Electromagnetic Accelerators of High Energy Particles," *Proceedings of the Physical Society*, vol. 52, no. 4, pp. 449-455, 1939.

[10] U. Navy, "The History of Electromagnetic Propulsion Device," *Naval Surface Warfare Center Dahlgren Division*, 2015.

[11] U. Army, "Rail Gun," Aberdeen Proving Ground, 1941.

[12] U. A. Force, "Lancet Launcher," *Air Force Research Laboratory*, 2012.

[13] U. Army, "High Altitude Research Project (HARP)," *United States Army Space and*

Missile Defense Command/Army Forces Strategic Command, 2014.

[14] J. Taylor, "Some new problems in electrodynamics," *Physics Today,* pp. 38-44, 1960.

[15] H. &. H. Davies, " A theoretical model for Electromagnetic Propulsion Device," *Journal of Applied Physics,* vol. 38, no. 5, pp. 2205-2212, 1967.

[16] R. &. T. J. Shulze, "Electromagnetic Propulsion Device launch for space applications," *Journal of Spacecraft and Rockets,* vol. 5, no. 17, pp. 473-480, 1980.

[17] R. &. R. J. Moir, "Space applications of Electromagnetic Propulsion Device," *Journal of Spacecraft and Rockets,* vol. 27, no. 2, pp. 151-158, 1990.

[18] R. B. &. M. J. W. Miller, "A numerical method for simulating electromagnetic fields," *Journal of Computational Physics,* vol. 15, no. 2, pp. 327-342, 1974.

[19] T. H. &. M. A. L. Dupont, "Computer simulation of electromagnetic launchers," *IEEE Transactions on Magnetics,* vol. 19, no. 5, pp. 2011-2016, 1983.

[20] J. J. &. N. R. W. Marzwell, "A computer model for Electromagnetic Propulsion Device design," *IEEE Transactions on Magnetics,* vol. 24, no. 1, pp. 74-78, 1988.

[21] D. A. &. R. S. C. Arnold, "A three-dimensional model for electromagnetic launchers," *IEEE Transactions on Magnetics,* vol. 29, no. 1, pp. 573-578, 1993.

[22] J. F. &. C. R. W. McCann, "Electromagnetic Propulsion Device model for material optimization," *IEEE Transactions on Magnetics,* vol. 34, no. 1, pp. 2-7, 1998.

[23] L. &. Sun, "Three-dimensional finite element method simulation of Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics,* pp. 161-164, 2001.

[24] K. W. P. H. S. Y. S. S. &. K. S. H. Kim, "Simulation study on the influence of Electromagnetic Propulsion Device design parameters on the launch performance.," *Electromagnetic Waves and Applications,* pp. 599-610, 2005.

[25] J. F. L. H. J. &. H. X. K. Wang, "Simulation of dynamic behavior of Electromagnetic Propulsion Device system based on two-dimensional finite difference time domain method," *Chineses Physics,* 2010.

[26] J. W. C. G. S. &. W. Y. Wang, "simulation on electromagnetic field distribution and dynamic behavior of Electromagnetic Propulsion Device system.," *Journal of Electromagnetic Waves and Applications,* pp. 1817-1828, 2010.

[27] Y. W. C. W. Y. W. J. &. G. W. Li, "Simulation on thermal behavior of Electromagnetic Propulsion Device system based on 3D finite element method.," *Journal of Electromagnetic Waves and Applications, 31(3),,* pp. 286-297, 2017.

[28] S. X. W. W. X. &. Z. Y. Xiao, "Numerical simulation on the dynamic behavior of Electromagnetic Propulsion Device system based on 3D FDTD method.," *Journal of Applied Physics,* 2020.

[29] D. G. &. C. W. B. Sanders, "Thermal analysis of a Electromagnetic Propulsion Device," *Journal of Applied Physics,* pp. 5651-5654, 1980.

[30] J. W. J. Z. X. &. L. Y. Tao, "Thermal effect of plasma on Electromagnetic Propulsion Device system," *IEEE Transactions on Plasma Science,* pp. 1245-1251, 2020.

[31] M. F. e. a. Jensen, "Boiling two-phase cooling of Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics,* pp. 303-306., 2003.

[32] A. R. e. a. Krauss, "Forced air cooling of Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics 17.1,* pp. 303-306, 1981.

[33] G. e. a. Liu, "Experimental investigation of a hybrid cooling method for Electromagnetic Propulsion Device," *Journal of Applied Physics,* 2011.

[34] S. e. a. Wei, "Microchannel cooling for high-power Electromagnetic Propulsion

Device," *Journal of Physics D: Applied Physics 53.2* , 2020.

[35] R. M. e. a. Teflon, "Experimental investigation of a liquid-cooled Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics,* vol. 27.1, pp. 510-513, 1991.

[36] R. e. a. Ghaffarian, "Carbon nanotube composites for cooling of electromagnetic launchers," *Journal of Applied Physics,* vol. 117.17, 2015.

[37] R. e. a. Kumar, "Analysis and design of thermal management system for electromagnetic Electromagnetic Propulsion Device," *International Journal of Mechanical and Production Engineering Research and Development,* vol. 9.5, pp. 369-378, 2019.

[38] D. e. a. Meng, "Liquid cooling for high-power Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics,* vol. 50.2, pp. 1-4, 2014.

[39] L. R. &. F. R. J. Rambo, "Instrumentation considerations for Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics,* vol. 16(2), pp. 319-321, 1980.

[40] J. J. &. M. D. W. Zielinski, "Fiber-optic cable sensitivity to magnetic fields generated by Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics,* vol. 28(1), pp. 432-437, 1992.

[41] J. A. &. R. R. A. Schiferl, "Electromagnetic Propulsion Device magnetic fields and their effects on radio-frequency systems," *IEEE Transactions on Magnetics,* vol. 36(1), pp. 244-248, 2000.

[42] J. E. &. K. T. B. Yonemura, "The effect of Electromagnetic Propulsion Device magnetic fields on laser interferometers," *IEEE Transactions on Magnetics.,* pp. 168-173, 2006.

[43] R. K. &. B. J. D. Leach, "Effect of Electromagnetic Propulsion Device magnetic

fields on digital cameras," *IEEE Transactions on Magnetics,* vol. 48(2), pp. 763-766, 2012.

[44] S. R. &. P. S. C. Talla, "Effect of Electromagnetic Propulsion Device magnetic field on electric field sensors," *IEEE Sensors Journal,* vol. 17(18), pp. 5979-5981, 2017.

[45] W. T. &. L. J. R. Magruder, "Magnetic shielding of Electromagnetic Propulsion Device," *IEEE Transactions on Magnetics,* vol. 39(1), pp. 225-230, 2003.

[46] S. C. &. M. G. R. Prasad, "Magnetic shielding of Electromagnetic Propulsion Device using ferrofluids," *IEEE Transactions on Magnetics,* pp. 3926-3929, 2011.

[47] J. E. &. H. R. E. Whittenburg, "Magnetic shielding of Electromagnetic Propulsion Device using superconducting materials," *IEEE Transactions on Magnetics*, vol. 55(2), pp. 1-5, 2019.

[48] M. O. Ali, "A Review on Self Stabilizing Platform in Scope of Merchant Navy Applications," IEEE, 2022.

APPENDIX 1

Operating Manual

T1=Temperature of rails through ir sensor

T2=Temperature of water inlet of exchanger

T3=Temperature of water outlet exchanger

S4=Angle of bigmotor display

S5=Angle of small motor display

S6=Flow rate sensor

Flow sensor readings:

The flow rate of the pump is shown on 4 digit display by the flow sensor. A rheostat is connected to the input of the water pump supply which is used to change the flow rate of pump in order to optimize the heat exchnge rate.

NUMPAD working:

In order to operate the platform the following steps are to be followed:

1. First the serial monitor shows the option to select either the pitch or yaw control of the platform.
2. "*" is to be pressed on NUMPAD if the small motor/yaw control is to be selected or "#" is to be pressed if bigmotor/pitch control is to be selected.
3. Then the direction of motion of the motors is to be specified and "A" or "C" is to be pressed for either Anti-clockwise or Clockwise direction respectively.
4. After selecting the direction of the respective control the angle upto which the platform has to be positioned is entered on the NUMPAD.
5. Finally button "D" on the numpad is pressed to confirm the selction.