# Design and Theory of Magnetohydrodynamic(MHD) Thruster

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*Abstract*— **This study focuses on the foundational design and theory of a Magnetohydrodynamic (MHD) Thruster, emphasizing the principles behind its operation. Using neodymium magnets and a simple DC power source, the project aims to explore the fundamental concepts of MHD systems and demonstrate their feasibility as a propulsion method.**

**The system employs neodymium magnets to generate a steady magnetic field and conductive electrodes submerged in a saline solution to facilitate current flow. Motion in the MHD system is driven by the Lorentz force, which acts on the conductive fluid moving within the magnetic field. This force, tied to the interaction of current, magnetic field strength, and fluid conductivity, forms the theoretical basis of the thruster's operation.**

**This project serves as a foundational step in the study of MHD propulsion, providing a conceptual framework and laying the groundwork for future experimental validation and performance optimization.**

***Keywords— Magnetohydrodynamics (MHD), Lorentz Force, Thruster Design, Neodymium Magnets, Ohm's Law, Conductive Fluids, Magnetic Field***

## I. Introduction

Magnetohydrodynamic (MHD) systems are innovative technologies based on the principle of moving electrically conductive fluids through a magnetic field. This technology has garnered significant attention as an alternative solution to traditional propulsion systems, particularly for underwater and space applications. MHD Thruster systems can generate thrust without requiring moving mechanical parts, utilizing conductive fluids and magnetic fields instead.

One of the most notable advantages of MHD Thrusters is their ability to provide silent operation compared to propeller-based systems. Traditional propeller-driven systems create mechanical vibrations and noise that can negatively affect marine ecosystems, particularly fish and other aquatic life. MHD systems, by eliminating mechanical components, offer an eco-friendly propulsion method that minimizes noise pollution, making them ideal for underwater environments. Furthermore, the low acoustic signature of MHD Thrusters makes them suitable for military applications and sensitive underwater research.

The fundamental principle of MHD systems relies on the Lorentz force, which arises from the interaction between an electric field and a magnetic field within a conductive fluid. This force is generated by inducing an electric current through the fluid while it is exposed to a magnetic field. The strength of the magnetic field, the conductivity of the fluid, and the magnitude of the applied current are the key parameters that determine the resulting thrust.

This study focuses on the foundational design and theoretical framework of an MHD Thruster. The design incorporates neodymium magnets to provide a steady magnetic field, saline water as the conductive medium, and DC batteries as the power source. The primary aim of this study is to understand the fundamental principles of MHD Thruster design and to evaluate the feasibility of the system based on theoretical considerations. Additionally, this study highlights the potential benefits of MHD Thrusters as silent, eco-friendly, and sustainable propulsion systems that eliminate the need for mechanical components. While this work serves as a conceptual foundation, it also sets the stage for future experimental validation and system optimization.

## II. Historical Background

Magnetohydrodynamic (MHD) systems, which study the interaction between electrically conductive fluids and magnetic fields, have roots in the early development of electromagnetic theory. The foundational work in this field can be traced back to Michael Faraday, who, in 1831, demonstrated that a conductor moving through a magnetic field generates an electromotive force (EMF) [1]. Faraday's pioneering experiments laid the groundwork for understanding how electromagnetic induction could be used in practical systems.

The formalization of the forces acting on charged particles in electromagnetic fields came later through the work of Hendrik Lorentz in the late 19th century. Lorentz mathematically defined the force, now known as the Lorentz force, as the combined effect of electric and magnetic fields on a charged particle.

MHD systems found practical application in the mid-20th century, driven by advancements in material science and energy technologies. During the 1960s, significant interest in MHD generators emerged, particularly for energy conversion systems, where hot ionized gases (plasma) were used to directly convert thermal energy into electrical energy without mechanical moving parts [2]. Parallel to these developments, MHD thrusters were explored as a propulsion system for underwater vehicles, offering advantages such as silent operation and minimal mechanical wear [3].

The first experimental demonstrations of MHD thrusters highlighted the potential for using conductive fluids, such as saline water, in conjunction with strong magnetic fields to generate thrust. These early systems utilized Lorentz force principles, where the interaction between the electric current flowing through the fluid and the magnetic field produced a force that propelled the fluid and, consequently, the vehicle. The absence of propellers and mechanical parts not only reduced noise but also eliminated many failure points, making MHD thrusters an attractive solution for military and scientific underwater applications [4].

In modern times, the focus has expanded to include environmentally friendly and sustainable energy solutions. MHD systems, including thrusters, benefit from advancements in magnet technology, such as the introduction of neodymium magnets in the 1980s, which provide stronger and more stable magnetic fields [5]. These developments have enabled more compact and efficient designs, suitable for both experimental research and practical deployment.

## III. Theoretical Background

### A. *Fundamentals of Magnetohydrodynamics (MHD)*

Magnetohydrodynamics (MHD) studies the behavior of electrically conductive fluids, such as saline water, liquid metals, or plasmas, under the influence of magnetic and electric fields. MHD systems operate by utilizing the interaction between:

- **Electric currents** $(\vec{J})$
- **Magnetic fields** $(\vec{B})$

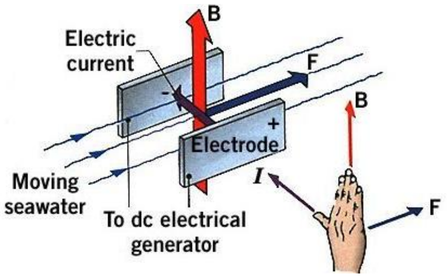


Fig. 1. Right Hand Rule Lorentz Force Direction

The Lorentz force is the fundamental mechanism behind the operation of MHD systems. It arises from the interaction between a moving charged particle, an electric field, and a magnetic field. For a single charged particle, the force is given by:

$$\vec{F} = q\,(\vec{E} + \vec{v} \times \vec{B}) \tag{1}$$

- $q$: Charge of the particle (C),
- $E$: Electric field (V/m),
- $v$: Velocity of the particle (m/s),
- $B$: Magnetic field intensity (T),
- $F$: Force acting on the particle (N).

In MHD systems, which involve a continuous conductive fluid rather than individual particles, the Lorentz force is expressed in terms of current density (J):

$$\vec{F} = (\vec{J} \times \vec{B}) \tag{2}$$

Here:

- J: Current density (A/m²),
- B: Magnetic field intensity (T),
- F: Total force acting on the fluid (N).

In conductive fluids, electric currents are driven by electric fields. Ohm's Law relates the current density to the applied electric field (E) as:

$$\vec{J} = \sigma\vec{E} \tag{3}$$

where:

- σ: Electrical conductivity of the fluid (S/m),
- E: Electric field (V/m).

Saline water, a common working fluid in MHD systems, provides sufficient conductivity due to dissolved ions, enabling effective current flow [2]. The magnitude of F depends on the alignment and strength of the magnetic field and current density, with the force maximized when the two are perpendicular [6].

### B. *Magnetic Field and Thrust Generation*

The magnetic field in MHD systems is typically generated using permanent magnets, such as neodymium magnets, due to their strong and stable field properties [5]. The thrust produced by an MHD thruster originates from the Lorentz force acting on the conductive fluid. The total thrust ($F_t$) can be calculated as:

$$\overrightarrow{Ft} = J.B.A \tag{4}$$

where:

- $F_t$ : Total thrust (N),
- $J$: Current density (A/m²),
- $B$: Magnetic field strength (T),
- $A$: Cross-sectional area of the fluid flow (m²).

Efficient thrust generation requires optimizing:

- **Magnetic Field Strength (B)**: Stronger magnetic fields enhance the Lorentz force.
- **Current Density (J)**: High current densities result in larger forces.
- **Fluid Properties**: High conductivity fluids, such as saline water, reduce resistance and improve current flow [7].

The resistance (R) of the fluid, which impacts current flow, is expressed as:

$$R = \frac{p.L}{A} \tag{5}$$

where:

- $\rho$: Resistivity of the fluid (Ω·m),
- $L$: Distance between electrodes (m),
- $A$: Electrode surface area (m²).

## IV. Design and Methodology

### A. *Magnetic Field and Thrust Generation*

The Magnetohydrodynamic (MHD) thruster in this study is designed to demonstrate the principles of fluid propulsion using electrically conductive fluids, magnetic fields, and electric currents. The system components include:

- **Conductive Fluid:** Saline water, chosen for its high ion concentration and conductivity.

- **Magnetic Field Source:** Neodymium magnets, providing a strong and stable magnetic field.
- **Electrodes:** Graphite plates to conduct electric current into the fluid.
- **Power Source:** A DC power supply, consisting of 1.5V batteries, to generate the required electric field.

The thruster operates by creating an electric current in the fluid, which interacts with the magnetic field to produce a Lorentz force, propelling the fluid and generating thrust.

| Components | Type | Property | Piece |
|---|---|---|---|
| **Electrode** | Graphite Plate | 80x25x100 | 2 |
| **Magnet** | Neodymium Bar | 80x25x100 | 2 |
| **DC Source** | AA Battery | 1.5V | 12 |

Table 1. Components

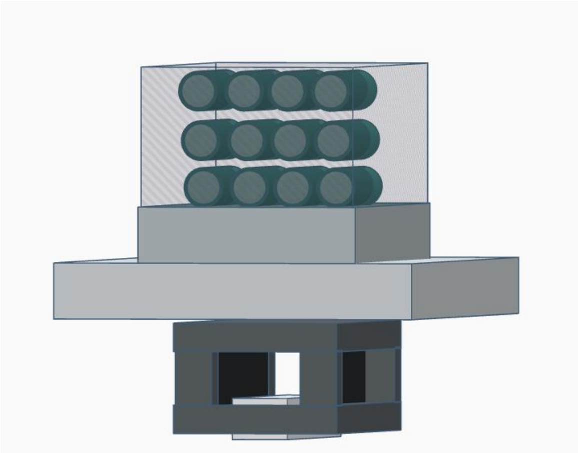

Fig. 2. 3D CAD

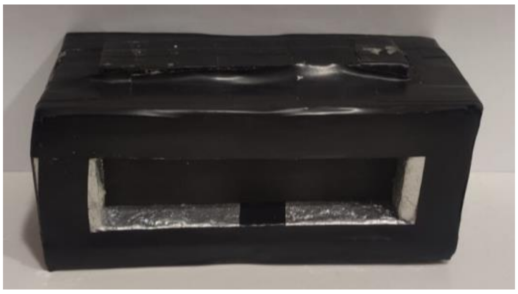

Fig. 3. MHD Thruster Side View

Fig. 4. Conductive Liquid Canal

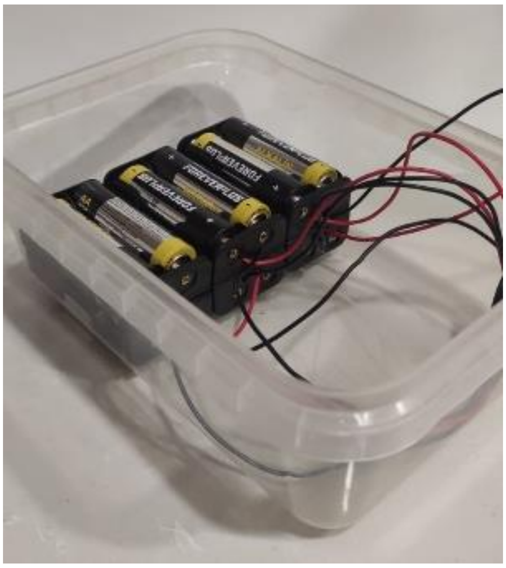

Fig. 5. Battery Compartment

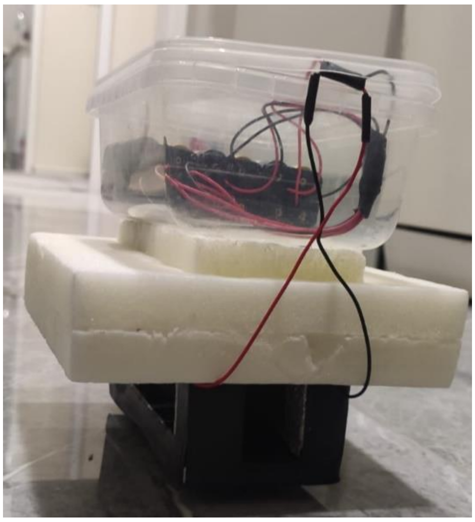

Fig. 6. Thruster and Upper Platform

In the figures, the design and assembly of the MHD thruster system are illustrated. Figure 2 presents the 3D CAD design for visualization purposes. From top to bottom, the components include the battery housing, the upper platform, and the thruster assembly. The thruster consists of two parallel graphite electrodes positioned perpendicular to two neodymium magnets located beneath them. Figure 3 provides a side view of the thruster, showing one of the graphite plates, offering a clearer perspective of the electrode arrangement. Figure 4 focuses on the conductive fluid flow chamber, where the space for fluid movement is shown. The chamber includes two vertically aligned parallel graphite electrodes on the left and right sides to facilitate current flow. Figure 5 highlights the battery housing, where batteries are connected in a 4S3P configuration to enhance current capacity. Finally, Figure 6 shows the fully assembled MHD thruster system, where the battery housing, platform, and thruster are securely mounted together, and the DC power supply is connected to the graphite electrodes, completing the operational setup.

## V. RESULTS

In **Figure 7**, three sequential images illustrate the progression of the project and the demonstration of thrust generation through the MHD thruster. The first image shows the initial setup of the thruster system, including the saline solution, graphite electrodes, and neodymium magnets. The second image captures the system in operation, where the interaction of the electric current and magnetic field produces the Lorentz force. This force drives the conductive fluid, causing a displacement. The final image highlights the resulting movement of the system, confirming the thruster's ability to generate and utilize thrust effectively. This sequence visually supports the theoretical principles of MHD propulsion and demonstrates the system's capability to achieve motion without mechanical components.

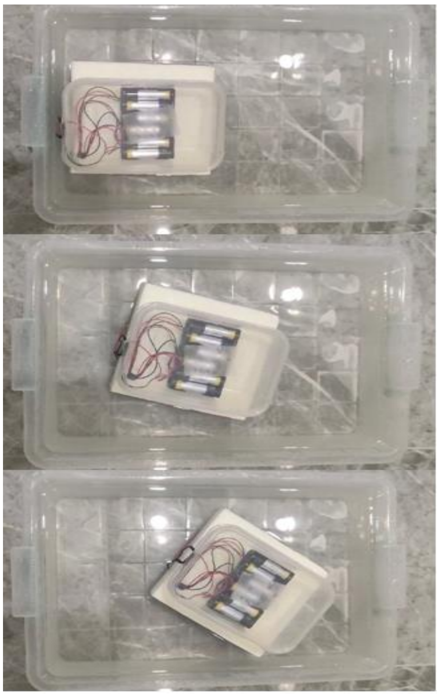

Fig. 7. Thrust Results

## VI. CONCLUSION

This study examined the design and theoretical foundation of a Magnetohydrodynamic (MHD) thruster. Utilizing the principles of Lorentz force and Ohm’s Law, the project successfully demonstrated the feasibility of using electrically conductive fluids, such as saline water, in conjunction with magnetic fields to generate thrust without mechanical components. The design incorporated neodymium magnets to generate a strong and stable magnetic field, graphite electrodes to enable current conduction, and a DC power source to drive the system. By building a fundamental model, the concept of MHD propulsion was realized, validating its theoretical principles through practical implementation. Visual representations, including 3D models and real-world images, further illustrated the design and operation of the thruster.

This project lays the groundwork for future research into enhancing system efficiency and exploring real-world applications, such as underwater propulsion and sustainable energy solutions.

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