DESIGN AND FABRICATION OF PROPULSION SYSTEM USING IONIC PRINCIPLE

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Abstract - *This is a research paper on Design and development of propulsion system using ionic principle. Ion thrusters have emerged as an efficient alternative to conventional propulsion systems due to their high specific impulse, resulting in minimal fuel requirements. While the thrust, they generate is significantly lower compared to chemical propulsion systems, ion thrusters excel in various mission applications, including orbital positioning for geostationary satellites, orbit and attitude control, and versatile mission profiles. Unlike chemical propulsion, which is unsuitable for long-duration missions, ion thrusters enable successful long-range missions. Electric propulsion (EP) facilitates numerous strategic missions by NASA and other space agencies, aiding in the exploration of our solar system, the discovery of new planets, stars, galaxies, and potentially habitable Earth-like planets in neighboring systems, and the search for extraterrestrial life. The development of EP technology supports these missions by integrating advanced technologies into ongoing projects. This article provides a concise overview of electric propulsion systems, with a specific focus on ion thrusters.*

Key Words: **Ionic Thruster, Corona Discharge, Ions, Propulsion System, Hall Thruster, Spacecraft Travel, Propellent, Final year Project.**

1.INTRODUCTION

An ion thruster is a spacecraft propulsion system that generates thrust by ionizing and accelerating propellant, differing from traditional chemical rockets which rely on combustion. It operates on the principle of electrostatic acceleration of ions, often using gases like xenon [1]. This technology, which dates to the early 20th century, has seen significant advancements in recent decades, particularly in space exploration. Ion thrusters are highly efficient, offering much higher specific impulse compared to conventional rocket engines, which is crucial for long-duration space missions due to their fuel economy [2]. The ionization process in these thrusters involves electron guns or RF antennas to create positively charged ions, which are then accelerated by an electric field to produce thrust. Although they generate lower thrust than chemical rockets, their ability to run continuously for extended periods makes them ideal for position maintenance, orbit control, and interplanetary travel [3]. This high efficiency and durability make ion thrusters suitable for applications requiring continuous low-thrust maneuvers, such as station keeping, orbit adjustments, and long-duration missions [4]. They are commonly used in geostationary satellites, deep space probes, and scientific missions where efficiency and longevity are prioritized over rapid acceleration [5].

1.1 Problem Statement

Develop a comprehensive design and modelling framework for an efficient and reliable ionic thruster, addressing key parameters such as propulsion efficiency, thrust-to-weight ratio, power consumption, and operational stability. This involves optimizing the thruster's geometry, electrode configuration, and power supply to maximize thrust generation while minimizing energy consumption and potential failure points. The goal is to achieve a practical and scalable propulsion solution suitable for various space missions, from satellite maneuvers to deep space exploration.

1.2 Objectives

- To develop a small-scale technology demonstrator that is propelled by ionization of air.
- To understand the working of ionization principle.
- To develop a thrust without a moving part.

2. OVERVIEW ABOUT IONIC THRUSTER

The ion engine operates on a straightforward principle, using a strong electric field between two grids acting as electrodes to accelerate heavy positive ions. These ions form a high-speed exhaust stream, generating relatively low thrust but achieving high specific impulse (Isp). The propellant must be ionized before this process. In an ionic thruster, a gas propellant enters a discharge chamber at a controlled rate. A hot, hollow cathode (negative electrode) at the center of the chamber emits electrons, which are attracted to a cylindrical anode (positive electrode) around the chamber walls. Some of the electrons collide with and ionize atoms of the propellant, creating positively charged ions. These ions are then drawn toward the grids to be accelerated.

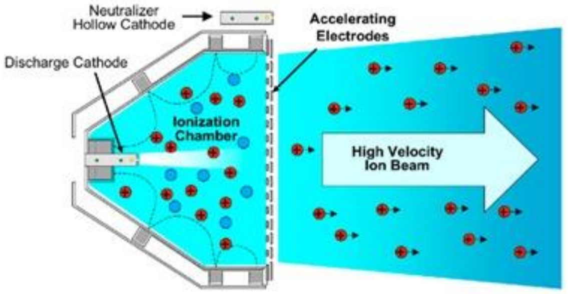

Fig -1: Ionic thruster

The key functional components of an ion thruster are:

- Ionization Chamber: Controls losses and influences the thruster's efficiency.

-Grids: Essential for ion extraction capabilities and subject to erosion from ion impacts.

- Neutralizer: Balances the charge of the exhaust stream.

- Power Supplies: Significantly impact the overall mass and the number of parts, influencing the power system's final weight.

3. COMPONENTS OVERVIEW

3.1 High Voltage Supply (Direct Current)

The high voltage DC supply, which can provide a potential difference up to 150kV(kilovolt), is the basic requirement for the ion thruster. To accomplish this requirement here, buck regulator and Phenovo DC 3.7 to 7.4V to 150kV high voltage generator Transformer Boost Inverter module through a push to on switch. Although the distributor claims to get the 800kv-1000kv potential difference, the output received was 100kV~150kV at 5V and 0.3A, though this method is not very efficient, without the access of high voltage measuring tools this is one of the reliable methods.

3.2 Copper Tubes as Cathode Side

Copper tubes serve as electrodes in ionic thrusters primarily due to their superior electrical and thermal conductivity. This allows them to efficiently transmit the electrical currents required to ionize the propellant, often a noble gas like xenon. These copper electrodes play a vital role in creating the electrostatic field that accelerates the ions, generating thrust. Furthermore, copper's excellent thermal conductivity helps dissipate the heat produced during ionization, preventing overheating and ensuring the thruster components maintain their structural integrity. The metal's durability and resistance to corrosion make it well-suited for the extreme conditions of space, contributing to the longevity and reliability of ionic thrusters on extended missions. The hollow copper of 5mm diameter is used as cathode sharp edge electrodes.

3.3 Copper Wire as Anode Side

The copper wire electrodes are essential in creating the electrostatic field that accelerates the ions to produce thrust. Additionally, copper's high thermal conductivity helps to dissipate the heat generated during the ionization process, which prevents overheating and maintains the thruster's structural integrity. Copper wire of 30 Gauge is used as electrode, sharp edges are created on wire to produce corona discharge.

3.4 Thrust Detector- Anemometer

The most dependable device for detecting wind thrust is the anemometer. Typically, wind velocity is measured using this instrument, and the wind thrust can be estimated based on the detector's area. In our study, we utilized the Lutron AM-4201 portable anemometer, which features a range of 0.4 - 30 m/s, a resolution of 0.1 m/s, and an accuracy of ±2%.

Fig -2: Anemometer Used for The Experiment

3.5 Weighing Scale:

Digital Kitchen Weighing Scale of 10kg X 1gm is Used.

Fig -3: Weighing Scale

4. CAD MODEL

The model for the thrusters has been prepared using SolidWorks software. It consists of two circular rings, one for the anode connection and the other for the cathode connection. Both rings have an inner diameter (ID) of 65mm and an outer diameter (OD) of 85mm. The anode ring features a groove to set a wire filament, while the cathode ring has a similar design but includes small semi-circular spaces for attaching copper wires. The model is fabricated using additive manufacturing.

The thruster model was designed specifically for propulsion purposes and created using SolidWorks software. The design includes two circular rings, each serving a distinct function: one for the anode connection and the other for the cathode connection.

Anode Ring:

Dimensions: The anode ring has an inner diameter (ID) of 65mm and an outer diameter (OD) of 85mm. It includes a groove along its circumference to securely set a wire filament. This groove ensures that the filament remains in place and maintains proper alignment during the thruster's operation.

Cathode Ring:

Dimensions: The cathode ring shares the same inner and outer diameters as the anode ring, with an ID of 65mm and an OD of 85mm. Unlike the anode ring, the cathode ring is designed with small semi-circular spaces along its perimeter. These spaces are specifically created to attach copper wires, which are essential for the thruster's function.

Both rings were meticulously modeled in SolidWorks, leveraging the software's advanced design capabilities to ensure precision and functionality. The choice of dimensions and features was driven by the need to create an efficient and effective propulsion system.

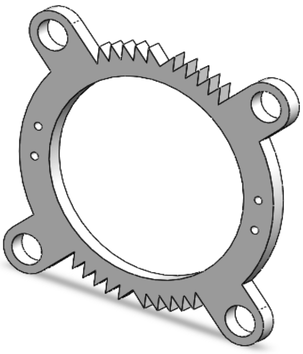

Fig -4: Anode Copper (Wire) Mounting

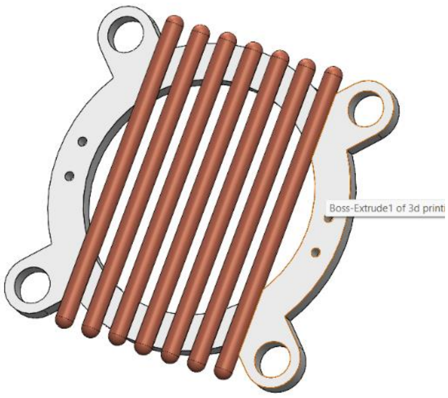

Fig -5: Cathode copper (tube) Mounting

The final model was fabricated using additive manufacturing, also known as 3D printing. This method was chosen for its ability to produce complex geometries with high precision and minimal material waste. Additive manufacturing allows for the production of the intricate features required in the anode and cathode rings, such as the groove for the wire filament and the semi-circular spaces for the copper wires.

By using additive manufacturing, the design ensures that the components are lightweight yet robust, capable of withstanding the operational stresses of ion thrusters. This approach not only facilitates the production of custom parts but also allows for rapid prototyping and iteration, enabling continuous improvement of the thruster design.

5. EXPERIMENTAL SETUP

Ionization Chamber: Construct a small-scale ionization chamber using materials that can withstand high voltages and provide good electrical insulation.

Electrode Configuration: Design anode and cathode electrodes within the chamber to create an electric field for ion acceleration, ensuring proper spacing for efficient ionization.

Power Supply: Utilize a high-voltage power supply to generate the necessary electric field for ionizing and accelerating air ions.

Measurement Instruments: Install voltmeters, ammeters, and pressure gauges to monitor voltage, current, and chamber pressure during the experiment.

Ionization Process:

1. Evacuate the ionization chamber to lower air pressure and facilitate ionization.

2. Introduce air and apply high voltage between electrodes to ionize the air molecules.

3. Monitor ionization by measuring current flow and observing pressure changes.

Ion Acceleration:

1. Apply an electric field to accelerate the ions, ensuring it is strong enough to overcome air density drag forces.

2. Measure acceleration voltage and current to calculate ion velocity.

Thrust Measurement:

1. Install a thrust measurement device, such as a balance or force sensor, to quantify the generated thrust.

2. Record thrust readings under varying experimental conditions, such as different voltage levels or air pressures.

Data Analysis:

1. Analyze the data to determine the relationship between applied voltage, ion current, and thrust.

2. Calculate the specific impulse and efficiency of the ion thruster using the measured thrust and power consumption.

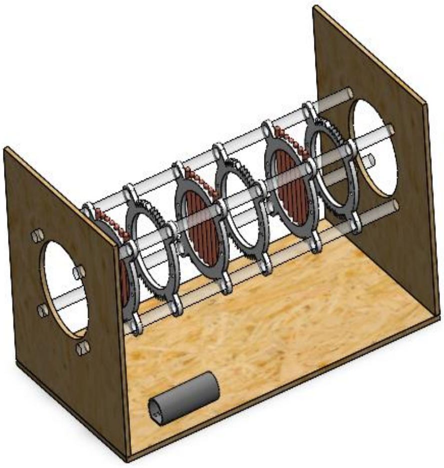

Fig -6: Assembly cad model

Considerations and Limitations: Air as a propellant has lower ionization efficiency compared to noble gases like xenon, resulting in lower thrust levels. The presence of nitrogen and oxygen in air may lead to the formation of undesirable byproducts, such as ozone, which could affect experimental results. Earth's gravity and atmospheric drag impose additional challenges for measuring thrust accurately.

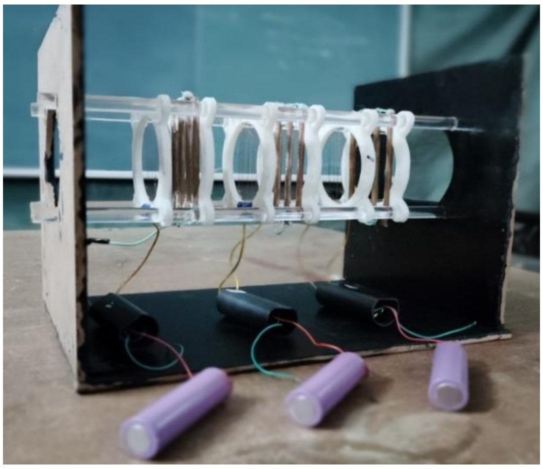

Fig -7: Actual image of Experimental setup

6. THEORETICAL CALCULATIONS

The efficiency of the ion thruster is dependent on thrust created by the ion thruster. Here We will try to make a mathematical model give the thrust created by the ionic wind. The equation of thrust is given as follows:

$$F = \frac{2\,\eta\,P}{g\,I_{sp}}$$

Where:

- F is the thrust force in N,
- η is the efficiency, Ionic thruster has a propulsive efficiency around 65–80%.
- P is the electrical power used by the thruster in W, (output voltage = 150kV, output current = 0.5Amp)
- I_{sp} is the specific impulse in seconds, generally ionic thruster has specific impulse around 2000–5000 s.

Considering propulsive efficiency as 75% and specific impulse as 3000 and substituting values in equation.

$$F = \frac{2 \times 0.75 \times 150 \times 10^{3} \times 0.5}{9.81 \times 3000}$$

$$F = 1.7838\ \text{N}$$

The thrust created by the ionic wind will be 1.7838 Newtons. Now, we will check with the experimental value of the force.

7. EXPERIMENTAL PROCEDURE AND OBSERVATIONS

7.1 Experimentation and Validation Using Anemometer

EXPERIMENTAL PROCEDURE:

Once done with the setup, move the grid cylinder slider 5cm away from the sharp edge electrodes to avoid the direct spark. Start the power supply to the circuit. We can control the circuit with push to on button. Press the button to initiate the ionization process between the grid cylinders and the sharp edge electrodes. Ensure that the circuit remains active for no more than 10-15 seconds to prevent overheating issues. Position the face of the anemometer's fan at an angle where it registers the maximum reading for the designated distance between the grid cylinders and sharp edge electrodes. Record this reading.

OBSERVATION TABLE:

Table -1: Observation Table

Distance $*10^{-2}$	Speed (m/s)	Speed (m/s)	Speed (m/s)	Average speed
3.0	1.25	1.30	1.25	1.26
3.2	1	1.1	1.05	1.05
3.4	0.9	0.9	0.9	0.9
3.6	0.8	0.8	0.9	0.83
3.8	0.6	0.7	0.6	0.63
4.0	0.4	0.4	0.4	0.4

Next, gradually move the grid cylinder slider away from the sharp edge electrodes at a slow pace and record the wind speed displayed by the anemometer. Repeat this process three times for each position and calculate the average of the three readings for accuracy.

7.2 Experimentation and Validation Using Weighing Scale

PROCEDURE:

Step 1: Put the ionic thruster model on the weighing scale.

Step 2: Tare the weight of the model to zero.

Step 3: connect the batteries and start the thruster.

Step 4: Note the reading of weighing scale.

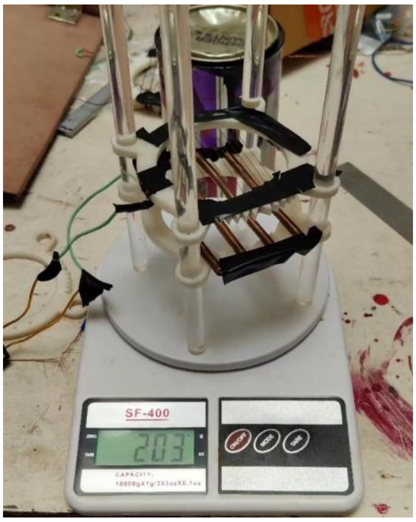

Fig -8: Thruster placed on weighing scale

Experimental Value of thrust created is 0.203 kg or 1.9914 N

8. CONCLUSION

As we conclude this experiment, we acknowledge its significance in the ongoing exploration and advancement of propulsion technology. The challenges we faced and the insights we gained serve as inspirations for future research and development. Through our investigation of ion propulsion and the use of air as a propellant, we have contributed to a growing body of knowledge that will propel us toward new frontiers.

Looking ahead, we envision a future where the principles uncovered in this experiment drive further innovation and discovery. By refining ion propulsion techniques and expanding our understanding of its applications, we open doors to numerous possibilities in both terrestrial and extraterrestrial realms. This experiment not only marks a milestone in propulsion technology but also stands as a testament to the relentless pursuit of knowledge and the human spirit of exploration.

In conclusion, the experiment with an ionic thruster using air as a propellant underscores the importance of curiosity, innovation, and perseverance in our quest to unlock the universe's mysteries. As we continue to push the boundaries of what is possible, we move ever closer to realizing our dreams of exploring the cosmos and deepening our understanding of the world around us.

9. FUTURE SCOPE

1. Deep Space Exploration: Ion thrusters are utilized in deep space missions due to their high specific impulse, enabling spacecraft to travel greater distances with minimal propellant. This efficiency can benefit future missions to outer planets and interstellar targets.

2. Orbital Station-Keeping and Debris Removal: Ion thrusters aid in satellite station-keeping, allowing satellites to maintain their positions in orbit and prolonging their operational lifetimes. Additionally, ion thrusters can support efforts to clear space debris.

3. Commercial Space Applications: As the commercial space industry expands, ion thrusters can facilitate satellite deployment, constellation maintenance, and in-space transportation.

4. Space Tourism: Ion thrusters could play a significant role in future space tourism missions, providing reliable and efficient propulsion for longer journeys beyond Earth's orbit.

5. Advanced Propulsion Research: Scientists are developing more advanced ion thruster technologies, including magnetic ion thrusters and other electric propulsion variants, which could enhance performance and efficiency.

10. ACKNOWLEDGEMENT

We would like to express our heartfelt gratitude to our project guide, Dr. S. V. Chaitanya, for their invaluable guidance. We are also deeply thankful to our team members, whose contributions were essential to the completion of this project. Additionally, we are indebted to our college staff for their valuable assistance throughout our journey. Finally, we extend our sincere appreciation to our families and friends for their unwavering support and understanding during the course of this project.

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