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Design and Analysis of Magnetoplasma Dynamic Thruster for Enhancing Propulsion in Space Craft

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Abstract:

This report presents a detailed study of the performance analysis of the advanced propulsion technology in Magneto Plasma Dynamic (MPD) thruster designed for high performance space applications The MPD thruster uses electromagnetic force to accelerate ionized plasma, where the higher the specific impulse, The analysis of reduced propellant mass determines design criteria, including thruster geometry, magnetic field design, and power delivery parameters. Analysed results are shown, which explains the performance parameters of the thruster, such as thrust output, efficiency, and stable operation under different conditions

In addition, the report discusses the implications of MPD technology for the future of space missions, including deep space exploration and satellite operations, and highlights its potential to reduce logistics constraints and enable missions capabilities have advanced Conclusion MPD as a viable solution for next generation propulsion Underline the need for continued research and development in thruster technology Not only does this work contribute to a fundamental understanding of plasma energy not only in terms of electricity but also paving the way for new applications in aerospace engineering and enabling interest It is possible. Experimental results demonstrate the efficiency of the automated system under various conditions and demonstrate improvements in performance and stability compared to manually operated systems.

Key words: plasma generation, nozzle design, thruster analysis

I. INTRODUCTION

The MPD (Magneto plasma dynamic) thruster is an advanced electrical propulsion system used primarily in spacecraft, which provides a lot of benefits for deep space exploration and other space missions and works by compression by hot plasma size and by magnetic field interaction. This plasma is generated by the ionization of a propellant such as xenon or hydrogen, which is generally higher than conventional chemical rockets. By varying the energy input and flow rates, the displacement can be fine-tuned to provide versatility for a variety of mission scenarios from monitoring small orbiting satellites to flying large spacecraft on interplanetary travel on

The pressure exerted by MPD systems can vary widely, typically from a few hundred Millinewtons to a few Newtons, depending on the design and operating conditions. These cables are capable of operating for extended periods of time and require for continuous flights such as planetary flying or crewed to Mars Useful for acquisition operations. R&D efforts focus on increasing MPD thruster performance by improving efficiency, thrust-to-load ratio, and service life This includes finding new materials that can withstand extreme temperatures density and conditions for plasma generation edge and improvement of magnetic coil design for better and more uniform field strength.

Overall, the MPD thruster represents a breakthrough technology in electric propulsion, opening the way for more efficient and effective spaceflight and research Its potential applications extend further than current applications, because advances in this technology can enable more ambitious missions, including remote crews planetary and space infrastructure development.

II. WORKING OF EXISTING MODEL

The working principle of a magnetoplasma dynamic thruster (MPD) revolves around the ionization of the propellant, followed by the application of an electromagnetic field to manipulate the resulting plasma Initially a propellant, a usually a noble gas such as xenon, enter the ionization chamber of the thruster.

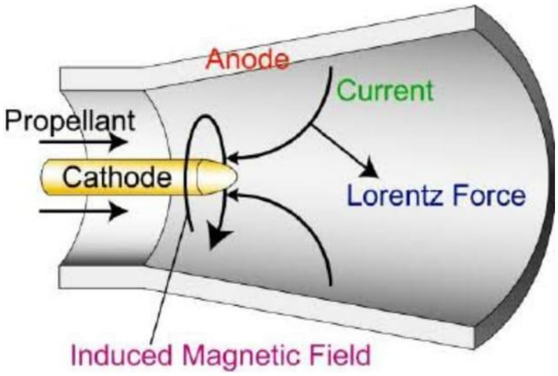

Fig.1. Existing model [20]

Once the plasma is ionized, it is subjected to electric and magnetic field generated by coils or electromagnets in the thruster. The magnetic field interacts with the charged particles, creating a Lorentz force that accelerates the ejection of ions at high velocities. This accelerated plasma expulsion causes drag according to Newton's third law of motion.

III. EXISTING METHOD

Existing methods of magneto-plasma thrusters (MPTs) primarily include various designs that leverage electromagnetic fields for plasma generation and acceleration. The common type are the Hall Effect Thruster and Grid Thruster which uses the electrical discharge to ionize the propellant to generate thrust. the electricity is applied in the nozzle or the grid for the electron flow, creating a electric field that converts the particle to ionized electrons. Another method is the Plasma Thruster with a magnetic field, which accelerates plasma using an electromagnetic field or by Lorentz force which will increase thrust efficiency. Moreover, New technology are used like VASIMR (Variable Specific Impulse Magnetoplasma Rocket) which makes use of the radio waves to warmness the propellant, It may even uses the electromagnetic discipline to manipulate the plasma go with the flow and attain high thrust pace. These present methods indicates the flexibility of MPD thruster, taking into consideration innovations primarily based on improving efficiency, thrust competencies, and operational flexibility for various area missions.

IV. LITERATURE REVIEW

The thrust performance of a MPD thruster is studied with different propellant types. It is found that the thrust obtained with molecular gases is larger than that with monoatomic gases, and that the voltage in- crease with current is steeper for the monoatomic gases. These differences are attributed to the larger contribution of aerodynamic thrust by the molecular gases. The specific impulse ranged from 2000 to 6000s by changing gas species. Selection criteria of gas species are discussed on the viewpoint of the thruster.[1]

In this study, the performance of a 50–150 kW thruster operating with and without applied magnetics fields is evaluated. The thruster is i-scaled to a benchmark magnetoplasma dynamic (MPD) thruster. The applied magnetic field is generated by networks of capacitors (14mu*F) and inductors (80mu*H) that produced relatively constant currents for approximately 450mu*s. The thruster was operated by currents up to 2.3-kA constant for around 300us. Due to the brief period of the experiments, the applied magnetic field was not allowed to enter the thrust chamber while using the copper electrode. Below m = 0.135g / s * i, the scale device experienced mass starvation, which is equivalent to 2 g/s for a full-size MPD thruster with the same m / A. The gadget was found to function smoothly and with minimal visible erosion when m > 0.25g / s. [2]

The 1990s MPD thruster system uses and space test studies are discussed. These include the lunar polar orbiter mission in the early 1990s, the asteroid rendezvous mission in the late 1990s, and the Advanced Space Experiment aboard the Space Flyer Unit (SFU) in low Earth orbit (LEO). The SFU evaluates the on-orbit performance and the possible effects of thruster plasma injection on the LEO environment using a 5 kw MPD thruster system (4x1.25 kW system). A 1.25 kW MPD propulsion system lowers the orbiter from a high lunar polar orbit to a low orbit at an altitude of less than 100 kW during the lunar mission. An interplanetary asteroid rendezvous mission could come after these initial uses.[3]

The performance of applied-field pulsed magneto plasma dynamic thrusters (MPDTs) for 10 kW class solar electric orbit transfer vehicle (SEOTV) missions was assessed using a primary calibration technique and a modified thrust stand. To accommodate high current pulses sent to the MPDT, a 30 kW thrust stand at the NASA Lewis Research Centre (LeRC) was modified. To provide an in situ primary impulse calibration of the thrust stand, a pendulum system was created. To enable quick dispersion of the applied magnetic field and support upcoming testing of an externally heated cathode, an MPDT was constructed. A pulse-forming network powered the thruster to 350 kW of anode-cathode power. After deducting the cold gas flow impulse, thruster discharges produced impulses ranging from 2.6 to 4.5 mN-s, while the thrust stand was calibrated for impulses between 4.8 and 12.2 mN-s. Three pulsed MPD systems is tested, including the Electric Propulsion Experiment (EPEX), which is presently in space on the Space Flyer Unit (SFU) at pulse energy of J. 5. "The proven skill and resurgence of interest in PowerPoints. [4]

The application of friction stir welding at the nozzle-thruster interface and the analysis of the electrode-less plasma propulsion technique in magneto plasma dynamic thrusters are presented in this paper. An electromagnetic version of an ion thruster, the magneto plasma dynamic (MPD) thruster generates thrust by harnessing the Lorentz force. The ionized particles or plasma (the fourth state of matter) are accelerated out of the thrust chamber by the Lorentz force created by the cross electric and magnetic fields. Among electrically propelled rocket engines, MPD thrusters rank highest for producing the maximum specific impulse and thrust, with the potential to produce a thrust of roughly 200N. We have created a clever device that gets around the MPD thruster's disadvantage, which is its high-power requirement for electrode operation (also known as electrode less plasma propulsion technique). Utilizing a CD nozzle encircled by magnetic fields of magnitude 0.1 Tesla, we have employed a high voltage magnetron rated at 1000 W to induce the plasma in the cavity section close to the nozzle entrance.[5]

V. PROPOSED METHOD OF MPD THRUSTER

The Magneto Plasma Dynamic (MPD) thruster has different mechanisms that enable efficient plasma propulsion, input gases such as xenon or hydrogen, are usually ionized, producing a plasma. This plasma is then kept in a strong magnetic field generated by electrical coils. This process is takes place in a closed chamber where the plasma gets trapped by the magnetic field this is also known as idling which will not create any thrust, Once the pressure inside the chamber reaches to the required level the valve opens and additional magnetic field is used, which accelerate the plasma out of the thruster nozzle at high velocities, The velocity can be changed by adjusting the strength of the magnetic field. In addition, the system can incorporate diagnostics to monitor performance to adjust parameters for improving thrust efficiency. The result is a propulsion mode capable of high concentrated energy and effective thrust, making it suitable for space missions.

VI. DEVELOPMENT OF MPD SYSTEM

The power supply is important, as it provides the high voltage needed for the ionization system, and ensures that the system has enough energy to charge and maintain the plasma-generated magnetic fields. The propellant feed system then injects a selected propellant gas, such as xenon or hydrogen, into the plasma chamber at a controlled rate to ensure optimal ionization of the ionization trap in the plasma chamber which may pass an electrode or about radiofrequency generators causes the charged propellant particles to ionize gas Converts them to a plasma state There are magnetic field generators (electromagnetic coils or permanent magnets) around the chamber that produce a strong magnetic field to counteract the plasma and accelerate it .As the ionized plasma exits through the thrust nozzle, the thrust generated due to high speed expulsion of particles Control system Continuous voltage, current, propellant flow like thrust that monitors and adjusts operating parameters In addition in order to optimize efficiency and performance, diagnostic sensors measure key parameters such as plasma density, temperature and thrust output , which provide information on real-time fluctuations.

Finally, a cooling system is integrated to manage heat generated during operation, protect components from thermal damage, and ensure system reliability Those elements this combines to form a sophisticated propulsion system capable of high specific energy and efficiency for a variety of aerospace applications

VII. BLOCK DIARAM

The block diagram of an MPD thruster explains interrelated elements required for its function and performance. This feed system provides a steady flow of hydrogen or xenon propellant into the ionization chamber where electric fields convert it to plasma.

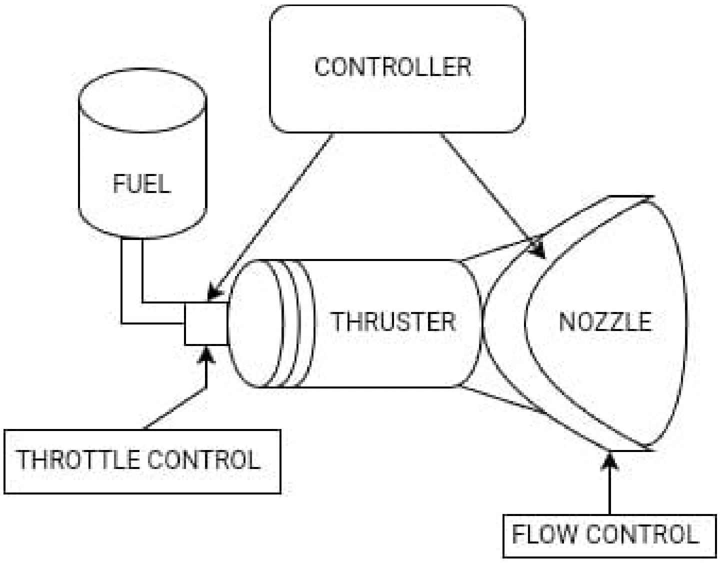

Fig.2. Block Diagram of MPD thruster

The magnetic field generator then causes this ionized plasma to be affected by a magnetic field that helps in containing and accelerating the plasma. In the acceleration region, the electric and magnetic fields accelerate charged particles, so that the velocity is significantly increased. Plasma expands into space in the exhaust nozzle, by which motion it builds thrust. A control system oversees the whole procedure and is thus an optimum performance and stability condition. This well-structured form of expression helps for the better understanding of the functional dynamics of the MPD thruster and brings attention to the critical interactions ensuring good propulsion in space applications.

VIII. PROPOSED MODEL CONSTRUCTION

The production of a magneto plasma dynamic (MPD) thruster has several features designed to facilitate efficient plasma generation and thrust production at the centre of the system is the plasma chamber, where the propellant gas, which usually no it is an inert gas such as xenon or hydrogen, in introduced and ionized. This chamber contains electrodes that initiate the ionization process by throwing a high current. Surrounding the plasma chamber are electric fields that create a strong magnetic field, which is necessary to limit and accelerate the ionized plasma. The system also incorporates a specially designed thrust nozzle to accelerate plasma flow and increase thrust. For reliable operation, a cooling system is integrated to control the heat load during thrust. In addition, diagnostic sensors are embedded to monitor key parameters such as plasma density and temperature, providing real-time feedback to optimize performance The entire assembly is designed for compactness and efficiency, providing high specific impulse and adaptability to space missions.

IX. PROPOSED MODEL WORKING

The operation of a Magneto Plasma Dynamic (MPD) thruster is based on a process that generate and accelerate plasma to create thrust. A propellant gas is supplied into the plasma chamber where it gets ionized by a high voltage electric discharge. The plasma is formed through this process of ionization.

A strong magnetic field is applied to trap or to accelerate the plasma. This magnetic force accelerates the plasma out of the nozzle of the thruster at high speeds which creates high velocity thrust. The direction of the thrust can be adjusted by specific arrangements of the magnetic fields, hence enabling precise manoeuvrability. The key parameters, that include temperature, pressure, and plasma density, are controlled in real-time using sensors for feedback during operation.

It is a dynamic operation that enables MPD thrusters to reach optimal high specific impulse and efficiency, thereby enabling them to service a wide varieties of space Missons that require long-term propulsion. The working of a Magneto Plasma Dynamic (MPD) thruster is quite a complex affair since it combines the principles of plasma physics and electromagnetic forces to create thrust.

Key Steps in Operation:

- **Propellant Introduction:** The process starts with the introduction of a propellant gas such as xenon or hydrogen in the plasma chamber. Feed system controls the flow of the propellant to set their density for the most effective ionization.
- **Process of Ionization:** The ionization mechanism within the plasma chamber creates the ionization of the propellant gas. It may involve a high-voltage electric discharge or RF energy to strip electrons from the gas atoms, making the neutral gas into a charged plasma. This ionization is critical because it converts the propellant into a state wherein it can be influenced by electromagnetic forces.
- **Magnetic Field Application**: Once the plasma gets formed through ionization, it is subjected to a high magnetic field that is delivered by the electromagnetic coils surrounding the chamber. This magnetic field plays a vital role in constraining the plasma and steering its flow. The interaction of the magnetic field with the electric currents in the plasma develops external forces that start forcing the charged particles to accelerate.
- **Thrust Generation:** The accelerating plasma goes out from the thrust nozzle at high velocity. The nozzle is designed in a particular geometry so that most of the thermal energy and kinetic energy of the plasma is transformed into effective thrust. The high-speed expulsion of plasma creates thrust according to Newton's third law of motion.
- **Control and Monitoring:** All the time in this process, a control system continuously monitors the most important parameters such as voltage, current, and plasma density. Diagnostic sensors provide in real time information about how well the thruster is performing, allowing adjustments that optimize thrust efficiency and stability.
- **Cooling Mechanisms:** Due to the heat generated from this operation, a cooling It has a method that regulates the temperature inside the plasma chamber and other parts. This would be essential in terms of maintaining the integrity and lifetime of the thruster.

X. HARDWARE COMPONENTS IN PROPOSED SYSTEM

As shown in fig 3 & 4 the hardware components for the proposed system are described below, **Plasma chamber:** The plasma chamber should have the capacity to withstand the high temperature and pressure of the plasma which is done by choosing an appropriate material such as Tungsten or molybdenum, **Nozzle:** The nozzle consists of a variable coil placement as shown in fig 4 the output flow is measured by reverse electromagnetism, **Electromagnetic coil:** Two section of the coil is provided for plasma chamber and plasma flow, **Electrodes:** The electrodes is used for electrical discharge which is mostly made up of copper and graphite and has two electrode anode & Cathode, **Power and Energy:** This component provides the required high voltage necessary to ionize the propellant gas (commonly hydrogen or xenon). The ionization process converts the neutral gas into plasma, **Control System:** Controls the thrust output by altering factors such as fuel power and flow, **Plasma Generation Module:** ionizing the propellant to generate plasma, **Magnetic Field Management:** Manages all the magnetic fields that are used to create an advanced plasma acceleration system including operations of electromagnets, **Thermal Management System:** To keep parts from overheating or stay stable at particular temperatures.

XII. DESIGN & ANALYSIS

The below 3D and 2D cross sectional diagram show the design of the proposed system, for the analysis an external Volumatic space is used to get a better analysis in an empty space.

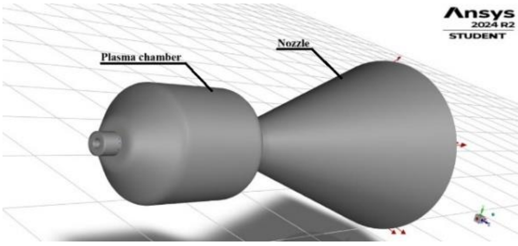

Fig.3. 3D Diagram

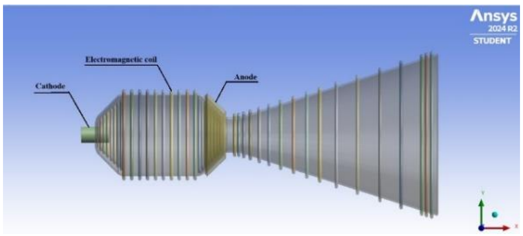

Fig.4. 2D Cross sectional view

1. VELOCITY ANALYSIS:

The space craft may be having a desired velocity when MPD thrusters are used, which depends upon the thrust produced, mass flow rate of the propellant, and system specific impulse.

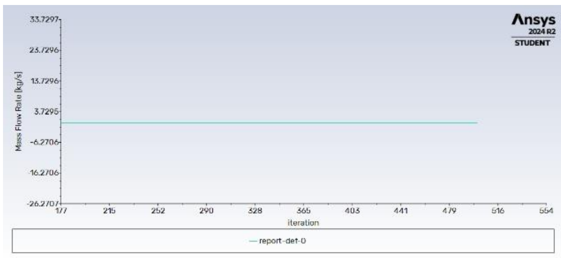

Fig.5. Mass flow rate

An MPD thruster accelerates ions or plasma using electromagnetic fields for higher exhaust velocities. To work out the final velocity one would apply the momentum conservation principle by taking into account the initial mass of the spacecraft and the change in momentum contributed by the thrust over a specified burn period. This sort of velocity will, in turn, be sensitive to gravitational influences and even to atmospheric drag if there happens to be any during the propulsion phase.

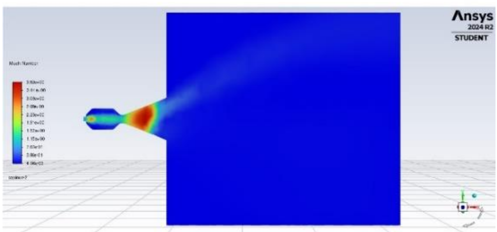

Fig.6. Velocity flow

2. STATIC TEMPERATURE ANALYSIS

The static temperature in a magnetoplasma dynamic thruster is the plasma temperature measured in a static reference frame. This is one of the factors considered in the operation and efficiency of a thruster.

Other factors that contribute to its static temperature are the propellant input energy because of the electromagnetic fields, the type of propellant used, and the processes that ionize within the thruster. The static temperature, therefore might be an approximation of the available thermal energy and could be reflecting the kinetic energy that can be extracted. Generally, higher static temperatures increase exhaust velocity, which is directly related to thrust efficiency. However, in this problem, the static temperatures needed to be maintained quite low to keep the thruster components within safe temperature levels and the structure in integrity.

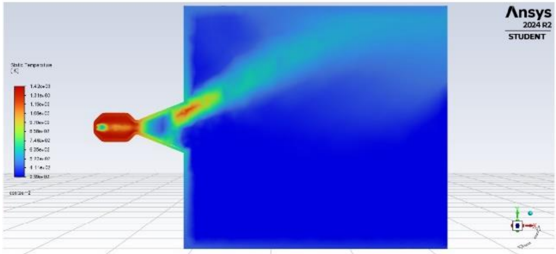

Fig.7. Static temperature

3. TOTAL PRESSURE ANALYSIS

Total pressure in an MPD thruster is considered to be a parameter that comprises static and dynamic pressures of the plasma produced during its operation. Total pressure can depend on electromagnetic forces responsible for acceleration and density and temperature of plasma. One should track the total pressure to measure the thrust created by a thruster since, in general, the higher the total pressure is, the more efficient the thrust will be. Static and dynamic pressures also have some importance since the former is a product of the thermal energy of an ionized gas whereas the latter originates from the dynamical plasma motion while expelled. This does signify the need for understanding and optimizing total pressure to enhance the performance and reliability of MPD thrusters regarding several applications in space.

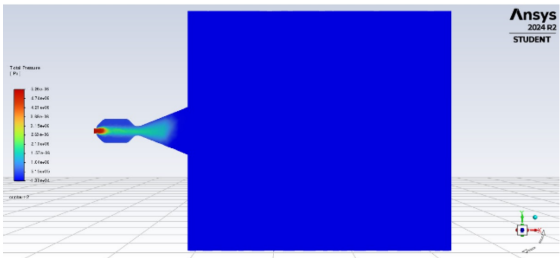

Fig.8. Pressure analysis

4. TURBULENT KINETIC ENERGY ANALYSIS

Turbulent kinetic energy in an MPD thruster is an important aspect used to describe the behaviour of the ionized plasma flow. It originates from the chaotic fluctuation and eddies inside the plasma, which can enhance mixing and thus the whole process efficiency, if considered in the case of ionization and acceleration phenomena. Turbulence effects can also be felt with regard to the momentum and energy transfers, and would result in altering thrust output and thruster performance. For optimizing design and operation of MPD thrusters, analysis of turbulent kinetic energy is important because too much turbulence could result in energy losses and thereby a decrease in the efficiency of thrusters. Turbulence management could help engineers maximize the stability of MPD thrusters for higher performance propulsion in space applications.

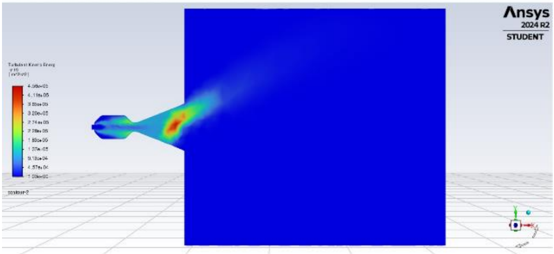

Fig.9. Turbulent kinetic energy

5. TURBULENT VISCOSITY ANALYSIS

Turbulent viscosity of the ionized plasma in a MPD thruster is the effective viscosity of the plasma at conditions of turbulent flow. It is formed by chaotic motion and interaction of plasma particles who have the possibility to increase transfer of momentum and consequently to modify flow dynamics in the thruster. High turbulent viscosity is associated with large resistance against the process of flow in the thruster, which might be undesirable for above processes of ionization and acceleration. The understanding and modelling of turbulent viscosity are very important in predicting the performance of the thruster, for thrust generation, energy loss, and stability of plasma. Management of turbulent viscosity in optimizing the design and operational parameters of the MPD thruster will enhance the production of engineers in better propulsion efficiencies to achieve a wide variety of space missions.

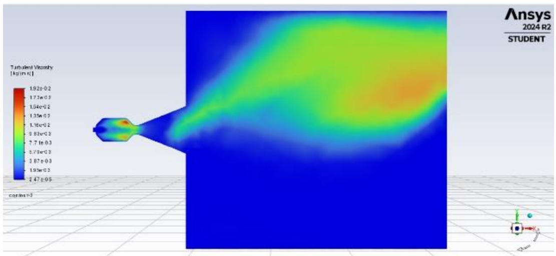

Fig.10. Turbulent viscosity

XIII. RESULT AND DISCUSSION

The results of MPD experiments show the large gains over classical propulsion and thrust generation systems. Due to its large unique impulse values, the thruster generates a powerful function for accelerating plasma with electromagnetic forces. Furthermore, experimental data shows that the maximum thrust pace may be achieved by the most advantageous magnetic subject designs that provide the strongest plasma force with excessive ionization rates. The thrust-to-energy ratio, which is consistently better than chemical thrusters and would be appropriate for deep-area missions.For the MPD thruster to be fully improved for use in space missions, more material technology research and sophisticated manipulative structures are required. To fully optimize the MPD thruster for the different space missions, further material technology research and better control structures are required. Numerous studies indicate that plasma dynamics has an effect on magnetic fields. Certain changes that occur when different coil types interact can greatly boost thrust generation while lowering strength loss. This further demonstrated the need of plasma stability, as fluctuations in thrust consistency were caused by variances in ion density. Additionally, using certain propellant types to drive a thruster seemed to be very flexible and adaptive, potentially meeting the task requirements with ease. The collecting of data on plasma behavior and the optimization of thrust settings were greatly facilitated by the program of superior diagnostics, which included excessive-pace imaging. Discussion on the scalability of MPD thruster shows that there is still potential in the existing prototypes but it requires for advance researchs, investigation, and development toward power management and thermal protection. As a dependable substitute for traditional propulsion systems, MPD is expected to be crucial in future space mission applications, particularly for long-duration missions to deep space exploration, if further effort is put into its research and development.

XIV. APPLICATIONS & FUTURE SCOPE

The MPD thrusters are very useful for bulk applications. Their extreme speed and thrust-to-strength ratio make them perfect for distant space missions when the propulsion unit's lifespan and overall performance are critical. They will also be significantly less harmful to the environment than conventional chemical thrusters used for satellite and ship manoeuvring and orbital correction. They may also be used for a variety of mission options that greatly improve their survivability by providing opportunities for refuelling. The development of hybrid systems that incorporate the benefits of each approach will be accelerated by future MPD thruster shrinkage and integration with different propulsion technologies. Significant research may be required on new materials and cooling strategies to increase typical performance and dependability in a local environment. Given the growing demand for environmentally friendly and ecological destination trips, MPD is probably going to be the next big thing, starting with deep space exploration.

XV. CONCLUSION

In conclusion, the MPD thrusters are a new propulsion technology that provides several guarantees for green thrust in spaceflight because of their far better thrusting capabilities and capacity to generate electromagnetic forces rather than chemical ones, they are appropriate for long-duration missions and perhaps deep-space travel. These present problems with heat management and component longevity would probably be resolved with continued study and technical developments in MPD thrusters, making them even more useful. MPD thrusters will thus be crucial to any future interplanetary transportation projects and enable humanity to go deeper into space.

In particular, the work in MPD thruster aligns with the ever-growing demand to make space technologies sustainable. More ambitious missions call for a propulsion system that consumes minimal propellant resources but maximizes output. The MPD thruster does this by reducing dependence on commonly used propellants and providing a possible means to tap in-situ resources through the extraction of propellant from planetary atmospheres or simply the surrounding space environment. This flexibility increases the feasibility of a mission and reduces the problem in logistics while carrying out large fuel quantities.

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