ION Thrusters with Integration of Swivel Nozzle as Thrust Vector Control

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Abstract— In any spacecraft installation of an ion propulsion system, it is likely that there will be a need to alter the position of the thrust vector with respect to the center of mass, in order to minimize attitude and orbital perturbations during operation. In addition, this offers a possible means of direct attitude control, or of unloading momentum wheels and similar devices. This control of the thrust vector is normally accomplished using a mechanically actuated gimbal platform. As such devices are heavy and expensive, and may suffer from reliability problems, alternatives are worthy of consideration. The integration of swivel nozzle as thrust vector control helps in directing the thrust and movement of spacecraft,satellite in the space for deep space explorations.

Keywords—ion thruster; thrust vector control(TVC); Swivel nozzle; deep space explorations.

I. INTRODUCTION

The" ION THRUSTERS WITH INTEGRATION OF SWIVELNOZZLE AS THRUST VECTOR CONTROL " design represents a groundbreaking disquisition into the realm of advanced spacecraft propulsion systems. Ion thrusters, known for their high effectiveness and dragged functional life, serve as the focal point of this design. The integration of swivel nozzle as thrust vectoring control adds a new dimension, aiming to enhance project and control perfection in space operations. This action stems from the growing demand for propulsion technologies that can optimize spacecraft performance, particularly in the environment of extended space disquisition and satellite operations. By combining the essential advantages of ion thrusters with the adaptive capabilities of thrust vectoring control, the design seeks to push the boundaries of traditional propulsion styles, potentially revolutionizing the way we navigate and propel spacecraft in the vacuum of space. Throughout this report, we claw into the intricate details of ion thruster operation, explore the significance of swivel nozzle as thrust vectoring control, and present the issues of our experimental trials. The design's overarching thing is to contribute precious perceptivity and advancements to the field of spacecraft propulsion, paving the way for more effective, protean, and precise disquisition beyond our earth.

A. ION THRUSTER

ION THRUSTER The most advanced kind of electric propulsion device is an ion thruster, which was first proposed in the 1910s. The first known electrostatic ion accelerator for propulsion was introduced by Robert Hutchings Goddard in 1917 , although it wasn't until Harold R. Kaufman constructed the first functional ion thruster at the NASA Glenn Research Center in 1959. In order to conduct a suborbital flight—that is, a spaceflight in which the spacecraft reaches space but its trajectory does not complete one orbital revolution— NASA Glenn launched two ion engines aboard the SERT 1 spacecraft in 1964 as part of the Space Electric Rocket Test (SERT) spaceflight test program in the 1960s. three months each .Since then, the system's core ideas have developed through iterative design improvements motivated by the demands of high efficiency, low propellant and structural mass, and a long operating lifetime—all essential components for space propulsion. The process of ionizing the propellant atoms is the most significant difference amongst the several configurations that have been proposed throughout history. The only thrusters that are still in use are the electron bombardment type, the radio-frequency ionized thruster, and the electron cyclotron resonance thruster. Other ideas, like duo plasmatron sources and Cesium Contact thrusters, have mostly been dropped, and two new unique devices, the Field Emission Electrostatic Propulsion (FEEP) and Ionic Liquid Recently, Ion Source (ILIS) was added to the roster . The power needed to run the gadget, which is directly influenced by the fuel used, is what makes the ionization process significant. Mercury was utilized as a fuel in the early designs, but because of its toxicity, the spacecraft frequently became contaminated. Xenon gas is used in modern ion thrusters. It is easily ionized and has a high atomic number. Additionally, because it is an inert gas, it causes little erosion, extending the engine's lifespan. A Hughes2 engine installed on the US Air Force's SCATHA satellite , which was built to gather information on spacecraft electrical charging, was the first xenon ion drive to ever fly. Several businesses then focused their energies on creating xenon ion engines. The NSTAR project was established by NASA Glenn and JPL (Jet Propulsion Laboratory) with the goal of creating ion engines for deep space travel. These engines served as the main propulsion system for the Deep Space 1 spacecraft, which demonstrated the ability of an ion thruster to be operated for extended periods of time during a scientific mission. The first xenon ion engine was used commercially by Hughes in August 1997 on Pan AmSat 5, a communications satellite that was launched using a Russian Proton rocket.

B. THRUST VECTOR CONTROL

Thrust vector control (TVC) is a technology used in propulsion systems to control the direction of the thrust produced by an engine. Instead of relying solely on aerodynamic control surfaces, thrust vector control allows for the adjustment of the direction in which the thrust is expelled from the propulsion system. This capability is particularly important in applications where precise control of the vehicle's orientation is required, such as in spacecraft, missiles, and certain aircraft. In thrust vector control systems, the nozzles or vanes through which the exhaust gases exit the engine are adjustable. The orientation of these nozzles or vanes can be changed dynamically to redirect the thrust. Mechanical TVC systems use mechanical actuators to physically reposition the nozzles or vanes. Fluidic TVC systems use fluid dynamics and pressure differentials to redirect the exhaust gases without relying on mechanical actuators. TVC is commonly used in spacecraft, rockets, and missiles to control their orientation and trajectory during flight. Thrust vector control is a valuable technology in the field of propulsion, allowing for enhanced control and maneuverability in various aerospace applications. Its use is particularly prevalent in space exploration, where precise control is critical for mission success.

C. SWIVEL NOZZLE

A swivel nozzle is a type of thrust vector control(TVC) system used in thrusters ,especially in spacecraft, and rocket. It allows the exhaust nozzle of a thruster to rotate or swivel causing the changes in the direction of the thrust vector. Working of swivel nozzle as TVC:

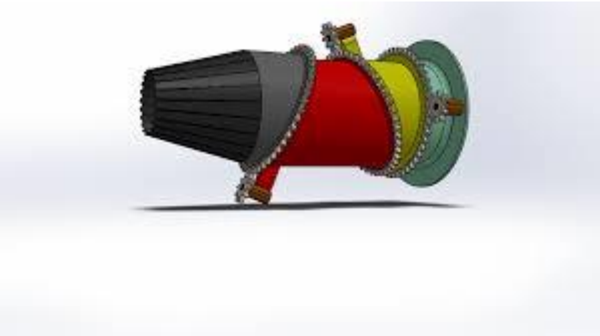

Fig: swivel nozzle

➢ Swivel nozzle is attached to the thruster’s exhaust nozzle.

➢ The nozzle is designed to rotate around a pivot point ,allowing it to change direction.

➢ Due to the rotation of nozzle, the direction of exhaust plume is altered, which in turn changes the direction of the thrust vector..

D. HOW ION THRUSTER WORK?

- An ion thruster is a sophisticated type of electric propulsion that uses electric fields to create thrust in order to accelerate charged particles, or ions. The following phases comprise the functioning of an ion thruster:

- 1. The Propellant Ionization Process Ionization of the propellant, often a noble gas like xenon, is the initial stage of the ion thruster process. A stream of electrons is directed at the propellant as it enters the thruster's ionization chamber. Some of the propellant's atoms lose one or more electrons as a result of this bombardment, changing into positively charged ions.

- 2. Acceleration of Ions After ionization, the positively charged ions are subjected to strong electric fields generated by a set of electrodes (commonly referred to as the "anode" and "cathode"). These electric fields cause the ions to accelerate to very high velocities. The ions can reach speeds up to 30 50 km/s, much higher than those achieved by traditional chemical propulsion systems. The accelerated ions are directed through the thruster and toward the exit nozzle.

- 3. Exhaust of Ions As the ions exit the thruster through the nozzle, they are expelled at high velocity. According to Newton’s third law of motion, for every action, there is an equal and opposite reaction. Therefore, the expulsion of ions generates a thrust that propels the spacecraft in the opposite direction. This process is highly efficient, as the thrust is generated by a continuous stream of ions rather than by the rapid combustion of fuel.

- 4. Emissions Neutralization The ions leaving the thruster are neutralized by a neutralizer to maintain the spacecraft's electrical neutrality. Usually, an electron cannon or similar type of electron injection is used for this. In the absence of neutralization, the spacecraft would build up a positive charge that would interfere with its operation or cause unintended interactions with its surroundings.

E. OBJECTIVES

- The "Ion Thrusters with Thrust Vectoring Control" project's goals are designed to direct and concentrate research and development activities toward particular objectives. These goals give the project team a precise framework for achieving significant results. The following are typical project goals:

- 1. Optimize Ion Thruster Performance: Examine and improve the chosen ion thruster's overall performance, paying particular attention to factors like efficiency, thrust, and specific impulse. Examine the possibility of enhancing propulsion capabilities by modifying the ion thruster's operational parameters or design.

- 2.Enhance Maneuverability and Control Precision: Investigate how the integration of thrust vectoring control improves the maneuverability and control precision of the spacecraft. Evaluate the system's responsiveness to dynamic space environments, including orbital adjustments and attitude control.

- 3.Create a Sturdy Thrust Vectoring Control System: Create and put into place a thrust vectoring control system that can dynamically modify the ion thruster's thrust's direction and amount. Make sure the control system can react in real time to changes in operational requirements and can be adjusted to different space mission circumstances.

- 4. Integrate swivel nozzle as Thrust Vectoring Control and Ion Thruster: Create a smooth connection between the swivel nozzle as thrust vectoring control system and the ion thruster. Assure the two technologies' efficiency, dependability, and compatibility when used together.
- 5.Evaluate the power consumption and system efficiency: Calculate the efficiency improvements brought about by combining ion thrusters with thrust vectoring control. Analyse the combined system's power consumption and contrast it with more conventional propulsion techniques. he word "data" is plural, not singular.

II. METHODOLOGY

The "ION THRUSTERS WITH INTEGRATION OF SWIVEL NOZZLE AS THRUST VECTOR CONTROL" project's methodology describes a methodical way to accomplish the goals. In order to investigate the integration of ion thrusters with swivel nozzles as thrust vector control, a number of procedures, tests, and studies are required. A thorough explanation of the process is provided below:

Literature review
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Ion thruster selection
↓
Swivel nozzle as thrust vector control
↓
Analysis and data collection
↓
Result validation

A. PROTOTYPE

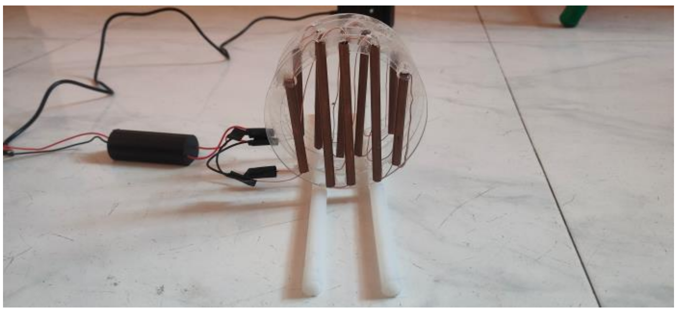


Fig: Prototype front view.

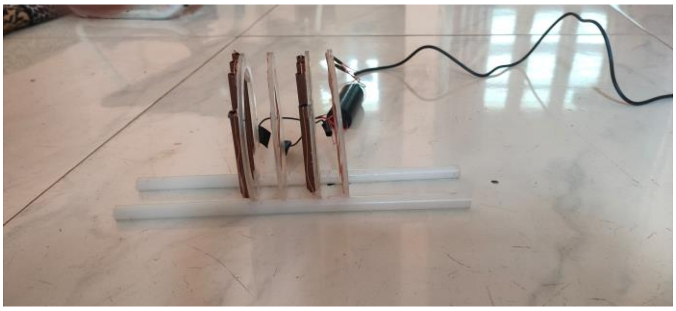


Fig :Prototype side view

B. DESIGN OF ION THRUSTERS WITH SWIVEL NOZZLE

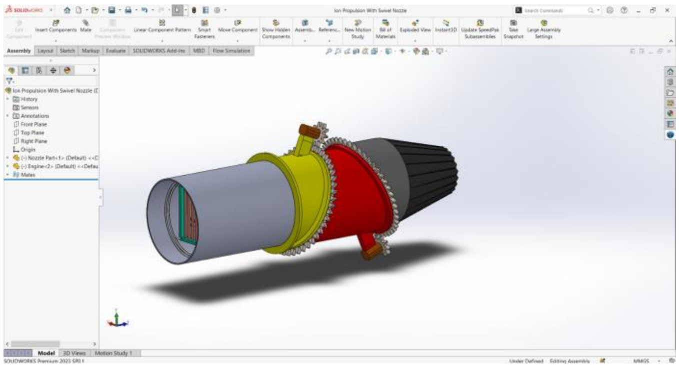
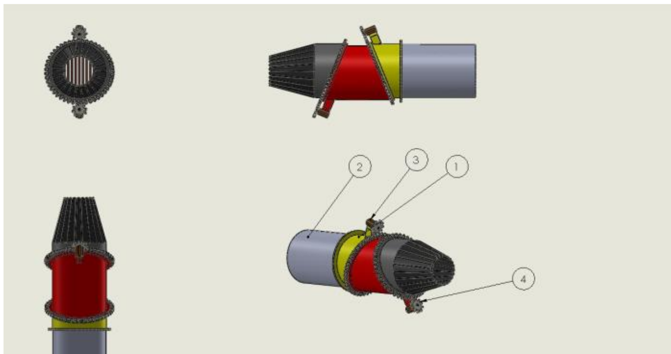


Fig: ion thruster with swivel nozzle.

Ion Thruster with swivel nozzle is represented in the above shown prototype design of an ion thruster with integration of swivel nozzle as thrust vector control . The design was made on solid works software.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Nozzle Part		1
2	Engine		1
3	Servo Moter		2
4	Gear		4

Fig: Design Description.

Engine : This is the part where the ion thrusters are placed where the ion engine produces a form of electric propulsion. An ion thruster creates a cloud of positive ions from a neutral gas by ionizing it.

Nozzle : The nozzle is used for altering the direction in x-axis and fixing the Y-axis and simultaneously. Servo motor is used to move the nozzle.

Servo motor: A servo motor is a type of motor that is designed to provide precise control of its angular position, acceleration, and velocity.

C. IMPLUSE CALCULATION :

We are supplying direct current from the source of 220-240V with the help of DC adapter of 12V and 1A.

we have current in ampere hour: 1Ah

Use the formula

I = Q/t to find the current (I), where Q is the charge (in ampere-hours) and t is the time (in hours). In this case, we'll assume the thruster operates for 1 hour (3600 seconds) to simplify the calculation:

I = 1Ah/1hour=1A

Now, we need to calculate the power (P), using the formula P=V×I,

Where, V is the voltage and I is the current:

P = 12V×1A=12W

We'll be using the ionization energy of nitrogen to calculate the number of moles ionized(1503kj/ml); 1mole of N_2=28gm.then,

= (0.012kj / s) × (1mole N_2 ionized / 1503kj) = 0.00022355 moles N_2 ionized/s.

Multiplying the number of moles ionized by the molar mass of N_2 , we get mass of ionized N_2 ions.

(2.23×10-4 moles N_2 ionized / s)×(28g N_2 ionized ions / 1 moles N_2 ionized)×(10-3 kg / 1g)

= (6.25×10-6 kg N_2 ions ionized / s)

Potential electric energy,

Uelectric = Voltage × Q [Convert the PEE into kinetic energy of an ion].

Mv2/2 = V×q.

The mass of N_2 molecule is derived using the molar mass of N_2 as well as Avogadro's number to get us the following mass of an N_2 molecule.

=(28gm N_2 / 1 mole N_2)×(1 mole N_2 / 6.023 × 1023N_2 molecules)×(10-3kg /1g)

=28gm of N_2/6.023× 1023N_2 molecule. =4.648×10-26 kg / 1 N_2 molecule.

As the voltage of our system is 12 V and q is a constant 1.6 × 10-19coulombs, we can plug in all of our variables to get the following speed for a N_2 molecule(v)

= [(2 × 12 × 1.6 ×10-19) / (4.648 × 10-26 kg)]1/2

= 9089.34 m/s

Thus , the impulse of our is as follows:

Impulse = (mass of N_2 ions ionized)×(Speed of N_2 ions ionized)

= 9089.34×6.25×10-6 = 0.0568 N / s.

Figures and Tables

TABLE I.

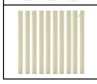
PICTURE	COMPONENT		
	NAME OF THE COMPONENT	*SPECIFICATION*	*QUANTITY*
	12V 1A DC Adapter	12V 1A	1
	400k Step-up Transformer:	400K	1
	Copper Wire	22swg	1m
	Copper Tubes	L=1M	1
	Acrylic disc	OD=10.4cm,ID=8cm,t=2cm.	4
	Plastic Nylon Rod Smooth	L=25cm, B=5cm,OD=10mm	2

Fig. 1. Explation of the figures and table

The above figure shows the components used for manufacturing for the ion thruster.the function of the components are explained below:

1.) 12V 1A DC Adapter: A power supply equipment called a 12V 1A DC adapter is made to transform wall outlet AC (alternating current) power into DC (direct current) power at 12 volts with a maximum output current of 1 ampere. Function: a.it takes 220-240V from the main source and converts it to regulated 12v DC output and 1 ampere maximum current.

2.) 400k Step-up Transformer: a "step-up power transformer " is a DC-DC converter or voltage booster that raises the input voltage to a higher output voltage. The "400k" indicates the maximum switching frequency.

3.) Copper Wire : Copper wire is used for the electrical conductivity through copper tube . naked copper wire is winded around the copper tube and on the acrylic disc, extending it to connect to step-up transformer.

4.) Copper Tubes : Wiring for electricity: Copper tubes can be used for electrical grounding systems or in specific electrical applications where their conductivity beneficial, even though they are less prevalent than other materials like copper wiring. Copper tube of 1m in length was cut in 6,8.8,9.2,9.5, and 6cm dimension and placed on two acrylic disc at distance of 1.5 and 2cm each. Five pieces of cut copper tube was placed on two acrylic disc and was winded with naked copper wire of 22 gauge and extending the wire to connect with the step-up transformer.

5.) Acrylic disc: An acrylic disc is a strong, adaptable material that is utilized in many different contexts, from industrial to home décor. It is well-known for its remarkable clarity and resilience to weathering and UV light, making it a great substitute for glass. Four Acrylic dis of 10.4cm outer diameter , 8cm inner diameter of thickness 3mm is cut through to place the copper tube at a distance of 2cm each. Out of four acrylic disc two of them were substituted copper tube and two of them were with naked copper wire winding, extending them to connect to step-up transformer.

6.) Plastic Nylon Rod Smooth: A smooth nylon rod is a highly versatile and durable plastic material known for its excellent mechanical properties and ease of machining. It exhibits high tensile strength, good wear resistance, and low friction, making it ideal for applications in engineering, manufacturing, and DIY projects. The smooth surface ensures minimal drag and resistance, which is crucial in precision components such as gears, bearings, and bushings. Additionally, nylon rods are resistant to chemicals, abrasion, and impact, ensuring longevity and reliability in various environments. Four Nylon rod of 25cm in length ,5cm width and outer diameter of 10mm is taken to place four the acrylic disc at the distance of 2cm apart from each other.

CONCLUSION

Ion thruster have a revolutionized space propulsion with its high efficiency, specific impulse, and fuel economy.by harnessing these capacities of electrical energy to accelerate ions, these thrusters have enabled loner -duration missions, reduced fuel consumptions, and increased payload capacity. Ion thruster have huge potential in deep -space explorations, interplanetary travel, satellite propulsion, space tugboats and nuclear electric propulsion like various other applications. The development of an ion thruster with integration of a swivel Nozzle as thrust vector control system represents a significant advancements in space propulsion technology. This innovative design enables precise control over the thrust vector, allowing for the improved maneuverability, increased efficiency and enhanced mission performance.

The key achievements of this project:

1.Successful Integration : The integration of swivel nozzle with Ion Thruster, demonstrated the reliable and efficient Thrust vector control system.

2.Improved performance: The system showed improved thrust efficiency, specific impulse and thrust vector control accuracy compared to traditional ion thruster designs.

3.Enhanced maneuverability: The swivel nozzle enabled precise control over the thrust vector, allowing for rapid attitude adjustment and improved mission flexibility. The ion thruster has huge future potential for deep space exploration, satellite constellations, spacecraft design with swivel nozzle, human mars Missons, electric propulsion for space tugs ,integration of heater in the ion propulsion system and many other further advancement and development can be done.

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