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Performance Analysis Ionic Thruster and Grid Configuration

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Abstract

Electric propulsion is a technology aimed at achieving thrust with high exhaust velocities, which results in a reduction in the amount of propellant required for a given space mission or application compared to other conventional propulsion methods. Reduced propellant mass can significantly decrease the launch mass of a spacecraft or satellite, leading to lower costs from the use of smaller launch vehicles to deliver a desired mass into a given orbit or to a deep-space target. In general, electric propulsion (EP) encompasses any propulsion technology in which electricity is used to increase the propellant exhaust velocity. Naturally, spacecraft designers are then concerned with providing the electrical power that the thruster requires to produce a given thrust, as well as with dissipating the thermal power that the thruster generates as waste heat. Total voltage across the screen and accelerator grid takes 1-2 kV and screen grid voltage is 200 V. Total voltage and ion current density are applied in finding the distance between screen grid and accelerator grid. Parameters of the grid are used to get thruster parameters such as thrust force, exhaust velocity, specific impulse and thruster efficiency.

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1. Introduction

Ionic thrusters generally use heavy inert gases such as xenon as the propellant. Other propellant materials, such as argon and krypton, have investigated in the past. Xenon is generally preferable because it is not hazardous to handle and process, it does not condense on spacecraft components that are above cryogenic temperatures, its large mass compared to other inert gases generates higher thrust for a given input power, and it is easily stored at high densities and low tank mass fractions. Therefore, the focus will be on xenon as the propellant in ionic thrusters, although performance with other propellants can examine using the basic information provided here.

Ion engine consists of a cylindrical structure delimited by a set of two (or three, depending on the thruster) precisely placed grids at the end side. Such grids have a matrix of tailored holes in order to extract the ion beam. The first grid called screen grid, whereas the second one referred to as the accelerator grid. When a third grid used, it known as decelerator grid. The other side of the cylinder bounded by a flat plate. The volume delimited by this structure (cylinder, grids and flat plate) refer to as the discharge chamber or ionization chamber.

The design of the grids is critical to the ion thruster operation and is a trade between performance, life, and size. Since ion thrusters need to operate for years in most applications, life is often a major design driver. However, performance and size are always important in order to satisfy the mission requirements for thrust and specific impulse (I_{sp}) and to provide a thruster size and shape that fits onto the spacecraft.

The life time of ionic thrusters is based on the accelerator grid erosion from ion sputtering. The erosion geometry is naturally divided into two regions. The first region is barrel erosion and the second region is caused by charge ions generated downstream of the accelerator grid.

Accelerator grid structure failure is the bridge between the holes has fractured by erosion, whole the structure was destroyed and cannot extract ion beam any normal. Structure damage caused by the accelerator grid ion sputter erosion involves two mechanisms.

- (1) Beam ions that energy equivalent to total acceleration voltage sputter on the upstream surface of accelerator grid.
- (2) Charge-exchange (CEX) ions that energy equivalent to accelerator grid voltage sputter on the downstream surface of accelerator grid that made pit and groove erosion.

The first type erosion mechanism can avoided by a reasonable geometry design and the second type erosion mechanism is the main factor that can lead to structure failure of accelerator grid.

1.1. Grid Configuration

To accelerate ions, a potential difference must be established between the plasma produced inside the thruster plasma generator and the ambient space plasma for two singly charged ion current densities at an acceleration voltage 1000-2000V.

For xenon, the characteristic aperture diameter at this voltage is on the order of 2 to 5 mm and will decrease if the applied voltage is reduced or the current in the aperture is increased. The ion current obtainable from each grid aperture is then limited by space charge. Multiple apertures must be used to obtain higher beam currents from the ion engine to increase the thrust.

Ions that miss the aperture are accelerated into the accelerator grid and can erode it rapidly. For this reason, a "screen" grid with apertures aligned with the accelerator grid is placed upstream of the accelerator grid to block these ions. This is the classic two-grid accelerator system. The screen grid is normally either allowed to float electrically or is biased to the cathode potential of the plasma generator to provide some confinement of the electrons in the plasma and so that ions that strike it have a relatively low energy and cause little

sputtering. In practice, the grids are made of refractory metals or carbon-based materials, and the apertures are close-packed in a hexagonal structure to produce a high transparency to the ions from the plasma generator.

The high-voltage bias supply (called the screen supply) is normally connected between the anode and the common of the system, which is usually connected to the neutralizer cathode (called “neutralizer common”) that provides electrons to neutralize the beam. Positive ions born in the discharge chamber at high positive voltage accelerated out of the thruster. The accelerator grid is biased negative relative to the neutralizer common to prevent the very mobile electrons in the beam plasma from back-streaming into the thruster, which produces localized heating in the discharge chamber by energetic electron bombardment, and ultimately overloads the screen supply if the back-streaming current becomes large. The ion beam is current neutralized and quasi-neutral (nearly equal ion and electron densities) by the electrons extracted from the neutralizer cathode.

A three-grid accelerator system, where a final grid called the “decelerator grid” placed downstream of the accelerator grid. This grid shields the accelerator grid from ion bombardment by charge exchanged ions produced in the beam back-flowing toward the thruster, and eliminates the downstream “pits-and-grooves erosion”. Three-grid systems then potentially have longer accelerator grid life than two grid systems and generate less sputtered material into the plume that can deposit on the spacecraft. These benefits offset by the increased complexity of including the third grid.

In actual design, the diameter of each accelerator grid aperture is minimized to retain unionized neutral gas in the plasma generator, and the screen grid transparency is maximized so that that the grids extract the maximum possible number of ions from the plasma.

In the two- or three-grid configurations, the geometry of the grid apertures and gaps intended to eliminate or at least minimize direct impingement by beam ions on the most negative potential electrode in the system, namely, the accelerator grid. This is required to minimize sputtering of the grid by the high-energy beam ions. Sputter erosion of the screen grid then becomes an issue only at high discharge voltages or due to the production of high-energy ions in the hollow cathode region that can bombard the screen grid. Likewise, the decelerator grid is biased near the beam plasma potential and back-flowing ions produced in the beam by charge exchange impact with very low energy, which causes little or no sputtering. For two grid systems, the back-flowing ions bombard the accelerator grid with essentially the grid bias voltage. This can cause significant sputtering of the downstream face of the accelerator grid and may determine the grid life. Ions generated between the grids by either charge exchange with unionized neutral gas escaping the plasma generator or by ionization from the most energetic back-streaming electrons do strike the accelerator grid and erode it. Charge exchange ion erosion of the accelerator grid ultimately limits the grid life.

2. Design Methodology

2.1. Ion Accelerator Basics

The thruster ion optics assembly serves three main purposes:

- (1) Extract ions from the discharge chamber
- (2) Accelerate ions to generate thrust
- (3) Prevent electron back-streaming

The ideal grid assembly would extract and accelerate all the ions that approach the grids from the plasma while blocking the neutral gas outflow, accelerate beams with long life and with high current densities, and produce ion trajectories that are parallel to the thruster axis with no divergence under various thermal conditions associated with changing power levels in the thruster. In reality, grids are non-ideal in each of these areas. Grids have finite transparency; thus, some of the discharge ions hit the upstream “screen grid” and are

not available to become part of the beam. The goal for screen grid design is to maximize the grid transparency to ions by minimizing the screen thickness and the webbing between screen grid holes to that required for structural rigidity. The maximum beam current density is limited by the ion space charge in the gap between the screen and accelerator grids. The maximum beam current density is,

$$J_{\max} = \frac{4\epsilon_0}{9} \sqrt{\frac{2e}{M}} \frac{V_T^{\frac{3}{2}}}{d^2} \quad (1)$$

Where V_T = the total voltage across the sheath between the two grids
 d = the distance between screen and accelerator grid
 M = mass of a xenon atom
 e = electron charge ($1.602176487 \times 10^{-19} \text{ C}$)
 ϵ_0 = permittivity of free space ($8.8542 \times 10^{-12} \text{ F/m}$)

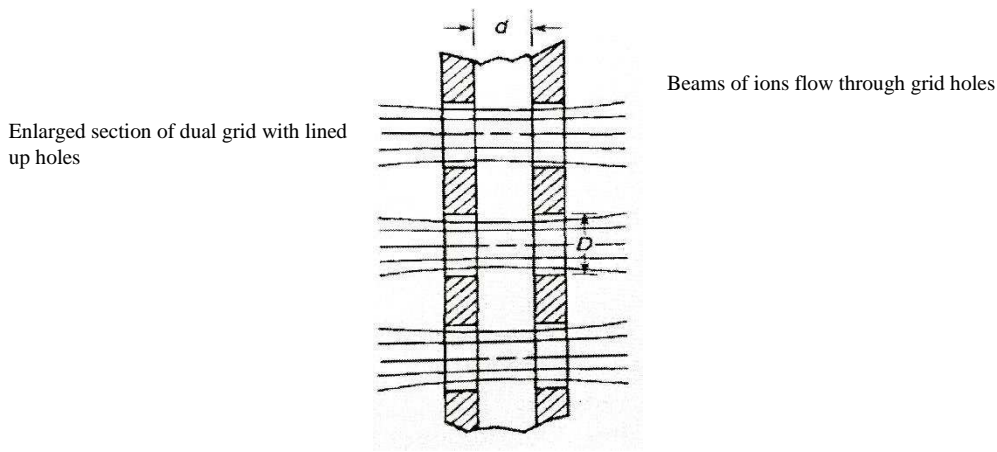


Fig.1. Showing enlarged section of the double grid for an electron bombardment of ion thruster

The ion velocity leaving the accelerator is

$$v_i = \sqrt{\frac{2eV_b}{M}} \quad (2)$$

Where, eV_b = the net beam energy

The effective electric field in the acceleration gap is

$$E = \frac{V_T}{L_e} \quad (3)$$

Where, V_T = the total voltage across the accelerator gap (the sum of the screen and accelerator grids)
 L_e = sheath thickness

$$V_T = V_s + |V_{\text{acc}}| \quad (4)$$

Where, V_s = screen grid voltage

V_{acc} = accelerator grid voltage

The maximum I_{sp} that is achievable is limited by the voltage that can be applied to the grids to extract a given current density before electrical breakdown or electron back-streaming occurs.

The thrust provided by the thruster computed, by using this equation is

$$F_t = 6.18 \times 10^{-12} \times V_{acc}^2 \times \left(\frac{D_{aperture}}{d} \right)^2 \times N_{aperture} \quad (5)$$

Where $D_{aperture}$ = aperture diameter

$N_{aperture}$ = number of aperture

The exhaust velocity of the thruster is

$$V_{exhaust} = 13800 \sqrt{\frac{V_{acc}}{M}} \quad (6)$$

Where, V_{acc} = accelerator grid voltage

2.2. Grid Expansion and Alignment

A significant issue in ion thrusters that utilize refractory metal grids is thermal expansion of the grids during thruster operation changing the acceleration gap dimension between the screen and accelerator grids. This will directly affect the ion trajectories and the perveance of the ion optics. Since the screen grid heated by direct contact with the discharge plasma and is usually dished outwards and designed with a minimum thickness to increase the effective transparency, the screen grid expansion is usually larger than the accelerator grid and the gap tends to decrease as the thruster heats up. For ion thrusters with refractory metal grids designed with concave grid curvature, the screen grid expands away from the accelerator grid and the perveance decreases, as the gap gets larger. In addition, concave grids have a smaller discharge chamber volume for a given thruster size, which adversely affects the discharge loss.

Another significant grid issue is alignment of the grid apertures. The ion trajectories assumed perfect alignment of the screen and accel grid apertures, and the resultant trajectories are then axis-symmetric along the aperture centerline. Displacement of the accel grid aperture relative to the screen grid centerline causes an off-axis deflection of the ion trajectories, commonly called beam steering. Mechanical misalignment of the grids due to manufacturing tolerances or thermal deformation can also produce aperture displacement and unintended beamlet steering. For this reason, precise alignment of the grid apertures and grid support mechanisms that minimize non-uniform thermal deformation are generally required to provide stable ion optics performance with minimal beam divergence.

2.3. Ionic Thruster Accelerator Grid Life

The most important wear mechanism in modern ion thrusters is accelerator grid erosion. A current of secondary ions generated downstream of the discharge chamber impacts the accelerator grid. These secondary ions are generated by resonant charge exchange (CEX) between beam ions and neutral propellant gas escaping from the discharge chamber. The cross section for resonant charge exchange is very large: on the order of a hundred square angstroms. These slow ions are attracted to the negatively charged accelerator grid, and most hit with sufficient energy to sputter material from the grid. Eventually the accelerator grid apertures become too large to prevent electron back-streaming or enough material is sputtered away that the grids fail structurally. The erosion geometry is naturally divided into two regions. The first region, barrel erosion, is caused by ions generated between the screen grid aperture sheath and the downstream surface of the accelerator grid. Charge exchange ions generated in this region impact the inside

surface of the accelerator grid aperture, which results in enlargement of the aperture barrel. As the barrel diameter increases, the grid must be biased more and more negatively in order to establish the minimum potential required in the aperture to prevent neutralizer electrons from back-streaming into the discharge chamber. Thruster failure occurs when, at its maximum voltage, the accelerator grid power supply is unable to stop electron back-streaming.

The second region of grid erosion is caused by charge exchange ions generated downstream of the accelerator. Since the beamlets are long and thin, inside each beamlet the radial electric forces dominate and expel the slow, charge-exchange ions into the gaps between the beamlets. Charge exchange ions generated in the region before the beamlets merge to form a continuous ion density attracted back to the accelerator grid by its large negative potential. On impact, these ions sputter away material from the downstream surface of the accelerator grid. Sputter erosion by these back-streaming ions results in a hexagonal “pits-and-grooves” erosion pattern on the downstream grid surface, which can lead to structural failure of the grids if the erosion penetrates all the way through the grid. Erosion of the accelerator grid aperture edge by back-streaming ions can also effectively enlarge the accelerator grid aperture diameter, leading to the onset of electron back streaming.

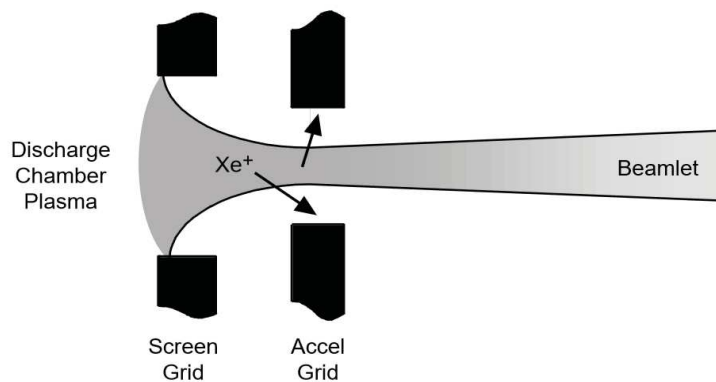


Fig. 2. Ions that cause barrel erosion generated by charge exchange upstream and within the accelerator grid aperture

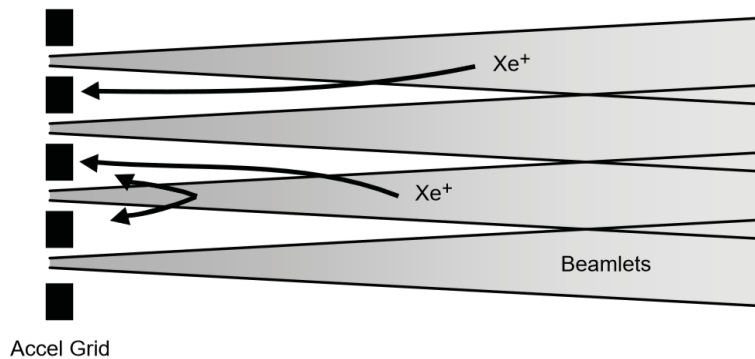


Fig.3. Ions that cause pits and grooves erosion generated between the downstream surfaces of the accelerator grid

2.4. Barrel Erosion

Charge exchange ions generated between the screen grid and the upstream surface of the accelerator grid impact the interior surface of the accelerator grid holes. These ions sputter away grid material, increasing the barrel radius. Assume that any ions generated downstream of the discharge chamber are not focused through the hole in the accelerator grid. For barrel erosion, the path length taken as the sum of the grid gap

and the accelerator grid thickness. The number of grid apertures is approximately the grid open area divided by the area per aperture.

$$N_{\text{aperture}} = \frac{f_a \pi r_{\text{grid}}^2}{\pi r_{\text{aperture}}^2} \quad (7)$$

Where, N_{aperture} = Number of apertures
 f_a = open area fraction
 r_{grid} = Grid radius
 r_{aperture} = Aperture radius

The number of apertures can be from hundreds to thousands and total force depend on it.

2.5. Calculation of Grid Parameters,

Assuming, $V_t = 1000 - 2000V$
 $V_{\text{screen}} = 200V$
 $V_{\text{acc}} = 800 - 1800V$
 $D_{\text{aperture}} = 1 - 5mm$
 $D_{\text{grid}} = 15 - 30cm$

The thrust range of ionic thruster is 25-250mN. The calculated grid parameters are used to get the maximum thrust force and exhaust velocity for ionic thruster of communication satellites.

For xenon propellant,

Total voltage across the accelerator gap,

$$V_t = 1300V$$

$$V_{\text{screen}} = 200V$$

$$V_{\text{acc}} = 1100V$$

open area fraction,

$$V_{\text{acc}} = 1100V \quad (\text{for accelerator grid})$$

$$r_{\text{grid}} = 14.5cm = 1.45 \times 10^{-1}m$$

$$r_{\text{aperture}} = 1.25cm = 1.25 \times 10^{-3}m$$

$$N_{\text{aperture}} = \frac{f_a \pi r_{\text{grid}}^2}{\pi r_{\text{aperture}}^2}$$

$$= \frac{0.24 \times \pi \times (1.45 \times 10^{-1})^2}{\pi \times (1.25 \times 10^{-3})^2}$$

$$= 3229.44$$

$$J_i = 139 \text{ A/m}^2$$

$$\text{Proton mass} = 1.6726 \times 10^{-27} \text{ kg}$$

$$\text{Molecular mass} = 131.293 \text{ AMU}$$

$$m_i = \text{ion mass}$$

$$= \text{proton mass} \times \text{molecular mass}$$

$$= 1.6726 \times 10^{-27} \times 131.293$$

$$= 2.196 \times 10^{-25} \text{ kg}$$

$$\text{Electron charge, } e = 1.6022 \times 10^{-19} \text{ C}$$

$$d = \left(\frac{4 \varepsilon_o V_T^2}{9 J_i} \sqrt{\frac{2e}{m_i}} \right)^{\frac{1}{2}}$$

$$= \left(\frac{4 \times 8.8542 \times 10^{-12} \times 1300^2}{9 \times 139} \times \sqrt{\frac{2 \times 1.6022 \times 10^{-19}}{2.196 \times 10^{-25}}} \right)^{\frac{1}{2}}$$

$$= 0.00127 \text{ m}$$

$$= 1.27 \times 10^{-3} \text{ mm}$$

$$D_{\text{aperture}} = 2.5 \times 10^{-3} \text{ m}$$

$$\text{Force, } F = 6.18 \times 10^{-12} \times V_{\text{acc}}^2 \times \left(\frac{D_{\text{aperture}}}{d} \right)^2$$

$$= 6.18 \times 10^{-12} \times 1300^2 \times \left(\frac{2.5 \times 10^{-3}}{1.27 \times 10^{-3}} \right)^2$$

$$= 2.916 \times 10^{-5} \text{ N}$$

The thrust provided by the thruster,

$$F_t = F \times N_{\text{aperture}}$$

$$\begin{aligned}
 &= 2.916 \times 10^{-5} \times 3229.4 \\
 &= 0.094 \text{ N} \\
 &= 94 \text{ mN}
 \end{aligned}$$

$$\begin{aligned}
 V_{\text{exhaust}} &= 13800 \times \sqrt{\frac{V_{\text{acc}}}{M}} \\
 &= 13800 \times \sqrt{\frac{1100}{131.293}} \\
 &= 39.944 \text{ km/s}
 \end{aligned}$$

For Krypton,

$$N_{\text{aperture}} = 3229.44$$

distance between screen and accel grids,

$$d = 0.00147 \text{ m} = 1.47 \times 10^{-3} \text{ mm}$$

$$\text{Force, } F = 2.2 \times 10^{-5} \text{ N}$$

$$\text{Total force, } F_t = 0.0698 \text{ N} = 69.8 \text{ mN}$$

$$V_{\text{ex}} = 49998.687 \text{ m/s} = 49.999 \text{ km/s}$$

For Argon,

$$N_{\text{aperture}} = 3229.44$$

distance between screen and accel grids,

$$d = 0.00179 \text{ m} = 1.79 \times 10^{-3} \text{ mm}$$

$$\text{Force, } F = 1.46 \times 10^{-5} \text{ N}$$

$$\text{Total force, } F_t = 0.0470 \text{ N} = 47 \text{ mN}$$

$$V_{\text{ex}} = 72414.89 \text{ m/s}$$

$$= 72.415 \text{ km/s}$$

The largest diameter of the grid and the smallest diameter of aperture use to achieve the largest number of aperture. The largest number of aperture decide the value of thrust. Exhaust velocity change depending on the voltage of accelerator and the molecular mass of the gas. If the dimension of the gap distance between grids is large, ions will miss the aperture and rapidly erode the surface of grid. The smaller gap distance will increase the temperature of grid and cause thermal deformation.

2.6. Definition and Ionic Thruster Parameters

2.6.1. Thrust

Thrust is the force supplied by the engine to the spacecraft. Since the spacecraft mass changes with time due to the propellant consumption, the thrust are given by the time rate of change of the momentum, which can be written as

$$F_T = \dot{m} v_{ex} \quad (8)$$

Where,

F_T = total thrust force

\dot{m} = propellant mass flow rate

v_{ex} = exhaust velocity

Propellant mass flow rate,

$$\dot{m} = \frac{F_T}{v_{ex}} \quad (9)$$

2.6.2. Kinetic Power

The kinetic power of an object is the energy that it possesses due to its motion. It is defined as the work needed to accelerate a body of a given mass from rest to its stated velocity. Having gained this kinetic energy unless its speed changes. The kinetic thrust power of the beam, called the jet power, defined as

$$P_{jet} = \frac{1}{2} \dot{m} v_{ex}^2 \quad (10)$$

Where,

P_{jet} = kinetic power

\dot{m} = propellant mass flow rate

v_{ex} = exhaust velocity

2.6.3. Input power

The electrical power input, P_{in} , to the thruster in watts, is usually the product of the electrical current and all associated voltages (hence the Σ -sign).

$$P_{in} = \Sigma IV \quad (11)$$

Where,

P_{in} = input power

I = total current

V = total voltage

The exhaust velocity is the function of the accelerator voltage, V_{acc} , imposed across the accelerating chamber or grids, the mass of the charged particle, μ , and its electrical charge e . In the conservation of energy equation, the kinetic energy of a charged particle must equal the electrical energy gained in the field, if there are no collisional losses. In its simplest form,

$$\frac{1}{2} \mu v_{ex}^2 = e V_{acc} \quad (12)$$

And another form,

$$\frac{e}{\mu} = \frac{1}{2} \times \frac{v_{ex}^2}{V_{acc}} \quad (13)$$

Where,

μ = mass of the charge particle

e = electrical charge

V_{acc} = accelerator gird voltage

V_{ex} = exhaust velocity

The total current, I , across the accelerator represents the sum of all the propellant mass (100% singly ionized) carried per second by the particles accelerated:

$$I = \left(\frac{e}{\mu} \right) \dot{m} \quad (14)$$

Where,

I = total current

\dot{m} = propellant mass flow rate

μ = mass of the charge particle

e = electrical charge

2.6.4. Specific Impulse

Specific impulse, termed I_{sp} , is a measure of thrust efficiency and is defined as the ratio of the thrust to the rate of propellant consumption. Specific impulse for constant thrust and propellant flow rate is

$$I_{sp} = \frac{V_{ex}}{g_0} \quad (15)$$

Where,

I_{sp} = specific impulse

V_{ex} = exhaust velocity

g_0 = specific gravity

2.6.5. Thruster Efficiency

Thruster efficiency is the kinetic energy of the exhaust jet emitted per second divided by the electrical input power into the device. Overall system energy efficiency is determined by the propulsive efficiency. Some thrusters can vary exhaust speed in operation, but all can be designed with different exhaust speeds. At the lower end of specific impulse, I_{sp} , the overall efficiency drops, because ionization takes up a larger percentage energy and at the high end propulsive efficiency is reduced. Optimal efficiencies and exhaust velocities for any given mission can be calculated to give minimum overall cost. The electrical efficiency of the thruster is defined as the kinetic power, P_{jet} , out of the thruster divided by the total input power, P_{in} .

$$\eta = \frac{P_{jet}}{P_{in}} \times 100\% \quad (16)$$

Where,

η = thruster efficiency

P_{jet} = kinetic power

P_{in} = input power

2.7. Thruster parameter calculation

The most propellant used in ion propulsion is xenon. Sometimes krypton and argon are used. So, thrusters using these three propellants are calculated.

For xenon thruster,

Inputs data;

Molecular mass of Xenon, $M = 131.293 \text{ AMU}$

Accelerator grid voltage, $V_{\text{acc}} = 1100 \text{ V}$

Discharge voltage, $V_d = 350 \text{ V}$

Total thrust force, $F_T = 94 \text{ mN}$

Exhaust velocity, $v_{\text{ex}} = 39.944 \text{ km/s}$

Specific gravity, $g_0 = 9.81 \text{ m/s}^2$

Calculated data;
Specific Impulse,

$$I_{\text{sp}} = \frac{v_{\text{ex}}}{g_0}$$

$$= \frac{39.944 \times 10^3}{9.81}$$

$$= 4071.79 \text{ s}$$

Propellant mass flow rate,

$$\dot{m} = \frac{F}{v_{\text{ex}}}$$

$$= \frac{94 \times 10^{-3}}{39.944 \times 10^3}$$

$$= 2.35 \times 10^{-6} \text{ kg/s}$$

Kinetic power,

$$P_{\text{jet}} = \frac{1}{2} \dot{m} v_{\text{ex}}^2$$

$$= \frac{1}{2} \times 2.35 \times 10^{-6} \times (39.944 \times 10^3)^2$$

$$= 1.875 \text{ kW}$$

Total current,

$$I = \left(\frac{e}{\mu} \right) \dot{m}$$

From equation (5.13),

$$\frac{e}{\mu} = \frac{1}{2} \times \frac{v_{ex}^2}{V_{acc}}$$

$$= \frac{1}{2} \times \frac{(39.944 \times 10^3)^2}{1100}$$

$$= 7.25 \times 10^5 \text{ C/kg}$$

$$I = 7.25 \times 10^5 \times 2.35 \times 10^{-6}$$

$$= 1.7 \text{ A}$$

Input power,

$$P_{in} = \sum IV$$

$$= (V_{acc} + V_d) \times I$$

$$= (1100 + 350) \times 1.7$$

$$= 2.465 \text{ kW}$$

Thruster efficiency,

$$\eta = \frac{P_{jet}}{P_{in}} \times 100\%$$

$$= \frac{1.875 \times 10^3}{2.465 \times 10^3} \times 100\%$$

$$= 76.1\%$$

Table 1. Comparison results of three propellant thrusters

Thruster parameter	Xenon thruster	Krypton thruster	Argon thruster
Atomic mass(AMU)	131.293	83.79	39.948
Accelerator voltage(V)	1100	1100	1100
Discharge voltage(V)	350	500	600
Total thrust force(mN)	94	69.8	47
Exhaust Velocity (km/s)	39.944	49.999	72.415
Specific impulse(s)	4071.79	5096.7	7381.7
Kinetic power(kW)	1.875	1.750	1.700
Input power(kW)	2.465	2.544	2.635
Thruster efficiency (%)	76.1	68.7	64.5

3. Conclusions

The total thrust force, specific impulse, input power and thruster efficiency are 94mN, 4071.79s, 2.465kW and 76.1% respectively in xenon propellant thruster. Thus, xenon propellant of thruster parameter result is reached within the thruster parameter limitation. The most propellant used in ionic thruster is xenon, which is easily ionized and has high atomic mass, thus generating a desirable level of thrust. Although the input power and exhaust velocity is smaller than krypton and argon, xenon propellant is higher thrust and thruster efficiency more than the two propellants. Therefore, xenon propellant is affordable for ionic thruster. For comparing the ion thruster thrust force results of the different types of propellant, the ion current density is the main parameter for thrust formation calculation. In calculation of plasma's electron current density at thermionic cathode and double sheaths the result is so large to compare the suitable result because it is difficult to determine those parameters in plasma.

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References

- [1] M. Lieberman and A. Lichtenberg, "Principles of Plasma Discharges and Materials Processing", New York: John Wiley and Sons, 1994.
- [2] F. F. Chen, "Introduction to Plasma Physics and Controlled Fusion", vol. 1, New York: Plenum Press, 1984.
- [3] D. M. Goebel and I. Katz, "Fundamentals of Electric Propulsion: Ion and Hall Thrusters", 1st ed. Hoboken, New Jersey: John Wiley & Sons, 2008.
- [4] I. G. Mikellides, I. Katz, and M. Mandell, "A 1-D Model of the Hall-Effect Thruster with an Exhaust Region," 37th Joint Propulsion Conference, Salt Lake City, Nevada, July 8–11, 2001.
- [5] G. R. Brewer, "Ion Propulsion Technology and Applications", New York: Gordon and Breach, 1970.
- [6] D. G. Fearn, Angela S. Cox, D. R. Moffitt, "An investigation of the initiation of hollow cathode discharge" Royal Aircraft Establishment Technical Report.
- [7] R. H. Goddard, "The Green Notebooks", vol. 1, The Dr. Robert H. Goddard Collection at the Clark University Archives, Clark University, Worcester, Massachusetts.
- [8] R. G. Jahn and E. Y. Choueiri, "Electric Propulsion. Technology Programmes," ESA Publications Division, 2002.