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THRUST GENERATION BY ION PROPULSION TECHNOLOGY

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Abstract:

Electric propulsion system proven to be a suitable and efficient alternative for conventional propulsion systems .Ion thrusters is one of the electric propulsion systems. It has very high specific impulse generation (Isp) and consumes very low amount of fuel. Ion thrusters can easily compete with chemical rockets propulsion, even if the thrust produce is very low compares to chemical propulsion. Ion propulsion system can be used for various space missions like orbit station keeping for geostationary satellite, orbit and altitude controlling, multi-goal missions. Ion thrusters are more compatible for deep space missions as they are tested for endurance test where as chemical proportion is highly unsuitable for deep space mission.

Keywords: Propulsion, specific impulse, Ion thrusters, Electric propulsion

Introduction

The first iron thruster system intended for north south station keeping on the communication satellite engineering test satellite (ETS) in 1995. Although a launch vehicle failure did not permit station keeping by this system the ion thrusters where successfully operated in space .The commercial use of ion thrusters in the United States started in 1997 with the launch of a Hughes xenon ion propulsion system (XIPS), and the first NASA deep space mission using the NASA solar electric propulsion technology applications readiness (NSTAR) ion thruster was launch in 1998 on deep space I J. R. Beattie et al.[1] since then Boeing launched their second generation 25 CM X IPS iron thruster system in 2000 for Station keeping applications on the high power 702 communication satellite .The Japanese have successfully used ion thruster system to provide the prime propulsion for Hayabusa asteroid sample return used in spacecraft has grown steadily worldwide.

Figure 1: Experimental Setup

Working Principle:

Ion thrusters employ a variety of plasma generation techniques to ionize a large fraction of the propellant. These thrusters then utilize biased grids to electro statically extract ions from the plasma and accelerate them to high velocity at voltages up to and exceeding 10 kV. Ion thrusters feature the highest efficiency (from 60% to >80%) and very high specific impulse (from 2000 to over 10,000 s) compared to other thruster types.

Working Methodology

Ion thrusters ionize propellant by adding or removing electron to produce ions. Most ion thrusters ionize propellant by electron bombardment.

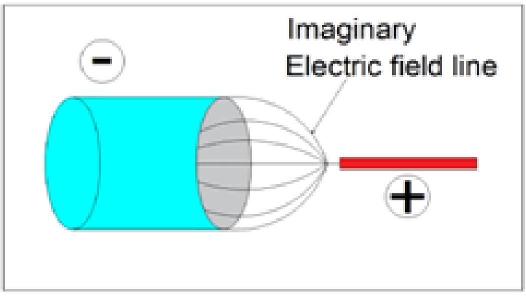

Figure 2: Imaginary electric field line

High energy electron colloids with a propellant atom, releasing electrons from propellant atom and resulting in a positively charged ion Ethan Dale et al.[2].

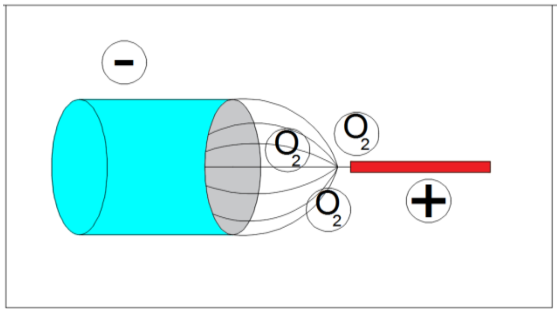

Figure 3: Ionization process

The gas produced consists of positive ions and negative electrons in proportion that results in no overall electric charge. This called plasma.

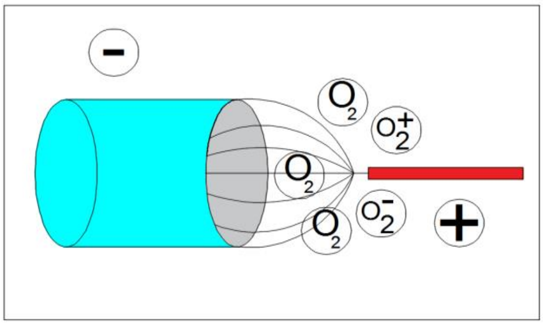

Figure 4: Ion Formation

Plasma has some of the property of gas, but it is affected by electric and magnetic fields Akshat Mohite et al.[3]. The most commonly used propellant is xenon, because it is easily ionize and has high atomic mass which generates desirable thrust when ions are accelerated A.Hemant Kumar Yadav et al.[4].

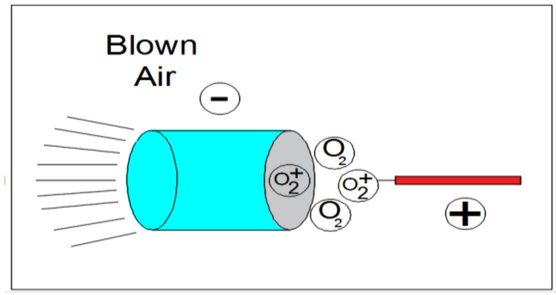

Figure 5: Thrust Generation

As xenon is an inert gas and hence has high storage density. Therefore, it is suitable for storing in a spacecraft. In most thrusters, electrons are generated with discharge hollow cathode called as thermionic emission Dan M. Goebel et al.[5].

Experimental Observations

In order to determine the amount of thrust of ion propulsion system, we provide the electric energy to ionize the neutral gas molecules Masahito Tagawa et al.[6].

Sr.	Input voltage	Step-up voltage	current	power
1.	3.7 volt DC	10000 Volt DC	0.16 Amp	1.6 KW

Calculations

The amount of power created by our transformer is calculated using the relationship between Power, voltage and current:

10,000 Volts * 0.16 Amps

= 1600 Watts/ 1.6 KW

-------(1)

As we need to convert watts into joules to use to calculate the moles of ion we can ionize,

We can use the fact that Watt = Joules/sec:

1.6 KW =1.6 **KJ/s**

As for our initial set up we ionizing air which consist of 80% nitrogen, we use the Ionization energy of nitrogen to calculate the numbers of moles ionized (1503 KJ/mole).

$$\frac{1.6KJ}{s} \times \frac{1\ mole\ N_{2\ ionized}}{1503KJ} = \frac{1.06\ \times 10^{-3}\ moles\ N_2 ionized}{1\ s}$$

------- (2)

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

The first variable needed to our impulse calculation:

$$\frac{1.06\ \times 10^{-3}\ moles\ N_2 ionized}{1\ s} \times \frac{28gN_2\ ionized\ ions}{1\ moles\ N_2\ ionized} \times \frac{10^{-3}\ kg}{1\ g}$$

------- (3)

$$= \frac{\mathbf{2.96\ \times 10^{-5}\ kg\ N_2\ ions\ ionized}}{\mathbf{1\ s}}$$

Now that we have the mass of N_2 ions ionized, we need to determine how fast each ion is moving. To do this we use the conservation of energy formula our ions well be travelling in an electric

Field, the potential energy of our system is potential electric energy. Potential electric energy is

Quantified as follows:

$$U_{electric} = voltage\ \times Q(charge\ of\ an\ electron)$$

------- (4)

As the potential electric energy will be converted into the kinetic energy of an ion, the

Conservation of momentum formula for our system comes out as follows:

$$\frac{1}{2}mv^{\,2} = Vq$$

------- (5)

Where m is the mass of nitrogen atom, v is the velocity of the nitrogen molecule, V is the

Voltage of the system and q is the electric charge constant. Solving for v gets us the following formula:

$$\mathrm{V}n_2\ molecule = \sqrt{\frac{2V_q}{m}}$$

------- (6)

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 a N_2 molecule:

$$\frac{28gN_2}{1\ moles\ N_2} \times \frac{1\ moleN_2}{6.022{*}10^{23}N_2 molecules} \times \frac{10^{-3}kg}{1g} = \frac{4.65{\times}10^{-26}kg}{1N_2 molecule}$$

------- (7)

As the voltage of our system is 10KV and q is a constant 1.6× 10^{-19} coulombs, we can plug in all of our variables to get the following speed f$or\ \ a\ N_2$ molecule:

$$\mathrm{V}n_2\ molecule = \sqrt{\frac{2(10kV)(1.6{\times}10^{-19}C)}{4.65{\times}10^{-26}Kg}} = 262{,}330\,\frac{m}{s}$$

------- (8)

Thus, the impulse of our space craft is as follows:

Impulse $=262{,}330\,\frac{m}{s} \times 2.96 \times 10^{-5} kg = 7.76\,Ns$

------- (9)

Therefore, the impulse of our ion thruster is *7.76 Newton seconds*

Conclusion

The use of electric propulsion system in space goes on increasing. As the ion thrusters are cost effective satellite system which requires very less amount of fuel for the propulsion of ions. Also they work for many more years in limited fuel compare to other chemical systems. So they are very useful and beneficial for the coming future years.

Future scope

Many organisations are started to use satellites of ion thrusters in order to extend the life of the satellites as well as efficiency and to reduce costs such as launching cost and operational costs. So in coming future there is a wide range of ion thrusters in aerospace industry.

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