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RESEARCH ARTICLE

PLASMA THRUSTERS AND ELECTRIC THRUSTERS: A REVIEW

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ABSTRACT

While traveling in space one of the hardest thing to do is stop or change directions without anything to push against or friction to slow things down spacecraft need to do all this hardwork by changing speed or path,. So they do this with the help of Pulsed plasma thrusters. The PPTs (Pulsed Plasma Thrusters) use Teflon, the same stuff that's on the frying pan to make spacecraft move around in the universe. And this method is being used since the 1960s. The chemical propulsion is the best and only option for takeoff from the ground and leavesthe atmosphere but in space not very useful. In space Electro-Magnetic propulsion (EM propulsion) becomes available, they are not strong enough to take rockets off the ground but are great once the earth's atmosphere is passed. PPTs are high-specific impulse thrusters, accelerating charged particles or ions are thrown out with Electric or Magnetic fields. Today we have all kinds of EM thrusters but the pulsed plasma thrusters or PPTs were the first ones ever flown in space. They were used in 1964 by the soviet ZOND 2 mission to Mars. In this paper, we briefly describe the development of plasma-based propulsion systems and are classically grouped according to the thrust generation process: electrothermal, electrostatic, and electromagnetic devices and further the concept of various electric thrusters are introduced.

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INTRODUCTION

Electric thrusters deliver a very small amount of thrust compared to their competitor chemical thruster, but they offer significant advantages for in-space propulsion as energy is not a factor to the propellant, therefore allowing huge energy bulkness.[1] since the chemical thrusters are of no use in space the plasma thruster or pulsed plasma thrusters are ideal for application in small spacecraft for altitude control, precision spacecraft control and low-thrust maneuvers. As the technological framework is not only for near-earth spacecraft or satellite network but its also for the future ambitious mission for a permanent lunar base and the mars colonization, the need for advanced space propulsion systems with the incredible efficiency is becoming increasingly evident. Due to their ability to provide a very high specific impulse andpotentially long service life, researchers are nowmore focused on their fuel consumption type rather than searching for a new thrust platform that utilizes plasma.[2] An ion is simply an atom or a molecule that has gained or lost one or more of its electron and so is remained with a positive or negative electric charge. And this process is called ionization. Gas is said to be ionized when it has some or all the atoms converted into ions.

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And plasma is an electrically neutral gas it means the summation of all the negative and positive charges --from a neutral atom, negatively charged electrons, and positively charged ions-- is zero. Though it has properties of gas it is also affected by electric and magnetic fields and is an excellent electricity conductor.[3] Lightning and light bulbs are the basic examples of plasma. All the electric propulsion mostly used plasma for ionic thrust and the electro-magnetic fields help to push the ions and electrons out to provide the thrust.

HISTORY: Dawn's mission is known for its many firsts. It is the first mission to orbit two interplanetary bodies, first to orbit an asteroid in the asteroid belt, and first, to orbit a dwarf planet, Dawn has achieved many feats in its long journey. And Dawn is NASA's first purely exploratory mission to use ion propulsion engines, it was devoted exclusively to science to be enabled by an ion propulsion system. An incredible accomplishment in the world of technology without which Dawn's multi-world mission would have been impossible.[11] The fact is that Ion propulsion isn't new. Ion propulsion, a type of electric propulsion, was originally conceived of in the early 1900s. In the year 1911 Konstantin Tsiolkovsky wrote apaper, hewas the first person to publically introduce the idea[10].However, Robert H. Goddard's handwrittennotebook dated September 6, 1906. So it is considered the first private document to mention electric propulsion.

(Source: http://www.nasa.gov/centers/glenn/about/fs22grc.html)

Image1 credit: NASA images Pulsed Plasma Thruster in operation

IMAGE 2 Conceptual working of DAWN satellite.(Source:NASA/JPL-Caltech PIA14125<https://www.solarsystem.nasa.gov>)

Despite its relatively early conception findings, it was considered more of science fiction. It took a lot of time for ion propulsion to make its way to be used in spacecraft as a propulsion system. But between these times some curious people were focused on this technology and believed it will be the key factor for the deep space propulsion system. The early experiment was carried out by Goddard at Clark University from the year 1916-1917. It was recommended for near-vacuum conditions at high altitude levels, but the demonstration for thrust was done with ionized air streams at atmospheric pressure. The idea was not accepted by many people as the thrust generation was not that much the amount. Its technology requirement outpaced the chemically propelled rocketry needed to launch such spacecraft.

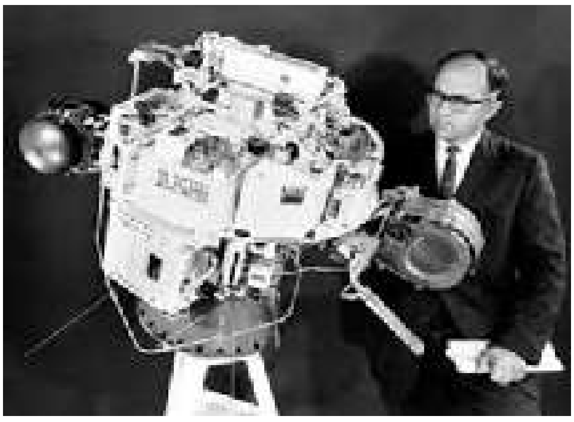

Image 3 SERT-1 Program Manager. Raymond J. Rules examining the spacecraft (Source: Photo ID: 64-SERT-11spacecraft.jpj)

Image 4 SERT-2 (Source: NSSDCA/COSPAR ID: 1970-009A)[25]

It reappeared in 1923 where Hermann Oberth explained his thoughts on the massive mass saving of electric propulsion and its application in spacecraft propulsion and attitude control.[12] Finally, in 1964 NASA's space electric rocket test 1 (SERT 1) tested this technology in space for the first time.[13] The engine was sent into suborbital flight where it operated for 31 minutes before falling back to earth, it was a successful test as it performed as planned. This test was followed by an orbital test, SERT-2, in the year 1970.[14] A type of electric propulsion named Hall Effect thruster, was in development in the U.S. as well as in the Soviet Union, independently during the year 1950s and 1960s. Hall Effect thrusters were majorly used by soviet satellites from 1972 until the late 1990s, they were not used as propulsion system mainly used for satellite stabilization.[16] More than 200 engines completed missions on the Soviet and Russian satellites.

Pulsed Plasma Thruster Operation: The PPT system includes a power source, power processing unit (PPU), energy storage unit, and the thruster itself. The power source can be any source of electrical power. Solar cells are generally used since the thruster operates at low power levels. The PPU converts the spacecraft power to charge the PPT energy storage unit. The energy storage unit provides high-current pulses through the thruster to perform work. Plasma thrusters are a class of electric propulsion in which the working medium has the form of plasma in the acceleration zone. The presence of plasma, both positive ions, and negative lycharged electrons, in the acceleration gap, distinguishes plasma thrusters from ion thrusters where the acceleration gaps contain only positively charged ions. In ion propulsion, the space charge field restricts the emissions of ions from the emitter (ion generator), and thus ion thrusters have a relatively low thrust density. And require a high acceleration voltage.

Image 5: EO 1 Earth orbiter flight pulsed plasma thrusters Credit: NASA (Source: <http://www.nasa.gov/centers/glenn/about/fs22grc.html>)

As a result, they can be efficient only with an acceleration voltage >1 kV and exhaust velocities of ≥30 km/s. Because the acceleration gaps in a plasma thruster contain both positive ions and electrons, no space charge is needed. For this reason, there are no limitations in theory on the thrust density in plasma thrusters, and the exhaust velocity may range from a few km/s to hundreds or more km/s. Of course, different plasma thruster designs are optimal for each range of exhaust velocities and power levels.[5] These plasma thrusters are distinguished based on the mechanism of acceleration of the plasma. These are mainly classified into three categories those are: thermal plasma thrusters; electromagnetic plasma thrusters (Ampere's force) and the third one achieve its acceleration through both kinetic gas pressure and Ampere's force.

Working of PPT: The pulsed plasma thrusters are advancing with time and the components used are becoming smaller and lighter. The heaviest components in the thruster are the capacitors and high voltage converter. So most of the alterations are being done to these components. Plasma thruster's structural designs are simple and basic. Since it work can be described in only 3 stages, first is the ablation of the solid propellant, it is done by providing an amount of energy to the propellant through the propellant feed spring. Then comes the ionization process in which the igniter passes electric current from the cathode to anode tube and due to this the atoms of the propellant get excited and are ionized. These ions are then pushed out due to Lorenz force hence creating thrust for the satellite or spacecraft.[6] Small thrusters are being used in CubeSat, nanosat, or small spacecraft to control the altitude, for low thrust maneuvers and precise control of spacecraft. The Pulsed Plasma thruster has several parameters, its behavior depends on many apparent factors like the material of the propellant, the distance or gap between the two electrodes, the length and width of the electrode, the voltage that is being supplied to the system. Some other not so apparent factors are also taken into consideration such as the temperature of the propellant, material of the electrode, the shape of the propellant or the shape of the electrode.[7]

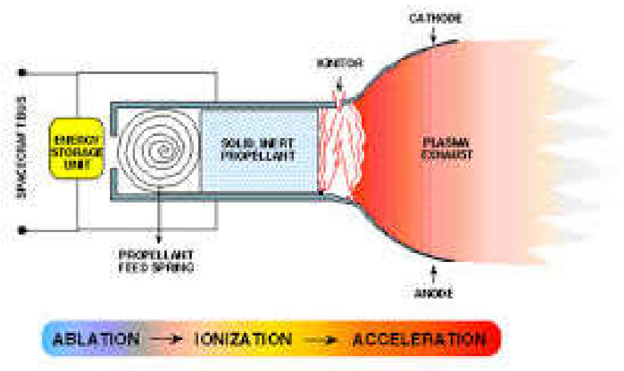

Image 6: Working principle of Pulsed Plasma Thruster. CREDIT: The world of David (Source: http://www.waynesthisandthat.com/ep2.htm)

Electric Thrusters: Electric thrusters come under the electric propulsion system. It is a class of propulsion that uses electric power to accelerate in space making use of propellant by different possible electrical and magnetic means. The EP thrusters are much more efficient than the conventional chemical thruster because of the use of electric power which enhances the performance of the propulsion system. The chemical thrusters require a lot of propellants compared with the electric thrusters to accelerate in space and since the spacecraft is unable to carry much more fuel it decreases the range of exploration.[8] Electric propulsion is specifically preferred for low-thrust and long-duration applications when the chemical thrusters and EP thrusters are compared, the EP is unable to produce much high voltage or electrical power on-board. It can provide a supply consistent amount of supply of energy though. A different propellant is used for different types of EP thrusters, some of them are rare gases (like xenon and argon) or a liquid metal.[9]

Components for Electric Propulsion System

The system is composed of four types:

- The thruster components
- The propellant components
- The power components
- Pointing mechanisms

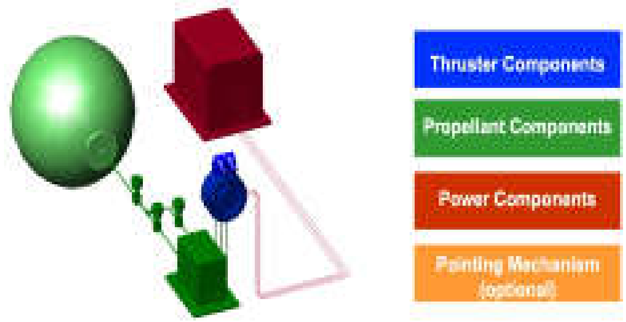

Image 7: Components of Electric Propulsion System Credit: - ESA. (Source: https://www.esa.int/ESA_Multimedia/Images/ 2015/06/EPS_Main_building_blocks#.Xx17bLwXe30.link)

Types of Electric Thrusters

There are different applications for the use of electric propulsion systems. The variety of missions require different types of propulsion system depending on the conditions and purpose of the spacecraft. To perform the variety of maneuvers in space the technology needs to face the different operational challenges.[10]

Based on the different electric propulsion system, the thrusters are:

- Gridded ion engine (GIE)
- Hall Effect Thrusters (HET)
- Pulsed plasma thruster (PPT)
- High-efficiency multistage plasma thruster (HEMPT)
- Magneto plasma Dynamic thruster. (MPD)
- Electrode-less thrusters.
- Field emission electric propulsion thruster (FEEP)

FUTURE ELECTRIC PROPULSION

The use of electrical power enhances the propulsive performance of the electric propulsion thrusters compared with conventional chemical thrusters. The main benefit that EP thrusters have is the amount of propellant required for propulsion, compared to the chemical system the EP requires very little mass to accelerate a spacecraft. And therefore the overall system is many times more mass efficient.[15] Electric propulsion is currently considered as a key and revolutionary technology for the new generations of commercial and scientific satellites.

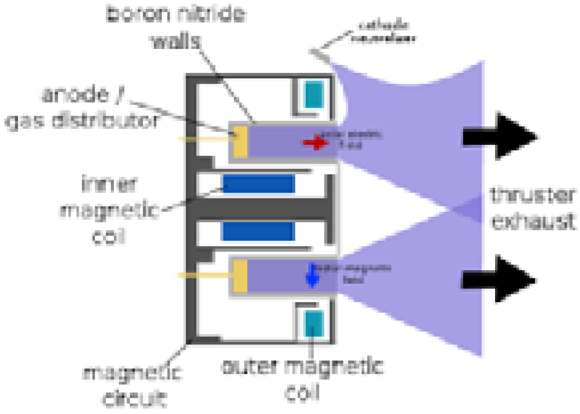

Figure 1 Hall Thruster[18]

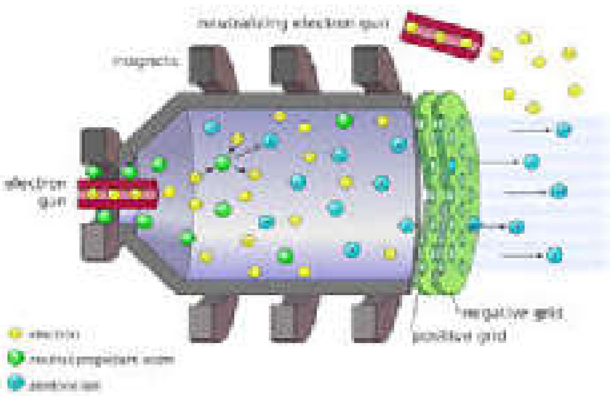

Figure 2 Gridded Ion Engine[19]

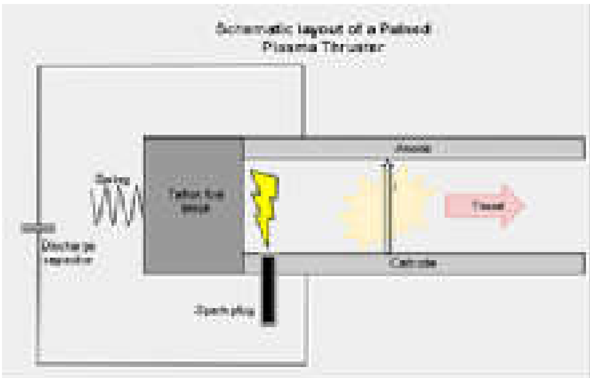

Figure 3 Plasma Pulsed Thruster[20]

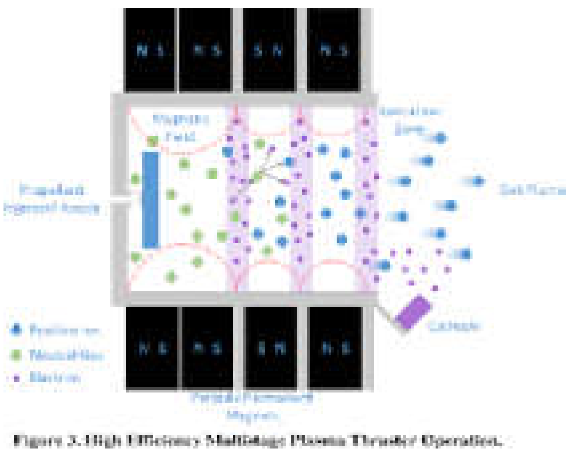

Figure 4 High Efficiency Multistage Plasma Thruster21

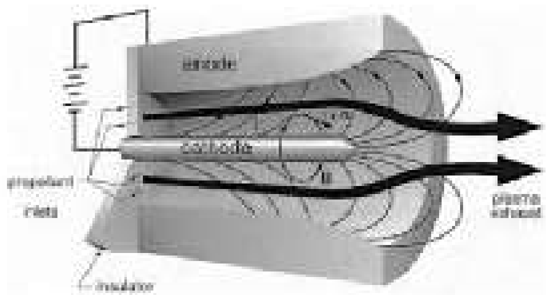

Figure 5. Magneto Plasma Dynamic Thruster22

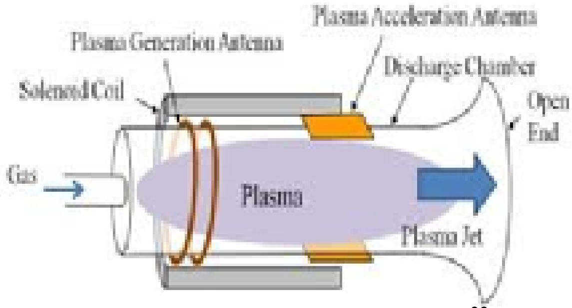

Figure 6 Electrode-less Thruster[23]

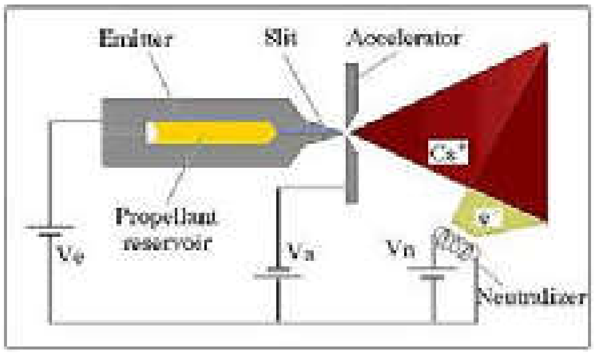

Figure 7. Field Emission Electric Propulsion Thruster[24]

The whole globes propulsion scientists are focusing on the development of a new generation of EPS (Electric Propulsion System).For commercial satellites in the telecommunication market, the EP is the aim for station keeping maneuvers and in many cases a requirement for satellite manufactures. As the use of EP for orbit raising and keeping the satellite in orbit or stabilization saves thousands of kilograms of mass and decreases the price of the satellite. And since the mass is reduced it saves the launching cost by hundreds of million dollars. The world is moving towards full electric and hybrid telecommunication platforms to satellite operators increasing interest in EP. Some of the new projects that are related to electric propulsions are Solar Electric Propulsion and Hybrid electric propulsion.

ISRO on Electric Propulsion System: The Indian Space Research Organisation (ISRO) is developing an electric propulsion system (EPS) with a higher thrust level that can reduce the dependence on chemical propellants. Unlike the chemical propulsion, the electric propulsion system is not limited in energy and can send a spacecraft further out at a low-level thrust with very little mass. ISRO is focusing on the development since it will reduce the cost of launching and a 4-ton satellite with EPS can do the work of a 6-ton satellite with the same efficiency.

Image 8. ISRO on developing EPS for heavy satellites (Source: ISRO/AFV/ISAC)

In addition to cost, the EP also has a few extra years of life expectancy compared to chemical propulsion. Currently, ISRO is dependent on foreign facilities located in Ariane, French Guiana, to launch heavier satellites. It uses Hall Effect thrusters for propulsion.[17] The EPS system was the first (trial) drone South Asia Satellite (SAS) - GSAT-9 launched in the year 2017 and is working satisfactory giving the required information. ISRO aims to increase the thrust level of electronic propulsion that presently hovers at below 300 millinewtons with this low thrust level, any spacecraft will have to wait up to 6 months to slowly reach its destination. Presently, the chemical propulsion used by the ISRO provides 440-Newton thrust, which sends the satellite to the final destination within a few days.[18]

Conclusion

As we are learning more and more about the universe, the curiosity of exploring new and fascinating things is what makes us push our boundaries. For this, the range and life of the satellite are needed to be improved and there steps in the Electric Propulsion System. It is our best option for future deep-space missions, as convectional chemical thrusters are not capable for a very long time and eventually die. The EP thrusters allow us to travel further in the deep dark space. The theories suggest soon the discovery related to anti-matter or ions would help in a giant leap for EP. Now the EP is being used as a primary thrust system and some advancements are being made to increase the power of EP thrusters like in support with Solar Electric Propulsion. This will help to transfer large masses over much larger distances, it can also be helpful for Mars Cargo or Deep Space transport Vehicles. The development of EP will not only help for propulsion but will also solve many other problems.

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