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A Review Paper on Design Aspects of Spacecraft Electric Propulsion Technology

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Abstract

A space shuttle is launched into space with the help of a rocket. A rocket is a machine that develops thrust by means of rapid expulsion of matter i.e. expansion of propellant. The major components of a chemical rocket assembly are a rocket engine, various types of propellants (the majority of which consist of fuel and an oxidizer i.e hypergolic liquid propellants), a frame to hold the components, control systems and a cargo such as a satellite. A rocket differs from other engines in that it carries its fuel and oxidizer internally, therefore it will burn in the vacuum of space as well as within the Earth's atmosphere. The cargo is commonly referred to as the payload. A rocket is called a launch vehicle when it is used to launch a satellite or other payload into space. Also it is a non-reusable launch vehicle. Once a rocket is launched, it will be irrecoverable. At present, rockets are the only means capable of achieving the altitude and velocity necessary to put a payload into orbit. Therefore the most important part of the rocket remains the propulsion system. It is the propulsion system that generates the thrust which enables the rocket to achieve the velocity that can counter the earth's gravitational force and take the rocket into space and thus, it is pivotal to research about new ways to propel the rockets, increase efficiency and reduce operation costs, etc. Ion thrusters have proven to be a suitable and efficient alternative to conventional propulsion systems. With very low demand on fuel due to very high specific impulse generation, ion thrusters can easily rival the chemical propulsion systems, even if the produced thrust is much lower. The system can satisfy various mission demands like orbit station keeping for geostationary satellites, orbit and attitude controlling and multi-goal missions. Whereas chemical propulsion is highly unsuitable for deep space missions, ion thrusters are also making it possible to reach out further into deep space. This paper represents a basic functioning of electric propulsion systems, specifically on the Ion Thruster with its design and functions.
Keywords: Electrostatic Propulsion, Ion Thruster, Hypergolic Liquid Propellants, Hall Effect

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I. INTRODUCTION

The journey of any satellite starts aboard some type of rocket-propelled vehicle, which is the only means available today for transporting it into space and overcoming the strength of Earth's gravitational field. As the ion propulsion system is ineffective in earth's atmosphere. The rocket usually puts the satellite into an initial orbit just a few hundred kilometers above the Earth's surface. Spacecraft propulsion is any method used to accelerate spacecraft's and artificial satellites. Space propulsion or in-space propulsion exclusively deals with propulsion systems used in the vacuum of space. Today there are basically two means of propulsion. The first and most common one is chemical propulsion, uses chemical reactions to produce a flow of fast-moving hot gas, thereby providing a strong push. The second uses the electrical power that can be generated from sunlight with solar photovoltaic panels to propel the spacecraft by more efficient means.

The big trouble with chemical propulsion is that, whilst it is capable of producing an enormous thrust, sufficient for example to lift huge rockets off the ground, it is quite a complex process. For instance, when liquid propellants are used, which is usually the case; it requires very complicated systems, with tanks, pipes, valves and very delicate control mechanisms. Also with lack of atmosphere i.e. in space rocket thrusters is to carry propellant as well as oxidizers for sufficient combustion this increases payload. As the propellant is highly inflammable, it is also quite a dangerous process.

II. ELECTRIC PROPULSION

As to overcome this basic problem another type of propulsion is very effective i.e. Electric propulsion. Electric Propulsion (EP) is a class of space propulsion which makes use of electrical power to accelerate a propellant by different possible electrical and magnetic means. The use of electrical power enhances the propulsive performances of the EP thrusters compared with conventional chemical thrusters. Unlike chemical systems, electric propulsion requires very little mass to accelerate a spacecraft. The propellant is ejected up to twenty times faster than from a conventional chemical thruster and therefore the overall system is many times more mass efficient. There are 3 basic types of electric propulsion systems, categorized according to the method used to accelerate the propellant as electro thermal, electrostatic, and electromagnetic.

Electrostatic thrusters are phenomenological more complex and analytically less tractable than either of electro thermal and electroststic devices. Also, the fundamental thermal limitations on attainable exhaust speeds and lifetimes associated with the heating and expansion processes of electro thermal accelerators can be categorically avoided if the propellant is directly accelerated by an external body force. Hence, in most of the projects or industrial spacecraft's electrostatic propulsion technology is preferred.

A. *Electrostatic Propulsion Technology*

In electrostatic propulsion ions are created and accelerated in electric field. A beam of atomic ions is accelerated by a suitable electric field and subsequently neutralized by an equal flux of free electrons. If the acceleration is caused mainly by the Coulomb force (i.e. application of a static electric field in the direction of the acceleration) the device is considered electrostatic.
Following devices are considered as Electrostatic system,

- Gridded ion thruster
- Hall effect thruster
- Colloid ion thruster
- Field Emission Electric Propulsion

B. *Gridded ION Thrusters*

The ion propulsion system (IPS) consists of five units:

1) The power processing unit (PPU)
2) the power source
3) Propellant management system (PMS)
4) The control computer and
5) The ion thruster.

The power source is usually any source of electrical power such as solar or nuclear power. A solar electric propulsion system (SEP) uses solar cells to generate power. A nuclear electric propulsion system (NEP) is using a nuclear heat source connected to an electric generator. The generated electric power by the power source is then converted by the PPU, supplying the power required for each component of the ion thruster. The generated electric power by the power source is then converted by the PPU, supplying the power required for each component of the ion thruster, such as the positive and negative grids, discharge chamber and the hollow cathodes. The PMS controls the propellant flow from the propellant tank. . An ion thruster moves ions by electrostatic repulsion. The neutral Xenon propellant enters from the propellant tank. Different types of Gridded ion thrusters are shown in fig. 1.

C. *Basic Elements of ION Thrusters*

1) *Ion Sources:*

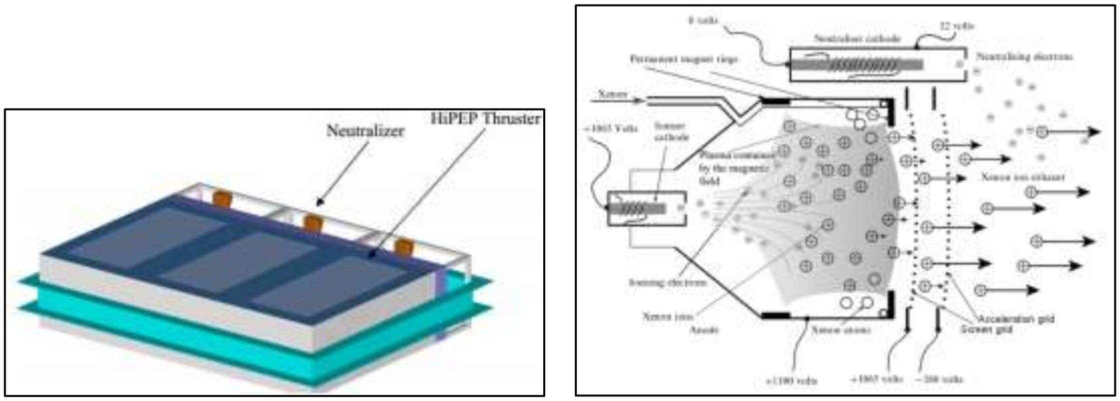
In practice, the most tractable propellants for electrostatic thrusters have proven to be cesium, mercury, argon, krypton, and most commonly xenon, and many possible sources of such ions of the requisite efficiency, reliability, and uniformity have been conceived and developed. The essential elements of the bombardment sources are some form of cylindrical discharge chamber containing a centerline cathode that emits electrons, a surrounding anode shell, and a permeating azimuthal and radial magnetic field that constrains the electrons to gyrate within the chamber long enough to ionize the injected propellant gas and to direct it, once ionized, to extractor and accelerator grids downstream.

2) *Accelerator Grids*

Practically all classes of ion thruster, the positive ions are extracted from the source and accelerated downstream by a system of grids configured to achieve the desired exhaust velocity with minimum beam impingement. A double or triple grid configuration is usually dished downstream to improve its mechanical and thermal stability against distortion. The upstream grid is maintained at a higher positive potential than required by the desired exhaust speed in order to enhance the ion extraction process and increase the space-charge limited current density that can be sustained. The downstream grid then reduces the exhaust plane potential to the desired value. This acceleration-deceleration has the advantages of higher beam density at a given net voltage and of reducing electron back streaming from the neutralized beam downstream.

3) *Neutralizers*

If the ion beam emerging from the downstream electrode is not to stall on its own interior potential profile, it must be electrostatically neutralized within a very few units of grid spacing. This is typically achieved by provision of a flux of electrons, usually from another hollow cathode discharge, which fortuitously mix effectively within the ion beam by means of a variety of microscopic and macroscopic internal scattering processes. Once so neutralized, this plasma constitutes a downstream "virtual electrode" that completes the axial potential pattern.



(A) (B)

Fig. 1: Different types of Gridded ion thrusters (A) HiPEP ion thruster [1] (B) NSTAR ion thruster [14]

III. HALL EFFECT THRUSTERS

New breakthroughs in durability and efficiency Innovators have developed new technologies that increase the operational lifetime of a Hall effect thruster (HET), which is used primarily on Earth-orbiting satellites and can also be used for deep-space vehicles. The operational lifetime of HETs is determined by the amount of time the thruster can operate before the plasma within the channel damages the magnetic system.

A. Operating Principles

If any electromagnetic accelerator is operated at low enough plasma density or high enough magnetic field, the current driven through it will divert from strict alignment with the applied electric field to acquire a component in the E × B direction(as shown in fig. 2)—a form of the well-known "Hall effect" that derives from the ability of the current-carrying electrons to execute significant portions of their cycloidal motions in the crossed fields before transferring their momentum to the heavy particles.

Hall thrusters consist of a coaxial annular cavity where plasma is created by passing current between the annular anode on the upstream end of an otherwise dielectric cavity and the externally located cathode. The propellant enters this plasma cavity via an annular manifold at the anode. A radial magnetic field is applied, either by ring-shaped permanent magnets, or through coils and soft iron yokes. The magnetic field greatly slows down the axial mean velocity of the electrons, which, due to the low collisionality prevailing, are forced to execute mostly Ej × Bj drift around the annulus, while being radially confined by sheaths on the insulating walls. The ions meanwhile, are only weakly affected by the magnetic field, and, if the density is low enough that collisions are rare, are simply accelerated by the electrostatic field to an exit velocity. Because of the quasi-neutrality facilitated by the presence of the electrons, no space-charge limitation arises in this type of thruster (as opposed to gridded ion thrusters). This flexibility is one of the main advantages of the Hall thruster, removing the strong thrust density limitation.

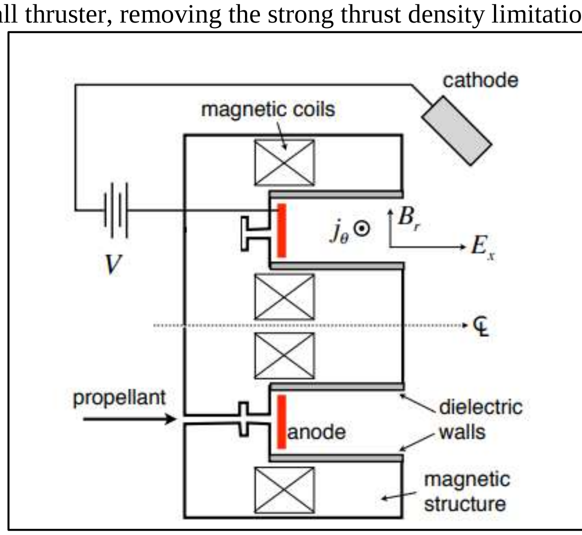


Fig. 2: Hall effect thruster [8]

B. Power Sources

Power source for Electric propulsion is most essential part or block of propulsion system. All of functioning of other parts is based upon source of power as input power is required for operation. Electric propulsion technologies generate thrust via electrical energy that may be derived either from a solar source, such as solar photovoltaic arrays, which convert solar radiation to electrical power, or from a nuclear source, such as a space-based fission drive, which splits atomic nuclei to release large amounts of energy.

1) *Solar electric propulsion:*

Solar electric propulsion (SEP) refers to the combination of solar cells and electric thrusters to propel a spacecraft through outer space.

2) *Nuclear electric propulsion:*

A nuclear electric rocket is a type of spacecraft propulsion system where thermal energy from a nuclear reactor is converted to electrical energy, which is used to drive an ion thruster or other electrical spacecraft propulsion technology.

C. *Power Conditioning:*

In any electric propulsion system, the engine and power conditioning must be developed as an integral unit. Ion engines are small, lightweight devices and the weight and size of the power conditioning often detracts from them. Electro-Optical Systems had three prime objectives: reliability, low weight, and extended operational life. One of the most significant problems with any ion engine power conditioning system is the containment of the high voltages while operating in a vacuum. This problem was successfully solved when a system was built which was capable of extended operation in vacuum.

The power necessary to operate the ion engine can be categorized as follows: (1) electrical power that renders directly into power in the beam, or thrust, and (2) power which is necessary for engine operation but which has no relation to thrust and is thus treated as a loss. Efficient, compact power processing / conditioning is essential at the system level. Electrostatic thrusters require high voltages - designing for vacuum can be challenging due to breakdown.

IV. CONCLUSION

In the domain of interplanetary flight, however, EP offers much more substantial advantages over chemical systems, which extend in several important cases to enabling missions that simply could not be performed by means of any other reasonably projected propulsion technology. Comparison of electric and chemical systems for any important mission, piloted or unpiloted, reveals that the basic dynamic distinction is between essentially impulsive thrust increments provided.

Electric propulsion include a more efficient propulsion system, less pollution, increased operational efficiency, especially at slow speeds (important for applications such as dynamic positioning), and flexibility in locating machinery compartments.

Multiple SEP TDM mission concepts were developed to investigate various options for performing a SEP TDM. These concepts ranged from an approximately 10,000 kg concept capable of delivering 4000 kg of payload. Low-cost and maximum velocity (ΔV) capability variants of a spacecraft concept based on utilizing a secondary payload adapter as the primary bus structure were developed as were concepts designed to be co-manifested with another spacecraft on a single launch vehicle.

Ion thrusters have proven to be a suitable and efficient alternative to conventional propulsion systems. Even if the produced thrust is much lower. The system can be used for various supreme mission demands.

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