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Electric Propulsion of Spacecraft and Rockets

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Abstract—An emphasis has been laid on the electric propulsion is through this research paper. The area tried to discuss is based on the basic principles of operation of electric propulsion and the various types of thrusters that are either operational successfully or in development phase. Electrically driven space propulsion systems are actually based the Newton's laws of dynamics. A rocket propelled spacecraft in free flight is accelerated from discharge of propellant mass. Its successful working is actually based on equation of motion, that is, conservation of the total momentum of the spacecraft and its exhaust stream. Final conclusion is given with a historical summary of the accumulated flight experience using this advanced technology.

Keywords—Electric propulsion, Ion thrusters, Propellant, Spacecraft, Colliod thruster, Electrodynamic Theter , Rocket .

I. INTRODUCTION

This paper gives an idea of the technology being followed in the Electric propulsion (EP) , its basic applications &its future aspect as in the space research purposes. Electric propulsion is actually a study of spacecraft propulsion where a propellant is accelerated by making use of electric power by different electrical or magnetic means. Different types of propellant can be used in electric propulsion system based on the type of thruster used and it can be a inert gas like Xenon or Argon, a liquid metal or any conventional propellant. With the help of this type of propulsion system, thrust ranges of 0.01 to 0.5N, with exhaust velocities of 1000 to 5000 m/sec can easily be obtained. Thrust is the force that the thruster applies to the spacecraft. The concept of EP was first tested in flight during 1960s. However, as an alternative to chemical thrusters for spacecraft propulsion, electric propulsion has recently been introduced in the past few decades. In electrically propelled systems less propellant is being used than chemical rockets as a result of which they have a higher exhaust speed and thus operate at a higher specific impulse rate than the usual chemically propelled systems. In EP, the thrust is much weaker than the conventional chemically propelled systems, due to the limited availability of electric power but are cable to provide smaller thrust for a long time [1]. Thus in these system higher speed can be obtained for long periods and thus can work better than conventional chemically propelled systems. However, for launching any propulsion from the surface of Earth, electric propulsion method is not suitable as thrust obtained from such systems is weak. EP now has become a mature and an advanced technology being used for in spacecrafts.

II. HISTORY

In India this idea of spacecraft propulsion was first proposed in 1911, introduced in a publication by Konstantin Tsiolkovsky. Robert Goddard had reflected the possibility of propulsion in near future in his researches. The nuclear reactor type electric propulsion was given by Dr. Tony Martin for interstellar Project, Deadlaus in the year 1973. But the theory was rejected because of its several drawbacks like very low thrust, the system or setup required to convert nuclear energy into electric energy was very heavy thus giving low speed [2]. The research continued on it to achieve the desired acceleration for propulsion. The first demonstration of electric propulsion was done with an ion engine on SERT-1 (Space Electric Rocket Test) spacecraft, which was launched on 20 July 1964. The Ion Auxiliary Propulsion System (IAPS) designed an 8-centimeter mercury Ion Propulsion System (IPS) for satellite station keeping [4]. It is expected that by 2020, all new satellites will make use of electric propulsion in order to give efficient results. Data shows that till 2013, over 200 spacecrafts operated throughout the Solar system were launched by using the latest technology of EP.

III. COMPONENTS

The Ion propulsion system (IPS) is composed of five major components, namely: the power source, power processing unit (PPU), propellant management system (PMS), the control computer, and the ion thruster. Any source of electrical power can be used as the IPS power source, but solar and nuclear sources are widely used. A solar electric propulsion system (SEP) uses the concept photovoltaic effect for power generation. A nuclear electric propulsion system (NEP) uses the concept of nuclear energy to drive an electric generator [3]. The electrical power generated by the power source is converted into the power required for the working of each component of the ion thruster by PPU. It further gives the potential required by the ion optics and discharge chamber and the high rated currents required for the hollow cathodes in the setup. The propellant flow from the propellant tank to the thruster is further controlled by PMS. The control computer has the job of controlling and monitoring the system

Paras Raina, Sakshi Sharma, and Sumeer Khajuria,"Electric propulsion of spacecraft and rockets," *International Journal of Scientific and Technical Advancements*, Volume 4, Issue 1, pp. 31-34, 2018.

performance from time to time. The ion thruster then processes the propellant and provides thrust to perform the task. Modern ion thrusters can provide propulsion to a spacecraft up to range of 200,000 miles per hour (mph). Also, the space shuttle can provide a top speed of around 18,000 mph. Latest ion thrusters can provide up to 0.5 Newtons (0.1 pounds) of thrust, which is equivalent to the force you would feel by holding nine U.S. quarters in your hand [4]. The only drawback of ion thruster is that they need to be operated for long time for the spacecraft to reach its top speed, thereby to compensate the low thrust effect. To overcome the risk of explosions associated with chemical propulsion, ion thrusters use rare gas for propellant .The most commonly used propellant is Xenon, but other gases such as Krypton and Argon may be used. The basic setup of typical EP system is shown in Fig. 1.

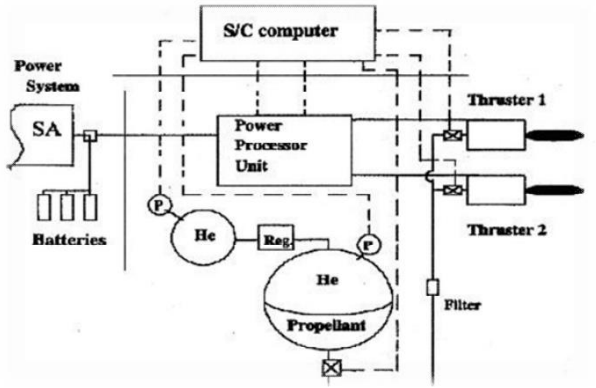

Fig. 1-Schematic of a typical EP system

IV. SUBDIVISION OF EP SYSTEMS

Ion/plasma drives

These drives make use of the electric power to obtain thrust from propellant being installed with the vehicle. They may or may not possess a rocket nozzle. They can be further divided as shown here;

- Electro thermal Propulsion

In this type of propulsion system, to increase the temperature of the bulk propellant, electromagnetic effect is used to generate plasma. The thermal energy generated is delivered to the propellant gas and then its kinetic energy is increased with the help of a nozzle of either solid material or magnetic fields. Gases like hydrogen, helium, ammonia are preferred propellants for these systems as they have low molecular weight [5]. An electro thermal engine uses a nozzle to convert the heat of a gas into the linear motion of its molecules. It is subdivided as:

Resistojets

This propulsion technique provides thrust by heating a nonreactive fluid. Here, electricity is sent through a resistor composed of a hot incandescent filament, thereby heating the expanded gas which is expelled through a conventional nozzle. Resistojets have been used in space researchs since 1965; however, with the launch of first satellites in the INTELSAT-V program in 1980, they have been commercially adopted for space researches. Now a days resistojet propulsions are being followed for orbit insertion and deorbit of LEO satellites.

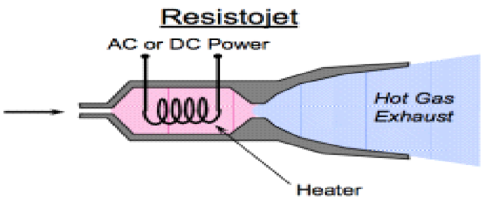

Fig. 2– Resistojet

In Resistojets, the gaseous propellant is passed around an electrical heater which is composed of the tubes heated radioactively from the outside and then uses a conventional nozzle to generate the appropriate thrust [6]. The heating effect generates a high upstream pressure through a given nozzle area. As far as the high-temperature heater is concerned, any gas can be used for propulsion

Arcjets

In this type of electric propulsion system, an electrical discharge (arc) is created along with the flow of a propellant being used like hydrazine or ammonia. Arcjets usually impart more energy to the propellant, as a result of which more work can be extracted out of each kilogram of propellant. But, this method suffers from the drawback of increased power consumption and high cost factor. The thrust effect obtained from these arcjet engines are very low compared with commercial chemical engines [8]. Arcjets are well suitable for keeping stations in orbit and can replace monopropellant rockets as well. The components of Arcjet are given in Fig. 3.

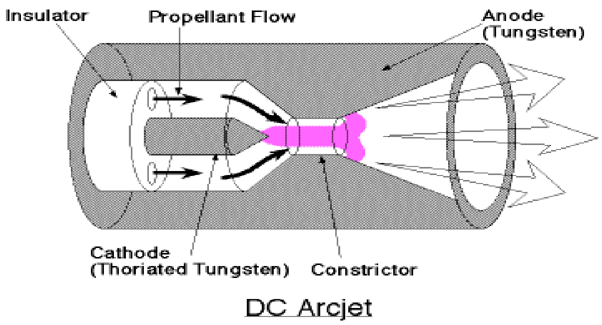

Fig. 3– Arcjet

- Electrostatic Propulsion

This technique follows the electrostatic effect in which a static electric field is being applied in the direction of the acceleration of the propellant, that is, the acceleration is caused by the Coulomb force. It works on the simple principle of electrostatic effect that electrostatic potential difference between two conductors can accelerate ions to produce thrust. The three main stages of an ion-thruster design are ion production, acceleration, and neutralization [9]. The typical diagram of ion thruster is shown in Fig. 4.

Paras Raina, Sakshi Sharma, and Sumeer Khajuria,"Electric propulsion of spacecraft and rockets," *International Journal of Scientific and Technical Advancements*, Volume 4, Issue 1, pp. 31-34, 2018.

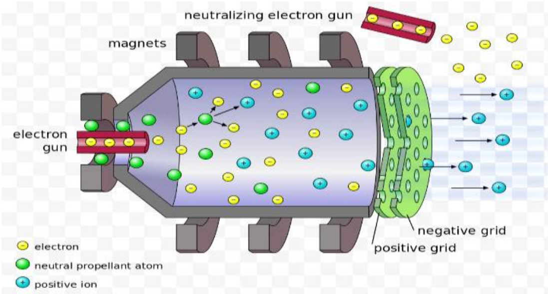

Fig. 4– Ion thruster schematic

Ion thruster

From the various researches, it can be depicted that the commonly used electrostatic thrusters are Cesium, Mercury, Argon, Krypton, but Xenon is by far the most widely used as thruster. It has got certain advantages like good efficiency, reliability, and uniformity. For causing bombardment of the ion sources, only three, the electron bombardment discharge source, the cesium-tungsten surface contact ionization sources, and RF discharge source, are proved efficient [7]. The bombardment source consists of a cylindrical discharge chamber containing a centerline cathode that emits electrons, surrounding which is present an anode shell. The azimuthally and radial magnetic field gyrate the electrons within the chamber so as to ionize the injected propellant gas and then direct it to the extractor and accelerator grids present downstream. This device has an efficient hollow cathode electron source, containing a secondary discharge source that emits electrons from the interior walls of the cathode cavity. The magnetic field required for this entire setup is composed of three ring magnets, having empirical configuration, thereby giving a grossly diverging but doubly cusped field pattern that uses the discharge from ionization in an optimized pattern [8]. In order to obtain maximum efficiency and discharge from ion source setup, the magnitude of its field is constantly adjusted, thereby minimizing the effect of doubly charged ions, which may sometimes erode the grids containing a centerline cathode that is the basic source of electrons. Typical values for xenon and mercury propellants would be in the regimes of 0.25 T and 30 V, respectively.

Accelerator Grids

In order to obtain the desired thrust from ion thruster, the positive ions are extracted from the source and directed downstream to provide desired acceleration with minimum beam impingement. A double grid pattern is provided downstream to improve its mechanical and thermal efficiency against all kind of obstructions and distortions [14]. The upstream part of the chamber is maintained at a higher positive potential, so as to enhance the ion extraction process to obtain the desired exhaust speed. While the downstream portion of the grid is maintained at lower potential comparatively. This configuration provides the ion beam an appropriate perforation, as a result of which an array of beam passes through with minimum impingementation. In this configuration of ion thruster, the downstream surface of the discharge plasma acts as a third electrode and it may provide instability to the grid as it is not independent of the discharge characteristics and applied grid voltages [9]. Sometimes complications arise due to double ions or neutrals that flow along with ion beam and may cause unnecessary bombardment of grid surfaces.

Neutralizers

The ion beam obtained at the downstream grid may sometimes accumulate over the grid walls, thereby causing unnecessary blocking of the grid. So, it required to electro statically neutralize the beam to provide appropriate grid spacing to avoid such circumstances. This can be made possible by providing a flux of electrons. This electron flux is mixed properly with ion beam by means of a variety of microscopic and macroscopic internal scattering processes.

- Electromagnetic Propulsion

In this propulsion technique, the effect of Lorentz force or the electromagnetic effect is considered to accelerate the ion

It can be subdivided into following categories:

a. Hall Effect Thruster
b. Magnetoplasmadynamic (MPD) thruster
c. Pulsed Plasma Thruster

These systems have the advantage of higher exhaust speeds than the electro thermal systems and higher thrust densities than electrostatic thruster, but suffer from disadvantage like higher complexity. The typical electromagnetic thruster is studied where some electrically conducting fluid, usually a highly ionized gas, is subjected to an electric field ***E*** and a magnetic field ***B***, perpendicular to each other and to the fluid velocity ***u***. The current density ***j*** obtained by the electric field interacts with ***B*** to provide an electromagnetic force ***f*** = ***j*** x ***B*** that provides necessary acceleration to the working fluid (ionized gas in this case). The current-carrying electrons produced by electric field are directed downstream by the magnetic field, to provide momentum to the heavy particles in the passage of the beam by collisions and/or by microscopic polarization fields [10]. It may be concluded that the working fluid, that is, the ionized gas, is macroscopically neutral and so overcome the space-charge limitations as in the electrostatic accelerators.

Non-ion Drives

Non ion drives, particularly Electrodynamics tethers are employed for satellite propulsion. These are long conducting wires which can operate on the principle of electromagnetic induction, as used in case of generators where electrical energy is obtained from mechanical (kinetic) energy and in motors, where electrical energy is converted into kinetic energy [11]. When direct current is applied through the tether, a Lorentz force is exerted against the magnetic field, and the tether finally accelerates the spacecraft at high speeds. This system makes use of long, strong conductors (particularly known as tethers) to change the orbits of spacecraft. This method is used successfully due to certain advantages like simplified space travel with low budget sail. It can be used either to accelerate or brake an orbiting spacecraft. In 2012, the company Star Technology and Research was awarded a

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$1.9 million contract to qualify a tether propulsion system for orbital debris removal [12]. Electromagnetic tether has got great number of applications in industry, government, and scientific exploration. A typical electromagnetic tether is shown in Fig 5.

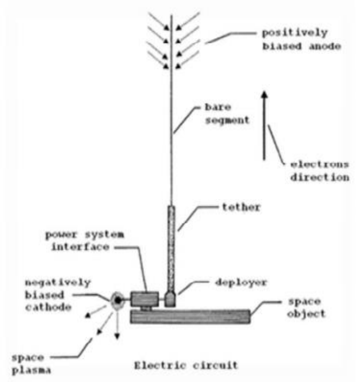

Fig. 5– Electrodynamic Tether

V. FUTURE

Due to low cost involvement and an optimum increase in the operational life of satellites, more and more companies are interestingly using satellites with electric propulsion effect. This produces savings that can be passed along to consumers. NASA particularly employs the ion propulsion as main propulsion on long missions as it is difficult or impossible to perform such tasks using other types of propulsion. Ion thrusters as main propulsion can be used to study the protoplanets, which were among the first bodies formed in our solar system, and thus researchers hope to gain valuable information about the solar system's early development. By The Jupiter Icy Moons Orbiter (JIMO) spacecraft will use an array of high-power ion thrusters as main propulsion. The spacecraft will investigate each moon’s composition, history, and potential for sustaining life [15]. Further researches are done on ion propulsion techniques to use this technology in effective way. Studies are being done to enhance the power level, higher speeds and time span of the thrusters.PPU and PMS technologies are being employed that will allow NASA to use lighter and more compact systems thereby increasing reliability. Also, carbon-based ion optics and ECR discharges may greatly increase ion thruster operational life, enabling longer duration missions or high-power IPS operation, thereby allowing the space researchers to continue researches of solar system for longer duration.

VI. CONCLUSION

Electric propulsion system is the best alternative to traditional chemical propulsion system from efficiency point of view. The high efficiency of electric propulsion system allows spacecraft to achieve target with less propellant. This technique has helped the researchers to sail high in the space for longer duration to obtain the efficient results. Electric propulsion system is the best way to save spacecraft fuel consumption and are well suited for long duration interplanetary missions of NASA. The technique will help the researchers to travel new destinations in the solar system that haven't been explored yet.

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