Electric propulsion system – ION Thruster

Akshat Mohite[1] Akhilesh Desai[2]

[1,2]*Dept. of Mechanical Engineering, A.P. Shah Institute of Technology, Maharashtra, India*

Abstract - *Ion thrusters have proven to be an appropriate and efficient alternative to standard propulsion systems. With very low demand on fuel thanks to very high specific impulse generation, ion thrusters can easily compete with chemical propulsion systems, albeit the produced thrust is far lower. The system is often used for various mission demands like orbiting station keeping for geostationary satellites, orbit and attitude controlling and multi-goal missions. Whereas chemical propulsion is very unsuitable for region missions, ion thrusters also are making it possible to succeed in out further into the region. Electric propulsion enables many missions that satisfy the strategic goals of NASA or any other space agency to explore our Solar System, to detect new planets, stars, galaxies and also not to forget other earth in neighboring planetary systems, and to search for life beyond our reach. Electric propulsion (EP) technology development is designed to support missions by introducing and infusing new technologies into projects. This paper represents a brief review of electric propulsion systems, specifically on the Ion Thruster.*

Key Words: Ion thruster, NEXT Thruster, NSTAR thruster, propulsion, Ions, Xenon

1. Introduction

As we have been continually watching in the science fiction movies the use of ion or electric propulsion for intergalactic space travel, even if not intergalactic scientists have started looking at this technology as an option for an interplanetary technology is a perfect combination of efficient fuel usage and electric power it becomes really cheap and faster than any other technology. In physics, ion propulsion is a type of electric propulsion used by spacecraft. As with any traditional method of rocket propulsion, ion propulsion depends on Newton's Third Law: for every action, there is an equal and opposite reaction. A typical rocket engine uses internal mechanisms to accelerate some type of exhaust away from the rocket. Since this constitutes a force on the exhaust, the engine experiences a force in the opposite direction. Crucially, propulsion requires that *mass be lost*

from the rocket to exhaust. Other vehicles, such as cars, use friction between wheels and road to provide a force and therefore do not need to expel mass. Operating in space or the atmosphere in which friction is minimal (there is nothing to "push off" of), rockets instead carry extra mass to accelerate. As the name suggests, ion propulsion works by accelerating ions.

2. Principal

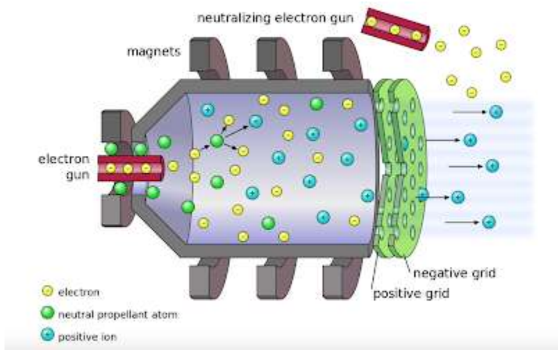

Fig 1. Electrostatic ion thruster (as in NASA's NEXT, and most other ion thrusters)

The above schematic illustrates the function of a gridded electrostatic ion thruster (which is usually what is meant by "ion propulsion"). On the left side, neutral atoms of the propellant move from storage tanks (not shown) into the ionization chamber. Simultaneously, an electrode fires electron into the chamber with high velocity. These electrons knock other electrons out of the neutral propellant atoms to create ions. As a result, the ionization chamber becomes filled with electrons and positive ions.

At the other end of the chamber are two grids. They are connected to a voltage source that maintains a static positive charge on the inner grid and an equal and opposite negative charge on the outer one. Two effects combine to remove many of the free electrons from the ionization chamber. First, the positively charged plate attracts electrons, conducting them out of the chamber. Second, the contents of the chamber are very hot. Since electrons are much lighter than the positive ions, they move faster with the same amount of thermal energy and have a greater chance of collecting on the grid. Soon, positively ionized gas (plasma) builds up in the chamber.

3. Advantages of ion propulsion –

Ion thrusters have many advantages over other forms of propulsion. In comparison with traditional chemical propellant, they are roughly 10 times more efficient, lightening the load of space-traveling craft and saving massive amounts of fuel for launch. This efficiency originates in part from the higher exhaust velocity of the xenon propellant particles, which are ejected from the spacecraft at speeds of 20-50 km/s! In addition, the electric power required to run ion engines is relatively small, on the order of a few kilowatts. In comparison, a typical microwave oven consumes 1.1 kW, and the power consumption is significantly less than that of a typical automobile. Solar panels can meet this power demand during flight, allowing ion thrusters to create smooth and continuous acceleration over the entire duration of a mission.

However, this efficiency comes at a price: ion propulsion produces very small thrusts. The first model of ion engine actually used in spaceflight, the NSTAR engine, produced a thrust of around 90 millinewtons. This is the same force that your hand would experience from a *single piece of paper* on Earth by gravity, a barely detectable force! However, this minute force can operate continuously, adding up to a significant acceleration over time in the frictionless environment of space. In comparison, space probes that operate on chemical propellant may exert thrusts in the hundreds or thousands of newtons (the equivalent of a couple hundred pounds at Earth's surface), but only for very short times.

4. Design and types of ion thrusters

Below given are the two examples of ion thrusters, NEXT and NSTAR. NEXT stands for NASA's Evolutionary Xenon Thruster. This is advancing to a high state of maturity. NSTAR stands for NASA Solar electric propulsion Technology Application Readiness which provides DS1 with the xenon ion propulsion system.

4.1. NSTAR

NSTAR is electrostatic ion thruster which was developed at Glenn Research center and manufactured by Huges and spectrum Astro.inc in the early 1990. It is an electrically powered spacecraft propulsion system uses electrical and possibly also magnetic fields to change the velocity of aircrafts. Velocity plays an important role in propulsion systems, the major advantage of this ion thruster is that it provides only the tiniest amount of thrust, roughly equivalent to the pressure of a single sheet of paper held in the palm of an hand approximately 10,000 times smaller than the thrust of the main engine on typical planetary aircrafts due to the low thrust that has been created the velocity of an aircraft slowly changes from low to high making it ideal for long missions. Compared to other available chemical propulsions, solar electric propulsions provide an economically stable and can open the door of exploration in deep space moving on to its physical nature NASA's NSTAR is 30-cm and can take an input up to 0.5KW to 2.3KW and by providing thrust from 19mN to 92mN. The specific impulse ranges from 1900s at 0.5KW to 3100s at 2.3KW. one of the major elements in the system was xenon.

4.1.1. Working:

The 30-cm diameter flight ion thruster fabricated by Hughes Electron Dynamics (HED) has four main components: the discharge chamber, which serves as the anode and the main structural element, the discharge cathode assembly, the neutralizer cathode assembly, and the external plasma screen which is grounded to the spacecraft. This engine is based on technologies developed by NASA and is designed to operate at critical conditions. Works on basic principle of ion thrusters that is by ionizing a natural gas by extracting some electrons out of atoms and creating a cloud of positive ions, the ions are accelerated by electrostatically by coulombic force along an electric field i.e. in our case xenon particles are accelerated. the question arises why xenon? Xenon being the heaviest inert gas, being inert provides the ability of this particle to not interact with other particles and being heaviest more thrust is created.

4.1.2. DESIGN:

1. As the spacecraft is moving away from the sun, hence the solar array will produce less input power. As according to the relation, low intensity of light low power generated, the above variations must be considered in the design.
2. NSTAR is designed in such a way that it can operate within a power range of 0.5KW-2.3KW.

The above range is actually the output thrust proportion.
Assuming a singly charged Xenon, iron having mass,
M_i =2.1802 x 10^{-25} kg.
q = 1.602177 x 10^{-19}C.
by the relation,

$$\left(\frac{M_i}{2}\right) X \left(V^2\right)$$

$$\sqrt{\frac{2M}{qV}} = \sqrt{\frac{2X2.1802X10^{-25}}{1.602177X10^{-19}X1280}}$$

For the given above power range, thrust force ranges as follows:

$$f_{min} = 0.046 \frac{mN}{W} x\ 500\ W$$
$$= 23.055\ mN$$

$$f_{max} = 0.046 \frac{mN}{W} X\ 2300W$$
$$= 106.55\ mN$$
$$\rightarrow \quad f \in [23.055, 106.055]\, mN.$$

In space for a PPU, input power of approx. 2KW reaches 75.34mN, the efficiency of NSTAR is greater than 99.6%.

4.2.3. IMPLEMENTATION OF NSTAR:

1. The above NSTAR technology was mounted on (DS1) mission, which is DEEP SPACE 1 mission. It is considered to be one of the most successful launch using new technology of xenon propellent. The mission was launch on 24 October 1998; the input power of thrusters was ranging from 0.48KW-1.94KW.

Fig 2. Artist concept of *Deep Space 1 (Credits – NASA)*

2. The DAWN mission was propelled by 3 xenon ion thrusters using one at a time they had an impulse of 3100s and produced a thrust of 90mN. It also included a change in velocity in space of 25,700mph (11.49km/sec). which created a significant record in space.

4.2. NEXT ion thruster.

The NASA Evolutionary XENON THRUSTER (NEXT) is an ion thruster about three times as powerful as the NSTAR. NEXT can afford many extra equipment like large delivery payloads, smaller vehicles and other mission enhancements. The NEXT engine is a type of solar electric propulsion in which thrusters the electricity generated by the spacecrafts solar panel to accelerate the xenon propellent to the speed of 90,000mph (145,000 km/s). it can also produce 6.9KW thrust to power and 236mN thrust .it the total impulse demonstrated by NEXT is 17 mN-s which is considered to be highest total impulse produced by any ion thruster. The PPU of NEXT-C ION thruster controls the power output to the thrusters. It consists of two powerful PPU's. the input produced by these two-power processing unit is 80 to 160V high and 28 V low.

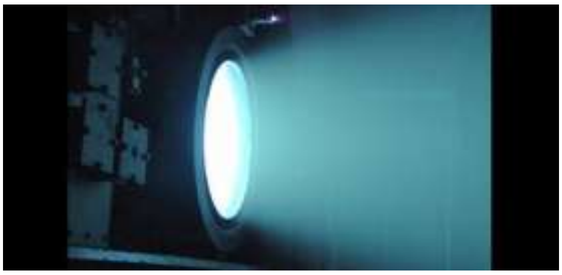

Fig 3. NEXT ion engine during testing (New Scientist Space, 2007)

4.2.1. CHARACTERISTICS:

The input power produced is 0.54KW-6.9KW. along with 236 max thrust ,4190s maximum specific impulse

According to the relation,

$$\frac{f}{W} = 0.046 \frac{mN}{W}$$
$$f_{\max} = 0.046 \frac{mN}{W} X 6900W$$
$$f_{\max} = 318.17mN$$

The previous models of NEXT Ion thruster had a reduced efficiency of 70%.

$$f_{\max} = 0.046 \frac{mN}{W} X 6900W X 0.7$$
$$f_{\max} = 222.72mN$$

The reduced value of maximum force gives a positive result in the process of improving NEXT Ion.

5. Ion propulsion in space –

As mentioned earlier, the electrical propulsion has been a lively area of development since the dawn of spaceflight. But it's only in recent years that electric propulsion has been utilized in commercial, scientific and military missions. Thrusters for electric propulsion systems use ionisable gases for propellant. For interplanetary missions, it's used because the main propulsion to realize a high Δv, e.g. region 1, SMART-1, Hyabusa, Bepi Colombo. Most of the electrical propulsion systems have low thrust levels compared to chemical thrusters, within the order of some mN up to 1N, but the general performance level is bigger than that of chemical propulsion systems by an element of 10 – 20. Chemical propulsion relies on the stored internal energy and is restricted with reference to its specific energy within the molecular bonds of its propellant, whereas energy in electric propulsion is obtained from an external power source like solar panels. The propellant to electric propulsion systems are often accelerated to very high velocities, hence achieve a really high specific impulse. the interior energy in chemical propulsion limits the utmost specific impulse to about 450s, in contrast to electric propulsion specific impulses of over 17,000 shave been obtained within the laboratory. this is often certainly an excellent advantage 100 of electrical over chemical propulsion.

6. units of ion thrusters

6.1. Power Processing Unit

They are circuit devices which converts an electrical input from a utility line into the appropriate voltage and current to be used for the device in question. They serve the same purpose as linear amplifiers, but they are much more efficient, since the use of linear amplifiers results in much power loss due to the use of a resistor to change the voltage and current. Another use of PPU's is that the generated electric power by the power source is converted by PPU by supplying the required power to each component of ion thrusters.

6.2. Power Source

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 also an nuclear electric propulsion system(NEP) is using a nuclear heat source connected to an electric generator .this energy generation is due to power source.

6.3. Propellant Management System (PMS)

The PMS controls the propellent flow from the propellent tank. It's design is sophisticated. PMD are seen inside spacecraft propellent tanks that use surface tension to ensure gas free liquid delivery. they are made using metals like titanium to allow their use in most corrosive propellants. They also do not have any moving parts and hence they are highly reliable.

6.4. Ion Thrusters

An ion thruster moves ions by electrostatic repulsion. The neutral Xenon propellant enters from the propellant tank. A hollow cathode emits electrons which impact the Xenon atoms, pounding loose an electron and creating positive Xenon ions. The positive ions are then pushed by gas pressure through holes in a positive grid. Then the electric field between the positive and negative grid accelerates the ions such that the ion beam is exhausted out through the nozzle .A hollow cathode plasma bridge neutralizer is placed at the exit of the nozzle which shoots out electrons to neutralize the ion beam. Otherwise the ions would be attracted back to the negative grid, cancelling out the thrust.

7. Conclusion

Ion thrusters have proven to be a viable and powerful alternative to conventional debugging systems. with very low fuel demand due to the very high specific current generation ion thrusters can easily compete with chemical systems even if the output power is very low. The system can be used for various mechanical requirements such as orbit station orbit for geostationary satellite orbit and position control and multi-purpose missions. While chemical resistance is not very suitable for deep space deployment ion thrusters also make it accessible at high speeds.

8. Biographies

Akshat Mohite –

Student at A.P. Shah Institute of Technology

Akhilesh Desai –

.P. Shah Institute
gy

9. References

[1] Rahaman, S. E., Barik, R. K., Singh, A. K., Shukla, S. K., Min, S. H., & Park, G. S. (2017). Design of high efficiency and high thrust grid system for ion thruster. Journal of Electromagnetic Waves and Applications, 31(17), 1816–1825.

[2] Machida, K., Toda, Y., Murakami, H., & Kudo, I. (1982). DESIGN OF ION THRUSTER SYSTEM FOR SATELLITE POSITION CONTROL. IFAC Proceedings Volumes, 14(2), 2283–2289.

[3] G.R. Scmidt, M.J. Patterson, S.W. Benson — The NASA Evolutionary Xenon Thruster (NEXT): The next step for U.S. deep space propulsion, IAC-08-C4.4.2, NASA Glenn Research Centre.

[4] Brophy, J. R., Kakuda, R. Y., Polk, J. E., Anderson, J. R., Marcucci, M. G., Brinza, D., Henry, M. D., Fujii, K. K., Mantha, K. R., & Stocky, J. F. (2000). Ion propulsion system (NSTAR) DS1 technology validation report. JPL Publication 00-10, October, August 2014, 52.

[5] E.Y. Choueiri — New Dawn for Electric Rockets, Scientific American, Feb 2009, 58 – 65

[6] F.M. Curran, J.S. Sovey, R.M. Myers — Electric propulsion: An evolutionary technology, IAF-91-241, 42nd Congress of the International Astronautical Federation, Montreal, CA, Oct. 5-11, 1991.

[7] P. Fortescue, G. Swinerd, J. Stark — Spacecraft System Engineering, Fourth Edition, A John Wiley & Sons, Ltd., 2011. R.G. Jahn — Physics of electric propulsion 1st ed., New York, McGraw-Hill, 1968

[8] W. Ley, K. Wittmann, W. Hallmann — Handbook of Space Technology, First Edition, A John Wiley & Sons, Ltd., 2008. National Aeronautics and Space Administration — Anatomy of an Ion Engine

[9] National Aeronautics and Space Administration — NASA's Evolutionary Xenon Thruster - The NEXT Ion Propulsion System for Solar System Exploration, Briefing prepared for New Frontiers AO, 200