

Electric Propulsion System using a Helicon Plasma Thruster

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Abstract: In recent years, a satellite using an electric propulsion system instead of a chemical propulsion system attracts attention in the satellite market, because the specific impulse of an electric propulsion thruster is higher than a conventional chemical propulsion thruster. So, the satellite using the electric propulsion system can transfer to geostationary earth orbit (GEO) using less propellant, and it can save the cost on of launch, and can mount a lot of additional payload for communication.

The EP system is going to have implementations for all orbit transfer vehicle as well as satellite.

In this study, we summarized configured propulsion system using EP system including the point of advantages, disadvantages, and applications. And we studied a concept of the new electric propulsion thruster which uses the Helicon Plasma.

Nomenclature

EP	: electrical propulsion
CP	: chemical propulsion
GTO	: geostationary transfer orbit
GEO	: geostationary earth orbit
ΔV	: increased velocity
Mg	: gross mass of spacecraft
Ms	: mass of system
M _L	: mass of payload
T	: time of transfer
F	: thrust power
I _{sp}	: specific impulse
η_t	: thrust efficiency
V _{ac}	: electric discharge voltage

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I. Introduction

In recent years, several satellites, about 20 to 25 satellites per year, are launched into orbit for satellite communication Services that is one of the space uses. The commercial satellites have many transponders as payload, and these transponders are used for communications between two points on the ground. In recently, the satellite communication services trend in the direction of high data traffic and increasing channels with broadbandization. COMSTAC GSO Forecast was a reported forecast of the commercial satellite launch market. The report is shown below Figure1.¹

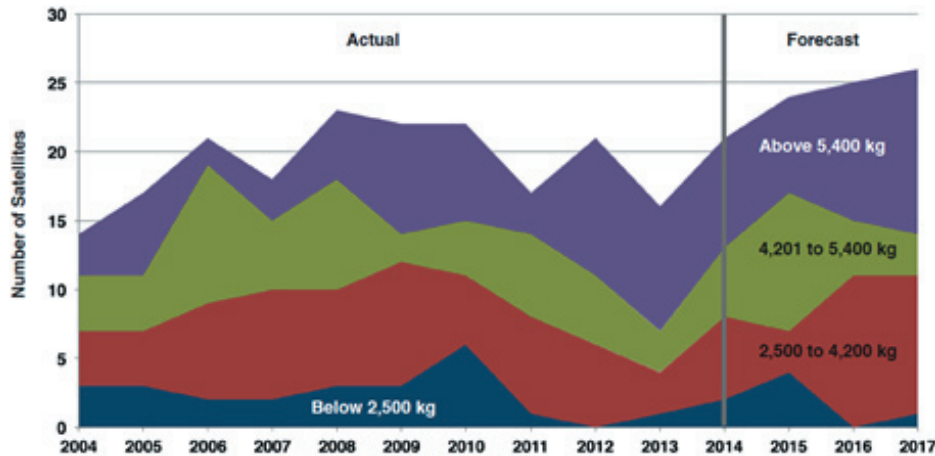


Figure 1. Trend in Satellite Mass Class Distribution

The commercial satellite market is becoming powerful and large scale, which requires on-board capability of payload like a transponder. In the figure shown above, the satellite using an electric propulsion system, hereafter will be referred to as 'EP system', instead of a chemical propulsion system, hereafter will be referred to as 'CP system', attracts attention in the aerospace market, because the specific impulse of the electric propulsion thruster is higher than the conventional chemical propulsion thruster. So, the satellite using the EP system can transfer to geostationary earth orbit using less propellant, save on the cost of launch, and mount a lot of payload for communication such as a transponder. On the other hand, the thrust power of the electric propulsion thruster is low compared with the chemical one. So, the satellite using the EP system cannot transfer to geostationary earth orbit quickly. It means that the satellite is going to lose some period of life time, and failure probability of satellite by radiation is going to increase when passing through a Van Allen Area for a long period. Furthermore, the satellite using the EP system needs to mount an additional solar wing and radiator depending on thrust efficiency in order to operate the system.

As mentioned above, we think that the EP system is going to have implementations for all orbit transfer vehicle like a space tug as well as satellite, the EP system is going to be desired the advantages below.

- Suitable thrust power
- Suitable specific impulse
- High thrust efficiency
- Variable thrust power and specific impulse

In this study, we summarized the configured propulsion system using the EP system including advantages and disadvantages and how to use the EP system on the spacecraft in the most effective way. Last, we studied a concept of a new electric propulsion thruster which uses Helicon Plasma.

II. Comparing between the EP System and the CP System

A. Prior Condition of system

Prior conditions of system study are shown below.

- Mission (GTO to GEO)
 ΔV : 3.6km/s (electric propulsion thruster)
 : 1.8km/s (chemical propulsion thruster)
 M_g : 2tons class
- Characteristic of electric propulsion thruster
 F : 300mN
 I_{SP} : 2000sec
 η_t : 40%
- Characteristic of chemical propulsion thruster
 F : 20N
 I_{SP} : 300sec

B. Advantages and Disadvantages

The specific impulse of an electric propulsion thruster is higher than a chemical one. Therefore, the spacecraft using EP system can save the propellant for transferring orbit. We studied the mass of propellant (M_p) of spacecraft to transfer orbit. In case of 2tons class spacecraft using EP system, the M_p for transferring orbit is up to 350kg. On the other hand, in the case of same spacecraft using CP system, the M_p for transferring orbit is up to 940kg. Therefore, the M_p will save 590kg by transfer orbit with EP system compared with CP system. This spacecraft can mount the payload instead of the saving propellant or can be launched at a low cost.

Next, we studied the transition time for getting ΔV . The thrust of the electric propulsion thruster is lower than the chemical propulsion thruster's one. Therefore, the spacecraft using EP system needs 260 days to reach geostationary earth orbit, whereas the spacecraft using CP system needs about 1 day to reach same orbit.

Table 1 M_p and T depend on the propulsion system

Propulsion System	ΔV	M_p	T
EP system	3.6 km/s	350 kg	260 days
CP system	1.8 km/s	940 kg	1 day

It's a disadvantage point that additional solar array wings and radiators are needed to use EP system. The amount of these components depends on the thrust power and thrust efficiency of EP system. For example, the 2 ton spacecraft using the EP system that is 40% thrust efficiency has the advantage of being able to save mass about 590kg compared by the using CP system. But, this spacecraft needs to mount additional components such as solar array wings, this advantage is going to reduce about 180kg. Therefore, we have to develop more efficiency EP system and lighter components for getting advantages of payload mass.

III. System Configurations

The system configuration of the spacecraft using the EP system is shown in figure 2. This system consists of an electric system, thermal system, propulsion system, and structure system. The additional solar array paddle and battery are contained in the electric system, and the additional radiator is contained in the thermal system.

The solar array paddle or the charged battery supplies an electrical power to a thruster via a power control unit and an electric power supply. An on-board computer sends commands to take control of the power control unit, valve

controller, electric power supply, and the deployment mechanisms. The thruster is supplied electrical power by the electric power supply and propellant via multiple valves and produces thrust. The radiator exhaust the thermal energy generated by the electrical power supply and the thruster exhaust to the out of the spacecraft. In this study, a total mass of these components is system mass (M_s), and payload mass (M_L) is M_g minus M_s . The comparative results of M_s and M_L in several cases are shown below.

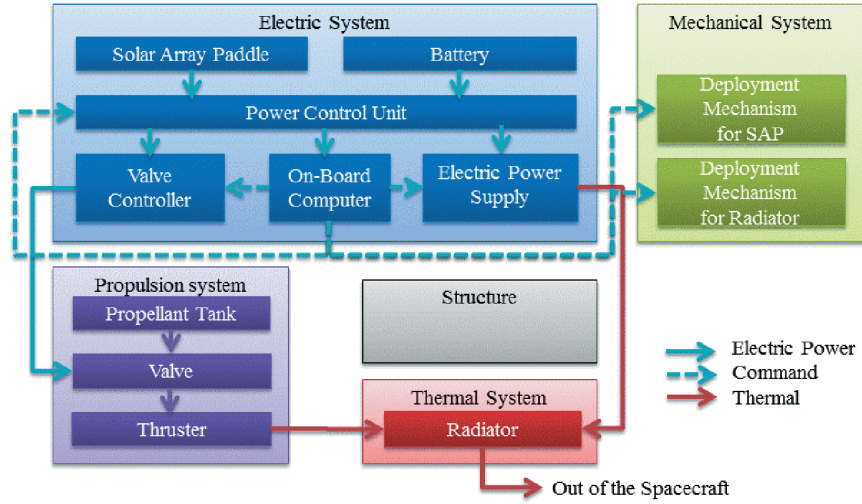


Figure 2. System Configuration of the Spacecraft

A. M_s and M_L depend on the thrust power

In this section, we study the M_s and the M_L depending on the thrust power : 300mN, 600mN, and 900mN. The comparative result is shown in figure 3(a).

In the case of a spacecraft using the EP system with thrust power of 300mN, the EP system needs to mount an electric system weighing 220kg, and a thermal system weighing 100kg. Then mount payload ratio of the gross mass of the spacecraft becomes 50% (1000kg). However, the mass of the electric system and the thermal system get heavy when the spacecraft is using a powerful EP system. In the case of a spacecraft using the EP system with the thrust power of 900mN, the EP system needs to mount the electric system weighing 540kg and the thermal system weighing 280kg. Then mount payload ratio of the gross mass of the spacecraft becomes 24% (490kg) and the mass of payload is less when using the CP system. It means that there is a potential to reduce the M_L when using a powerful EP thruster than the M_L using CP system and not get advantage point even with the use of the EP system.

B. M_s and M_L depend on the specific impulse

In this section, we study the M_s and the M_L depending on the specific impulse from 1000 sec to 5000 sec. The comparative result is shown in figure 3(b).

In the figure 3(b), a mass of propellant decrease with the increasing of the specific impulse. The mass of EP system is most light-weight when using EP thruster with the specific impulse of 2000 sec. However, the mass of EP system becomes increasing when using EP thruster with the specific impulse over 3000s, then the payload mount ratio reaches 40% (800 kg) when using EP thruster with the specific impulse of 5000 sec. It's means that the mass of propellant decrease with increasing the specific impulse, on the other hand, an electrical power needed for the EP thruster with increasing the specific impulse, as a result, the mass of electric system increase and not mount a lot of payload.

As mentioned above, the thrust power and the specific impulse of the EP thruster are recommended to adjust based on the thrust efficiency, specification of solar array paddle and radiator, and mission definition like the payload mass and increased velocity.

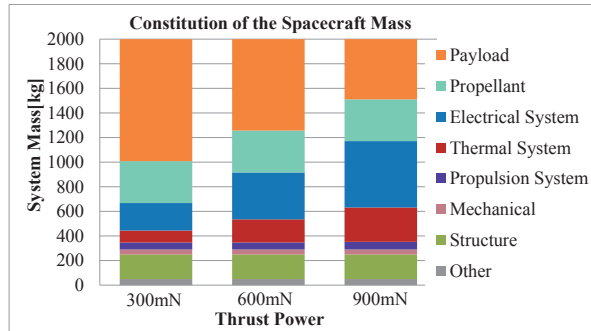


Figure 3(a) Constitution of the Spacecraft Mass depend on the thrust power

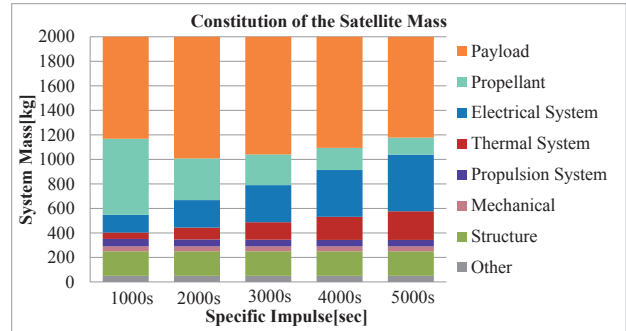


Figure 3(b) Constitution of the Spacecraft Mass depend on the specific impulse

IV. Applications

In this section, we study the application of the EP system in the future.

A. All-Electric Propulsion Satellite Bus

The EP system for station keeping has been used on a commercial satellite than before. However, EP system for orbit rising has been rarely used on the one.

In March, 2015, the commercial satellite using EP system “702SP” manufactured by Boeing Satellite Systems, Inc was launched, and this satellite became the first to transfer orbit using EP system. It is advantage point that the All-Electric satellite bus can save the propellant, and launch at a low cost. In the case of a communication satellite, it can mount more antennas and transponders, and get increased sale of communication too. On the other hand, it is concerned about delaying the delivery and deteriorating the solar array paddle caused by passing through the Van Allen Area.

B. Space-Tug

There is the concept of the spacecraft for transferring some mission components like the transponder and the observation equipment. These spacecraft is called the Space-Tug. In the case of using the Space-Tug for transferring to the target orbit, the payload launched to LEO or GTO by the rocket is got trapped by the Space-Tug at first phase. At the next phase, the space tug is supplied a propellant of round trip from the payload, then the space tug transfers payload to the target orbit using the EP system. At last phase, the Space-Tug separates the payload when the Space Tug arrives at the target orbit. And the Space-Tug returns to the waiting orbit.

It's advantage point using the Space-Tug that the payload does not need to mount the additional solar array paddle, battery, and radiator for the orbit rising, and can mount a lot of payload instead of system equipment. The thruster of the Space-Tug is recommended to have function of variable specific impulse due to the spacecraft adjusting mission as a mass of payload and time of transferring.

V. Helicon ElectroStatic Thruster (HEST)

We have been developing a new concept thruster that has functions about variable thrust power and variable specific impulse since 2012. The new one is called Helicon Electro Static Thruster (HEST). We have been getting the test data and researching the performance of HEST at Nagoya University.

A. Overview and Test Result of the HEST

HEST consists of the Helicon Plasma Source and the Plasma Accelerator. The Helicon Plasma Source consists of the ceramic tube, Helical Antenna, water-cooled solenoid coil, and so on. The ceramic tube is placed on the center axis of a water-cooled magnetic coil. The water-cooled magnetic coil produces the magnetic field about 100mT. The radio frequency (RF) power supply supplies RF power with 13.56MHz to the Helical Antenna. The helicon plasma is produced by the supplied the RF power and the magnetic field.

The Plasma Accelerator consists of the ring anode, magnetic field produced by the water-cooled magnetic coil and the permanent magnet, Hollow cathode, and so on. The schematic of the HEST is shown below Figure 4.²

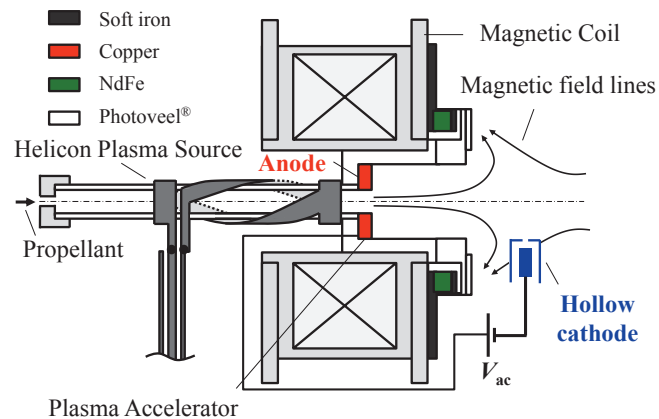


Figure 4 The schematic of the HEST

When the Helicon Plasma produces by the Helicon Plasma Source and the electric discharge voltage (V_{ac}) is applied between the ring anode and the hollow cathode, the ion are accelerated by the electrostatic field, and neutralized by the hollow cathode.

The thrust efficiency of HEST is up to 10%, but it is needed to bring up to over 40% for using the spacecraft. The low thrust efficiency is caused by a lot of power loss. The one factor is that the discharge current between the ring anode and the hollow cathode is too large. Another factor is that the helicon plasma production cost is too low.

We are going to have to measure at multiple parameters, for example, changing shape of anode and size of helicon plasma source, and redesign the magnetic field.

VI. Conclusion

As a result of the system case study, the mass of the solar array paddle and the radiator is dominant in the total mass of the spacecraft using the EP system. And if the performance of the solar array paddle and the radiator become high, the total mass of the system is going to decrease. And the mass of these components depends on the thruster performance. Therefore the spacecraft using the EP system have to select suitable thrust power and specific impulse.

We have been studying about new concept thruster (HEST) with Nagoya University. The HEST can generate thrust power, but it should take measures against about thrust power and thrust efficiency in the future.

Acknowledgments

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References

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