Hall Electric Propulsion System on Technological Test Satellite Program

IEPC-2009-054

Presented at the 31st International Electric Propulsion Conference, Michgan University
Spetember 20 – 24, 2009

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Abstract

More and more Hall thrusters are now being applied on many different spacecrafts due to its attractive advantage, such as an excellent combination of high specific impulse (as compared to chemical thrusters) and high thrust-to-power ratio (as compared to ion thrusters). On the basis of developing experimental prototype and engineering model of hall thrusters, Shanghai Institute of Space Propulsion (SISP) has successfully developed Hall electric propulsion system with power of 700W, involved two hall thrusters, one Power Processing Unit (PPU) and a set of Xe-propellant storage and supply unit. The system will serve as Hall Electric Propulsion Demonstration System, applied on a technical test satellite to carry out space flight test. The task of space flight test will cover: thruster ignition test, calibration of orbital characteristics, accumulation of data-base for orbital application and assessment of orbital life-time.

1. Introduction

Great advantages and application potential of Hall Electric Propulsion technology on board of Geo-stationary satellites have been entirely proved by accumulated success of flight experience abroad in the passing decades. Under the support of National Hi-Tech Space Program, SISP take the lead in developing Hall Electric Propulsion technology in China. After going through theoretical analysis, prototype development, lifetime reliability assessment, and Hall Electric

Propulsion System integration, now SISP engages in developing Hall Electric Propulsion Demonstration System and will apply on technical test satellite to carry out space flight test for comprehensive demonstration and validation of the competitiveness and effectiveness of application of Hall Electric Propulsion System.

This paper will briefly review the development course of Hall electric Propulsion in SISP, demonstrate the main characteristics and duration-test results of Hall thruster, also aim at flight on Tech-test satellite to analyze and design the Hall Electric Propulsion System.

2. The Development Course of Hall Electric Propulsion in SISP

Since 1998 SISP has begun to develop Hall Electric Propulsion and is regarded as an organization, which firstly investigated Hall Electric Propulsion under financial support of National Hi-Tech Space Program in China. The main works are following:

- Before 2000 SISP concentrated on preparing work conditions - as a base for consequent development and experiment of thruster prototype, such like installation of vacuum chambers for electric thruster characteristic experiment and hollow cathode characteristic test respectively, mini-thrust measurement equipment, plasma diagnostic instrument and etc.
- In 2001 SISP successfully developed Hall thruster prototype and systematically tested the main characteristics of prototype, carried out studies like optimization of thruster characteristics, development of engineering model and requirement definition of power processing unit (PPU), accumulated necessary knowledge and experience for future engineering model and PPU development.
- From 2002 to 2003, SISP developed the engineering model of 40mN Hall thruster, fulfilled the development of PPU and accomplished the integrated test of thruster and PPU.
- In 2004, SISP accomplished long durability assessment test for Hall thruster, thruster accumulated working for 550 hours under vacuum conditions.
- From 2005 to 2007，SISP accomplished development of relative modules for Xe propellant storage and supply unit, developed Hall electric propulsion demonstration system prototype, and realized integrated experiment for whole Hall electric propulsion

system.

- In 2008，SISP began to carry out technical assessment and systematical design of Hall electric propulsion system on technical test satellite.

3．Hall Thruster and its Characteristics

The engineering model of Hall thruster and its in operation are shown in Fig.1. The performance of thruster are shown in table 1.

The thruster is a closed electron-drift type Hall thruster with 70mm diameter. The thruster contains two main parts: the thruster module and hollow cathode. The thruster module consists of an anode-gas-distributor, a ceramic discharge chamber and a magnet system. The cathode is hollow type scheme with BaW emitter and set in heater for regulation of electron current emission level.

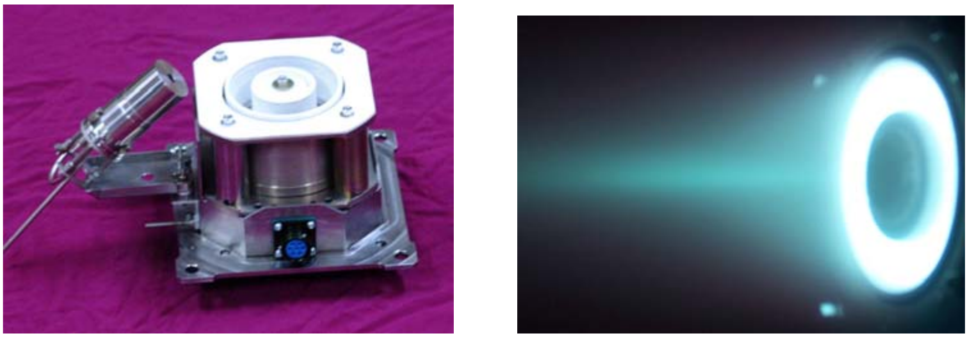

Fig.1 EM Hall thruster and its in operation

Table 1 The performance of Hall thruster

mode / parameter	Nomina mode	Adjustment Range	remark
Thrust	40 mN	30~58 mN	
Specific Impulse	1500 s	1300~2000 s	
Discharge Power	660 W	380~1100 W	
Lifetime	3000~4000 h	1000~2000 h	estimated

Volt-ampere characteristics of the thruster were obtained in a vacuum chamber with a background pressure of 1×10^{-2} Pa. The xenon flow rate to the hollow cathode was 2.0 sccm. The magnetic field strength was adjusted for minimum discharge current at each operating condition and corresponded to a maximum magnetic field at the mean channel diameter. The volt-ampere characteristics for thruster xenon flow rate of 15, 18, and 20 sccm are shown in Fig. 2.

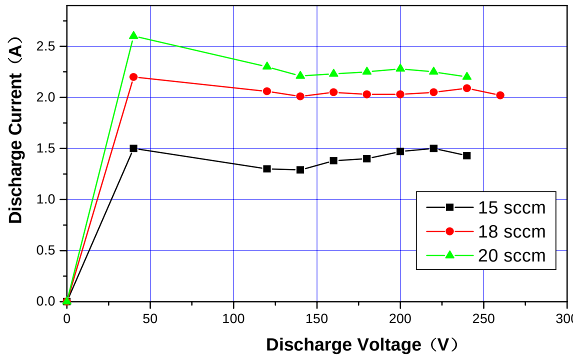

Fig.2 Volt-ampere characteristics of the thruster

The lifetime of Hall thruster is mainly dependent on erosion level of discharge chamber wall sputtered by ion bombardment. Generally speaking, when erosion depth is equal to or more than discharge chamber wall thickness, thruster life end. Two ways are usually adopted to assess Hall thruster life: one is long-term life-test of thruster in vacuum condition, lasting till invalidation of Hall thruster. The other is thruster assessment test of several hundreds hours, then gathering erosion data of discharge chamber wall during the test, extrapolating data by an empirical formula to preestimate thruster life-time.

For preestimating Hall thruster life-time, thruster had operated for accumulated 550 hours, Fig3 shows the change of shape and configuration of discharge chamber before and after a test of 550 h. The ion bombardment erosion tendency of discharge chamber was predicted by data extrapolation of an empirical formula:

$$\mathrm{Y}(t) = L\ln(1+\frac{C}{L}t)$$

Where Y(t) is erosion value from time t; C is some experimentally determined constants, which depend on the mode of operations and the material of channel walls; and L is the characteristic value, which depends on the density of atoms and the electron temperature. Generally, L will be in a range of 3 to 4mm,and C will be several tens mm/Kh.

Fig.4 and 5 demonstrate the result of extrapolation for internal and external wall of discharge chamber, it is shown that test results are almost coincident with the rule calculated by a formula (correlated coefficient >99%). Thus it can be seen that extrapolation curves on the whole can reflect the change of internal and external wall. These curves are authentic to preestimate life-time.

Fig.3 Appearance of discharge Chamber of thruster before & after 550h operation

From two extrapolation curves in Fig. 4 and Fig.5, it is shown that after 4000h operation the maximum erosion depth of internal and external wall are 4.05mm and 2.57mm respectively. The actual thicknesses for internal and external wall are 4.3mm and 3mm respectively. Both of them are bigger than the maximum erosion, so we can conclude that the life-time of Hall thruster can reach 4000h.

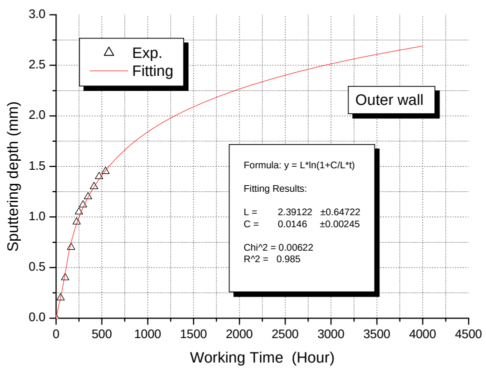

Fig.4 Extrapolation of external wall sputter erosion along with working time

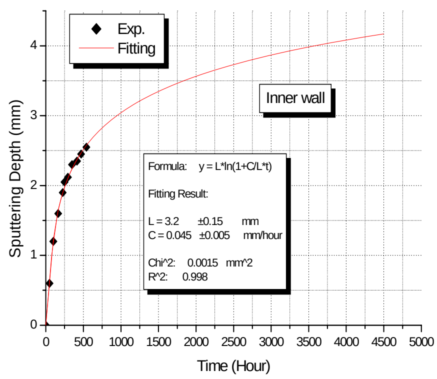

Fig.5 Extrapolation of internal wall sputter erosion along with working time

4. **Consideration of Hall Thruster Flight Test**

In order to speed up the space application of Hall electric propulsion in Chinese Spacecraft, the flight test is the basic procedure. The technical test satellite on which applied Hall electric propulsion system is a solar-stationary satellite with orbital altitude 700km, orbital circle period about 96 minutes and design life about 3 years. Hall electric propulsion system will be installed in the direction of X axis of the satellite to control the satellite orbit. Through Hall electric propulsion system space fight test, we plan to reach the following goals:

1）Validation of space environment adaptability

After satellite enters in orbit, turn on Hall electric propulsion system, test its ignition reliability and operation stability, check the endurance of Hall electric propulsion system and its component (Hall thruster, hollow cathode, Propellant storage and supply unit, PPU and etc.) on launch condition, validate operation security, reliability and effectiveness in orbital environment, find some unpredictable problems related to space application undiscovered in ground test.

2）Validation of effective operation in space

After turning on Hall electric propulsion system, through monitoring satellite orbital data and attitude, assess system operation effectiveness and parameters in real space environment, lay a foundation for future application. Simultaneously, carry out multi-ignition and accumulated life test to validate long durability operation in space environment.

3）Accumulation of flight experience and knowledge

Through flight test, obtain the experience and knowledge of application of Hall electric propulsion system on spacecraft, such like temperature of the key elements, thruster plume effect and plasma distribution in the vicinity of spacecraft due to back flow plume during system operation.

4）Validation of compatibility with spacecraft

Validate compatibility of Hall electric propulsion system with spacecraft, evaluate the influence of operation of Hall electric propulsion system on the function of spacecraft, such as interference with power supply primary input bus-line, magnetic effect, communication interference, spacecraft surface potential change due to plasma plume, sputter and contamination of thermal control surface, optical surface and solar battery array by thruster plume.

5. Design of Hall Electric Propulsion System

For fulfilling the task of Hall electric propulsion system flight test, the system is now being developed in SISP. Fig.5 shows a scheme of designed Hall electric propulsion system.

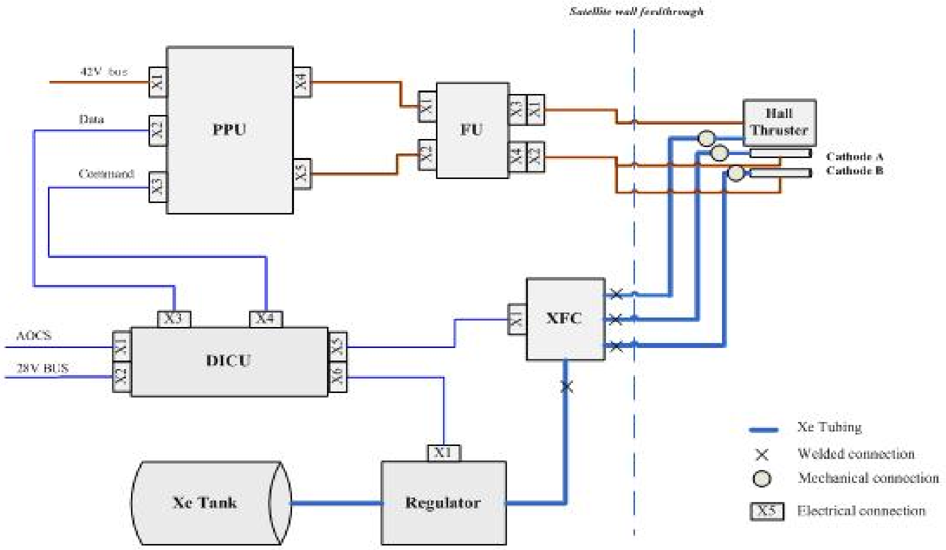

Fig.5 Scheme of Hall electric propulsion system

Components of system are: 1 Xe tank, 2 high pressure latch valves, 1 set of two stages regulator, 2 XFC units, 2 thrusters, 1 set of PPU, fill/drain valve, high/low pressure transducer and filters and etc.

Required accumulated flight test time for Hall electric propulsion system is more than 1000h, on/off times-1000. a Xe tank of 7 liters can satisfy the requirements. Downstream of tank is equipped with a fill/drain valve for pumping the tank, filling and draining Xe. Downstream of regulator is equipped with another fill/drain valve to pump the tube.

For preventing failure of opening high-pressure latch valve, the system uses two parallel-deployed high-pressure latch valve. Because the requirement for propellant flow rate is stricter in electric propulsion system, regulator of 2 stages is applied in series in system to raise regulator output pressure accuracy and minimize pressure fluctuation, at the same time, downstream of regulator is added a reservoir to further stabilize input pressure of XFC unit. Along system tubes are equipped with 2 pressure transducers, one for measuring pressure in Xe tank, another for measuring regulator output pressure and XFC input pressure.

In system there have 2 thrusters (for each thruster 2 cathode neutralizers are installed) to verify thruster switch function in orbit, and simultaneously function as redundancy for each other. A XFC unit is equipped in front of each thruster to realize precise mini-flow control and distribution for thruster and its hollow cathode.

As an important part of the system,，PPU is constituted by the following modules :

- Interface on the Primary input power bus, insures main bus protection, voltage level conversion and galvanic isolation required by the thruster supplies.
- Thruster power supplies, the 4 types of electrodes of the Hall Thruster (anode, magnet, heater, ignitor) are supplied according to their specific power profile.
- XFC power supplies, PPU supplies the Xenon Flow Controller: opens or closes the xenon valves and controls the discharge current by the regulation of the xenon flow via the thermothrottle power supply.
- TC/TM interface with the satellite communication bus.

6. Summary

The paper reviews the development course of Hall electric propulsion technology in SISP, demonstrates the main properties and long-term life test for Hall thruster developed by SISP, introduces the main task of flight test of technical test satellite equipped with Hall electric propulsion system.

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