The Electric Propulsion Development in LIP

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Abstract: The electric propulsion development in Lanzhou institute of physics (LIP) has begun in 1974. Since then two types of electric propulsion have developed by LIP, which includes the ion electric propulsion series of LIPS-80, LIPS-100C, LIPS-200, LIPS-200D, LIPS-300T, LIPS-400M and the Hall electric propulsion series such as LHT-35, LHT-60D, LHT-70, LHT-100, LHT-140D. Thrusters that developed are planned to implement the flight tests, for example, satellite NSSK mission, LEO spacecraft orbital maintaining and NEA mission.

I. Summary of the Electric Propulsion Development in LIP

Lanzhou institute of physics (LIP) was built in 1962 with the main research area of vacuum and cryogenics technology. LIP had begun to develop electric propulsion since 1974 and has become the most famous corporation in electric propulsion field of China after 40 years. The flight tests and formal applications of the electric propulsion, which developed by LIP, are realized firstly in China. The electric propulsion development in LIP can be divided into four stages:

The first stage is foundation research, which lasted from 1974 to 1992, during which LIP successfully developed two laboratory models of ion electric propulsion, LIPS-80 and LIPS-90 respectively, among which LIPS-80 has been awarded the first class national diploma.

The stagnancy is from 1993 to 1999. There was no progress in technology because of the interruption of finance.

The revival study is from 2000 to 2007. Under the support of the national finance investment, LIP restarted its electric propulsion development with the inspiration of electric propulsion application in foreign. Laboratory model (LM) and engineering model (EM) of the LIPS-200 ion electric propulsion had been developed at that time. Meanwhile, LM of LHT-70 Hall electric propulsion was developed as well.

The last stage of accelerated development is from 2008 to 2013. In 2012, successful realization of the flight test for the SJ-9A satellite shows that LIPS-200 ion electric propulsion system could be applied to GEO satellite's NSSK mission. The ion electric propulsions of LIPS-200, LIPS-200+, LIPS-300 and LIPS-400 and the Hall electric propulsions such as LHT-35, LHT-60, LHT-100 and LHT-140, which developed by LIP are planned to achieve different space missions, including near Earth asteroid, orbit transferring ,drag-free control, large LEO spacecraft orbit maintaining and deep space exploration.

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II. Electric Propulsion Products and their Performance

2.1 Ion Thrusters

Table 1 presents the ion thrusters developed by LIP since 1974. Thrusters were denominated by its beam diameter (ie. grid diameter). C stands for continuous adjustment working model, D represents double working mode, triple and multiple working modes are denoted by T and M respectively. All of the thrusters are propelled by xenon except LIPS-80 which propelled by mercury. The photographs of LIPS-80, LIPS-200 and LIPS-300T are shown in Figure 1.

Table 1. LIP's Ion Thrusters and Their Performance

Ion thruster	**Main Performance**			
	Power(W)	Thrust(mN)	Specific impulse(s)	Maturation
LIPS-80	240	5	2700	LM
LIPS-90	450	15	2900	LM
LIPS-100C	50～650	1～15	500～3000	LM*
LIPS-200	1000	40	3000	FM
LIPS-200D	1500	60	3000	EM
	1000	40	3000	
LIPS-300T	4800	175	3500	LM
	3600	130	3500	
	2200	80	3200	
LIPS-400M	3000～7000	90～200	3500～4500	LM*

*being developed

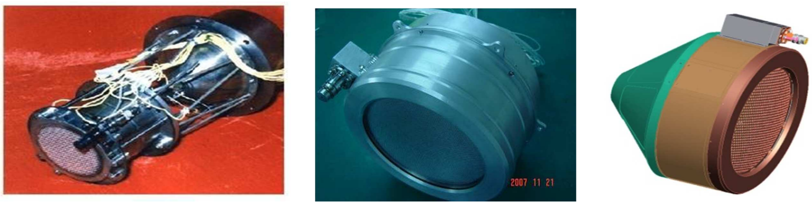

Figure 1. Ion Electric Propulsion Products of LIP

2.2 Hall Thrusters

All of the Hall thrusters developed by LIP since 2000 are shown in Table 2. Each thruster is denominated by the outside diameter of its discharge channel, and D stands for double working modes. Figure 2 presents the photographs of LHT-60D, LHT-70 and LHT-100.

Table 2. LIP's Hall Thrusters and Their Performance

Hall thruster	**Main Performance**			
	Power(W)	Thrust(mN)	Specific impulse(s)	Maturation
LHT-35	250	10	1200	LM*
LHT-60D	1300	50	2600	EM
	1300	80	1500	
LHT-70	660	40	1500	EM
LHT-100	1350	80	1600	EM
LHT-140D	4500	280	1700	LM*
	3000	170	1900	

*being developed

Figure 2. Hall Electric Propulsion Products of LIP

2.3 Power Processing Units

LIP has developed the power processing units (PPU) corresponding to ion thruster and Hall thruster respectively. Each PPU is denominated by its input power and input voltage. Table 3 lists the PPU's main performance, and Figure 3 shows the photographs of PPU-1300-42 and PPU-1300-100.

Table 3. LIP's PPUs and their Performance

Main performance	**PPU-1300-42**	**PPU-1300-100**	**PPU-1700-100**
Input power(W)	1300	1300	1700
Input voltage(V)	42±2	100±5	100±5
Efficiency (%)	≥85	≥85	≥90
Weight(kg)	17	12	13
Total on-off Number	400	12000	400
Total operation time (h)	200	22000	400
Reliability at the end of life	0.99	0.98	0.99

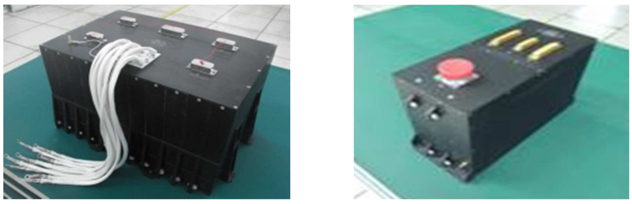

Figure 3. The PPU Products of LIP

III. Applications of the Electric Propulsion Systems

3.1 Flight Test on SJ-9A Satellite

The flight test of the LIPS-200 ion electric propulsion systems (IEPS) on SJ-9A satellite is the first space flight for the China's electric propulsion. The IEPS is shown in Fig.4, including ion thruster (IT), PPU, electric-propulsion control unit (ECU), xenon tank (XT), pressure regulation unit and flow control unit (PRU&FCU), line connection unit (LCU). Among them, LCU's function are not only the cable connecting box between PPU and IT, and but also the electric-check interface.

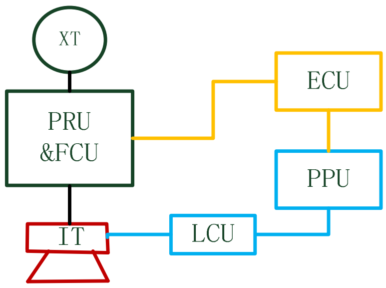

Figure 4. the IEPS on SJ-9A satellite

LIP has begun to develop the IEPS for the flight test on SJ-9A since 2008, and it was delivered in 2011. The SJ-9A satellite was launched on October 14, 2012, and it's first firing was implemented on November 5, 2012. By the end of July, 2013, the IEPS has fired more than 130 times with each time lasted for 10 minutes, and the accumulated time is more than 20 hours. The telemetry data shown that the IEPS and its elements were in normal state, the IEPS was compatible with other systems on the satellite, and the performance index in the orbit has met expection. The details can be found in reference [1]. The test is still underway, and all tests are going to be finished in 2013.

3.2 NSSK of GEO Communication Satellite

The first DFH-3B satellite using electric propulsion is developed by Communication Satellite Department of CASC. The constitute of NSSK IEPS is shown in Fig.5. Four LIPS-200 ion thruster （IT）were divided into two groups of S-IT at South side and N-IT at North side. Two IT of each group are installed on one thruster gimbal assembly （TGA）correspondingly. Anyone of the two power processing unit (PPU) can supply power to each IT through the choice of the thruster selection unit (TSU). Propellants are stored in two xenon tanks (XT). One of pressure regulation unit (PRU) can be used to adjust entrance pressure of four flow control unit (FCU). Each FCU can supply specified xenon flow rate to the corresponding thruster. The electric- propulsion control unit (ECU) is in charge of the IEPS's operations, and supplies the interface with satellites.

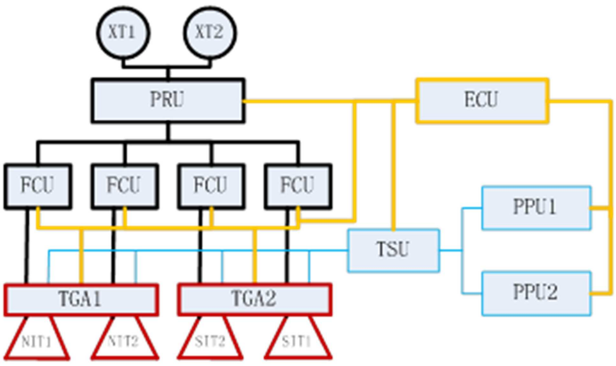

Figure.5 the IEPS for GEO Satellite NSSK

The main performance parameters of the IEPS were shown in Table 4. The satellite is going to be launched in 2015, which will be the first formal application of the China' electric propulsion system. The IEPS flight model is being developed and lifetime of the IEPS EM is being tested. The specific progress can be found in reference [2].

Table 4. the IEPS Performance for DFH-3B NSSK mission

Performance element	**Parameter value**	**Performance element**	**Parameter value**
Input power(W)	1300	Beam divergence angle(º)	≤30
Thrust(mN)	40±4	Efficiency of PPU (%)	≥90
Specific impulse(s)	3000±150	Net weight (kg)	150
Total Number of Firing	6000	Xenon mass（kg）	85
Total operation time (h)	12000	Reliability for 15 years	0.95

3.3 Flight Test on XY-2 Satellite

A single-stringed Hall electric propulsion system (HEPS) that is based on LHT-100 will be flight-tested on XY-2 satellite. The HEPS is shown in Fig.6, including Hall thruster (HT), PPU, Filtering Unit (FU), electric-propulsion control unit (ECU), xenon tank (XT), pressure regulation unit(PRU) and flow control unit (FCU). The main performance parameters of the HEPS were shown in Table 5.

XY-2 will be launched in 2015 and it is a GEO orbit satellite. The flight test purposes of the HEPS include validating its adaptability to the space environment, scaling its performance in orbit, and validating its compatibility with the satellite's other systems.

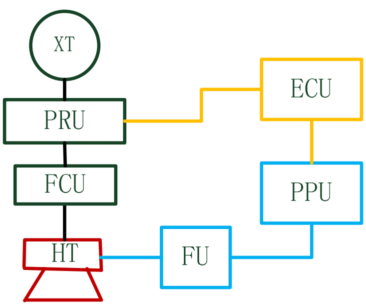

Figure 6. the HEPS on XY-2 satellite

Table 5. the HEPS Performance for XY-2 Flight Test

Performance element	Parameter value	Performance element	Parameter value
Input power(W)	1500	Efficiency of PPU (%)	≥90
Thrust(mN)	80±8	Net weight (kg)	≤50
Specific impulse(s)	1500±150	Xenon mass(kg)	3
Total Number of Firing	50	Reliability for 3 years	0.98

3.4 The Orbit Maintainance for a Large LEO Spacecraft

The large LEO spacecraft has orbit altitude from 350 km to 400 km, and its average atmospheric drag ranges from 80 to 203 mN. The main restriction for orbit maintained by electric propulsion system is power upper limit of 2.7 kW. Therefore the LHT-100 Hall electric propulsion is the most suitable one.

The HEPS shown in Figure 7 for orbit-maintaining includes 4 HTs, 4 PPUs, 2 XTs, 1 PRU&FCU and 1 ECU. Each PPU supplies power to only one thruster, and a pair of thrusters operate instantaneously to provide thrust to finish the orbit-maintaining task, and the other pair of thrusters serve as backups. The main performance parameters of the HEPS were shown in Table 6. The spacecraft is planned to be launched in 2018.

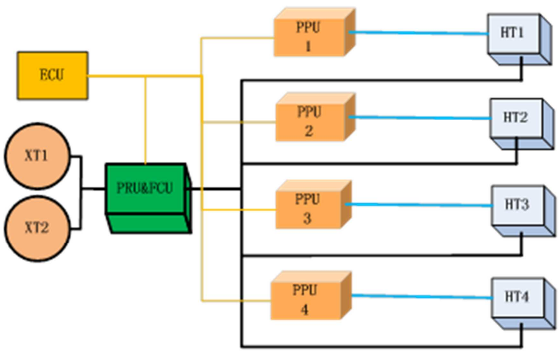

Figure 7. the HEPS on Large LEO Spacecraft

Table 6. the HEPS Performance for Large LEO Spacecraft Orbit-maintaining

Performance element	Parameter value	Performance element	Parameter value
Input power(W)	≤2700	Total operation time (h)	≥8000
Thrust(mN)	160±10	Efficiency of PPU (%)	≥92
Specific impulse(s)	1500±100	Net weight (kg)	≤100
Total Number of Firing	≥9000	xenon for every year(kg)	200

3.5 Near-Earth Asteroid Mision

The mission analysis result shows that the delta velocity for near-Earth asteroid (NEA) mission should be up to 6 km/s. High specific impulse ion electric propulsion system can be used to perform the orbit-transferring in the cruising period of the NEA mission. On the other hand, thruster should has a flexibility to the changes of input power, because of solar arrays output power changes with distance to the sun. Therefore the ion electric propulsion based on the LIPS-200D with double operation modes was chosen. The constitute of the IEPS for the NEA mission given by Figure 8 includes 4 ITs, 4 PPUs, 3 XTs, 1 PRU, 4 FCUs, 1 ECU and 4 TGAs. Each PPU can supply power to two thrusters, and two thrusters operate instantaneously to finish the propulsion tasks in the cruising period and the others serve as backups. The main performance parameters of the IEPS were shown

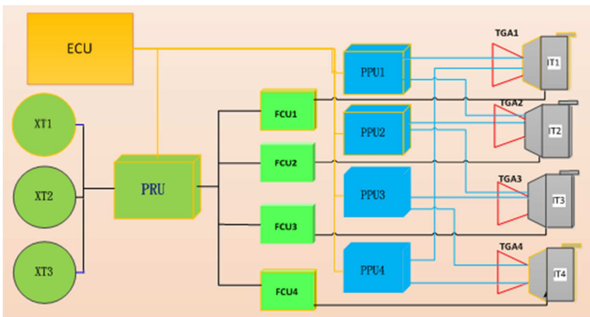

Figure 8. the IEPS for the NEA Mission

in Table 7. Two LIPS-200D thrusters can provide five levels of thrust. The spacecraft is planned to be launched in 2016～2018.

Table 7. the IEPS Performance for the NEA Mission

Performance element	Parameter value	Performance element	Parameter value
Input power(W)	≤3500	Total Number of Firing	≥2000
Thrust(mN)	120	Total operation time (h)	≥15000
	100	Reliability at EOF	0.95
	80	Efficiency of PPU (%)	≥90
	60	Net weight (kg)	≤160
	40	Xenon Mass (kg)	460
Specific impulse(s)	3000	Shutdown time(s)	≤5

IV. Diagnostic Instruments and Test Facilities

4.1 The Electric Propulsion Diagnostic Instruments

LIP has developed the electric propulsion Diagnostic Instrument (EPDI) that can match electric propulsion test requirements. The EPDIs are composed of Langmuir probe (LP), Faraday probe (FP), retarding potential analyzer (RPA), Weinen probe (EB), quartz crystal microbalance (QCM), Laser interferometry thrust gauge (LITG), and beam divergence angle equipment (BDAE). The photographs of EB, RPA, QCM, BDAE are shown in Figure 9. The last photograph is a compact diagnostic unit of LP, RPA and QCM developed for the SJ-9A flight test.

Figure 9. The Electric Propulsion Diagnostic Instruments

4.2 The Electric Propulsion Test Facilities

LIP has developed the TS series test facilities for electric propulsion ground test. The symbols, usage functions and performances of these facilities are shown in Table 8. The photos of TS-6, TS-6T and TS-7 are shown in Figure 10 respectively.

Table 8. LIP's Electric Propulsion Test Facilities

Symbol	Usage Function	Performance
TS-3	Acceptance and lifetime test of high voltage insulators	Vacuum chamber: Φ1.0 m×1.0 m, limit vacuum: 1×10^{-4}Pa, molecular pump
TS-4	Acceptance and lifetime test of thermal throttle assembly	Vacuum chamber: Φ0.5m×0.7m, limit vacuum: 1×10^{-2}Pa, mechanical pump
TS-5	Acceptance and screening test of hollow cathode	Main chamber:Φ1.0 m×1.0 m,4 subchamber Φ0.25m,limit vacuum:1×10^{-4}Pa,molecular pump
TS-5A	Reliability and lifetime test of hollow cathode	8 chamber Φ0.3m×0.4 m and 2 chamber Φ0.4m×0.6m, base pressure 5×10^{-5}Pa，operational pressure 2×10^{-2}Pa, mechanically dry pump
TS-6	Development test for new thruster	Vacuum chamber: Φ2.0m×5.0m，sub-chamber Φ0.8m×0.8m，limit vacuum 1×10^{-4}Pa，oil diffusion pump
TS-6T	EMC test	Main chamber Φ2.0m×5.0 m, sub-chamber for electromagnetic wave transparency, diffusion pump
TS-6A	Performance test for thruster and system	Main chamber Φ2m×5m,sub-chamber Φ0.8m×0.8m，operational pressure 1.0×10^{-3}Pa at 14sccm xenon, cryopump.
TS-7	Lifetime test for thruster or system	Main chamber Φ3.8m×8.5m, sub-chamber Φ1.5m×1.6m，operational pressure 4×10^{-4}Pa at 14sccm xenon and 4×10^{-3}Pa at 58sccm xenon , cryopump.

Figure 10. Photos of TS-6, TS-6T and TS-7

4.3 The Electric Propulsion Ground Equipments

LIP has developed the electric propulsion ground equipment, including thruster simulator (TI), high-purity xenon filling equipment (XFE), the demarcation equipment for very low flowrate of xenon, and xenon-leaking detector. The LIPS-200 TI and XFE developed for SJ-9A satellite IEPS are presented in Figure 11.

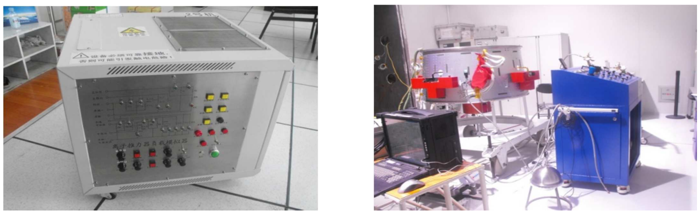

Figure 11 LIPS-200 TI and XFE developed for SJ-9A IEPS

V. The EPS Application Plan in the Future

Besides the electric propulsion application projects that are ensured and mentioned before, other application programming of LIP's electric propulsions are shown in Table 9. It involves drag-free control, all electric propulsion satellite, deep space exploration, and communications satellite station keeping [3].

Table 9. The Application Programming of LIP's Electric Propulsion

Type	**EPS**	**Application**
Ion thruster	LIPS-100C	Drag-free control of the gravity gradient satellite
	LIPS-200	NSSK
	LIPS-200D	NEA mission, NSSK and WESK
	LIPS-300T	All electric propulsion satellite, main belt asteroid mission
	LIPS-400M	the Jupiter exploration mission
Hall Thruster	LHT-35	orbit maintaining of small satellites
	LHT-60D	Orbit maintaining and transferring of small satellites
	LHT-100	orbit maintaining of Large LEO spacecraft
	LHT-140D	orbit transferring of spacecraft

References

[1] Tianping Z. Initial Flight Test Results of the LIPS-200 Electric Propulsion System on SJ-9A Satellite. IEPC2013-47, International Eelectric Propulsion Conference, The George Washington University, USA,2013.

[2] Tianping Z. The LIPS-200 Ion Electric Propulsion System Development for the DFH-3B Satellite Platform. IAC-13-C4.4.10, 64th International Astronautical Congress,Bejing, China,2013.

[3] Tianping Z. Developments and applications of the electric propulsions in LIP. CSA Annual Academic Conference, Bejing, China,2012.[in Chinese]