An Overview of Electric Propulsion Activities in China

Xiaolu Kang

Shanghai Spaceflight Power Machinery Institute, Shanghai, P.R. China, 200233

CO-AUTHOR:

Zhaoling Wang	Shanghai Spaceflight Power Machinery Institute (SPMI)
Nanhao Wang	Shanghai Spaceflight Power Machinery Institute (SPMI)
Anjie Li	Center for Space Science and Applied Research of CAS (CSSAR)
Guofu Wu	Lanzhou Institute of Physics (LIP)
Gengwang Mao	Northwestern Polytechnical University (NPU)
Haibin Tang	Beijing University of Aeronautics and Astronautics (BUAA)
Wenhua Zhao	Tsinghua University

Abstract

Electric propulsion development activities in China are currently being carried out at a fast rate for future application on new generations of Telecommunication and Scientific satellites. Much attention was paid to: a) Hall Effect thrusters; b) Ion thrusters; c) Arcjets; d) Resistojets; e) Pulsed plasma thrusters; f) Microwave Plasma thrusters. This paper presents a review of the Chinese development in this field. The activities include the building of experimental facilities, basic research, engineering development, and future intended program.

Introduction

Electric Propulsion (EP) is an advanced space propulsion Technology. The significant performance benefits of electric propulsion over conventional chemical systems translate directly into significant economic benefits. Reductions in the propellant mass requirements to provide a given total impulse are translated into increased payloads, reduced launch vehicle requirements, and/or increased spacecraft life. Furthermore, electric propulsion is being adopted by several scientific and Earth observation missions where EP technologies will be used to provide the primary propulsion functions or to perform highly precise control operations.

There are many types of electric propulsion systems. These can be classified to their physical method of operation into the following three major categories:

- Electrostatic Systems: Hall Effect thrusters; Ion thrusters; Field Emission thrusters
- Electrothermal Systems: Resistojets; Arcjets; Microwave plasma thrusters
- Electromagnetic Systems: Magneto-Plasma-Dynamic thrusters; Pulsed Plasma thrusters

Over the past three decades, many kind of electric propulsion technologies had been developed and investigated in some Chinese academic institutes and industrial companies. These electric propulsion technologies involve Hall Effect thruster, Ion thruster, resistojet, Arcjet, Pulsed plasma thruster, and microwave plasma thruster. Main Chinese research and development centers of electric propulsion are:

Shanghai Spaceflight Power Machinery Institute (SPMI), Center for Space Science and Applied Research of Chinese Academy of Sciences (CSSAR), Lanzhou Institute of Physics (LIP), Northwestern Polytechnical University (NPU), Beijing University of Aeronautics and Astronautics (BUAA), and Tsinghua University.

This paper presents a review of the Chinese development in this field and the programmes under preparation.

Thruster Development

Resistojet

With Resistojets successfully flew on many spacecrafts in recent year, it was selected as a future candidate for Chinese Spacecraft because it has many advantages, such as simple structure, easy to control and inheritance of mono-propellant hydrazine thruster technology. Under the support of China Aerospace Science and Technology Corporation (CASC), SPMI had developed a resistojet model (Fig. 1) in 1992. The performance of the resistojet was as following:

- Thrust 400mN
- Specific impulse 295 s
- Input power 500 W

Because of no flight mission and limited specific impulse, this activity was stopped in 1996.

Recently, there is a trend to renew the activity supported by CASC.

Arcjet

Aiming at the Chinese Geostationary satellite NSSK and orbit repositioning mission, CSSAR had built a laboratory system of 1KW class Arcjet thruster. The start-up characteristics and discharge characteristics had also been investigated using Nitrogen and Argon as propellant.

Another program continuing to conduct Arcjet thruster research was carried out under the support of the National Natural Science Foundation of China (NNSFC). The objective was to develop a pulse width modulated power supply as thruster's power supply and to investigate the performance of thruster using a mixture of Nitrogen and Hydrogen as propellant.

Under some finance support from National education ministry of China, BUAA and Tsinghua University had also made efforts on Arcjet technology. Both universities had built an Arcjet thruster and experimental system. Efforts on key technology are being carried out in both universities.

Hall Effect thruster (HET)

In order to provide a new thruster for the NSSK of Chinese geostationary satellite, Hall thruster was selected as a candidate due to its high impulse and high rate of thrust. The experimental research started in 1996 and had carried on at SPMI since then, the following works had been finished.

Test facilities

The Hall thruster test facility (Fig. 5) had been inaugurated at SPMI in 1996. The facility is 1.2-meter in diameter and 3.36-meter long, and has two 600mm –diffusion pumps to maintain vacuum levels of approximately 10^{-3} Pa for Hall thruster operation up to about 1400W. This facility at present is being used for test of mid-power Hall thruster. Additional facility (Fig. 6) for hollow cathode test had also been inaugurated at SPMI, it is 0.5-meter in diameter and 1.2-meter long, and has two 300mm-cryopumps to maintain vacuum levels below 10^{-4} Pa for cathode test.

A new facility is being constructed at SPMI, it is 3-meter in diameter and 9-meter long. This facility can be used for Hall thruster plasma diagnostics and plume effects evaluation.

Thrust measurement system now used in SPMI is based on the basic electromagnetic balance principle. The accuracy of thrust measurement mainly depends on the arrangement of wires of the thruster power supplies and the pipes Xenon supplies for the thruster. Because of vibration induced by mechanical vacuum pumps, the thrust measurement uncertainty is about 10%.

Low-power Hall Thruster development

In order to meet the future needs of the small satellite's missions, SPMI had developed a laboratory model of low-power hall thruster (Fig.3) with 10mm average discharge diameter of accelerating channel. The laboratory model contains two main parts: the accelerator and hollow cathode. The accelerator has the ordinary scheme with magnet. The cathode is hollow type scheme with set in heater for regulation of the electron current emission level. Xenon is used as propellant.

The performance of low-power HET thruster is as following :

- Thrust 10mN
- Specific impulse 980s
- Input Power 200 W
- Thruster mass 0.5Kg

Because of ion sputtering on the thruster chamber wall, the lifetime of thruster is limited. In addition, the efficiency is not satisfied.

Mid-power hall thruster development

Based on intensive research and a great number of tests in Hall thruster, a mid-power Hall thruster had been developed (Fig. 4). Xenon is also used as propellant.

The performance of mid-power HET was tested in the facility above. Its basic performance is showed as following :

- Thrust 40mN
- Specific impulse 1600s
- Efficiency 50%
- Input Power 660 W
- Thruster mass 1.5Kg

Some experiments of Hall thruster

Because of power shortage for some geostationary satellites, in general, the electric propulsion system takes the redundant power energy in the beginning of satellite life (BOL). With the power decline of solar array, the electric propulsion system needs to operate at low power mode in the end of satellite life (EOL). For this reason, the characteristics of Hall thruster developed at SPMI had been investigated at low power mode.

The thruster was operated below their nominal power. Their discharge characteristics, thrust, thrust efficiency, specific impulse, and thrust cost at different operating parameters were investigated experimentally. It has been shown that the thrusters operated at low power mode have stable discharge characteristics.

EP system integration

In order to speed up the space application of electric propulsion, the flight test is the fundamental procedure. For flight test of Hall thruster, an electric propulsion system based on of Hall thruster is now being developed in SPMI. The structure of hall thruster propulsion system consists of two HET thrusters, two xenon propellant storage tanks, xenon flow rate control unit, and power processing unit (PPU).

Ion thruster (IT)

The research and development of Ion thruster had been started in CSSAR as early as 1968. During the period of 1968-1973, two types of electron bombardment ion thruster using mercury as propellant had been developed. One was 12 cm in diameter, the other was 6 cm in diameter. Some of performance experiments were carried out. After that, the investigation of ion thruster turned on the ion source and non-propulsion application, especially for material modification.

From 1974-1986, under the support of Chinese Academy of Space Technology (CAST), LIP had developed successfully an engineering model of 8 cm ion thruster using mercury as propellant (Fig. 7). The main performances and construction were as following:

- Thrust: 5mN
- Specific impulse: 2744 s
- Input Power: 240 W
- Beam diameter: 80mm
- Length: 400 mm
- Mass: 28Kg

Due to the pollution problem of mercury, LIP had turned to develop ion thruster using Xenon as propellant from 1988. After more than 5-year efforts, an ion thruster using Xenon as propellant had been developed at LIP (Fig. 8). Its main performance was

- Thruster: 10-15mN
- Specific impulse: 2940 s
- Input Power: 400-450 W
- Beam diameter: 90 mm

In order to meet the needs of Chinese new generation communication satellite, an ion thruster with beam diameter 20cm is now being developed at LIP recently.

Pulsed plasma thruster (PPT)

PPT research and development started at CSSAR in 1970, the engineering model of PPT propulsion system had been developed (Fig. 9) since then, it used the solid Teflon as propellant.

The system consists of three major subsystems. They are thruster body, ignition subsystem and power conditioner and telemetry signal converter subsystem. The thruster body has two independent nozzles, which can work alternately. All of the propellant and its feed system, spark plug and ignition subsystem in each nozzle work independently without any influence to each other. The power conditioner, the main energy storage capacitor and the discharge ignition capacitor are common.

The performance of the thruster system was below:

- Propellant Solid Teflon
- Main capacitor 2μf/2 KV
- Ignition capacitor 10μf/150V
- Average impulse bit 6.5 mg –s
- Average Isp 280 s
- Thruster efficiency >2%
- System mass 2.75Kg

The thruster had been tested successfully in space in Dec. 1981. After that, the investigation of PPT focused on improving its performance and designing new thruster model. Because of no flight mission, this work was stopped in 1988.

In the recent years, under the support of Chinese Academy of Science (CAS), CSSAR renew the PPT research and development aiming at the on-board control of small satellite constellations.

Microwave plasma thruster (MPT)

Under the support of National Hi-Tech Foundation of China, two sets of atmospheric experimental system had been built in Northwestern Polytechnical University. Some of key techniques of

MPT, which include selection of resonant mode, coupling mechanism between microwave and propellant gas, startup and stable working of plasma, had already been broken through.

The ability to create and maintain plasmas at mid (500~1,000W) or low (70~150W) microwave power levels under atmospheric condition has been demonstrated with propellants such as helium and argon. MPT can operate at high chamber pressure (from 100 kPa to 600kPa absolute) with fixed configuration. The values of microwave power, chamber pressure and flow rate have been measured under atmospheric condition. Photos of 1,000W MPT testing and 100W MPT testing are illustrated in Figure10 and 11 respectively. At the same time, the vacuum experimental system (Φ 1.2m $\times$ 3.0m and limited pressure is 0.02Pa) and virtual instrumentation measurement system have also been built. Next work is to concentrate on test within vacuum tank and extensive propellants such as nitrogen, ammonia and hydrogen will be fulfilled. At the same time, main working parameters of MPT such as thrust, temperature of electron, concentration of electron at exit of nozzle, etc. will be accurately measured to calculate the performance of MPT.

Summary

Over the past three decades, a lot of investigations on Electric propulsion had been done in China. The periods can be divided into two main parts.

One is the primary period from 70th to 80th. In this period, a lot of EP thrusters had been investigated. A series of EP test facilities have been developed in some Chinese institutes. These works established the technological base for the electric propulsion. From these thrusters, some of potential candidates will arise for the Chinese satellite on-board application in the future.

Another period is a developing period from the early 90th. With the pace of EP applications increased in the world, electric propulsion programs in China is being restarted. Many EP technologies are being developed by support from various organizations. Development efforts focus on Hall thruster, ion thruster, and arcjet.

Acknowledgments

The authors gratefully acknowledge the help from Center for Space Science and Applied Research of CAS (CSSAR), Lanzhou Institute of Physics (LIP), Northwestern Polytechnical University (NPU), Beijing University of Aeronautics and Astronautics (BUAA), and Tsinghua University.

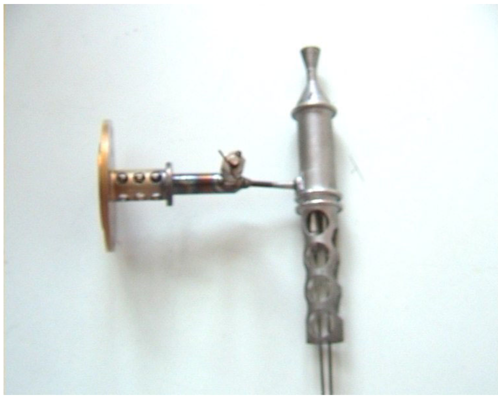

Fig. 1 The picture of resistojet

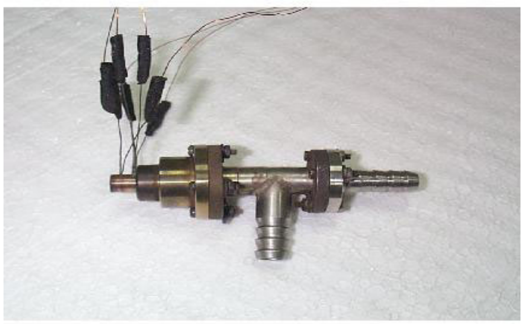

Fig. 2 The picture of arcjet

Fig. 3 The picture of Low-power HET

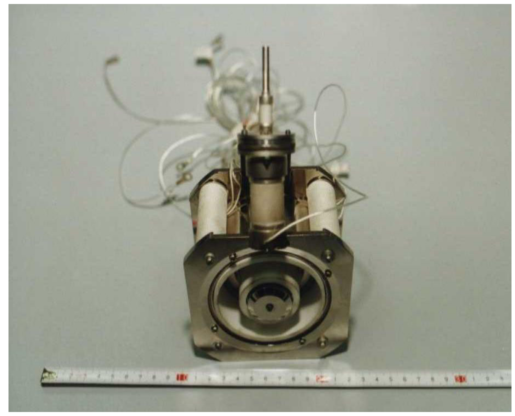

Fig. 4 The picture of mid-power HET

Fig. 5 HET Test facility

Fig. 6 cathode test facility

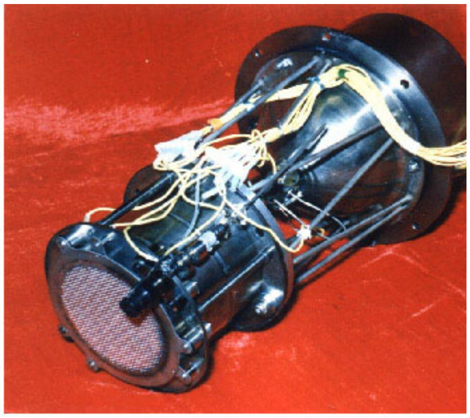

Fig. 7 The picture of Mercury ion thruster

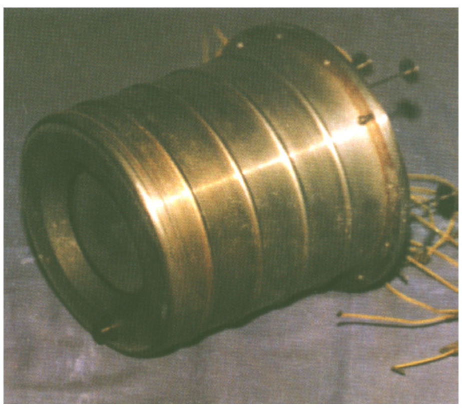

Fig.8 The picture of Xenon ion thruster

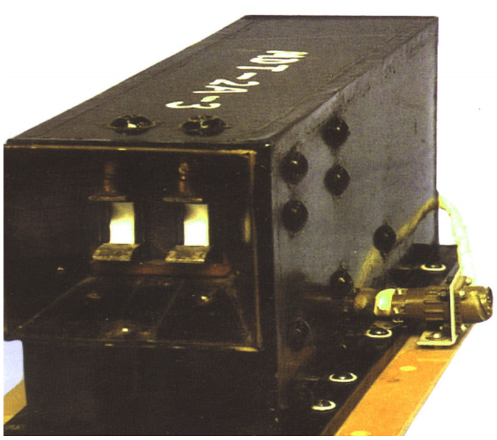

Fig.9 The picture of PPT

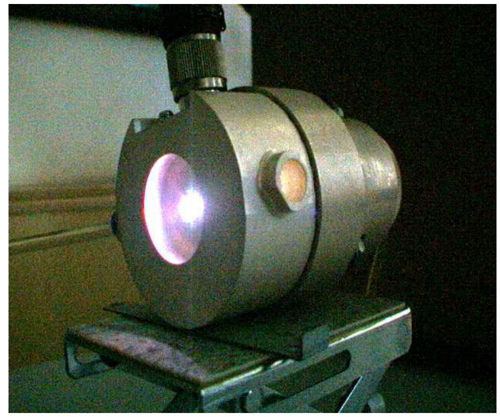

Fig.10 The picture of 1,000W MPT testing

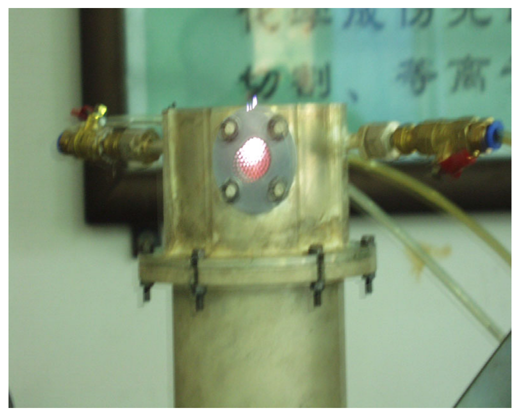

Fig.11   The picture of 100W MPT testing