Review of works on Electric propulsion at Keldysh Research Center

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Abstract

The article describes the work on creation electric propulsion, conducted at the Keldysh Research Center. An overview of the achievements in the development of the Hall and ion thrusters, as well as studies of the basic physical processes occurring in the thrusters of this type. A brief description of the experimental framework to carry out full cycle of tests of electric propulsion systems at the stage of ground tests.

Keywords

spacecraft; electric propulsion; ion thruster; Hall thruster

Introduction

One of the main objectives for the development of space systems is the deployment of orbital groupings and new generation spacecraft of different dimensions with a long service life.

The use of electric propulsion (EP) instead of chemical engines will extend the life of satellites and share of the payload through more efficient use of the propellant. The main field of the modern use of EP is a correction of the orbit spacecraft. In addition to the recent use of EP to solve transportation problems in the near and outer space are actively being worked.

The Keldysh Research Center is actively involved in the development of various types of EP [1]. In recent years the major work on EP in the Keldysh Research Center are conducted towards the development of the Hall and ion thrusters. These types of thrusters have found the widest application in the world practice of EP use on board the spacecraft for various purposes. Works are carried out as part of the Federal Space Program of Russia, and in the framework of contracts with foreign customers.

Hall Thrusters

The Keldysh Research Center has developed a series of Hall thrusters with power from 200 W to 6 kW and thrust from 10 to 380 mN. The basic thruster's characteristics are presented in Table 1.

Table 1

The main characteristics of the Hall thrusters developed at the Keldysh Research Center

Thruster	KM-45	KM-60	KM-88	KM-5	KM-7
Power, kW	0.2-0.45	0.45-1.1	1-2.5	1.35-2.5	3.5-6
Thrust, mN	10-28	30-50	50-105	80-140	200-380
Specific impulse, s	1250-1500	1250-2200	2000-3000	1600-2100	1700-2650

Thruster KM-45 (Figure 1) with nominal values of thrust and power of 18 mN and 350 W was developed by order of the Indian Space Research Organization (ISRO) and is designed for small satellites (up to 500 kg) [2]. Thruster passed a full cycle of ground tests in accordance with the requirements of the customer, its flight tests were to be held on board the spacecraft GSAT-4 in 2010, but because of the abnormal work of the rocket third stage spacecraft was not placed in orbit.

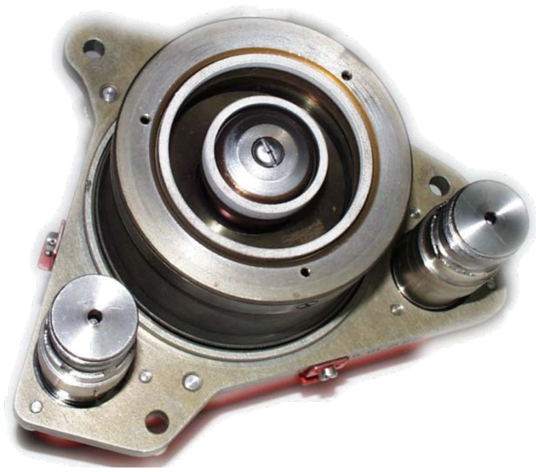

Figure 1 – Hall Thruster KM-45

Hall thruster KM-60 is being developed for the new satellite platform «Express-1000» produced by the JSC «Academician M.F. Reshetnev «Information Satellite Systems». With 900 W of power and 42 mN of thrust specific impulse at the beginning of life is more than 2000 s. Within the work a correction unit (CU), which includes not only the thruster, but the flow control unit is being developed. Ground tests of the CU are fully completed. Life test of the CU had duration of 4100 hours; the total momentum of thrust during the test exceeded 600 kN×s. At the end of testing the CU remained operational, test stopped due to achieve the required parameters of the life test program. Cathodes for KM-60 have passed autonomous life tests on number of starts with 20,000 switching of each. Appearances of the thruster KM-60 before and after the endurance test are shown in Figure 2. Production of the first batch of thrusters is complete and flight acceptance tests have conducted. In 2013-2014 flight tests of the CU based on thruster KM-60 is planned.

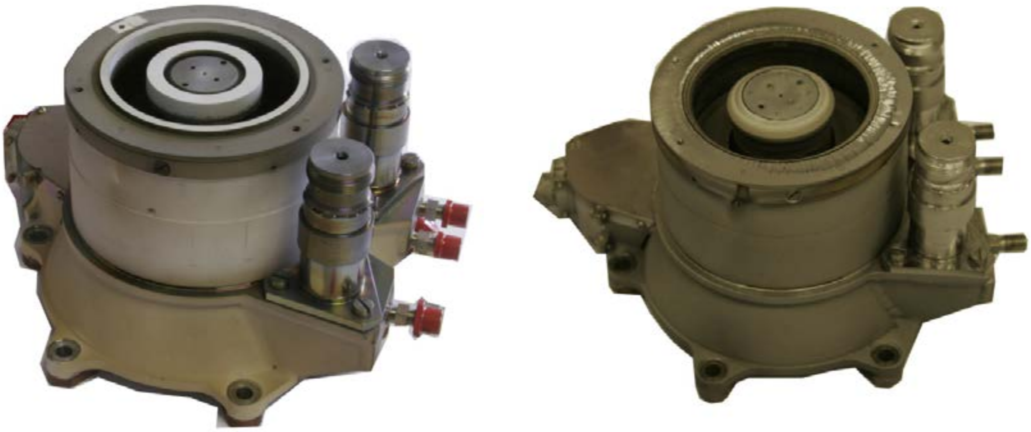

Figure 2 – Hall thruster KM-60 before the endurance test and after their completion

Commissioned by ISRO Hall thruster KM-88 was developed (Figure 3), which at rated power 1650 W has thrust 72 mN and specific impulse of more than 2100 s [3]. Thruster passed a full cycle of ground tests, including vibration tests at very high load (21 g_{RMS} on three axes). The first batch of flight engine was manufactured and delivered to the customer. Flight tests of thrusters are planned on the spacecraft «ACS-1». As part of the engine barium tungsten cathodes are used, which have passed autonomous working out cycle, including life tests for 4000 switches.

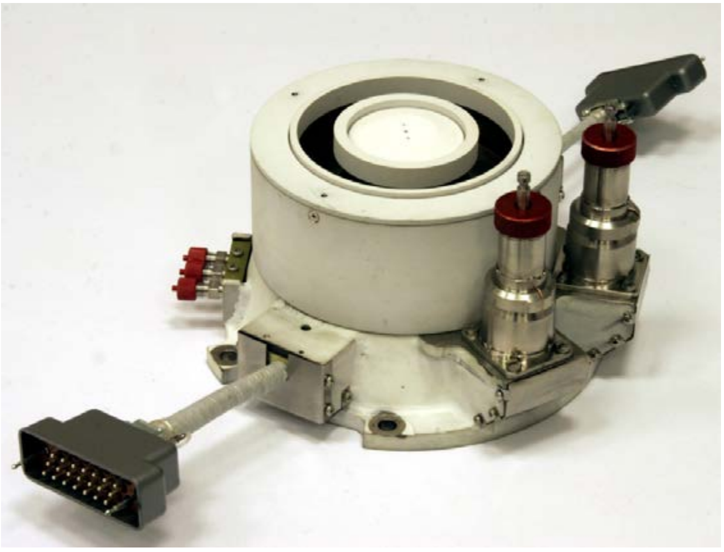

Figure 3 – Hall Thruster KM-88

In June 2002, the flight testing of the thruster KM-5 (see Figure 4) has been launched as part of a series communication geostationary satellite «Express A4» [2]. Thruster is used to keep the spacecraft on the inclination. Total operating time of the thruster is more than 2000 hours. Thruster was designed as a multi-mode for power ranges 1.35-2.5 kW. As a part of «Express A4» the thruster was used with power 1.35 kW.

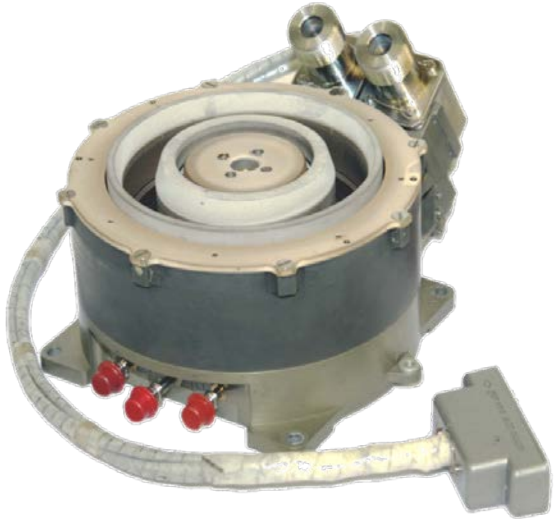

Figure 4 – Hall thruster KM-5

Thruster KM-7 (Fig. 5) is a three-level power - 3.5 / 4.5 / 6.0 kW with nominal power 4.5 kW [2]. Thruster developed by order of SPI Inc. (USA), have passed ground endurance tests for flight test in the spacecraft «Express A3», but flight tests failed due to unavailability of power supply and control unit.

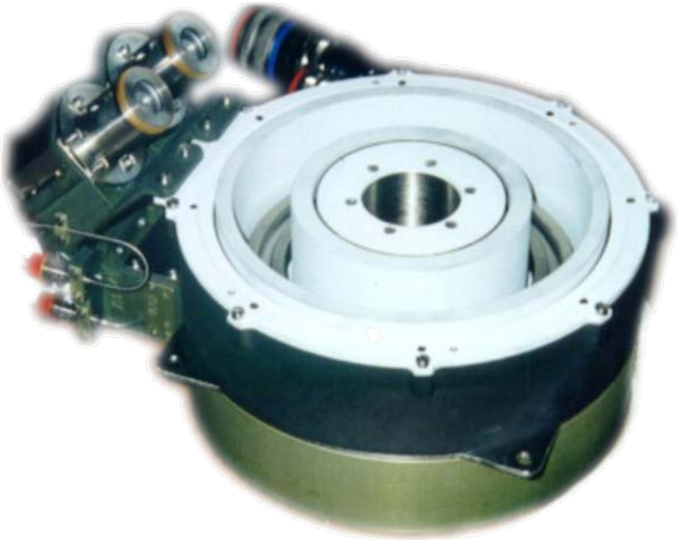

Figure 5 – Hall thruster KM-7

Ion Thrusters

The Keldysh Research Center initiated work on the development of ion thrusters of different power. Activities to address the main problems associated with the creation of ion thrusters and working out of the thruster technology are carried out.

Laboratory models of thrusters ID-300 and ID-300V (Figure 6) are developed and tested. Thruster ID-300 with power 2-4 kW, which has a thrust of 80-120 mN at a specific impulse 3500-4500 s is the prototype of the thruster, which can be used for orbit correction of heavy geostationary spacecrafts.

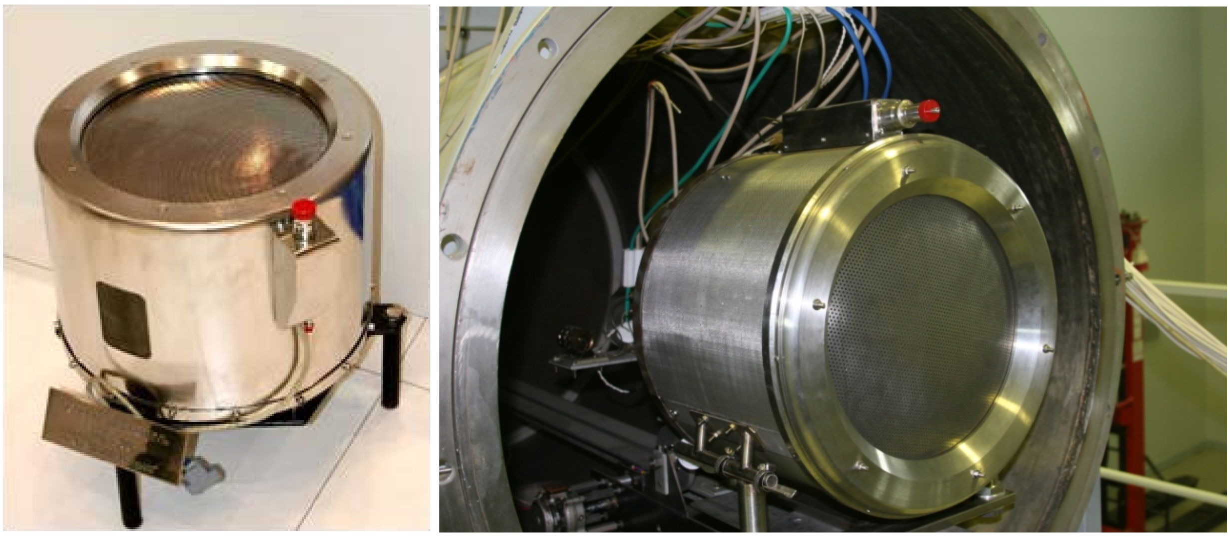

Figure 6 – Ion Thrusters ID-300 and ID-300V

One of the promising areas of space technology is the use of EP for transport operations in the near-Earth space and interplanetary missions. In this regard, in Russia from 2010, a project to create a transport-energy module, equipped with electric propulsion system (EPS) with total electrical power of 1 MW and specific impulse up to 7000 s is carried out.

For working out of the technology of ion thrusters with high specific impulse using the experience gained during the development of the thruster ID-300, the model of the ion thruster with high specific impulse ID-300V is created. Nominal thruster power is 10 kW at 220 mN thrust and specific impulse of 7000 s.

A preliminary design of the thruster IT HP (Ion Thruster with High Power) which is planned to be used as a basis for creating EPS of megawatt class is developed. The engine has a nominal power of 32 kW at 725 mN thrust and specific impulse 7000 s.

Experimental Facilities

Keldysh Research Center has modern experimental facilities that allow the full cycle of working off products. A set of test laboratories includes the facility of environmental test, vibration and shock benches for testing to external influences, installations of fire and life tests of cathodes installation for thermal vacuum testing and apparatus for measuring the thrust vector.

For fire and life tests of thruster’s cryovacuum chambers CVC-35 and CVC-90 (Figure 7), equipped with devices to measure the thrust and other diagnostic equipment are used.

Figure 7 – Cryovacuum Chambers CVC-35 and CVC-90

Cryovacuum chambers CVC-35 has a diameter of the main body 3 m and volume of 35 m^3, and equipped with cryogenic pumps with a total pumping speed 42 m^3/s.

The chamber is equipped with a control and measurement system, which allows for testing of thrusters in a fully automatic mode. The main purpose of the chamber is an endurance test of Hall thrusters.

Vacuum chamber CVC-90 has a diameter of 3.8 m and volume of 90 m^3, and equipped with cryogenic pumps with a total pumping speed for Xenon 129 m^3/s. The chamber is equipped with two pre-chambers, which allow operational testing and replacement thrusters without air vent in the main part of the vacuum chamber. The chamber is used for fire tests of Hall and ion thrusters.

Research Activity

The research program is aimed primarily at addressing the key challenges of creating EP with high specific impulse (over 2000 s).

Regard to Hall thruster, studies on optimizing the design of thrusters with high specific impulse, including the optimization of the magnetic field topology [4, 5], and works to ensure the lifetime of the thrusters and the stability of their work are conducted. A spectroscopic method of plasma diagnostics to determine the intensity of the ceramic elements erosion of the discharge chamber [6, 7] is developed. Testing of the method showed that the erosion rate, measured by plasma spectroscopic diagnostics is in satisfactory agreement with the results of direct measurements of the sputtered material. In thrusters developing a method of shortened life test, which allows multiple reduce the time needed to evaluate the life of the thruster is widely applied [8]. Experimental and numerical studies of the discharge structure, in particular, the mechanisms of anomalous transport of electrons in crossed electric and magnetic fields, including anomalous drift associated with fluctuations in plasma are conducted [9].

With regard to ion propulsion works on the study of physics of the discharge in the gas discharge chamber (GDC) are conducted as well as creation of the mathematical model of the ion thruster, which includes modeling of GDC and ion optics with taking into account the thermal state of the elements of the thruster.

Work to study cathodes for EP is underway, including the study of the possibility of new and more effective types of emitters and emitter circuits.

Conclusion

Complete experimental facilities allowing carrying out a full range of ground-based experimental testing of EP is created in the Keldysh Research Center. Extensive research and development activities aimed at creating new types of thrusters and reducing the cost of working out are conducted. Experience in creating of flight models of thrusters and their mass production is accumulated.

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