Abstract

An electric thruster is considered, which is a plasma accelerator of the Hall type with the closed electron drift and dielectric accelerating channel. Its parameters are as follows:
- nominal power 4.15 kW;
- xenon flow rate 15 mg/s;
- thrust 250 mN.

The thruster includes an anode unit, containing a magnet system, a dielectric accelerating channel in the form of an annular slot, a cathode-neutralizer unit with a W-Ba emitter, a flow control unit and a power processing unit.

The thruster is notable for its short switching-on time (less than 1 s), which enables to use it for solving a wide range of problems.

The thruster is provided with two perfected filamentless cathodes-neutralizers of 10000 hour lifetime each. One of the cathodes is redundant. The absence of any heater in the cathode and low temperature of the emitter ensure high reliability and lifetime of the whole thruster.

The anode unit has a perfect gas distributing anode, ensuring uniform distribution of the gas along the accelerating channel, and a magnetic system with a controlled magnetic flux. The thruster is perfectly compatible with any spacecraft, as there are no substances deposited, and the electromagnetic oscillations and noises are of a low level.

An effective accelerated lifetime test methodology has been developed as applied to this thruster.

Introduction

The electric thruster of 4 kW power, denominated T-160, is a plasma accelerator of the Hall-type with the closed electron drift and dielectric accelerating channel. The appearance of this thruster is shown in the photograph in Fig.1. The thruster consists of two main units - an anode unit (AU) and a cathode-neutralizer unit (CNU). In addition, to ensure the thruster operation, a propellant flow control unit (FCU) and a power processing unit (PPU) are being developed. The thruster was designed on the basis of great experience of studies.
development and operation of similar thrusters of lower power, accumulated in Russia. It is well known that the first investigations of thrusters of this type were initiated in the 1960s; the first space experiment was conducted in 1972, and they started to be used at various spacecrafts (SC) in the 1980s. For this reason, the thruster T-160 designers tried to utilize the available data as much as possible. Any modifications were induced step by step, and these modifications were intended to improve one or the other of thruster characteristics. However, succession of each next model with respect to the previous one was observed, as even the prototypes, on the base of which the T-160 thruster was developed, were of reasonably high operation characteristics.

1. Anode Unit

The anode unit is the main unit of the thruster, in which plasma accelerates and thrust is created immediately. The anode unit contains an accelerating channel, a magnetic system, a gas distributing anode as well as electric and gas communications.

The accelerating channel is of the annular form, and is of 26 mm width, 40 mm depth (which is a distance from the exit edge to the anode) and 160 mm outer wall diameter (Fig.2).

The magnetic system consists of poles, ensuring an azimuthally-uniform magnetic field in the accelerating channel, magnetic circuits, magnetic shunts and five magnetizing coils. Four of them are placed symmetrically on the outer magnetic circuit elements, and the fifth coil is situated on the central magnetic circuit. The magnetizing coils have separated outlets for feed supply, so the coils and discharge can be fed in series and independently, if a separate power source is available, thus ensuring the adjustment of the magnetic flux. The magnetic shunts serve to redistribute the magnetic intensity along the accelerating channel to obtain its optimum configuration ensuring stable and efficient ionization and acceleration of ions. In the first variant the inner and outer poles of the magnetic system and insulator edge are placed at the same distance from the anode. Currently, thruster model tests are being conducted; this thruster has a modified geometry of the magnetic system and accelerating channel with a deepened inner magnetic pole, and in the event of obtaining positive results, a similar design may be used for the thruster T-160.

The gas distributing anode contains an internal labyrinth, ensuring uniform distribution of the propellant around the azimuth of the accelerating channel. The gas is supplied to the gas-distributing anode at two diametrically opposite points.

Fig. 2.

1 - cathode-compensator; 2 - anode; 3 - accelerating channel; 4 - magnetic system
The anode has a developed current-receiving surface, which ensures thruster stable operation even when a significant portion of the anode external surface is covered with deposits.

The central magnetic circuit of the magnetic system has a cylindric cavity, in which the cathode-neutralizer unit is placed.

Such location of the cathodes ensures an axisymmetric configuration of the design and increases its overall dimensions. The mass of the thruster T-160, containing the anode and cathode units and cables, does not exceed 7 kg.

2. Cathode-Neutralizer Unit

The cathode unit contains two identical cathodes-neutralizers. Normally one of them operates, and the other one duplicates it if necessary, being in a "cold" reserve.

The cathode-neutralizer is a hollow cathode having an emission element which is made of porous tungsten saturated with salts of barium; its operating temperature is 1100...1150 °C. Fig. 3 and 4 present a photograph and schematic of the filamentless cathode. This cathode has a number of advantages in comparison with common cathodes with an emitter based on lanthanum hexaboride. First, a lower operating temperature (that of LaB₆ cathodes is 1500...1700 °C) allows to reduce significantly the activator entrainment and increase the cathode lifetime. Second, the discharge may be ignited at the tungsten-barium cathode with the help of auxiliary high-voltage impulses at an uprated flow of the propellant without the preliminary heating of the emitter, so the time of preparation of the thruster to its operation is reduced from 150...200 s (when using LaB₆ cathodes) to 1 s. Presently, investigations of the two following cathodes-neutralizers types are on the way: 1) filamentless cathodes with a tungsten-barium emitter; 2) combined tungsten-barium cathodes, which along with the tungsten-barium emitter and capability of the filamentless ignition have additional heating element (a filament). This heating element can be intended for either initial heating the emitter to streamline the start-up process, especially when it is impossible for some reasons to increase the propellant flow into the cathode at the thruster start-up, or preliminary or preventive heating to recover emission properties of the emitter (regeneration), taking place in the event of poisoning the cathode at ground tests.

Fig. 3

Fig. 4.

1 - emitter; 2 - heater; 3 - getter unit; 4 - igniting electrode; 5 - insulators; 6 - case
3. Propellant Flow Control Unit

The flow control unit (FCU) is developed for propellant supply and its flow control. Its basic parameters are as follows:

- Propellant: xenon
- Inlet pressure: 2 atm
- Anode flow rate: 15 mg/s (±10%)
- Cathode flow rate: 0.5 mg/s (+100% at the start-up)

The unit schematic is shown in Fig. 5.

4. Power Processing Unit

The power processing unit is intended to convert the primary electric power source voltage (27 V) into the thruster main discharge feeding voltage (300 V) and a number of voltage for auxiliary and controlling circuits. The converter input power is 4.5 kW, the conversion efficiency is 92%, the output power is 4.15 kW. The power processing unit mass does not exceed 20 kg.

5. Integrated Thruster Characteristics and Electromagnetic Radiation Reduction

The thruster T-160 is designed for the supplied nominal power of 4.15 kW at the voltage of 300 V. However, when developing the engine, a possibility of varying operating parameters in a wide range without significant deterioration of its characteristics was provided. Thus, the thruster can operate at its nominal power while the voltage ranges from 200 to 400 V. Varying the power supplied within the range from -50 to +20% is also possible. The thruster efficiency is at least 52% at its nominal operating regime, and when deviating from the nominal within the above-mentioned range it remains at least 48...50%. To ensure the thruster to operate with its control in a wide range of power and voltage, the PPU and FCU are required to be modernized.

The investigation of the electromagnetic radiation of the filamentless cathode model thruster jet in the radio-frequency band (1...8 GHz) allowed to define the regimes, at which a reduced level of electromagnetic noises takes place. The investigations of feeding circuit oscillations in the frequency range up to 100 kHz also showed that there are regimes, at which the oscillations level is essentially reduced. At the present time, the reasons and sources of the oscillations are studied in all frequency bands, and the optimization of the thruster parameters in "low-noise" regimes of its operation is on the way.

6. Reliability and Lifetime Provision

The design lifetime of the thruster T-160 is 8000 hours. Long-time demonstration tests of one thruster are planned. It is impossible to confirm the lifetime value and determine the reliability characteristics for a reasonable period of time with the help of the classical techniques, as an extremely large number...
of tests is required. So we are working now on accelerated test methodology (ATM). Several thrusters will be tested for relatively short time (not more than 1000 hours), and, based on the test results, the thruster T-160 lifetime will be predicted. The lifetime prediction is based on the study of change of the degradation main parameters, which determine the engine's failure, and estimation of their critical values. Besides that, the experimental data to be obtained will be used for conducting numerical experiments on modelling the thruster operation, which will allow definition of the most important characteristics of the thruster reliability.

Conclusion

The development and manufacture of the Hall-type thruster of 4 kW power have been completed. The experimental tests conducted have confirmed the design characteristics of the thruster. Currently, the work on improving the thruster characteristics and its preparation to space tests are on the way.