Special design features and test results of an electric jet stationary plasma Hall's thruster for 4.5 kW, usually referred as T-160, will discussed in this paper. Research of T-160 characteristics demonstrated that the thruster has a high efficiency (more than 60%), a low current oscillation rate in power circuits and a low level of magnetic noises.

Introduction

T-160 was designed so that the unit could be used in a NEPSTP Program with a TOPAZ-2 unit (1). Due to the fact that the financing for this program was terminated, the thruster was not subjected to a complete cycle of necessary tests. However, preliminary tests showed that the thruster has very high characteristics and good potential for the future applications with higher power units. The thruster has relatively high characteristics in a broad power range, therefore it can be used in spacecraft's orbit correction systems as well as the primary thrust unit when a spacecraft is transferred from one orbit to another, for example from a low altitude to a geostationary orbiter repositioning of communication or observation satellites.

Special Feature of T-160 Design

The thruster is a plasma accelerator of Hall type with a closed electron drift and a dielectric accelerating channel. Fig. 1 demonstrates a picture of T-160. The thruster consists of two main parts: an anode medium and a cathode-neutralizer medium.

The anode medium has a dielectric accelerating channel, in which formation and acceleration of plasma takes place. The anode medium also contains a magnetic system, an anode gas-distributor, and electric and gas pipe lines.

The accelerating channel has a ring shape and is 26 mm. Diameter of its external wall is 160 mm. Walls of the accelerating channel are fabricated from a Barium Nitride material.

* Keldysh Research Institute of thermal Processes (NIITP), Moscow, Rusia.
** International Scientific Products, San Jose, CA.
The magnetic system contains two poles which provide azimuthal balance of the magnetic field in the accelerating channel of magnetic core, magnetic shunts and five magnetic coils. Four coils are located symmetrically on external magnetic cores elements. The power supply for this can come from a separate current source as well as from a series connection of the main discharge into the circuit.

The central magnetic core of the system has a cylindrical cavity in which a cathodeneutralizer unit can be installed. Such a placement of cathodes will decrease dimensions and unsymmetric features of the system's design. The weight of T-160 with an anode and cathode mediums and connecting wiring does not exceed 7 kg.

A new cathode-neutralizer with a Wolfram-Barium emitter was developed specifically for the T-160 thruster. Its picture is shown on Fig. 2. The cathode design has a special heating element for start-up heating of a W-Ba emitter. There are two ways to initiate a discharge in this cathode: 1) a start-up without preliminary heating of the emission element at a higher gas flow and 2) a start-up with preliminary heating of the emission element at a nominal gas flow.

Testing Equipment

Tests on T-160 were conducted on NIITP units (Russia) and in NASA LERC (USA). The NIITP facility has a horizontally arranged vacuum chamber with 1.6 m diameter, 6.3 m width, and a full volume of 13 m³. There are four panel sections of cryogenic or nitrogen pumps inside the chamber. Outgasing system contains two forevacuum pumps, diffusion pump for a preliminary outgasing, three Helium units with a total capacity of 1.5 kW when the temperature of Helium panels is 10 K, and four nitrogen screens. The total area of helium panels is 220 m² and that of nitrogen screens - 80 m².

A thrust measuring device also is located inside the chamber. T-160 thruster is installed on this device. The chamber is supplied with observatory windows for visual and optical analysis as well as photography.

The power source of T-160 allowed to control a discharge voltage from 150 to 320 V at a current level of 20 A. Connection of the thruster took place through a special LC-filter with inductivity of 30 mH, "shunted by the active?" 100 ohm resistance and two capacitors of 0.5 and 2.0 micro Forads.

Test Results of T-160

Fig. 3 shows a volt-ampere characteristics of T-160 with Xe flow through the anode of 11.3 mg/s, through the cathode 1.0 mg/s and current in coils of magnetic system - 5.85 A (during the tests, coils of magnetic system were supplied from a single power source). According to discharge physics in the thruster, the current does not depend from the applied
voltage, and when in changes from 100 to 320 V, changes in the current don’t exceed 10 % of its average value. (Fig. 3).

Fig. 4 and Fig. 5 demonstrate dependencies of the thrust and efficiency of the thruster from the applied voltage, at the same level of flow and current rate in magnetic coils. Thrust lineary grows from 18.5 to 25.5 g. Efficiency grows significantly from 32 % at 100 V and up to 65 % at 320 V (Fig. 5).

Fig. 6 shows interrelationships of thrust and efficiency of the thruster from Xe flow through the anode at constant discharge voltage and current in magnetic coils. We can see that at 300 V, the thruster has relatively high characteristics in a broad power range, and its efficiency stays at 55-65 % at power level of 2-5 kWt.

Parameters of work of the thruster were confirmed during the tests in LeRC. Its efficiency at a power level close to nominal (4.5 kWt) was 60-65 %.

T-160 thruster can be started in two different ways: 1) fast way (when a cathode is not preliminary heated with an increased Xe flow through the cathode) and 2) slow way (when a cathode is preheated at a nominal flow rate level). Research and analysis demonstrated that both ways are reliable and provide a continuous discharge ignition.

Operation of T-160 was steady in all power range tested. Current oscillations which were measured at the thruster's input (entrance) (without filters), at 300 V does not exceed 15-20 % from the nominal current value. An "oscillogram" of discharge current oscillations received during T-160 tests at LeRC is shown on picture 7. An amplitude of discharge current oscillations does not exceed 1.5-2 A at current level of 15 A.

Research of plasma stream (flow) parameters were conducted during tests at LERC. Fig. 8 shows a density distribution of the ion current in a plasma stream at a distance of 1 m from the thruster. A half-angle of a stream digression (separation) does not exceed 20-25 %.

Registration of electro-magnetic fields during T-160 stand tests was conducted in order to evaluate a possible effect of the power unit on a radio-electronic equipment in a spacecraft. Changes in the spectral density and the electro-magnetic irradiation field voltage were conducted at frequencies of 1.42, 4.7, 4.5 GHz.

Spectral density of electro-magnetic irradiation $S_f$ (W/m$^2$ MHz) and electric field intensity $E$ [V/(m MHz)] was studied. Research of these parameters and their spectral dependencies allows to determine electron temperatures of the quasi-balanced (thermal) level of electro-magnetic irradiation and the level of its unevenness.

Results of spectral density of electro-magnetic irradiation and field voltage of irradiated interferences measurements are presented in the following table and confirm a high level of electro-magnetic noises, generated by the thruster in analyzed frequency ranges.
Table 1

<table>
<thead>
<tr>
<th>Frequency, GHz</th>
<th>Spectral power of electromagnetic irradiation, W/(m² x MHz)</th>
<th>Field voltage of the irradiated electromagnetic interference, E, V/(m x MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.42</td>
<td>$(4-6) \times 10^{-11}$</td>
<td>$(2.0-2.2) \times 10^{-9}$</td>
</tr>
<tr>
<td>2.7</td>
<td>$(1.5-2) \times 10^{-10}$</td>
<td>$(3.5-4) \times 10^{-9}$</td>
</tr>
<tr>
<td>4.5</td>
<td>$(3-4) \times 10^{-10}$</td>
<td>$(4.5-5.5) \times 10^{-9}$</td>
</tr>
</tbody>
</table>

**Conclusion**

Tests of T-160 showed that the thruster has high characteristics in a broad power range. In particular, its efficiency is 60-65%, the thruster operations were steady and reliable. It can also be characterized by a low level of electro-magnetic irradiation. Unfortunately, the thruster did not pass long duration tests therefore we cannot confidently judge about its life time. During the operating time in test conditions, erosion of accelerating channel walls was not observed and preliminary forecasts show that an insulator's life time has to be about 8000 hours.

We would like to thank specialists from LERC and John Sankovich personally for the opportunity they provided to conduct tests at LERC and for the test results they provided.

**References**


Fig. 2. T-160 cathode neutralizer

Fig. 3. T-160 volt-ampere characteristic

Fig. 4. T-160 thrust-voltage dependence

Fig. 5. T-160 efficiency-voltage dependence

Fig. 6. T-160 thrust-efficiency-mass flow dependence

Fig. 7. Current oscillation of T-160 thruster

Fig. 8. Ion current density of T-160 jet