ELECTROMAGNETIC INTERFERENCE OF STATIONARY PLASMA THRUSTER

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ABSTRACT

The results of the radio frequency emission measurements performed during the stationary plasma thruster testing are presented. The thruster operating modes have been investigated depending on applied discharge voltage and xenon propellant flow rate. The relationships between spectral density of electromagnetic radiation power in the frequency range of 0.5 to 10 GHz and thruster performance characteristics have been obtained. The generalized information on the electromagnetic emissions and the unstable thruster operating modes are presented in relation to discharge voltage.

INTRODUCTION

The important conceptual phase of plasma stationary thruster design is electromagnetic compatibility evaluation of electric propulsion systems and spacecraft radio communication equipment. It is essential that electromagnetic fields produced by spacecraft propulsion systems are less than the standard emission limits over the equipment operating frequency range [1]. Electromagnetic interference of stationary plasma thruster is associated with high-frequency plasma instabilities in a main discharge chamber and non-equilibrium plasma plumes [2]. Electromagnetic radiated emission measurement are correlated with the analysis of physically realizable mechanisms of plasma instabilities under specific plasma accelerating conditions. The thruster radio frequency image as electromagnetic interference contributor based on the experimental and analytical evaluation results can be used to estimation of space communication efficiency.

The electromagnetic compatibility is most essential for increased power performance characteristics of stationary plasma thrusters.

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Fig. 1. Schematic diagram of SPT-100 electromagnetic environment evaluation in the vacuum test facility at the Scientific-Research Institute of Thermal Processes.

Fig. 2. High-frequency probe for plasma wave measurements.
using the standard radiation source. The standard radiation field was performed by the discharge noise generator with spectral radiation density specified beforehand.

Electric and magnetic antennae were located to evaluate the electromagnetic field components at different positions inside vacuum facilities. The measurements made it possible to evaluate the radiation field density in the vicinity of propulsion engines. The distributions of plasma instability fields in a thruster discharge chamber were defined by the high-frequency plobes (Fig. 2) to identify the configuration of radiated emission contributors. The thresholds of electromagnetic wave generation were determined from discharge voltage and xenon flow rate dependencies.

The energy parameters of radiated emissions such as spectral radiation energy density, non-equilibrium emission degree as related to the thermal level and electric field intensity in the radio set frequency band were used independently of measurement conditions and instrumentation.

Radio Frequency Measurement Results

The SPT operating modes were characterized by the multitude of plasma instabilities and oscillations generated over a wide range of frequencies and scales. The oscillations located in a plasma accelerating chamber and power circuits were considered in the other experimental works produced previously.

The generalized information on plasma instabilities and plasma wave in relation to an operating mode at the discharge voltage-current performance and frequencies presented in Fig. 3. The plasma oscillations in the wide can produce the electromagnetic interference, essential to radio frequency communication efficiency. The electromagnetic fields are excited by magnetic sound waves and electron plasma.

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Fig. 3. Classification of the SPT-70 instabilities according to oscillation frequencies and thruster operating modes at a voltage/current characteristics.
oscillations as a result of electron and ion stream instabilities in a plasma accelerating chamber. The report presents the results of radiated emission measurements in the frequency range of an electron Langmuir frequency in the main discharge chamber.

The radio frequency tests in the frequency range 0.5 to 10 GHz have been carried out for different experimental models of SPT-70 and SPT-100. The radiated emission intensity in SPT operation didn't exceed $10^{-9}$ to $10^{-7}$ W/m²·MHz that was significantly less then the specification limits for electromagnetic interference power. At the main operating points the SPT electromagnetic interference satisfied the compatibility requirements.

The overall characteristics of electromagnetic environment are presented in the Table 1 for experimental SPT-70 model ("Fakel" Enterprise, 1972). The most extensive electro-magnetic radiated emission in the frequency range of 1 to 10 GHz originate from an ionization region of SPT accelerating chamber with unstable electron velocity distribution function. The conditions for electron stream instability during plasma accelerating process take place in the vicinity of the discharge chamber wall as indicated from experimental field distributions obtained by the high-frequency probe. The electromagnetic radiated emissions from an external region of the thruster exhaust plume by thermal plasma oscillations in the frequency range of 0.5 to 1 GHz.

The non-equilibrium radiated emissions essentially depend on the thruster discharge voltage. The high-frequency electromagnetic interference (Fig. 4) and the low-frequency plasma plume oscillations (Fig. 5) are most intensive at high-voltage modes of the investigated SPT thruster modifications.

The electromagnetic field environment generated by SPT-70 accelerating chamber is most intensive at the specified discharge current range (Fig. 6) associated with xenon-flow rates in the range of 1.5 to 2.5 mg/s.

Table 1. Spectral and energy parameters of electromagnetic environment produced by SPT-70

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Electromagnetic interference source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band, GHz</td>
<td>Ionization region of accelerating chamber</td>
</tr>
<tr>
<td>Spectral radiated emission density, W/m/MHz</td>
<td>$10^{-9}$ - $10^{-8}$</td>
</tr>
<tr>
<td>Non-equilibrium radiated emission degree</td>
<td>$10^2$ - $10^3$</td>
</tr>
<tr>
<td>(with respect to the thermal level)</td>
<td>Discharge voltage</td>
</tr>
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</table>

Fig. 4. Radiated emission intensity in relation to SPT-70 discharge voltage
The experimental results are in agreement with theoretical electron stream instability model of an accelerating Hall plasma region [2]. The instability spectrum is determined by electron langmuir oscillation frequencies in a main discharge chamber. The maximum frequencies of these oscillations do not exceed 10 GHz. The indicated magnitude is limited frequency of electromagnetic interference spectrum at the nominal SPT operating modes that should be allowed for in the spacecraft communication design. The electromagnetic interference density of the SPT-100 experimental model is 1 - 1.5 orders of magnitude more than the SPT-70 interference density (Table 2).

Under SPT-100 operating conditions, the discharge voltage thresholds of electromagnetic interference generation are absent at voltage/current characteristics and the radiated emissions exceeded the thermal level are observed to be at any operating mode. The important experimental result consists in the fact that the highest efficiencies are achieved at the thruster operating modes characterized by low level of the electromagnetic interference. This fact can be used in the remote sensing control of SPT operating during the ground-based tests.

The envelope of radio frequency interference represents a random impulse process with noise peak

Table 2. Correlation of electromagnetic environment produced by different SPT modifications

<table>
<thead>
<tr>
<th>Frequency band (L, S and C band), GHz</th>
<th>SPT-70, &quot;FAKEL&quot; Enterprise, 1972</th>
<th>SPT-100, &quot;FAKEL&quot; Enterprise/NIITP, 1993</th>
</tr>
</thead>
<tbody>
<tr>
<td>(220 V, 2.5 A)</td>
<td>Spectral radiated emission density, W/m² MHz</td>
<td></td>
</tr>
<tr>
<td>1 - 2</td>
<td>5 x 10⁻⁹ - 10⁻⁸</td>
<td>10⁻⁸ - 10⁻⁷</td>
</tr>
<tr>
<td>2 - 4</td>
<td>(1-3) x 10⁻⁹</td>
<td>(2-5) x 10⁻⁹</td>
</tr>
<tr>
<td>4 - 7</td>
<td>7 x 10⁻¹⁰ - 10⁻⁹</td>
<td></td>
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duration of 0.01-0.1 ms and random appearance time of 1-5 ms.

The radiated emission directivity have been evaluated from the electromagnetic field distributions inside of the vacuum test facility. Because the facility dimensions are considerably in excess of the radiated emission wave length, the metal facility doesn't exert resonance action on the high-frequency fields distribution in the frequency band of 3 GHz. Under measurement conditions in the used metal facility, the radiated emission directivity is specific to the lowvoltage operating modes. At the highvoltage modes the radiated emission field generated by the thruster is smoothed out in the vacuum test facility and the SPT field distribution is similar to the isotropic field of the standard microwave plasma discharge generator used for calibration measurements. The expansion of the SPT radiation pattern can be explained by the interference generation from the SPT structure components contacted with the plasma instability regions. Thruster input current leads and operating mode diagnostics elements can be considered as radiated interference contributors and active antennae with plasma wave excitation. The possibility of the structure component radiation is supported by experimental results. The plasma wave energy conversion in an instability plasma region is observed to be by an electric unloaded probe used in the experiment. Under test conditions, when the metal structure components of spacecraft systems are in contact with the instability plasma plume, the radiated interference intensity in the frequency range of 2 to 4 GHz can increase by 1-1.5 orders of magnitude.

CONCLUSION

The electric propulsion systems based on the stationary plasma thruster modifications at the nominal operating modes exhibit the low level electromagnetic interference characteristics. An electromagnetic environment produced by the thruster doesn't impact substantially on spacecraft systems at low earth orbit satellites and satisfy the compatibility requirements.

The electromagnetic compatibility evaluation is necessary for increased power performance and at off-normal operating modes of stationary plasma thruster.

The thruster radiated interference could potentially impact on long-range communication and space scientific instrumentation. Because of this, the electromagnetic compatibility measurements are to be an important component of thruster ground-based tests.

There is a need to develop a theory, as applied to the stationary plasma thruster, for a complete understanding of the electromagnetic wave generation and evaluation of space communication efficiency.

REFERENCES