Self-electromagnetic emission from a thruster with anode layer operating with krypton and xenon

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Abstract. This paper considers the study of self electromagnetic emission from the experimental model of low-power thruster with anode layer (TAL) developed by the Bauman Moscow State Technical University. The measurements were carried out during the thruster operation on krypton and xenon for three operating modes: 600 W, 800 W and 1000 W at a discharge voltage of 300 V. Parameters of the generated electromagnetic fields were measured in frequency range from 1 GHz to 12 GHz in the filter bandwidth of 1 MHz. The receiving antenna was installed at a distance of 1 m from the thruster exit plane, perpendicularly to its axis. The results of analysis and comparison of TAL emission spectral characteristics during its operation on krypton and xenon are presented.

1. Introduction

Today, the global rocket and space industry is one of the main consumers of the total amount of xenon produced (about 15 thousand m³/year). This rather rare inert gas has already become a traditional propellant for electric propulsion systems (EPS) used to control the spacecraft motion [1]. Expansion of the range of tasks performed by small satellites, from single educational and scientific projects [2] to multi-satellite communication systems (OneWeb, Starlink) [3,4] has led to an increase in the number of satellites launched [5]. Equipping thousands of satellites with electric propulsion systems using xenon is a technological and economical problem. Krypton, a much more accessible inert gas, seems to be the most promising alternative propellant for electric propulsion [6,7]. The undeniable advantage of krypton is the possibility for its use in combination with the available test-bench infrastructure, designed for testing xenon-fed EPS, cathode neutralizers and propellant storage and supply systems, without its significant modification.

However, with the changeover to krypton, it is necessary to provide an increased krypton density in the discharge region [8,9] in order to provide thrust characteristics comparable to those obtained with xenon. This influences the krypton thruster lifetime negatively. Another problem originating with the changeover to a new propellant is the unknown level of the thruster self electromagnetic emission arising from various instabilities and intrinsic plasma oscillations [10,11]. Such emission can disrupt the operation of the onboard equipment. Electromagnetic compatibility (EMC) studies are conducted to assess the effects of interaction of thruster-generated emission with components of onboard systems [12-15].
This paper presents the results of study of self emission from a single-stage thruster with anode layer (TAL) during its operation on krypton and xenon.

2. Methods and materials

2.1. TAL experimental model
The self electromagnetic emission from a thruster with anode layer was studied using an experimental model developed by the Research and Educational Center "Ion-Plasma Technologies" of the Bauman Moscow State Technical University. The thruster design is based on the scheme of a single-stage accelerator with azimuthal electron drift and electrically conductive walls of the accelerating channel [1] (figure 1). A special feature of the thruster design is the use of a magnetic shunt for profiling the magnetic field distribution in the accelerating channel. Such solution allowed us to offset the magnetic field maximum beyond for the thruster exit plane, to reduce the depth of the accelerating channel and, consequently, to provide a long lifetime of the device. In this thruster, the working chamber of the gas distributing anode is used as a shunt.

Structurally, the thruster (figure 2) consists of the anode unit and the magnetic system that simultaneously acts as a load-bearing body. The thruster is equipped with one central and four peripheral electromagnetic coils. The average diameter of the accelerating channel is 38 mm, its width and depth are 13.5 mm and 6 mm, respectively. The geometry of accelerating channel has been pre-optimized to operate on krypton. The poles were covered with thin stainless steel screens. For testing, the thruster was equipped with a cathode-neutralizer produced by the Experimental Design Bureau "Fakel".

2.2. Test facility and description of the experiment
Research tests aimed at the determination of self electromagnetic emission from TAL experimental model were carried out at the combined electro-vacuum test facility U-2V of the Moscow Aviation Institute [10]. It comprised two separate connectable zones: a vacuum one and a measuring one (figure 3). The vacuum zone was a horizontally arranged cylindrical vacuum chamber (VC) (4) with the volume of about 18 m³, diameter of 2 m and length of 5.5 m. The chamber high-vacuum pumping was provided by cryogenic pumps (5) with the total pumping capacity of over 100 000 l/s. Before thruster firing, the residual pressure was not higher than 2×10⁻⁶ Torr. During the thruster (3) operation, the VC pressure was maintained within the range of (2 – 4)×10⁻⁵ Torr.

Figure 1. Schematic of the thruster with anode layer. Figure 2. Photo of the thruster with anode layer (Bauman Moscow State Technical University).
Figure 3. Arrangement of test facility comprising shielded anechoic chamber (SAEC) [10].

The measuring part is a mobile shielded anechoic chamber (1) with an integrated radio-transparent fiberglass vacuum cylinder (2). SAEC is mounted on the platform (6), which can move relative to the fixed main vacuum chamber along the rail track (7). In the working position, the radio-transparent vacuum cylinder is joined to the main vacuum chamber, forming a common vacuum volume. The SAEC internal surfaces are lined with the pyramid-shaped absorbers made of radio-absorbing material. The effective range of the absorbers is from 0.3 GHz to 18 GHz and higher with an anechoic coefficient of not worse than -20 dB. Measuring antennas (17) are installed on the dielectric floor (10) mounted inside SAEC. They are connected to the measuring equipment (18) located outside SAEC via a panel with feed-through connectors.

The TAL experimental model operating on xenon and krypton was tested at the discharge voltage of 300 V with three power levels of 600 W, 800 W and 1000 W (table 1).

Table 1. Parameters of TAL operation on xenon and krypton at the test facility U-2V of RIAME MAI.

| Propellant | Anode flow rate, mg/s | Discharge voltage, V | Discharge current, A | Discharge power, W | Dynamic pressure, $\times10^{-5}$ torr |
|------------|-----------------------|----------------------|----------------------|--------------------|-------------------------------------|
| Xe         | 2.0                   | 300                  | 2.05                 | 600                | 3.0                                 |
| Xe         | 2.5                   | 300                  | 2.66                 | 800                | 3.7                                 |
| Xe         | 3.1                   | 300                  | 3.33                 | 1000               | 4.4                                 |
| Kr         | 1.47                  | 300                  | 1.99                 | 600                | 2.0                                 |
| Kr         | 1.92                  | 300                  | 2.66                 | 800                | 2.4                                 |
| Kr         | 2.33                  | 300                  | 3.33                 | 1000               | 2.9                                 |
TAL was mounted inside the radio-transparent vacuum cylinder using a dielectric holder (figure 4) movable along the guides. The thruster axis coincided with the vacuum volume symmetry axis. The thruster base axial position was fixed as the center in order to provide orientation for the line of sight of the measuring antenna phase center outside the vacuum volume.

![Figure 4. TAL mounted inside the radio-transparent vacuum cylinder.](image)

The measuring antenna P6-123 with an operating frequency range from 0.9 GHz to 12.4 GHz and linear polarization was installed on the working floor inside SAEC. In this frequency range, the horn design provided low voltage standing-wave ratio (VSWR) and monotonous gain factor dependence on frequency. The principle of antenna system operation is based on the conversion of the power flux density of the electromagnetic field in the antenna aperture into the corresponding high-frequency power in the link. During the experiments, the following antenna angular location relative to the thruster geometric axis was chosen: \((90\pm5)^\circ\). The angle was measured from the direction of the thruster plasma plume. The antenna mounting elements allowed changing its polarization by \(90^\circ\).

3. Results and discussion

The experimental data were processed by converting the power values measured at the output of the measuring antenna into the values of the electric field strength in its aperture.

Results are presented in the form of spectral response curves (figures 5, 6), where the frequency from 1000 MHz up to 12000 MHz is plotted along the horizontal axis and the calculated electric field strength with the quantity dimension of dBmkV/m/MHz is plotted along the vertical axis.

A background radiation level corresponding to the non-operating thruster is present in all figures.

(a) Vertical polarization (VP)  
(b) Horizontal polarization (HP)

![Figure 5. TAL emission spectrum during its operation on xenon.](image)
Analysis of the experimental results of the TAL interference emission evaluation in the frequency range of 1000 MHz -12000 MHz for the discharge modes of 600 W, 800 W and 1000 W showed that TAL has a broadband emission spectrum recorded in the frequency band from 1 GHz to 4 GHz for both kinds of propellant.

During its operation on xenon, the TAL power variation within 600-1000 W did not lead to significant increase in emission level in frequency range of 1-3 GHz. At the same time, the level of emission with horizontal polarization was 2-5 dB lower than with vertical polarization.

During its operation on krypton, the TAL power variation within 600-1000 W caused a more significant emission level variation in frequency range of 1-3 GHz: up to 7 dB for horizontal polarization and up to 10 dB for the vertical one. At the same time, the level of emission with horizontal polarization was also 2-3 dB lower than with vertical polarization.

4. Conclusion
Based on measurement results, the following conclusions can be made:
- emission spectra recorded during the TAL operation on xenon and krypton coincide qualitatively, having a higher level for krypton;
- vertical polarization dominated in the studied modes for both propellants;
- compared to xenon, the maximum emission level excess during the TAL operation on krypton was about 10 dB in the frequency range from 1 to 2 GHz for vertical polarization.

When studying the background radiation, about 4 groups of discrete frequencies were detected, in which the dominant narrow-band external interferences were recorded. Their sources are the base stations of mobile operators: GSM-900 (925-960) MHz; GSM-1800 (1805-1880) MHz; UMTS (3G): (2110-2170) MHz; LTE (4G): (2600-2700) MHz.

These interferences enter the vacuum chamber through the pumping system channels and without installing special barrier systems into their links it is difficult to prevent their penetration. Therefore, measurements on these frequencies were excluded, which is seen as the blanks in the plots.

The thruster electromagnetic emission essentially depends on its power supply system characteristics, so for the development of flight model of electric propulsion system on the basis of TAL operating on krypton the data obtained require further clarification and study.

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