INVESTIGATION OF SELF-HEATED HOLLOW CATHODES OPERATION POSSIBILITY IN WATER MOIST STREAM OF HIGH-PRESSURE CONDITION

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Abstract

At present we have new practical using of a gas discharge, that needs plasma producing in number of pressure levels: MPD – generators, lasers of a gas discharge, plasma – chemical reactors, neutralizers of a electric charging gas environments ect.

So in [1] it was shown that the electric propulsion system (EPS) could be used for solving of a spacecraft (SC) surface different electric charging problem. But, as the specialists researching in MPI of UESA shows, the space electric charge of analog level is in a last of powerful electric supply vapor turbo generators. Specialist's estimation has shown that neutralizing of a electric charge can increase of a turbine efficiency from 0,5 up to 1,5 %.

We have carried out number of experiments aim of which were the researching of EPS working possibilities in high pressure (from $0{,}5\cdot10^3$ up to $50\cdot10^3$ Pa) conditions, operation conditions in vapor-stream atmosphere and neutralizing capability of a plasma generator, foundation of start regimes.

Theoretical part

At first it is necessary to mark main conditions of the plasma neutralizer operation.

1. This is very important from EPS, environment pressure (from 2 up to 50 $*10^3$ Pa) point of view.
2. The reactive hard environment for all points is in high temperature condition (more then 500 ^{0}C).
3. Existence of a space charge, distribution scheme of which is shown on the fig. 1. Also approximation dependence is presented.

It is necessary to mark the 3 zone: I – zone with small gradient of a potential, II – transition zone, III – zone with maximum space charge.

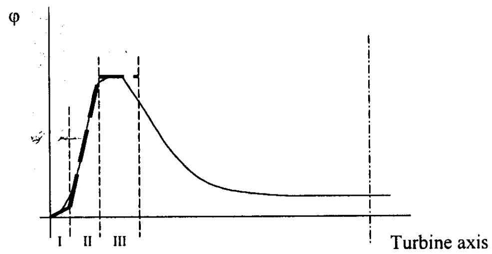

Fig. 1 Potential distribution on a turbine length.

Most important question of pre-theoretical investigations is the question about plasma electron component transportation possibility in high-pressure environment.

One of analyze variants is a studying of electrons energy distribution function (EEDF) transformation. It is well known that the EEDF in of all particulars direction movement condition could be described by the equation [2]:

$$f(\varepsilon)=\frac{1}{\sqrt{4\pi\varepsilon_h kT_e}}\exp\left(-\frac{\varepsilon+\varepsilon_h}{kT_e}\right)sh\left(\frac{2\sqrt{\varepsilon\varepsilon_h}}{kT_e}\right) \quad (1)$$

In electrical field presence case the energy of direction movement for each electron could be computed by equation:

$$\varepsilon_h = e\frac{E}{l} \quad (2)$$

where l - is the length of a electron with energy ε :

$$l=\frac{1}{n_a\sigma_{ea}(\varepsilon)}=\frac{kT_a}{P_a\sigma_{ea}(\varepsilon)} \quad (3)$$

Pa, Ta – the density and the temperature of a neutral component, E – the electric field. In the (2) the any electron elementary collisions (exclude the electron-atom type of collision) were, because the ionization degree that was obtained by experiments is vary small. Calculations of (1) with (3) were carried out.The computation data of electrons energy distribution function (EEDF) dependencies from the are shown in the fig. 2. More particular calculation had shown possibilities of a discharge evolution and breakdown by a high-voltage electric discharge type between the I and II zones and maximum space charging.

So for determination of the described problem it is necessary to obtain the quantity of electrons which will reach the border of the I – II zone.

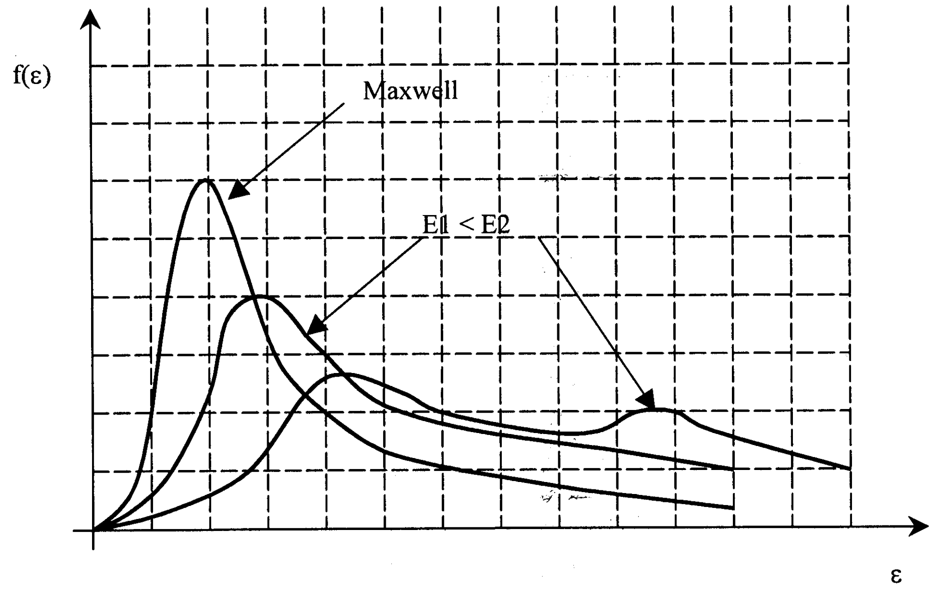

Fig. 2 Transformation of the EEDF in the second zone limits.

When

$$kTe >> kTa \tag{4}$$

condition, we have γ~0 and intensity of electric field is small (these conditions is for first zone) we could consider electrons drift velocity $v_{dr} \sim E$ i.e. $v_{dr} = \mu E$, where μ- coefficient of mobility. So in the coordinate system which moves with the v_{dr}, the equation of electron balance could be written like this:

$$\frac{dn}{dt} = N^{+} - N^{-} \tag{5}$$

Where N^{+}, N^{-}- velocity of a electrons generation and loosing. We consider processes of a adhesion also allows the electron loosing:

$$M + e^{-} \to M^{-} \tag{6}$$

(M- any molecule or atom).

The estimation of a all types ionization, recombination processes velocity had shown that these processes were to be disregarded. Only dissociation adhesion processes of electrons is to be taking account:

$$\begin{aligned} H_2O + e^{-} &\to OH + H^{-} \\ H_2O + e^{-} &\to H_2 + O^{-} \\ H_2O + e^{-} &\to H + OH^{-} \end{aligned} \tag{7}$$

Taking in to account (5):

$$\frac{dn_e}{dt} = -\beta n_e n_a \tag{8}$$

β - the constant of a reaction velocity. Solution of the equation (8) is the function:

$$n_e = n_{eo} \exp(-\beta n_a \tau) \tag{9}$$

n_{eo}- the concentration of electrons in the exit from the neutralizer. If use space variation:

$$n_e = n_{eo} \exp(-\beta n_a \frac{x}{\mu E}) \tag{10}$$

Calculation of (10) had shown that the borders of I and II zones could reach electrons quantity more then necessary one for the neutralization.

Experimental part

The researching was carried out by 2 stage. On first stage the EPS in role of plasma neutralizer in high-pressure conditions (from 10^3 up to $50 \cdot 10^3$ Pa) of atmosphere set, characteristics were studied. Two type of neutralizers were researched (fig. 3. and fig. 4.).

Ignition was made by high-voltage (1,2 kV) power supply source, with shortcut current 300 mA with a voltage between electrodes. After the breakdawn the main discharge was developed up to stationary parameters (discharge current at about 7 A). Hollow thruster (HT) as a neutralizer was tested in pressure 1...50 10^3 Pa in a atmosphere gas. It was noted that increasing of pressure increases the discharge voltage from 30 up to 60 V with unstable arcing (in pressure level more than 50 10^3 Pa). On electrical probe (plate 10 cm^2), that was under negative potential in relation to HT cathode, the neutralizing current was up to 50 mA. The dependence of a neutralizer voltage with so current level is shown in the fig. 6. It is obviously that with operating neutralizer the potential of space charge (which is defined by arcing voltage) decreases from 10 down to 2 times with pressure increasing from 1 up to 25 10^3 Pa. So expediency of neutralization by plasma method is obviously.

Next very important stage was researching of a glow discharge evolution beginning regimes between electrodes, one of which is grounded (the turbine body) and another is under space charge potential.

The voltage of a breakdown ignition as environment pressure function with neutralizer and without it is shown in fig. 7. The result is obvious.

Researching of neutralizer in a vapor atmosphere shows, that on probe (plate 50 cm^2) with voltage 20 kV, neutralizing current was about 200 mkA in a distance to probe 150 mm.

Pre-experiments has shown working capability of EPS in a so hard conditions, high quality of space discharge neutralizing.

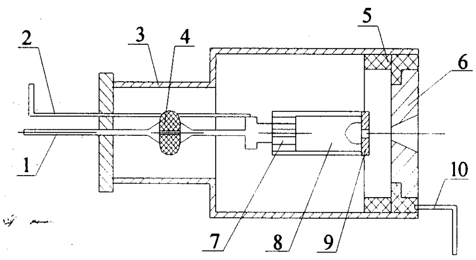

Fig. 3 The developed neutralizer, which is based on SHC technology

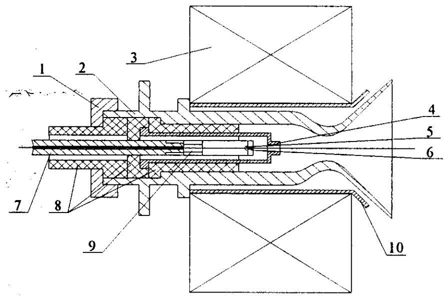

Fig. 4 The developed neutralizer, which is based on MPD technology.

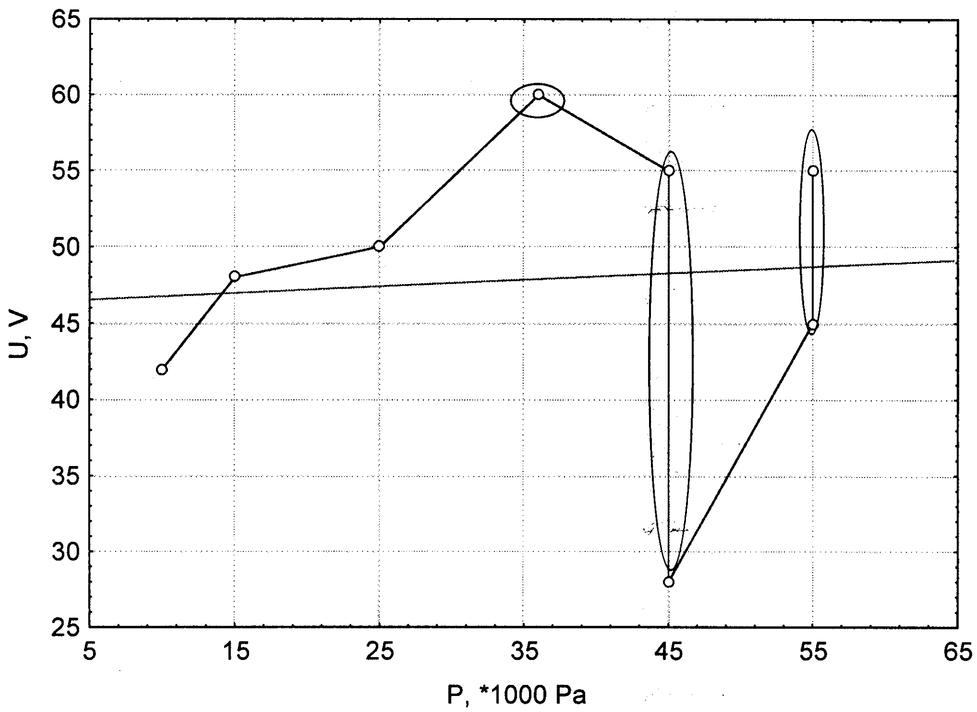

Fig. 5 EPS operating in a pressure range from 3,5 up to 23 10^3 Pa.

- zone of unstable arcing.

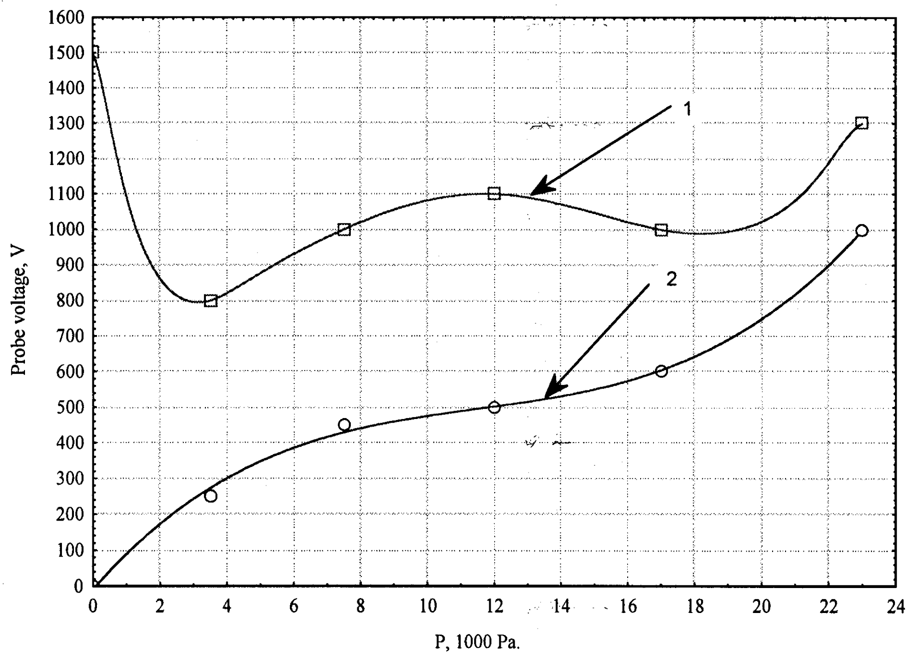

Fig. 6 1 – traditional source operating;
2 – proposed source operated.

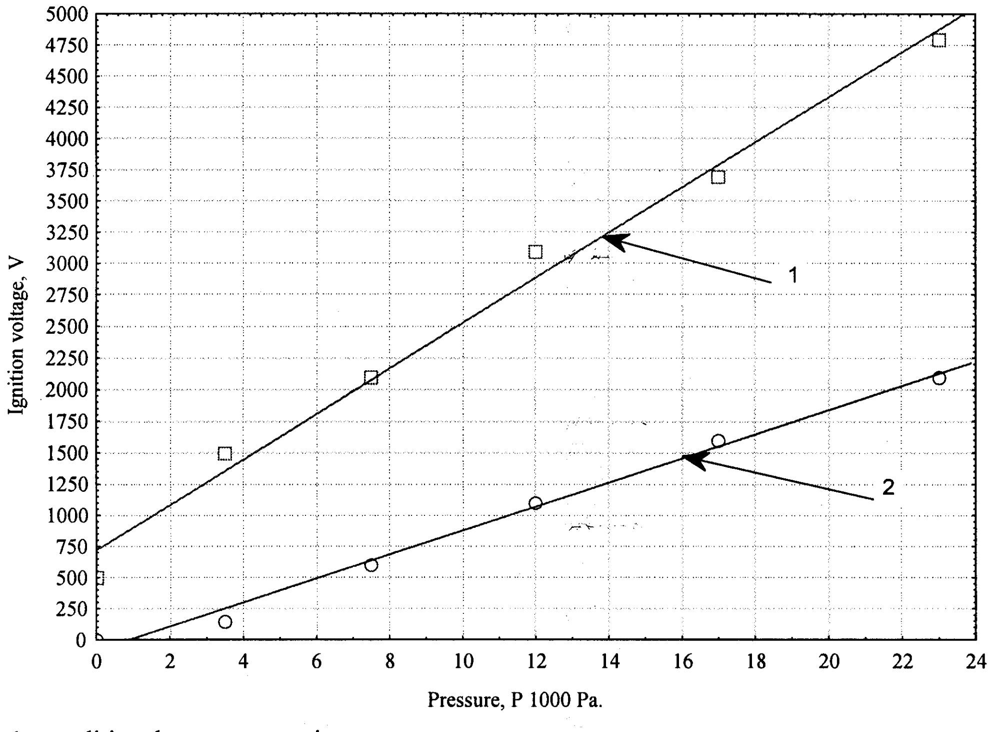

Fig. 7 1 – traditional source operating;
2 – proposed source operated.

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[1] Кошелев Н. Н., Лобов С. А., Лоян А. В. "Исследование режимов работы электроракетной двигательной установки в качестве нейтрализатора дифференциальной зарядки космического летательного аппарата", *Материалы III конгресса двигателестроителей Украины*, Рыбачье, 1998 г, стр 533-538.

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