INVESTIGATION OF POSSIBILITY TO INCREASE THE TRUSTIER EFFICIENCY, DISCHARGE EFFICIENCY AND THE SPD LIFE-TIME BY INFLUENCE TO THE SPEED OF THE NEUTRAL PROPELLANT GAS STREAM

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Abstract

Present researches has been carried out to find a ways of the creation of SPT with the operation power not more when 0.5 kW and with the high enough performance (specific impulse I_{sp} and thrust efficiency η_F).

In order to solve this problem the method (which not used before) of reducing of neutral gas flow velocity (GV) that will increase the gas concentration in the discharge chamber (DC) has been proposed. This effect has been reached due to the using of the new material and the nontraditional DC geometry for the DC creating.

Using of this method will allow to increase the DC lifetime, to decrease the SPT operation power while the gas ionization efficiency shall be able keep at the constant level.

During experiments has been received : η_F=58%, operation power N~0.5 kW, anode mass flow rate m_a=1.43 mg/s for Xe, I_{sp}=1930 s, discharge voltage V_d=260 V.

The experiment result has confirmed the possibility to use the proposed method for creating SPT with the high enough performance and with comparatively low operation power.

Introduction

Principal SPT diagram in Russia was proposed by professor A.Morozov, under his leadership in the Kurchatov institute of atomic energy, the complex of the fundamental researches was fulfilled and the first SPT laboratory models were created. In that time some possible ways were developed to improve the SPT performance. Due to the investigation of scientists of various countries, especially in Russia, was showed the possibility to developed the modern SPT.

One of problems that must be solved by the designer of a modern SPT models is to create thrustier with the comparatively low power level and with the high enough performance. It is possible to solve this problem by way of the discharge current decreasing, that requires decreasing of the anode gas mass flow rate. Then it is necessary to decrease the DC geometrical size [1] to keep the high enough gas concentration for the effective gas ionization (GI). But the decreasing of the geometrical size do not allow to give a high enough value of η_F , I_{sp} [1], [2]. Thus the problem of the effective gas ionization was not solved. The method (which not used before) of GV reducing that will increase the gas concentration in DC has been proposed to solve this problem.

As the SPT base model (BM), for further modifying, was used the SPT model which has been created for the 0.5 kW operation power level and the anode mass flow rate more than 2 mg/s with the high performance.

Influence of the neutral gas flow velocity on the SPT operation efficiency

The purposes of our research are as follows:

1) to carry out the theoretical estimate calculation of GV influence on the GI efficiency in the DC and also to research the SPT operation power decreasing than condition of effective GI is keeping.

2) to carry out the theoretical estimate calculation of possibility of the SPT life-time increasing by way of decreasing of the specific power ion stream impact on DC than condition of effective GI is keeping.

1. In DC there is a region so called the lay of ionization and acceleration (LIA) with length L_l . Alone LIA take place the basic U_d reducing. In order that in LIA the effective GI take place it is necessary

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that the ionization path of an atom λ_i (in the cathode direction) must be less than L_l

$$\lambda_i < L_l \qquad (1).$$

For $\lambda_i = V_a / (<\sigma_i V_e> n_e)$ and $n_e = m_a / (SMV_i)$

$$\lambda_i = (V_a SMV_i) / (<\sigma_i V_e> m_a) \qquad (2),$$

where: M- atom mass; V_a ,V_i - typical gas velocity of an atoms and ions alone the DC channel; $<\sigma_i V_e>$ - ionization rate factor.

Then for effective GI in DC it is necessary to limited the mass flow rate m_a :

$$m_a/S > (V_a V_i M)/(<\sigma_i V_e> L_l) \qquad (3).$$

At the SPT operation, in LIA, is forming the ion stream with density $Q_i = n_a <\sigma_i V_e> L_l n_e$ where n_a - concentration of the neutral atoms. As frequency of an ionization electron-atom collisions $\nu_i = n_a <\sigma_i V_e>$

$$Q_i = L_l n_e \nu_i \qquad (4).$$

Value of the electron stream density Q_e in LIA

$$Q_e = n_e b_\perp E \qquad (5),$$

where: elektric field strength $E = U_d/L_l$,$b_\perp$ -- possibility of electron to move to the anode in E×B fields due to an electron-atom collisions with frequency ν_e .

$$b_\perp \sim \nu_e / (EB^2) \qquad (6).$$

From requirement $Q_i = Q_e$, and (6) follows

$$L_l = (U_d/B\omega_e)^{1/2}(\nu_e/\nu_i)^{1/2} \qquad (7),$$

where $\omega_e = eB/m_e$. In our case we can admit [3], that

$$(\nu_e/\nu_i)^{1/2} = const \qquad (8).$$

Then

$$m_a/S > K\, V_a \qquad (9),$$

where we shall be think that $K=(B\omega_e)^{1/2}(\nu_e/\nu_i)^{1/2}M/<\sigma_i V_e>$ =constant and is not depend from V_a and the geometrical sizes.

Thus from (9) follows that if we shall reduce m_a and at the same time V_a it is possible to keep the effective GI (than S is constant). Also as I_d is reduced as m_a is reduced and so we can to reduce the input operation power N.

2. Let examine dependence of DC life-time from SPT operation parameters and DC geometrical sizes. DC life-time depend on the density j_{iw} of the ion current which droped on the DC wall, the DC wall thick δ , ion energy that is determined by U_d.For the seting acceleration regime

$$j_{iw} = c_{iw} m_a / (Md\pi b) \qquad (10),$$

where c_{iw} - fraction of the summary ion flow that is droped on the DC wall. For the estimate calculation we shall be think that the velocity of the volume DC material sputtering by ions S_v

$$S_v \sim k_v U_d \qquad (11),$$

where k_v coefficient of S_v . Then the velocity of the wall thick reducing V_s

$$V_s \sim k_v U_d j_{iw} \qquad (12),$$

and as time of DC sputtering $\tau_s = \delta / V_s$,

$$\tau_s \sim (b^2 d)/m_a \sim b / V_a \qquad (13).$$

Thus results (9), (13) of an estimate calculations show than specific ion stream power impacting is reducing (by the way of the simultaneously decreasing of m_a and I_d) it is possible to increase the DC life-time at constant geometrical sizes. At the same time it is possible to keep effective GI by way of the GV reducing.

Vacuum facility and influence of the vacuum chamber pressure on an experimental results

SPT operation parameter measurements has been carried out at the dynamic vacuum pressure in the vacuum chamber P=2--2.5*10^{-4} Torr, which has been keeping by two turbormolecular pumps at summary productivity 2500 l/s.

In order to measure thrust was used the compensation thrustmeter with error not more than 5% at measuring thrust in the range 1--5 g.

There are a data of the vacuum chamber pressure influence to the SPT operation parameter (discharge current I_d , thrust F). These data has been given before present researches for operation parameters U_d=190 V, m_a=1.6 mg/s Fig. 1. These dependencies: I_d(P), F(P) has been used to treat an experimental results.

The experimental modifying SPT model and an experimental results

For further modifying has been used the SPT model which was created for the 0.5 kW operation power level and the anode mass flow rate more than 2 mg/s with the high performance due to the so called magnetic screen using [4]. The gas flow through the anode-gasdistributer alone the DC channel radius. The scheme of the thrustier is shown on Fig. 2.

In order to decrease GV alone the DC channel has been used a new materials for DC creation and the DC nontraditional geometry.But modyfying DC has not leaded to necessity to change neither desing nor size of the BM magnetic curcuit.

The base geometrical sizes of MM are a very same that sizes of BM: the median diameter of the DC channel d=5.5 sm, the cross-section area of the DC channel S=24 sm^2 , the channel length L=2.6 sm . Cathode-neutralizer was a plasma hollow cathode using W-Ba emitter–modifying cathode M3.07KH[5].

The electric circuit of a magnetic coils was feeded by the current of the discharge circuit (thus the coil current I_c equal to the discharge current I_d). Optimization of the I_c due to the I_d decreasing has not been made.

Dependencies $F(U_d)$, $I_d(U_d)$ has been given at the chamber pressure $2\text{--}2.5*10^{-4}$ Torr (for N_2). Dependence $I_d(U_d)$ are show at Fig.4,5 without correcting. Dependencies $F(U_d)$, $I_{sp}(U_d)$, $\eta_F(U_d)$ has been corrected to the condition at the vacuum chamber than the pressure $P=5*10^{-5}$ Torr (according to the date Fig.1).

During experiments with the MM m_{a1}=0.93 mg/s , m_{a2}=1.26 mg/s , m_{a3}=1.43 mg/s that is less, than it is necessary for the effective ionization in BM (with the similar geometrical sizes).

Appearance of the U_d on I_d dependence (VID) is typical for the effective gas ionization in DC that has confirmed the advantages of MM comparatively with BM.

Dependencies: $I_{sp}(U_d)$, $\eta_F(U_d)$, $I_d(U_d)$, appearance of VID Fig.3 ... 6 are show the high enough performance at the comparatively low operation power level of MM.

It is possible, that the high I_{sp} , η_F and F has been given due to the increasing of the two-charge ion part in the summary ion stream.

Thus the modifying of the BM in order to decrease GV allow to decrease the operation power level then the SPT performance is at the high enough level.

Also decreasing of the specific power impacting of the ion stream on DC of MM (comparatively with BM) allow to wait increasing of the DC life-time.

Conclusion

Theoretical estimate calculations and an experimental date (η_F=58 % , operation power N~0.5 kW, I_{sp}=1930 s) are confirming the possibility to support the high enough SPT performance at the mass flow rate decreasing (and correspondently at the decreasing of the operation power) by the influence on the GV when the DC cross-section area is constant.

An estimate calculations show the possibility of the SPT life-time increasing (by way of the decreasing of the specific ion stream power impact on the DC outlet surface) when the SPT performance is keeping.

Thus the method of the influence on GV for the SPD performance increasing seems perspective enough.

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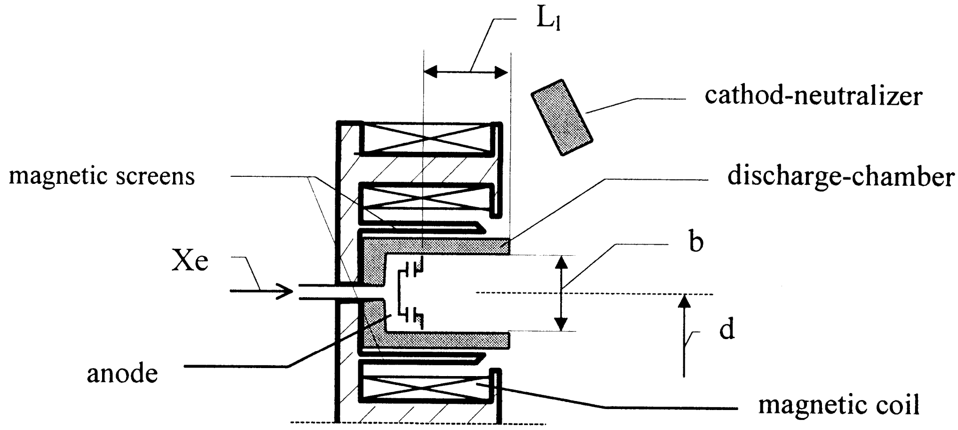

Fig.1. Sheme of Base Model.

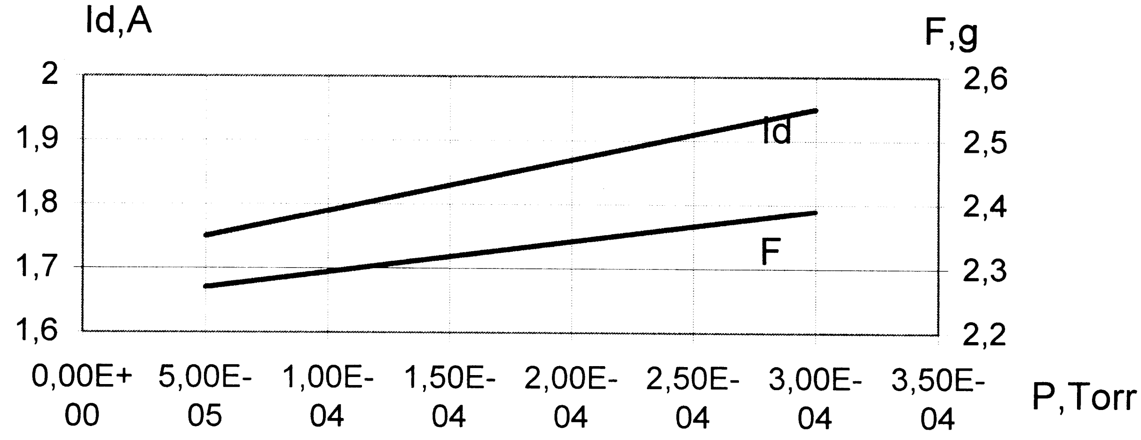

Fig.2.Dependencies Id(P), F(P) for Ud=190 V, ma=1.6 mg/s
(from previouse resurch experiments)

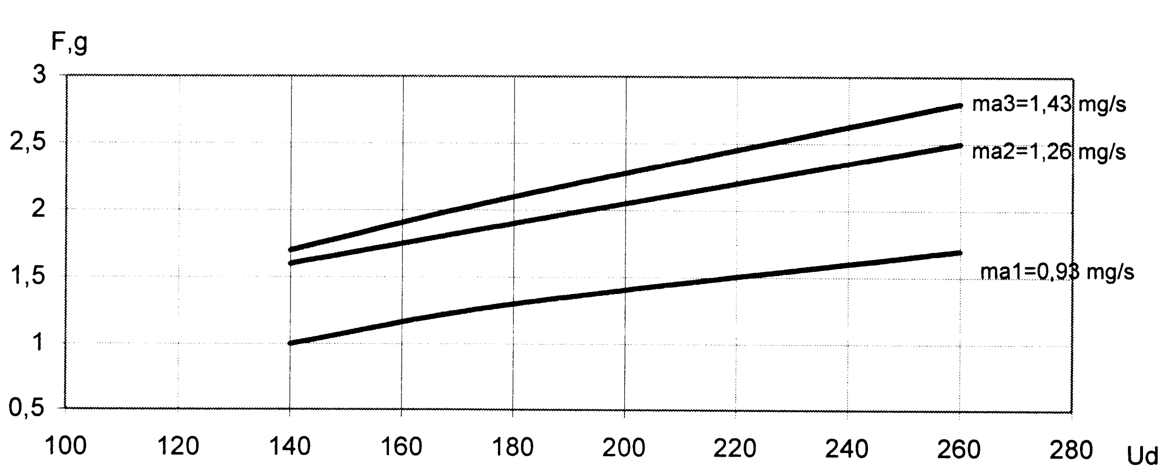

Fig.3. Dependence F(Ud) for MM. Data had been given at P=2--2,5*10-4 Torr and than was corrected acording to dependence F(P) Fig.1.

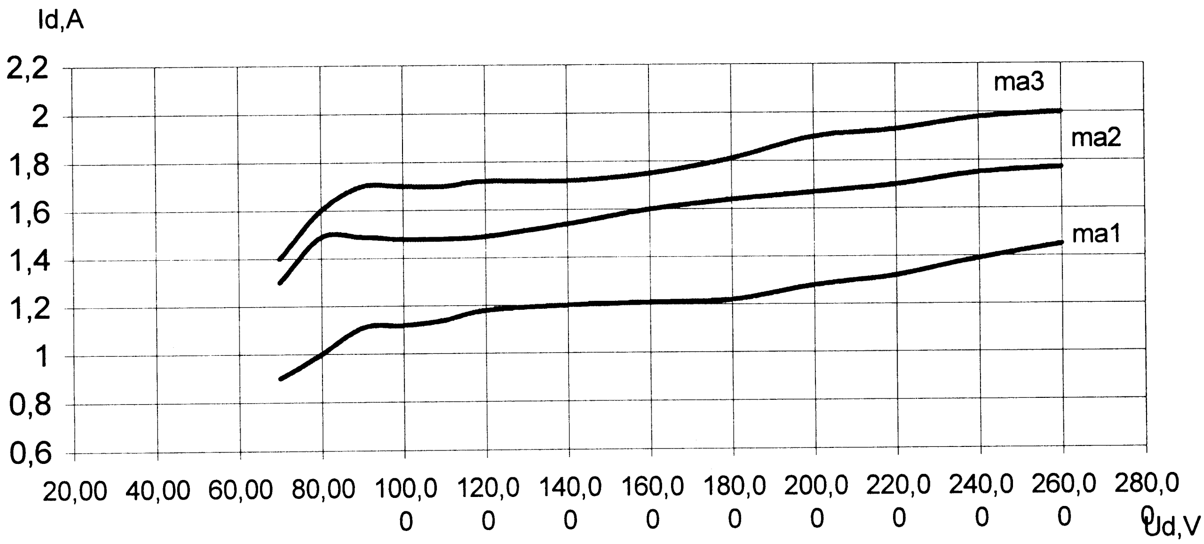

Fig.4. Voltage-current dependence VID for BM. Data was not corrected.

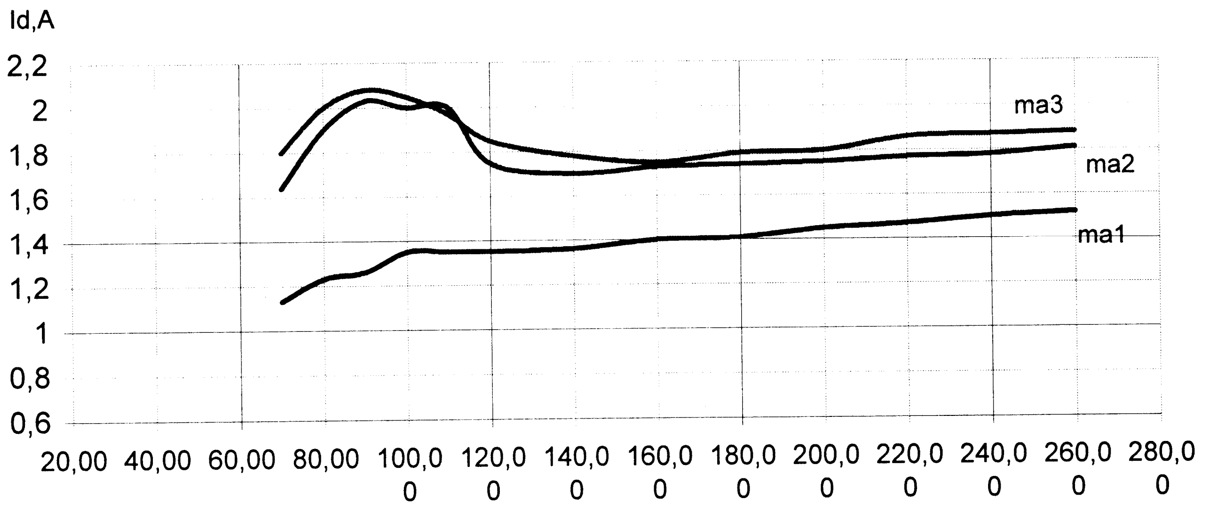

Fig.5. Voltage-current dependence VID for MM. Data was not corrected.

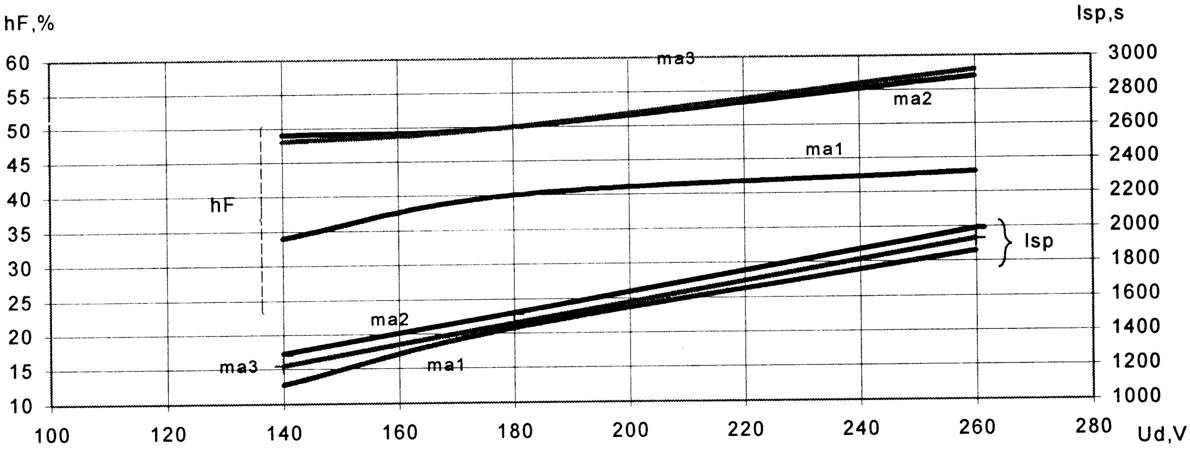

Fig.6. Dependence Isp(Ud),hF(Ud) for MM. Data was corrected.
Curve Isp(Ud) for ma2 lie higher then curve Isp(Ud) for ma3.