SPT Operation in "Machine-Gun" Mode

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Abstract: In the given work the main integral parameters of the plasma source, operating both in the stationary mode and in the mode with short pulses of the duration $(20 \div 50)$ms ("machine-gun" mode) are presented. The thrust efficiency ~54% has been obtained for the stationary mode. For the " machine gun" mode the efficiency has been equal to ~57% for the mode τ_{pulse}=50ms and Q=10. The jet divergence for the both modes has been of the order $\pm 15^0$. It has been shown the insulator carrying away for the "machine gun" mode is smaller, than for the steady one.

Nomenclature

U_d	=	discharge voltage.
W	=	power
$\dot{m}$	=	mass flow rate
F	=	thrust
η	=	efficiency
$F/\dot{m}$	=	specific pulse
$\tau_{pulse}=\tau_{dis}$	=	pulse duration
Q	=	relative pulse duration

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I.   Introduction

FOR small Space Apparatus (SA), which have been widely used in new technologies (a communication, a meteorology and so on), one may use stationary plasma thrusters (SPT) of the power ≤100W [1-3]. One of its advantages is the fact, that the same thruster is able to operate both in the continuos mode and in the mode of short pulses ("machine-gun" mode). In the first case the question is about the trajectory correction of SA, and in the second case – about the maintaining of SA on the given trajectory.

We have manufactured and tested the plasma source, operating both in steady mode and in the "machine gun" mode. "Machine-gun" mode has been realized with the help of pulse gas feeding into the thruster discharge chamber and by interrupting of the electric power supply. The integral parameters of the plasma source have been measured under its operating in steady and "machine gun" modes.

The gabarit sizes of this SPT (which has been name by K-0) are: the diameter $\varnothing=85mm$, the length $l=43mm$. The internal diameter of the external channel has been equal to 45mm. The source K-0 has the buffer volume of length 15mm and diameter 60mm [4].

II.   K-0 Integral Parameters in Stationary Mode

In the stationary mode xenon mass flow rate has been varied from 0,8mg/s up to 1,2mg/s, the discharge voltage has been varied in the band from 200V up to 300V.

On the Fig.1 the discharge VACs are given for the pointed out mass flow rates, and there are represented the thrust, the efficiency and the specific pulse as a function of the applied voltage on the Figs.2-4 accordingly.
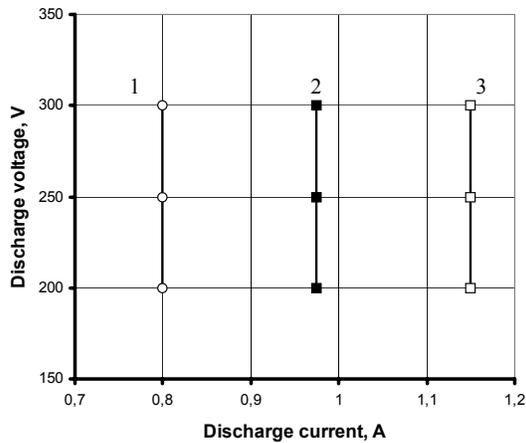

Figure 1. The dependence of the discharge current from the discharge voltage.

$\dot{m} = 0,8$ mg/s; 2- $\dot{m} = 1$ mg/s; 3- $\dot{m} = 1,2$ mg/s.
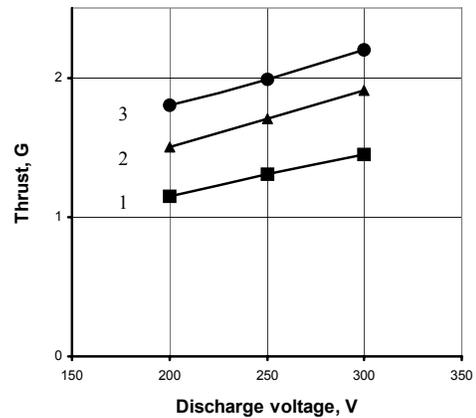
Figure 2. The dependence of the thrust from the discharge voltage.

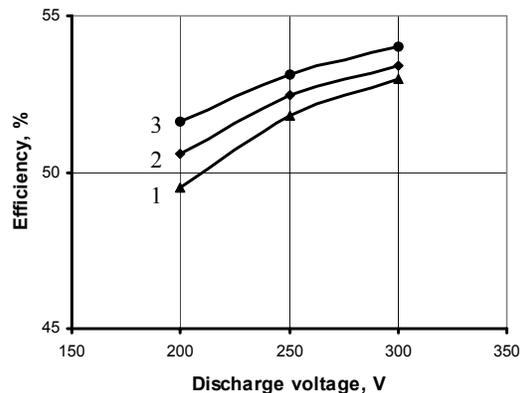$\dot{m} = 0,8$ mg/s; 2- $\dot{m} = 1$ mg/s; 3- $\dot{m} = 1,2$ mg/s.

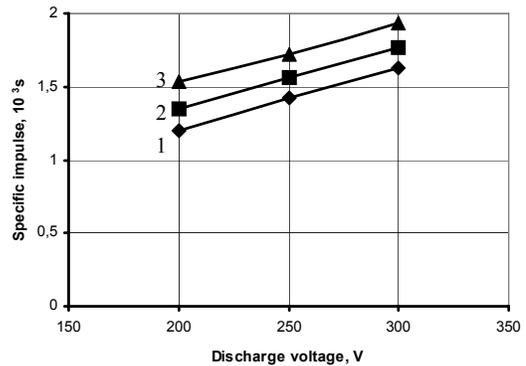**Figure 3. The dependence efficiency from discharge voltage.** 0.8 мг/с: 2- 1.0 мг/с: 3- 1.2 мг/с.

Figure 4. The dependence of the specific impulse from the discharge voltage. 1- 0,8 мг/с; 2- 1 мг/с; 3- 1,2 мг/с

Under the maximal input parameters the thrust efficiency equal to 54% has been obtained. Therewith the thrust has been equal to 2,2g.

For comparison the integral parameters of SPT-50, BHT-200X2B and K-0, operating in the steady mode under input power ~200W are represented i[††]n the Table 1.

Table 1. Performances of the models SPT-50, BHT-200X2B and K-0

Model	SPT-50	BHT-200X2B	K-0
Power, W	170	207	200
U_d, V	398	300	250
$\dot{m}$, mg/s	0,51	0,74	0,8
F, mN	8,0	11,4	12,9
η_a, %	37	42	52
$F/\dot{m}$,s	1594	1570	1640

Comparing the characteristics of SPT-50, BHT-200X2B and laboratory model K-0 we see that the parameters of K-0 are significantly higher than the parameters of SPT-50 and BHT-200X2B.

III.   K-0 Integral Parameters in "Machine-Gun" Mode

The measurement of the integral parameters in the "machine-gun" mode has been carried out under the pulse duration τ_{pulse}=20ms and relative pulse duration Q=3, and also under τ_{pulse}=50ms and Q=10.

The "machine-gun" mode of SPT can be realized either by the pulse interruption of the propellant feeding into the accelerator anode or by a combined method. In the last case the gas feeding is interrupted and by the synchronized way after some time interval the discharge circuit is interrupted. The signals shapes are represented on the Fig.5, therewith Fig.5a corresponds to the case when the gas feeding is only interrupted, and Fig.5b corresponds to the case, when the combined method of the discharge interruption is realized. As it is seen from the Fig.5b under the combined method of SPT turn-on, the fronts of the discharge current pulses sharply decreases down to (0,5÷1,0) ms.

The integral parameters have been measured under K-0 operation in the "machine-gun" mode for the "abrupt" fronts.

The experiments have shown, that for the first mode (τ_{pulse}=20ms and Q=3) the integral characteristics have slightly differed from the characteristics under the thruster operation in the steady mode.
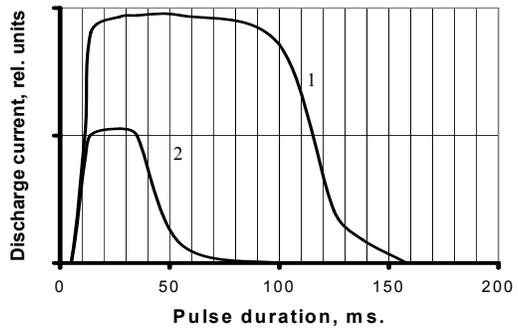
a
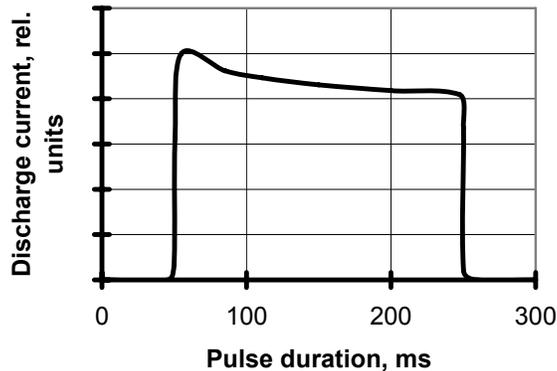
b

Figure 5. Discharge time. a- 1- τ_{dis}=100 ms, 2- τ_{dis}=20 ms
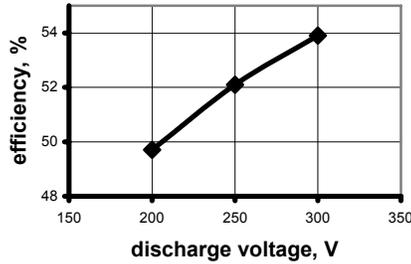b- τ_{dis}=200 ms, Q=4, $_\Delta\tau$=10 ms.
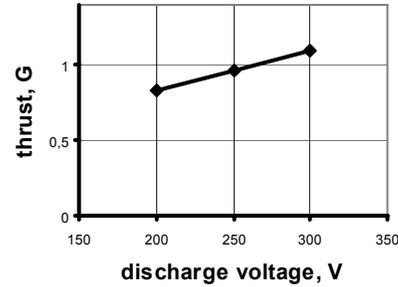
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Figure 6. Dependence of middle thrust from the U_d

Figure 7. Dependence anode
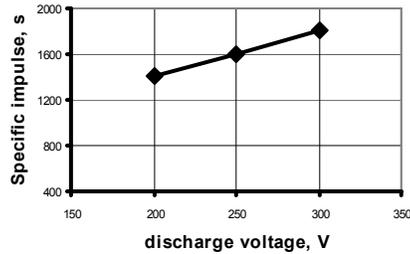
Figure 8. Dependence specific impulse from the U_d τ_{dis}=50 ms, Q=10, $\dot{m}$ =0,6 mg/s.

Figure 9. The dependence efficiency from the mass flow rate.

Under the increasing of the pulse duration up to τ_{pulse}=50ms and relative pulse duration up to Q=10 the thruster efficiency has been increased. Under discharge voltage 300V and the mean mass flow rate 1mg/s the efficiency of the source, operating in pulse mode, has reached the value ~57%, which is by 4% higher of K-0 efficiency under it operating in the steady mode for the same input parameters. This fact is seen from the Figs.6-8, where the mean thrust, the anode efficiency and specific pulse as the functions of the discharge voltage are shown. The curve of the dependence of the efficiency from the mass flow rate for τ_{pulse}=50ms and Q=10 is presented on Fig.9. The efficiency as a function of the power is represented on the Fig.10 (for the "machine-gun" mode – on Fig.10a, for the steady mode – on fig.10b).
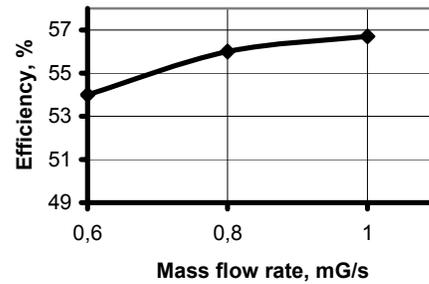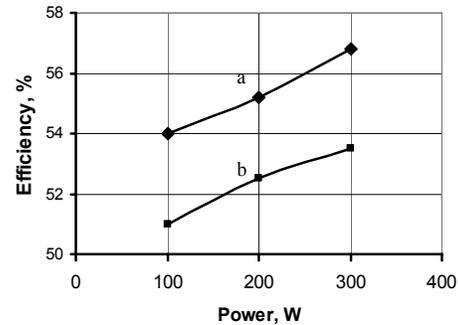

Figure 10. The dependence efficiency from the power. a- pulse operation τ_{dis}=50 ms, Q=10. b- steady state operation.

IV. Determination of Source Jet Divergence in Pulse Mode

The determination of the jet divergence in the pulse mode has been carried out with the help of the same probe as has been used for the determination of the divergence in the steady mode. The principle of the determination and the calculations of the divergence are described in detail in Ref. [1]. We have obtained, that the half-angle of divergence in the pulse mode does not exceed $(15 \div 16)^0$.

V.   Measurement of Insulator Carrying Away in Pulse and Stationary Modes

The measurements of the carrying away of the external and internal channels mass has been carried out after 5 hours of continuous source operation in pulse and steady modes. The source has operated under the mean xenon mass flow rate $\dot{m} = 0.6\,mg\,/\,s$ and the discharge voltage U_d=300V for the both cases.

Before the source switch-on the channels have been cleaned by the abrasive cloth and their weighing has been carried out on the analytical balance, allowing to determine the body mass in grams up to the forth sign after the point.

Then the source K-0 operated ion pulse mode. The pulse duration has been equal to τ_{pulse}=50ms and relative pulse duration Q=5. During 5 hours of operation the source has made 72000 "shots". After this the repeat weighing of the channels and the measurement of the width of the "erosion belts" has been carried out.

The same experiment has been carried out in the stationary mode too. All conditions of the experiment ($\dot{m}$, U_d, the currents in the magnetic coils) have remained the same.

The results of the experiment are represented in the Table 2.

Table 2.

	Pulse Mode		Stationary Mode	
m_{0ext}, g	17,4332		17,3972	
m_{1ext}, g	17,4236		17,3900	
Δm_{ext}, g	0,0096		0,0072	
m_{0int}, g	8,5952		8,5730	
m_{1int}, g	8,5888		8,5612	
Δm_{int}, g	0,0064		0,0118	
L_{ext}, mm	6		4,5	
L_{int}, mm	9		9	
$\dfrac{\Delta m_{ext}}{\Delta S_{ext} \cdot \Delta t}$	ΔS_{ext}=847,8 mm^2	$6{,}3{\cdot}10^{-7}$ mg/mm^2·s	ΔS_{ext}=635,85 mm^2	$6{,}3{\cdot}10^{-7}$ mg/mm^2·s
$\dfrac{\Delta m_{int}}{\Delta S_{int} \cdot \Delta t}$	ΔS_{int}=635,85 mm^2	$5{,}6{\cdot}10^{-7}$ mg/mm^2·s	ΔS_{int}=635,85 mm^2	$10{,}3{\cdot}10^{-7}$ mg/mm^2·s

The following designations are made in the Table 2: m_{ext} is the mass of the external channel, m_{int} is the mass of the internal channel, l_{ext} is the width of the "erosion belt" on the external channel, l_{int} is the width of the "erosion belt" on the internal channel and ΔS is the area, from which the ceramics has been sputtered.

As it is seen from the Table 2, the carrying away of the external channel mass in the pulse mode is equal to 0,0096g, that is some bigger, than in the stationary mode, for which the carrying away is equal to 0,0072g. On the contrary, the carrying away of the internal channel mass in the pulse mode is smaller than for steady one, and it is equal to 0,0064g, while for the stationary mode its value is 0,0118g.

The total carrying away of the insulator mass under the source pulse operation mode after 5 hours of its continuous operation is equal to Δm_Σ=0,016g; for the steady mode the total mass carrying away is bigger and it is equal to Δm_Σ=0,019g.

VI.   Conclusion

As a result of the performed work SPT K-0 has been manufactured, which operates both in the stationary and in the pulse modes.

The integral parameters have been measured. In the stationary mode the measurements have been carried out for the xenon mass flow rates $\dot{m} = 0.8\,mg\,/\,s$, $\dot{m} = 1.0\,mg\,/\,s$ and $\dot{m} = 1.2\,mg\,/\,s$.

The discharge voltage has been varied in the band from U_d=200V up to U_d=350V with the step 50V. In the "machine-gun" mode under the pulse gas feeding into the anode the measurements have been carried

out under the same input parameters with the pulse duration τ_{pulse}=20ms and τ_{pulse}=50ms and relative pulse duration Q=10. Under the pulse source operation, when τ_{pulse}=20ms and Q=3, there have been obtained approximately the same integral parameters, as for the stationary mode.

Under the source operation in the stationary mode for the xenon mass flow rate 0,8mg/s and discharge voltage 250V the thrust efficiency equal to 52% has been obtained. The specific pulse had value 1640s. The half-angle of the source jet divergence has been equal to $\pm15^{0}$.

The integral parameters of the adjusted model K-0 with the abrupt fronts of the discharge current pulses for τ_{pulse}=50ms and Q=10 have been measured. Therewith we have been a success to increase the source efficiency up to 57% under $\dot{m} = 1{,}0mg \, / \, s$ and discharge voltage 300V. The measurement of the carrying away of the model insulator mass has been carried out in the pulse and stationary operation modes of the source K-0. It has been shown that the total insulator carrying away under the pulse source operation is smaller than under the operation in the stationary mode.

The measurement of the jet divergence for the adjusted source K-0 has shown that the half-angle of divergence is equal to $\pm15^{0}$.

References

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