External anode layer thruster parameters at a high specific impulse regimes.

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Abstract

Possibility to use potentially high life time thruster scheme with external anode layer for regimes with 3000...4000 sec specific impulse are considered. Laboratory xenon D55 thruster was tested in a range of discharge voltage up to 1100V . Specific impulse 3300 sec with 0.6 efficiency were obtained. Any limits for applied discharge voltage, connected with discharge physics, were not found in the tested range of discharge voltage.

Nomenclature

Vd - discharge voltage,
Id - discharge current,
T - lifetime,
P - thruster power consumption,
B - magnetic field,
Isp - specific impulse,
η - efficiency,
t_a - temperature,
A - propellant atomic mass.

Introduction

Electric propulsion systems with Hall type thruster - stationary plasma thruster (SPT) and thrusters with anode layer (TAL) - now can find wide application as orbit keeping propulsion systems [1,2].
The typical specific impulse for existing flight Hall thrusters is about 1500 sec. The existing thrusters, as well as SPT and TAL, have passed through a long and expensive stage of development and qualification. Only this significant efforts allow to consider this technology as a real one for practical application. Nevertheless number of for perspective projects, such as using Electric Propulsion for orbit raising or interplanetary missions, require to change operating point and to use thrusters with significantly higher specific impulse - up to 3000 ...4000 sec [3] .

The new requirements raise a question about possible ways of their technical realization, which have to be specially studied and verified. It is important, that a new working point or new design will require new qualification of a thrusters. Obviously, the most logic variant is to use as much as possible already tested and flight qualified design and engineering basis. It allows to reduce research and qualification efforts. However the possibility to achieve the new level of parameters on the already existing and qualified thrusters is not clear and requires additional researches.

As for thrusters with a anode layer, which can be considered as one of most progressive option and are now under active development [1,2,4], it is possible to point out two possible ways of high specific impulse mode realization.

1. To find a possibility to increase discharge voltage in one-stage TAL [5].
2. To use double -stage TAL, which was developed just for realization of high Isp mode [6].

In the first case, it is possible to save advantages of the high lifetime scheme with external anode layer and to use most of previous experience of the flight hardware elaboration and qualification [1,2,4] . However the specific of the thruster operation in regimes with high Isp not studied and requires experimental researches.

In the second case the realization of the high Isp does not cause doubts, however lifetime of the thruster, especially in respect to the first - ionization stage - of the double-stage TAL, is not clear and also require research efforts.

Existing today information it is not enough for the choice of the thruster variant for new level of parameters.. Therefore both TAL versions should be studied in more details in high Isp regimes.

The goal of the work, presented in this article, is to study a possibility to increase Isp in a one-stage thruster with external anode layer.

In general, there are a number of limitations on a discharge voltage increasing and the possibility to increase specific impulse. These limitations can be divided into two groups:

- Basic physical limitation, for example, infringement of propellant ionization processes , appearance of instabilities and so on,
- Technical, such as isolation. overheating and other.

Unfortunately, the numerical analysis of possible physical limitations is practically impossible, because an adequate mathematical model does not exist, especially for the processes in a hollow anode.

General consideration of a physical processes in the TAL's discharge zone allows to expect, that for high-voltage modes may be required other magnetic field distribution as compared with one using for Isp 1000...2000 sec. As it follows from the consideration, presented in [5], the value of a magnetic field B should be increased in accordance with following equation:

$$B \sim Vd^{1/2} \quad [5]$$

The Hall thrusters - both SPT and TAL - have some minimum of a propellant flow density, when the thrusters provide high propellant ionization and thrust efficiency. It limits the possibility to reduce discharge current and keep the same power consumption to prevent thruster overheating at high voltage regimes.

Heating of a thruster at high voltage regimes , and, correspondingly, thruster anode temperature increasing, can results in the change of ionization processes. Anode temperature determines the initial propellant atoms velocity and, so that, the probability of it's ionization in the discharge zone. Following equation shows interrelation between minimal propellant flow density j_{min}, which requires for high ionization, and anode temperature t_a:

$$j_{min} \sim (B\, t_a^{1/2})/A \quad [6]$$

It is whence visible, that the increase of anode temperature reduces probability of ionization and can require design efforts to keep it at acceptable level.

Lifetime of a Hall thrusters -T - depends on power consumption also. Usually, as a first approach , the following dependence is considered:

$T \sim 1/P$
where T - lifetime,
P - Hall thruster power consumption.

In the TAL with external anode layer direct sputtering of the thruster elements by accelerated ion flow practically is eliminated. So , it is possible to assume , that in a difference with traditional Hall thrusters schemes, for external anode layer scheme this dependence not workable , and increasing of discharge voltage and power consumption do not lead to proportional lifetime reducing.

Experimental study

The experimental researches of high specific impulse mode in a thruster with external anode layer at the first phase, presented in this paper, had a goal to study a possibility to operate at high discharge voltage and increased power consumption in principle, without taking into account technical limits of used hardware. So that ,the thruster was tested as well in thermal equilibrium regimes as in regimes with relatively short firing time (about 1 ...2 minutes) , when the thruster temperatures not exceed acceptable limits.

The last mode can have practical application, for example .for attitude control systems, when required operating time is enough small and thruster's element will not reach thermal equilibrium. Similar cyclorama were considered also as one of operating mode for EPDM flight experiment [2].

The experiments were done with use of laboratory D55 thruster at TsNIIMASH facility.
The thruster and used equipment are the same as in [7]. During the tests following parameters were measured :
Vd - discharge voltage.
Id - discharge current,
current and voltage in magnet coil circuits,
Xenon mass flow rate.
The tests were done with TsNIIMASH laboratory cathode.

The thruster was tested in a range of discharge voltage up to 1100 V. The upper voltage was limited by used power supply parameters. Thruster was tested in steady-state and periodical modes. Operating time with using periodical mode was about 1- 3 minutes, which is enough for measurement of the thruster parameters. After operating the thruster was could down several minutes.

Obtained results are shown on Figure 1. Specific impulse (Isp) and efficiency (η) are given as a function of discharge voltage (Vd). The Isp and efficiency were calculated without taking into account cathode mass flow and power for magnetic coils.

In the tests specific impulse up to 3300 sec was reached with thruster efficiency 0.6. The reached discharge power is about 3 kW for stationary regime and 5 kW for periodical turn-on/turn-off operation. The upper limit of the power at a thermal equilibrium mode was limited by temperature of magnetic system elements.

One can see on the Figure, that there are no changes in general character of the Isp and efficiency with discharge voltage increasing . It indicates that working processes in discharge have no significant changes also. Any limits for applied discharge voltage, connected with physics of discharge, were not found in a tested range of Vd.

Conclusion

The performed test program is considered as a simple initial stage to verify direction of the next stage activity. Obtained results allow to consider the existing high lifetime scheme with external anode layer not only for orbit keeping application with specific impulse 1000...2000 sec, but also as a prospective technology for future electric propulsion missions with required Isp - 3000...4000 seconds.

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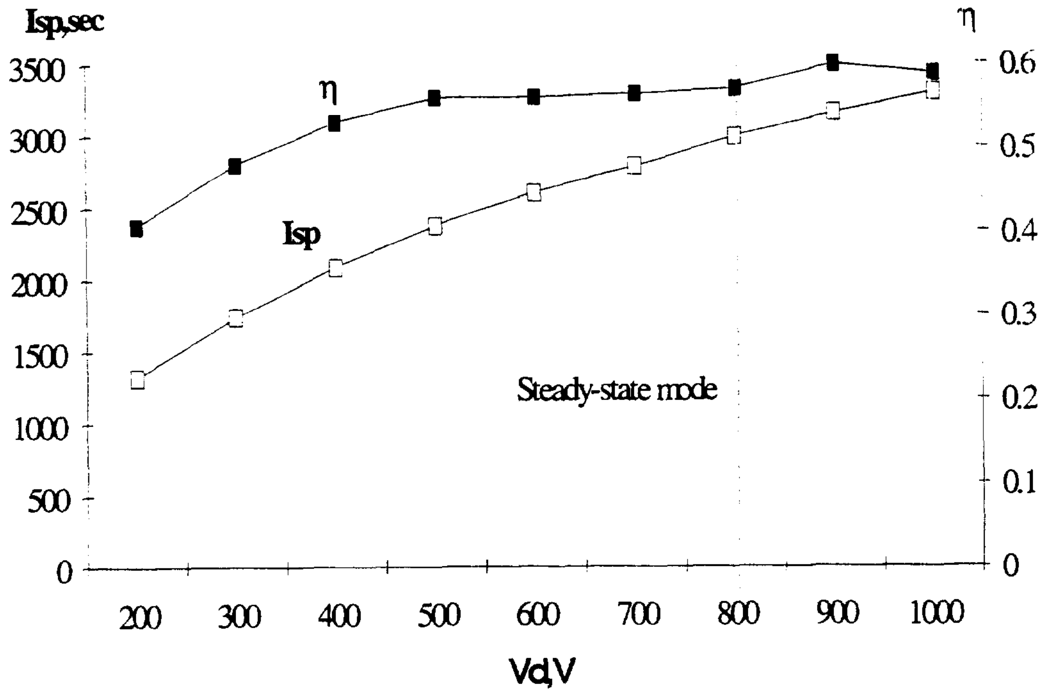

Figure.

D55 specific impulse and efficiency versus discharge voltage.