

The Comparison of Results of Tests of Low-Power Hall Thrusters: SPT and TAL

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Titov M.¹, Loyan A.², Rybalov O.³, Maksymenko T.⁴
National Aerospace University “KhAI”, 61070 Kharkiv, Ukraine

Abstract: In the article the comparison of test results of low-power (30-150 W) SPT and TAL are presented. Recently developed in KhAI laboratory model of low-power thruster with anode layer TAL-23 is compared with SPT-20M. The difference in magnetic systems and the distribution of magnetic flux density in discharge chamber is considered. The thermal condition of the thrusters is touched upon. Performance characteristics of TAL-23 were measured and their comparison with SPT-20M characteristics is done.

Nomenclature

B_r	=	radial component of magnetic flux density, mTl
U_d	=	discharge voltage, V
I_d	=	discharge current, A
I_{coil}	=	coil current, A
$\dot{M}_a$	=	anode mass flow rate, mg/s
$\dot{M}_c$	=	cathode mass flow rate, mg/s
P	=	thrust, g
J_s	=	specific impulse, s
N	=	power (with power for magnetic coil and cathode), W
η	=	total efficiency

I. Introduction

At present time solution of questions of orbital maneuver of satellites (orbit active correction, station keeping, satellite orientation) is successfully solved by using electric propulsion. In connection with the extension of tasks solved with the help of micro-satellites a topical problem is developing of low-power electric propulsion. Propulsion systems with power consumption 50-200 W exist, but only as research, because reducing power consumption of the thrusters below 100 watts is accompanied by abrupt decrease of its efficiency [1]. There are projects low-power stationary plasma thrusters (SPT), demonstrated good results [2]. The second type of Hall effect thruster (HET) - the thruster with anode layer (TAL) operated at powers up to 100 watts is little investigated. If to compare the characteristics of both types of HET, the TAL has a number of parameters which can be better than in SPT [3] - this causes an increased interest in low-power TAL.

¹ Research assistant, STC STE “KhAI”, titov@d4.khai.edu.

² Leading researcher, head of department, STC SPE “KhAI”, loyan@khai.edu.

³ Research assistant, STC SPE “KhAI”, rybalov@d4.khai.edu

⁴ Researcher, STC SPE “KhAI”, taras@d4.khai.edu.

II. General Guidelines

A. Development of low power TAL

In the National Aerospace University “KhAI” a low power Hall effect thruster SPT-20M was developed and tested. This thruster in the range of consuming power 30-100 W shows good-enough characteristics: thrust 2-4 mN with a total efficiency 25-40 % [4].

Recently the first steps in creation the low power anode layer thruster have been done and as a result the laboratory model TAL-23 (mean diameter of discharge chamber is 23 mm) was developed Fig. 1.

The starting point for choosing the main parameters of construction of TAL-23 (overall dimensions, diameter of magnet core, coil location, number of coil turns, materials and so on) was information about SPT-20M. In Fig. 2 the scheme of TAL-23 is shown.



Figure 1. General view of laboratory model of low-power Thruster with Anode Layer TAL-23.

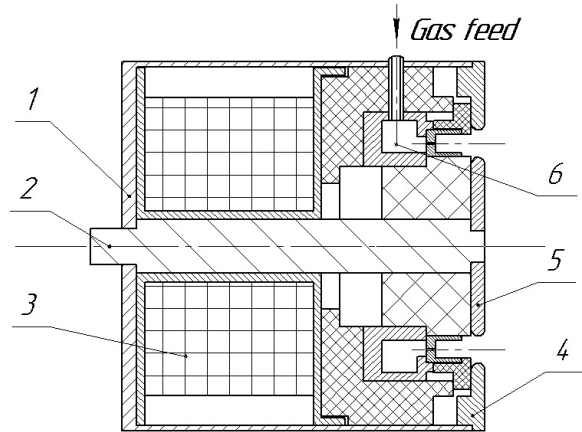


Figure 2. TAL-23 construction:

1 – magnetic conductor; 2 – magnet core;
3 - magnetization coil; 4 – outer polar tip; 5 - inner polar tip; 6 - anode-gas-distributor.

B. Comparison of TAL-23 and SPT-20M magnet circuits

The magnetic system (MS), which should form the optimal magnetic field, is a critical aspect during creating a HET. A good example of the importance of MS on the integral characteristics of low-power HET is an example of creating MIT 50W [3], the efficiency of which did not exceed 6.3%. According to the authors, the reasons of so low efficiency are errors in the design of the magnetic system. Therefore, the task solution intended for developing the optimal magnetic field is relevant and important step. Problems arising during the development of MS are well known, and include the following [5, 6]:

- 1) magnetic saturation when decreasing magnetic conductor section;
- 2) asymmetry, defocusing and nonuniformity of magnetic field in discharge chamber of the thruster;
- 3) demagnetizing (the magnetic conductor temperature approaches to Curie point).

For solving listed above problems, especially complicated during development of low-power thrusters in view of their small dimensions, the investigation of thruster magnet system was carried out. In the work [7] the influence of geometry of magnet system elements on the distribution of parameters of magnetic field in the chamber of the thruster was determined. All efforts in magnet system optimization were directed to getting the maximal gradient of magnetic flux density component B_r , what is especially typical for TAL [8], and assurance of

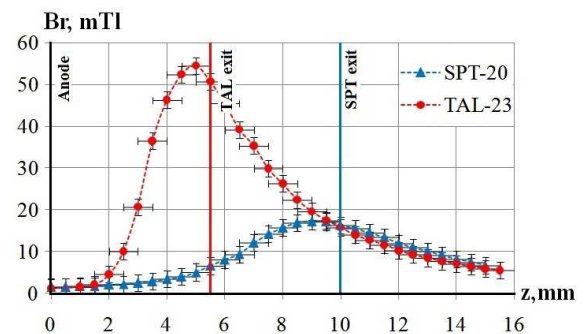


Figure 3. The distribution of B_r on radially intermediate region in discharge chamber for SPT-20 and TAL-23, ($I_{\text{coil}}=2\text{A}$, prestarting operation; experimental data).

minimal energy expenditure for creating magnetic field.

TAL-23 has the same elements of magnetic system as SPT-20M. Exclusions are the discharge chamber width and length. In TAL-23 they are less than in SPT-20M. On the Fig. 3 the radial magnetic-flux density on radially intermediate region in discharge chamber for SPT-20M and TAL-23 is shown.

C. Comparison of thrusters thermal condition

As far as during the thruster operation it undergoes heat loads, the question concerning the effect of heating on the distribution of the magnetic field remains opened. In the work [9] there are presented detailed results of the study of the thermal state of the TAL-23. On the Fig. 4 the dependence of B_r in the discharge chamber on the heat power is shown. The significant degradation of magnetic field occurs during input heat powers more than 200 W (decrease of B_r is more than 15% and the symmetrical magnetic field profile breaks down).

If to compare the thermal field of TAL-23 and SPD-20M at the regime of 100W power consumption, the maximum temperature for the TAL-23 (the inner pole tip) is 540 °C, and for the SPT-20M (at the edge of the inner ceramic) is 690 °C; that at 150 °C higher than for TAL-23 at the same operating regime. On the Fig. 5 the temperature distribution for thrusters during their operation is given.

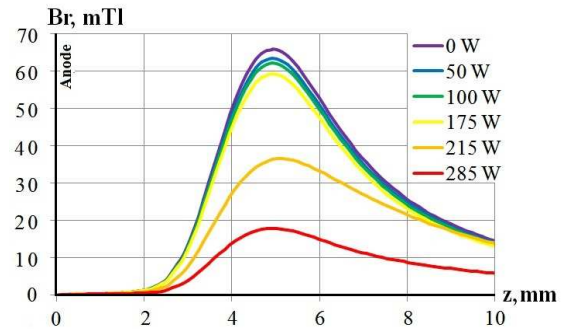


Figure 4. The dependence of distribution of B_r on input heat power for TAL-23 ($I_{coil}=3A$; theoretical data).

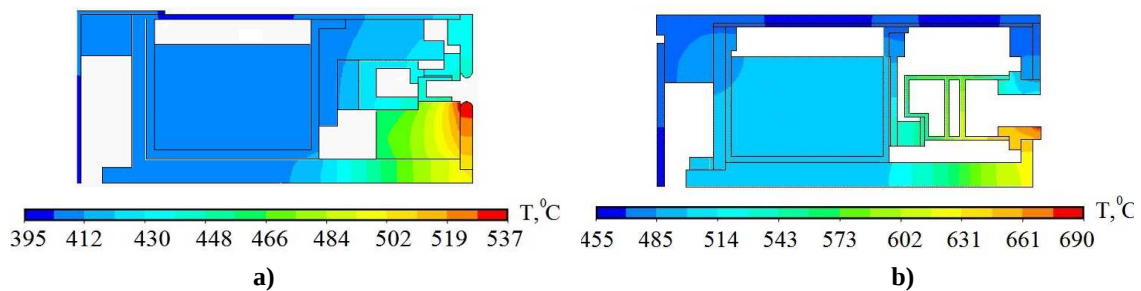


Figure 5. The temperature distribution in constructions of TAL-23 and SPT-20M (power consumption 100 W; theoretical data): a – for TAL-23, b – for SPT-20M.

D. Comparison the performances of SPT-20M and TAL-23

The tests of TAL-23 were carried out in the KhAI vacuum chamber. All systems including power supply system, gas storage and supply system, thrust balance system, measuring instruments were the same as during the tests of SPT-20M [10].

Measuring of the current-voltage characteristics (Fig. 6) was carried with the next mass flow rates: 0.2, 0.26, 0.3 and 0.34 mg/s. Mass flow rate through the cathode was constant 0.06 mg/s. Coil current 1,2 A.

The dependence of thrust on discharge voltage is shown in Fig. 7.

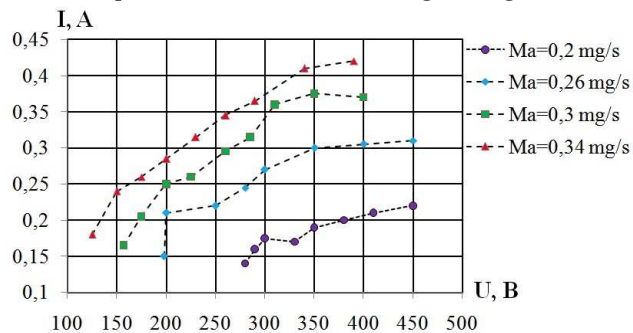


Figure 6. Current-voltage characteristics of TAL-23.

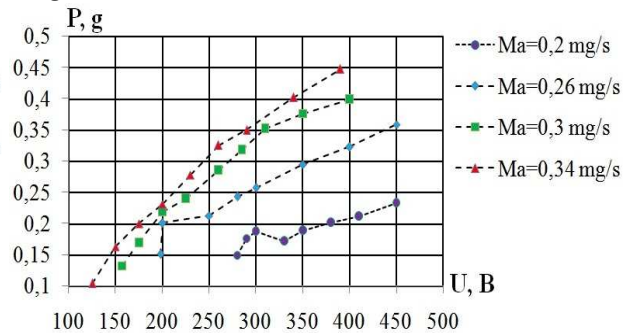


Figure 7. The dependence of thrust on discharge voltage for TAL-23.

In the Fig. 8 and Fig. 9 the dependences of thrust and total efficiency on power consumption for TAL-23 and SPT-20M are shown. Fig. 10 demonstrates specific impulse J_s vs TAL-23 power consumption. Specific impulse (1) and total efficiency (2) were calculated using well-known formulae [8]:

$$J_s = \frac{P}{Ma}, \quad (1)$$

$$\eta = \frac{P^2}{2 \cdot Ma \cdot N}. \quad (2)$$

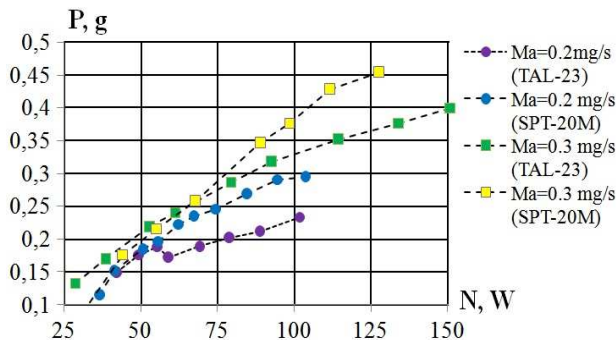


Figure 8. Thrust vs power consumption for TAL-23.

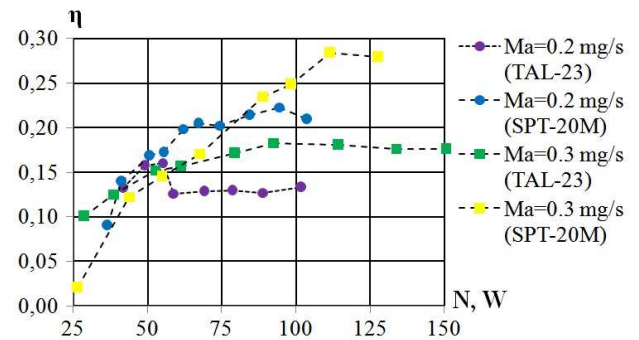


Figure 9. Total efficiency vs power consumption for TAL-23.

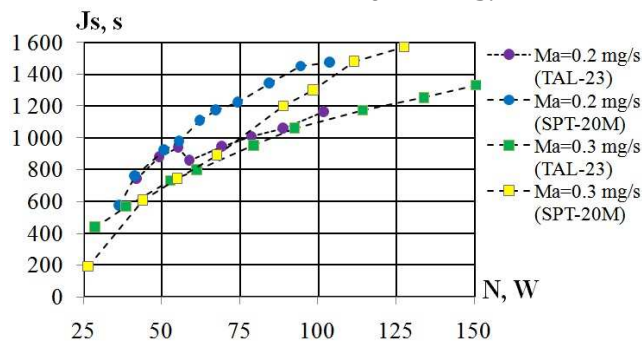


Figure 10. Specific impulse vs power consumption for TAL-23.

As we can see from Fig. 8, 9 and Fig. 10 TAL-23 has lesser characteristics (thrust, efficiency and specific impulse) than SPT-20M. The tendency to increasing thrust and specific impulse with increasing the consuming power is revealed for both thrusters. Also the efficiency for TAL-23 as SPT-20M has a limit value. Similar behaviors occur for all anode mass flow rates.

III. Conclusions and perspectives of further investigations

The low-power anode layer thruster was developed at KhAI. The first researches of its operation are done. The achieved characteristics in 100 W regime are: thrust near 3 mN, specific impulse 1200 s and efficiency 18%. The results of tests show that low-power TAL can compete with low-power SPT even if now SPT-20M excel TAL-23 in specific characteristics. However low-power TAL requires additional works in search of optimal operational regimes. The investigation of low-power TAL plasma parameters and its plume, investigation of thruster life-time should be done.

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