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METHOD FOR THE EROSION RATE MEASUREMENTS OF STATIONARY PLASMA THRUSTER INSULATORS

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Розроблено метод оптичної емісійної спектроскопії зі скануванням плазми через коліматор (ОЕССК). який дозволяє реєструвати випромінювання окремо з кожної стінки розрядної камери (РК) стаціонарного плазмового двигуна. В результаті експерименту методом ОЕССК отримані залежності відносної швидкості ерозії внутрішнього і зовнішнього ізоляторів від струмів котушок. Визначено струми котушок, при яких спостерігається практично рівномірний знос стінок РК

Ключові слова: стаціонарний плазмовий двигун, оптична емісійна спектроскопія, розрядна камера, відносна швидкість ерозії

Разработан метод оптической эмиссионной спектроскопии со сканированием плазмы через коллиматор (ОЭССК), который позволяет регистрировать излучение отдельно с каждой стенки разрядной камеры (РК) стационарного плазменного двигателя. В результате эксперимента методом ОЭССК получены зависимости относительной скорости эрозии внутреннего и наружного изоляторов от токов катушек. Определены токи катушек, при которых наблюдается практически равномерный износ стенок РК

Ключевые слова: стационарный плазменный двигатель, оптическая эмиссионная спектроскопия, разрядная камера, относительная скорость эрозии

1. Introduction

Stationary plasma thruster (SPT) is one of the plasma thruster (PT) types systematically applied in space since the past century [1]. Despite the fact that some SPT characteristics (efficiency, specific impulse, lifetime)~~,~~ are dominated by the ion plasma thruster (IPT) parameters, there is a great interest ~~to~~ in this type of PT. It is seen from a number of SPT significant advantages [2]. First of all, if to compare SPT with IPT, it has relatively simple design and technology of production. Second, SPT does not require a complex power supply unit and this is very important for the spacecraft design. Propulsion system on the base of SPT has better characteristics such as weight and production time. Relevance for the SPT development is the number of customers of this plasma thruster. One of the main areas of SPT modernization is the thruster lifetime [3].

2. Literature review and problem statement

One of the main factors that limits the thruster lifetime is a discharge chamber (DCh) wear [4]. The analysis of customer's requirements to a new generation of SPT showed that the required operational time of propulsion system is 12 to 15 years [5]. Summarizing data about the declared SPT lifetime [3], it is seen that today SPT developers cannot guarantee fulfillment of customer requirements to the thruster lifetime. This is one of the reasons that limits the application of SPT in space. However, considering numerous works in the area [1–5], it is possible to point out research directions that will allow increasing SPT lifetime characteristics.

SPT designers distinguished two main directions of increasing the thruster lifetime: development of new materials and investigation of DCh wear dependences on plasma parameters [1].

Search and research of the new materials is an exhaustive work that will require significant material investment and it is also time-consuming. Without any doubts, a positive result will lead to the increased lifetime of DCh and thruster, but it will not affect SPT designs and thrusters that are already in operation.

Research of DCh wear depending on SPT parameters has been provided for many years. Main compositions of ceramic materials that are the most resistant to ion bombardment have been identified. Among them are boron nitride (BN) and boron nitride with silicon oxide additives BN + SiO_2 [7]. However, there is no list of recommendations following which it would be possible to estimate thruster lifetime with sufficient accuracy without its testing [8].

One possible reason is that it is very difficult to summarize and analyze all the information. For example, there is an investigation of DCh erosion depending on the ion flux angle [9]. Such an investigation is mainly used for the mathematical modeling and simulation of processes that take place in the thruster. However, theoretical model developers prove that the error of such a computation is not lower than 50 % [10]. It is rather difficult to use such data for the SPT or during SPT testing. Mainly, it is connected with the limitations of diagnostic apparatus. For example, there is no information about what percentage of ion flux and with what energy and at what angle interacts with an insulator. That is why it is necessary to provide lifetime tests. The result of such tests is applied for the prediction of thruster lifetime.

For example, in the space propulsion laboratory of the National Aerospace University named after N.E. Zhukovsky (Kharkov, Ukraine), accelerated lifetime tests of low power 150 W SPT were provided. The goal was to obtain the data about the erosion rate of ceramic insulators with different percentage of SiO_2. The tests were initiated from pure boron nitride (BN) and further the additives percentage of SiO_2 was increased in the range: 5, 10, 20, 35 and 50 %. Similar density of ceramic parts was selected from the set of insulators. The difference of density was not more than 7 %.

To perform such an experiment, the thruster design was modified to provide an ability to disassemble ceramic insulators without any mechanical damage [11]. For each of ceramic couples (DCh inner and outer walls), the test time was 68 hours. All test time was divided into 4 cycles with the duration of each test of 17 hours. After each cycle, the test was stopped, thruster was removed from the vacuum chamber and mass loss was measured for each of the insulators on the weight machine WA-21 with an accuracy of 0.1 mg. Also, with the help of a measuring microscope (with the accuracy of 0.005 mm), the width of the erosion belt was measured.

Thruster operation parameters were the following:

– discharge voltage 300 V;

– anode mass flow rate 0.3 mg/s;

– cathode mass flow rate 0.03 mg/s.

The value of the coil current was selected from the criteria of minimal discharge current. It was accepted that for each of ceramic types, the discharge current was in the range of 0.34 to 0.36 A or 0.35 A ±3 %. At the same time, the coil current varied in the range of 2.0 to 2.6 A.

Despite the fact that the thruster design in all experiments was identical, the width of the erosion belt for ceramic walls was different. Mass losses and erosion rates of the outer (OI) and inner insulators (II) were not similar. In one case, the wear of II was higher, whereas with another the wear of OI was higher.

A similar result was obtained in Kaliningrad (Russia) during the SPT-100 tests [12] on the time base of 3000 hours. The results of the DCh walls wear control showed that the difference in the insulator erosion rates was 30 %. During the next test, the magnetic coil currents were changed and it was accepted that the difference in the insulators erosion rates was not higher than 10 %.

According to the information provided, it is obvious that research of the DCh erosion rate behavior depending on the SPT operational regime is of great interest. This is due to the fact that, without resorting to changes in the thruster design, it is possible to increase its lifetime significantly. The fulfillment of this task is possible by selecting the operating mode of the SPT with the similar wear of the DCh walls. However, an important issue is the method of erosion rate control.

Weight control methods for the 1.3 kW SPT lead to significant problems [11]. It is possible to develop the SPT-100 design that can be easily assembled and disassembled. However, taking into consideration that the insulator dimensions of SPT-00 are much bigger that SPT-20, disassembling of the thruster can lead to significant mechanical breaks of DCh walls. In addition to the above, the erosion rate of SPD-100 is less than that of a low-power thruster, while the weight of insulators is greater. Therefore, the mass measurement will be performed with a greater error.

Following from that, during the testing of medium and high power SPT, measurements of the radial erosion rate are performed [12]. The radial erosion rate is the difference in the coordinates of the ceramic edge before and after the experiment. In other words, the offset of the insulator edge is monitored. However, this kind of experiment is very long, complicated and expensive. First of all, for each regime, the thruster operating time should be about 50 hours. This is due to the fact that the erosion rate of SPT-100 is relatively weak and is equal approximately to several microns per hour. Secondly, it is not difficult to calculate that, for example, for 9 SPT regimes under investigation, the total experiment time will be 450 hours or 56 working days. In addition, it is necessary to include the time of vacuum facility preparation, re-installing of the thruster and its measurements.

The best way for such a case is to provide measurements directly during the thruster operation. Different integral non-intrusive measurement methods (various types of spectroscopy, laser-induced fluorescence, etc.) are applied. However, the methods known to date do not allow registering both the azimuthal irregularity in the wear of insulators and the difference in the erosion rate of SPT DCh walls [8]. For example, during erosion rate diagnostics by means of optical emission spectroscopy (OES) method, integral data are registered, in other words, from the whole radiation volume of the DCh eroding surfaces [6]. In this case, it is not possible to obtain the radiation spectrum of each of the DCh walls.

As observed from the provided information, there is a need to develop a measurement method that could provide information on the erosion rate from local DCh areas directly during thruster operation [1].

As it was shown before, SPT lifetime largely depends on the criterion of the thruster operating regime selection. Basically, this criterion is the minimum discharge current, which is determined by varying the thruster magnetic system coil currents. But, as was obtained during research in Russia [12], there is another criterion of the thruster operational regime selection – uniformity of wear rate for both of DCh walls.

3. The aim and objectives of the study

The goal of the work is to determine thruster operational regime with the uniform wear of both DCh insulators.

To achieve the goal, the next tasks should be fulfilled:

1. Development of a method that can provide information about the insulator erosion rates during the experiment.
2. Development, production and testing of experimental equipment for the erosion rate measurements of DCh walls during the experiment.
3. Experimental determination of erosion rate separately for each of 1.3 kW SPT DCh walls depending on the coils currents.
4. Determination of thruster operational regime selection criteria.

4. Development of the optical emission spectroscopy method with scanning of plasma through collimator

4. 1. Research of 1.3 kW SPT lifetime depending on the DCh insulators erosion rate

In the National Aerospace University named after N. E. Zhukovsky electric propulsion laboratory, tests of

1.3 kW SPT were performed. The parameters of SPT operation were the following: discharge voltage 300 V, anode mass flow rate 4 mg/s, cathode mass flow rate 0.35 mg/s. Currents of 5 and 5 A for outer and inner coils were selected according to the criterion of minimal discharge current. Before the experiment, the DCh insulators edge coordinates were measured. After 50 hours of thruster operation, radial erosion measurements were performed. According to the results, it was confirmed that the radial erosion of the inner insulator was by 30 % higher than the radial erosion of the outer insulator.

In order to understand how the difference in radial erosion influences the thruster lifetime, the radial erosion rate theoretical model was developed. Prediction of the insulators radial wear is shown in Fig. 1.

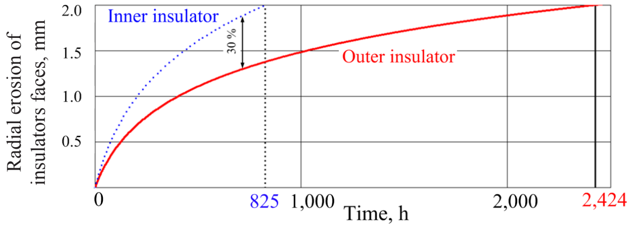

Fig. 1. A theoretical model of DCh edges wear at the condition that the inner insulator erosion rate is by 30 % higher than that for the outer insulator

The calculations showed that the wear time of the 2 mm II is equal to 825 hours. At the same time, the wear time of the 2 mm OI is approximately four times higher and equals to 2,424 hours. The data shows that the thruster lifetime will be significantly limited by the II lifetime.

4. 2. Specific erosion rate

Plasma density in the area of SPT exit and plume is relatively low, for example, in comparison with the cathode plasma density. Such a plasma can be described with corona model (CM). According to CM, levels population are under the influence of the strongest collision processes (collision ionization). There is a small percentage of excited ions in comparison with the percentage of ions in the ground level. Excited levels populations are determined from the balance between collision excitation and spontaneous relaxation (1):

$$ne\cdot N_g(z)\cdot X(Te,g,m)=N_m(z)\cdot\sum_{n<m}A(m,n), \tag{1}$$

where ne is the electron concentration, m^{-3}; $N_g(z)$ is the population of the ground level g; X(Te, g, m) is the collision ionization rate coefficient; Te is the electron temperature, eV; $N_m(z)$ is the population of m level; m, n, g are the values of the principal quantum numbers; $\Sigma_{n<m}A(m, n)$ is the sum of probabilities of all excited states.

Particles transition from the excited state to the ground state causes quanta emissions that are registered as spectral lines. The intensity of spectral line (J_{mg}) is determined as

$$J_{mg}=\frac{h\cdot c}{\lambda}A_{mg}\cdot N_m(z)=$$
$$=\frac{h\cdot c}{\lambda}A_{mg}\cdot\frac{ne\cdot N_g(z)\cdot X(Te,g,m)}{\sum\limits_{n<m}A(m,n)}. \tag{2}$$

During optical emission spectroscopy measurements, the total intensity or radiation power is registered. The measured intensity value (I) depends on all parameters of expression (2) and also on the characteristics of experimental equipment and radiation source (3). The expression of the registered spectral line intensity is

$$IS_{OK}=\int\limits_{l}\int\limits_{\Omega}\int\limits_{S_{OK}}J_{mg}\,dl\,d\Omega\,dS_{OK}, \tag{3}$$

where l is the plasma radiance thickness; Ω is the solid angle; S_{OK} is the area of optical receiver. It is a constant value in all the experiments so was not included to further equations.

From the physical point of view, the value J_{mg} in the expression (3) is the specific value J_{SP} of the measured spectral line intensity I from the unitary plasma thickness from the unitary solid angle. The parameters of equation (2) depend exclusively on the plasma parameters in the local area, that is why formula (3) can be rewritten as

$$I=J_{SP}\int\limits_{l}\int\limits_{\Omega}dl\,d\Omega. \tag{4}$$

Let us consider all values of expression (4). After the atom has left the insulator crystal lattice, during some period of time τ it is in the excited state. The atom has a potential energy that will be lost with photon after its transfer to the ground state; and also, kinetic energy. By means of kinetic energy, the atom will pass the way $l=\tau\cdot\upsilon a$, where υa is the atom velocity. From this, it is seen that the value ∫dl, of expression (4) is a path of the atom in the excited state. Schematically, the described process is presented in Fig. 2.

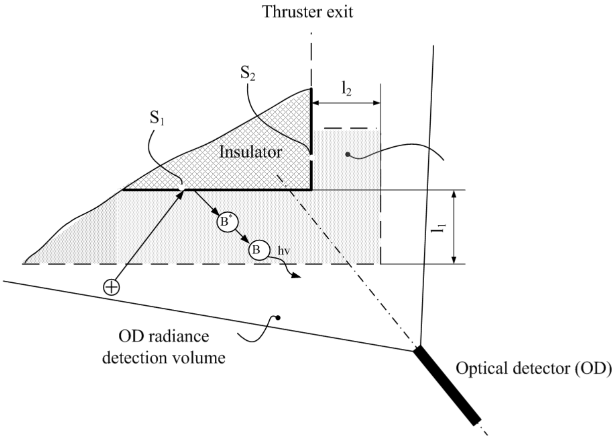

Fig. 2. Insulator atoms radiance volume

The parameter ∫dΩ is determined as a relation of radiation surface areas (S_1 and S_2), Fig. 2, to the square of distances (r_1 and r_2) from source to the radiation detector.

From this, the expression of the measured intensity will be written as

$$I=J_{SP}\left(l_1\cdot\frac{S_1}{(a+r_1)^2}+l_2\cdot\frac{S_2}{(a+r_2)^2}\right)=$$
$$=J_{SP}\left(\frac{V_{RS\_1}}{(a+r_1)^2}+\frac{V_{RS\_2}}{(a+r_2)^2}\right), \tag{5}$$

where V_{RS_1} and V_{RS_2} are the insulators radiation volumes inside the DCh and out of the thruster exit.

a is the coefficient, determined during the calibration of radiance power depending on the distance from the radiation source to the optical detector.

Registered line intensity (5) depends on the difference between the radiance volume V_{RS} and the radiation detection volume V_D. The OES method is used with lenses to achieve the dimensions of radiation detection volume to be significantly higher than the dimensions of thruster (radiation source). So, in one measurement, summarized intensity of all components (both DCh walls, magnetic poles, core and cathode) is registered.

Proceeding from the above, a method of optical emission spectroscopy with the scanning of plasma through the collimator (OESSC) has been developed. In other words, the method of OES was transformed from integral to local. The idea of this method is to significantly decrease the detection volume to such an extent that it was smaller than the dimensions of the radiation volume (Fig. 3).

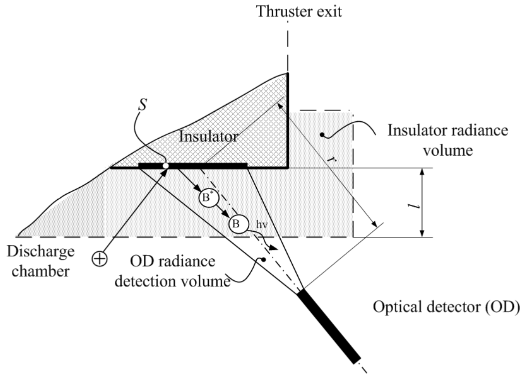

Fig. 3. A scheme of insulator radiance measurement with the OESSC method

With the dimensions of the radiance surface area (S), excited atom pass (l), dimensions of detection volume (V_{RS}), distance from the insulator to the optical detector r, it is easy to determine the specific line intensity (J_{SP}) (6).

$$J_{SP}=\frac{I}{\dfrac{V_{RS}}{(a+r_1)^2}}. \qquad (6)$$

The erosion rate is determined from the well-known expression [2]:

$$Er=I^{B}_{249.77}\frac{I^{Xe}_{828.01}}{I^{Xe+m}_{484.43}}, \qquad (7)$$

where $I^{B}_{249,77}$ is the line intensity of the excited boron atom; $I^{Xe}_{828,07}$ is the line intensity of the excited xenon neutral atom; $I^{Xe+m}_{484,43}$ is the line intensity of the excited xenon ion.

By substituting the expressions for the specific intensities (6) in this dependence (7), we obtain the equation of the specific erosion rate Er_{SP} from the unit volume of the insulator radiation:

$$Er_{SP}=\frac{I^{B}_{249.77}}{\dfrac{V_{R\_}}{(a+r_B)^2}}\times\frac{\dfrac{I^{Xe}_{828.01}}{\dfrac{V_{R\_Xe}}{(a+r_{Xe})^2}}}{\dfrac{I^{Xe+m}_{484.43}}{\dfrac{V_{R\_Xe+m}}{(a+r_{Xe+m})^2}}}, \qquad (8)$$

where V_{R_B}, V_{R_Xe}, V_{R_Xe+m} are the radiation volumes of boron, xenon and metastable xenon ion, respectively; r_B, r_{Xe}, r_{Xe+m} is the distance from the optical detector to radiation volumes of boron, xenon and metastable xenon ion, respectively.

By performing measurements with the OESSC method and using the expression (8), the erosion rate of separate SPT parts is determined.

4. 3. Experimental equipment of the OESSC method

The complex of the OESSC method was developed to provide measurements [7], Fig. 4. The complex consists of a spectral block and the optical detector (OD) displacement system. The spectral block consists of four small-sized high-resolution spectrometers (1).

The characteristics of the developed spectral block:

– spectral range 240 to 850 nm;

– resolution of spectrometers of ultraviolet (UV) region 0.04 nm, visual region 0.3 nm, infrared region 0.08 nm.

To provide a high accuracy of measurements, spectrometers of UV region are equipped with the detector temperature stabilization and control unit in the range of 20 to 25 °C. To exclude the atmosphere absorption of UV lines intensities, the block of spectrometers is equipped with a nitrogen supply system.

Specialized optical cable was developed to perform measurements with 4 spectrometers simultaneously from a similar unit of plasma volume. One part of the cable (8) is installed in the vacuum chamber (7). It has 4 optical fibers in one metallic sheath. It is connected to the adapter, inside which fibers are branched out into separate cables and then are connected to the spectrometers.

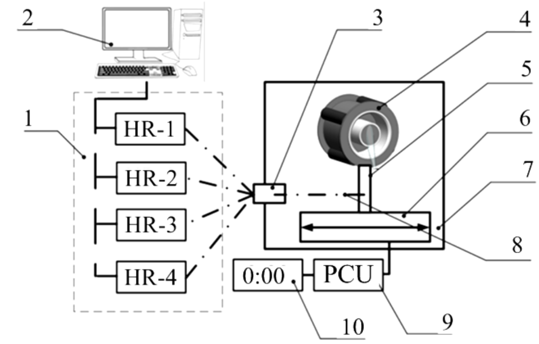

Fig. 4. A scheme of the OESSC method measuring complex: 1 – high-resolution spectrometer block; 2 – computer; 3 – adapter; 4 – SPT; 5 – optical detector; 6 – motion mechanism; 7 – vacuum chamber; 8 – optical cable; 9 – power and control unit (PCU); 10 – position indication

The registered radiance volume depends on the optical cable divergence angle. The divergence angle of the standard optical cable is 24.5° [7]. Installation of the Gershun tube (collimator) on the optical cable helps to decrease the registered radiance volume. A part of the cable inside the vacuum chamber and collimator is connected to one unit that is called optical detector (5). The calculated and measured value of the optical detector divergence angle is 5.40. This helped to decrease the radiance detection volume 11 times.

The displacement system consists of the motion mechanism (6), which provides positioning of OR (5) relative to the thruster (4). Control of the motion mechanism is performed with the help of the power supply and control unit (9), coordinates of OR are controlled by the system of position indication (10).

5. Results of the DCh walls erosion rate research with the help of the OESSC method

The experiment with the OESSC method was performed with the following thruster parameters: discharge voltage (Ud) 300 V, anode mass flow rate 4 mg/s, cathode mass flow rate 0.35 mg/s. According to the data obtained in previous experiments, the time of erosion rate total stabilization is 3 hours. After this period of time, measurements with the OESSC method were performed. Initially, the spectrum of the inner insulator, and then the spectrum of the outer insulator were registered. To perform measurements with the error lower that 3 %, 12 registrations of data were performed in each of SPT operational regimes. The parameters of the experiment are presented in Table 1, where Iic is the inner coil current, Ioc is the outer coil current and Id is the discharge current.

Table 1

Experiment parameters

№	Ud, V	Iic, A	Ioc, A	Id, A
1	300	6.0	6.0	4.30
2			5.0	4.34
3			4.0	4.45
4		5.0	6.0	4.34
5			5.0	4.40
6			4.0	4.50
7		4.0	6.0	4.43
8			5.0	4.50
9			4.0	4.65

As a result of the experiment, the dependences of the II and OI erosion rate on the coils currents were obtained. Fig. 5 shows the dependence of the II erosion rate on the coils currents. As it is seen from the results, when the inner coil current decreases, the II erosion rate goes down. And vice versa, with the decrease of the outer coil current, the II erosion increases.

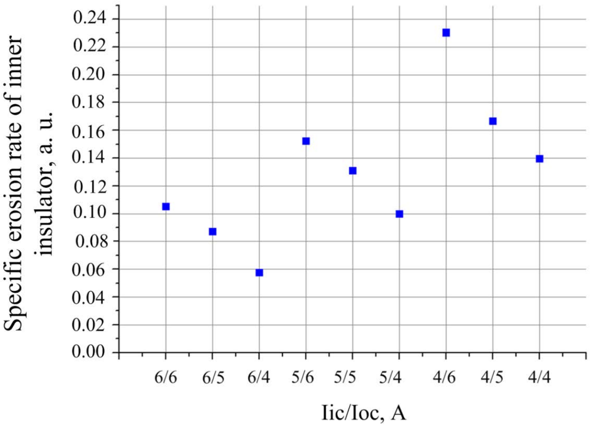

Fig. 5. Dependence of the inner insulator erosion rate as a function of the coils currents

Fig. 6 shows the dependence of the OI erosion rate on the coils currents. When the inner coil current decreases, the erosion of OI falls. And with the decreasing of the outer coil current, it increases.

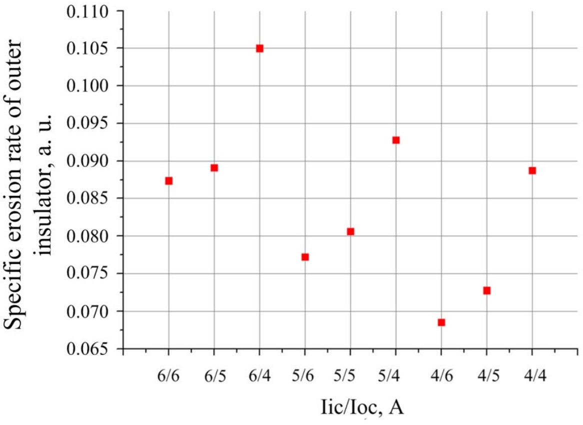

Fig. 6. Dependence of the outer insulator erosion rate as a function of the coils currents

After this, the comparison of erosion rates of different insulators is performed, the results are presented in Fig. 7.

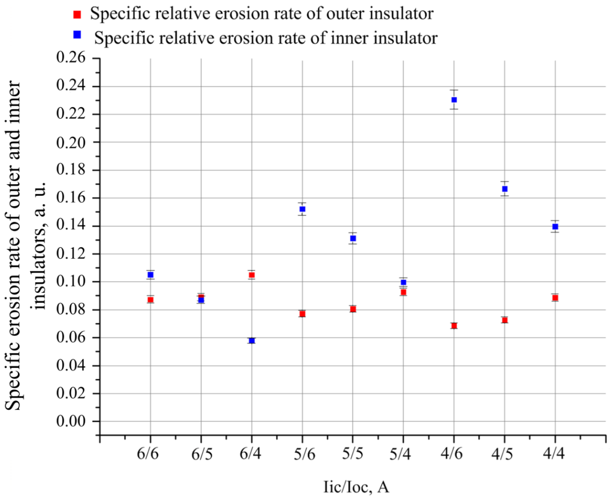

Fig. 7. Dependence of the ceramic insulators specific erosion rate as a function of the coils currents

As it is seen from Fig. 8, the dependences of the outer and inner insulator erosion rates have a common intersection point. It shows that with the coils currents equal to 6 A for the inner and 5 A for the outer coils, the wear of both wall surfaces is practically the same. The difference between the erosion rates of inner and outer insulators is 2 %. As it is seen from Table 2, the inner and outer coils at a current of 6 A and 5 A respectively, the discharge current is not minimal. It means that the SPT operation regime with the minimal discharge current does not correspond to the SPR operational regime with a uniform erosion rate of insulators.

6. Results discussion of the SPT DCh erosion rate research with the OESSC method

The analysis of the experimental data results showed that there is such a thruster operational regime at which the DCh walls wear is uniform. Based on the obtained data of specific erosion rates, the prediction of the SPT DCh walls radial erosion rate was modeled as shown in Fig. 8.

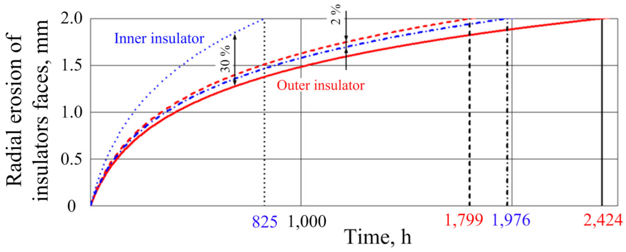

Fig. 8. A theoretical prediction model of the insulators faces radial erosion rate at the condition that the wear rate of OI is by 2.0 % higher than that of II

According to the calculation results, it was found that at the coils currents of 6 and 5 A, the 2 mm II face wear time is 1,976 hours. The wear time of the 2 mm OI face is 1,799 hours. The results show that the thruster lifetime in such an operational regime will be 2.2 times higher.

The research results showed the main advantages of the developed method.

1. The OESSC method allows the research of different regimes of SPT operation during one day of an experiment. This is very significant in terms of modern technologies development rate.

2. With the help of the OESSC method, it is possible to determine the SPT operational regime with the uniform wear of DCh walls during the first hours of the experiment. Due to this, the costs of the experiment and accordingly the costs the whole propulsion system manufacturing are reduced.

3. The research of SPT operational regimes helps to increase the thruster lifetime significantly.

4. The developed method is appropriate for different plasma thrusters with different designs and power levels. This is important from the point of view of the diagnostic apparatus requirements for the electric propulsion systems investigation.

The method disadvantage is that measured data are in units, not in “habitual” measurement units, as with direct methods (mm/s, mg/s). But this is not difficult to change with the usage of two (direct and OESSC) methods in one experiment. After that, the data of erosion is recalculated to absolute wear rate by means of correlation coefficients.

The analysis of the method conception showed possible error sources: errors of experimental equipment and errors of the calculation model.

To determine the experimental equipment error, the experiment was provided. The goal of it was to collect spectral block statistical data. The optical detector was set in a stationary position relative to the thruster, without any motion. Fifty spectrums were registered. After this, standard deviation σ (9) and confidence intervals a (10) were calculated.

$$\sigma=\sqrt{\frac{1}{n\cdot(n-1)}\cdot\sum_{i=1}^{n}\left(\left|I_i^M-I\right|\right)^2}, \qquad (9)$$

$$a=\pm 3\cdot\sigma, \qquad (10)$$

where n is the number of measurements; i is the sequence number of the measurement; I_i^M is the measured line intensity; I is the average intensity value of all measurements.

One more time standard deviation was calculated for the measured data set I_i^M, that is in the range of confidence intervals a (9). The line intensity absolute measurement error ΔI is calculated according to the expression (11), as a product of the standard deviation and the Student’s test ts:

$$\Delta I=ts\cdot\sigma. \qquad (11)$$

The relative error is determined as:

$$\varepsilon I=\frac{\Delta I}{\bar{I}}\cdot 100\,\%. \qquad (12)$$

Further, taking into account the calculated values, boron erosion rate absolute errors were determined ΔEr^B (13):

$$\Delta Er^B=\sqrt{\sum_{i=1}^{n}\left(\frac{\partial}{\partial I^B, I^{Xe}, I^{Xe+}}Er\left(I^B, I^{Xe}, I^{Xe+}\right)\right)^2} \qquad (13)$$

and relative errors (14):

$$\varepsilon Er=\frac{\Delta Er}{\bar{Er}}\cdot 100\,\%. \qquad (14)$$

In Fig. 9, the erosion rate measurement error depending on the number of measurements is presented.

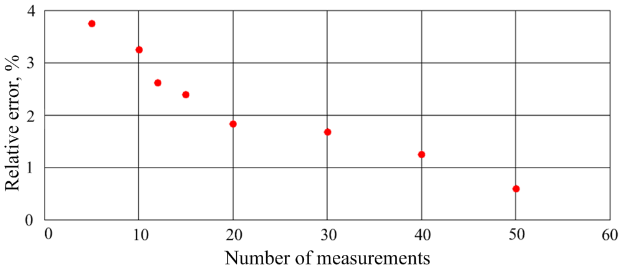

Fig. 9. A relative error of the HR spectral complex erosion rate depending on the number of measurements

The analysis of calculations showed that twelve measurements of the spectrum are enough to obtain relative errors lower than 3 %.

The error of calculation of equation (3) can be decreased with the usage of the collision-radiative model instead of corona model. But for today this is not possible because there is an absence of reliable reference data on the spectral constants for the lines of excited boron atoms.

7. Conclusions

As a result of the work:

1. The method of optical emission spectroscopy with the scanning of plasma through collimator was developed (OESSC). This method allows measuring the radiance of the outer and inner DCh walls separately during the SPT operation.

2. The OESSC method experimental equipment was designed, manufactured and tested. It includes the spectral block and the optical detector positioning system.

3. The experiment with the OESSC method was demonstrated. The erosion rate for each of ceramic walls in different thruster operational regimes was researched. It was found that at the coils currents of 5 and 6 A for outer and inner coils, respectively, there is a uniform wear of DCh

walls. It is shown that due to selection of SPT magnetic system parameters, it is possible to significantly increase the anode block lifetime.

4. According to the results, it is shown that there exist at least two criteria of thruster operational regime selection: the regime with minimal discharge current and the regime with the uniform wear of SPT DCh walls.

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