The peculiarities of hollow cathodes erosion at non-incandescent switching on

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Abstract

The problems of development of self-heated hollow cathodes (SHHC), which emitter is heated up to operational temperatures through interaction with gas discharge, are considered. There is described the technique of account of cathode erosion in start period using measured start integrated characteristics: the discharge current and voltage, the intensity of radiation of excited or ionized activator atoms and plasmagenerate gas consumption through cathode orifice. The measurement complex on the base of computer is described, it permits to fulfill completely all requirements to the character of experimental dates. There are shown the results of measurements while SHHC operated on currents 7A and 21A. For the first time were carried out the accounts of start erosion according to described technique. There are discussed the results of self-heated start erosion peculiarities.

Introduction

The effective application of Electric Propulsion Engines as engines of orbit correction for execution of active geophysical experiments, as high-effective sources of ions and electrons of various energies in technological processes of making films has caused the requirements in perfection of designing and studying of physical processes occurring in various EPE units.

However, the applicance of EPE are at present considerably limited by its dynamic characteristics. So, to example, it is known that EPE can already make the serious competition to existing systems of SpaceCraft orientation, especially in case of long-life satellites and systems which requires precise basing. However, its application is constrained by long preparatory pre-start time, mainly for start preparation of good developed heated cathode.

The similar situation is observed in case of technological application. So, the time of active period of film producing by hollow cathode is 30-120 s, and the start preparation of heated cathode takes inadmissible large part of whole technological period.

The use of self-heated hollow cathode (SHHC) permits to reduce considerably, to 1-5 s, the time of start (in this case under term the "start" we understand the time from submission of start command to cathode reaching the stationary operating mode). The emitter heating from environment to operational temperature is executed directly by gas discharge afterwards of it switching on.

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The given technique of start permits considerably simplify the design of cathode and increase its reliability. Besides, the power supply system is simplified and its weight is decreased by absence of power supply start heater.

The investigated problem

One of the defects of the SHHC is the significant start erosion. It is difficult to calculate this erosion. The existing methods of measurement of cathode erosion in stationary operating mode are good developed, however their applications is connected with significant time expenditures, or with necessity of using of very complicated and expensive measurement hardware.

One of the probable methods of definition of stationary hollow cathode erosion may be the quantitative spectral method [1] which was the base method of cathode erosion measurement during start from cold condition.

The experimental equipment and technique

The experiment scheme and measuring complex is submitted on Fig.1. The measuring complex consists of the central computer, which provides through devices of interface the management of power supply of main and switching on discharges, carries out the testing of measuring blocks and devices, provides the measurement of all necessary parameters, primary processing of experimental information and it displaying on graphic display and recording.

Experiment measured the following parameters: the current and voltage of discharge, the radiation intensity of excited or ionized atoms of activate component (3BaO*Al2O3*CaO) and the value of dynamic vacuum in experimental chamber. The error of measurement made up the value not exceeding 1% for first three parameters and not more than 3% for the latter. The dynamic changes cathode consumption were conducted according to technique stated in [2]. The calibration of this method was executed by precision static consumption-meter with measurement error not exceeding 1%. The dynamic vacuum in chamber at consumptions of plasmagenerate gas (xenon)-M=(0.1-1.2) mg/s was supported on level (1...9)*10^-6 Pa by high vacuum unit.

The cycle of measurements was carried out in time not exceeding 1 ms with frequency 10-100 Hz, that permits to justify the following main assumptions with high degree of reliability:

1. For time of measurement does not happen the considerable changes of main discharge parameters.
2. For time between cycles of measurements happens the total shift of whole plasma volume which radiation falls in monochromator.
3. Is neglected by back movement of activator component to cathode.

Physical-mathematical statement of experiment

Outcoming from such specially selected conditions of experiment it is possible in each moment of measurement to define the weight of yielded cathode material which outflowes with plasmagenerate gas and is located in studied volume:
where $n_a$ - the concentration of atoms of weight $m_a$ located in studied volume $V$.

The value of yielded material for time from beginning of cathode start till time $t_s$ is possible to calculate by following way:

$$m(t_n) = \sum_{i=1}^{n} m(t_i)$$

(2)

or for erosion rate:

$$m_{an} (t_n) = \frac{\sum_{i=1}^{n+1} m(t_i) - \sum_{i=1}^{n} m(t_i)}{\Delta t} = \frac{m(t_{n+1})}{\Delta t} = \frac{n_a(t_{n+1})V}{\Delta t}$$

(3)

where $\Delta t$ - the time between measurements.

Thus, it is necessary to calculate the concentration of atoms and ions of studied element on each for account of start erosion rate, that is possible by measurement of intensity of it radiation from plasma:

$$I = \frac{h v}{4 \pi} \sum_{k=1}^{k-1} \frac{A_{ki}}{A_{ki}} \int_{\varepsilon_{ea}}^{\infty} \sigma_{ea}(\varepsilon) f(\varepsilon) d\varepsilon$$

(4)

where $l$ - length of beam in plasma, $h$ - Plank constant, $v$ - frequency.

The electron concentration can be expressed from Ohm law, neglecting the diffusive current:

$$j = en_e V_e = n_e \cdot \frac{e^2}{m_e \nu_{ea}} E$$

(5)

While describing the current density through current and area of plasma jet section, as well as taking into account, that

$$\nu_{ea} = n_e \cdot \int_{0}^{\infty} \sigma_{ea}(\varepsilon) f(\varepsilon) \nu(\varepsilon) d\varepsilon$$

(6)
and weak dependence of cathode drop from current we get the expression for account of yielded material value concerning to level of stationary erosion:

\[
\frac{\dot{m}_{er}(\tau_{-})}{m_{er}} = \frac{I(\tau_{-}) \cdot J(\tau_{-}) \cdot U(\tau_{-}) - \Delta \phi_{-}}{I \cdot J(\tau_{-}) \cdot U - \Delta \phi_{-}} \cdot \frac{\dot{m}_{xe}}{m_{xe}(\tau_{-})}, \tag{7}
\]

where \(U, I\) - discharge parameters, \(\Delta \phi_{-}\) - cathode drop, and factor \(\beta_{-}\) is calculated by expression:

\[
\beta_{-} = \frac{\int_{\varepsilon_{0}}^{\infty} \sigma_{o}(\varepsilon_{-}) f(\varepsilon_{-}) \varphi(\varepsilon_{-}) d\varepsilon_{-} \cdot \int_{\varepsilon_{0}}^{\infty} \sigma_{ee}(\varepsilon_{-}) f(\varepsilon_{-}) \varphi(\varepsilon_{-}) d\varepsilon_{-}}{\left[\int_{\varepsilon_{0}}^{\infty} \sigma_{o}(\varepsilon_{-}) f(\varepsilon_{-}) \varphi(\varepsilon_{-}) d\varepsilon_{-} \cdot \int_{\varepsilon_{0}}^{\infty} \sigma_{ee}(\varepsilon_{-}) f(\varepsilon_{-}) \varphi(\varepsilon_{-}) d\varepsilon_{-}\right]_{r}}. \tag{8}
\]

The value of factor \(\beta_{-}\) does not considerably change at characteristic changes of electronic temperature 2-3 eV (Fig.2). Thus the final formula for definition of relative start erosion:

\[
\frac{\dot{m}_{er}(\tau_{-})}{m_{er}} = \frac{I(\tau_{-}) \cdot J(\tau_{-}) \cdot U(\tau_{-}) - \Delta \phi_{-}}{I \cdot J(\tau_{-}) \cdot U - \Delta \phi_{-}} \cdot \frac{\dot{m}_{xe}}{m_{xe}(\tau_{-})}. \tag{9}
\]

The analysis of received results of erosion measurements

On Fig.3 the results processed on above stated techniques of SHHC start erosion definition are submitted. The analysis of submitted experimental data allows to allocate three stages of start erosion. The first, which duration does not exceed 10-15 s, is consequence of spot regime of cold cathode emitter work (according to the principle of Shleenbek minimum it is possible only this form of discharge in this state). In this period the erosion of material can reach 25% from summary erosion. The cause of the second peak of erosion (to 75-80%) is the effect of gas consumption decrease while SHHC starts [2]. On the final stage, the insignificant mass of material erodiates, there are observed the weak changes of all discharge parameters and then they gradually achieves their stationary significances.

The conclusions

The largest cathode erosion takes place on the second stage. Therefore, for developing of low erosive SHHC start we must pay the heaviest attention to the organization of gas processes occurring at start.
References


Fig. 1. The scheme of measurement complex.

Fig. 2. The factor $\beta$ dependence versus temperature

Fig. 3. The discharge parameters dependences versus time:
1 - discharge voltage; 4 - radiation intensities of Ba$^+$ lines;
2 - discharge current; 5 - start erosion;
3 - consumption variations;