HIGH-TEMPERATURE SYSTEM OF THE ELECTRICAL CURRENT CONVERSION FOR POWERFUL EPT.

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Abstract

The operating characteristics of the theoretical and experimental investigations of the high-temperature radiation-resistant current conversion system developed in Moscow State Tecnical University by N.E. Bauman are described. The main attention was concentrated on electric strength of interelectrode gap and disclose state of plasma ventiles.

In present the question of the current conversion in order to concordance of the space power supply and the powerful EPT of the space vehicle is paid the great attention with elaboration of the perspective power-propulsion system (PPS), which converse the electrical power into jet thrust of the value up to 10^5 - 10^6 W. As the power supply is considered the nuclear reactor with thermionic converter (TEC) which is most compact and power-capacios. Ought to mention that the function of the space nuclear reactor has a number of peculiarities influencing on the vehicle's systems including the current conversion system and EPT:

- alpfa. beta. gamma, neutron radiation;
- high function temperature of the reactor's elements (up to 700 - 800 K);
- high density heat stream.

Low efficiency of TEC reqires the using sufficiently large heat-radiators. fig. 1. The electrical power conversion takes place with the lost of energy that leads to using the heat-radiators for the current converters too. Using the solid semiconductors as the current conversion ventiles which are disposed far from the nuclear reactor with TEC into protective containers leads to reduction of the summary current converter efficiency and mass efficiency of the whole power-propulsion system.

In this elaboration the question of using of the high-temperature radiation-resistant plasma current conversion system (HTP-system) including the high-temperature thermionic ventiles for powerful EPT is actual.

The scheme of the current conversion in the HTP-system is under construction as following:

1. Conversion of DC of the TEC into AC by means of the thermionic controlable ventiles.
2. The increase of the AC voltage by means of the high-temperature transformer (from 10-100 V up to 1000-10000 V).
3. The detection of the AC high level voltage into DC.

This approach permits to combine the space nuclear power supply with TEC and the current coverter - HTP-system. because it have like operating temperature. the same operating body.

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can be disposed out of the protective containers. On this base there is the considerable mass economy of the HTP-system and PPS. it is important for the space vehicle.

The special place in HTP-systems is occupied by the thermionic ventiles with cesium filling. Its appearance is connected with the development of the research works of the thermionic conversion of the heat energy into electrical. The interest to this ventiles is conditioned by following:

- the using of the thermionic metal cathode with cesium film permits to increase its resourse (or ventile's resourse) in regimes with the high current density;
- the high efficiency in view of low losses of the discharge voltage in disclose state of ventile (δU_d = 1 - 2 V);
- the high operating temperature (up to 800 - 1000 K) which facilitates the heat elimination of Jole losses of power and permits to use this ventiles in heat- and power-strained supplies.

The main problems of the creation of this ventiles are following:

1. The realization of the low-voltage non-self-maintaining arc discharge in disclose stste of ventiles providing the voltage drop no more than 0.5 -1.5 V.
2. The control of the discharge ignition and its turning off in the interelectrode gap (IEG) of the thermionic ventile and reduction of the control electrical power.
3. The proving of the electric strength of the IEG of the ventiles to the reverse arc breakdown in its close state.

The solution of this problems permits to design the HTP-systems for powerful EPT.

CONTROLABLE VENTILES - GRID SWITCHING VENTILES (GSV)

1. CHARACTERISTICSES OF THE GSV IN DISCLOSE STATE

The investigation of this question (theoretically and experimentally) was spared much attention [1-5]. The authors of this paper carried out the investigation of the GSV on the metal-ceramics models. the parameters of the thermophysics condition are following:

- the operating cesium vapour pressure p_{cs} = 0.133 - 3 Pa;
- the cathode temperature T_c = 1250 -1800 K;
- the anode temperature T_a = 580 -1050 K.

GSV has plane-cylindrical geometry: the value of IEG (cathode - anode) was 2 - mm. the grid has thickness near 1 - 2 mm. its transparenty was 0.2 -0.4 (it is the ratio of the holes square to the grid square). the hole diameter d_h = 0.5 - 1.5 mm (like that the grid influences on the discharge in IEG essentially).

In disclose state of IEG is realized the non-self-maintaining arc discharge into cesium vapour with thermionic cathode:

- the voltage discharge drop (in dependence on the value of the vapour pressure and the length of IEG Δ_{ieg}) was δU_d = 1.5 - 5 V at the current density 3 - 10 A/sm^2. that is coincided with the results of many research works completely. The voltage-current characteristics (V-C) of the discharge divide into two groops

conditionally, fig. 2:
- V-C with the part of the current saturation:
- V-C with the part of the negative differential conductivity of the discharge - $dj_d/dU_d < 0$.

The significantest characteristics of the GSV are the critical values of the discharge voltage and current characterizing the moment of the self-arbitrary current turning off in the IEG.

The authors [4,5] carried the experimental investigations of the influence of the external factors on the arc discharge in disclose ventile state:
- the influence of the cross magnetic field;
- the influence of the grid-cathode potential.

On the whole the using of the cross magnetic field of the small strength (up to 300 Gs) permits to control the non-self-maintaining arc discharge parameters in disclose state of IEG efficiently. The carried out research works of the disclose state of GSV [1-5] permited to estimate at theits ability on the electrical power in dependence on the operating parameters and external electric circus and to make the conclusion about possibility of the creation of the GSV with the specific electrical power more than 1 kW/sm^2 (the specific power to unity of the electrode surface), the efficiency η_{gsv} = 94 - 98 % at the source voltage (TEC) up to 100 V and more and operating temperature T_{gsv} = 800 - 1000 K.

2. CONTROL OF THE DISCHARGE IN THE GSV

On foundation of the discharge control in GSV there is the deformation of V-C (of the disclose state) when the critical values of the voltage δU_c and current density j_c are achieved. The authors [2,3] discovered for the first time the existance of two grid function regimes for the GSV in dependence on the vapour pressure p_{cs} and grid temperature T_g:

- the grid is used only for the discharge ignition at the its positive potential and maintance in close state GSV (the value of the discharge voltage ϕU_d is independent from the grid potential U_g) - this is thyratron regime;

- the grid is used for the discharge ignition and its turning off (the value of the discharge voltage δU_d is influenced from the grid potential) - this is tacitron regime.

The experimental investigations [2,3] and other research results are showed this control method of the discharge current is possible in very narrow range of the cesium vapour pressure p_{cs} = 0,01 - 0.1 Pa, moreover the cesium vapour pressure more than barium vapour pressure [2]. And increase of cesium pressure in IEG more than 0,133 Pa the grid losses the control propeties. The securing of the stability of the vapour phases in IEG of GSV in this case are permeted the complicated design solution and decrease the summary reliability of it.

The authors [6-9] carried out the research works showing the ability of the essential expansion of the function vapour

pressure range in IEG without the control loss. One of the method is the using of the external cross magnetic field for the control of the non-self-maintaining arc discharge [4,5]. The indisputable advantages of this method are following:
- the independence of the discharge current control from the polarity of control current impulse feeding the magnetic coil;
- the absence of the direct cnnection between the control circus and the arc discharge in GSV.

This method is very efficient at $j_d \simeq j_c$ and $\delta U_d \simeq \delta U_c$ when the non-self-maintaining arc discharge is very sensual to the balance between the recombination and generation velocities for charged particles. In this case the grid is plaing a part of the collector of the electrons in the discharge deflecting by the magnetic field; that fact is confirmed experimentally. Ought to mention the arc discharge turning off takes place at small values of the cross magnetic field strength: $B_\perp$ = 50 - 300 Gs at this the dependeces $B_\perp(j_c)$ and $U_{gt}(J_c)$ have similar form, fig. 3. However, unlike the grid potential regime of the discharge current control by the cross magnetic field the turning off takes place at cesium pressure up to 2,33 Pa, and the barium pressure is decreased on one-two orders, that fact facilitates the construction of the vapour sources.

At the same time the summary influence of the cross magnetic field and grid - cathode potential on the arc current turning off in disclose state of IEG was investigated and showed that in this case the value of the necessary grid potential decreases almost in two times.

3. ELECTRIC STRENGTH OF IEG TO THE REVERSE ARC BREAKDOWN

The regime of the reverse arc breakdown (the ignition of the self-maintaining arc discharge) was investigated in cesium vapour in the main experimentally. The results of this research works are showed that the value of the breakdown voltage depends on the vapour pressure and its temperature.

The authors of this paper carried out the investigations of the reverse breakdown in cesium vapour and the discharge of the disclose state of the high-voltage thermionic diode (HVTD). [6-9]. HVTD has the following pairs of the electrodes (cathode - first):
- stainless steel - stainless steel;
- stainless steel - tantalum;
- molybdenum - stainless steel;
- molybdenum - molybdenum.

The range of the thermophysics parameters was:
- operating pressure of cesium vapour p_{cs} = 1 - 30 Pa;
- operating vapour temperature T_a = 580 - 1050 K.

The curve form the dependence of the breakdown voltage U_b of IEG on the vapour pressure and its temperature $U_b(p_{cs}, T_a)$ are showed on fig. 4. This experimental results about the main role of the thermophysics parameters is showed that the cathode temperature T_k and the length of IEG Δ_{ieg} don't influence on

U_b. This fact permits to optimize parameters T_k and Δ_{leg} of HVTD for the increasing its efficiency. The dependence for the breakdown voltage was surprising:

$$U_b = \left[(T_a^* - T_{a0}) \frac{\varkappa_{areak}^2 m_a}{\varepsilon_0 k e n_a} \right]^{1/3}$$

where $\varkappa_{areak}$ - heat conduction of the vapour atoms, T_a^* - the critical value of the excited atoms temperature in "cathode glow", from which the breakdown is begining, n_a - atom concentration, m_a - atom mass, e - electron charge, k - Bolzman constant, ε_0 - dielectric constant.

The experimental results is corresponding to theoretical calculations.

Conclusions

1. The high-temperature GSV and HVTD with the cesium vapour can be used in the current conversion system for powerful EPT seccessfully.
2. The using GSV and HVTD with the cesium vapour permits to design the current conversion system on the operative voltage up to 1000 - 10000 V and current 100 - 1000 A at the function temperature 600 - 1000 K.
3. The using GSV and HVTD in HTP-systems of current conversion permit to decrease the mass-dimention characteristics of the space nuclear power supply with TEC up to 5 - 10 times.

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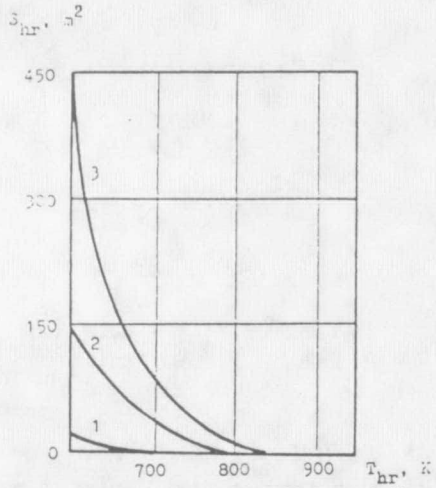

Fig. 1. The surface of the heat-radiator of the current conversion system in dependence on the its temperature. 1 - δP_c = 5 kW, 2 - δP_c = 50 kW, 3 - δP_c = 200 kW.

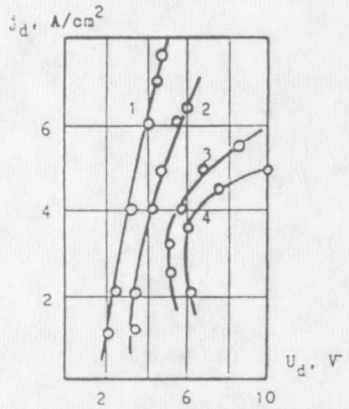

Fig. 2. V-C characteristics of the D.V. T_a = 1593 K. P_{Cs} = 1,104 Pa, P_{Ba} = 0,03 Pa.
1 - $B_\perp$ = 0, 2 - $B_\perp$ = 80 Gs, 3 - $B_\perp$ = 160 Gs, 4 - $B_\perp$ = 210 Gs.

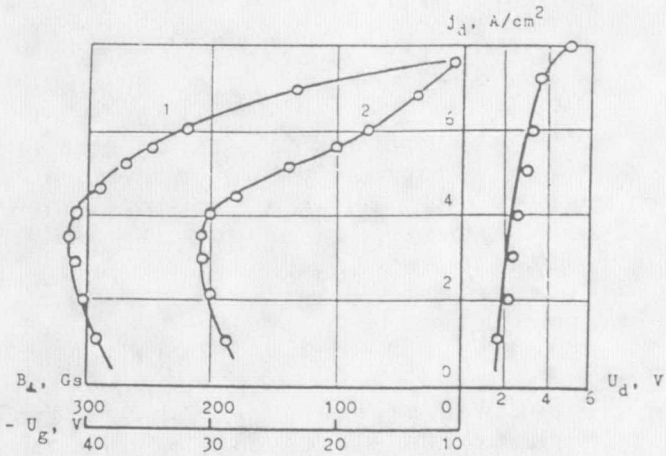

Fig. 3. The comparison of the current control method of the arc discharge turning off.
1 - U_g = 0, 2 - $B_\perp$ = 0.

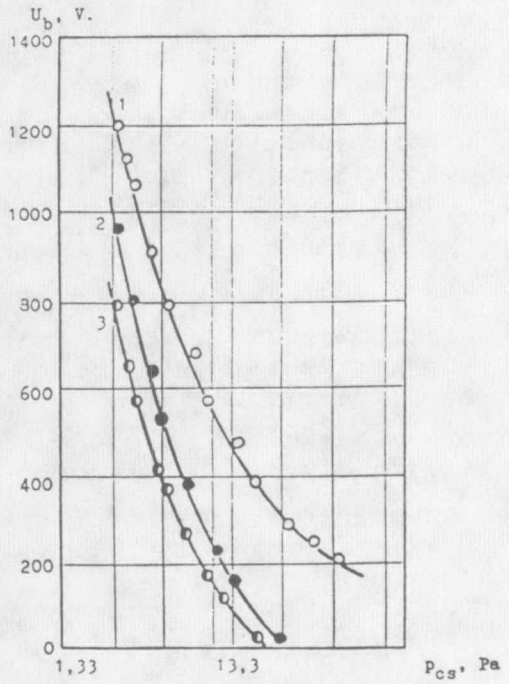

Fig. 4. The electric strength of IEG of HVTD to the reverse arc breakdown.
1 - T_a = 659 K, 2 - T_a = 709 K, 3 - T_a = 745 K.
the electrodes - molybdenum, Δ_{ieg} = 3,6 - 8 mm.