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CALCULATION OF EFFICIENCY FOR THE HEATING BY AN ELECTRON BEAM FROM THE PLASMA CATHODE[1])

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The calculation of the heating of a moving conductor in a system of cylindrical electrodes is carried out. It starts from the currents arising on the basis of processes on the electrode surface and in space, and follows the losses caused by them. The efficiency calculated for the given electrode configuration increases with the voltage, especially at its lower values.

РАСЧЕТ ЭФФЕКТИВНОСТИ НАГРЕВА ПОСРЕДСТВОМ ЭЛЕКТРОННОГО ПУЧКА ИЗ ПЛАЗМЕННОГО КАТОДА

В работе приведен расчет нагрева движущегося проводника в системе цилиндрических электродов. Исходя из токов, возникающих в этом процессе на поверхности и в пространстве, рассчитаны соответствующие потери. Эффективность нагрева, рассчитанная для данной конфигурации электродов, увеличивается с напряжением, особенно при его низших значениях.

I. INTRODUCTION

In the technology of heating by a beam of accelerated electrons the cold cathode in the glow-discharge is more frequently used than the hot cathode requiring a high vacuum of the order of 10^{-3} Pa. The apparatus with a glow-discharge works with a pressure in units of Pa, which diminishes the requirements on the pump stand and enables to solve easily the entrance and exit of the heated material into, respectively, out of the discharge, which is important for many technical applications. In our case the heating of the conductor passing through continually in the direction of the axis of the system of cylindrical electrodes is considered according to Fig. 1. A heated conductor on the earth potential forms the central anode CA, opposite that the cylindrical cathode is placed. Its free (working) area is limited by the screening electrode A, which works as a screen and as an auxiliary anode too. The electrode A has a flowing potential, the cathode K has a negative

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high voltage U_{KC} to the earth. To achieve the discharge current I_K of the order of 10^2 mA to 1 A by voltages U_{KC} of 10^3 to 10^4 V, the pressure of the gas (air) in the electrode space according to Fig. 1 is in units of Pa. The dimensions in Fig. 1 are in mm.

One of the important quantities, whose knowledge is necessary in the case of the technical application of this kind of heating, is the efficiency of heating depending on the discharge current and voltage. Because the high voltage glow-discharge between cylindrical electrodes has not been sufficiently investigated so far (as evident from the available literature), it was necessary to build, for the calculation of the efficiency, a model of the conditions in the discharge, which is in accordance to the observed characteristics of the mentioned discharge.

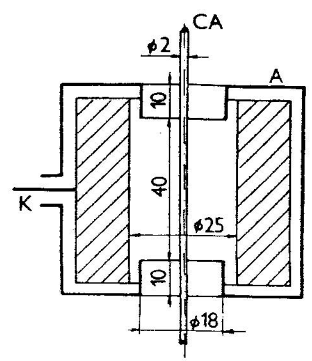

Fig. 1.

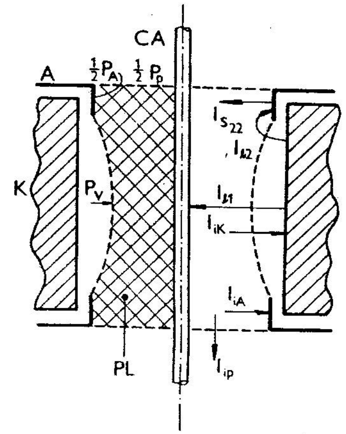

Fig. 2.

II. CALCULATION OF THE HEATING EFFICIENCY

The discharge between electrodes is maintained with a constant voltage U_{KC} and a current I_K. The input performance is then

$$N = U_{KC} I_K . \tag{1}$$

For the calculation of the efficiency of the heating η of the electrode CA we evaluate the sum of losses N_z on the other electrodes (A and K) and in the surrounding space and we obtain

$$\eta = \frac{N - N_z}{N} 100\,\% . \tag{2}$$

Calculating we suppose that one part of the electrode space is filled up by the plasma of the positive column (the area PL on the left side in Fig. 2), which is

limited by 2 circular areas P_p at the external space, by 2 cylindrical areas P_A at the auxiliary anode and by a space area of the discharge P_V, which depends on the free area of the cathode $P_K(P_V = K_2 P_K)$. Between the cathode and the positive column there is the cathode region, over which nearly all the voltage U_{KC} extends. The electrode A, isolated from other electrodes, is slightly negative with respect to the central anode (cca 10—30 V), according to the measurement on the experimental apparatus; thus $U_{KA} \doteq U_{KC}$. Under these assumptions flow at the discharge and between the electrodes currents, represented on the right-hand side of Fig. 2 I_{e1}, I_{e2} — currents of fast electrons emitted from the cathode K, I_{s22} — current of secondary (slow) electrons, ejected by the electron current I_{e2}; I_{iK}, I_{iA}, I_{ip} — currents of ions from positive column to cathode, auxiliary anode and free space.

Following relations are valid for the introduced currents:

$$I_K = I_{eK} + I_{iK} \quad I_{eK} = I_{e1} + I_{e2} \quad I_{e2} = K_1 I_{e1} \tag{3}$$

$$I_{s22} = \delta I_{e2} \tag{4}$$

$$I_{eK} = \gamma I_{iK} . \tag{5}$$

In the equation (3) the coefficient K_1 expresses the division of the cathode electron current on the components I_{e1} onto the central anode CA and I_{e2} to the auxiliary anode A. In Eq. (4) and Eq. (5) δ expresses the coefficient of the secondary electron emission due to electron impact, γ is the analogous coefficient for the positive ion impact.

Ion currents represent the random flow of positive ions passing along the idealized surface of the positive column, for which the well-known relations are valid:

$$\begin{aligned} I_{iK} &= (1/4)\, n_i v_i e P_V \\ I_{iA} &= (1/4)\, n_i v_i e P_A \\ I_{ip} &= (1/4)\, n_i v_i e P_p \end{aligned} \tag{6}$$

where n_i represents the density of plasma ions and v_i their mean random velocity. The loss at the auxiliary anode causes an undesirable temperature rise and can be expressed by the equation:

$$N_{zA} = U_{KA} I_{e2} - \varphi_A I_{s22} + U_i I_{iA} , \tag{7}$$

which expresses heating by electron current, the cooling effect by electron emission and heating by the internal energy of the impacted ions. The loss at the cathode

$$N_{zK} = U_{KA} I_{iK} + U_i I_{iK} - \varphi_K I_{iK} - \varphi_K I_{eK} \tag{8}$$

is due to the heating by kinetic energy of the impacted ions, to the internal energy and to cooling effects during the neutralization of the impacted ions and the

Table 1

φ_A [V] Fe	φ_K [V] Al	U_i [V] air	δ Fe	γ Al	Discharge voltage
4.6	4.2	15			
			0.8	1.3	$U_{KC}=3$ kV
			0.7	2.2	5
			0.62	4.0	10
			0.55	4.5	15

electron emission from the cathode. The internal energy of the flowing-off ions escapes into the free space:

$$N_{zp} = U_i I_{ip} . \tag{9}$$

For the total loss $N_z = N_{zA} + N_{zK} + N_{zp}$ we obtain, using Eq. (3)—(9), the expression

$$N_z = \frac{I_K}{1+\gamma}\left\{U_{KA}\left[\frac{K_1\gamma}{1+K_1}+1\right] + U_i\left[\frac{P_A+P_p}{K_2P_K}+1\right] - \frac{K_1\gamma\delta}{1+K_1}\varphi_A - (1+\gamma)\varphi_K\right\}. \tag{10}$$

The numerical evaluation of Eq. (2) using Eq. (10) is carried out for the system according to Fig. 1 and for the voltages $U_{KC}=3-5-10-15$ kV. At the same time

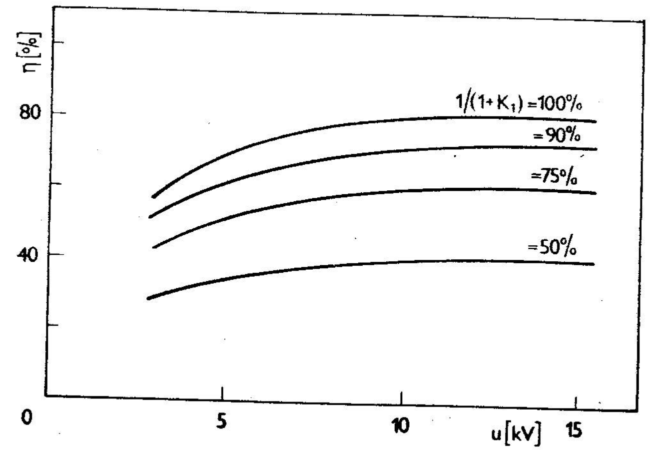

Fig. 3.

4 alternative values of the coefficient K_1 are taken into account: $K_k = 1/(1+K_k) = 0.5$; then the electron emission from the 50 % cathode free area flows into CA), $K_1 = \frac{1}{3}$ $(1/(1+K_1)=0.75$; then 75 % of the electron emission flows into CA), $K_1 = \frac{1}{9}$ (90 % of the electron emission flows into CA) and $K_1 = 0$ (all the electron current from the cathode flows into CA). Further we suppose that the coefficient $K_2 = 1$. Values of work functions φ_A, φ_K of the ionization potential U_i and of the secondary electron emission coefficient δ and γ for elected alternatives and used materials are introduced according to [1] in the Table 1. Results of calculations as a relation of $\eta = f(U_{KC})$ on the selected values of $1/(1+K_1)$ are represented in Fig. 3.

III. RESULTS EVALUATION

According to the measurements [2], the efficiency η diminishes fast for the discharge volatge $\leqslant$5000 V.

According to the measured efficiencies $\eta \geqslant 70$ % for $U_{KC} = 10$ kV most of the free cathode area is used for the electron bombardment of the central electrode CA.

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