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INFLUENCE OF THE TEMPERATURE OF ELECTRODE MATERIAL ON ITS DISINTEGRATION UNDER THE ACTION OF AN ARC DISCHARGE IN HYDROGEN

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Translation of "Vliyaniye temperatury materiala elektroda na yego razrusheniye pod deystviyem opornykh pyaten dugi v vodorode," Fiz. i Khim. Obrab. Mater., No. 2, March-April 1973, pp. 19-23.

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16. Abstract An analysis is made of the electrophysical processes occurring at the end surface of rod electrodes during constant and alternating arc discharge in hydrogen. Experiments are reported on the effect of surface temperature of tungsten electrodes on their erosion. The influence of activating additions of thorium oxide, the structure of the tungsten, and the gas surrounding the electrode on the specific thermal loading and the erosion of the electrodes is discussed.

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INFLUENCE OF THE TEMPERATURE OF ELECTRODE MATERIAL ON ITS DISINTEGRATION UNDER THE ACTION OF AN ARC DISCHARGE IN HYDROGEN

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Study of materials in terms of tungsten erosion in an /12* arc discharge reveals the lack of systematized information on the causes of electrode disintegration. Goryachev and Zelenin [1] feel that a tungsten cathode's stability is profoundly influenced by its rake of tool and voltage on the arc. Sergeyev et al. [2] consider that gas flow rate and current magnitude are the influencing factors. Obviously, this approach does not identify physical conditions which determine the magnitude and nature of erosion. The authors of reference [3] state that the primary factor affecting erosion is specific heat flux across the arc spot. In their opinion, electrode wear is caused by vaporization. However, they do not show how the extent of erosion changes when an electrode's thermal condition changes or what factors determine minimum disintegration and maximum current load.

In considering the problem of electrode disintegration, one must assume an energy balance on the boundary between the solid body and the current-carrying plasma. Ways to decrease erosion are best determined by identifying the primary parameters which define an electrode's working conditions and the extent of its disintegration. Let us consider the energy balance [4] on the cathode

$$Q_k + I_g S_i [(U_k + U_i) - \varphi] - Q_n \qquad (1)$$

where Q_k is total heat flux to the cathode; Q_n is heat

*Numbers in the margin indicate pagination in the foreign text.

flux from the cathode; I_g is the arc current; S_i is the current's ion component; U_k is potential cathodic voltage drop; U_i is ionization potential; φ is cathode material work function, and on the anode,

$$Q_a + I_g(U_r + U_a + \varphi)S_e - Q_n \qquad (2)$$

where Q_a is total heat flux to the anode; U_r is the potential characterizing the amount of heat energy transmitted to the anode by electrodes; U_a is anodic potential drop; S_e is the current's electron component.

We feel that the primary reason for disintegration is heat flux to the electrode, especially its density [4]. Then arc current, as shown in (1) and (2), has a considerable effect on Q_k and Q_a.

The type of electrons emitted from a cathode is /20 related to its surface temperature. Emphasizing the important role which the temperature of electrode T's working surface plays in the nature of processes at the point where the arc closes, we note that T is a function of total heat flux to the electrode. Changing the tungsten's dimensions, configuration, and cooling rate may have a significant effect on Q_e, T_e, and electrode erosion. Thus, it is apparent that the magnitude of current, the electrode's dimensions and heat flux to it, and its working surface temperature determine its rate of disintegration.

The effect of these parameters on erosion was studied on a setup consisting of two pure or thoriated (VT-15) tungsten rods cooled on their ends and placed on the same axis with 20-25 mm between the ends and the arc path. Time for one closure was about 15 min, erosion magnitude was measured with accuracy to 10^{-4} g. Electrode length varied from 6 to 60 mm. Erosion, electrode temperature, and heat flux to the electrode were

derived as a function of current load imposed on the rod's cross section.

The erosion curves of the cathode and AC arc electrode (figure 1) have typical maxima and minima. Visual inspections showed that, at current loads at which rod end temperature is below 1650°C, the arc closure contracted, the area of the bright spot (defined as the surface emitting electrons) is small, and therefore, specific heat flux to the electrode is maximum. Contraction of the arc discharge on the electrode indicates the possible existence of autoelectron or thermo-autoelectron emission.

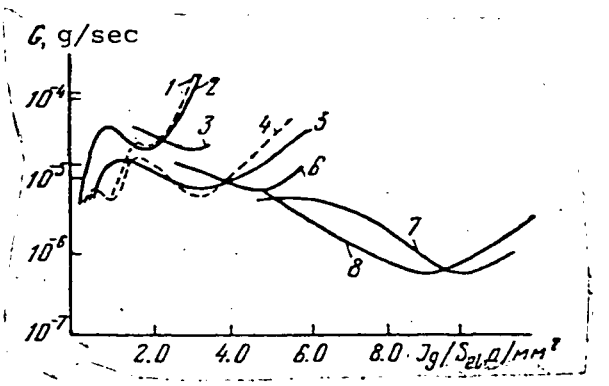

Figure 1. Tungsten rod erosion as a function of current density: 1 - AC, L_e = 60 mm, $WThO_2$; 2 - AC, L_e = 60 mm, W; 3 - AC, L_e = 40 mm, W; 4 - Cathode, L_e = 60 mm, $WThO_2$; 5 - Cathode, L_3 = 60 mm, W; 6 - Cathode, L_3 = 40 mm, W; 7 - Cathode, L_e = 6 mm, W; 8 - Cathode, L_e = 10 mm, W.

The current's ion component may constitute more than 75% of total current [5]. Heat flux concentration causes hot spots and rapid tungsten disintegration. An increase in electrode temperature leads to a sharp increase in the area of the bright cathode spot and of the surface which possesses high thermoelectronic emission efficiency. If the compensating effect of the electron current on the positive three-dimensional

charge is to be complete and the cathode is to have a strong field, the following condition must be satisfied [5]:

$$j_i/j_i > (m_e/m_i)^{1/2} \quad (3)$$

where j_i is ion current density; j_e is electron current density; m_i, and m_e are the mass of the ion and electron, respectively.

From inequality (3) we find that, for a hydrogen arc, /21 the limit for ratios j_e/j_i will equal 0.297. This probably occurs during the shift from autoelectron to thermoelectron emission. It has been noted that, when an electrode operates in these conditions, there is a chaotic shift in the arc spot caused by sharply pronounced gas turbulence, nonuniform emission properties of individual segments of the electrode working surface, etc. Reference [6] has established that, when an arc spot shifts, the rate of change in the temperature of the tungsten cathode in the arc closure area, as recorded by a BFEP-1 unit, reaches 10^4 deg/sec from 1,400 to 4,000°C.

Let us consider cathode working conditions when I_g = 100 a and T_e = 2,000°C. According to data [7], current density in the cathode spot on tungsten equals $(3\text{-}7)\times10^4$ a/cm^2. Projecting the spot through a lens on a matte-finish screen has made it possible to establish that the bright area where the discharge comes in contact with the cathode equals about 1 mm^2. Using thermoelectron emission current density as a function of temperature [7], let us plot the graph for the increase in thermoemission current in the spot after it moves to the new location (figure 2).

Apparently, at this time there existed auto- and auto-thermoelectron emission, which leads to high specific heat flux and an increase in electrode erosion. For alternating current, movement of the spot leads to even greater tungsten

disintegration, which is caused by abrupt cooling of the electrode as current passes zero. The spot may not stabilize in one place in 0.4 sec, since the compressed cathode spot possesses high mobility, while thermal collisions lead to the appearance of electrode material vapor jets and an arc shift on the electrode. The time it takes the discharge to travel along the electrode's surface can be considerable, and tungsten erosion increases.

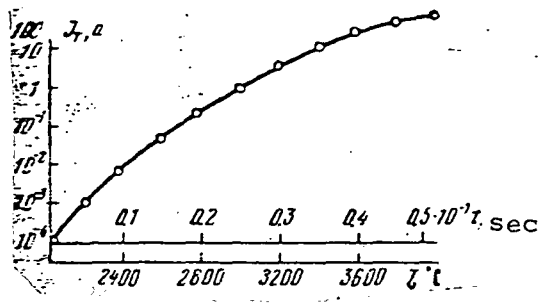

Figure 2. Increase in thermoemission current in an arc spot.

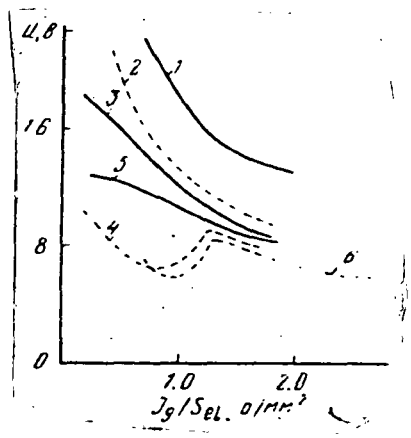

Figure 3. Voltaic equivalent of heat flux as a function of current load: 1 - Anode, L_e = 40 mm, $WThO_2$; 2 - Anode, L_e = 40 mm, W; 3 - AC, L_e = 40 mm, W; 4 - AC, L_e = 40 mm; 5 - Cathode, L_e = 40 mm, W; 6 - Cathode, L_e = 40 mm, $WThO_2$.

An increase in the overall temperature of the working end of the rod reduces the time required for the arc spot to concentrate and the magnitude of the current density in the spot. After the spot stabilizes in one place, its tendency to shift diminishes. Note that, in this example, thermoemission becomes significant only at spot temperatures above 3,800°C. The type of working gas has a considerable effect on the /22 extent of heat fluxes to the electrode. Thus, if the voltaic equivalent of heat flux for a tungsten cathode in helium equals 4-6 V; it equals 3-4 V in argon. Figure 3 shows the voltaic equivalent (U_B) for tungsten in hydrogen, obtained by

experiment. The high value for U_B is due to recombination of hydrogen atoms on the surface of the electrode. Adsorption of hydrogen on tungsten affects the nature of near-electrode process, increasing the magnitude of the potential barrier. It is assumed that a change in work function must be a function of the extent to which the electrode surface is shielded by the adsorbing gas [8]:

$$\Delta(e\varphi) = 4\pi\delta\theta\mu_0 \qquad (4)$$

where δ is the number of places on the surface accessible for adsorption; θ is the percentage of adsorbed places; μ_0 is the dipole moment of the atom-surface adsorption system.

$\Delta(e\varphi)$ for hydrogen is about 0.5 eV and decreases as temperature increases because of the sublimation of hydrogen from the tungsten surface.

The action of tungsten in argon, whose dipole moment equals zero, occurs without an arc spot at rod end temperatures above 3,000°C [9]. In these experiments, the spots had sharply pronounced boundaries and they could not be eliminated by changing electrode end temperature conditions. An increase in the overall temperature of the rod's working end leads to a change in the nature of emission processes, an increase in the current's electron component, redistribution of heat flux near the arc closure over a larger area, reduction in cathodic voltage drop because of the shift from autoelectron to thermoelectron emission, a decrease in the potential barrier on the boundary between the current-carrying plasma and the solid body, and, in general, a reduction in electrode erosion.

An increase in current load on the tungsten rod to a value at which the electrode melts causes the electrode material to spray, forming bands of solidified metal droplets on the quartz tube. The cathode's erosion curve exhibits an upward bend.

The causes for and the nature of electrode disintegration in alternating current are similar to those for a cathode.

The increase in erosion in alternating current as compared to direct current results from accelerated dynamic processes in the near-electrode area and the presence of anodic conditions in one of the half-periods.

The change in the tungsten work function and anodic voltage drop on the tungsten when current load and electrode temperature increase is slight. Therefore, when current rises, heat flux to the rod increases continuously, having a decisive effect on electrode disintegration.

Experiments have shown that the anode spot, defined as the bright surface, increases more rapidly than I_g; on an anode, this is about equal to the electron component [7]. From this one might conclude that specific heat flux to the anode decreases. The increase in erosion under these circumstances makes it possible to assume that disintegration is not local, but is determined by the vaporization of tungsten from the high-temperature area near the arc closure. The thorium-activated end of the tungsten exhibits a three- to fourfold reduction in work function as compared with that of pure tungsten for a cathode and AC electrode at no more than 1,800°C. If the electrode reaches T_e greater than 1,800°C, its erosion increases sharply. This is because of the disintegration of the activating coating, which is /23 superior in terms of the rate at which the activator diffuses from deep layers and because of thorium depletion in the working end of the electrode to depths of several millimeters [9]. Electrode material work function increases to a level found under identical conditions in pure tungsten. An increase in rod working end temperature results in a change in its structure: crystals grow [10]. An increase in grains reduces the length of their boundaries on the electrode surface,

creating conditions for redistribution of impurities located along the crystal boundaries to a smaller area, and this decreases tungsten disintegration. Thorium oxide films on the crystal boundaries inhibit their growth [10], creating conditions for increased electrode material erosion in vaporizing conditions above 1,800°C. Heating relatively easy-to-fuse (as compared with tungsten) ThO_2 causes the thorium oxide films to melt around the crystals and to expel them in thermal collisions associated with the presence of mechanical forces occurring during local and rapid heating of the material [11]. Note that the function a thoriated electrode in hydrogen is complicated because the thorium oxide on the electrode's working surface is reduced to pure thorium, the work function of which is greater than that of its oxide.

Analysis of this material shows that the level of tungsten rod electrode erosion depends on the thermal conditions for the working surfaces of the rods, which is determined by current load, heat flux to the electrode, temperature of its working end, and its dimensions. Depending on thermal conditions, the erosion curve for the cathode and AC electrode has two extrema. Thus, at a rod end temperature of about 1,650°C, tungsten disintegration is maximum; at about 3,000°C, minimum.

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