EROSION OF THE ELECTRODES IN HIGH-VOLTAGE HIGH-CURRENT WATER DISCHARGES

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The erosion of electrodes under the action of an electric discharge in a liquid as a factor limiting the lifetime of high-power switching apparatus or as the basis for the working process in electric spark and electrical erosion technology has now been studied quite well with the oscillatory form of the current pulse with a duration of 10^{-6}-10^{-2} sec and comparatively low power (<10^7 W) developed in the discharge channel [1-3]. The rapid progress made in recent years in the development of the powerful high-voltage pulsed techniques and widespread use of high-current spark dischargers with liquid insulation in pulse-forming circuits make the questions of erosion stability of electrodes in such discharges, whose operational state is characterized by a short time (10^{-9}-10^{-7} sec) and a high rate of liberation of energy (10^7-10^{12} W) in the discharge channel, of great interest. There is practically no published information on the erosion of electrodes under such conditions.

In this work we study the erosion of electrodes in high-voltage high-current dischargers with water insulation with commutated-current pulse durations of 10-45 nsec and a power of 10^7-10^{10} W developed in the discharge channel.

The dischargers commutated coaxial forming lines with a wave impedance of 3.5-100 Ω, charged up to a voltage of 50-1000 kV. The amplitude of the discharge current was equal to 1-150 kA. The length of the interelectrode gap in the dischargers varied from 0.4 to 6 cm. The volume of the metal ejected from the surface of the electrodes, which most completely characterizes the change in the form of the electrodes in high-current dischargers and permits estimating the operational lifetime, was used as the main quantitative indicator of electrode erosion. We used an MKU-1 microscope to evaluate the nature and quantitative indicators of the erosion. The volume of the metal V ejected from the surface of the electrodes was evaluated by a computational method, which approximated the erosion crater by a segment of a sphere. Control weighing with subsequent evaluation of V (these studies were performed with the use of model electrodes) showed that the calculation using the formula for the volume of a spherical segment gives a quite accurate value of the volume of the metal ejected from the surface of the electrodes (the disagreement does not exceed 10-20%). Erosion of electrodes consisting of the following materials was studied: 12Kh18N10T stainless steel, titanium, tantalum, tungsten, kirit (an alloy of 30% copper and 70% tungsten), L62 brass, copper, aluminum, magnesium, and lead.

It was established that the intensity of the erosion depends not on the polarity of the electrode, but rather on whether the electrode is "active" or "passive" (an electrode is said to be "active," according to the terminology adopted in this work, if the formation of the discharge begins on it). In the single-channel commutation mode, after the discharge is activated on the "active" electrode, a distinct erosion crater, whose form is nearly that of a spherical segment, forms (Fig. 1a). Several (2-5, and sometimes more) poorly defined craters form on the opposite electrode (Fig. 1b). This difference in the nature of the erosion-induced destruction of the electrodes is explained by the branching of the central stem of the breakdown channel, after it traverses a path equal to approximately one-half the length of the interelectrode gap in the discharger, into several branches, some of which participate in the commutation of the current (Fig. 2).

Figure 3 shows the dependence of the volume of metal V_a ejected from the surface of the "active" electrode on the quantity of electricity q flowing through the discharge channel within a single actuation of the discharger. The quantity of electricity transmitted by the discharge channel was estimated from the oscillograms of the discharge current. A typical oscillogram is shown in Fig. 4.

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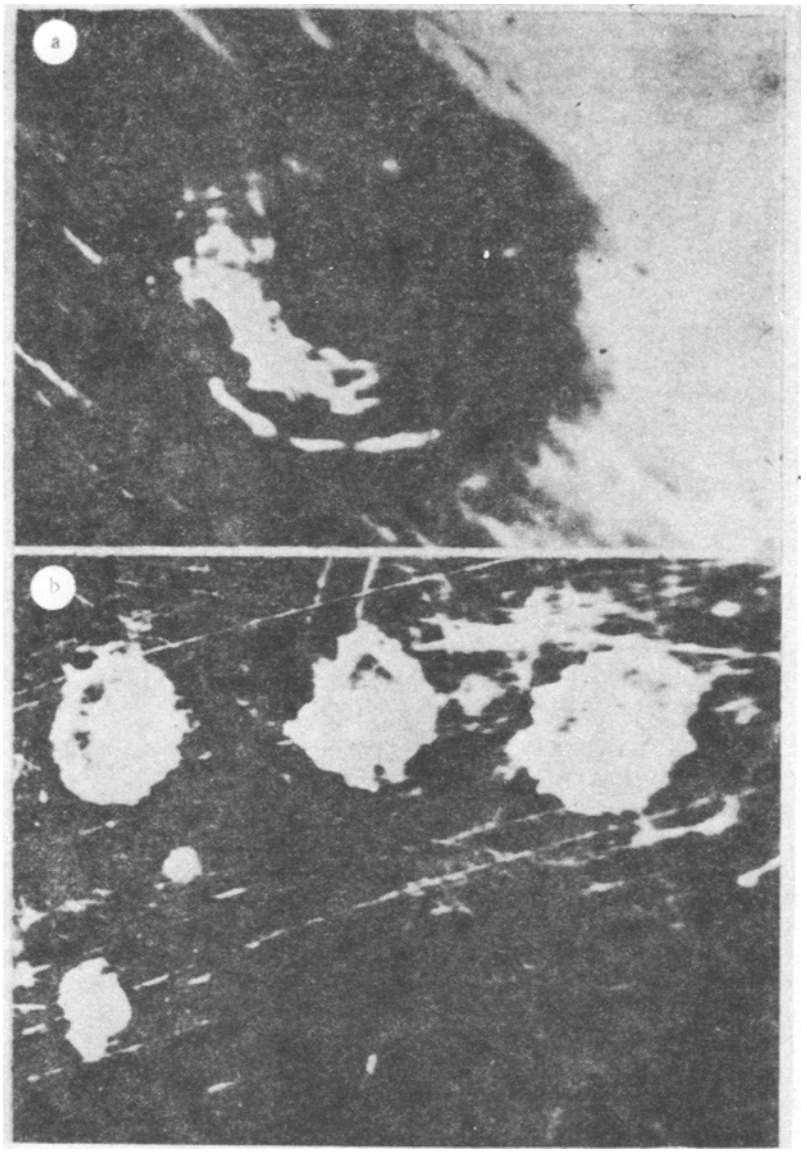

Fig. 1

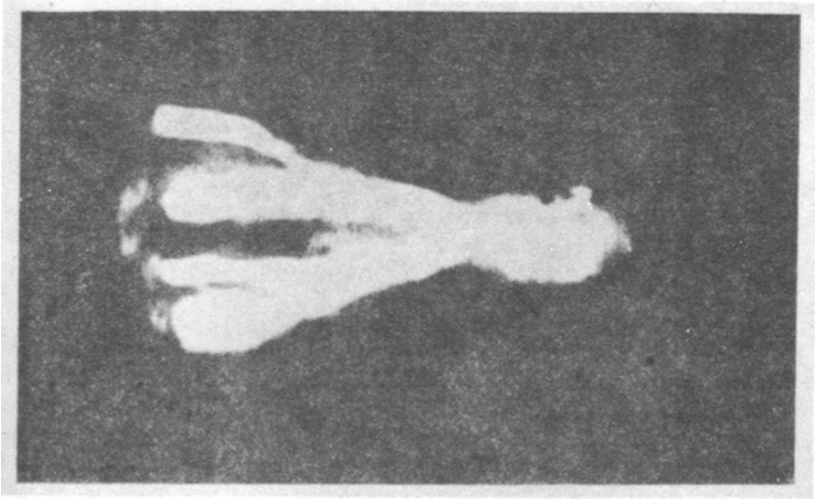

Fig. 2

The dependence shown in Fig. 3 for the "active" electrode can be described by an expression of the type

$$V_a = kq^n, \tag{1}$$

where n is a dimensionless parameter, which is practically independent of the electrode material and is equal to approximately 1.3; k is a coefficient determined by the material of the electrodes. For stainless steel electrodes k ≈ 100 (q and V_a are measured in units of C and mm^3, respectively).

The volume of metal ejected from the surface of the "passive" electrode can be found from the expression

$$V_p = k \sum_{i=1}^{m} q_i^n, \tag{2}$$

where q_i is the quantity of electricity transmitted by a separate branch of the discharge channel; and k have the same values as for the "active" electrode; and m is the number of branches participating in the commutation.

It follows from expressions (1) and (2) that when the discharge channel is branched, in view of the fact that n > 1, V_a is always greater than V_p. This causes less erosion wear of the "active" electrode in multichannel water discharges than in single-channel dischargers, which was pointed out in [4]. At the same time the volume of the metal ejected from the surface of the electrodes depends to a large extent on the nature of the current distribution over the discharge channels. Minimum erosion wear of electrodes is observed with a uniform current distribution over all discharge channels. In this case the volume of metal ejected from the surface of the "active" electrode is equal to

$$V_a = kN(q_{tot}/N)^n; \tag{3}$$

here q_{tot} is the total amount of electricity transmitted by the discharger and N is the number of discharge channels participating in the commutation.

In the more general case with a multichannel breakdown, when the current is not distributed uniformly over the discharge channels, V can be estimated from the expression (2).

When water is replaced by transformer oil under comparable conditions the erosion of the electrodes remains practically unchanged and the expressions (1)-(3) can be used to estimate V. An experimental check showed that the error in the calculation using expressions (1)-(3) does not exceed 20%.

In studying electrical erosion of electrodes, criteria for erosion resistance are introduced and erosion series, with whose help it is possible to select a priori electrode materials, compared according to their resistance to erosion, are constructed. A general criterion for erosion resistance applicable to all operational states of the electrodes does not exist. This is attributable to the fact that as the operational state of the electrodes changes, the heating conditions of the metal, determining the electrical erosion, change also, as a result of which not only the quantitative erosion indicators, but also the mutual position of the metals in the erosion series change [3]. The erosion series obtained in this work has the form

Pb, Mg, Al, Cu — Zn, Cu, Fe, Ti, Ta, W — Cu, W.

Of the published criteria for erosion resistance, the most widely used ones are L. S. Palatnik's criterion [5] and the criterion proposed in [6], according to which the stability of the electrode material is determined by the expressions $\lambda c \nu T_{melt}$ and $cT_{melt}/(k_b U'_{eq})$, where λ is the coefficient of thermal conductivity, c is the specific heat capacity, ν is the density, T_{melt} is the melting temperature, k_e is the coefficient of ejection of metal, and U'_{eq} is the equivalent voltage drop at the electrodes. The application of these criteria to the erosion conditions in this work shows that they do not describe the erosion series obtained. For example, according to L. S. Palatnik's criterion copper has a higher resistance to erosion than titanium and according to the criterion proposed in [6] V must be approximately the same for both copper and titanium electrodes, while according to the data obtained V for titanium electrodes is almost two times smaller than for copper electrodes.

In high-current water dischargers, commutating the forming lines, the erosion resistance of electrodes correlates quite well with the melting temperature of the material (with a con-

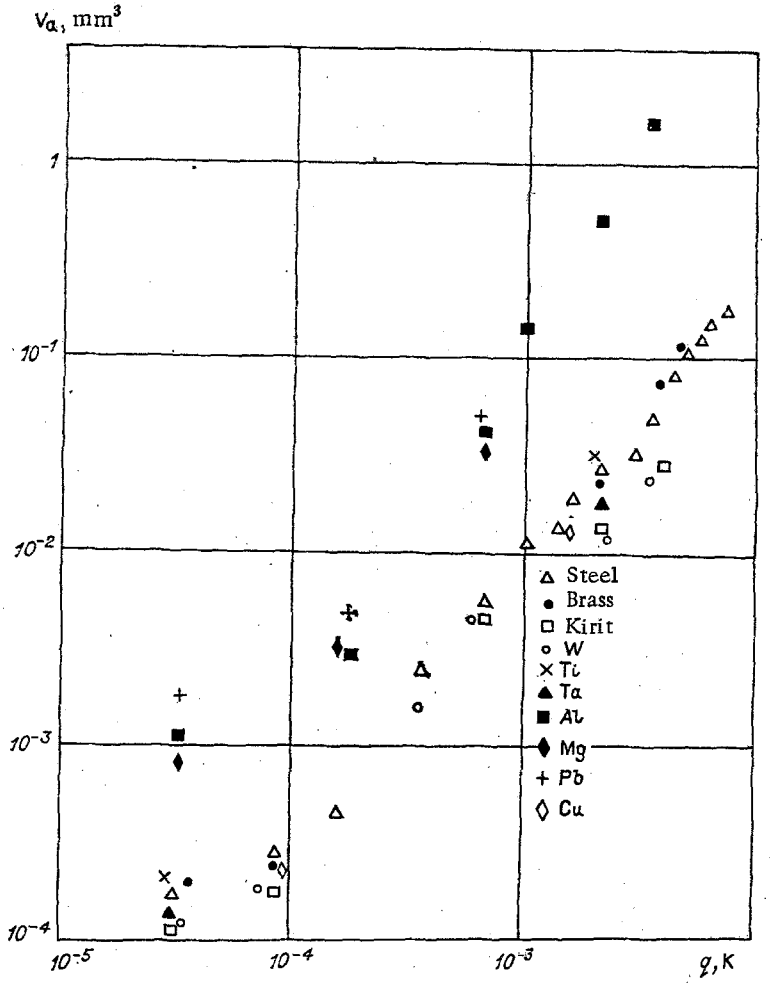

Fig. 3

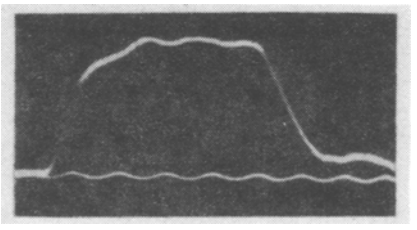

Fig. 4

fidence probability of 0.95 and an error of 0.1, the correlation coefficient is equal to ~0.8), which can be adopted as the criterion for their erosion stability.

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