MASS TRANSFER AND CRATER GEOMETRY OF A SPARK DISCHARGE IN A HERMETICALLY SEALED CHAMBER

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Results are presented of investigations of the dependence of crater diameter and depth and of transfer of electrode material for a spark discharge in transformer oil under an external pressure ranging from $1.01 \cdot 10^5$ to $252.5 \cdot 10^5$ N/m^2. The results obtained are discussed from standpoint of the role of the transient pressures and the surface and thermophysical properties of the liquid metal.

The electrical erosion during a spark discharge in an hermetically sealed chamber filled with transformer oil depends appreciably on the external static pressures [1]. The authors of [1] explain this relationship in terms of the different values of the transient pressures in the discharge gap, by the surface properties of the electrode material, and by the conditions of removal of fused metal from the interelectrode space. It was noted that the external static pressures must be appreciably influenced both by variation of the dimensions of the gas bubble, and by the transfer of metal at considerable static pressures may also be one cause of decreased electrical erosion, as determined by the weight of the electrode before and after a discharge. In addition, the external static pressures must have an appreciable influence on the spark discharge channel diameter, and therefore, on the size of the crater formed.

For an experimental verification of the above hypotheses we made simultaneous oscillographic and high-speed photographic records of the discharge, and measured the erosion, the diameter and depth of the craters formed, as well as the amount of metal transferred between electrodes.

The experimental apparatus, which has been described in [1], allowed us to conduct electrical discharges in an hermetically sealed chamber with external static pressures from $1.01 \cdot 10^5$ to $252.5 \cdot 10^5$ N/m^2. The investigation was carried out with individual contactless discharges (C = 100 μF, U = 1000–2000 V) between cylindrical electrodes of copper and Armco iron, whose working surfaces had been previously polished. The diameter and depth of the craters were measured on a PMT-3 microscope.

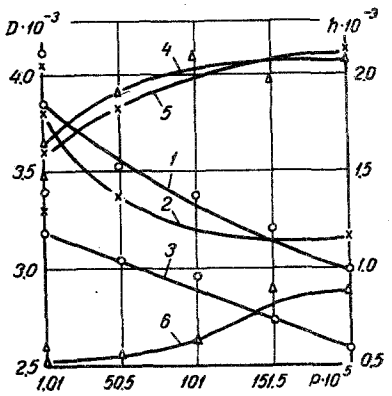

Fig. 1. Variation of crater diameter D, m (1–3) and depth h, m (4–6) for discharge in an open chamber, as a function of external pressure P, N/m^2, in a liquid dielectric medium with C = 100 μF, U = 2000 V for Cu (1 and 4) and Fe (2 and 5), and for U = = 1200 V for Cu (3 and 6).

It may be seen from Fig. 3 that the crater depth increases monotonically while the diameter decreases, as external static pressure is increased.

For a discharge in a gas medium similar laws were predicted theoretically by Drabkina [2], and obtained experimentally by Gerechkori [3].

The experimentally obtained dependences may be easily explained by contraction of the channel of the

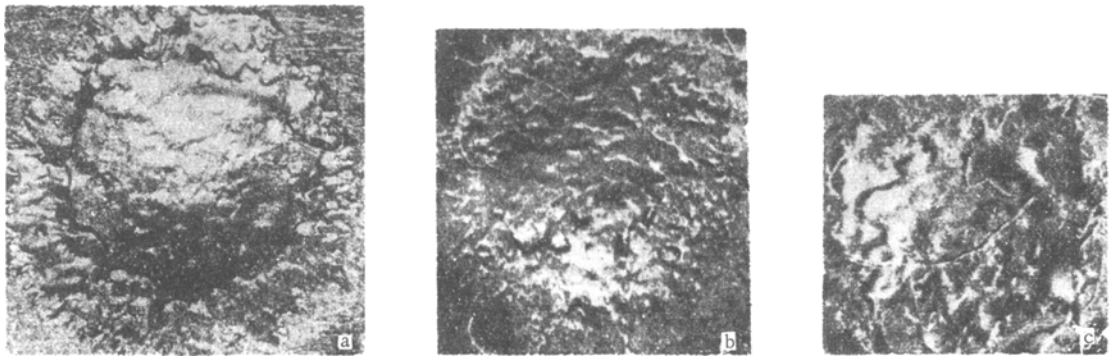

Fig. 2. Photographs of craters on the surface of Armco iron for discharges in transformer oil, with U = 2000 V, C = 100 μF, and external pressure P, N/m^2 of: a) $1.01 \cdot 10^5$; b) $101 \cdot 10^5$; c) $202 \cdot 10^5$.

spark discharge due to the steadily increasing counter-pressure of the liquid with increase of static pressure.

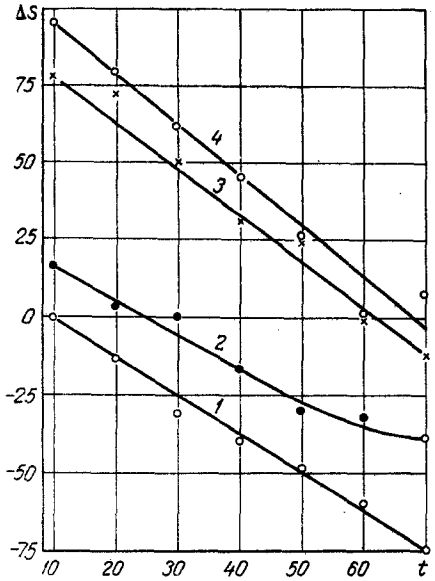

Fig. 3. Dependence of the difference in density of the chosen lines, ΔS, proportional to the logarithm of the concentration of material in the arc gap, on the burn-off time t, sec, for a discharge in open chamber (1) and in a hermetic chamber (2), with $P = 151.5 \cdot 10^5$ and $50.5 \cdot 10^5$ N/m^2 (3 and 4).

As is shown by the current and voltage oscillograms, the value of the energy liberated during the discharge does not depend on the external static pressure.

Decrease of the discharge channel diameter, for the energy liberated during the discharge, leads to contraction of the surface thermal source and thus to increase of the thermal power per unit area of the electrode surface. Therefore there will also be an increase in the depth of fused metal for a certain decrease in crater diameter.

It may be seen from the photographs presented (Fig. 2), that with increase of external pressure, the nature of the crater structure changes appreciably. For a discharge in transformer oil at atmospheric pressure (Fig. 2a), the crater surface (apart from the peripheral region) is quite smooth. This is due to the fact that practically all of the fused metal removed from the electrodes is thrown out of the interelectrode gap and scattered into the surrounding medium. At the increased static pressures (Fig. 2b and c) there are good pictures of particles of crystallized metal which has either not been thrown beyond the end surface of the electrodes or has fallen back onto it again upon collapse of the gas bubble. The nature of the linearly deposited metal particles (Fig. 2c) shows that the second postulate is more probable.

The transfer of metal at various static pressures was investigated by two methods: 1) by spectral analysis, and 2) using radioactive isotopes.

In the first case the investigation was conducted according to the following technique. The discharge was created between a copper (cathode) and a nickel (anode) electrode under the same conditions. After the discharge the cathode with nickel transferred to it served as one of the electrodes in a spectral analysis. The second electrode (copper) was sharpened to an angle of 14°. The distance between the electrodes in the spectral analysis was 2 mm. Burn-off spectrograms were recorded for 10 sec each (over 70 sec) on an ISP-28 spectrograph with the aid of a DG-2 arc generator at a current (without burn-off) of 5 A and a spectrograph slit width of 0.015 mm. The photographic plates (type I) were developed for 3 min in standard Ghibisov developer. Microphotometry of the spectral lines (Ni 3050.8 Å and Cu 3073.8 Å) was done on a MF-2 microphotometer. The chosen lines were homologous pair.

It may be seen from Fig. 3 that with increase of arc burning time the nickel is gradually burned off. The greatest amount of nickel was transferred to the anode at an external static pressure of $P = 50.5 \cdot 10^5$ N/m^2 (curve 4). The least concentration of nickel on the copper was observed in the case of a discharge at atmospheric pressure (curves 1, 2).

Figure 4 (curve 1) shows the results of the investigation of transfer, as obtained with the aid of radioactive isotopes. A cylindrical copper electrode of mass 0.003 kg, used as the anode, was activated prior to the experiment in a vertical channel of the IRT-2000 atomic reactor of the AS BSSR. The neutron flux at the specimen location was 10^{13} neutrons/cm^2 · sec. The

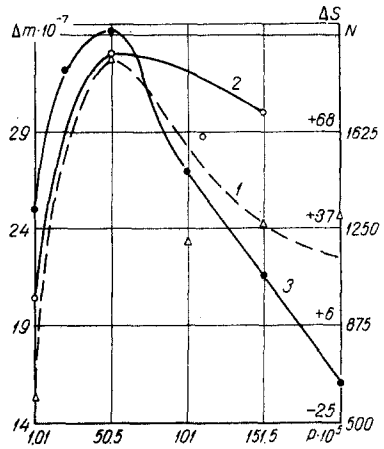

Fig. 4. Dependence of the number of pulses N (1), the difference of density for a burn-off time of 10 sec, ΔS (2), and the total erosion Δm, kg (3) on the external pressure P, N/m^2.

electrode serving as the anode was irradiated for 10 sec. Following irradiation the copper contains several β-active isotopes, the two most active contributors being Cu^{66} with a half-life of 51 min, and Cu^{64} with 13 hr; the latter is the more convenient for our test. For this reason the specimen was de-excited for 4 hr, at

which time the Cu^{66} isotope had practically completely decayed. We may therefore consider that the specimen possessed only a β-activity of half-life 13 hr. The electrodes which had served as cathodes during the discharges were evaluated for β-activity in a lead castle with an end-window SBT-7 counter and a scaler under identical conditions, the background count being not more than 20/min. From a comparison of the dependence of the difference of density, ΔS, on P (for a burn-off time of 10 sec) with the dependence of the β-activity of the cathode N, on P (curve 1) it may be seen that the two methods give results that are in qualitative agreement. Maximum transfer occurs in both cases at a pressure of $50.5 \cdot 10^5$ N/m^2, then followed by the higher pressure, $151.5 \cdot 10^5$ N/m^2, and quite small transfer is observed in the case of discharge in a hermetic chamber without external static pressure.

High-speed photography of the expansion process of the gas bubble, performed using a SKS-1m camera (4000 frames/sec) showed that with increase of external static pressure the limiting size of the gas bubble and its expansion and collapse times decreased appreciably. Thus, at a static pressure of $P = 50.5 \cdot 10^5$ N/m^2 (C = 100 μF, U = 1200 V) the maximum radius of the gas bubble was 0.47 cm, and 0.63 cm in the hermetic chamber, and for discharge in a pool of liquid with a free surface, 1.6 cm.

The collapse time of the gas bubble (t), as calculation has shown [4], is proportional to $P_0^{-5/6}$, where P_0 is the external static pressure corresponding to the hydrostatic pressure at the depth of explosion of a chemical explosive. At an external static pressure of $P = 50.5 \cdot 10^5$ N/m^2, the time of first expansion of the gas bubble is roughly 750 μsec, and 1250 μsec for a pool discharge.

With further increase of static pressure the limiting size of the gas bubble diminishes and becomes commensurate with the dimensions of the end faces of the electrodes.

The experimental data permit an explanation of the dependence of the value of the electrical erosion on the external static pressure (Fig. 4, curve 3) for a discharge between copper electrodes.

As may be seen from Fig. 4, at static pressures up to $50.0 \cdot 10^5$ N/m^2 the total erosion increases, while with further increase of the static pressure, the value of the electrical erosion falls sharply.

The increase in the value of the electrical erosion at pressures $P < P_{cr}$ ($P_{cr} = 50.5 \cdot 10^5$ N/m^2 for the case shown in Fig. 4) is associated, as shown in [1], with increase in the amount of metal thrown off from the electrodes due to the large transient pressures in the interelectrode gap. The above hypothesis is confirmed by the relatively even eroded surface of the metal for $P < 50.5 \cdot 10^5$ N/m^2 (Fig. 2a) and by the increased depth of the craters with increase of static pressure for a relatively small change in diameter (Fig. 1).

The reduction of erosion at large static pressures ($P > P_{cr}$) is due mainly to decrease in size of the gas bubble and to the consequent increase of the fraction of liquid metal returned to the electrodes upon collapse of the bubble.

A second cause is the considerable reduction of crater diameter with increase of static pressure, as follows from Fig. 1. Transfer of metal cannot be considered as the cause of this type of change in electrical erosion, since the curves $\Delta m = f(P)$ and the transfer curves are qualitatively similar in form.

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