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# INVESTIGATION OF THE PARAMETERS OF A NONSTATIONARY ARC SPOT ON A COPPER CATHODE BY THE THERMOSPECTROSCOPIC METHOD. II. DYNAMICS OF MOVEMENT OF THE SPOT

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*Indirect data on the features of the dynamics of a cathode spot in different erosion regimes have been obtained by investigation of the fluctuations of the intensity of radiation from the arc of the 5218 Å CuI copper spectral line modulated by the rotational frequency in a magnetic field. It has been revealed that the velocity of the cathode spot in the regime of intense radiation of this line in macroerosion is always lower than that in the regime of weak radiation in microerosion, whereas the variance of its distribution is, conversely, higher. A hypothesis for the relationship between the line-radiation intensity and the occurrence of a cathode copper-vapor jet affecting the mobility and dynamics of the spot and, in terms of them, the erosion has been proposed.*

**Introduction.** As has been reported in [1], to determine the density of the current in a cathode arc spot by the thermospectroscopic method we measured the intensity of the radiation of the 5218 Å CuI spectral line of copper from the arc rotating in a coaxial gap in a magnetic field. The beginning of an intense radiation of this line was taken as the beginning of macrofusion in the spot and the beginning of macroerosion, i.e., an intense form of erosion, instead of the low-intensity one called "microerosion." In [2, 3], in experiments on a vortex electric-arc heater (EAH), An'shakov et al. observed the outflow of high-power cathode jets from the spot in passage of erosion from the low-intensity form to an intense one; these jets destroyed the structure of the vortex flow and disturbed regular rotation of the arc. This disturbance of the vortex stabilization of discharge was considered by An'shakov et al. to be predominantly responsible for the erosion becoming intense. Since we recorded the rotational velocity of the arc in both regimes — before the increase in the intensity of the copper spectral line and after it, which, presumably, corresponded to the regimes of micro- and macroerosion, the results of such recording also had to contain information on the features of the arc motion in them in the total absence of vortex stabilization of the discharge. To obtain this information we carried out special processing of the experimental results.

**Experimental Procedure.** The experiments were carried out on a coaxial electric-arc unit with magnetic movement of the arc and axial feeding of a gas to the discharge zone. The unit had been described earlier (see [4, 5]) in detail; therefore, we do not give its description here. In these experiments, the image of the entire coaxial interelectrode gap with an electric arc moving in its circle was projected onto the section of a light guide, after which the light signal was fed to the entrance slit of a spectrometer. A small segment of the aperture of the interelectrode gap was covered by an opaque screen. Owing to this, the light signal was modulated by the rotational frequency of the arc in the gap.

Applying the fast Fourier transformation in the Origin program to processing of the signal of the line intensity recorded with a system of data acquisition on a computer, we could extract this frequency, which enabled us to determine the rotational velocity of the arc simultaneously with recording of the line intensity and to tie the results of these

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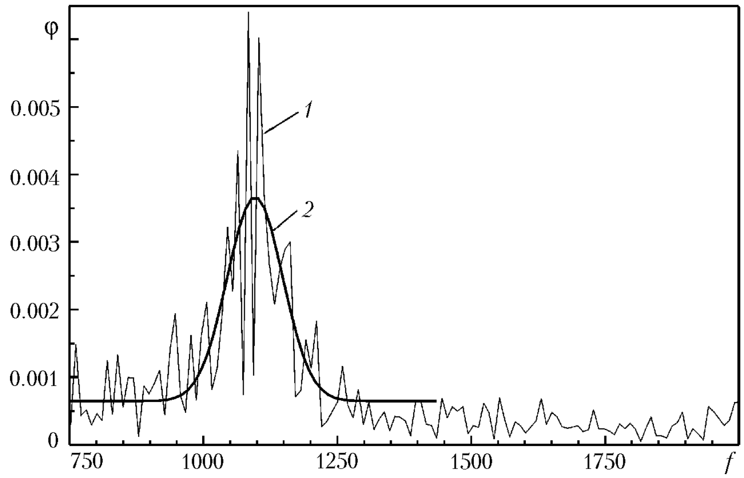


Fig. 1. Intensity $\varphi$ of the 5218 Å CuI spectral line as a function of the frequency of modulation of $f$ by the rotational frequency in the interelectrode gap: 1) result of processing of the optical signal with a Fourier transformation (FFT); 2) approximation of the result of the FFT with the Gauss function (Eq. (1)). $\varphi_0 = 0.00065 \pm 0.00012$, $f_m = 1096.254 \pm 6.502$, $w = 103.624 \pm 14.304$, and $A = 0.392 \pm 0.054$.

measurements to each other. The experiments were carried out in the nonstationary thermal regime of heating of a cathode; their duration was 2–2.5 sec. The experimental procedure has been described in [1] in greater detail.

**Results of the Experiments.** The existence of two regimes — those of micro- and macroerosion — was shown earlier in [7, 8]. Here we have assumed that it is a sharp increase in the intensity of the radiated copper line that corresponds to the onset of macroerosion, which is stimulated by the macrofusion in the spot, in accordance with a thermal erosion model [6–10]. As has been mentioned above, An'shakov et al. [2, 3] assumed that the disturbance of vortex stabilization of the arc by cathode jets could mainly cause the sharp increase in erosion observed (the microerosion becoming macroerosion). However, we showed in [7–9] that an analogous passage from micro- to macroerosion was also observed in axial vortex-free feeding of the gas and purely magnetic movement of the arc. Therefore, we assumed that the initial physical cause of the increase in erosion was the cathode reaching the critical thermal regime, in which macrofusion causing the ejection of cathode jets observed in [2] began in the spot, rather than the destruction of the vortex. These jets with a high concentration of an easily ionized metal vapor created a natural attachment of the arc to the point of their ejection, decreasing the mobility of the spot. In this case, based on the fact that the movement of the arc column is directly related to the movement of the arc, the velocity of motion of the arc must also decrease in its magnetic movement as the cathode jets appear. To check this we compared the regimes of movement of the arc before the beginning of intense radiation of the 5218 Å CuI line and after it under the assumption that the sharp increase in the copper-line intensity precisely indicates the ejection of a cathode jet and the beginning of macroerosion.

Figure 1 shows a typical example of Fourier transformation of the intensity of the copper spectral line modulated by the rotational velocity of the arc and the approximation of its frequency distribution by the normal distribution (Gauss function):

$$\varphi = \varphi_0 + \frac{A}{w\sqrt{\pi/2}} \exp\left[-2\left(\frac{f - f_m}{w}\right)^2\right]. \qquad (1)$$

Equation (1) is written in the form used by the Origin program, which was applied by us to processing of the experiments. Here $\omega$ is the doubled standard deviation of the frequency or the doubled square root of the variance characterizing the distribution width. The parameters of the normal Gauss distribution were subsequently used for comparison of the regimes of movement of the arc in microerosion — before the intense radiation of the line — and macroerosion

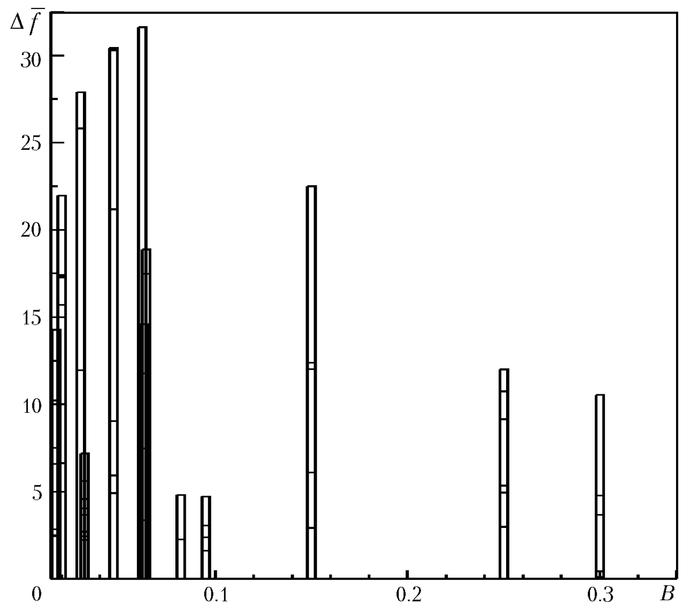


Fig. 2. Relative increment in the rotational frequency of the arc $\Delta\bar{f} = (f_{\mathrm{mi}} - f_{\mathrm{ma}})/f_{\mathrm{mi}}$ in the microerosion regime as compared to macroerosion as a function of the induction of the external magnetic field *B*.

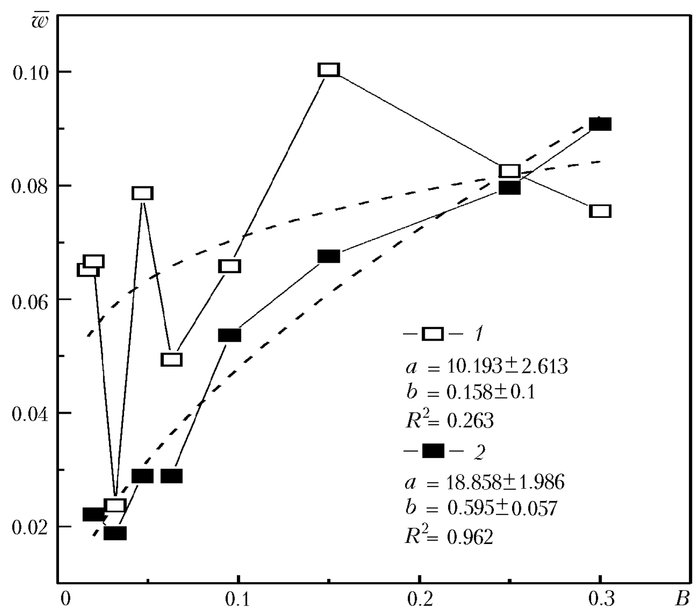


Fig. 3. Relative doubled standard deviation of the rotational frequency of the arc $\bar{w} = w/f_{\mathrm{m}}$ in fractions of the average value $f_{\mathrm{m}}$ for the regimes of microerosion (1) and macroerosion (2) vs. induction of the magnetic field *B*. Dashed curves show the power approximations of experimental results. The parameters of the approximation $\bar{w} = aB^b$ are given on the margins of the figure.

— after the beginning of radiation. Figure 2 gives the histogram of the relative increment in the rotational frequency of the arc in the interelectrode gap $\Delta\bar{f} = (f_{\mathrm{mi}} - f_{\mathrm{ma}})/f_{\mathrm{mi}}$ in the microerosion regime as compared to macroerosion. It is clear from the figure that this increment is always positive, i.e., the velocity of movement of the spot in the microerosion regime is always higher, and that $\Delta\bar{f}$ decreases with increase in the magnetic field. In [11, 12], Szente et al. proposed that the influence of the processes on the cathode surface on the arc motion be allowed for with a special "surface-resistance force" applied to the arc spot in addition to the aerodynamic-resistance force applied to the arc column. The ponderomotive force moving the arc column in a magnetic field is in proportion to the field. Therefore, as the magnetic field increases, it begins to dominate over the surface-resistance force, decreasing the effect of the latter. This may be the reason why the difference between the rotational frequencies/velocities of the arc decreases in micro- and macroerosion (Fig. 2) with increase in the magnetic field.

Figure 3 compares the doubled relative standard deviation of the rotational frequency of the arc $\overline{w} = w/f_{\mathrm{m}}$ in percent of the average frequency $f_{\mathrm{m}}$ for the regimes of micro- and macroerosion. It is seen that this width is larger for the macroerosion regime; the difference between them decreases with increase in the field. The latter is attributable to the fact that surface resistance affects the arc velocity for larger fields less, since the aerodynamic resistance of the column itself becomes dominant. An increased spread in data in macroerosion is clearly seen, which speaks of the less regular motion of the arc in this regime. The increase in the distribution width of the velocity of movement and the spread in data may be a consequence of the attachment of the arc to the point of ejection of the cathode jet and the declined mobility of the spot.

## CONCLUSIONS

From a comparison of all the above data, we can propose a hypothesis according to which a sharp increase in the intensity of the 5218 Å CuI copper spectral line is caused by the ejection of a cathode jet of a copper vapor with the beginning of macroerosion in the spot. These cathode jets, as has been shown in [2], are also related to the passage from the low-intensity form of microerosion to an intense form of macroerosion, which, apparently, holds in purely magnetic rotation of the arc (without gasdynamic rotation). The cathode jet tied to a certain point of the electrode and possessing a high conductivity can reduce the mobility of the cathode spot, decreasing the value and increasing the variance of the distribution of the arc velocity.

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## NOTATION

$A$, $a$, and $b$, empirical coefficients in the approximations; $B$, magnetic induction, T; $f$ and $f_{\mathrm{m}}$, instantaneous and average rotational frequency of the arc in the coaxial gap, Hz; $R$, correlation coefficient; $w$, doubled standard deviation of the rotational frequency of the arc $f$ from the average value $f_{\mathrm{m}}$; $\overline{w} = w/f_{\mathrm{m}}$, the same, in fractions of the average frequency; $\Delta\overline{f}$, relative increment in the rotational frequency of the arc in the interelectrode gap in passage from macro- to microerosion, %; $\varphi$, intensity of the 5218 Å CuI spectral line of copper, arbitrary units; $\varphi_0$, constant term in the approximation of the distribution of the intensity of the 5218 Å CuI spectral line by the rotational frequency of the arc $f$ by the Gauss function, arbitrary units. Subscripts: mi, microerosion; ma, macroerosion; m, average (mean) value.

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