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Abstract

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I. G. Kesaev

ON THE DIVISION OF THE CATHODE SPOT OF AN ELECTRIC ARC

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Detailed observations of the cathode spot of a low-pressure mercury arc show that during its existence the spot is in a process of continuous fragmentation, or division. Under ordinary conditions of a spot moving randomly over the cathode, the process of division itself proves to be largely veiled, and only the final result is accessible to observation—the appearance of two or a larger number of emission centers moving at a considerable distance from one another, when the latter become sufficiently stable. A convenient and at the same time simple method for observing the division of the spot is to photograph the trace of the spot during its ordered motion in a magnetic field tangential with respect to the cathode. On the basis of such photographs it proved possible to establish certain regularities in the division of the spot and to relate them to the capacity of the latter for directed motion in a magnetic field.

In Fig. 1 there is presented a group of photographs, enlarged in the ratio 5 : 1, of the trace of the spot in a nonuniform magnetic field on a thin layer of mercury covering a copper plate. The field was produced by an electromagnet with parallel pole pieces situated below the plate and separated by a gap 1 cm wide. The equilibrium pressure of the mercury vapor in the discharge space corresponded to a temperature of 20–22°. With the indicated arrangement of the experiment the spot tends to move along the line of symmetry of the field in the region of the maximum intensity, which under the conditions of Fig. 1 was about 520 oersted. The individual photographs in the group differ in the values of the arc current, increasing from the upper photographs to the lower ones. Consideration of the photographs presented, and of photographs similar to them, leads to the following conclusions.

1. The branchings of the light band in the photographs are always directed toward the side of motion of the spot, which in its type belongs to the so-called "retrograde" motion. They are traces of images of moving autonomous spots formed as a result of the division of the original cathode spot.
2. After separation, the emission centers move away from one another, revealing a kind of repulsion; some soon disintegrate, whereas others take upon themselves the entire arc current.

3. As the current is increased, the character of the division becomes more complicated owing to an increase in the number of branchings that possess a considerable lifetime and in turn undergo division. As a result, the number of simultaneously acting spots increases with the current; on the average, the current per spot is about 8 A. Nevertheless, even at the minimum currents at which a stable arc exists, division of the spot takes place and may remain unnoticed owing to the rapid disintegration of the branchings.
4. There are two types of branching—symmetric and asymmetric. In the first case both branches deviate at equal angles from the axis of symmet-

field, which corresponds to the division of the spot into two approximately equal parts. In the case of asymmetric division, the smaller current corresponds to the larger angle of deviation and, as a rule, to the shorter lifetime.

5. As the spots move apart, the angle between the branches decreases, and in symmetric division sooner or later the branches become parallel, reaching the equilibrium distance l_e.
6. To each specified current and field there corresponds a quite definite l_e, which increases with increasing current and with decreasing field strength.
7. The initial angle of divergence of the branches in an extremely weak field approaches π, which corresponds to the spots being repelled in diametrically opposite directions. With increasing field strength the angle decreases.
8. The magnetic field has a noticeable stabilizing effect on the cathode spot. This is clearly seen in the photograph in Fig. 2, in which, when the spot moves away from the axis of symmetry, the branches turned toward the increasing field prove to be more stable; this is the cause of an additional deviation of the entire ensemble toward the axis of symmetry.
9. Division of the spot also takes place in the absence of an external magnetic field, which introduces into this process only the quantitative changes indicated in the preceding points, and also causes directed motion of the entire ensemble of spots, facilitating observation.
10. The intervals between successive acts of spot division turn out to be distributed over a certain range of values near the most probable time interval of about $1 \cdot 10^{-5}$ sec, which corresponds to a spot-division frequency of 10^5 per 1 sec.
11. Division of the cathode spot is one of the causes of the chaotic displacement of the spot over the cathode surface observed in the absence of an external magnetic field.

The observations listed here can be explained and systematized by applying to the individual parts of the cathode spot the principle of maximum field, considered in the preceding work for the simple case of the motion of a single spot in an

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Fig. 2. Photograph of the trace of a cathode spot that began its motion away from the axis of symmetry of the field, indicated by the dashed line.

Figure 2: Fig. 2. Photograph of the trace of a cathode spot that began its motion away from the axis of symmetry of the field, indicated by the dashed line.

external magnetic field (1). According to this principle, the direction of motion of the spot at every point of the trajectory must coincide with the direction of the steepest increase, at the boundary of the spot, of the strength of the resultant magnetic field, which is the result of the superposition of the external field (H) and the self-field (H_i) of the current intersecting the cathode within the limits of the spot. Passing to the problem of the motion of two or more spots in the field of the electromagnet H_{em}, by H_i one should understand the field of the autonomous current i associated with the spot under consideration, whereas the field H external with respect to it represents the geometric sum of the fields of the remaining currents, H_k, and the field H_{em}. In its general form this problem is associated with solving a system of equations, and a special difficulty lies in the redistribution, which is not amenable to control, of the current among the individual centers of emission. Nevertheless, a number of essential conclusions can be drawn without solving this complex problem, if one confines oneself to determining the direction of motion for a specified arrangement of the currents, or to determining the trajectory in the particular case of symmetric division.

The simplest case is that of two commensurable currents, sufficiently far removed from one another, situated only in one another’ s mutual field ($H_{\text{em}} = 0$). It is easy to see that, according to the principle of maximum field, both currents must move away from each other along the straight line connecting them. The addition of the field of the electromagnet causes an additional displacement of each current, but even in this case the mutual field of the currents continues to exert a repelling action (which should not be associated with any force).

A consistent solution of the problem of spot division in an external field is impossible without a concrete model of the cathode spot. In the present brief

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it is sufficient to take as given that the spot has the form of a line moving in the direction of the normal and undergoing division in the transverse direction (^{2}). Application of the principle of the maximum field to the subsequent motion of autonomous currents leads to the following conclusions.

The direction of motion of each current, for a given arrangement of them, depends on the ratio of the magnitudes of the inhomogeneity of the external field in the plane of the cathode, $\partial H/\partial x$ and $\partial H/\partial y$, and of the quantities $\dfrac{H_y}{H}\dfrac{0.2i}{r^2}$ and $\dfrac{H_x}{H}\dfrac{0.2i}{r^2}$, representing the asymmetry of the superposition of the fields H and $H_i = \dfrac{0.2i}{r}$ along the axes x and y, where r is the effective radius of interaction of an autonomous spot with the external magnetic field. According to the estimate made in the preceding paper (^{1}), on the basis of a study of the trajectory of a single spot in the field of an electromagnet, its value was found to lie between $3 \cdot 10^{-2}$ and $9 \cdot 10^{-2}$ cm for currents from 3 to 15 A.

By itself, the inhomogeneity of the external field forces the spot to move in the direction of increasing field, whereas the asymmetry of the superposition of the fields determines the so-called "reverse" motion, as well as the mutual repulsion of the currents. Applying these ideas to the experimental conditions of Fig. 1, it is easy to explain the observations listed above in items 2, 4, 5, 6, and 7. A particularly valuable possibility for a quantitative check of the theory is provided by determining the equilibrium distance l_e between the branches in the case of symmetric division of the spot. According to the indicated interpretation, the quantity l_e should be regarded as twice the distance x from the axis of symmetry of the field at which the repulsive action of the mutual field of the currents $H_y = 0.2\,i/2x$ is balanced by the action of the inhomogeneity of the electromagnet field $\partial H_w/\partial x$, which forces the currents to move toward the axis of symmetry (for sufficiently large x, the inhomogeneity of the mutual field of the currents may be neglected). It follows from this that l_e can be determined from the equation

$$\frac{\partial H_w}{\partial x} - \frac{H_y}{H_w}\frac{0.2i}{r^2} = 0,$$

which, for the field distribution H_w used in the experiments, leads to the approximate formula

$$l_e = \frac{0.4}{H_w r}\, i.$$

Determining l_e from the data obtained by processing photographs such as Fig. 1 and similar ones, it was possible to estimate the values of the radius r, which were found to lie between $1 \cdot 10^{-1}$ and $4 \cdot 10^{-1}$ cm. The values of r found are sufficiently close to those obtained in the preceding paper from data on the study of the trajectory of a single spot in a magnetic field. Thus, an estimate of r on the basis of experiments on the study of the motion and division of the spot leads to approximately identical quantities.

The data presented in this work indicate that the autonomous emission centers formed as a result of division of the spot move away from one another under the influence of the mutual magnetic fields of the currents associated with them. The indicated interaction can only be intensified at short distances; from this it may be concluded that the most important cause of division of the cathode spot at low pressures is the arc' s own magnetic field, localized in the region of the spot and repelling its individual parts. This repulsive action of the field is not connected with interaction forces between individual elementary currents, but is based on the facilitation of emission conditions at the periphery of the cathode spot.

The conclusion drawn in this work concerning the tendency of the cathode spot toward continuous division or self-disintegration under the influence of the magnetic field of the arc may at first sight appear to contradict the fact of the existence of sta-

of a mobile cathode spot. This apparent contradiction disappears if one takes into account a number of additional stabilizing factors. Attention is drawn to the fact that the repelling action of the field, due to the asymmetry in the superposition of the external and intrinsic fields, must decrease as the magnitude of the separated part of the spot diminishes. On the other hand, the continuously occurring redistribution of current is of essential importance; owing to it, the disintegration of one of the spots leads to the restoration of the other and to the return to it of the share of current it had lost. Under such circumstances, the instability of small emission centers is equivalent to the existence around the spot of a barrier insurmountable for them, which at the same time prevents the complete disintegration of the spot.

Taking the indicated phenomena into account leads to the conception of parallel processes of continuous division and restoration of the cathode spot.

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CITED LITERATURE

[1] I. G. Kesaev, DAN, **112**, No. 4 (1957). [2] K. D. Froome, Proc. Phys. Soc. (B), **62**, 805 (1949).

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