CRITERIAL GENERALIZATION OF THE CHARACTERISTICS OF AN ELECTRIC ARC IN A MAGNETIC FIELD

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Similarity criteria are derived for an arc moving in a transverse magnetic field when the length of the arc is large enough not to enter into the system of determining (limiting) parameters. An analysis of experimental data is presented in terms of these criteria.

In studying the behavior of an arc in a magnetic field greatest stress is at the present time laid upon experimental work, the corresponding theory having been insufficiently extensively developed. Published data relating to such characteristics of arcs in magnetic fields as velocity and electric field strength were obtained in two types of apparatus:

1) in a railotron, in which the arc moved in a direction normal to its axis under the influence of a magnetic field, and a balance was established between the aerodynamic and magnetic forces, when the arc had accelerated to the equilibrium velocity; 2) in an apparatus in which the arc was held between fixed electrodes in a transverse gas flow by means of a magnetic field.

In order to generalize experimental data relating to the properties of an arc in a railotron, similarity criteria in which the electrode gap was taken as characteristic dimension were proposed in [1]. However, it is quite clear that, as the gap between the electrodes of the railotron increases, and the phenomena close to the electrodes have less and less effect on the properties of the main part of the arc column, the extent of the gap should have less and less effect on the arc parameters being studied. The only dimension which would be really characteristic of the problem at hand would be one related to the cross section of the arc column, but this in turn would have to be a determinable parameter. In order to describe the phenomena in question we must therefore introduce other similarity criteria not containing the characteristic dimension.

For steady-state motion (neglecting radiation and the induced electric field) we may derive a number of criteria by using the momentum, energy, and Maxwell's equations and Ohm's law. Regarding the parameters E (electric field), V (arc velocity), and D (transverse dimension of the arc) as determined parameters, we may find three complexes

$$A_V = \frac{V\sqrt{\rho\mu_e}}{B}, \qquad A_E = \frac{E}{h\sqrt{\rho\mu_e}}, \qquad A_D = \frac{BD}{\mu_e I}$$

These will be functions of a fourth

$$A = \frac{\sigma h \mu_e^2 \sqrt{\rho\mu_e}\, I}{B^2}$$

Here B is the magnetic induction, I is the current, ρ, σ, and h are the characteristic values of the density, electrical conductivity, and enthalpy, μ_e is the magnetic permeability. It is also assumed that, to a certain approximation, the effect of the Mach and Reynolds numbers on the properties of the arc may be neglected.

Figure 1 shows the results of a generalization of experimental data relating to the velocity of an air arc in a magnetic field obtained in a railotron with copper electrodes [2-5], and the velocity of the flow passing around an arc held stationary in the flow by means of a magnetic field [6]. The first data are divided

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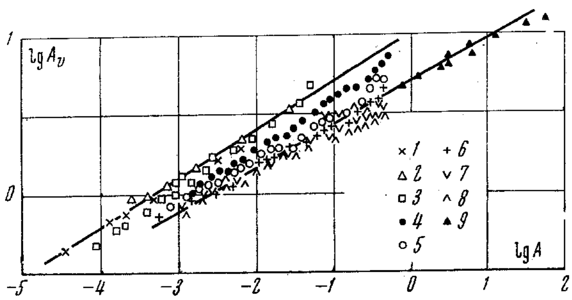

Fig. 1

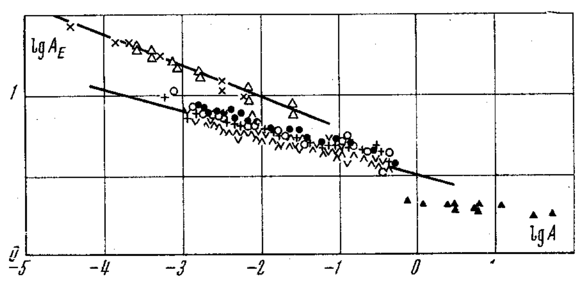

Fig. 2

into two groups, depending on the manner of supplying a current to the arc. In the experiments of [2-4], and to some extent in those of [5], the current was fed unilaterally to the rails (points 1, 2, 3 in Fig. 1), and, quite apart from the external field, the magnetic field due to the current passing through the electrodes also affected the motion of the arc. In the experiments of [5, 6], with bilateral feeding of the current to the rail (points 4-9 in Fig. 1), there was no such extra effect. We see from Fig. 1 that the corresponding two groups of points are well separated.

The experimental points of [5] (bilateral feeding of current to the rail) are to a certain extent split up into layers, depending on the gap between the electrodes, but for fairly large gaps (over 2 cm) they intermingle, confirming the earlier comments as to the effect of interelectrode distance on the properties of the arc. The arc velocities obtained in [5] for large gaps with bilateral feeding agree with the results of [6], and are described by the power relation

$$A_V = 4.7 A^{0.27} \tag{1}$$

or, for unilateral feeding,

$$A_V = 9.6\, A^{0.30} \tag{2}$$

In the calculation the following values were taken for the characteristic quantities:

$$\mu_e = 4\pi\cdot 10^{-7}\ \text{h/m} \quad h = 3\cdot 10^5\ \text{J/kg} \quad \sigma = 100\ \text{mho/m} \quad \rho = 1.18\ \text{kg/m}^3.$$

Figure 2 shows the results of a generalization of the experimental data obtained in [2, 3, 5, 6] regarding the electric field strength, calculated from the formula

$$E = \frac{u - u_+}{L}$$

Here L is the distance between the electrodes, $u_+ = 24$ V is the sum of the electrode potential drops in an air arc [2]. The enumeration of the experimental data in Fig. 2 is the same as in Fig. 1.

The generalizing relationships take the following form for the unilateral inflow of current:

$$A_E = 3.7\, A^{-0.20} \tag{3}$$

and for the bilateral inflow, with large gaps between the electrodes,

$$A_E = 3.25\, A^{-0.135} \tag{4}$$

The results of [6] evidently differed from those of [5] because of the weakness of the magnetic field in [6], leading to a smaller increase in electric field than that obtained in the case of a freely burning arc.

On comparing Eqs. (1)-(4), we see that the relationship between the electric field and the arc velocity for the unilateral inflow of current takes the form

$$E \sim V / \sqrt{I}$$

(in agreement with [2, 3]), and for the bilateral inflow

$$E \sim (V\sqrt{I})^{1/2}$$

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