CRITERIA FOR GENERALIZING THE CHARACTERISTICS OF VARIOUS TYPES OF ELECTRIC ARCS

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The criterial relations presented can be used to generalize the characteristics of various types of electric arcs—arcs in transverse and longitudinal flows, arcs in magnetic fields, free-burning arcs. The form of the criteria varies with the given primary quantities.

References [1–4] describe the basic processes and present criterial relations for generalizing the characteristics of certain types of electric arcs. However, they do not cover all the cases of practical importance, although ungeneralized experimental data are available. The reason for this is, apparently, the lack of suitable criteria. These criteria can be obtained by the methods of the theory of similarity. The difficulty is that the complexity of the phenomenon implies a large number of possible dimensionless complexes. In practice it is desirable to use only some of them, treating the similarity as approximate.

The most important processes can be selected by making a numerical evaluation of the differential equations using characteristic values of the primary quantities. Calculations made for a heavy-current arc burning in an air stream at atmospheric pressure have revealed the desirability of the experimental verification of a limited number of criteria. The recommended dimensionless relations for various types of arcs are presented in the table. The criteria are arranged in order of their probable significance.

Of course, the table covers only the more important cases. The first four types relate to rail guns. They illustrate how the form and number of the criteria vary with the given conditions. Coaxial arc heaters are represented by only one type with different solenoid supplies. Similar formulas are obtained for heaters with annular electrodes.

Linear plasma generators are represented by simple and complex configurations. From these examples, however, it is easy to construct formulas for any type of discharge chamber. In this case it is important that the length of the arc can be fixed or depends on the discharge conditions. In the latter instance the Kn number may play a certain role. The Reynolds number is influential only at very small gas flow rates, but in practice it cannot be distinguished from the Peclet number, which for electric arcs is evidently more important.

In free-burning arcs the criteria reflecting free convection and heat conduction are assumed to be the most important. However, the magnetic self-field and the radiation are also taken into account in the formula in order to show what criteria may, under certain conditions, be responsible for the divergence of the characteristics when the first two generalized arguments are insufficient. In the case of a stationary arc in a flow a formula of type 2 is suitable, but the criterion W^2/gL should be kept in mind, since the gravitational forces may be commensurable with the aerodynamic and electromagnetic ones. In other types of arcs the gravitational forces are unimportant, but the volume radiation and heat conduction may sometimes be appreciable despite the considerable turbulence. In such cases the criteria $\sigma_0 Q_0 L^4/I^2$ and $\varkappa_0 T_0 \sigma_0 L^2/I^2$ must also be taken into account.

Existing generalizations of the experimental data for certain types of arcs show that three or four criteria are usually sufficient for practical formulas. However, in certain cases, especially for discharge chambers with a complex configuration, this number may be insufficient. Accordingly, in the table the number of criteria is sometimes given "with a reserve." The most important of them must be selected by generalizing the experimental data.

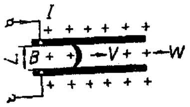
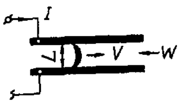
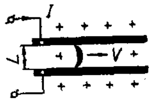
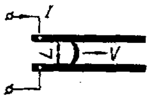
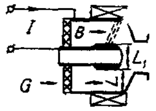
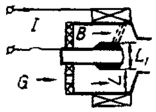
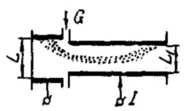
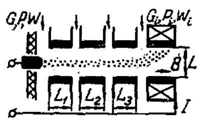
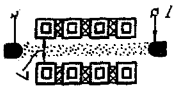
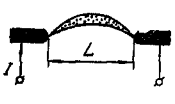
At the same time, the table does not include certain criteria, common to all types of arcs, that are important under certain conditions. For example, in the presence of a considerable variation of the temperature or composition of the medium it is necessary to introduce the parametric criterion T/T_0 (or h/h_0). When the discharge chamber has a complex geometric configuration, it is desirable to use the criterion L_i/L_0, and in the case of the heating of different gases supplied to the chamber at several points the parameters G_i/G, P_i/P, W_i/W, etc. Type 8 is presented as an example of this situation.

The characteristic values of the physical properties at constant gas composition and fixed initial temperature may be disregarded and the generalization based on the corresponding dimensional complexes. Otherwise the reference scales of the physical properties can be taken from [5] or found by another suitable method.

It is sometimes desirable to use combinations of the dimensionless complexes, which frequently leads to a simplification of the calculations. Thus, instead of the above-mentioned generalizations of the functions it is possible to take any combination of them with generalized arguments and also to use combinations of generalized arguments. Thus, for example, in an arc of type 5 instead of $\rho_0 \omega L^3/G$; $UL\sigma_0/I$; $\sigma_0 G^3/\rho_0^2 L^3 I^2$ one can use $\rho_0 \omega^2 L^3/IB$; $UI/h_0 G$; $G^2/\rho_0^2 h_0 L^4$, respectively, and so on.

Table

Criterial Relations for Generalizing the Characteristics of Electric Arcs

No.	Type of arc	Relation	Remarks
1		$\frac{V}{W}=f\left(\frac{IB}{\rho_0 W^2 L}, \frac{\mu_0 I}{BL}, \frac{P}{\rho_0 W^2}, \frac{\rho_0 W h_0 \sigma_0 L^3}{I^2}\right)$ $\frac{UL\sigma_0}{I}=f\left(\frac{\rho_0 W h_0 \sigma_0 L^3}{I^2}, \frac{\rho_0 \sigma_0 W^3 L^3}{I^2}, \frac{IB}{\rho_0 W^2 L}, \frac{\mu_0 I}{BL}\right)$	Known, I, B, W, L To be determined, V, U
2		$\frac{V}{W}=f\left(\frac{\mu_0 I^2}{\rho_0 W^2 L^2}, \frac{P}{\rho_0 W^2}, \frac{\rho_0 W h_0 \sigma_0 L^3}{I^2}\right)$ $\frac{UL\sigma_0}{I}=f\left(\frac{\rho_0 W h_0 \sigma_0 L^3}{I^2}, \frac{\rho_0 \sigma_0 W^3 L^3}{I^2}, \frac{\mu_0 I^2}{\rho_0 W^2 L^2}\right)$	Known, I, W, L To be determined, V, U
3		$\frac{\rho_0 V^2 L}{IB}=f\left(\frac{PL}{IB}, \frac{\mu_0 I}{BL}, \frac{\rho_0 h_0^2 \sigma_0^2 BL^5}{I^3}\right)$ $\frac{UL\sigma_0}{I}=f\left(\frac{\rho_0 h_0^2 \sigma_0^2 BL^5}{I^3}, \frac{\sigma_0^2 L^3 B^3}{\rho_0 I}, \frac{\mu_0 I}{BL}\right)$	Known, I, B, L To be determined, V, U
4		$\frac{\rho_0 V^2 L^2}{\mu_0 I^2}=f\left(\frac{PL^2}{\mu_0 I^2}, \frac{\rho_0 \mu_0 h_0^2 \sigma_0^2 L^4}{I^2}\right)$ $\frac{UL\sigma_0}{I}=f\left(\frac{\rho_0 \mu_0 h_0^2 \sigma_0^2 L^4}{I^2}, \frac{\sigma_0 \mu_0^3 I^2}{\rho_0}\right)$	Known, I, L To be determined, V, U
5		$\frac{\rho_0 \omega L^3}{G}=f\left(\frac{\rho_0 IBL^3}{G^2}, \frac{\mu_0 I}{BL}, \frac{\rho_0 PL^4}{G^2}, \frac{\sigma_0 h_0 GL}{I^2}, \frac{L_1}{L}\right)$ $\frac{UL\sigma_0}{I}=f\left(\frac{\sigma_0 h_0 GL}{I^2}, \frac{\sigma_0 G^3}{\rho_0^2 L^3 I^2}, \frac{\mu_0 I}{BL}, \frac{\rho_0 IBL^3}{G^2}, \frac{L_1}{L}\right)$	1. Known, I, G, B, L, L_1 To be determined, ω, U 2. Solenoid supplied from independent current source,
6		$\frac{\rho_0 \omega L^3}{G}=f\left(\frac{\rho_0 \mu_0 I^2 L^2}{G^2}, \frac{\rho_0 PL^4}{G^2}, \frac{\sigma_0 h_0 GL}{I^2}, \frac{L_1}{L}\right)$ $\frac{UL\sigma_0}{I}=f\left(\frac{\sigma_0 h_0 GL}{I^2}, \frac{\sigma_0 G^3}{\rho_0^2 L^3 I^2}, \frac{\rho_0 PL^4}{G^2}, \frac{L_1}{L}\right)$	1. Known, I, G, L_1, L To be determined, ω, U 2. Solenoid connected in series with arc
7		$\frac{UL\sigma_0}{I}=f\left(\frac{\sigma_0 h_0 GL}{I^2}, \frac{\sigma_0 G^3}{\rho_0^2 L^3 I^2}, \frac{\lambda}{L}, \frac{L_1}{L}\right)$ $\frac{l}{L}=f\left(\frac{\sigma_0 h_0 GL}{I^2}, \frac{\sigma_0 G^3}{\rho_0^2 L^3 I^2}, \frac{\lambda}{L}, \frac{L_1}{L}\right)$	1. Known, I, G, L, L_1 To be determined, l, U 2. Solenoid supplied from independent current source,
8		$\frac{UL\sigma_0}{I}=f\left(\frac{\sigma_0 h_0 GL}{I^2}, \frac{\sigma_0 G^3}{\rho_0^2 L^3 I^2}, \frac{L_i}{L}, \frac{G_i}{G}, \frac{W_i}{W},\right.$ $\left.\frac{\rho_0 IBL^3}{G^2}, \frac{\mu_0 I}{B, L}\right)$	1. Known, I, G_i, P_i, W_i, B, L_i To be determined, U 2. Solenoid supplied from independent current source,
9		$\frac{EL^2\sigma_0}{I}=f\left(\frac{\varkappa_0 T_0 \sigma_0 L^2}{I^2}, \frac{\sigma_0 Q_0 L^4}{I^2}, \frac{PL^2}{\mu_0 I^2}\right)$	Known, I, L, P To be determined, E
10		$\frac{UL\sigma_0}{I}=f\left(\frac{\rho_0^2 h_0^2 \sigma_0^2 g L^7}{I^4}, \frac{\varkappa_0 T_0 \sigma_0 L^2}{I^2},\right.$ $\left.\frac{\mu_0 I^2}{\rho_0 g L^3}, \frac{P}{\rho_0 g L}, \frac{\sigma_0 Q_0 I^4}{I^2}\right)$	Known, I, L To be determined, U

A more detailed justification of the selection of criteria will be published shortly.

NOTATION

B is the magnetic induction; E is the electric field strength; I is the current; L is the dimension; U is the voltage; V is the arc velocity; W is the gas velocity; l is the length of the arc; σ is the electrical conductivity; $\varkappa$ is the thermal conductivity; Q is the integral radiant emittance per unit volume; h is the enthalpy; ρ is the density of the gas; μ_0 is the permeability of the free space; λ is the mean free path; ω is the rate of rotation of the arc; P is the gas pressure; T is the temperature; G is the mass flow rate of the gas; g is the free-fall acceleration. Subscripts: 0—characteristic value; i—ordinal number.

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