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THE CHARACTERISTICS OF THE ELECTRIC ARC BURNING IN AIR IN THE TUBES OF DIFFERENT DIAMETERS

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Abstract: The radial temperature distributions of the arc burning in air in the vertical water-cooled tubes of 10, 12, 16 and 20 mm diameters and the electron density dependence on temperature were determined. Experimentally determined and theoretically calculated radial temperature distributions agree. The arc burning in the tubes of 10, 12 and 16 mm diameters behave as the stabilized one, which is not the case in the tube of 20 mm diameter when heat convection is necessary to be taken into consideration. The values of the electric field strength have been calculated also.

1. *Introduction*

The characteristics of the electric arc: the temperature in the arc axis, the radial distribution of the temperature, the strength of the electric field in the arc and the current intensity, depend mainly on the nature of the gas in which the arc is burning, the pressure and the potential applied.

To simplify the calculations of the arc characteristics, we considered a regular shape model of the arc with the most simple symmetry, known as the cascade one, constructed and described first by Maecker$^{1)}$. The channel diameter in this arc is defined by the cascade plates that make the arc plasma cylindrically symmetrical.

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Applying the Elenbaas-Heller equation and having in mind that the LTE conditions can be fulfilled in the investigated arc plasma[2], it is possible to calculate the characteristics of the arc on the basis of the known value of the thermal and electrical conductivities of the atmosphere in which it burns.

In our work we investigated the characteristics of the arc burning in the vertical water-cooled metal tubes of different diameters and compared them with those of the free-burning arc.

2. *The stabilized arc*

For the arc in the stationary state characterized by equilibrium between the electric power fed in and the energy loss due to the thermal conduction the energy balance can be expressed by Elenbaas-Heller equation

$$\sigma E^2 + \frac{1}{r}\frac{\mathrm{d}}{\mathrm{d}r}\left(r\varkappa\frac{\mathrm{d}T}{\mathrm{d}r}\right) = 0, \tag{1}$$

where σ is the electrical conductivity, E the electric field strength, r the distance from the arc axis, $\varkappa$ the thermal conductivity, T the absolute temperature.

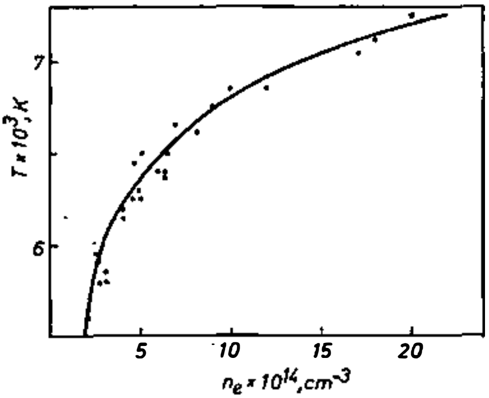

Fig. 1. Experimentally determined electron density in air in the temperature range from 5500 K to 7250 K.

The method for calculation of the electrical conductivity in air is given in Ref.[3]. In this paper we used our experimentally determined electron densities, given in Fig. 1, the curve of the electrical conductivity as the function of temperature and obtained shown in Fig. 2. The thermal conductivity is taken from the Ref.[4]. Both, the electrical and thermal conductivity are functions of the gas composition, its temperature and pressure. Data concerning the thermal conductivity cited in Refs[5, 6, 7)] are not quite consistent, but deviations in the temperature range from 1000 K to 7000 K, in which we examined the arc plasma, are not so essential as to influence our conclusions.

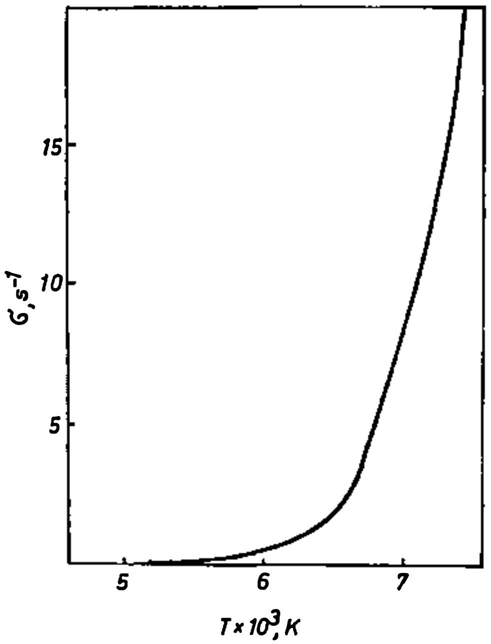

Fig. 2. Electrical conductivity of air as a function of temperature.

If we assume that the pressure is constant during the burning of the arc. than σ and $\varkappa$ of air, are depending on the temperature only.

Introducing the heat function S, defined as

$$S(T) = \int_{T_{\text{wall}}}^{T} \varkappa(T) \, \mathrm{d}T \tag{2}$$

the Elenbaas-Heller equation may be written in the form

$$\sigma(T) E^2 = -\frac{1}{r} \frac{\mathrm{d}}{\mathrm{d}r}\left(r \frac{\mathrm{d}S}{\mathrm{d}r}\right). \tag{3}$$

Since the axial component of the electric field strength E is independent of r, the electrical conductivity σ can be expressed as the function of S. The procedures for the approximative solutions of this equation are given in Refs.[8, 9, 10]. In this work we applied the Schmitz and Uhlenbusch method[9, 10]. The whole region of the arc can be divided into three zones. In the outer zone the electrical conductivity might be neglected. The other two zones conduct the electric current and the function $\sigma(S)$ can be approximated by two straight lines. If the relative radius $\varrho = \frac{r}{R}$ (where r is the radial coordinate and R is the distance between the arc axis and the tube wall), and T_{wall} (the absolute temperature of the wall) are introduced, the Elenbaas-Heller equation for these three zones might be written as

$$
\begin{aligned}
&-\frac{1}{\varrho}\frac{\mathrm{d}}{\mathrm{d}\varrho}\left(\varrho\frac{\mathrm{d}S}{\mathrm{d}\varrho}\right) = 0, && S_w < S < S_1,\\
&-\frac{1}{\varrho}\frac{\mathrm{d}}{\mathrm{d}\varrho}\left(\varrho\frac{\mathrm{d}S}{\mathrm{d}\varrho}\right) = A_1 S + B_1, && S_1 < S < S_2,\\
&-\frac{1}{\varrho}\frac{\mathrm{d}}{\mathrm{d}\varrho}\left(\varrho\frac{\mathrm{d}S}{\mathrm{d}\varrho}\right) = A_2 S + B_2, && S_2 < S < S_0.
\end{aligned}
\tag{4}
$$

The solutions of these equations are

$$
\begin{aligned}
&S(\varrho) = S_w - \frac{K\Delta_2}{2I_0(\lambda_1)}\ln\varrho, && 1 > \varrho > \varrho_1,\\
&S(\varrho) = S_1 + \frac{K}{4}\pi\left\{\Delta_1 I_0\left(\lambda_1\frac{\varrho}{\varrho_1}\right) - \Delta_2 N_0\left(\lambda_1\frac{\varrho}{\varrho_1}\right)\right\}, && \varrho_1 > \varrho > \varrho_2,\\
&S(\varrho) = \frac{K}{\lambda_2^2} I_0\left(\lambda_2\frac{\varrho}{\varrho_2}\right) - \frac{B_2}{A_2}, && \varrho_2 > \varrho > 0,
\end{aligned}
\tag{5}
$$

where $\lambda_1, \lambda_2, \Delta_1, \Delta_2, K$ are constants obtained from the relations cited in Refs.[9, 10], I_0, I_2 are the first order and N_0, N_2 the second order Bessel functions.

On the basis of the expressions for the functions $S(\varrho)$ obtained in this way and the Equ. (2), it is possible to calculate the curve of radial temperature distribution.

The electric field strength can be obtained from the relation

$$E = \frac{\lambda_1}{R\sqrt{A_1} \cdot \varrho_1}, \tag{6}$$

and the current density from the equation

$$I = 2\pi E R^2 \int_0^1 \sigma \, [T(\varrho)] \, \varrho \, d\varrho. \tag{7}$$

3. *Experimental*

The changes of the following arc characteristics: the radial temperature distribution, the electron density distribution and the axial electric field strength, due to the arc discharges in water-cooled tubes of different diameters were investigated. Vertical metal tubes with diameters of 10, 12, 16 and 20 mm were used. All tubes had the side openings covered with quartz plates. The radial temperature distribution in the arc was determined by means of the spectroscopic two-line method based on the intensity ratio of the lines ZnI 307,20 nm and ZnI 307,59 nm. The electron density was determined on the basis of intensity ratio of magnesium lines MgI 279,6 nm and MgII 285,2 nm as well. The Zeiss PGS-2 spectrograph was used; the slit width was 40 μ and its height 14 mm. A 9-amp dc-arc between graphite electrodes at the air pressure of 1 at, was burning. By using a Dove prism the arc image at the slit was turned by 90°. A cross-section at

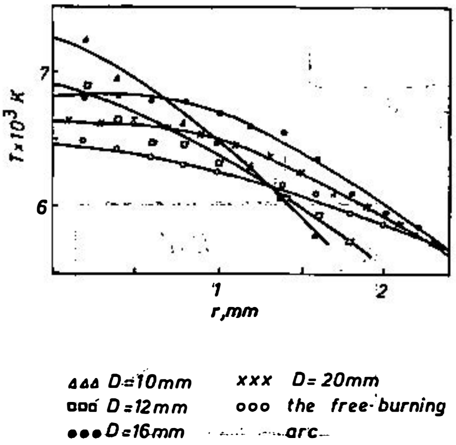

Fig. 3. Experimentally determined radial temperature distribution of 9 amp dc arc burnig in tubes of 10, 12, 16 and 20 mm diameter, in air at normal pressure, compared with the radial temperature distribution of the free-burning arc.

the center of the electrode gap was observed. The transition probabilities were taken from Ref..[11]. The radial distribution of the radiation density was determined according to Abel integral equation. The calculation was made with the aid of tables[12]. Ilford N30 Ordinary plates were used.

The experimental results of the radial temperature distributions of the arc burning in the tubes of 10, 12, 16 and 20 mm diameters compared with the one of the free-burning arc, are represented in Fig. 3.

4. *Discussion*

To calculate the theoretical values of the arc characteristics it is necessary to know the electrical and the thermal conductivity of the atmosphere in which the arc is burning.

From the experimental data given in Fig. 3 it can be seen that the arc in the most narrow tube has the highest axial temperature and that the gradient of the radial temperature distribution of the arc burning in the tubes of different diameters is not the same.

The complete theoretical radial temperature distributions from the arc axis to the tube-wall were calculated according to Schmitz's and Uhlenbusch's method. The theoretically calculated radial temperature distribution curves for the arc burning in the tubes of 10, 12, 16 mm diameters (Fig. 4) are in accordance

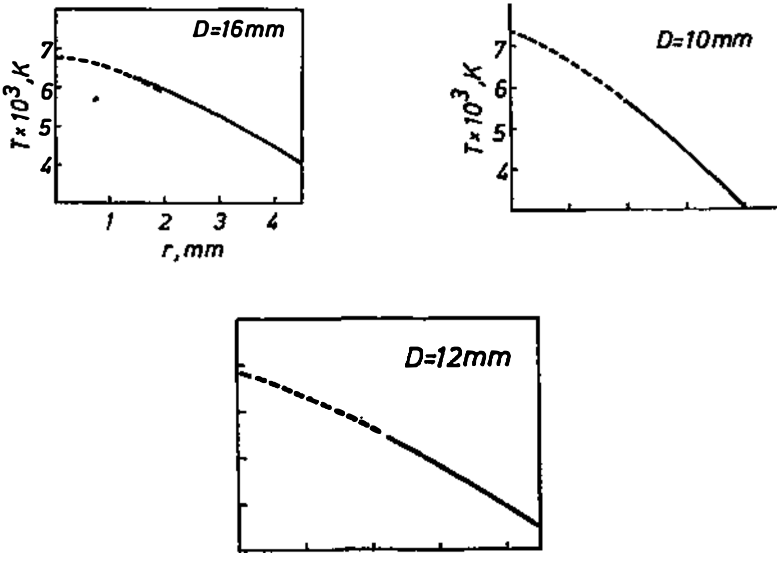

Fig. 4. Theoretically calculated radial temperature distribution for 9 amp dc arc burning in tubes of 10, 12 and 16 mm diameter, in air at normal pressure. Results of experimental determinations are represented with dotted curve.

with the experimentally determined ones, in the corresponding investigated temperature regions. Meanwhile, for the arc burning in the tube of 20 mm diameter, the radial temperature distribution (Fig. 5) differs considerably from the one calculated according to the Elenbaas-Heller equation.

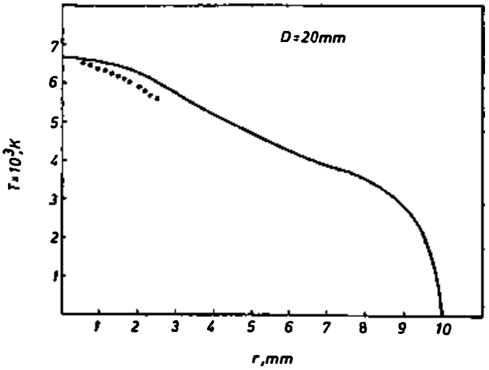

Fig. 5. Theoretically calculated radial temperature distribution for 9 amp dc arc burning in 20 mm diameter tube, in air at normal pressure. Results of experimental determinations are represented by circles.

This shows that the arc burning in the tubes of 10, 12 and 16 mm diameters can be considered as stabilized where the transport of the heat by the convection can be neglected. In these cases the experimental conditions can be expressed with the equation (1), but when the arc is burning in the tube of 20 mm diameter, these conditions are not fulfilled. The comparison between the curve of the radial temperature distribution for the arc in the tube of 20 mm diameter and for free-burning arc shown in Fig. 1 points out to the similarity of these two curves. This is not the case with the arc burning in more narrow tubes.

The calculated values for E (the electrical field strength) according to the equation (6), are in the Table.

TABLE

the tube diameter in mm	E V/cm	the temperature in the arc axis in K
10	32,6	7250
12	27,3	6950
16	24,5	6850

Since the experiment is carried out at the constant electric current intensity of 9 amp, the decrease of the tube diameter causes the increase of the electrical field strength. This fact enables to explain the changes of the temperature in the arc axis in dependence on the tube diameter. The higher electric power in the more narrow tubes causes an increase of the temperature in the arc axis.

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KARAKTERISTIKE ELEKTRIČNOG LUKA KOJI GORI U VAZDUHU U CEVIMA RAZLIČITIH PREČNIKA

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Sadržaj

Merena je radijalna raspodela temperature i elektronske gustine u luku koji gori u vazduhu, u vertikalnim cevima prečnika 10, 12, 16 i 20 mm, čiji su zidovi hlađeni vodom. Na osnovu podataka za toplotnu i izračunatu električnu provodljivost vazduha teorijski je određena radijalna raspodela temperature u luku, primenjujući Elenbaas-Heller-ovu jednačinu. Dobijeno je slaganje teorijski izračunatih i eksperimentalno izmerenih raspodela temperature u luku koji gori u cevima prečnika 10, 12 i 16 mm što ukazuje da se luk u ovim slučajevima ponaša kao stabilisan a što nije slučaj za luk koji gori u cevi prečnika 20 mm. Teorijski su izračunate vrednosti jačine električnog polja u luku.