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HEAT TRANSFER COEFFICIENT IN THE PROXIMITY OF THE ELECTRIC Arc

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The analysis of experimental data shows that the heat transfer coefficient α from an electrode loaded with an arc increases with the decreasing distance from the front of the electrode. In the front of the electrode it reaches the value of about 300 W . m^{-2} . K^{-1}.

I. INTRODUCTION

The study of the energetic balance of the switching arc [1], [2] represents, in the opinion of the authors, a new approach to a computation project of extinguishing devices for l.v. switchgear, quite independent of Mayr's and Cassie's models. As a part of this program the energetic balance of horizontal Cu electrodes loaded with an arc burning freely in the air [3] has been studied.

This paper pays attention to the analysis of the experimental data of these measurements from the point of view of the heat transfer coefficient.

II. THE APPLIED METHODS

The measurements were carried out on Cu-bar-form electrodes with diameters of 7.8, 15.9 and 19.9 mm.

The second electrode was a graphite one. As a power supply unit a welding transformer was used, the current during the measurement was within the range of 40 up to 70 A, the arc voltage of 15 up to 35 V. The maximum input supplied into the arc was about 2100 W, however, usually from 1400 up to 1800 W. The length of the arc was 1 to 2 mm. At the end of the Cu electrode at the distance $x = L'$ (L' — the active length of the electrode) a through-flow cooler was situated.

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During the measurement the temperature distribution along the active length of the electrode (by means of Fe-constantan thermoelements), the electrical input of the Q_0 arc and the heat output Q_1 transferred by the electrode into the cooling water in the place $x = L'$ were evaluated.

The distance of the measuring points Δl was 15 to 30 mm. The minimum distance of the first thermoelement from the electrode face was 5 mm.

For respective sections of the bar with the length Δl, in the end points of which the temperatures were known the components of the energetic balance Q_i ($i = 1, 2, 3$) were computed in compliance with the following relations:

— heat output removed through conduction Q_1

$$Q_1 = S \, . \, \lambda \frac{\Delta T}{\Delta l} = \frac{\pi \, . \, d^2}{4} (395 - 0.07 \, T_p) \frac{\Delta T}{\Delta l} . \qquad (1)$$

The dependence $\lambda(T)$ according to Šorin [4].

— heat output removed through convection into the ambient air Q_2

$$Q_2 = \pi \, . \, d \, . \, \Delta l \, . \, \alpha(T_p - T_0) \qquad (2)$$

— heat losses through radiation Q_3

$$Q_3 = \pi \, . \, d \, . \, \Delta l \, . \, \varepsilon \, . \, \sigma(T_p + 273)^4 . \qquad (3)$$

The dependence $\varepsilon(T)$ according to Tesař [5].

For the computation of the components Q_1 according to relations (1) to (3) the experimental values of ΔT in the quasistationary state of the thermal field in the Cu electrode were used.

The computation began at the end of the bar ($x = L'$) where the component Q_1 was known and went on towards the front of the electrode. The component Q_3 was not dominant for the used arrangement. For respective sections the computation was reiterated through the change of α in the component Q_2 as long as the balance of the partial outputs was reached. At the beginning of the computation the table value $\alpha = 15 \, \mathrm{W\,m^{-2}\,K^{-1}}$ was assumed, which corresponds to the boundary between the quiet and the moving air.

III. OBTAINED RESULTS AND DISCUSSION

The established characteristics of $\alpha = f(x)$ and S — form and for the respective dimensions of electrodes used they are represented in Figures 1 to 3. The highest values of in the proximity of the front of the electrode reached in the examined cases $\alpha_{max} = 265$ up to $295 \, \mathrm{W\,m^{-2}\,K^{-1}}$ and kept this value in the length between $x = 10$ to 15 mm. Though the values of α_{max} show a sinking tendency in dependence on d, S, on the heat flow at the front of the electrode Q_1 or on the ratio Q_1/S, the changes are in the scatter band of the measured values α_{max}.

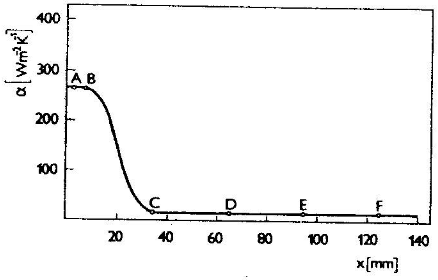

Fig. 1. Course of α along the length of the Cu electrode ∅ 19.9 mm, active Length $L' = 140$ mm. The measuring points are denoted by the Letters A to F.

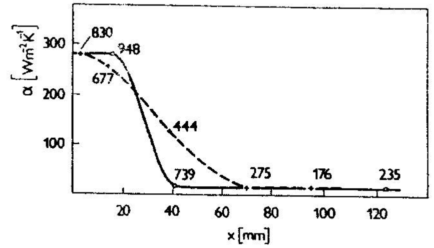

Fig. 2. Course of α along the length of Cu electrode ∅ 15.9 mm solid line — $L' = 130$ mm, dashed line — $L' = 105$ mm. The measured temperatures (in °C) in the quasistationary state are indicated as parameters at individual measuring points.

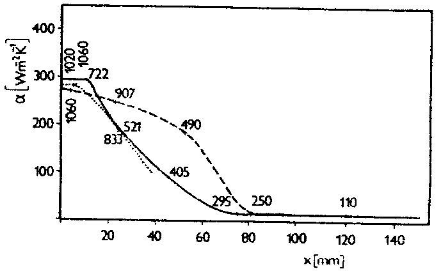

Fig. 3. Course of α along the length of Cu electrode ∅ 7.8 mm solid line — $L' = 150$ mm, dashed line — $L' = 95$ mm, dotted line — $L = 38$ mm. The measured temperatures (in °C) in the quasistationary state are indicated as parameters at individual measuring points.

A transition of α to higher values than $15 \, \mathrm{W\,m^{-2}\,K^{-1}}$ occurs at temperature values within the order of hundreds of centigrade degrees and depends on the diameter d of the electrode and on its activa length L'.

The accuracy of determining the values α or α_{max} depends on the accuracy of the bar temperature determination in a certain place. The accuracy of temperature measurement by means of thermoelements can be estimated at ±3 %.

An example of the electrode temperature increase up to the quasistationary state, reached in time about 240 sec, is given in Fig. 4.

The high values of α_{max} in the proximity of the electrode front are caused not only by high temperatures in those places, but also by the influence of the increased flow of the discharge plasma and of the ambient surroundings caused by the arc itself. Under the applied experimental conditions (length of the arc 1 to 2 mm, a graphite antielectrode) the flow was even more pronounced.

From Figs. 1 to 3 it follows that the decrease of coefficient α with an increasing distance from the electrode face, on which the arc is burning, is influenced also by the electrode diameter. With the increasing diameter of the electrode the ratio of the arc root area and the electrode face area is diminishing, wherewith the shielding of the cylindrical part of the electrode against the flow actually increases.

The described phenomenon contributes to an increased heat removal from the electrodes in the proximity of the electric arc the electrodes are freely situated in the ambient medium. The knowledge of this phenomenon helps to understand the phenomena connected with the arc burning and may contribute to a higher accuracy of experiments and detailed computations. In case of the switchgear, especially a l.v. one, the electrodes are mostly surronded by other assembly parts and consequently the condition of creating an undisturbed heat convection is not fulfilled. However, even here a certain heat removal from the electrodes in the proximity of the electric arc takes place. Even when including this phenomenon into the customary computation of the switchgear, the safety of the design will be ensured.

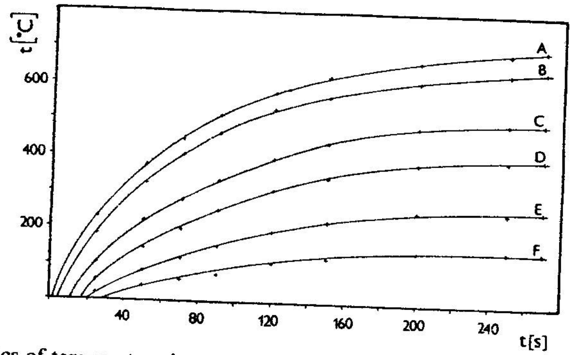

Fig. 4. The dynamics of temperature increase up to the quasistationary state for the Cu electrode, Ø 19.9 mm, $L' = 140$ mm. For positioning the measuring points with respect to the electrode face see Fig. 1.

APPLIED SYMBOLS

d — diameter of the electrode [m]
L' — active length of the electrode [m]
Q_0 — electrical input of the arc [W]
Q_1 — heat output removed through heat conduction [W]
Q_2 — heat output removed through convection into the ambient air [W]
Q_3 — heat losses through radiation [W]
S — electrode cross section [m^2]
T_0 — ambient temperature [°C]
T_1, T_2 — temperatures at the ends of the section length Δl [°C]
T_p — medium temperature $T_p = (T_1 + T_2)/2$ [°C]

ΔT — temperature differences at the length Δl [K]
α — heat transfer coefficient [W m^{-2} K^{-1}]
ε — emissivity (the applied value is valid for heavily oxidized copper) $\varepsilon = 0.45$
λ — heat conductivity [W m^{-1} K^{-1}], approximated in compliance with Šorin [4] $\lambda = (395 - 0.07\,T_p)$
σ — Stephan—Boltzman constant. $\sigma = 5.7 \times 10^{-8}$ W m^{-2} K^{-1}

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КОЭФФИЦИЕНТ ТЕПЛОПЕРЕДАЧИ В ОКРЕСТНОСТИ ЭЛЕКТРИЧЕСКОЙ ДУГИ

На основе экспериментальных данных сделано заключение, что коэффициент теплопередачи в окрестности электрода электрической дуги увеличивается с уменьшением расстояния от торца электрода. На торце электрода этот коэффициент достигает значения около 300 Вт . м$^{-2}$. К$^{-1}$