RADIAL DISTRIBUTION OF THE HEAT-FLUX DENSITY IN THE BEARING SPOT OF A PLASMA CUTTING ARC

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The results are reported from an experimental study of the laws governing the variation of the heat-flux density in the bearing spot of a cutting arc as a function of the arc polarity as well as the design and operating parameters of the plasmatron.

The efficiency of plasma cutting of metal is determined primarily by the amount of thermal energy transferred by the arc to the metal being cut and its concentration on the frontal surface of the cut. The most suitable plasmatron operating conditions, therefore, are those that ensure the highest energy concentration, which results in intensified melting of the metal and more rapid formation of a separating surface.

The degree of thermal-energy concentration on the surface of the metal being separated is expediently evaluated from the magnitude and nature of the radial distribution of the heat-flux density in the bearing spot of the arc. The accuracy of thermophysical calculations is enhanced substantially if local instead of average values of the specific heat flux are used in the thermophysical calculations.

Analysis of the methods of experimental investigation of heat fluxes shows that the radial distribution of the heat-flux density in the arc spot can be obtained by employing both nonstationary and stationary methods [1]. The use of stationary methods with water-cooled sensors, however, is preferable since they permit measurements to be carried out over a long time and, hence, with great accuracy.

Stationary methods include the sectional-electrode method [2], which is most applicable to the determination of the heat-flux density in the bearing spot of an arc. We should point out that in the case of a plasma cutting arc, with an extremely high thermal-energy concentration, this method has been made feasible by the development of a rotating sectional electrode [3]. The design of this electrode ensures increased heat transfer from the arc to a section as a result of the rapid displacement of the bearing spot of the arc along its cylindrical surface.

In studies with a rotating sectional electrode the plasmatron is set up above one of the electrode sections and the working arc is struck. The plasmatron is moved along the rotation axis toward the section boundary, crossing it. At the same time a differential thermocouple mounted in one of the sections records the temperature difference $\Delta T(x)$ of the water at the inlet and outlet of this section when the bearing spot passes through the separating plane.

At a constant cooling-water flow rate through the sectional electrode the variation of the heat flux in a section of the electrode is determined by

$$Q(x) = G_w c \Delta T(x),$$

where x is the running coordinate that characterizes the position of the bearing spot of the arc relative to the boundary between sections; G_W is the cooling-water flow rate; and c is the heat capacity of the water.

The radial distribution q(r) of the heat-flux density in the bearing spot of the arc is obtained by graphic differentiation of the Q(x) curve, previously smoothed by the method of least squares, and numerical solution of Abel's integral equation, using the procedure expounded in [4].

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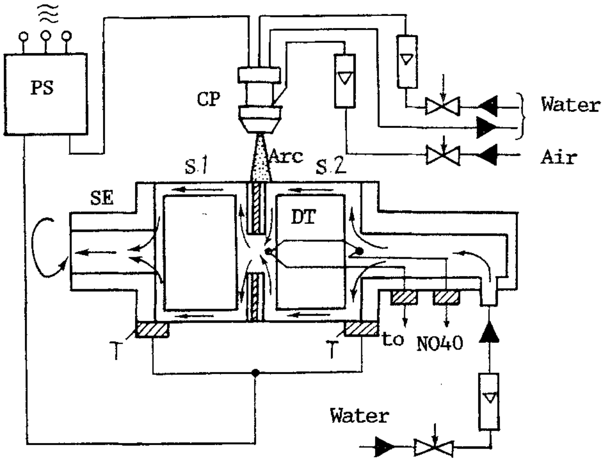

Fig. 1. Experimental setup for studying the heat fluxes in the bearing spots of a cutting arc.

Here we report the results of our studies of the magnitude and nature of the radial distribution of the heat-flux density in the bearing spot of the arc of a plasmatron with an internal copper electrode [5], with variation of its design and operating parameters.

The studies were carried out on a setup (Fig. 1) containing a cutting plasmatron CP, a power supply PS, a rotating sectional electrode SE, and control, measuring, and monitoring equipment. The rotating sectional electrode consists of two cylindrical copper sections S1 and S2, separated by a thermally and electrically insulating spacer with a thickness of $0.15 \cdot 10^{3}$ m. Mounted into one section is a differential thermocouple DT, whose leads are connected to an N040 light-beam oscillograph via contact rings. A TV-4 lathe was used as the drive for rotating the electrode and moving the plasmatron. One pole of the power supply was connected to the plasmatron and the other was connected to both sections of the electrode by means of graphite brushes T.

The following quantities were kept constant in all the experiments: rotational speed of the sectional electrode 75 rps; rate of plasmatron travel $0.95 \cdot 10^{-3}$ m/sec; cooling-water flow rate through the sectional electrode and plasmatron, respectively, 0.17 and 0.15 kg/sec; and operating current of the arc 100 A. The following plasmatron design and operating parameters were varied: flow rate of plasma-forming air from $1.08 \cdot 10^{-3}$ to $1.42 \cdot 10^{-3}$ kg/sec; distance between plasmatron and sectional electrode from 10^{-2} to $2 \cdot 10^{-2}$ m; and diameter of nozzle channel from $2.7 \cdot 10^{-3}$ to $4.0 \cdot 10^{-3}$ m. The experiments were carried out with forward and reversed current polarities. The arc was first struck in one section, at the maximum distance from the boundary between the sections so as to reduce the amount of heat reaching the other section. When the plasmatron operating conditions had been established we switched on the mechanism for moving the plasmatron and turned on the oscillograph. The only oscilloscope traces deemed suitable for further processing were those which did not have any abrupt surges, i.e., the smooth variation of the cooling-water temperature in the control section was not disrupted.

Moreover, in order to eliminate the error due to the thermal inertia of the sectional electrode because the cooling water flowed in only one direction through both sections, we used the averaged curve as the calculated curve of water-temperature variation in the control section. We obtained the averaged curve by superimposing two oscilloscope traces, one of which was taken as the bearing spot of the arc moved toward the control section and the other was obtained as the bearing spot moved in the reverse direction. The diameter of the hot spot of the arc was taken to be equal to the distance on the oscilloscope, on the appropriate scale, at which the heat flux in one section changed from the value equal to the total heat flux in the electrode to the value equal to the sensitivity threshold.

The oscilloscope traces were processed and the radial distribution of the heat-flux density in the bearing spots of the arc was calculated in succession on a SM-3 computer, using the methods indicated above.

Figures 2, 3, and 4 show the experimental radial distribution of the heat-flux density in the bearing spots of the arc, respectively, at different distances from the plasmatron nozzle edge to the surface of the sectional electrode, nozzle-channel diameters, and plasma-forming air flow rates.

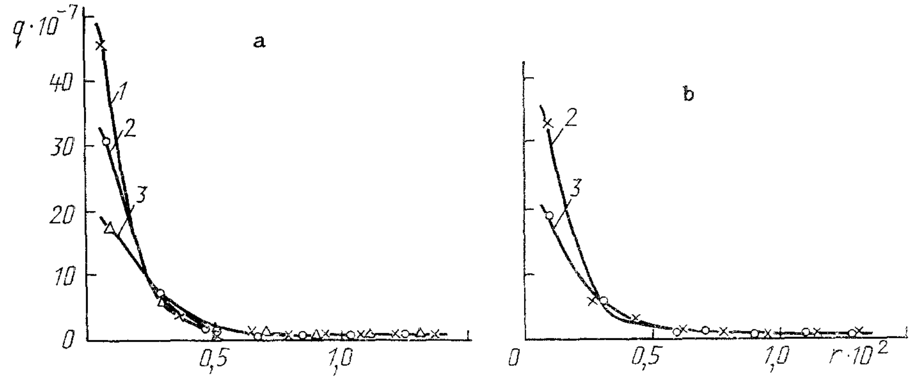

Fig. 2. Radial distribution of the heat-flux density in the bearing spots of the arc with forward (a) and reversed (b) current polarities, plasma-forming air flow rate $1.25 \cdot 10^{-3}$ kg/sec, nozzle-channel diameter $3.4 \cdot 10^{-3}$ m, and different distances from the plasmatron nozzle edge to the workpiece, 10^{-3} m: 1) 10; 2) 15; and 3) 20.

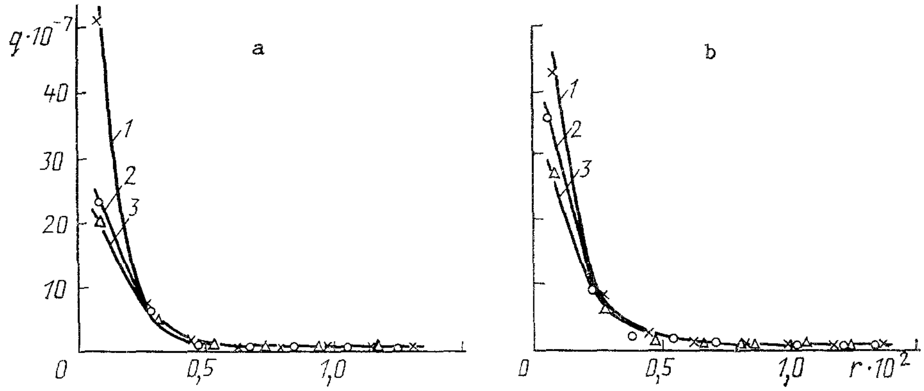

Fig. 3. Radial distribution of the heat-flux density in the bearing spots of the arc with forward (a) and reversed (b) current polarities, plasma-forming air flow rate $1.08 \cdot 10^{-3}$ kg/sec, distance from plasmatron nozzle edge to the workpiece $15 \cdot 10^{-3}$ m, and different diameters of nozzle channel, 10^{-3} m: 1) 2.7; 2) 3.4; and 3) 4.0.

Analyzing the dependences obtained, we can note that when the distance from the plasmatron nozzle edge to the sectional electrode increases from 10^{-2} to $2 \cdot 10^{-2}$ m under forward current polarity (the sectional electrode is the anode) the heat-flux density at the center of the spot decreases from $42 \cdot 10^7$ to $18 \cdot 10^7$ W/m², and the diameter of the hot spot increases from $1.6 \cdot 10^{-2}$ to $2.2 \cdot 10^{-2}$ m. With the current polarity reversed (the sectional electrode is the cathode) the heat-flux density at the center of the spot decreases from $34 \cdot 10^7$ to $20 \cdot 10^7$ W/m² and the diameter of the hot spot increases from $1.9 \cdot 10^{-2}$ to $2.2 \cdot 10^{-2}$ m when the distance between the plasmatron and the electrode increases from $1.5 \cdot 10^{-2}$ to $2.0 \cdot 10^{-2}$ m.

Similar laws also appear when the nozzle-channel diameter increases (Fig. 3). For example, when the diameter is increased from $2.7 \cdot 10^{-3}$ to $4.0 \cdot 10^{-3}$ m with the plasmatron operating at forward polarity the heat-flux density at the center of the hot spot drops from $51 \cdot 10^7$ to $20 \cdot 10^7$ W/m² and the diameter of the hot spot grows from $1.9 \cdot 10^{-2}$ to $2.3 \cdot 10^{-2}$ m while with the polarity reversed the changes are from $44 \cdot 10^7$ to $28 \cdot 10^7$ W/m² and from $2.0 \cdot 10^{-2}$ to $2.13 \cdot 10^{-2}$ m, respectively.

From Fig. 3 we see that the variation of the plasma-forming air flow rate within the indicated limits has only a minor effect on the magnitude of the heat-flux density at the center of the spot and on the nature of its radial distribution over the spot. The laws governing the variation of the heat-flux density at the center of the spot and the diameter of the hot spot as a function of the air flow rate are more complicated.

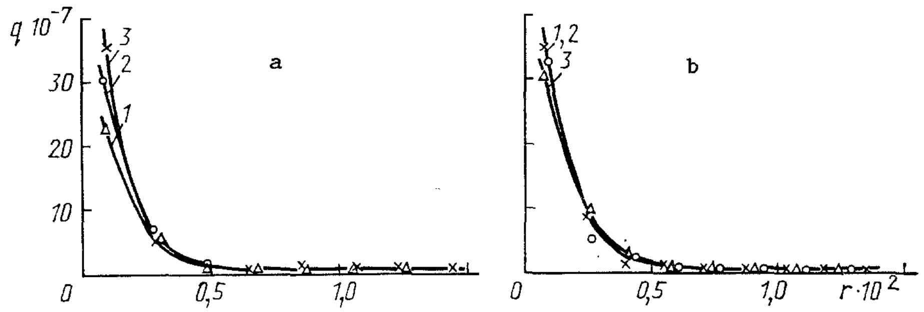

Fig. 4. Radial distribution of the heat-flux density in the bearing spots of the arc with forward (a) and reversed (b) current polarities, distance from the plasmatron nozzle edge to the workpiece, $15 \cdot 10^{-3}$ m, nozzle-channel diameter $3.4 \cdot 10^{-3}$ m, and plasma-forming air flow rate, 10^{-3} kg/sec: 1) 1.08; 2) 1.25; and 3) 1.42.

CONCLUSIONS

1. The heat-flux density distribution over a bearing spot of the arc can be described approximately by the function

$$q(r) = q_{\max} \exp(-kr^2),$$

where q_{max} is the heat-flux density at the center of the spot; and $k = q_{max}/q_{av}$ is the coefficient of the concentrated heat flux in the spot.

2. The magnitude and nature of the radial distribution of the heat-flux density in the bearing spot of the arc with direct and reversed polarity differ only slightly.

NOTATION

Here, Q(x) denotes the experimentally measured variation of the heat flux in one section of the sectional electrode; $\Delta T(x)$ is the variation of the temperature difference at the inlet and outlet of the control section of the sectional electrode; x is the coordinate; G_w is the cooling-water flow rate through the sectional electrode; c is the heat capacity of the water; q(r) is the heat-flux density at a distance r from the arc axis; d is the diameter of the plasmatron-nozzle channel; G is the plasma-forming air flow rate through the plasmatron; h is the distance from the plasmatron to the sectional electrode; q_{max} is the heat-flux density at the center of the bearing spot of the arc; and $k = q_{max}/q_{av}$ is the coefficient of concentrated heat-flux in the spot.

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