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GASDYNAMIC CONTROL OF ARC MOTION

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It is shown experimentally that by modifying the gas flow field in the inner electrode of a vortical plasmotron, it is possible to improve the efficiency of electromagnetic scanning of the arc and diminish the erosion of the electrode. The prospects of gasdynamic scanning for creating a plasmotron with a long service life is discussed.

Copper is finding ever increasing use in plasma technology as a material for producing the anodes of plasmotrons as well as cathodes in the case of elevated discharge currents or high operating pressures, when thermoemissive cathodes turn out to be inoperative [1]. It is beginning to be used even in single-electrode metallurgical plasmotrons, in which high-melting electrodes with a fixed arc spot have been traditionally used [2]. Therefore, the problem of the service life of copper electrodes with a moving arc spot remains timely at present.

One of the well-known methods of increasing the service life of such electrodes is to scan the arc spots of the arc along the length, in addition to their motion along the circumference of the electrodes. Various methods of longitudinal scanning have been suggested: electromagnetic [3, 4] and gasdynamic [5]. Despite the comparative simplicity of the realization of the former, they have not been developed extensively because of their inadequate efficiency. Purely gasdynamic methods are more complex since they require the use of special, rather sophisticated or unwieldy devices for commutating the gas flow.

It has been well-known that the internal tubular electrode of a vortex plasmotron operates under extremely difficult conditions and therefore has a minimal service life. This is explained by its complex internal gas dynamics, which is characterized by the presence of two coaxial gas flows: external, directed from the vortex chamber to the end face wall, and internal, near-axial, directed from the end face wall to the exit (Fig. 1). In this electrode the tangential and axial velocity fields have a number of specific features that characterize not only plasmotrons but also other apparatus of such geometry [6] and facilitate the onset of the arc discharge instability. In particular, the direct and reverse flows deform the radial portion of the arc discharge, which closes on the electrode, by displacing separate portions of it in opposite directions. Moreover, upon passage of gas from the external swirled flow to the internal one the angular velocity of rotation increases in the near-axial zone in accordance with the law of momentum conservation. This causes the appearance of circumferential shear stresses in the zones of slippage of concentric gas layers, too, during their rotational motion.

When these slipping layers flow around the radial portion of the arc, which closes on the electrode, shear stresses invariably cause deformations that destabilize the arc column and lead to irregular displacement of it with lags in the same place. The above leads to local superheating and more rapid erosion of the electrode [7, 8]. In order to eliminate these undesirable phenomena, it is necessary to regulate the motion of the arc largely by improving the internal gas dynamics of the electrode. Thus, the setting up of a flow with quasisolid rotation of gas in the internal electrode cavity by releasing a portion of the operational flow through an annular gap made it possible to preclude instabilities associated with deformation of the arc column in the azimuthal direction and to reduce the level of erosion of this electrode [7]. However, this method is not always acceptable technically because of the presence of harmful impurities in the gases conducted away from the plasmotron and a decrease in its efficiency.

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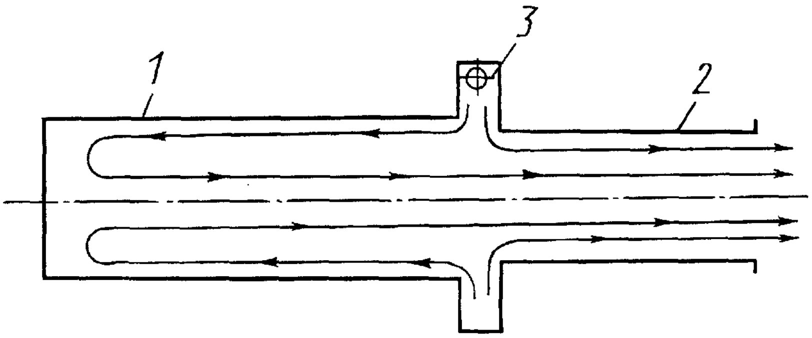


Fig. 1. Schematic of a vorticity plasmotron and flows in its electrodes: 1, 2) electrodes; 3) vortex chamber.

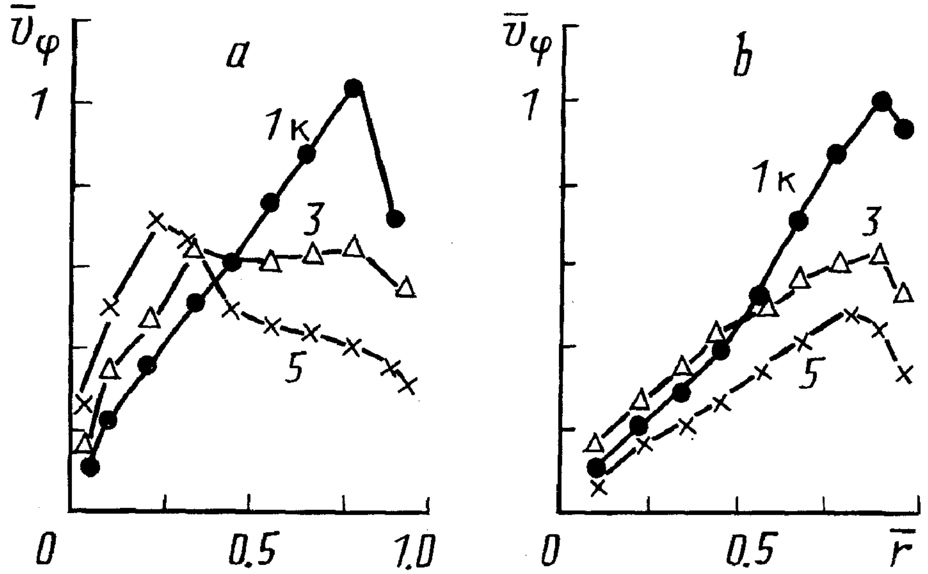
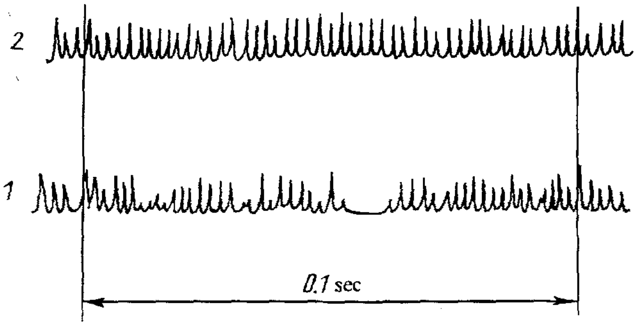


Fig. 2. Radial profiles of dimensionless tangential velocity $\bar{v}_\varphi$: a) in an ordinary electrode; b) in a modernized electrode ($\bar{v}_\varphi = v_\varphi / v_{\max}$, $\bar{r} = r/r_{\max}$). The figures at the curves denote distance (in diameters) from the section of swirling.

In investigating experimentally the velocity fields of a gas in a blind electrode by means of a laser-Doppler flow meter (LDFM), attention was drawn to the part played by a boundary layer on the end face wall, where gas passed from the external to the internal flow, which carried considerable angular momentum and caused an increase in the angular velocity in the near-axial zone. By controlling the flow at this place, it is possible to expect a change in the flow pattern in the entire electrode. This was indicated indirectly in works dealing with the study of cyclones, in which an increase in the end wall roughness led to a shift in the tangential velocity maximum to a large radius [6].

Our experiments with the use of an LDFM showed that an artificial increase in the end wall roughness of the internal electrode by producing micrononuniformities on it with dimensions on the order of the electrode radius made it possible to extend the region of quasisolid gas rotation practically up to the boundary layer on the cylindrical surface of the electrode. This is evident from a comparison of radial profiles of the tangential velocity obtained at various distances from the vortex chamber in an ordinary and a modernized electrode (Fig. 2). The part played by the macrononuniformities on the end face wall of a modernized electrode consists in the suppression of angular momentum transport to the flow axis by the end face radial flow.

The results obtained were used in an operating plasmotron whose geometry is depicted in Fig. 1. The angular velocity of the radial portion of the arc in the internal cathode was recorded by means of photosensors installed in the end face cap of the electrode. In the improved electrode, all other things being equal, both the



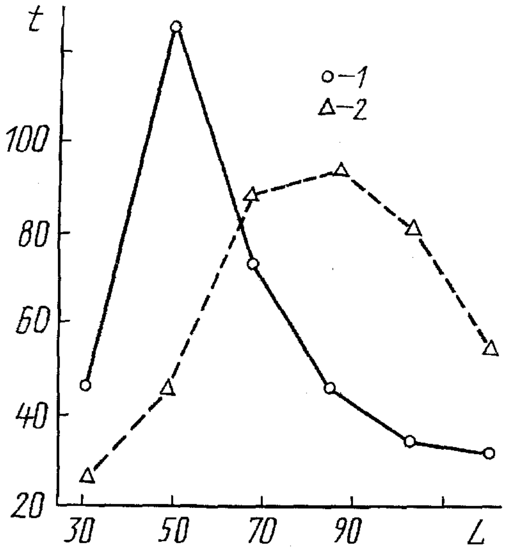


Fig. 3. Oscillogram of the rotation of an arc cathode spot: 1) in a conventional electrode; 2) in an ordinary electrode.

Fig. 4. Distribution of the wall temperature along the length of the electrode: 1) without scanning; 2) with scanning at a frequency of 22 Hz. t, °C; L, mm.

uniformity and the mean velocity of the displacement of the cathode arc spot increased (Fig. 3). The volt-ampere characteristic hardly changed in this case.

The setting up of a flow with quasisolid rotation of gas in the cavity of the internal cathode made it possible to implement more efficiently the aforementioned method of displacement of the attachment point of the arc along the length of the electrode by means of a scanning magnetic field produced by successive switching of solenoids located on the cathode. The frequency and sequence of switching were determined by a thyristor switch. To monitor the change in the thermal regimes of the electrode and indicate the position of arc attachment, thermocouples were stamped into the outer surface of the cathode, since monitoring the internal surface temperature for this purpose is unjustifiably complicated.

Figure 4 shows the distribution of the external surface temperature along the length of the modernized electrode without scanning of the cathode arc attachment (one solenoid was used) and with alternate switching of three solenoids with a frequency of 22 Hz. The zone of the effect of the arc expanded in the latter case, while the maximum heating of the electrode surface decreased markedly, i.e., the effect of distribution of the heat load onto a larger area was observed. In an ordinary electrode with a smooth end face surface even in the presence of a scanning magnetic field the arc was attached in one cross section, and the temperature profile was similar to that with a single solenoid. This testifies to the low efficiency of magnetic scanning in the quasipotential vortex occurring in this electrode. When the switching frequency of the three solenoids was decreased to 1 Hz, with the remaining conditions being preserved, the zone of longitudinal displacement of the arc expanded to three diameters, but three erosion grooves were detected on the electrode, and three distinct maxima on the temperature profiles. This provides a basis for the conclusion that with such a low frequency of scanning a local temperature field has time to form in each zone of predominant occurrence of arc attachment. In this case, the thermal stress of the electrode does not decrease, and an increase in its service life is achieved only with an increase in the expended mass of the electrode.

In spite of the fact that in these regimes at an arc current of 600 A the specific erosion is not large ($6 \cdot 10^{-9}$ kg/kC with operation in air and $4.4 \cdot 10^{-9}$ kg/kC in technical nitrogen), it can be decreased still further by increasing the number of commutating solenoids and making the longitudinal displacement of the arc more nearly continuous. From the results of the calculations in [9] it follows that in the case of ideal scanning of an arc by means of six solenoids, rather than one, it is possible to decrease the level of specific erosion threefold and decrease the depth of erosive destruction thirtyfold.

In conclusion it should be noted that the positive results obtained with magnetic scanning in no way means that the development of rather simple gasdynamic scanning methods has become less urgent. The issue is that the magnitude of the magnetic field induction influences substantially the specific erosion of an electrode via the heat transfer conditions on its surface. At the same time, efficient scanning often requires magnetic fields that substantially exceed their optimal values from the viewpoint of minimization of specific erosion. At the same time, intense gasdynamic effects on arc attachments cause a decrease rather than an increase in specific erosion and therefore are preferable. As a result, the optimum solution could be a combination of weak magnetic effects and intense gasdynamic effects. To that end, a simple gas distributor was developed and tested on the plasmotron described above. It is powered from the compressed air supplied to the plasmotron, does not require a special drive or maintenance, and transforms a continuous gas flow into two flows pulsating in opposite phase. These flows were supplied to two identical vortex chambers installed at the beginning and end of the internal electrode. The magnetic-field solenoids on the electrode were completely disconnected. With this kind of scanning, under certain operating conditions an amplitude of longitudinal displacement of arc attachments that constituted more than three diameters was obtained along almost the entire length of the electrode. Further studies will be carried out along the lines of optimization of combined magnetic and gasdynamic effects on the arc to obtain minimum erosion.

REFERENCES

1. Electric Arc Plasmotrons. Prospectus [in Russian] (edited by M. F. Zhukov), Novosibirsk (1977).
2. S. L. Camacho, in: Proc. of the International Workshop on High-Temperature Plasma Tests in the Processes of Materials Treatment, Frunze (3-9 September) (1990).
3. Patent No. 966103 (Great Britain), MKI H05 B7/18, published 03.08.64.
4. Patent No. 1520365 (Great Britain), MKI H05 B7-12, published 09.08.78.
5. M. F. Zhukov, A. S. Koroteev, and B. A. Uryukov, Applied Dynamics of a Thermal Plasma [in Russian], Novosibirsk (1975).
6. A. N. Saburov, Aerodynamics and Convective Heat Transfer in Cyclone Heaters [in Russian], Leningrad (1982).
7. A. I. Sudarev and A. N. Timoshevskii, in: Thermophysical Investigations [in Russian], Novosibirsk (1977), pp. 94-98.
8. A. V. Bolotov, É. D. Degraf, and V. N. Musolin, in: Abstracts of Papers Submitted to the 7-th All-Union Conf. on Low-Temperature Plasma Generators, Pt. 1, Alma-Ata (1977), pp. 50-53.
9. L. I. Sharakhovskii and V. N. Borisyuk, in: Abstracts of the Papers of the Submitted to the X-th All-Union Conf. on Low-Temperature Plasma Generators, Pt. 1, Minsk (1986), pp. 79-80.