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TEMPERATURE OF HEAVY-CURRENT CYLINDRICAL HOLLOW CATHODE

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Introduction. The first papers on discharge with hollow cathode were published about twenty years ago /1,2/. The discharge of this type we used as a heavy-current source of ions. Later investigations on hollow cathode application were developed in laboratories of different countries. Physical investigations under the leadership of Prof. Delcroix /3/ and practical use of the discharge with hollow cathode by Ulvac Co. in metallurgy should be especially mentioned /4/.

At Baikov Institute of Metallurgy experiments to study energy-physical and technological parameters of heavy-current discharge with hollow cathode are under way /5-7/. This paper presents results of temperature condition studies for cylindrical tungsten cathode. The obtained data characterize electric transfer on the cathode, its energy balance and erosion mechanism.

Experimental assembly and investigation conditions. The assembly to study cathode temperature condition consists of a cathode unit with a hollow tungsten electrode, water cooled copper anode with a crater for liquid metal, sealed chamber, d.c. power source, gas-evacuation system and measurement equipment.

Brightness temperature of the cathode providing the wave length \( \lambda = 0.65 \text{ mkm} \) was measured in experiments. Power dissipated from cathode by heat conductivity was determined by the temperature of water cooling cathode. The arc current was in the range from 300 up to 3300 A, consumption of plasma forming gas - from 0.05 up to 0.26 cm³/sec, the cathode diameter was equal to 0.4-2 cm, the wall thickness - 0.2-0.5 cm and the cathode length - 6-12 cm. Experiments were mainly conducted in argon by pressure in the chamber of 0.4 torr. In some tests helium, nitrogen and hydrogen were used as a plasma forming gas.

Cathode temperature. By large currents two maximums of temperature are observed on the cathode surface: the first maximum \( T_{1m} \) - in the cathode active zone, the second maximum \( T_{2m} \) - near cathode fixing in a cooling holder (Fig.1).

The typical temperature of the active zone for tungsten cathode is equal to 2900-3300 K. Value and position of the temperature maximum essentially depend on the arc current and gas consumption through cathode. By current increasing from 800 up to 3000 A the maximum temperature rises according the empiric equation

\[
T_{1m} = 1750 I^{0.075}
\]

and its position is shifted to the working end of the cathode. Providing \( I = 800 \text{ A} \) the maximum is at a distance of 4 cm from the outlet end, and by \( I = 3000 \text{ A} \) - 2 cm.

By varying gas consumption the maximum temperature changes negligibly. Gas consumption essentially effects the maximum position. Thus, by argon consumption through cathode of 26 and 0.5 cm³/sec its maximum temperature did not change practically and was equal to 3300 K. By gas consumption of 26 cm³/sec the maximum temperature was at the electrode tip and by consumption of 0.5 cm³/sec - at the distance of 18 mm from it. Shift of the active zone providing current and gas consumption change is obviously explained by varying pressure in the electrode cavity.

Gas type effects cathode temperature con-
dition negligibly. Thus, if plasma-forming gas is argon the temperature of outer surface was equal to $3250^\circ K$, in case of nitrogen and helium - 3270 and $3300^\circ K$ correspondingly.

The second maximum near cathode fixing in the holder is obviously explained by two factors: 1) cathode is not being cooled by electron emission and 2) electrode is heated by full discharge current in this region (outside the active zone). The temperature may be determined with enough accuracy from Lenz-Joule and Stefan-Boltzmann equations:

$$T_m = \sqrt{\frac{\rho J^2}{\pi^3 \sigma}}$$

Here $\varepsilon$ - integral coefficient of radiation, $G$ - Stefan-Boltzmann constant, $\rho$ - specific electric resistance, $d$ - cathode diameter and $h$ - cathode wall thickness.

As it follows from Eq. (1) and (2) the temperature outside the spot rises more rapidly by the current than in the spot. This is the reason for limiting current of the cylindrical hollow cathode caused by electrode melting near its fixing in the holder. Critical current density in the tungsten cathode body, determined experimentally by its melting, is equal to 4,6-5,6 kA/cm$^2$ (Fig.2).

![Fig.2. Change of the first (1) and second (2) temperature maximum depending on the current density in the electrode.](image)

1. - by brightness temperature ($d=2,6$ cm; $h=0,2-0,3$ cm), 2. - by electrode melting ($d=0,4-0,6$ cm; $h=0,2-0,3$ cm)

Cathode energy balance. Study of cathode temperature condition allowed to determine components of its energy balance. Power introduced into the cathode in the active zone consists of energy streams caused by ions energy moving to the cathode $P_i$ and Joule heating $P_A$. Energy outlet occurs due to radiation $P_r$; electrons emission $P_e$; heat conductivity $P$ and evaporation of cathode material $P_v$.

Power dissipated from the cathode by radiation essentially depends on the arc current and forms 45-75% of full power emerged on the cathode. Power dissipated by heat conductivity is equal to 8-14%. Power consuming on electrons thermoemission may be equal to 20-40%. The electron current part is 0,6-0,8. It rises with increasing the discharge current.

Rate of electrode erosion is satisfactorily described by Lengmour equation and requires about 1% of the energy.

Ions moving to the cathode are the main energy source in the active zone. If the discharge current is essentially lower (in some times) than the limiting one, the power transferred by ions is equal to 85-90% of the full energy emerged in the active zone.

Cathode voltage drop calculated on the basis of energy balance in the active zone is equal to 16-20V.

Conclusion. Analysis of the temperature condition of a tungsten hollow-cathode has shown that electric current of such a cathode is provided by thermo-emission mechanism. The limiting current of a cylindrical cathode has been defined experimentally. Its value is caused by electrode melting due to Joule overheating of an electrode outside the cathode spot.

References