CERTAIN MAGNETOGASDYNAMIC EFFECTS IN A

HIGH-CURRENT ARC WITH A GAS STREAM

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The heating of a hydrogen stream driven lengthwise through an electric arc within a narrow channel has been studied and the results are discussed.

There is not much information available in the technical literature on the heating of hydrogen to high temperatures in an electric arc. Meanwhile, a study of this problem is definitely interesting from both the scientific angle of exploring the arc processes and the practical angle of investigating its possible technical applications. We will discuss here some performance characteristics of an electric arc with a hydrogen stream which the authors have noted during their experiment.

The study was made with an apparatus shown in Fig. 1. An arc was sustained between graphite sleeve inserts 4 inside the electrodes 5. Hydrogen was fed into the discharge chamber through tangential holes in the gas ring 1 and was let out through the anode diaphragm and the cathode diaphragm inside the respective electrode cavities, while stabilizing the electric arc column in the process.

The electric field intensity and the thermal flux density were measured along the diaphragms. In order to facilitate the thermal flux measurements, these diaphragms were assembled in water–cooled segments separated from one another by electrical and thermal insulation. The thermal flux was determined from the rate of water flow through individual segments and the corresponding drop in water temperature between entrance to and exit from a segment. This temperature drop was recorded with resistance thermometers. Simultaneously, the segment potentials were recorded on the basis of microammeter (internal resistances 20 kΩ/V) readings. In series with the microammeters were connected 20 MΩ resistors. In order to establish the distribution of electric field intensity, furthermore, the diaphragms were made seamless and insulated probes were installed along them (Fig. 1b).

Proper correspondence between the probe potentials and the potentials along the arc column was ensured by the internal resistance of the recording instrument. In order to check the readings, the internal resistance of the instrument was reduced to 100 kΩ. Such a change in the resistance did not cause a change in the recorded potential, which agreed with the results in [1-4]. The effect of current leakage into the water coils was eliminated by performing this part of the experiment with uncooled diaphragms and insulated wire probes. The main dimensions of the discharge chamber were as follows: d = 4 mm, l_d = 5-20 mm, D_{gr} = 30 mm, δ = 7 mm, D_e = 8.5-10 mm, L_e = 120 mm, G_G = 1-2 g/sec.

The profile of the electric field intensity along a diaphragm is shown in Fig. 2, on the basis of measurements with insulated probes, at a 460 A arc current. Along the first 5 mm of the diaphragm the field intensity is higher than 220 V/cm, along the next 5 mm it drops to zero. Then there follows an appreciable jump up to 90 V/cm and another drop to below zero. At the end of the diaphragm the intensity rises again. The error in the voltage measurements was ±5 V while the potential jump reached 20 V, and was systematically repeated in all tests. The negative value of field intensity cannot, therefore, be attributed to a measurement error.

On the same diagram are also shown profiles of thermal flux density along a diaphragm at two levels of arc current: 400 A (curve 2) and 470 A (curve 3). In the middle section of this diaphragm the thermal flux drops to zero or even becomes negative. As the arc current is increased, the minimum point shifts toward the gas ring and the magnitude of the negative thermal flux becomes greater. For the 470 A arc
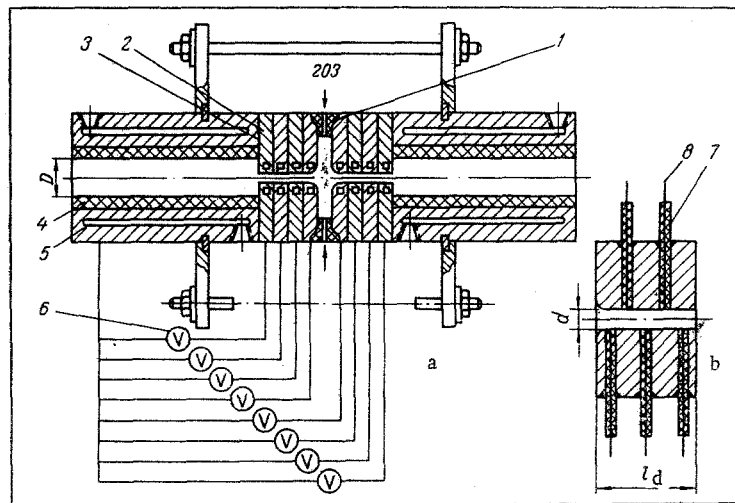
Fig. 1. Schematic diagram of the test apparatus: a) plasma-
tron with segmented water-cooled diaphragms; b) seamless
diaphragm with insulated probes: 1) gas ring; 2) cooled
diaphragm segment; 3) electrical insulation layer; 4) graph-
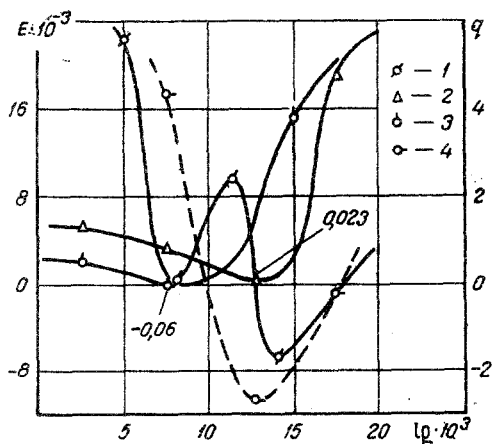ite insert; 5) electrode body; 6) voltmeter; 7) ceramic tubing;
8) probe.

Fig. 2. Variation of the electric field
intensity and of the thermal flux density
along a diaphragm (d = 4 mm, D_e = 8.5
mm, G_G = 2 g/sec): 1) E,V/m at I
= 460 A; 2) q, kW/cm² at I = 400 A; 3)
q, kW/cm² at I = 470 A; 4) E, V/m at
I = 500 A.

current (curve 3), part of the diaphragm (the second 10 mm
segment) was made in one piece and, therefore, a slight
shift of the minimum point on this profile toward the elec-
trode could occur. The negative drops are here within the
accuracy of the recording instrument. On the whole, the
error in the thermal flux density measurements did not
exceed ±0.15 kW/cm².

In Fig. 2 has also been plotted a curve (4) of the field
intensity profile along a diaphragm at a 500 A arc current
and a 2 g/sec flow rate of hydrogen, on the basis of total-
voltage readings in the plasmatron with diaphragms 5, 10,
15, and 20 mm long. This curve is less accurate, because
there are fewer test points and processes possibly occurring
in the electrode have been disregarded. However, this curve
confirms the results of measurements made with insulated
probes. Analogous curves plotted for different current levels
from 200 to 500 A confirm the appearance of an internal emf
and its increase with higher current. Zero crossover of the
E-profile occurs at currents from 400 A up at a gas flow
rate of 2 g/sec. Analogous results have been obtained with
a gas flow rate of 1 g/sec. At this gas flow rate the electric
field intensity E becomes negative at a somewhat higher
current of about 500 A. The trends of the q-profiles are analogous. In most cases the negative electric
field intensity was noted at the anodic diaphragm. In some cases, however, this phenomenon was also
noted on both sides of the plasmatron.

Apparently, this trend of both the electric field intensity E and the thermal flux density q along a
diaphragm is determined by the same process. The initial sharp drop in E can be explained by an in-
creasing electrical conductivity of the channel, which is due to a widening of the arc column and a rise of
the arc temperature during the heating of the gas. The causes of the subsequent intensity drop are not yet
quite understood.

The data obtained here are not sufficient yet for drawing any definitive conclusions as to the causes
of the observed phenomenon. It may be assumed that the drop in q at individual segments of the narrow

channel is related to the conversion of the kinetic energy of moving charged particles to potential energy during near-sonic oscillations generated in the critical heat mode. At that time the section area of the arc column and thus the thermal resistance of the near-electrode gas layers can change drastically.

The decrease in thermal fluxes at individual channel segments may occur, to some extent, as a result of thermal choking or magnetic pumping of gas into the electrically conducting channel region. It should be remembered here that a similar trend of the $q(l_d)$ profile has been noted during the heating of other gases with an electric arc [5], although this is not yet definitively understood.

The appearance of negative electric field intensities could be explained by a sudden widening of the arc column, which causes a sharp increase in the electrical resistance of the near-electrode layer. At the same time, there appears a large potential difference between the wall and the arc. It is, therefore, worthwhile to study the possibility of negative electric field intensities arising under actual conditions.

The trend of the phenomena occurring in an electric arc with a gas stream does not exclude the possibility of negative electric field intensities arising during fluctuations of the arc diameter as the gas stream reaches the velocity of sound. A "thermal nozzle" may be formed at that time, where the thermal energy is expended on accelerating the gas and raising the electric potential. This process cannot occur unidirectionally and it must be oscillatory in nature, which agrees with test data.

At some point along the profile (apparently, in connection with attaining the velocity of sound) the internal emf of the arc increases sharply and a potential jump results. The potential energy is increased at the expense of the thermal and the kinetic energy of the stream. Further down the stream there occurs a succession of jumpwise polarity reversals of the internal arc emf, which is apparently related to near-acoustic fluctuations of the gas velocity as well as to periodic expansions and contractions of the arc channel. Adiabatic contraction and expansion of gas in the boundary layer results in its fast cooling and heating, respectively. In some cases the temperature of the boundary layer may drop below the initial temperature, which results in a thermal flux reversal through the diaphragm from the cooling water to the heated gas.

Estimates show that at current densities above 10^5 A/cm^2 this phenomenon of polarity reversals in the electric field may be due to intensive oscillations of the diffusion-current gradient in the stream of charged particles, also due to the Hall emf generated by interaction between the radial components of current (within the range of sudden changes in the arc diameter) and the magnetic field of the axial current component.

NOTATION

d is the diameter of diaphragm, mm;
l_d is the length of diaphragm, mm;
D_{gr} is the diameter of gas ring, mm;
δ is the gap between diaphragms, mm;
D_e is the diameter of electrode, mm;
G_G is the gas flow rate, g/sec;
E is the electric field intensity, V/cm;
q is the thermal flux density, kW/cm^2;
I is the electric current, A;
L_e is the length of electrode.

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