USE OF A HEAVY-CURRENT STABILIZED ARC TO PRODUCE AN AIR PLASMA WITH A TEMPERATURE OF UP TO 35,000°K

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UDC 533.9.07

We consider two versions of heavy-current arc discharge chambers with vortex stabilization, making possible the production of an air plasma to a temperature of 35,000°K, without contamination by electrode material. We study the space-time stability of the plasma formations that are produced.

We have recently seen descriptions of several continuous-action and pulse-regime discharge installations which made it possible to reduce stable axisymmetric plasma formations without contamination by electrode material [1-3]. Such installations exhibit a number of advantages relative to the unit currently in use in connection with quantitative studies of the thermophysical and optical properties of exceedingly hot gases and their mixtures. In a discharge chamber operating in a low-current regime ($I \approx 10$ A), a temperature of 20,000°K was obtained [2] at the axis of the arc filament, and this corresponds to the maximum regimes of the best contemporary adiabatic compression tubes. Transition to higher-current regimes opens the way for further elevation of temperature. However, this problem has been dealt with exclusively in connection with the case of pulse discharge [3].

In this article we discuss the results obtained in a study on the use of heavy-current stabilized arc discharges to produce a long-lasting air plasma with a temperature of tens of thousands of degrees. We apply the principles of the heavy-current plasma-jet generators in the development of this discharge chamber. The initial version of the chamber (Fig. 1a) was reminiscent of a bilateral plasma generator [4] in which the gas streamlining the arc is discharged from the vortex chamber through two tubular electrodes. The jets which were formed as a result, in our case, represented secondary plasma formations. The object of our research was the central segment of the discharge channel. We undertook the task of designing a unit to provide for the maximum possible space stabilization of this channel segment and to eliminate its contamination with the products of electrode erosion. To reduce the level of erosion, the electrodes were cooled with running water at a pressure of 6 atm. The movement of the products of erosion in the direction of the central zone of the chamber was restricted by means of a gas flow and through the insertion of special diaphragms which serve also to provide for the spatial stabilization of the central segment of the discharge channel.

The inside diameters of the chamber of the stabilization diaphragms were 90 and 5 mm, respectively. The gas flow rate was ~1 g/sec. The arc was powered by an RMV-500 mercury rectifier. A high-frequency generator was used to ignite the discharge. At currents of up to 500 A it was possible to produce an arc filament in the discharge chamber that produced virtually no destruction of the electrodes and diaphragms.

Two quartz windows in the housing of the chamber were used to keep the central segment of the arc filament under observation. The purity of the plasma was monitored and the temperature profile was determined by spectroscopic methods. The emission spectra of the plasma filament were photographed along the lateral cross section. One of the characteristic sections of the spectrogram obtained with an ISP-30

Institute of Physics, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 16, No. 6, pp. 1101-1105, June, 1969. Original article submitted August 1, 1968.

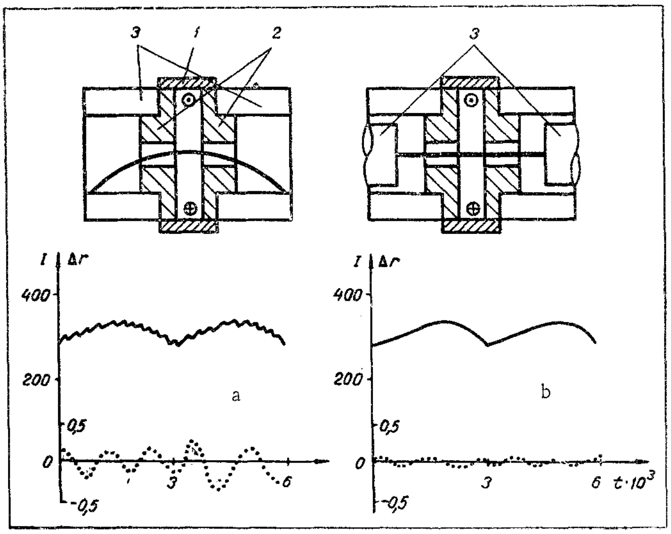

Fig. 1

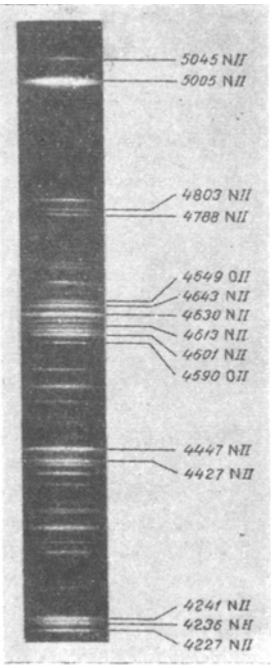

Fig. 2

Fig. 1. Basic diagrams of the two types of chambers to produce a pure air plasma by means of heavy-current arc discharge, the oscillograms of the current (solid lines) and the lateral displacements of the plasma filament with the passage of time (dotted lines): 1) cylindrical chamber; 2) stabilizing diaphragms; 3) electrodes; I, A; Δr, mm; t, sec.

Fig. 2. A portion of the emission spectrogram for the air plasma (p = 1 atm, I = 300 A).

spectrogram is shown in Fig. 2. Spectral analysis shows that the spectra include only the lines of nitrogen and oxygen atoms and ions, i.e., the products of the thermal decomposition and ionization of the air. The lines for the material of the stabilization diaphragms and electrodes are entirely absent in the spectra, which indicates the high degree of purity for the plasma produced.

The space-time stability of the arc filament was monitored by means of an SKS-1 M high-speed camera, converted for operation on a continuous basis. The arc filament was projected with an F = 150 mm condenser onto the plane of an intermediate slit cutting a thin plasma disk which was projected by means of another condenser onto the moving film of the high-speed camera (Fig. 3a). The time sweep of the luminescence of the plasma disk was parallel to the axis of the arc filament. The time resolution of the sweep, determined by the width of the slit and the speed of film motion, amounted to $\sim 3 \cdot 10^{-5}$ sec (for a slit width of 0.7 mm). The space connection of the plasma-filament cross section on the film was achieved by positioning a thin wire on the slit, perpendicular to the latter. A typical segment of the time sweep for the discharge chamber under consideration is shown in Fig. 3b.

Examination of the time sweeps demonstrates that the stability of the arc filament produced here is substantially better than the stability of conventional arc discharges, as well as of the Maecker arc with similar current regimes [5], although the latter does show slight pulsations in brightness. The frequency of filament brightness pulsation is ~3 kHz, and its diameter in this case varies from 4 to 5 mm. We also noted slight displacement of the filament axis at a frequency of about 1 kHz. Investigations have demonstrated that the observed fluctuations in brightness and in the position of the filament axis are primarily associated with the circular motion of the electrode spot over the inside surface of the tubular electrodes, setting into rotation the plane in which the distorted arc channel is located. The shunting of the arc [4] may also exert some influence on filament stability.

In this paper we have considered the possibility of a further rise in the stability of the arc filament. With this purpose in mind, we altered the design of the electrode units so that the arc bases were fixed in position at the electrodes. In this new version of the chamber (Fig. 1b) intensively cooled flat tungsten rods served as the electrodes, and these were placed within the tubular electrodes. The "connection" of the arc

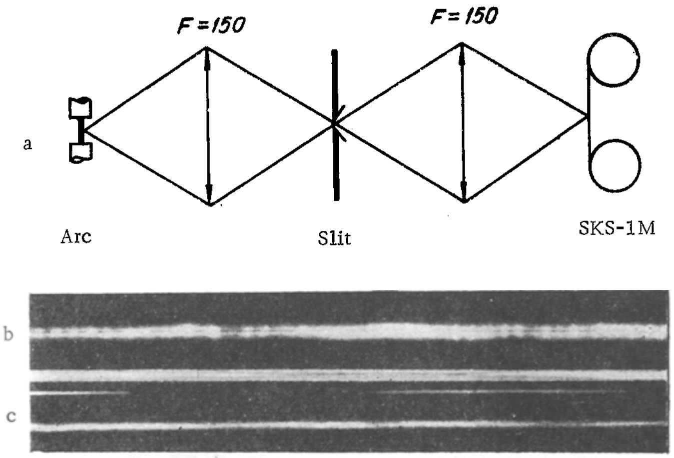

Fig. 3

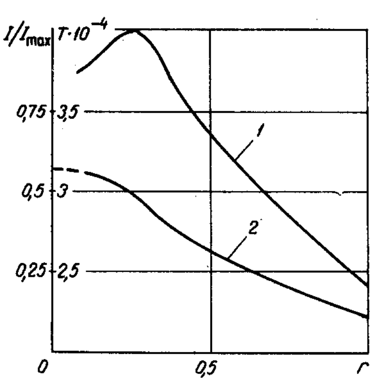

Fig. 4

Fig. 3. Optical diagram for a study of the space-time stability of an arc plasma filament (a) and the time sweeps of the emission from the plasma filament: b and c correspond to the electrode designs of Fig. 1a and 1b, respectively.

Fig. 4. Radial profile of the intensity of the NII line $\lambda = 5045$ Å (1) and the resulting temperature distribution (°K) along the radius (mm) of the discharge channel (2).

bases to the centers of the tungsten rods was achieved by the gas flow. This design made it possible to produce an arc discharge which resulted in virtually no destruction of the electrode or of the diaphragm and lasted for as long as 10 sec. This was sufficient to perform measurements without the use of high-speed instruments.

Limiting the motion of the electrode spots during the time of the discharge actually led to a pronounced improvement in the stabilization of the plasma filament (Fig. 1b). Both the space displacements of the filament and its brightness fluctuations diminished. As we can see from the oscillograms, the corresponding fluctuations in the current also disappeared. Analysis of the time sweeps demonstrated that the lateral displacements of the channel in this case do not exceed 5% of the channel radius.

It should also be noted that there was a reduction in the light diameter of the current-conducting channel in comparison with the original version. The arc filament, with a current strength $I = 300$ Å has a diameter of ~3 mm. The average current density in the filament correspondingly is greater than 3000 A/cm^2. If we consider that the current density in conventional arc discharges amounts to only several tens of amperes per square centimeter, we can expect a pronounced rise in temperature in the resulting plasma formations.

The axial symmetry of the plasma filament and, correspondingly, of its spectra makes it possible to determine the temperature profile on the basis of the Larenz method [6], which is based on a comparison of the experimental radial intensity profile with the theoretical temperature relationship for the emission intensity of the given line. Figure 4 shows the experimental profile of the emission intensity for the N II line $\lambda = 5045$ Å after Abelian conversion for discharge in air ($I = 300$ A, $p = 1$ atm), on the basis of which we constructed the temperature profile in the filament. The data on the composition of the air plasma needed to calculate the temperature dependence of the line under consideration were taken from [7].

Measurements show that the arc filament is a plasma formation that from the standpoint of temperature is nonuniform. At the discharge axis the temperature reaches 32,000°K, while at a distance of 1 mm from the axis it is 20,000°K. Temperature was not measured at more distant points of the filament because of the relative limited ability to record radiation by a photographic method.

The difference between the electron and gas temperatures in the air at $p = 1$ atm in the temperature interval between 20,000 and 30,000°K, as demonstrated in [3], did not exceed 0.1%. The temperature measured in this case is therefore the gas temperature. The temperature recorded at the axis of the arc filament is close to the limit value for the given method of localizing the discharge. A further increase in the current strength will lead to virtually no noticeable increase in the axial temperature, since there will be a sharp increase in the diameter of the plasma formation in this case, as a consequence of the increased energy losses resulting from conduction and radiation of heat.

The strong relationship between the temperature and the magnitude of the current is noted only for low values of the current. Thus, for example, with I = 12 A the maximum temperature in the air (p = 1 atm) is equal to T_{max} = 14,000°K, for I = 300 A we have T_{max} = 32,000°K, and for I = 4 kA we have T_{max} = 35,000°K [3]. It is interesting that such a temperature limit (T ~ 35,000°K) is found in conventional high-voltage spark discharges in air [8].

The discharge chambers described in this paper can be used not only to produce and to investigate highly heated air, but other atmospheres as well.

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