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MEASUREMENT OF THE TEMPERATURE OF A PULSATING ELECTRIC ARC DISCHARGE

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A simple method for determining the temperature on the axis of an oscillating arc column is proposed.

Determination of local temperatures in an inhomogeneous optically thin plasma of an axisymmetric arc discharge is associated with laborious measurements of spectral line intensities long hords of the arc column and with the need to perform accurate computations in processing experimental data. In the case of a pulsing discharge, additional difficulties arise that are associated with carrying out measurements of line intensities along a certain chord with a high time resolution, as is required in order to use the Abel transformation. However, when determining probabilities of transitions or parameters of a plasma it is possible to confine ourselves to information on the temperature at the discharge center. In the present paper it is shown that it is possible to determine the temperature at the center of a pulsating arc discharge without using the Abel transformation, by merely measuring the intensity of radiation of a certain spectral line integrated over the diameter of the entire arc column. Here, simple experimental instrumentation with no time resolution is used.

The radiation intensity measured along the direction normal to the discharge axis is defined by the formula

$$I(x) = 2 \int_{0}^{\sqrt{R^2 - x^2}} \varepsilon(r)\, dr, \tag{1}$$

where $\varepsilon(r)$ is the radiation coefficient at a distance r from the plasma column axis; R is the radius of the source; $r^2 = x^2 + y^2$, $0 \le r \le R$. Using the inverse Abel transformation, it is possible to determine the emissivity for a certain measured value of the lateral intensity of the radiation of a line $I(x)$. For plasma in local thermodynamic equilibrium (LTE), the temperature $T(r)$ can be determined for a known emissivity from the formula

$$\varepsilon(r) = \frac{hcAGn(r)}{4\pi\lambda U(r)} \exp\left[-E/kT(r)\right], \tag{2}$$

where E is the energy of the radiating level; A is the probability of transition from that level; G is the statistical weight; λ is the radiation wavelength; $n(r)$ is the concentration of the component; $U(r)$ is the sum of states.

In computations employing the Abel transformation use is usually made of numerical methods. Since in this procedure it is necessary to differentiate the measured value of the distribution $I(x)$, the error in determining $\varepsilon(r)$ greatly exceeds the measurement error for $I(x)$. To reduce this error in the determination of temperature, various techniques of data processing by the Abel transformation method are used. Recently, A. A. Kurskov and coworkers suggested an approximate method [1] in which the Abel transformation is not used whatsoever for determining the temperature or emissivity of a low-temperature plasma in an optically thin cylindrical plasma source. The method is applicable for the case $T < T_m$, where T_m is the normal radiation temperature of the line. The method is based on a rapid exponential decrease in the plasma emissivity with a decrease in the temperature in the direction of the plasma column periphery, as is seen from Eq. (2). Therefore, the basic contribution to the line radiation intensity measured along a literal profile is made by radiation from a narrow zone around the center of the chord located along the x coordinate. Correspondingly, formula (2) can be simplified to

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$$\varepsilon(r) \simeq \varepsilon(x) \exp\left\{-\frac{E}{k}\left[\frac{1}{T(r)} - \frac{1}{T(x)}\right]\right\}. \tag{3}$$

Expansion of $1/T(r)$ in a Taylor series yields

$$1/T(r) \simeq [1/T(x)]\left\{1 + [y/R^*(x)]^2\right\},$$

where

$$R^*(x) \equiv [-(1/2x)\, d(\ln T)/dx]^{-1/2}.$$

Substituting the resulting equation into Eq. (1) from [1], we obtain an approximate expression for $I(x)$:

$$I(x) \simeq \sqrt{\pi}\, \varepsilon(x)\, R^*(x) \sqrt{kT(x)/E}. \tag{4}$$

By analogy with the approximation of $\varepsilon(r)$ it is possible to obtain an approximate expression for $\varepsilon(x)$ as a function of ε_0:

$$\varepsilon(x) \simeq \varepsilon_0 \exp\left\{-\frac{E}{k}\left[\frac{1}{T(x)} - \frac{1}{T_0}\right]\right\}. \tag{5}$$

Here T_0 and ε_0 are the temperature and emissivity at the plasma column center. The temperature distribution over the column radius can be approximated by the expression [2]

$$T(x) = T_a + T_0 \exp(-x^2/2\sigma^2),$$

where T_a is the ambient temperature and σ is the arc column half-width. For an arc column oscillating in a discharge channel we may write $I_i\sigma = I_i'\sigma'$, where I_i is the radiation intensity of a certain line integrated over the diameter of the nonoscillating arc column; I_i' is the integral value of radiation of the same line over the diameter of the discharge channel in which the arc oscillates; σ' is the standard deviation of the radiation intensity in the discharge channel. Simple algebraic transformations yield an expression for determining the axial temperature from the relative intensity of two lines I_1 and I_2 of an oscillating arc column

$$T_0 \simeq \frac{E_2 - E_1}{k}\left[\ln \frac{E_1}{E_2}\frac{I_1}{I_2}\frac{\lambda_1 A_2 G_2}{\lambda_2 A_1 G_1}\right]^{-1}, \tag{6}$$

where the values of $I_i = \int_{-\infty}^{+\infty} I_i(x)dx$ for $T_a \ll T_0$ and $(E/kT) \gg 1$ were approximated for a small region of x near the arc center.

As follows from the foregoing, to determine an arc temperature without using the Abel transformation it is sufficient to measure just the space-integrated radiation intensities of two spectral lines.

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