Evaluating space and time oscillations of plasma radiant intensity by studying beam radial temperature

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Abstract. Effects of space and time pulsations of non-stationary plasma on radiant intensity and the radial temperature of plasma are studied. The case, when plasma simultaneously non-stationary both in time and in space is examined. The influence of these perturbations on accuracy of definition of plasma optical features is shown.

1. Introduction
It is well-known fact that both electroarc and high-frequency plasmas are not stationary [1-2]. The electric current and voltage, as well as speed and luminance of a stream of plasma are subjects of oscillation. There are many reasons causing instability of arc arrangement in space, such as interacting of arc with intrinsic magnetic field, circumambient convection, strong electric fields, turbulent flow fluctuations and others. By studying the space oscillations of electric arc in a plasma generator with fixed arc length [3-4], it has been established that the space displacement of an arc can influence temperature of plasma and its radial distribution considerably. High-frequency argon plasma also can be non-stationary. By examining the temperature on a discharge axis in plasma ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectrometry) as a function of the inductive frequency, it was shown that frequency growth leads to temperature reduction on the discharge axis [5]. Besides, it was shown that the space pulsations in ICP-AES plasma are insignificant by comparison to that in arc plasma, whereas time dependent oscillations can be essential. Accounting for the fact that both the space and time pulsations are always presented in plasma, this work has a deal to studying simultaneously space-time pulsations in plasma.

2. Studying technique
Spectroscopic determination of the temperature of axially symmetric plasma is carrying out by experimental establishment of the lateral intensity distribution of the arc. Then, the radial radiation intensity is deriving by means of Abel's integral transformation [6]. Finally, one fixes a temperature distribution on arc radius by using temperature dependence of the radiation intensity [6]. At the same time, if the plasma displaces in the space, the intensity distribution on the arc altitude is observing with a crude error. To reduce a lapse, we are using the Fredholm equation of the first kind [4]:

$$I_v(x) = \int_{-R}^{R} q_v(x') \varphi(x - x') \, dx'.$$  \hspace{1cm} (1)
Here, $I_v(x)$ is the observed distribution function and $q_v(x)$ is the true distribution function that is that corresponded to the absence of oscillations, $\phi(x)$ — a distribution function of oscillations of a radiant. This equation belongs to the class of mathematical physics inverse problems. When $\phi(x)$ is presented by following Gaussian law:

$$\phi(x) = \frac{1}{\sigma_x \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma_x^2}\right),$$  

(2)

the exact solution of equation (1) takes the form [6]:

$$q_v(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} I_v(\theta) e^{-i\lambda' (x-\theta)} \, d\lambda' \, d\theta.$$  

(3)

Here, $\sigma_x$ — arc root-mean-square deviations. Observed distribution of $I_v(x)$ is often expressed by

$$I_v(x) = I_v(0) e^{-\sigma_x^2}.$$  

(4)

Therefore, the solution (3) will equal to

$$q_v(x) = \frac{I_v(0)}{\sqrt{1-2\alpha \sigma_x^2}} \exp\left(-\frac{\alpha x^2}{1-2\alpha \sigma_x^2}\right).$$  

(5)

In the case of the temporary pulsations of plasma presented by the following normal distribution function:

$$f(T-T_c) = \frac{1}{\sigma_T \sqrt{2\pi}} \exp\left[-\frac{(T-T_c)^2}{2\sigma_T^2}\right],$$  

(6)

where $\sigma_T$ — temperature root-mean-square deviations, the average emittance follows to expression:

$$\bar{\varepsilon}(T_c) = \int \varepsilon(T) f(T-T_c) \, dT.$$  

(7)

3. Plasma model

Let each point of axially symmetric plasma exhibits simultaneously two oscillation modes: a) the space oscillations of arc described by the function (2) and b) temporary temperature variations yielded to expression (6). During computing, we were using Fredholm equation (3) with intensity distribution on arc altitude taken in the form (4). By numerical calculations of $\varepsilon_r(r)$, intensity distribution on arc radius, we applied Abel's integral transformation [7]:

$$\varepsilon_r(n) = -\frac{N}{40R} \sum_{j=0}^{N-1} b_{jk} I_v(x_j), \quad x_j=j/N; \quad r_k=k/N; \quad j, k = 0...N-1.$$  

(8)

Coefficients $b_{jk}$ are tabulated in [7]. Calculations were performed for $q(0) = 1, \alpha = 10; \sigma_x = 0.1, 0.2,$ and $0.3; \sigma_T = 1000, 2000,$ and $3000$, temperature of arc axis $T_{co} = 8000, 12000,$ and $15000$ K in argon plasma. Argon spectral line $\text{Ar I 415.8 nm}$ has been chosen during computing. Dependence of the relative emittance on temperature for the yielded line is presented in fig. 1 by the curve 1. The curves 2, 3, and 4 of figure 1 are displayed in the presence of pulsations for $\sigma_T = 1000$ (2), $2000$ (3) and $3000$ K (4). Accounting for known radial emittances, temperature distributions on arc radius were
determined. The results of calculation of the radial temperatures for axis temperature $T_{CO} = 12000$ K at simultaneously presence the space oscillations well as temporary ones of plasma, at $\sigma_x = 0.2$, $\sigma_T = 1000$, 2000 and 3000 K are pictured in figure 2-a, and those at $\sigma_T = 2000$ K, $\sigma_x = 0.1$, 0.2, and 0.3 – in figure 2-b. The curve 1 of figure 2-a corresponds to the true distribution of the temperature. It is seen from presented graphs that pulsations of temperature and the space oscillations of arc can distort noticeably a temperature profile. Temperature pulsations lead to rise the radial temperature on whole profile and to appreciable rise of temperature on periphery. Transverse vibrations of arc disturb a temperature profile so that the temperature is downgraded in paraxial areas and it rises on peripheries (see figure 2-b) in order to profiles become more fill.

![Figure 1](image1.png)

![Figure 2](image2.png)

4. References
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