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MEASUREMENT OF THE BRIGHTNESS TEMPERATURE DISTRIBUTION OF PLASMA BUNCHES

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UDC 533.9.07+535.231.6

The study of the radiation characteristics of a moving plasma bunch occupies an important place in the investigations of high-velocity plasma jets. One of the aspects of these researches is the development of experimental methods of investigating the distribution of the radiation spectral intensity and of the brightness temperature along a plasma (gas-plasma) jet. Thus, the radiation intensity and brightness temperature of a gas jet were measured in [1, 2] by using stationarily mounted light guides that recorded the radiation intensity as a function of the time. The resolution of such a method is constrained by the "viewing angle" of the light guides since the integrated intensity over the apertures was actually recorded.

The possibility is shown in this paper of reproducing the brightness temperature distribution along a plasma jet on the basis of a simple high-speed photographic sweep (for instance, by using a SFR) and subsequent photometric processing. The method developed was used to find the distribution of the radiation spectral intensity and the brightness temperature of plasma jets from a tubular, cumulative-gas charge [3, 4] and an explosive plasma compressor [5]. The shock front was successfully resolved, i.e., distributions were obtained of the above-mentioned parameters starting with the domain preceding the shock.

1. Let us consider a plasma jet being propagated over an opaque channel along which a narrow transparent slit of width a very much less than the transverse channel dimension is made. The slit image rotates continuously on a film in a direction perpendicular to the channel axis. A photographic sweep is made through a light filter that cuts off radiation in a narrow wavelength band. It is assumed that continuous photographic recording is accomplished by using the ideal photorecorder introduced in [6]. The velocity D of jet motion during the recording is considered constant. A continuous photographic sweep at velocity u yields the image displayed in Fig. 1 on the film, where 1 is the channel over which the plasma moves, 2 is the direction of plasma jet motion, 3 is the transparent slit in the channel and 4 is the photographic film. Time is measured from the arrival of the first perturbation in the channel section AB selected. Projection of the section AB on the film corresponds to the segment A'B' of the x axis. The position x = 0 is determined by the initial increase in the optical density, which exceeds the fog density. It is seen that the line CD on the recording, and all the lines parallel to it, are lines of constant blackening. If y is the coordinate along the plasma jet (in a coordinate system coupled to the jet) and I(y) is the radiation intensity distribution along the jet (at the wavelength cut off by the light filter), then the energetic exposure on the film along the x axis is determined by the following relationships [6]:

$$H(x)=\begin{cases} K\int\limits_0^{x/u} I(Dt)\,dt, & 0\leqslant x\leqslant \alpha a,\\ K\int\limits_{(x-\alpha a)/u}^{x/u} I(Dt)\,dt, & x\geqslant \alpha a, \end{cases} \qquad (1.1)$$

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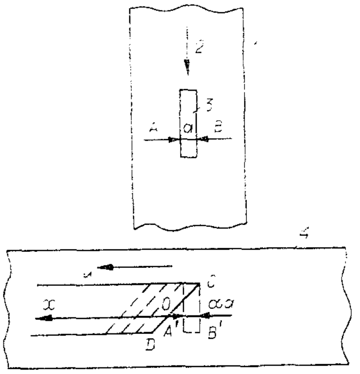

Fig. 1

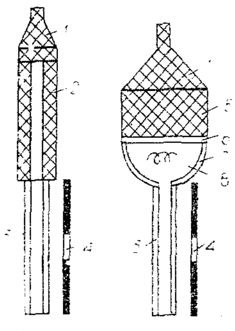

Fig. 2

where K is a coefficient related to the aperture optics of the photographic recorder, and α is the magnification factor of the photographic recorder optics (as a rule $\alpha < 1$). When the film transmission coefficient is in the linear range of the characteristic curve (as can be achieved by application of different neutral light filters), the energetic exposure is related to the opacity of the film by the relationship

$$\lg (S(x)/S_0) = \gamma \lg (H(x)/H_0), \tag{1.2}$$

where S(x) is a quantity reciprocal to the transmission factor (the film opacity) along the x axis, γ is the film contrast factor, and S_0 and H_0 are the opacity and energetic exposure of the standard source, respectively. The contrast factor γ is determined by photographing the standard source by using a step light attenuator. It follows from (1.2) that

$$H(x) = H_0 10^{\frac{1}{\gamma}[\lg S(x) - \lg S_0]}, \tag{1.3}$$

where $H_0 = KI_0\tau$ (I_0 is the spectral intensity of the standard source and τ is its exposure time). Equating (1.1) and (1.3) and then differentiating with respect to x, we obtain an expression to determine the radiation spectral intensity along the jet

$$\begin{gathered} I(y) = \frac{I_0 \tau D}{\gamma} \frac{d\left[\lg S\left(\frac{uy}{D}\right)\right]}{dy} \ln 10 \cdot 10^{\frac{1}{\gamma}\left[\lg S\left(\frac{uy}{D}\right) - \lg S_0\right]} \quad \left(0 < y < \frac{\alpha a D}{u}\right), \\ I(y) - I\left(y - \frac{\alpha a D}{u}\right) = \frac{I_0 \tau D}{\gamma} \frac{d\left[\lg S\left(\frac{uy}{D}\right)\right]}{dy} \ln 10 \cdot 10^{\frac{1}{\gamma}\left[\lg S\left(\frac{uy}{D}\right) - \lg S_0\right]} \\ \left(y > \frac{\alpha a D}{u}\right). \end{gathered} \tag{1.4}$$

[The logarithms of the opacities are retained in (1.3) and (1.4) since many photometric instruments are calibrated in precisely these quantities.] The expression (1.4) yields a continuous distribution of the radiation intensity for $0 < y < \alpha a D/u$. For $y > \alpha a D/u$ such a distribution is found only at separate points with the spacing $\Delta y = \alpha a D/u$. As the slit width a increases, the range of action of the first expression in (1.4) is broadened. Hence, the radiation intensity distribution is successfully restored sufficiently well ahead of the shock front and directly behind it. As a diminishes, the spacing Δy is diminished for the second expression from (1.4). The intensity distribution for the part of the plasma jet far from the shock front (jet middle and "tail") is here restored well. Applying a slit variable in width (step), the advantages of these two cases can be combined on one photo record.

2. The radiation intensity distributions for two sources of high-speed plasma jets were determined by the above-mentioned method: a tubular cumulative-gas high explosive charge [3, 4], and an explosive plasma compressor [5].

Displayed schematically in Fig. 2a and b are the tubular cumulative-gas high-explosive charge and the explosive plasma compressor, respectively [1 is a plane wave generator, 2 is the tubular charge, 3 is a vitreous channel, 4 is a rectangular slit in the screen, 5 is a cylindrical high explosive charge, 6 is the metal plate to be hurled, 7 is a hemispherical compression chamber, and 8 is 0.5 g of the working substance ($C_6H_{10}O_5$)]. The glow of a shock in air produced by the tubular high-explosive charge was used as standard source. The brightness temperature of the standard was determined by the shock velocity from tables [7].

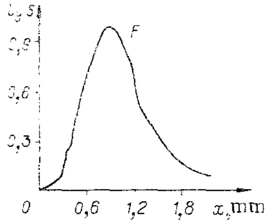

Fig. 3

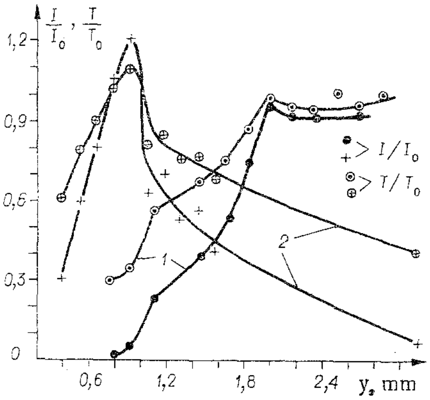

Fig. 4

The transparent rectangular slit in the channel was formed by using a screen, as is shown in Fig. 2. A vitreous channel was used in the tests. As a plasma bunch moves in such a channel, high pressure and temperature act on its walls, which can result in a loss of transparency of the glass. However, the radiation intensity of the shock front, found by the method described above, equalled the front intensity taken off through the channel endface in the experiments with the tubular cumulative-gas charge, and these values turned out to be identical with good accuracy. This indicates that no loss of glass transparency occurs during the recording. Losses in glass transparency because of radiation could not occur since the threshold of glass damage under the effect of radiation equals 470 GW/cm^2 [8], which considerably exceeds the maximum intensities of radiation in the tests described.

The characteristic distribution of the logarithm of film opacity as a function of the coordinate x on the film is presented in Fig. 3. The point F in Fig. 3 from which the change in sign of the derivative starts, corresponds to $y = \alpha a D/u (x = \alpha a)$. In Fig. 4 ($\lambda = 0.475\ \mu$m) are the distributions of the spectral radiation intensities [$I_0 = 3.5 \cdot 10^{15}$ J/(m$^3 \cdot$sec)] and of the brightness temperatures (T_0 = 18,000°K) of the high-velocity plasma jets for the above-mentioned two sources, the tubular cumulative-gas charge (curve 1) and the explosive plasma compressor (curve 2). The temperature profiles obtained for the explosive plasma compressor agree well with the results of a numerical modelling executed in [9].

The error in the method described to measure the brightness temperature is comprised from the same factors as in the other photographic methods [10]. The greatest error in the tests was in the determination of the contrast factor of the photographic material and reached 30% for the determination of the absolute values of the radiation spectral intensity. This error can be reduced significantly by using more perfect technique and more qualitative photographic layers [10].

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