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EXPERIMENTAL STUDY OF AN MHD SOURCE OF LIGHT WITH A TC LAYER

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The possibility of using a high-temperature current layer initiated in a plasma flow as a powerful source of light with a wide range of emission is demonstrated. The study was performed on a setup with a disk MHD *channel in the regime of a high-temperature current layer* (TC *layer*) *generation in argon and sodium plasma flows.*

Key words: *source of light,* MHD *channel,* TC *layer, radiation flux, bolometer.*

The proposed source of light, in which a high-temperature current layer (TC layer) acts as an emitter, differs from the known variants employing, e.g., a layered pulsed discharge [1] by the fact that its structural elements are not destroyed, which allows the development of a powerful large-volume pulsed-periodic source of light with a significant lifetime. Such a source can be used in technological processes.

In choosing a particular scheme of the setup, we kept in mind that the most complete investigations of inhomogeneous flows with the TC layer, as applied to energy-conversion problems, were performed on a setup with a disk MHD channel [2, 3]. The analysis showed that such a scheme is also promising for the development of a source of light.

Figure 1 shows the layout of the experimental setup consisting of a pulsed source of plasma, disk channel, and electric magnet. The setup version in Fig. 1 has an electric-discharge shock tube used as a source of argon plasma. The tube consists of a coaxial accelerator (Marshall gun 800 mm long) and an attached channel 2000 mm long. The inner diameter of the channel is 56 mm. The accelerator is connected to a set of capacitors of the IS 5-200 type with a total capacitance of 3200 μF and a working voltage of 5 kV; a controlled vacuum discharger serves as a commutator. The source of plasma is connected to a channel formed by two Plexiglas disks 60 mm thick and 340 mm in diameter. The disks are placed at a distance of 20 mm from each other and are attached to a vacuum receiver enclosing the channel. One of the disks has sockets for gauges. Before the experiment, the setup is filled by argon to a pressure of several hundreds of pascals. The capacitor discharge through the accelerator generates a strong shock wave and a plasma flow behind it, which propagate toward the disk channel. Thus, for an initial pressure of 267 Pa, the length of the shock-heated gas plug reaches approximately 40 cm, its velocity is 5000 m/sec, and the time of gas exhaustion into the MHD channel is up to 100 μsec. An electroerosion pulsed plasmatron with an operation time of approximately 10 msec and flow rate of 1 kg/sec was used as a source of sodium plasma.

With allowance for parameters of this setup, we estimate whether it can be used as a source of light, assuming that the flow regime with a developed TC layer in argon is established. We assume that the Joule heating is equal to radiative losses in a unit volume of the TC layer: $j^2/\sigma \approx \operatorname{div} \boldsymbol{S}$; $j^2/\sigma \sim \sigma(uB)^2$ and $\operatorname{div} \boldsymbol{S} \sim S/l$. Here u is the flow velocity, B is the induction of the magnetic field, σ is the conductivity, and l is the characteristic size of the TC layer. Assuming that each elementary volume of the TC layer emits energy in the same amount as a hemispherical volume of radius l inscribed into this elementary volume, we obtain the radiation flux $S = \varepsilon\sigma' T^4$, where ε is the emissivity of the hemispherical volume and σ' is the Stefan–Boltzmann constant. The conductivity is determined by Spitzer's formula $\sigma = 1.56 \cdot 10^{-2} T^{3/2}/\ln\Lambda$, where $\ln\Lambda$ is the Coulomb logarithm, and $\varepsilon(p, T)$ is determined from the data of [4]. For $u = 10^3$ m/sec, $B = 0.65$ T, $p = 0.1$ MPa, and $l = 10^{-2}$ m, we obtain the approximate value of temperature in the TC layer equal to 12,000 K and the radiation flux $S = 1.5$ kW/cm^2.

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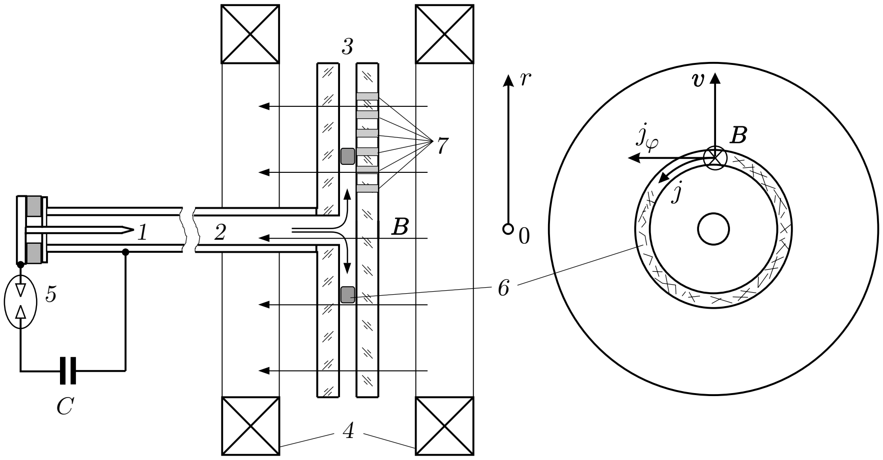

Fig. 1. Layout of the experimental setup: 1, 2) pulsed source of plasma [coaxial accelerator (1) and channel (2)]; 3) disk channel; 4) electric magnet; 5) controlled vacuum discharger; 6) TC layer; 7) sockets for gauges.

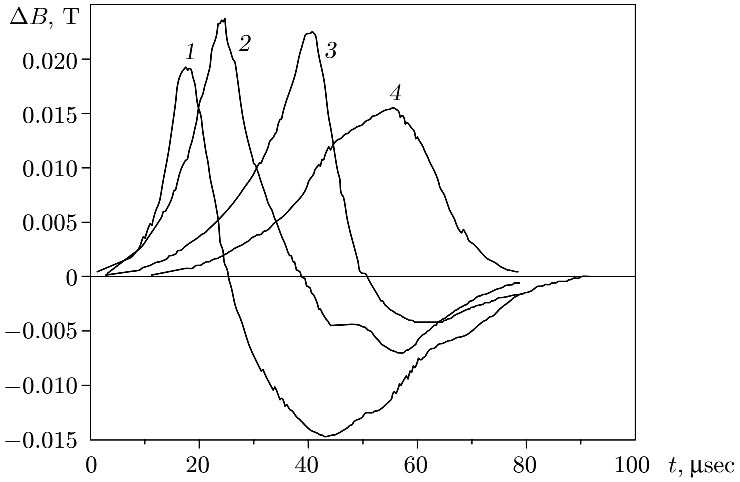

Fig. 2. Deformation of the magnetic field versus the time for $r = 70$ (1), 100 (2), 130 (3), and 160 mm (4).

After an appropriate upgrading of the setup, a set of experiments was performed to choose its operation regimes and refine the initial conditions under which the TC layer emerged spontaneously in the argon and sodium plasma flow behind the front of the shock wave propagating in the disk channel across the magnetic field. With the help of magnetic probes, localization of the current region was performed in the experiments, and the current strength, magnetic field deformation, and TC layer velocity were measured. The deformation of the magnetic-field component ΔB normal to the disk surface of the channel (Fig. 1) was counted from the level of a uniform constant excitation field B. Seven magnetic probes located along the channel radius at a distance of 15 mm from each other were used in the experiments; the measurement error was smaller than 10%. The sodium radiation spectrum in the visible range and the emission brightness as a function of time were measured at some points along the radius.

Let us analyze the changes in the magnetic field in an argon plasma flow with TC layer displacement along the channel radius for $B = 0.32$ T. Figure 2 shows the dependences $\Delta B(t)$ for different distances r from the channel center. Curves 1–3 corresponding to three smaller radii have an N-shaped form typical of variation of the magnetic field at the point with the TC layer moving nearby. The sector with the negative derivative dB/dt corresponds to the flow region occupied by the TC layer.

Distributions of the magnetic field deformation in the channel over the radius at different times, which were obtained from the dependences $\Delta B(t)$ given in Fig. 2 and correlated with the photographic record of the flow, are

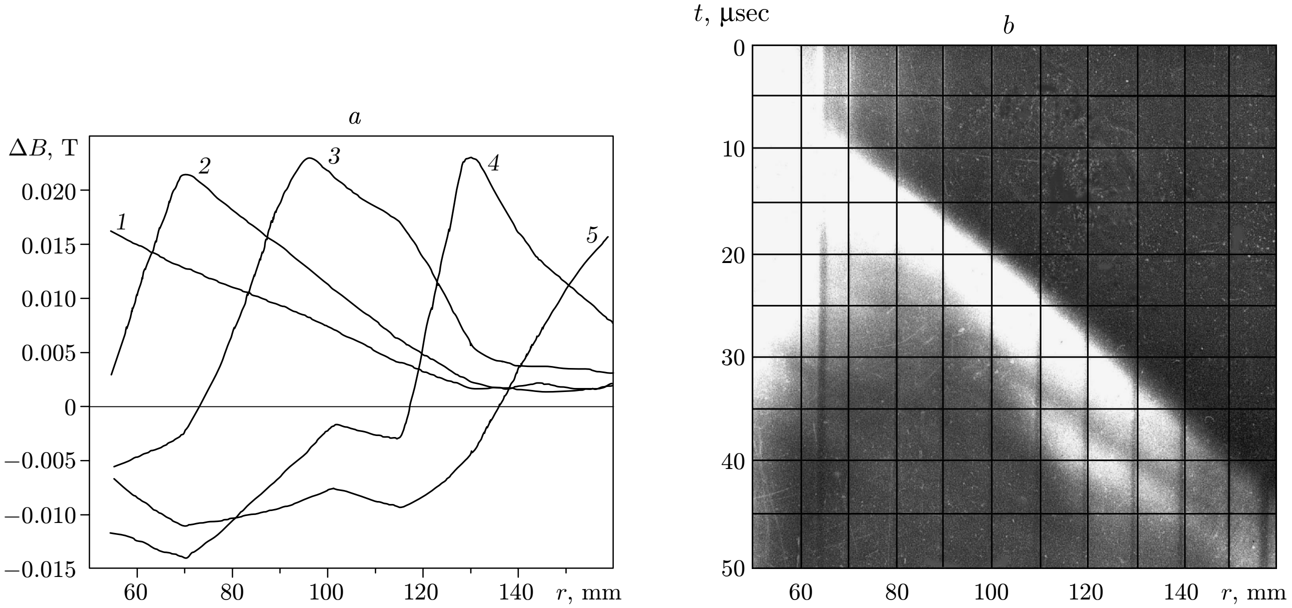

Fig. 3. Distribution of magnetic-field deformation compared to the photographic record of the flow in the channel: (a) distribution of ΔB in the channel [$t = 5$ (1), 10 (2), 18 (3), 32 (4), and 50 μsec (5)]; (b) photographic record of the flow with the TC layer.

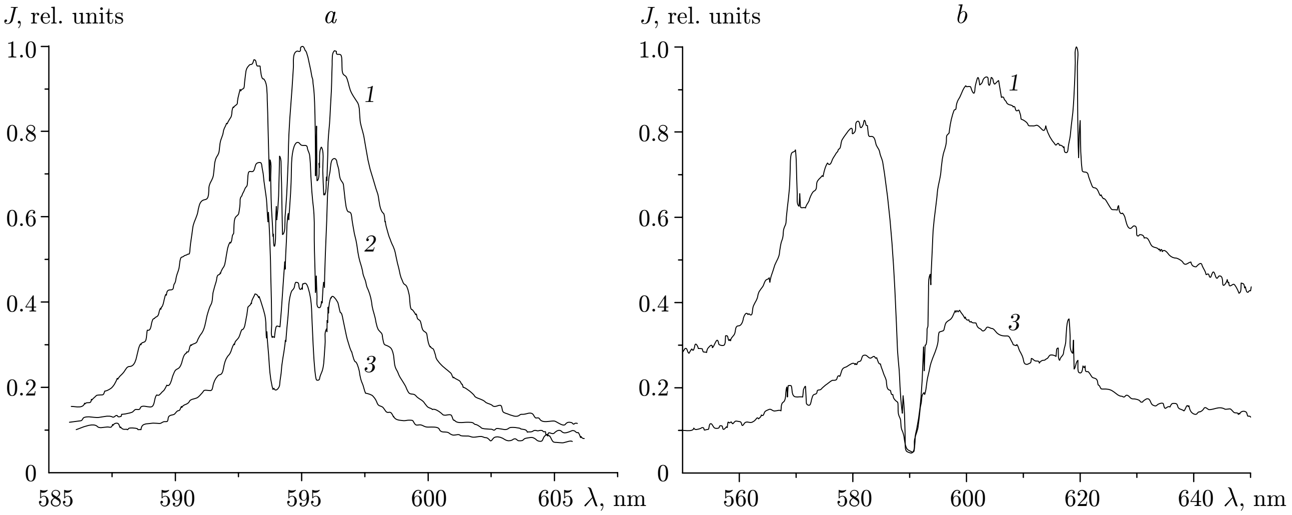

Fig. 4. Emission spectra of the sodium plasma flow for $B = 0$ (a) and 0.64 T (b): $r = 70$ (1), 115 (2), and 160 mm (3).

shown in Fig. 3. The distributions $\Delta B(r)$ were obtained by linear interpolation between the experimental points. As the TC layer moves up to the coordinate $r = 130$ mm, the current density in the layer increases, which is manifested in the increase in the gradient dB/dr and in the decrease in the TC layer width. As a result of deceleration of the TC layer in the magnetic field, a compression wave emerges in the upstream direction; this wave initiates the appearance of another current layer with the current density much lower than that in the TC layer. Upstream motion of the wave with the current layer causes expansion of the luminescent region, which is clearly seen in the photographic record (Fig. 3b). The photographic record also shows the inflection of the fore front of the flow, which is normally observed in the TC layer formation at the moment when the shock-wave front overtakes the TC layer. Note, according to the results of the present experiments, it is sufficient to use only one technique for identification of the TC layer in the flow: measurement of magnetic field deformation by magnetic probes, photographic records, measurement of pressure distribution in the channel, etc.

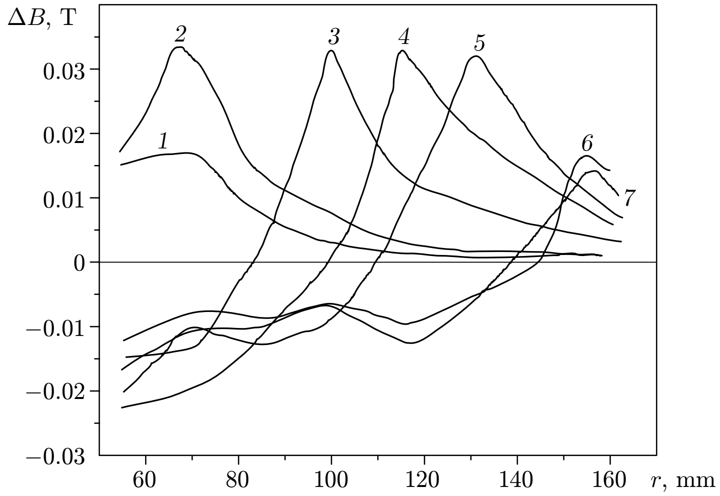

Fig. 5. Magnetic field deformation versus the coordinate r for $t = 10$ (1), 15 (2), 29 (3), 42 (4), 48 (5), 57 (6), and 60 μsec (7).

The changes in the emission spectrum caused by the development of the TC layer in the plasma flow were registered in a sodium plasma flow. Based on the analysis of photographic records, we chose an operation regime of the setup with a TC layer arising in sodium plasma. The time-integral spectrum of the sodium plasma flow was obtained in the absence of the magnetic field and with $B = 0.64$ T when the TC layer appeared. Figure 4a shows the radiation spectra in the vicinity of the yellow sodium doublet, obtained in the absence of the magnetic field for three values of r. Almost the entire plasma emission registered is located in this part of the spectrum. Figure 4b shows similar spectra for $B = 0.64$ T. The resonance lines in Fig. 4b are wider by an order of magnitude, and continuum radiation is substantially more intense. In contrast to the argon plasma spectrum, sodium emission is concentrated in a relatively narrow band, which can be useful in creating the source of light.

The operation regime for the setup and the position of the point for measuring the maximum power of TC layer emission were chosen on the basis of the measured results on magnetic field deformation at various distances from the channel center. This technique allows one to easily identify the stage of TC layer development and to determine the coordinate with the maximum current amplitude. Appropriate measurements were performed by magnetic probes located in the channel at different distances from the channel center and registering the change in the magnetic induction vector component normal to the channel plane. Figure 5 shows the magnetic field deformation as a function of the coordinate r. The initial pressure of argon was 267 Pa and $B = 0.64$ T. The decrease in the magnetic field is caused by the TC layer passing along the observation point; the higher the current density, the more intense magnetic field deformation, and the sharper the apex, the sharper the front boundary of the TC layer. Two stages of TC layer evolution are typical of this regime: the point $r = 90$ mm corresponds to the stage of the maximum development and the stage of degradation is observed for $r > 130$ mm.

Figure 6 shows the synchronized dependences of magnetic field deformation and brightness of plasma luminescence on time; the latter was measured by a photodiode mounted into the channel wall and registering the radiation flux normal to the channel wall. The probes were located at a distance $r = 90$ mm. The brightness maximum corresponds to the region of the TC layer (zone with reduced magnetic induction).

The radiation flux was measured by a platinum bolometer, which has an almost constant spectral sensitivity within the entire range of wavelengths emitted by the TC layer and can be calibrated comparatively simply. Figure 7a–c shows the scheme of the bolometer mounted in the channel wall, the scheme of its calibration, and a typical calibration signal, respectively. The bolometer consists of a metal casing and a sensor made of platinum wire 3 μm in diameter and protected by a thin (0.2 mm) glass window. The sensor is connected to the coaxial cable. The small diameter of the wire ensures rather high time resolution. The calibration was performed in vacuum; the reference element was a molybdenum band 30 mm wide, which was heated by current up to a brightness temperature of 2000 K. The band temperature was controlled by an ÉOP-66 pyrometer. The distance between the band and the bolometer sensor was 20 mm. The bolometer and the band were separated by a copper-molybdenum shutter of the electromechanical gate. When the reference element reached a steady temperature, the shutter was opened for

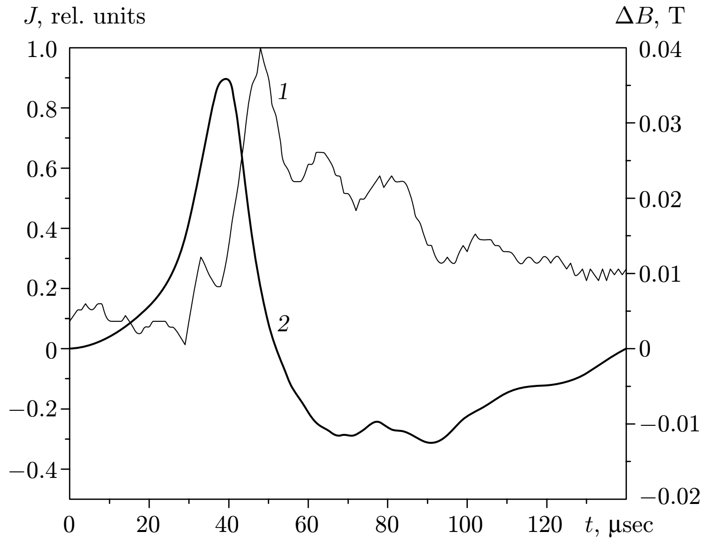

Fig. 6. Brightness of plasma luminescence (1) and magnetic field deformation (2) versus time.

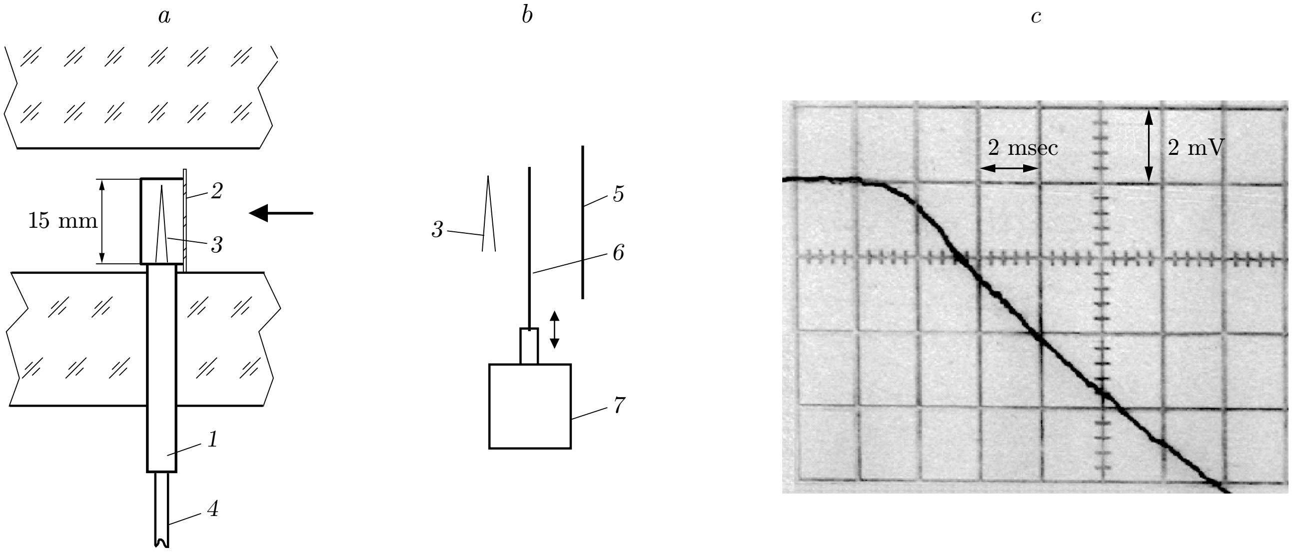

Fig. 7. Measurement of the radiation flux: (a) scheme of the bolometer; (b) bolometer calibration; (c) typical calibration signal; 1) metal casing; 2) glass window; 3) sensor; 4) coaxial cable; 5) molybdenum band; 6) copper-molybdenum shutter; 7) electromechanical gate.

0.1 sec. The bolometer signal (Fig. 7c) depended linearly on time during at least 10 msec; the dependence of the signal on the radiation absorbed by the bolometer was almost linear up to an amplitude of 8 mV. The radiation flux from the band was $S_0 = \sigma' T^4 \approx 9 \cdot 10^{15}$ W/m^2. The rate of variation of the bolometer signal, which is proportional to the radiation flux, was 0.7 V/sec.

To measure the radiation flux from the TC layer, we chose the operation regime of the setup in which the strongest MHD interaction was observed: the initial pressure of argon was 267 Pa and $B = 0.64$ T. In this regime, the maximally developed TC layer is formed at a distance of 90 mm from the center; this layer starts to decompose at a distance of 130 mm because of the strong deceleration. To synchronize the TC layer passage near the bolometer located at a distance of 115 mm from the center, the magnetic probes were placed at distances $r = 100$ and 130 mm. Figure 8 shows the synchronized signals from the probes $U_{\rm pr}$ (curves 1 and 2) and from the bolometer $U_{\rm bol}$ (curve 3). The TC layer is localized in the vicinity of the maximum signal from the probes. The TC layer velocity at the point $r = 100$ mm is considerably higher than its velocity at the point $r = 130$ mm, where TC layer decomposition begins. Thus, the bolometer is located in the region of the strongest MHD interaction. The record of the bolometer

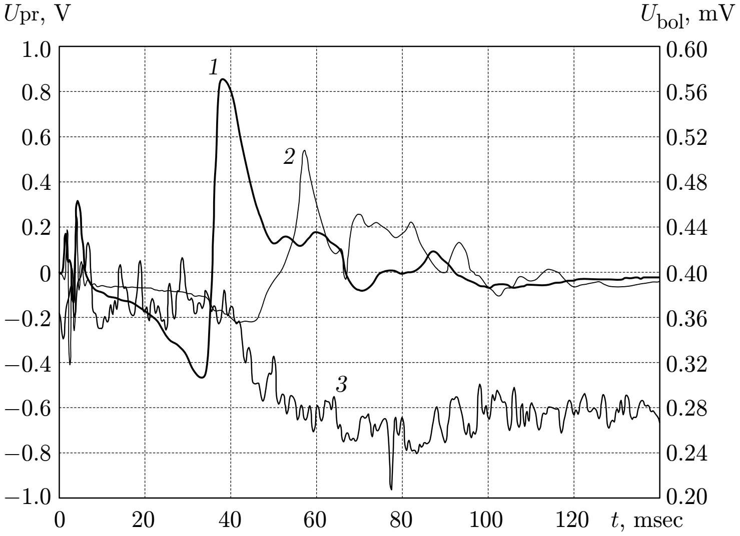

Fig. 8. Synchronized signals from the magnetic probes and bolometer: curves 1 and 2 refer $U_{\rm pr}$ for $r = 100$ (1) and 130 mm (2); curve 3 refers to $U_{\rm bol}$.

signal has two horizontal sectors ($t \leqslant 30$ μsec and $t \geqslant 80$ μsec) and a sector where signal reduction is observed (30 μsec $< t <$ 80 μsec). The horizontal sectors of the bolometer-signal curve correspond to time intervals with low irradiation of the bolometer. The sector with decreasing signal corresponds to TC layer passage near the point of 115 mm, where the radiation flux is significant. The results of bolometer measurements show that its time resolution is rather high, and the time of signal reduction corresponds to the time needed for the TC layer to pass along the bolometer. The temperature of the bolometer wire is almost constant after TC layer passage. This allows us to neglect wire cooling due to heat exchange with the ambient gas in measuring the radiation flux from the TC layer. The noise level is determined by parameters of the amplifier.

Let us estimate the radiation flux. The rate of voltage variation was about 8 V/sec, which corresponds to the flux $S = 8S_0/0.7 \approx 1$ kW/cm^2 and confirms the estimate given in the beginning of the present work. The specific power of Joule heating under the present test conditions (with a characteristic current density of approximately 400 A/cm^2 and e.m.f. of about 10 V/cm [3]) is $W \approx 5$ kW/cm^3. A comparison of the values of S and W also supports the conclusion of theoretical investigations of the TC layer about the role of radiation as the main stabilizing factor at the nonlinear stage of evolution of overheating instability [5, 6].

Finally, we note that the results obtained allow us to conclude that the use of the considered variant of the MHD energy converter as a powerful source of light in appropriate technological processes is rather promising.

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