Role of diaphragm in the particle balance in a tokamak

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A diaphragm of special construction was used to measure the distribution of the hydrogen-line emission near the diaphragm.

As demonstrated earlier by bolometric measurements,[1] the bulk of the energy input to a macroscopically stable plasma pinch in a tokamak is consumed by the diaphragm, and only 10–30% appears on the surface of the liner in the form of radiation and fast neutrals. It was shown in [2] that the intensity of the hydrogen lines in the TM-3 installation is 5–10 times larger in the cross section where the diaphragm is located than in sections that are far from it. This naturally creates the danger that the region near the diaphragm can serve as a source of protons that are unaccounted for in [3], where the rate of arrival of the protons in the plasma was calculated from the absolute intensity of the hydrogen-emission lines far from the diaphragm. The axial dimension of the region with increased concentration of particles arriving at the diaphragm can be estimated if one knows the ionization cross section σ_i of the neutral atoms and their velocity v_0

$$l \sim \lambda_i = \frac{v_0}{\langle \sigma_i v_e \rangle n_e}. \qquad (1)$$

Here λ_i is the free path prior to ionization, n_e the electron concentration, and v_e the electron velocity. The averaging is over the Maxwellian distribution of the electrons.

The quantity v_0, however, remains quite indefinite, since we do not know the processes that occur on the diaphragm. It is therefore of interest to measure directly the intensity distribution of the hydrogen emission lines near the direction of θ (Fig. 1). Since the number of diagnostic inspection windows in the tokamak is limited, we constructed a special tungsten diaphragm which was introduced into a horizontal sleeve of the TM-3 installation, and could be moved equatorially, without breaking the vacuum, along the outer wall of the discharge chamber, at an angle θ up to 16°.

The radius of this diaphragm was 5 cm larger than that of the main diaphragm located in the section F, and therefore[1] the influence of the latter on the discharge could be neglected.

The hydrogen line was observed by means of a horizontal sleeve B and by means of two vertical through sleeves A and C. In the last two cases the spectral instruments were collimated in such a way that they could "see" only the glow of the plasma volume, and did not receive the light reflected from the wall. The instrument located in sleeve B was not collimated, and consequently could register reflections from the walls. This instrument gave an emission region about 1.5 times larger than the collimated instrument. It was possible to introduce through windows A and E two identical bolometers, the sensitive surface of which was mounted at the level of the liner wall. The bolometer in sleeve E served as a monitor. The electron concentration was measured through sleeve D by means of a microwave radio-interferometer.

The experimental results are shown in Fig. 2. Curves 1, 2, and 3 show the distribution of the intensity of the emission of the H_β hydrogen line, registered by the collimated instruments through sleeves A and C for the third, fifth, and seventh milliseconds of the discharge, respectively. The curves obtained with instruments A and C were matched together by normalization. It is easy to see that the region of increased intensity is localized in all three cases in a narrow band near the diaphragm (3–5 cm). This value agrees well with that calculated from formula (1) under the assumption that v_0 corresponds to a neutral-atom energy ~1–2 eV. When the emission intensity ratio near the diaphragm and far from it is approximately 5, the contribution of the diaphragm to the total balance turns out to be small. The role of the diaphragm decreases in this

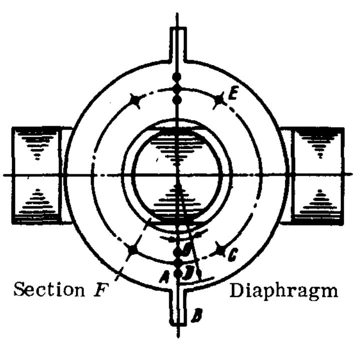

FIG. 1. Experimental setup.

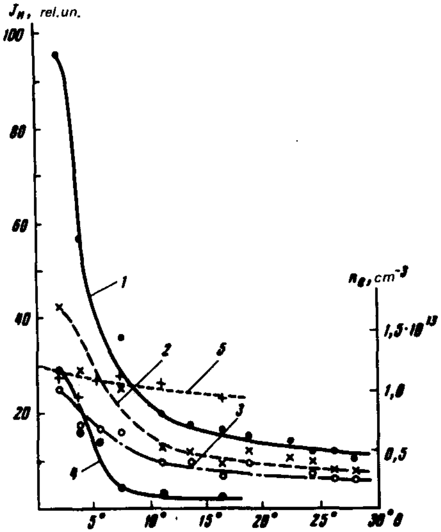

FIG. 2.

case towards the end of the discharge. In these measurements the bolometer registered, with allowance for the length distribution, only about 15% of the energy input. The signal of the bolometer A depends little on its distance to the diaphragm. This is not surprising, since the bolometer "sees" a large section of the plasma (on the order of 2—3 radii of the diaphragm), thus averaging the effect introduced by the diaphragm. Within the limits of measurement accuracy, the electron concentration (curve 5, Fig. 2) does not depend on the distance to the diaphragm. In Fig. 3, the concentration averaged over the radius of the plasma pinch becomes comparable with the integral of the additional emission ΔJ_H due to the diaphragm, integrated over the angle $\theta : I = \int J_H \, d\theta$. It can be concluded that the number of hydrogen atoms coming from the diaphragm is proportional to the electron concentration.

In one of the investigated discharge regimes we observed a weakly developed blow-out instability. The negative voltage spikes are accompanied by bursts of hydrogen-line emission intensity. Figure 2 (curve 4)

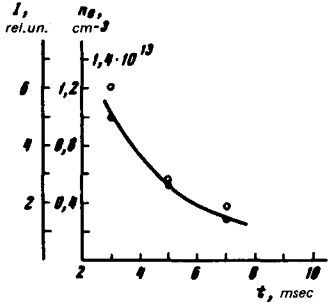

FIG. 3. Time dependences of the quantities $I = \int \Delta J_H \, d\theta$ and n_e: ○ – n_e, ● – I.

shows the dependence of such a burst on the distance to the diaphragm. The dimension of the region of increased emission is the same as in the stable regime. The fraction of the additional emission near the diaphragm at the instant of instability amounts to 30% of the total intensity of the hydrogen flash.

Reviewing the experimental material, we can draw the following conclusions: 1. The influx of hydrogen atoms from the diaphragm in the TM-3 installation has little effect on the total particle balance. The bulk of the protons entering the plasma comes from the walls. 2. The velocities of the hydrogen atoms moving away from the diaphragm correspond to an energy ~1—2 eV. 3. During the blow-out instability, the gas detached from the wall is quite appreciable, in spite of the fact that the main interaction is between the plasma and the diaphragm.

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