Experiments on initiating the *H* confinement mode by a radial electric field in the TUMAN-3 tokamak

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The effect of a deliberately imposed radial electric field on the plasma confinement characteristics in a tokamak has been studied. This field can trigger a transition to the *H* confinement mode and back during ordinary ohmic heating. When the polarity of the field is reversed, the current flowing in the electrode–plasma–wall circuit changes significantly.

Previous experiments in the TUMAN-3 tokamak revealed a spontaneous transition to a regime of improved energy and particle confinement: the "ohmic *H* mode."[1,2] According to the existing theoretical ideas[3–7] and experimental observations,[8,9] the transition to the *H* mode is accompanied by an increase in the radial electric field or its gradient near the plasma edge. The purpose of the series of experiments which we are reporting here was to test the suggestion that the *H* mode might be initiated by an electric field deliberately imposed at the plasma edge. Specifically, the radial field was produced by means of an insulated electrode with a molybdenum tip, which was inserted 3–4 cm inside the outermost closed magnetic surface, from the outer side of the tokamak. The maximum projected area of this tip onto the plane perpendicular to the longitudinal magnetic field was 3 cm^2.

Experiments involving the application of a potential to the electrode were carried out in discharges with the parameters typical of the TUMAN-3: $B_t = 0.45$ T, $I_p = 90$ kA, $R/a = (0.53\ \text{m})/(0.22\ \text{m})$, $\bar{n}_e = (1\text{–}1.4)\times 10^{13}$ cm^{-3}, $T_{e0} = 0.3$–0.4 keV, $T_{i0} = 0.1$–0.14 keV, and $Z_{\text{eff}} = 2$. Once the quasisteady stage of the discharge was reached, a voltage was applied between the electrode and the chamber wall (the limiter was at the chamber potential). The transition to the *H* mode occurred when a negative voltage above 0.25 kV was applied (this was the "minus *H* mode"). It also occurred when a positive voltage above 0.5 kV was applied (this was the "plus *H* mode") (Fig. 1), but the improvement in confinement was more obvious when the *H* mode was initiated by a negative voltage. In the minus *H* mode the derivative dN/dt is higher, and the $D\alpha$ emission, which is proportional to the source of particles, is lower. Estimates of the particle lifetime in the minus *H* mode, in the plus *H* mode, and in the mode of ohmic heating yield $t_p^-/\tau_p^+/\tau_p^{Oh} = (7.9\ \text{ms})/(4.3\ \text{ms})/(2.5\ \text{ms})$. Also larger in the case of a negative field is the increase in the intensity of the soft x-ray emission, which reflects the electron temperature near the discharge axis. This change is qualitative evidence of a greater increase in τ_E in this case. Experiments with auxiliary heat-

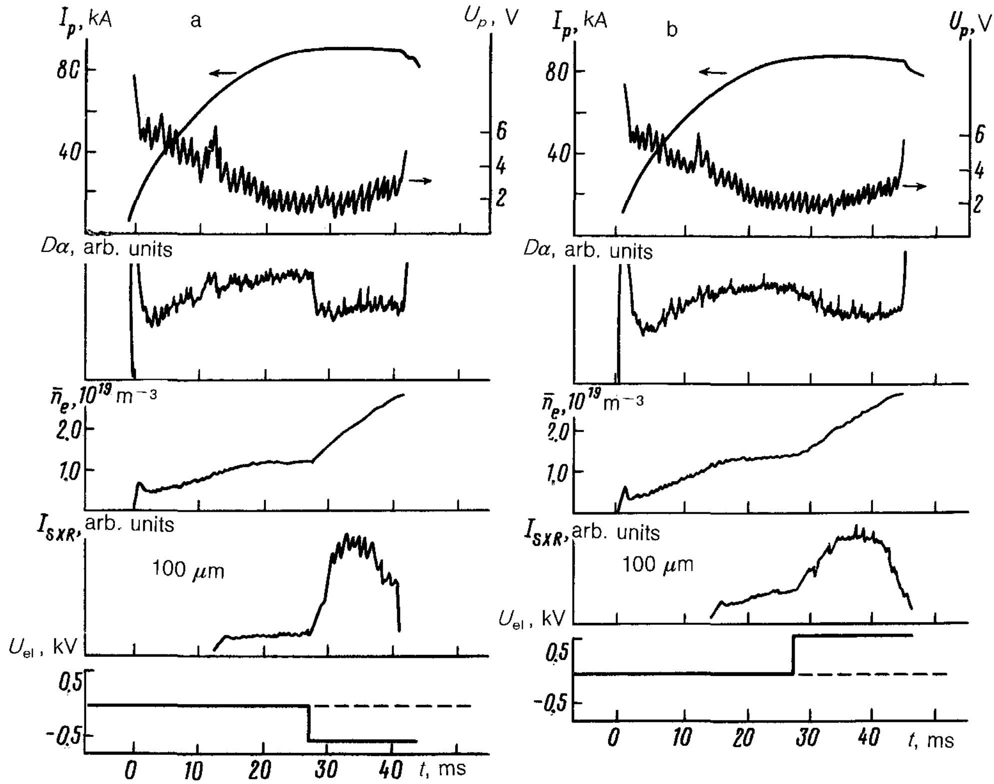

FIG. 1. Oscilloscope traces of the plasma current, the loop voltage, the $D\alpha$ emission intensity, the average density, and the intensity of the soft x-ray emission in discharges with an H mode initiated by the application of a negative (a) or positive (b) potential to the electrode.

ing in the TEXTOR tokamak have also revealed a more pronounced increase in τ_p in the minus H mode. On the other hand, the energy confinement was higher in the plus H mode,[10] in contrast with our results.

The phenomenology of the H mode in the case of a negative polarity of the applied voltage is the same as that of the spontaneous ohmic H mode.[1] This circumstance suggests that the natural sign of the field in the ohmic H mode is negative. Support for this suggestion comes from an experiment in which a positive potential was applied to the electrode under conditions corresponding to the ohmic H mode (Fig. 2). After the voltage was applied, the increase in the density and in the intensity of soft x radiation came to a halt, and the $D\alpha$ emission returned to the level of the original ohmic heating. In other words, the regime of improved confinement was terminated. This evolution of the plasma properties corresponds to the notion of a strong radial electric field at the plasma edge in the H mode and a comparatively weak

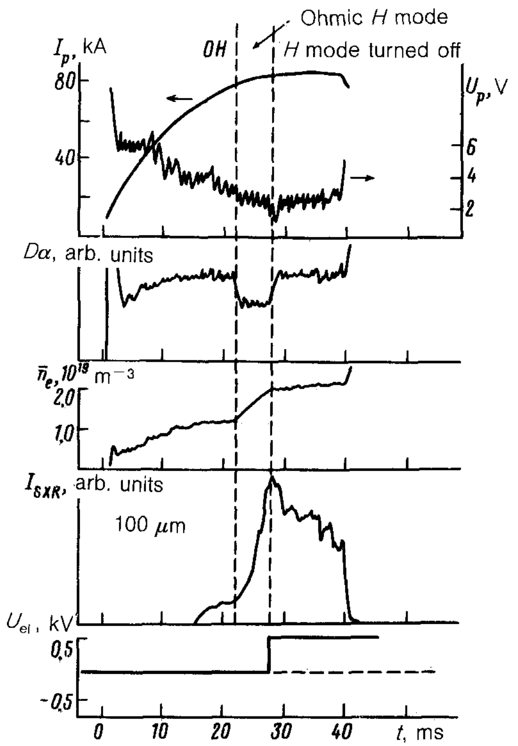

FIG. 2. Oscilloscope traces of the plasma current, the loop voltage, the $D\alpha$ emission intensity, the average density, and the intensity of the soft x-ray emission in a discharge in which the ohmic H mode is turned off when a positive potential is applied to the electrode.

field in the regime of ordinary confinement. When the improved-confinement regime (the ohmic H mode) arises spontaneously, the radial that forms has a negative sign.

In order to compare the results with theoretical models of the L–H transition and to learn about the transport mechanisms, we would like to measure the radial conductivity of the plasma at its edge. Such measurements can be carried out with the help of an electrode, provided that it does not limit the plasma cross section, and provided that its area is large enough to collect the current flowing between the magnetic surface on which the probe lies and the outermost closed magnetic surface. In our case the electrode was small, and it was inserted to a distance inside the outermost closed magnetic surface such that the plasma parameters $[n_e(r), T_e(r)$, and $Z_{\rm eff}]$ were not perturbed before a voltage was applied. The value of the saturation ion current in this case should be

$$I^{i,\rm sat} = en_i \times 0.6\sqrt{T_e/m_i} \times 2S = 30-50 \;\; \text{A},$$

where S is the cross-sectional area of the conducting part of the electrode. The saturation current $I^{i,\rm sat}$ corresponds to 20% of the charge of the diffusion flux carried by the

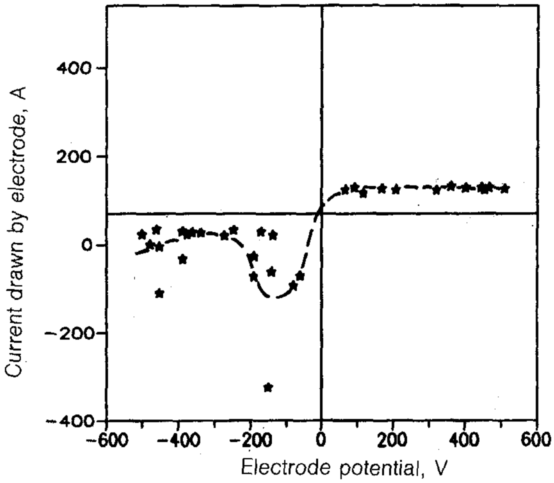

FIG. 3. Current-voltage characteristic of the electrode–plasma–wall circuit.

ion component, eN/τ_p. Figure 3 shows the results of a measurement of the current-voltage characteristic for the experimental geometry outlined above. Plotted along the abscissa here is the voltage applied to the electrode (this voltage differs from the potential difference applied to the plasma by an amount equal to the voltage drop in the electrode sheath). On this characteristic, the currents are higher in the case of negative polarities, in contrast with the data obtained at the CCT.[11] The current drawn by the electrode in this case is higher than the saturation ion current. The radial current density cannot be explained on the basis of the neoclassical theory unless we invoke an anomalous viscosity and an anomalous inertia.[3,7] Yet another distinguishing feature of this characteristic is the obvious decay in the current upon an increase in the negative voltage. This decay seems to reflect the difference between the properties of the plasma edge in regimes with ordinary and improved confinement. A low radial field and a high current correspond to ordinary confinement, while a high radial field and a low current correspond to the H mode.

In summary, our experiments lead to the following conclusions. (1) A radial field produced at the plasma edge by an external source causes a transition to the H mode, regardless of the polarity of this field. (2) When a spontaneous transition to the improved-confinement regime occurs, a negative electric field forms near the outermost closed magnetic surface. (3) The application of a potential of unfavorable (positive) polarity turns off the ohmic H mode. (4) In the case of a negative polarity, the current in the electrode–plasma–wall system is higher than that in the case of a positive polarity, and it decreases upon the transition to the H mode.

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