

Effects of the Toroidal Electric Field Perturbation on the Radial Electric Field and Confinement Bifurcation in the TUMAN-3M Tokamak

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Abstract

Plasma current profile was modified using current Ramp Up and Down or, alternatively, magnetic compression scenarios on the TUMAN-3M tokamak. It was found that the fast current profile evolutions in these experiments led to confinement mode transitions. However, the direction of the confinement bifurcation (improvement at the L-H transition, or degradation at the H-L transition) correlates with the sign of toroidal electric field perturbation, rather than with the peaking or broadening of current profile itself. A novel mechanism of the radial electric field generation based on "non-ambipolar" radial drift of electrons and ions is proposed. This mechanism is capable of explaining the observed peculiarities of the confinement evolution.

Keywords:

tokamak, H-mode, confinement bifurcation, radial electric field

1. Introduction

The interest to radial electric field formation mechanisms has increased in the connection with the possibility of the transport barrier formation [1] in tokamaks in absence of powerful source of heating and toroidal momentum (so-called ohmic H-mode transition). A new mechanism of a radial electric field formation has been proposed recently [2,3]. This mechanism is suitable for E_r emerging explanation in ohmically heated tokamak plasma in absence of powerful external source of toroidal momentum and heating power. The underlying idea of this approach is taking into account the electron Ware drift flow that leads to a radial current excitation and radial electric field build up. In the TUMAN-3M tokamak, this radial

current is caused by the difference in electron and ion collisionalities: at the edge of the TUMAN-3M plasma electrons are in banana regime, whereas ions are in plateau. The maintenance of zero total radial current requires the transverse conductivity current, and so the radial electric field, to emerge. The accurate modeling of the TUMAN-3M H-mode discharge evolution using this approach is given in [2]. The main goal of the present study is to check the validity of the model in the greatest possible number of different experimental conditions.

As the Ware drift velocity, which is a crucial parameter of the model discussed, is proportional to the E_ϕ/B_θ , the experimental setup was arranged in a way

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that allowed creating a perturbation of toroidal electric field E_ϕ . Two methods of E_ϕ perturbation were used. The first was the fast plasma Current Ramp Down/Up (CRD and CRU, correspondingly) with the average speed 25 MA/s. The second method used was the magnetic compression of plasma column by a rapidly increasing toroidal magnetic field. In this scenario, a perturbation of the toroidal electric field at the plasma edge arises due to the increase in internal inductance of plasma column, caused by the compression. Both methods of E_ϕ perturbation were utilized in two different modes of ohmic confinement (L and H), thus leading to different consequences.

2. The CRD and CRU in the H- and L-Modes of Confinement

Earlier, it was found that CRD in the TUMAN-3M led to the H-mode termination [3]. The obvious reason for this is a change of sign of the Ware drift velocity, which caused the destruction of radial electric field E_r needed for H-mode sustaining. In the present study, we have utilized a positive perturbation of the E_ϕ caused by the CRU as a trigger, which forces the transition from the L- to the H-mode. For this purpose, the target discharge was initially in the ordinary OH regime

(ohmic L-mode). The CRU was activated at the flat top of the discharge. If the speed and the step of the CRU exceeded some threshold values, the CRU led to the H-mode transition, Fig. 1a. In a frame of the model discussed above, the cause of the transition is the increase in radial drift of trapped electrons (caused by the E_ϕ ramp up), which leads to the negative E_r formation. The transition to the regime of improved confinement has a clear bifurcation character: (i) it happens only if the threshold in control parameter is exceeded, and (ii) after the transition takes place, the (high) level of confinement remains approximately constant. Another indication of the bifurcation nature of confinement in the TUMAN-3M can be found in the CRU experiment in the Ohmic H-mode, Fig. 1b. In this case, the H-mode was initiated in advance by a short pulse of gas puff. The indication of the confinement improvement is drop in D_α emission accompanied by plasma density rise. Then, the confinement degraded for some reason, possibly due to the peripheral MHD activity. The CRU activated at $t = 66$ ms returned the discharge to the regular H-mode level of confinement, but no further improvement of the confinement was observed. In other words, the CRU in this experiment didn't cause a transition to another stable state of the

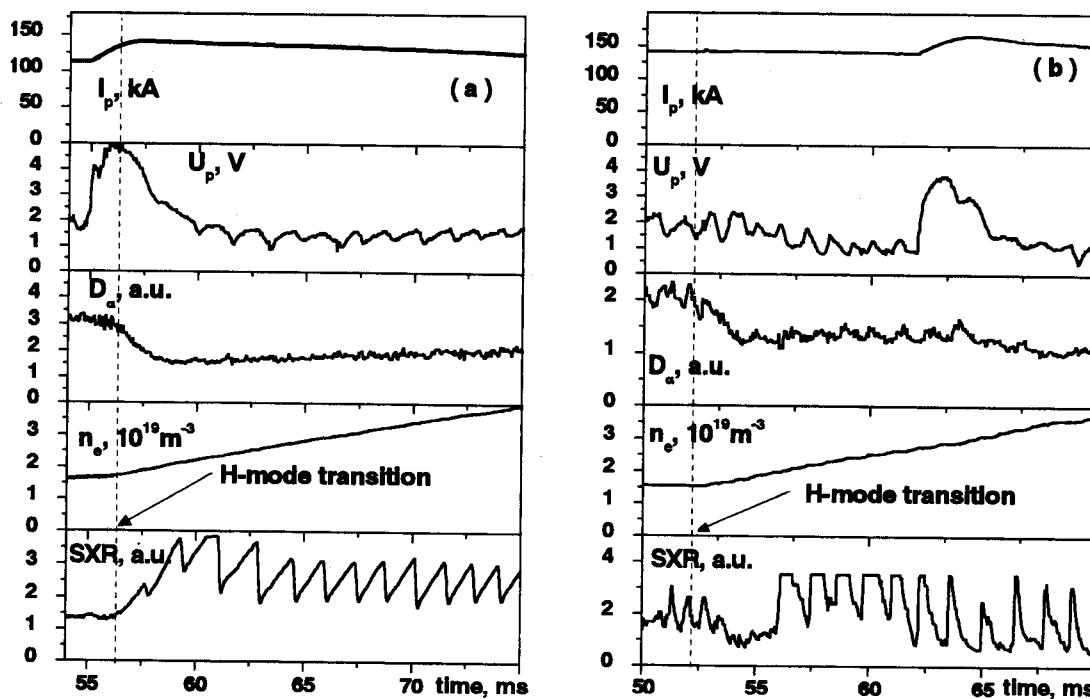


Fig. 1 The Current Ramp Up (a) in the L-mode causes the L-H transition and (b) in the H-mode sustains the high level of confinement.

confinement, but rather sustained the regular H-mode level.

The L-H transition in the CRU experiment on the TUMAN-3M was simulated by the BATRAC code [4], assuming the transport coefficients to be given functions of the radial electric field shear $|\partial E_r/\partial r|$. The radial electric field was calculated self-consistently, following the model discussed above. The calculated radial profiles of E_r are shown in Fig. 2. It clearly indicates that strong inhomogeneous radial electric field generates at the plasma periphery shortly after the beginning of fast current ramp up, thus leading to the H-mode transition.

When the CRD is applied to the L-mode plasma, the reversal of the radial drift of trapped electrons leads to the positive E_r generation. Generally speaking, if $|E_r|$ and $|\partial E_r/\partial r|$ are large enough, the H-mode transition should be possible in this case too. However, one could expect that $|E_r|$ in the CRD case should be smaller than in the CRU. This is due to the fact that positive E_r induced by the CRD is counteracted by the negative neoclassical field E_r^{NEO} , whereas in the CRU experiment both the perturbation-induced E_r and E_r^{NEO} are negative, giving higher absolute value of resulted E_r . Moreover, as it was found in edge plasma biasing experiments on the TUMAN-3 [5], the L-H transition triggering requires higher $|E_r|$ value for positive E_r than for negative. It could explain the failure of L-H transition initiation by the CRD in the experiments described - as it is seen from the Fig. 3, the CRD in the L-mode didn't produce noticeable effect on confinement.

3. Magnetic Compression in L- and H-Modes

The compression of plasma column by a fast ramp of toroidal magnetic field has been used on the TUMAN-3 tokamak earlier to reach high values of plasma temperature and density. An improvement of the confinement has been observed in this case as well [6]. In order to clear up the role of a radial electric field perturbation in this change of the confinement, the magnetic compression experiment was repeated on TUMAN-3M recently, with significant changes in the scenario: (i) to minimize the power income from the compression itself, only $\delta B_T/B_T = 20\%$ ramp of toroidal magnetic field was used, (ii) to increase the perturbation of both the toroidal and radial electric fields, the rise time of magnetic field was made as short as 1.7 ms, (iii) the gas puff rate was kept constant. It was found that even in this case the magnetic compression leads to the

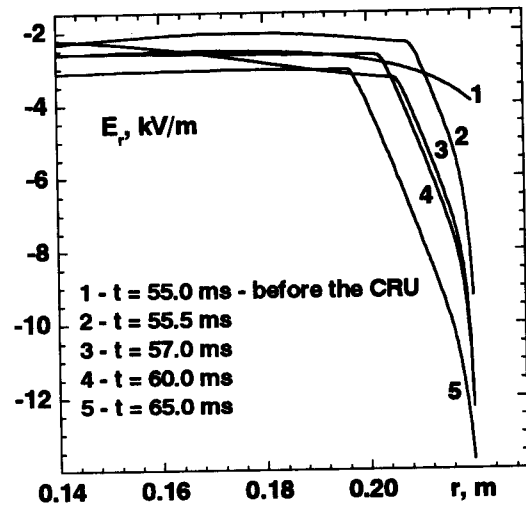


Fig. 2 The calculated radial electric field profiles before (curve 1) and during (curves 2-5) the Current Ramp Up.

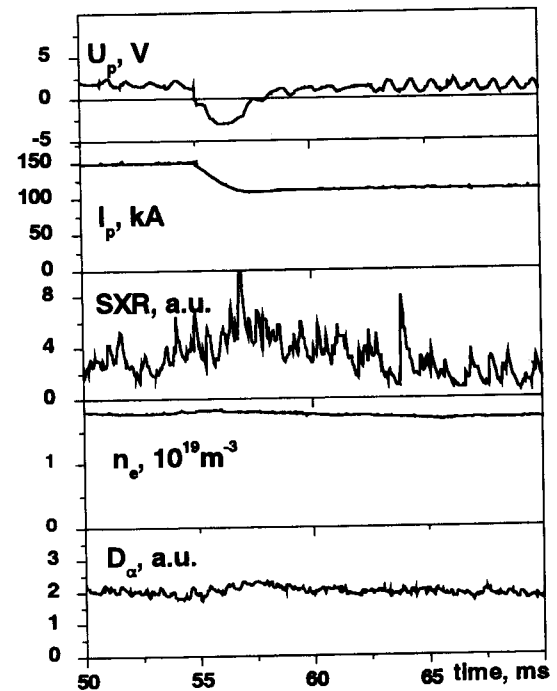


Fig. 3 The Current Ramp Down in the L-mode doesn't change the confinement.

transition into the H-mode of confinement, see Fig. 4. Magnetic compression causes the increase in internal inductance of plasma column, and, as a result, in toroidal electric field E_ϕ . According to the model discussed above, increase in E_ϕ results in radial electron current excitation, which leads to radial electric field

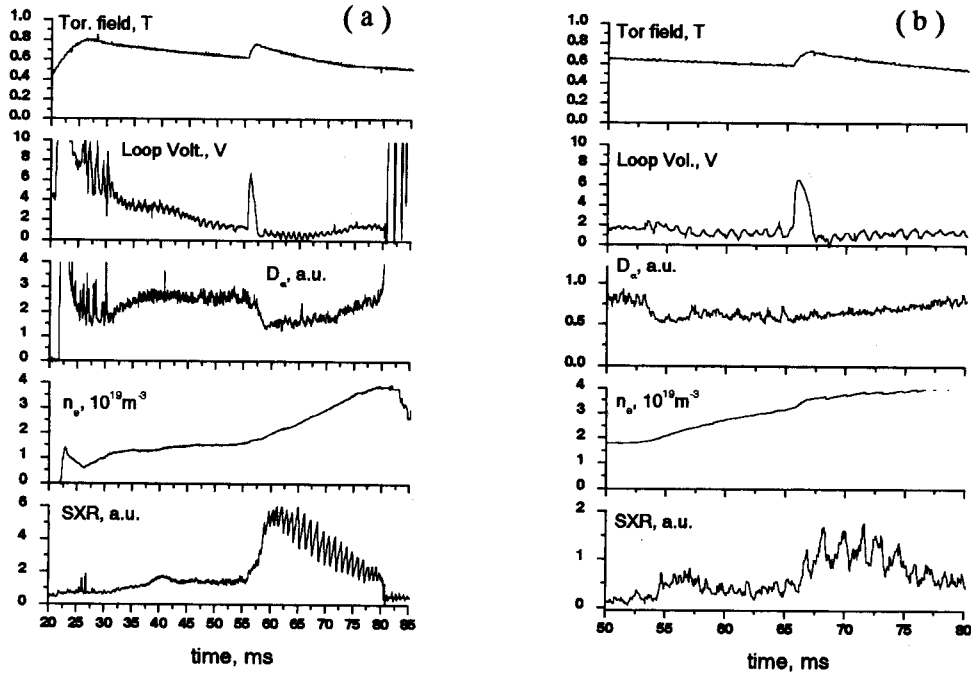


Fig. 4 Temporal behavior of the B_r , U_p , D_α emission, $\langle n_e \rangle$, and SXR radiation in the shot (a) with H-mode triggered by the magnetic compression, and (b) with the compressions of the ohmic H-mode plasma.

Table 1 E_ϕ perturbation effect on the confinement bifurcation on the TUMAN-3M.

INITIAL MODE OF CONFINEMENT	PERTURBATION	CURRENT PROFILE EVOLUTION	PERIPHERAL E_ϕ EVOLUTION	CHANGE IN ELECTRON WARE DRIFT V_r^c	RESULT
L	CRU	Broadening	Rise	$ V_r^c $ rises, $V_r^c < 0$	L \rightarrow H
H	CRU	Broadening	Rise	$ V_r^c $ rises, $V_r^c < 0$	H
L	CRD	Narrowing	Drop	$ V_r^c $ drops, $V_r^c > 0$	L
H	CRD	Narrowing	Drop	$ V_r^c $ drops, $V_r^c > 0$	H \rightarrow L
L	Compression	Narrowing	Rise	$ V_r^c $ rises, $V_r^c < 0$	L \rightarrow H
H	Compression	Narrowing	Rise	$ V_r^c $ rises, $V_r^c < 0$	H

build up, needed for the L-H-transition. The detailed analysis of this experiment is given in [7]. Note that, contrary to the CRU case, magnetic compression causes narrowing of the plasma current profile.

If magnetic compression was applied to the ohmic H-mode plasma, it caused no change in confinement regime, see Fig. 4b.

4. Discussion

Two possible methods of E_ϕ perturbation: plasma current ramp and magnetic compression- were used as a trigger of confinement mode transition on TUMAN-3M tokamak. The results of these experiments are collected in Table 1.

No correlation was found between confinement switching and the plasma current profile evolution. The

L-H transition was observed when plasma current profile has been broadened (fast plasma current ramp up experiment), or narrowed (magnetic compression experiment). Rather, confinement correlates with the sign of E_φ perturbation: positive δE_φ causes L-H transition (or sustains the H-mode, if it was switched on earlier). Contrary, negative δE_φ leads to the H-L transition or preserves the L-mode if it was the initial state of confinement. This behavior may be understood in a frame of radial electric field generation model, which explains the E_r generation, by a radial current caused by the electron Ware drift in perturbed toroidal electric field δE_φ .

5. Acknowledgment

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