EDGE TRANSPORT BARRIER EVOLUTION IN CURRENT RAMP DOWN EXPERIMENT IN OHMIC H-MODE ON TUMAN-3M TOKAMAK

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INTRODUCTION

Current ramp down (CRD) experiment were performed on TUMAN-3M tokamak earlier [1] in attempt to increase the normalized beta β_N. For this purpose, the fast CRD (with maximum rate up to 25MA/s) was performed during the ohmic H-mode stage, when stored energy was close to its maximum attainable level. Note that no auxiliary heating was used in these experiments, so the increase in plasma energy and particle content may be attributed solely to the improvement of plasma confinement caused by the H-mode transition. However, just after the CRD has been switched on, the degradation of the confinement took place. This is clearly seen from waveforms of plasma parameters evolution shown in Fig.1: plasma density increase changes to decrease (in spite of constant gas puffing rate), and D_α emission returns back to the L-mode level. So, one can conclude that the CRD terminates the H-mode. This behavior is somewhat unexpected, because the CRD experiments performed on other tokamaks show rather the improvement in the confinement. For instance, on COMPASS-D, the CRD lead to a specific peripheral MHD activity suppression, and transition from ELMy to ELM-free H-mode was observed [2]. The H-mode transition stimulated by the CRD has been observed on the JIPP T-IIU tokamak [3].

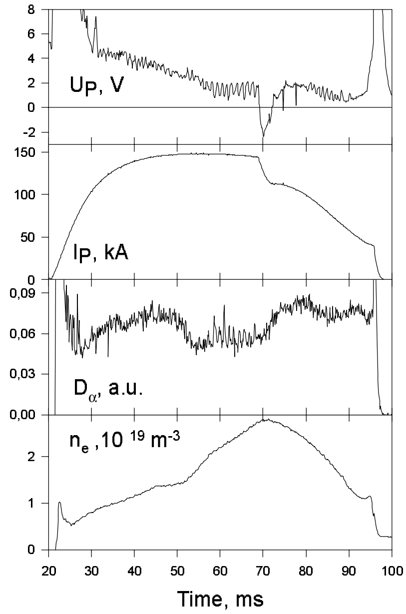

Fig.1. Time traces of plasma current, loop voltage, D_α emission and plasma density in the H-mode discharge with the CRD.

An obvious explanation that the H-mode termination on TUMAN-3M results from peripheral electron thermal balance breaking caused by CRD, is hardly valid. First, the ohmic heating power on TUMAN-3M is significantly higher than the value given by a scaling for threshold power [4] (this situation is typical for the ohmic H-mode in tight tokamaks). Second, the time delay between CRD and H-mode termination is very small, if any, whereas the energy confinement time in ohmic H-mode on TUMAN-3M is as high as 20 ms.

The goal of this paper is to clear up the physics of the H-mode termination by the CRD on the TUMAN-3M tokamak.

MECHANISM OF E_r GENERATION AT THE CONDITION OF $\nu_e^* \ll \nu_i^*$

It is experimentally shown on many tokamaks that L-H transition is a result of turbulent transport suppression by the sheared $\mathbf{E_r \times B}$ rotation [5]. The cause of $\mathbf{E_r}$ excitation, however, can be very different depending on size and parameters of the machine. In a large tokamak with external source of momentum and heating power, like the JET and the DIII-D, the strong pressure gradient and/or fast toroidal rotation build up $\mathbf{E_r}$. This mechanism, obviously, is not applicable to the ohmic H-mode in TUMAN-3M.

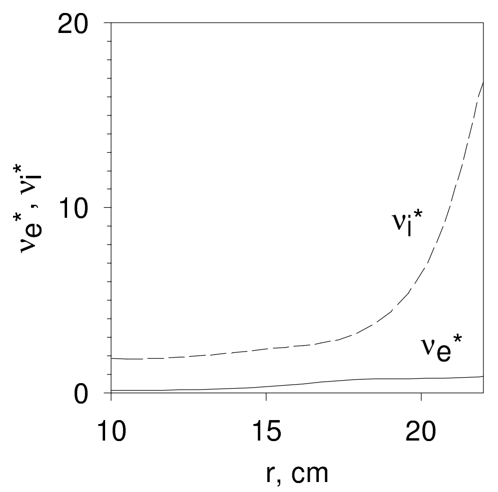

Fig.2. Ion and electron effective collisionality in the ohmic H-mode in TUMAN-3M.

A new approach was developed in [6] to describe the ohmic H-mode evolution in TUMAN-3M tokamak. This approach is based on the fact that, in absence of effective auxiliary heating, electrons and ions at the plasma periphery are in different modes of collisionality. Namely, in typical ohmic heating discharge in TUMAN-3M $\nu_e^* < 1 < \nu_i^*$, i.e. ions are in "plateau", whereas electrons are in "banana" regime, see Fig.2. This difference is caused by a significant inequality in electron and ion temperatures in ohmicaly heated regimes. Typically for **r/a** ≈ 0.8 in the ohmic H-mode in TUMAN-3M $\mathbf{T_i}$ is of the order of 40 eV, whereas $\mathbf{T_e}$ can be as high as 120 eV. Hence, the Ware drift is much stronger for electrons than for ions in ohmic H-mode in TUMAN-3M, leading to excitation of radial current directed outwards:

$$\mathbf{J_b = -2.3ne\varepsilon^{0.5}(E_\varphi/B_\theta)F(\nu_e^*,\nu_i^*)}$$

where function $\mathbf{F(\nu_e^*,\nu_i^*)}<0$ if $\nu_e^* < 1 < \nu_i^*$ [7]. In a steady state no net radial current is allowed in a tokamak, therefore the banana particle current has to be canceled by transverse conductivity current:

$$\mathbf{J_b + \sigma_\perp(E_r - E_r^{neo}) = 0}$$

Here $\sigma_\perp$ is transverse conductivity of tokamak plasma [7, 8]. This condition requires the radial electric field to differ from the neo-classical value. In a steady state of TUMAN-3M discharge $\mathbf{J_b}>0$, this leads to excitation of a radial electric field negative in sign, which is known to be favorable for H-mode transport barrier creation. Thus, taking into the consideration the radial current caused by the difference in radial drifts of electrons and ions when they are in different modes of collisionality, one could explain why a strong radial electric field might arise in ohmically heated tokamak plasma.

CRD EFFECT ON PERIPHERAL TRANSPORT BARRIER EVOLUTION

The mechanism discussed in previous section is capable of explaining the CRD influence on the ohmic H-mode.

Fast decrease in plasma current is accompanied by the reversal of toroidal electric field $\mathbf{E_\phi}$ at the plasma edge, whereas poloidal magnetic field $\mathbf{B_\theta}$ retains its sign. Hence, the Ware drift velocity (which is proportional to $\mathbf{E_\phi \times B_\theta}$) becomes directed outwards. This is followed by a transient change of the direction of the radial current $\mathbf{J_b}$, which now acts to destroy negative $\mathbf{E_r}$ that was formed on the ohmic H-mode stage. The profiles of radial current of the trapped particles calculated using ASTRA transport code for two time points–before the CRD and at the maximum of negative loop voltage spike, are shown in Fig.3. As a result, "natural" ohmic H-mode radial electric field decreases, and H-mode terminates. In addition, in time dependent toroidal electric field $\mathbf{E_\phi} \neq$const(t), a correction arises to the standard Ware drift [9]. This may enhance the radial electric field decay even more. The situation is similar to the experiment on TUMAN-3 ohmic H-mode termination by a positive biasing applied to the plasma edge by an external electrode [6].

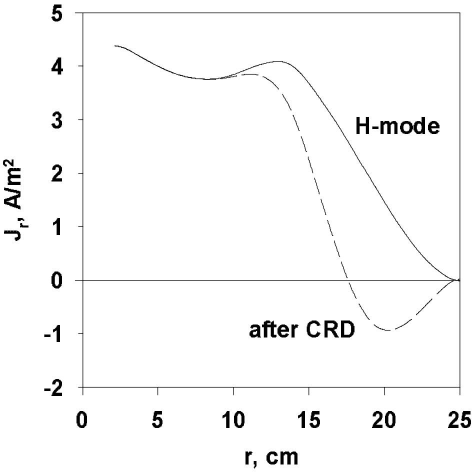

Fig.3. Calculated profiles of trapped particle current before and after the CRD.

Characteristic time of these processes is determined by a poloidal rotation relaxation, which is governed by neoclassical longitudinal viscosity [8] and is of the order $\nu_i^{-1} \leq$ 1ms for TUMAN-3M plasma parameters. This might explain very short time delay between CRD switching on and ohmic H-mode termination.

Recently, the CRD in ohmic H-mode has been repeated on TUMAN-3M in better vacuum conditions created by a successful boronization. In these experiments the impurity content was very low: $\mathbf{Z^{eff}} \approx 1$, loop voltage was approx. 0.8 V. Time traces of plasma current, loop voltage, SXR and D_α emission and plasma density are shown in Fig.4. One can see that in this experiment the CRD has caused only a transient termination of the H-mode: plasma density increase resumes and D_α returns to H-mode level after the end of negative spike on loop voltage. This picture clearly indicates the influence of Ware drift reversal on peripheral transport barrier evolution, in accordance to the mechanism described above. On the other hand, it is not clear yet why in pure plasma with $\mathbf{Z^{eff}}$ close to unity (i.e. with more pronounced skin effect when the current profile is being changed), the effect reveals itself as a transient H-mode termination only. More accurate analysis of radial electric field evolution and its influence on the confinement, coupled with transport simulation, is needed for the complete understanding of this effect.

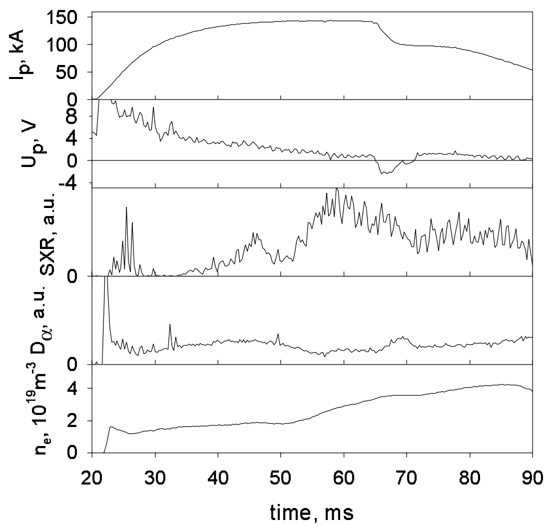

Fig.4. Plasma parameters evolutions in the H-mode plus ITB shot with the CRD.

Possible explanation for the temporary effect of CRD on the H-mode in a discharge with low impurity content may be as follows. It was found on TUMAN-3M earlier that low $\mathbf{Z^{eff}}$ H-mode discharges with high current (>100 kA) feature the internal transport barrier

(ITB) formation [10]. The two transport barriers–the ITB and a peripheral one, are clearly seen on profiles of plasma parameters [11]. Besides, one of the characteristic features of the ITB discharges in TUMAN-3M is slow D_α decay during the H-mode transition. One can compare the D_α behavior at the moment of the H-mode transition in an ordinary H-mode shot (Fig.1) and in a shot with H-mode plus the ITB (Fig.4). Because of the ITB, the particle and energy flux through the boundary plasma region is significantly decreased. According to the approach described above, the CRD causes the changes in the plasma transport only in the peripheral plasma, not affecting the ITB region. It looks like the presence of the ITB changes the peripheral transport barrier dynamics, forcing plasma to recover the high confinement mode after the completion of the transient process caused by the CRD.

SUMMARY

The approach based on taking into account the difference of regimes of ion and electron collisionality is used for the explanation for $\mathbf{E_r}$ formation in the ohmic H-mode. This mechanism is recruited for the explanation of the CRD influence on the H-mode. This approach (i) predicts the negative sign of $\mathbf{E_r}$ in the ohmic H-mode, in accordance with previous TUMAN-3 experiments; (ii) explains why the CRD destroys the peripheral transport barrier; and (iii) gives a short time delay between the CRD and the H-mode termination, coinciding with experimentally observed one. When CRD is applied to the H-mode plus ITB plasma, the ITB helps plasma to return to the H-mode confinement regime.

ACKNOWLEDGMENTS

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