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Dependences of ITB Characteristics on Plasma Parameters in T-10 Reversed Shear Plasmas

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Electron Internal Transport Barrier (eITB) formation has been demonstrated in T-10 reversed shear plasmas [1]. Plasma current profile with reversed magnetic shear in the core region (r/a<0.35) has been produced by Electron Cyclotron Resonance Heating (ECRH) during plasma current ramp-up. This paper is devoted to the discussion of recent T-10 experiments focused on the investigation of the dependences of eITB characteristics on q profile and ECR power value. Attempt to split between threshold power value and critical magnetic configuration has been done.

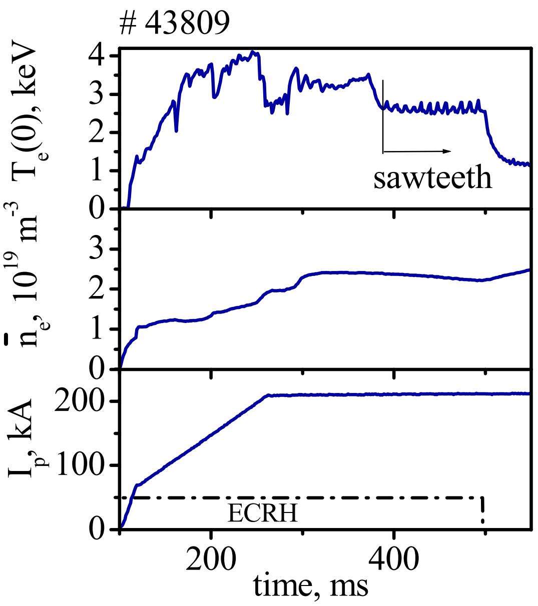

Fig. 1 Typical scenario of T-10 discharge with reversed shear and ITB formation.

ECRH power has been applied during the plasma current ramp-up phase to create the reversed shear magnetic configuration. ECRH power (up to 1.1 MW in these experiments) has been applied at the instant of the plasma current switch-on. It has led to the formation of well pronounced electron Internal Transport Barrier. Typical experimental scenario is presented in Fig. 1. Electron ITB formation has been detected at 30-50 ms after ECRH switch-on.

Important feature of these T-10 discharges with reversed shear is pronounced MHD activity, that appears when q(r) profile with s<0 crosses rational values of q_{min} : q_{min}=3, 2 [1]. Electron ITB is affected by the development of this MHD activity, which leads to the temporal eITB shrinkage (at q_{min}=3) or temporal eITB disappearance (at q_{min}=2). Electron ITB deterioration in all reversed shear discharges in T-10 correlates with the appearance of m=1/n=1 mode in plasma core [1]. This effect is seen on Fig. 1 just before the development of sawtooth oscillations.

The quality of eITB can be characterized in terms of temperature gradient (Fig. 2). It is seen that the best quality of eITB is reached when q_{min} value is high $q_{min}>2$. Decrease of q_{min} below the value of $q_{min}=2$ leads to the development of MHD modes decreasing the temperature gradient. Note here that the evolution of q profile has been taken from ASTRA calculation by the same way as it has been explained in [1]. Calculated q profiles have been additionally controlled by peculiarities of MHD activity.

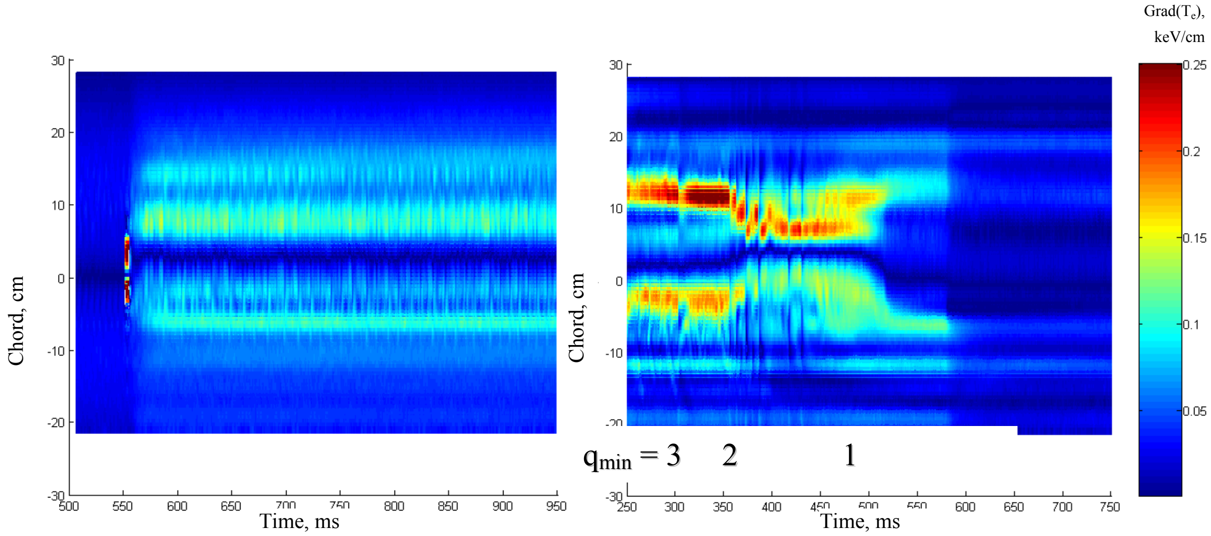

Fig. 2 Evolution of the temperature gradient in usual T-10 L-mode (leftt), i.e. monotonous q(r) profile, and in ITB case (right). Global discharge parameters and heating power value are the same in both cases. ECRH power has been applied at t=550 ms in L-mode case and at t=200 ms (together with I_p switch-on) in ITB case presented on this figure.

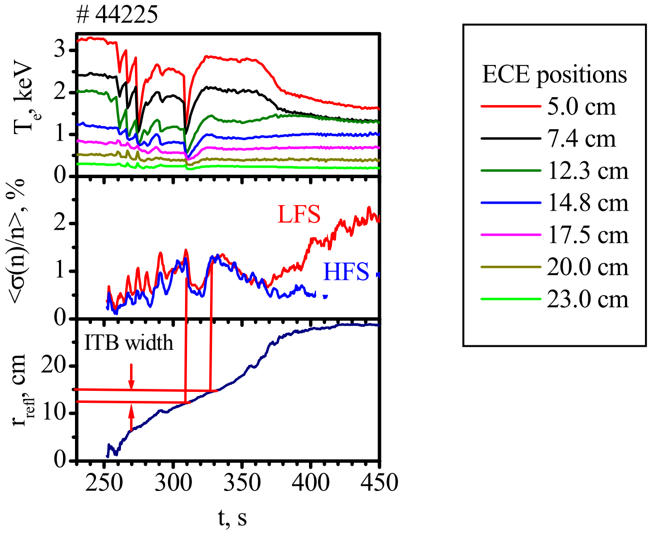

Fig. 3 Temperature evolution measured by ECE diagnostics from different chords, turbulence amplitude measured at Low and High Field Side, position of reflection layer (at LFS) for the typical shot with ITB formation.

Measurements of plasma turbulence in regime with eITB have been made by correlation reflectometry. The measurements have been carried out on both Low and High Field Sides. It is seen (Fig. 3) that the turbulence amplitude decreases sufficiently when reflection layer goes through the ITB region. It is necessary to note that the behavior of turbulence is different (has no decrease) when the reflection layer lies outside of ITB.

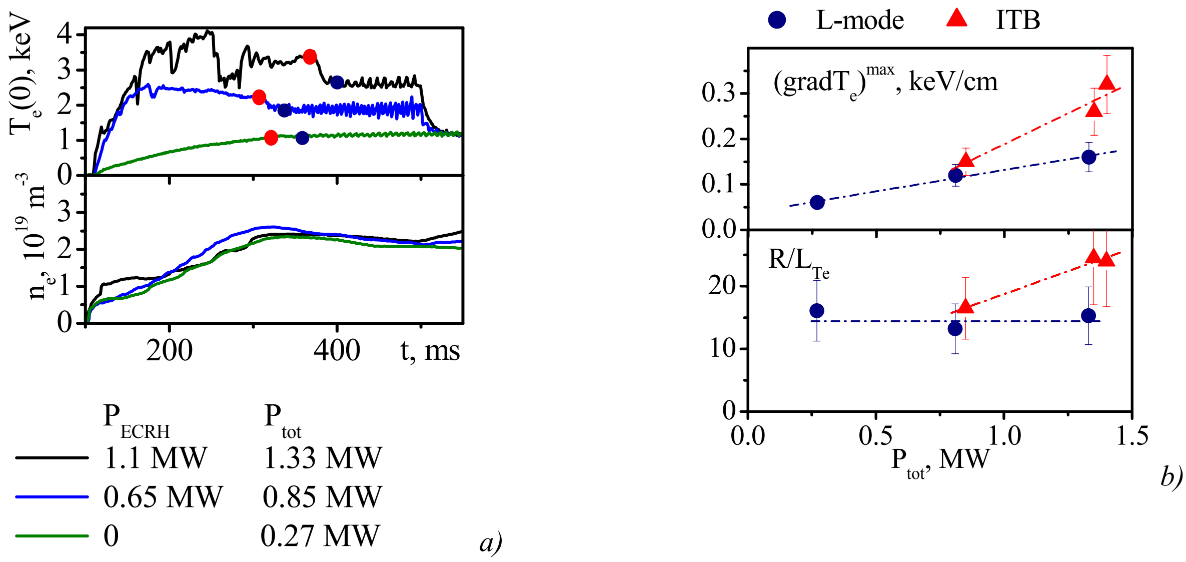

Fig. 4 (a) typical shots for investigation of power dependence of ITB characteristics. Typical instants for comparison between L-mode and ITB are shown by coloured circles; (b) dependence of ITB characteristics on total heating power in comparison with the L-mode.

Dependence of the ITB characteristics on input power applied during the current ramp-up phase has been investigated. Two characteristic time instants have been chosen: in ITB phase of discharge just before the eITB deterioration and on L-mode (sawtoothing) part of discharge just before the sawtooth crash (Fig. 4, a). This allows us to compare L-mode and ITB regime at the similar conditions. Only q(r) profile seems to be different. To measure ITB quality three values have been taken: central temperature, temperature gradient and normalized temperature gradient, R/L_{Te} (where L_{Te}= - Grad(T_e)/T_e). It is seen in Fig. 4,a that the relative enhancement of central electron temperature in ITB in comparison with L-mode increases with the heating power. Fig. 4, b shows that the heating power increase leads to the growth of the temperature gradient in both L-mode and ITB plasmas. However increase of Grad(Te) value inside of ITB (maximal gradient value has been taken) is more pronounced. Important feature is observed from the comparison of R/L_{Te} values. In L-mode case the value of R/L_{Te} remains constant in a whole region of applied heating power: from pure ohmic discharges to discharges with $P_{ECRH}\cong1$ MW. It can be interpreted as an achievement of the critical temperature gradient. In eITB case the reached value of R/L_{Te} increases with the heating power increase. Threshold total heating power value for this effect can be estimated as P_{th}=0.75 MW and seems to be the threshold power for the formation of favourable magnetic configuration. The maximal value of normalized temperature gradient achieved in this discharges at P_{ECRH}=1.1 MW is ~ twice higher than one typical for similar L-mode discharges.

The increase of the reached temperature gradient with the power increase more obviously seems to be the result of difference in the magnetic shear value inside of the q=1 surface at the instant when the q=1 appears in plasma. This is seen from the comparison of the q(r) profile evolution in ohmic discharge and in case with the highest ECRH power applied to the plasma (Fig. 5). In ohmic discharge the current diffusion time is low and plasma current profile (and q(r) profile) becomes monotonous very early, when $q_{min}>2$. In case of powerful ECRH heating q(r) profile evolution is slowed down and q(r) remains nonmonotonous with the reversed or weak shear area in the core until q_{min} becomes close to unity. This means that the turbulence suppression can be expected due to the stabilizing effect of the magnetic shear. In agreement with the calculations presented in [2] temperature evolution can be well described taking into account anomalous transport suppression by the negative magnetic shear in these ITB discharges.

Therefore the following features of T-10 discharges with ITB formation can be marked basing on the set of special experiments. 1) Decrease of turbulence amplitude is observed inside of eITB region. 2) eITB quality depends on the heating power value. In the contrast to L-mode case the value of R/L_{Te} increases with the heating power increase. It can be interpreted as the result of increase of the critical temperature gradient due to the turbulence suppression. 3) Electron ITB evolution in reversed shear discharges is the complex effect of reversed magnetic shear and MHD activity on heat transport.

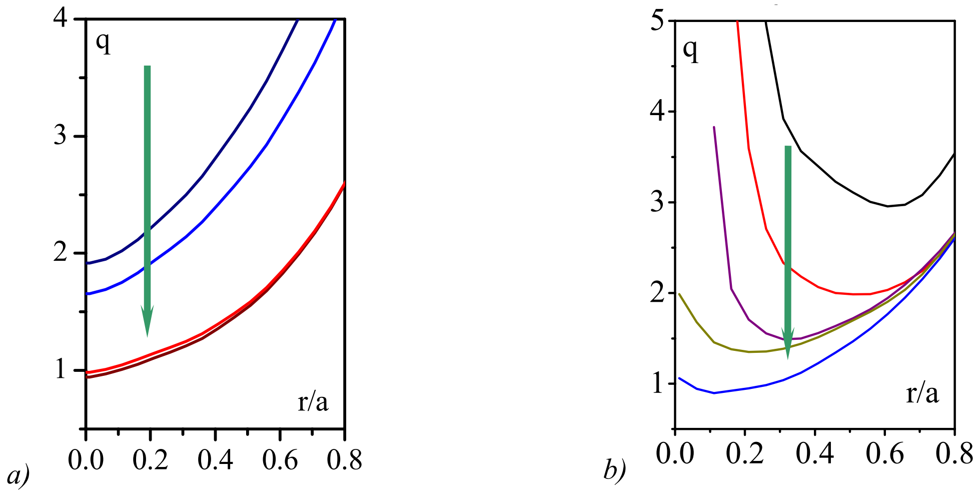

Fig. 5 Difference in q(r) profile evolution in ohmic discharge (a) and in discharge with early ECRH application, P_{ECRH}=0.95 MW (b). Direction of changes with the time is shown by arrows.

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[1] Kirneva N.A. et al Plasma Phys. Control. Fusion 47 (2005) 1787

[2] Kirneva N.A. et al In Proc. of 33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.30I, P-4.086 (2006)