§26. Effects of Energetic Ions on Interchange Modes and Control of the MHD Modes

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In LHD, large amplitude bursting modes are often observed in finite beta plasmas heated by perpendicular neutral beam injection (PERP-NBI). It was confirmed that the modes are destabilized by resonant interaction between resistive interchange mode (RIC) perturbations and helically trapped energetic ions (H-EPs) generated by the PERP-NBI, of which initial energy is E=35-40 keV and their pitch angle is χ~90° [1, 2]. The modes were named EIC (*E*nergetic ion driven resistive *I*nter*C*hange mode) having an m=1/n=1 radial mode structure localized at the rotational transform ι=1 resonant surface, where m and n are poloidal and toroidal mode numbers, respectively. In this collaboration research, the impacts of EIC on background plasma confinement and also ECH effects on the EIC were studied.

In our paper [2], the impacts of EIC on the background plasma are described in detail. Here, the main results are summarized. Each EIC burst generates negative plasma potential spike up to $\Delta\phi$~20 keV. This means the generation of large radial electric field of E_r~ -85 kV/m near the edge where the ι=1 surface resides. The loss rate of the EPs is estimated from the time derivative of the radial electric field at the EIC onset. Thus estimated loss reaches ~ 15-30 %. The stored energy obtained from the diamagnetic loop W_{dia} is the sum of the kinetic energy of the bulk plasma W_{kin} and the kinetic energy of helically trapped EPs having χ~90°, $W_{\perp EP}$. The time evolution of dW_{dia}/dt is shown in Fig.1. In this figure, an EIC is excited at t=4.478 s and persists for ~3 ms. For ~0.4 ms from the onset of EIC, dW_{dia}/dt shows a sudden drop of ~0.8 MW. This drop corresponds to the drop of $dW_{\perp EP}/dt$ and indicates the EP loss induced by EIC. The absorbed PERP-NBI power is estimated to be ~3MW, so that the EP loss rate is ~30%. Thus estimated EP loss rate agrees well with that estimated from the rapid change of E_r. Accordingly, the EIC bursts lead to large loss of the helically trapped energetic ions. On the other hand, Figure 1 indicates that the signal dW_{dia}/dt increases rapidly by dW_{dia}/dt ~1.9 MW just after the initial drop due to the EP losses. The net increase of dW_{dia}/dt from the value just before the EIC onset is ~1.1 MW. This indicates the transient increase in W_{kin} by the EIC burst, that is, the transient improvement of bulk plasma confinement. The improvement is thought to be due to the large E_r shear generation near the edge by EIC.

Effects of ECH on EIC were studied in plasmas with strong bursting EICs. When high power on-axis ECH was applied, electron temperature T_e increases noticeably even at the ι=1 resonant surface near the edge as well as the plasma center. By the on-axis ECH, EICs were clearly suppressed [3]. The mechanism of the EIC stabilization is under investigation. Here, we discuss the

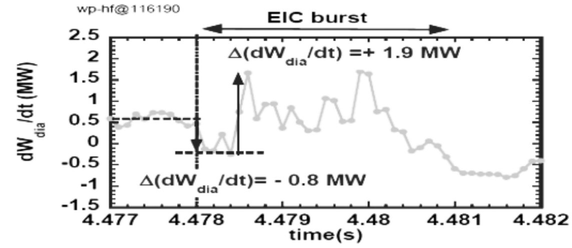

Fig.1 Time evolution of the time derivative of the stored energy measured by a diamagnetic loop dW_{dia}/dt in an EIC event.

effects of ECH on the confinement of H-EPs. The T_e at the ι=1 surface reaches ~2keV with n_e~0.5x10^{19} m^{-3}. The slowing down time of H-EPs is estimated to be τ_s~0.75 s. Since the initial energy of H-EPs is relatively low (E=35 keV), the pitch angle scattering time is τ_d~0.32 s and smaller than τ_s, where the effective charge Z_{eff}=3 is assumed. In the EIC study, the amount of H-EPs can be estimated from $W_{\perp EP}$=W_{dia}-W_{kin}, because the diamagnetic loop detects the stored energy of EPs having χ~90°, $W_{\perp EP}$. Accordingly, $W_{\perp EP}$ can be estimated reliably with $W_{\perp EP}$=W_{dia}-W_{kin}, on the condition of τ_s<<τ_d. However, this estimate is not appropriate for the condition of $\tau_s/\tau_d \geq 3$ during the ECH phase. Actually, thus estimated $W_{\perp EP}$ remains almost unchanged without the increase corresponding to the 3 times increase of τ_s by ECH. Instead, the quasi-stationary values of $W_{\perp EP}$ before and during ECH are estimated by the following simple model equation as,

$$\frac{dW_{\perp EP}}{dt} + \frac{W_{\perp EP}}{\tau_{sE}} + \frac{W_{\perp EP}}{\tau_{loss}} = P_{abs}. \quad (1)$$

Here, τ_{loss} is the loss time determined by the pitch angle scattering to the loss cone at χ~60° and is approximated as $\tau_{loss} \sim 0.3\tau_d$. The quantity τ_{sE} is the energy relaxation time and $\tau_{sE} = \tau_s/2$ and P_{abs} the absorbed power of the PERP-NBI. From eq.(1), $W_{\perp EP}$ in the steady state value is expressed as,

$$W_{\perp EP} = \frac{\tau_{sE}\tau_{loss}}{\tau_{sE}+\tau_{loss}} P_{abs} = \frac{\tau_{loss}}{1+\tau_{loss}/\tau_{sE}} P_{abs}. \quad (2)$$

The characteristic loss time of H-EPs are τ_{loss}~0.10s and τ_{sE}~0.13 s at the ι=1 surface just before ECH, and τ_{loss}~0.10s and τ_{sE}~0.38 s during ECH. The change rate of $W_{\perp EP}$ by ECH is estimated as,

$W_{\perp EP}$[during ECH]/ $W_{\perp EP}$[before ECH] ~ 1.4. (3)

Under the condition of the noticeable increase in the H-EP pressure, a possible stabilization mechanism by ECH might be associated with the reduced growth rate and/or the shrinkage of the eigenfunction of RIC, with the enhanced magnetic Reynolds number S.

[1] X.D. Du et al., Phys. Rev. Lett. **114** (2015) 155003 (2015).
[2] X.D. Du et al., Nucl. Fusion **56** (2016) 016002.
[3] X.D. Du et al., presented at 25th International Toki Conf., Nov. 3-5, 2015.