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

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In LHD, perpendicular neutral beam injection heating (PERP-NBI) with low beam energy of E_o ~35 keV is attempted to increase bulk ion temperature by maximizing ion heating power-fraction. The PERP-NBI generates helically trapped beam ions having the pitch angle of ~90°. In an inward-shifted configuration, the beam pressure of the energetic trapped ions can reach a certain level because of rather good confinement of the trapped ions, so that the energetic ions would destabilize some MHD instabilities. Actually, resistive interchange mode (RIC) marginally stable or slightly unstable is destabilized through resonant interaction between the helically trapped energetic ions and the MHD modes [1]. This mode called EIC (energetic ion driven resistive interchange mode) exhibits a bursting character and rapid frequency chirping. The eigenfunction of EIC having m=1/n=1 structure (m, n: poloidal and toroidal mode numbers) has a character similar to RIC localized at the ι=1 rational surface near the plasma edge. The EIC triggers transient confinement improvement. However, this beneficial event requires non-negligible penalty for the trapped energetic ions, i.e., considerable energetic ion loss. The final goal of this collaboration research is to develop a reliable control method of RICs as well as EICs in a plasma with large content of energetic ions, with help of externally applied magnetic perturbations and an optimized scenario of heating and current drive with NBIs and electron cyclotron waves.

As the first step of this collaboration, effects of resonant magnetic perturbations (RMPs) on EIC have been investigated in so-called high-ion-temperature plasmas shown in Figs. 1 a) and 1 b), where EIC bursts are observed during the PERP-NBI phase and the toroidal field strength is B_t=2.75T. In Fig.1 c), time evolutions of magnetic probe signal (MP) are compared for three shots: case (A) without RMPs, case (B) low RMPs of I_{RMP}/B_t=0.2kA/T and case (C) doubled RMP magnitude for that in case (B), i.e., I_{RMP}/B_t=0.4kA/T, where I_{RMP} and B_t are the RMP coil current and toroidal field, respectively. In these shots, one beam line of PERP-NBI is applied from t=3.3s to t=4.8s, and the other PERP-NBI is super-imposed from t=3.9s to t=4.5s. Note that in case (C) the PERP-NBI power applied from t=3.3s becomes half from t=3.66s due to the beak down of one ion source. The MP signals less than 10 kHz are dominated by EIC burst and RICs in these shots. The frequencies of EIC and RICs do not change noticeably by the application of RMPs, so that the MP signal shown in Fig.1(c) is nearly proportional to the magnetic fluctuation amplitude at the MP position. In the case (B) that weak RMP is applied, the magnetic fluctuation amplitude is clearly enhanced by a factor of two, compared with the case (A) without RMP. Many negative spikes in dW_{dia}/dt trace become more visible in case (B), of which spikes indicate the losses of the energetic ions by EIC burst. Here, W_{dia} is the stored energy measured by diamagnetic measurement and contains the component of helically trapped energetic ions. When the RMP amplitude is further increased by a factor of two, the fluctuation amplitude is clearly reduced down to about half of that in case (A) without RMPs. Note that in case (C) W_{dia} decreases noticeably from t~3.8s due to the beak down of the PERP-NBI. The negative spikes in dW_{dia}/dt disappear indicating complete suppression of EIC bursts. However, the reduction of the magnetic fluctuation level and complete suppression of EIC bursts in case (C) are thought to be caused by the appreciable reduction of the amount of helically trapped energetic ions and the total plasma beta value, and not to be caused by a direct effect of RMP. Nevertheless, it is interesting that the RMPs enhance the magnetic fluctuations in case (B) with even small RMPs. If the mechanisms of the enhancement are clarified, the RMPs might be employed for control of EIC and also RICs in a favorable way. The most interesting research target of this collaboration is to clarify if both RIC and EIC are stabilized on the condition that the beam beta of helically trapped energetic ions exceeds the threshold of EIC [1] with above mentioned techniques, as similar to sawtooth suppression in a tokamak plasma.

[1] X.D. Du et al., Phys. Rev. Lett. **114**, 155003 (2015).

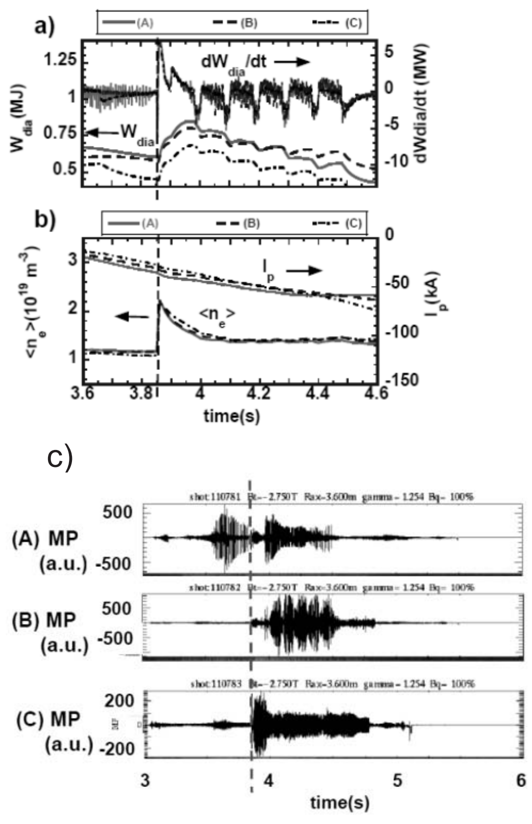

Fig.1 Discharge waveforms of W_{dia}, dW_{dia}/dt, I_p, $<n_e>$ and magnetic probe signals (MPs) in three shots: (A) without RMPs, (B) with I_{RMP}/B_t=0.2 kA/s and (C) I_{RMP}/B_t=0.4 kA/s.