IMPACT OF MHD ACTIVITY ON ENERGETIC ELECTRON DYNAMICS IN LHCD-ASSISTED PLASMA SCENARIOS IN ADITYA-U TOKAMAK

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In tokamaks, the energetic electrons are predominately generated during the Lower Hybrid Current Drive (LHCD) and Electron Cyclotron Resonance Heating (ECRH)-assisted scenarios contributing to the non-inductive current drive and heating of the plasma, respectively. However, In the presence of an external electric field, the energetic electrons in plasma can be accelerated to very high energy, becoming "runaway" electrons. If left unchecked, these electrons could severely damage the plasma-facing components on any tokamak as large as ITER. Hence, studying the dynamics of energetic particles is crucial for the safe operation of large-scale fusion devices like ITER.

In the ADITYA-U tokamak, the low energy hard X-ray (LHXR) having an energy range of ~20-200 keV is primarily produced by the suprathermal electrons generated largely during lower hybrid waves injection. These LHXRs are detected by the CdTe detectors located outside the vacuum vessel as shown in Fig. 1 (a). In contrast, the high energy hard X-ray (HHXR), detected by NaI scintillator detectors (see Fig. 1 (a)) having an energy range of ~1-3 MeV produced by the runaway electrons (REs) are always present in the plasma discharges and are modulated by the Magnetohydrodynamic (MHD) activity. The modulation of hard X-ray (HHXR, ~1-3 MeV) by the MHD instabilities such as sawtooth oscillations and drift tearing modes has been extensively studied in the ADITYA-U tokamak as well as other tokamaks [1][2][3][4].

We report the novel findings on MHD-activity-driven periodic modulation in LHXR in ADITYA-U tokamak. The modulation in the LHXR starts appearing above a threshold value of the poloidal magnetic field perturbation i.e. $\delta B_\theta/B_T \sim (1-10)e^{-5}$, measured at the location of the Mirnov probe. The threshold for LHXR is found to be 4-5 times less than that of HHXR ($\delta B_\theta/B_T \sim (10-40)e^{-5}$) as shown in Fig. 1 (b). This reveals that the threshold magnetic field perturbation modulating the dynamics of non-thermal energetic electrons in tokamaks is dependent on the energy of these electrons i.e. $\delta B_\theta/B_T \propto E$.

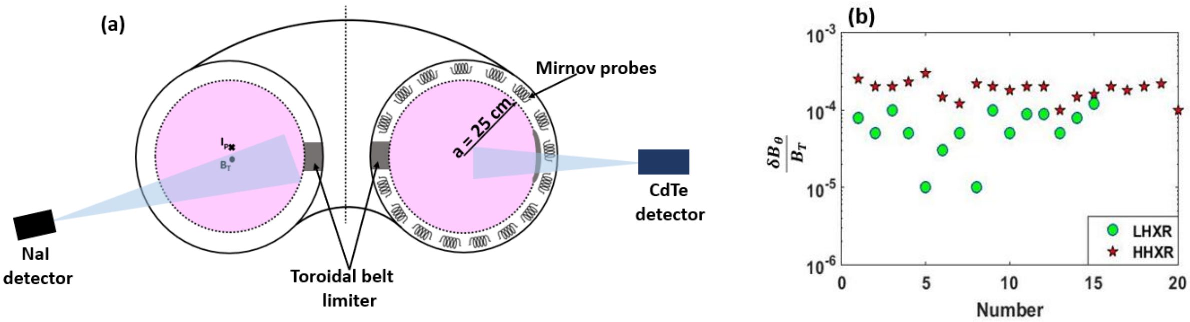

Fig. 1: (a): Schematic of the diagnostics used for LHXR, HHXR, and MHD measurement; (b) Threshold magnetic field comparison for LHXR and HHXR

The MHD activity driven modulation in the LHXR and HHXR is shown in Fig. 2. The Continuous Wavelet Transform (CWT) of the LHXR, HHXR, and MHD during the flat-top (t ~ 70.0 - 74.5 ms) for plasma discharge #37677 shows the correlation between MHD activity and LHXR and HHXR. At t = 71 ms, the MHD frequency decreased from 7 kHz to 5.4 kHz due to the injection of gas puff and this is promptly reflected in the LHXR and HHXR emissions indicating that the energetic electrons dynamics is strongly affected by the MHD activity.

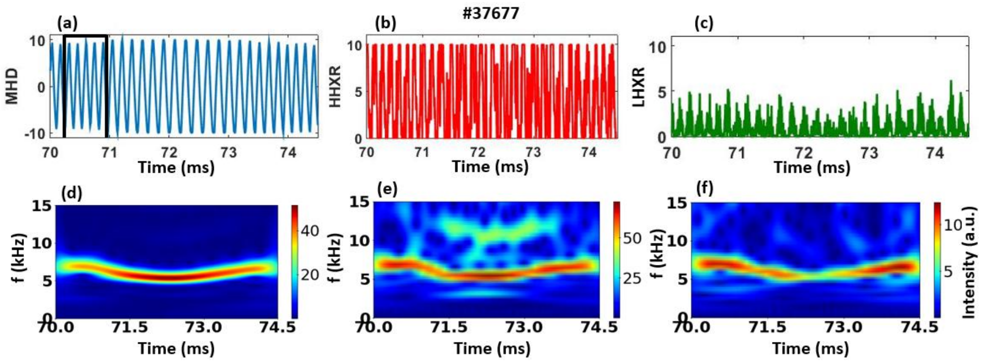

Fig. 2: (a) the MHD activity (solid black line: gas puff), (b) HHXR, (c) LHXR for #37677 for t = 70.0-74.5 ms; (d), (e), (f): the CWT of MHD, HHXR, and LHXR, respectively

A detailed analysis revealed that along with the periodic modulation of LHXR, there appears a phase difference between the LHXR and HHXR in the LHCD assisted plasma discharges in the ADITYA-U tokamak. For #37677, the LHXR and HHXR are in phase before t = 71 ms at which the gas puff is turned off, which decreased the MHD frequency and consequently a phase difference starts developing between LHXR and HHXR for ~ 4 ms before they start again in phase with each other (as shown in Fig. 3). This has been observed in several plasma discharges and different experimental conditions i.e. reversing the direction of toroidal magnetic field and ohmic current.

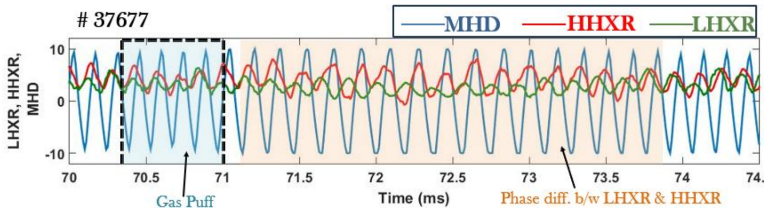

Fig. 3: Variation of phase difference between LHXR and HHXR for #37677

The study highlights that high-energy and low-energy runaway electrons respond differently to MHD perturbations, influencing their confinement and transport. This reveals that the transport of energetic electrons in presence of MHD activity is dependent on energy of the electrons. These observations enhance the understanding of the interactions between different electron populations and the MHD activity within tokamak plasma which can help in designing control strategies for mitigating runaway electron effects, optimizing plasma confinement, and ensuring the stability of future fusion devices.

References

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