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Impact of MHD activity on the dynamics of energetic electrons in ADITYA-U tokamak

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In tokamaks, energetic electrons are predominantly 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 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. In contrast, the high energy hard X-ray (HHXR), detected by NaI scintillator detectors 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 Fig1. The MHD activity driven modulation in the LHXR and HHXR is shown in Fig. 2.

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 (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.

This 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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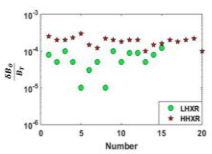

Fig. 1.: Threshold magnetic field perturbation for LHXR and HHXR

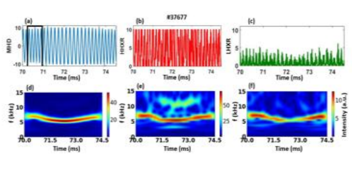

Fig. 2: (a) the MHD activity (solid black line: gas puff), (b) HHXR, (c) LHXR for #37677 for t = 70.0-74.5 ms; (d), (e), (f): the CWT of MHD, HHXR, and LHXR, respectively

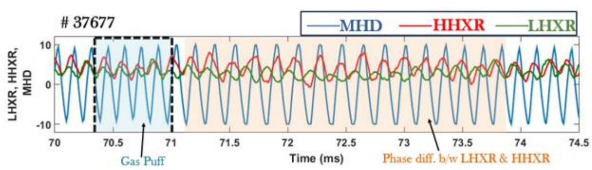

Fig. 3: Phase difference between LHXR and HHXR