SYNOPSIS

EFFECT OF ELECTRON CYCLOTRON WAVES ON PLASMA WITH RUNAWAY ELECTRONS

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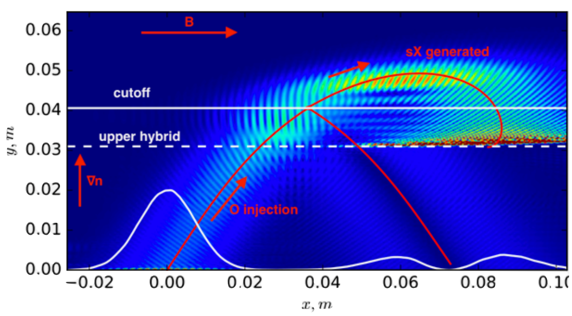
Runaway electrons generated during tokamak disruptions are a major concern for the safe operation of future tokamaks. These energetic electrons can carry significant current and cause severe damage to a tokamak. Interaction of runaway electrons with waves is one of the potential mechanisms for their mitigation. This study investigates the effect of electron-cyclotron (EC) waves on post-disruption plasma with runaway electrons. Both the direct resonant wave-particle interaction and the indirect effect due to the heating of the ambient plasma are considered. We report on DIII-D experiments in which EC heating during the runaway electron plateau resulted in a significant increase of plasma density, loop voltage and runaway synchrotron emission.

"Free space" Ordinary (O) and eXtraordinary (X) mode EC waves are routinely used for plasma heating (ECH) and current drive. However, these modes do not interact directly with relativistic electrons and cannot be injected into plasma with a density above the corresponding cutoff density. In contrast, the internal slow-X mode (sX) is capable of resonant interaction with runaway electrons, and there is a possibility for the generation of sX-mode via the so-called O-sX mode conversion process (see Fig. 1). The O-sX-mode conversion has been previously investigated for heating and current drive in overdense plasmas of tokamaks [1] and stellarators [2] and is considered for future experiments [3].



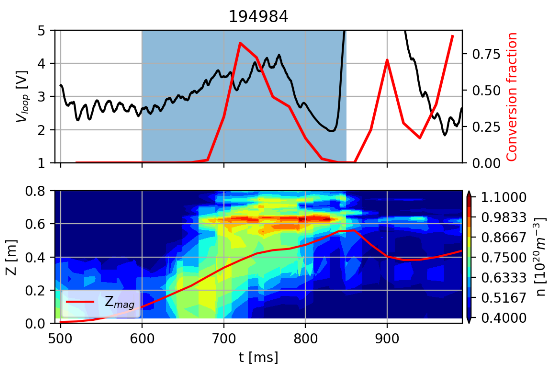


Fig. 1 (Left) Example Full Wave calculation of the O-sX conversion process. O-mode is injected from the bottom left and is partially reflected from the corresponding cutoff. The generated sX-mode is compressed near the Upper Hybrid resonance surface. Fig. 2. (Right) Time-trace of DIII-D shot #194984. The increase of the loop voltage is registered when ECH (grey area) enters O-sX-mode

conversion regime as plasma is moved upward (mode conversion fraction is indicated with red curve). The corresponding plasma density measurement (along the vertical Thomson Scattering chord) shows formation of a strong density peak near the O-mode cut-off (bottom panel), where the sX mode should predominantly reside.

Efficient O-sX conversion requires careful control of the plasma configuration and the O-mode launch parameters. We have developed a scheme that allows efficient O-sX conversion in the post-disruption runaway plateau regime on the DIII-D tokamak. We report on experiments conducted on DIII-D in which the application of ECH during the runaway electron plateau resulted in a significant increase of the background plasma density (apparently exceeding the cutoff density), together with a doubling of the loop voltage and of the runaway electron synchrotron emission. These observations indicate an effective mitigation of the runaway electron beam. The effect is more pronounced when the pre-calculated O-sX conditions are met, a characteristic density spike forms on the density profile in this case (see Fig. 2).

Full wave modelling predicts a relatively high conversion efficiency of up to 75% for optimal O-sX conversion conditions in the experiment. The reflected power may have been dissipated at the plasma edge or at the wall, but most of the power is expected to heat the surrounding plasma via collisional dissipation and to interact resonantly with the runaway beam.

Kinetic modeling and 1D impurity and neutral transport modeling suggest that collisional dynamics play a significant role in the observed effects. Heating of the ambient plasma increases the ionisation level of the argon impurities and their local concentration, making runaway scattering more efficient. This effect appears to overwhelm the resonant interaction.

Although we observed a pronounced effect of the ECH on post-disruption runaway plateau, we did not register any direct evidence of a resonant wave-particle interaction (the indirect effects due to background modification appear to overwhelm it). Nonetheless, our study highlights the potential of ECH/O-sX heating as a novel approach to control runaway electrons via one of the two mechanisms: heating of the background plasma or resonant wave-particle interaction.

Work supported by US DOE under DE-FC02-04ER54698 (D3D), DE-SC0021622 (Frontiers), DE-SC0022270 (CU), and DE-FG02-07ER54917 (UCSD). This work was supported by the US Department of Energy Office of Fusion Energy Sciences at Lawrence Livermore National Laboratory (LLNL) under contract No. DE-AC52-07NA27344. This work was supported by the US Department of Energy Office of Fusion Energy Sciences at Oak Ridge National Laboratory (ORNL) under contract No. DE-AC05-00OR22725.

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