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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. Therefore, mitigating runaway electrons is essential for the safety and efficiency of fusion devices. 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. "Free space" O- and 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 is capable of resonant interaction with runaway electrons.

We report on experiments conducted on the DIII-D tokamak, where the internal slow X-mode was generated via the so-called OXB (Ordinary- to eXtraordinary- to Bernstein-) mode conversion, a process previously explored in space plasmas to understand planetary radio emissions, auroral kilometric radiation, and particle acceleration. The OXB process has also been considered for heating and current drive in overdense plasmas of tokamaks and stellarators.

In this experiment, the application of ECH during the runaway electron plateau resulted in a significant increase in background plasma density, along with a doubling of the loop voltage and runaway electron synchrotron emission. These observations indicate effective mitigation of the runaway electron beam. It is noteworthy that when pre-calculated OXB conditions are met, a characteristic density spike forms on the density profile.

Kinetic modeling and 1D impurity and neutral transport modeling suggest that collisional dynamics play a significant role in the observed effects. The modeling indicates that a further increase in background density and temperature is prevented by strong line emission resulting from high argon (Ar) concentration. A reduction in Ar content is expected to allow for higher background temperatures, potentially permitting kinetic instabilities of the runaway electron beam.

The study highlights the potential of ECH/OXB heating as a novel approach to mitigate runaway electrons.

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