Measurement and modeling of sawtooth induced fast ion transport on DIII-D

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Transport of neutral beam generated fast ions in the presence of sawteeth is investigated experimentally at the DIII-D with a suite of newly developed imaging energetic particle diagnostics, which includes two Imaging Neutral Particle Analyzers (INPAs) and one Imaging Fast-Ion D-Alpha (IFIDA) diagnostic. The INPAs and IFIDA measure fast ions that charge exchange with injected beam neutrals and thus provide the local fast-ion distribution. The two INPAs are sensitive to passing and trapped fast ions with energy > 20 keV. The IFIDA integrates fast-ion density in the energy range of 40-80 keV and provides a spatial profile of passing fast-ion density with spatial resolution of ~2 cm and time resolution of 5 ms. The quality of IFIDA images has been significantly improved by optimizing the filter bandpass region and by adding a second camera to measure the background Bremsstrahlung image. The INPA and IFIDA images before and after sawteeth show that high energy (E>40 KeV) passing fast ions are strongly redistributed from the core to the region outside of the q=1 surface, and the central fast ion density can be reduced by ~30%. Lower energy (E<40 keV) passing fast ions have a similar trend, but the relative change is <10%. The trapped particles in all energies are weakly affected, and a few percent increase of trapped particles in the region just outside the q=1 surface is observed. TRANSP code with kick model and gyro-fluid FAR3d code have been applied to model sawtooth induced fast ion transport, and the simulation results qualitatively agree with the measurements. The TRANSP simulations with kick model show a core fast-ion density reduction similar to experimental observations. The FAR3d linear simulations reproduce the destabilization of an internal kink mode in the core with a frequency similar to the experimental observations. The FAR3d nonlinear simulations show that the breakdown of the magnetic flux surface leads to a partial de-confinement of the thermal plasma and fast ions. The FAR3d simulations with passing fast-ion distribution as input shows sawtooth can cause 3-6% fast ion losses. The measurements and modeling results also qualitatively agree with Kolesnichenko's theory on sawtooth–fast ion interaction. A detailed comparison will be made towards validating Kolesnichenko's theory.

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