Magnetic reconnection rate during sawtooth crashes in ASDEX Upgrade and EAST

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Sawtooth oscillations are internal relaxation events in a tokamak, in which the heat and current in the core of the plasma are redistributed at regular intervals in time. The oscillations are characterized by a fast loss of electron thermal energy in the central region (i.e., crash) followed by a slow recovery (i.e., ramp-up). Despite extensive studies on the instability and its control, the theoretical understanding of the phenomenon, particularly the crash phase, remains incomplete.

The sawtooth crash phenomenon is a driven magnetic reconnection with a strong guide field (a magnetic field directed perpendicular to the merging field lines). While magnetic reconnection rate in collisional plasma can be successfully described by single-fluid Sweet–Parker model, the same phenomenon in the semi-collisional and collisionless plasmas (fusion relevant) has a more complex nature and observed on the much faster rate than described by the Sweet–Parker model. Three approaches can reproduce the observed reconnection rate in nature and laboratory: plasmoids (multiple X-line reconnection), plasma turbulence, and two-fluid effects (electron pressure gradient, electron inertia, and the Hall term). However, there is no consensus within the community on which approach - or combination of approaches - is responsible for fast reconnection. Our study focuses on the two-fluid effects. In the presence of a strong guide field, the Hall term can be neglected, while the electron pressure gradient and the electron inertia play a key role in accelerating magnetic reconnection in semi-collisional and collisionless plasmas by altering the structure of the current layer.

Magnetic reconnection during a sawtooth crash in a tokamak can be characterized by the radial velocity of the hot core. This radial velocity was measured with with electron cyclotron emission imaging diagnostic in ASDEX Upgrade and EAST tokamaks [2,3]. The measurements were compared with nonlinear two-fluid simulation. The findings demonstrate qualitative agreement with theoretical predictions, indicating that two-fluid effects, such as parallel electron pressure gradient and electron inertia, are required to explain the experimental results. Contrarily, the crash time of the Kadomtsev model (based on single-fluid Sweet–Parker model), which is based on a single-fluid picture of magnetic reconnection, disagrees with the experimental results.

Based on data from the ASDEX Upgrade and EAST experiments, as well as simulation results, the reconnection rate for ITER is estimated. The latter can be used to model fast ion redistribution during the sawtooth crashes.

References

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