Numerical studies on sawtooth crashes
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Sawteeth are quasi-periodic events, that flatten the plasma pressure profile inside the q=1 surface on a very short time scale due to a growing m/n=1/1 magnetic island caused by an internal kink mode (q being the safety factor, and m and n are the poloidal and toroidal mode numbers, respectively). Large amplitude sawtooth crashes are able to even trigger additional instabilities such as neoclassical tearing modes that degrade the plasma confinement outside the q=1 surface. In this paper, the dynamics of the sawtooth crash is studied numerically in cylinder geometry using both the reduced MHD equations and two-fluid equations up to realistic Lundquist number S~10^9.

In the framework of reduced MHD equations, for a low Lundquist number, S<10^7, usual sawtooth reconnection as predicted by Kadomtsev's model is found: a m/n=1/1 magnetic island grows while the original core shrinks. For higher S values, however, the mode growth is found to be qualitatively different, and the reconnection process has three phases: (1) Linear and early nonlinear phase: The m/n=1/1 island grows and a thin plasma current sheet forms at the resonant surface; (2) Nonlinear phase: The current sheet brakes up and secondary islands grow. The secondary islands later coalesce into one secondary island, and the reconnection rates become much faster than that described by the Kadomtsev model; (3) Tearing mode phase: The 1/1 and the secondary islands slowly change in the tearing mode time scale. The saturation of the latter stops the fast reconnection process. The final state is a helical equilibrium with two coexisting islands.

In the framework of two-fluid equations, fast sawtooth crashes with crash times comparable to experimental observations (of the order of 50μs) are found for plasma parameters typical for ASDEX Upgrade discharges. Secondary islands also appear for sufficiently high S values, but they usually survive only for a short period during mode growth. The electron pressure gradient in the generalized Ohm's law is the dominant effect, allowing for the fast reconnection and the X-point structure. Furthermore, a local sheared plasma flow is found to be driven by the internal kink mode. This plasma flow is in the counter (co-) current direction inside (outside) the q=1 surface during the linear phase and propagates towards the magnetic axis during nonlinear mode growth. After the sawtooth crash, the driven plasma rotation is in the co- (counter-) current direction inside (outside) the q=1 surface, in agreement with TCV experimental observations.