Fast sawtooth reconnection at realistic Lundquist numbers

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As in many astrophysical plasmas, magnetic reconnection in low collisional fusion plasmas is found to be much faster than predicted by resistive MHD theory. For the most ubiquitous fast reconnection events in tokamaks, the quasi-periodic sawtooth crashes, the observed reconnection times are of the order of \(\sim 100\ \mu s\), several orders of magnitude faster than predicted by the Kadomtsev model \cite{Kadomtsev}. In two-dimensional resistive MHD simulations at high Lundquist numbers however, one finds that the Sweet-Parker current layer becomes unstable to a super-Alfvénic plasmoid instability \cite{Loureiro}. Without a guide magnetic field, the critical S value for the onset of this instability has been found to be approximately \(10^4\), with the linear growth rate of the instability scaling as \(S^{1/4}\). In the fully developed statistical steady state, the normalized average reconnection rate becomes nearly independent of S \cite{Bhattacharjee}.

A similar behaviour is observed in resistive MHD simulations of sawtooth reconnection in cylindrical geometry with circular plasma cross section at realistically high Lundquist numbers (\(10^7 \ldots 10^9\) - based on the toroidal field). After the initial growth of an \(m/n=1/1\) island, a thin current layer develops at the X-point region, which becomes tearing unstable, breaking up into one or several islands (plasmoids). The number of plasmoids increases with the S-number, concomitant with a narrowing of the current layer. This formation of the plasmoids significantly accelerates reconnection. Later on, however, the secondary islands coalesce - independently of the magnitude of S - into a single island, ultimately giving rise to a long-living helical state. Two-fluid effects – in the case of fusion plasmas the parallel electron pressure gradient in Ohm’s law - further accelerate the reconnection process. An X point rather than a Sweet-Parker current sheet forms which allows for larger plasma outflow velocities \cite{Schmidt}. For sawtooth reconnection, we find reconnection times as experimentally observed, independently of the Lundquist number for \(S>10^7\).

\cite{Bhattacharjee} A. Bhattacharjee, Y.-M. Huang, H. Yang, and B. Rogers, Phys. Plasmas 16, 112102 (2009).

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