EFTC 2017
17th European Fusion Theory Conference
9 - 12 October 2017, Athens - Greece

Fast secondary reconnection and the sawtooth crash

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The sawtooth cycle is an almost periodic oscillation of temperature in a tokamak plasma, characterized by a slow growth and a fast collapse [1]. The internal kink mode instability is typically considered an ingredient of this cycle, although in resistive MHD theory its growth rate is found too slow to account for the observed fast sawtooth collapse, especially in weakly collisional plasmas. For these reasons, non-collisional effects are usually called for to explain experimental observations [2].

In this work, we approach this problem from a different point of view, by performing an analysis of secondary reconnecting instabilities in thin current sheets with both resistive and electron inertia effects. We show that when the current sheet is generated by a primary instability of the internal kink type (large Δ' regime), reconnection proceeds thanks to a secondary tearing-mode developing on a time scale much shorter than the primary instability characteristic time. By applying these results to the purely resistive reconnection regime, we obtain estimates in agreement with the numerical results obtained by Yu et al. [3] for the nonlinear dynamics of the internal kink instability in a cylindrical tokamak.

By extending the analysis to include electron inertia terms, we find that non-collisional physics becomes important for the sawtooth crash when the Lundquist number exceeds a value which scales like $S\sim(R/d^e)^{12/5}$ in terms of the tokamak major radius R and of the electron skin depth d^e. This value is commonly achieved in present day devices. By comparison, the criterion for the transition to the collisionless regime of the internal kink is $S\sim(R/d^e)^3$, hard to achieve except in JET. As collisionality is further reduced, the characteristic rate increases, approaching Alfvénic values when the primary instability approaches the collisionless regime. One finds that the overall minimum normalized growth rate of the secondary instability scales like $\gamma\sim(d^e/\mathrm{R})^{2/5}$, corresponding to a crash time in the tens of microseconds range as observed in experiments. One can conclude that taking into account secondary instabilities in the sawtooth mechanism provides an explanation of both fast crashes and of their broad range of occurrence in experimental devices [4]. Further results of the ongoing work aimed to assess the above picture with numerical simulations will also be presented at the conference.

References

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