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Strong toroidal electric field generation during sawtooth crashes

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Sawtooth crashes are common phenomena in tokamaks and play a significant role in tokamak performance, as they can trigger neoclassical tearing mode instabilities on other rational surfaces. Although they have been observed for more than 40 years, the physics underlying the fast reconnection during sawtooth crashes remains unclear. Since the reconnection rate is proportional to the parallel electric field, a strong toroidal electric field should be generated during fast crashes. Recently, a strong core inductive electric field, which is several orders of magnitude larger than the resistive diffusion of the plasma current on the magnetic axis, has been observed during sawtooth crashes on DIII-D. [1]

In this work, we numerically investigate sawtooth crashes with Resistive-, Hall-, and bi-fluid MHD models through the three-dimensional, toroidal-geometry, nonlinear MHD code CLT.[2] The bi-fluid MHD model is slightly different from the Hall-MHD model by neglecting ion polarization drift term in generalized Ohm's Law. The evolutions of the maximum values of the toroidal electric field with the three different models are shown in Figure 1. At the beginning, the toroidal electric field is balanced by the resistive diffusion ($\eta J_0 \sim 3\times10^{-6}$). It significantly increases during sawtooth crashes. With Resistive-MHD model, the maximum value increases 100 times. However, with Hall- or bi-fluid MHD model, the maximum toroidal electric field can be 1000 times larger than the resistive diffusion, which is well consistent with experimental observations.

The generation of a strong toroidal electric field leads to fast reconnection during sawtooth crashes, and it is the reason why there is an explosive growth in bi-fluid or Hall-MHD simulations (Figure 2). The strong toroidal electric field and the explosive growth are related to two-fluid effects and are often attributed to the parallel electron pressure gradient. However, we find that the polarization drift term in the generalized Ohm's law is also critical during the fast reconnection process. For bi-fluid MHD simulation, the maximum growth rate is 0.0069 and is 250% larger than its linear growth rate; for Hall-MHD simulation, the maximum growth rate is 0.0106, which is 50% larger than that in bi-fluid MHD simulation.

The polarization drift term in the generalized Ohm's law is related to the formation of the quadrupole field. In this talk, we will also provide a theoretical analysis to explain how it plays an essential role within the reconnection layer. Without this term, the kinetic Alfven wave, which is crucial for fast reconnection with strong guiding field, is filtered. This is the reason why the maximum value of the toroidal electric field in Hall-MHD simulation is much larger than that in bi-fluid simulation.

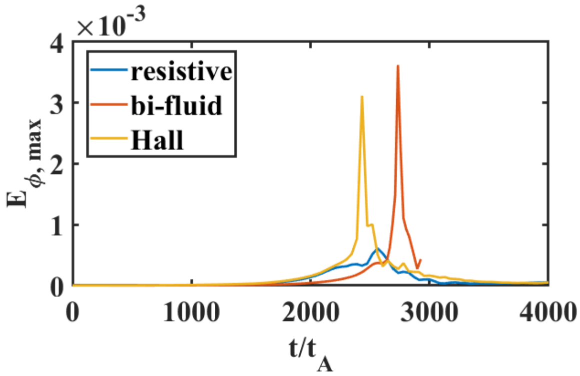

fig 1 Evolutions of the maximum values of the toroidal electric field during sawtooth crashes with resistive-, bi-fluid, and Hall- MHD models.

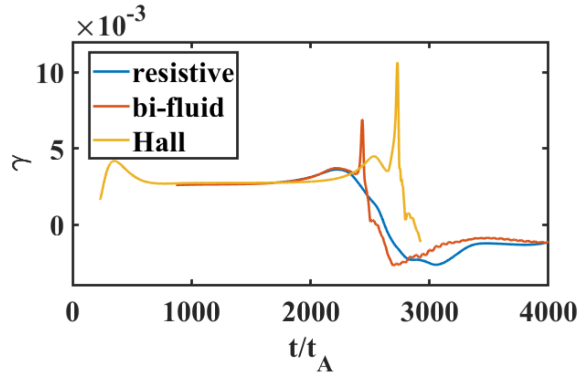

fig 2 Evolutions of the growth rate during sawtooth crashes with resistive-, bi-fluid, and Hall- MHD models.

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