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# Two-fluid sub-grid-scale viscosity in nonlinear simulation of ballooning modes in a heliotron device

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Nonlinear growth of ballooning modes in a heliotron device is studied by means of two-fluid numerical simulations. A model to substitute an influence of the scales smaller than the grid size, Sub-Grid-Scale (SGS), on the scales larger than the Grid Scale (GS) is introduced. A simulation with the SGS model, a Large Eddy Simulation (LES), of two-fluid MHD model successfully shows growth of the ballooning modes with a diamagnetic flow and nonlinear saturation, showing usefulness of the LES approach.

In order to enable two-fluid simulations of ballooning modes and clarify saturation mechanism of the modes in a heliotron device, we focus on influences of the SGS modes truncated because of the finite numerical resolution, instead of adopting an unphysically large viscosity. Since the truncation often contaminates nonlinear dynamics of the GS modes, compensating the influences of the SGS modes to the GS modes by a SGS model is essential. The SGS terms in two-fluid momentum equations can be modeled by the SGS viscosity and the resistivity which are composed of the rate of strain tensor, the fluctuation part of current density and two model constants.

Firstly the two model constants are calibrated by comparing a direct numerical simulation and LESes of homogeneous magnetized Hall MHD turbulence. A full 3D simulation of the ballooning modes in Large Helical Device with a small viscosity shows that the the SGS viscosity can become locally considerably large. Secondly, it is shown in full-3D two-fluid MHD simulations that a diamagnetic flow generated by the two-fluid term is coupled with the ballooning modes and restricts the instability to relatively low modes. By the use of the SGS model, our LESes are carried out without numerical instability even though high modes grow in linear phase, and the computational cost is reduced to about 1/64 of a precise simulation with a large number of grid points.

In summary, our two-fluid MHD LESes achieve a nonlinear saturation of ballooning modes with a small viscosity. The LES approach enables a drastic reduction of the computational cost and better representation of dynamics in two-fluid simulations. The SGS-modeling in the pressure equation is left for future. Further results together with related subjects such as slab Rayleigh-Taylor instability will also be reported.

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