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LHDバルーニング不安定性の２流体ラージ・エディ・シミュレーション
Two-fluid Large Eddy Simulation of Ballooning Instability of LHD

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Nonlinear evolution of ballooning modes under influences of two-fluid effects in Large Helical Device (LHD) is studied by means of Large Eddy Simulations (LES). LES is a method of a numerical simulation in which governing equations are coarse-grained and models 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) are introduced in the filtered equations. We have developed SGS models suitable for two-fluid MHD simulations. Our LESes show growth of the ballooning modes preserving linear nature well and nonlinear saturation, representing usefulness of the LES approach.

We focus on SGS effects which are often truncated because of the finite numerical resolution. It is well known that a simple and artificial truncation of high (SGS) modes without compensation of influences of high modes on low (GS) modes can often bring about strong back-scatter of the energy toward low modes. In order to avoid the backscatter, we need to compensate the influences of the SGS modes to GS modes by a SGS model is essential. Our SGS models for the momentum, pressure and magnetic field equations consist of the rate of strain tensor S_{ij}, the current density J_i, temperature T and three model ν_{SGS}, κ_{SGS}, η_{SGS} as [1,2]

$$
\begin{aligned}
\tau_{ij} &= -\nu_{SGS}\widetilde{S}_{ij}, \\
\Phi_i &= -\kappa_{SGS}\overline{\rho}\frac{\partial \widetilde{T}}{\partial x_i}, \\
E_i^M &= -\eta_{SGS}\overline{J}_i. \\
\nu_{SGS} &= C_\nu \mu_{SGS}, \\
\kappa_{SGS} &= C_\kappa \mu_{SGS}, \\
\eta_{SGS} &= C_\eta \mu_{SGS}, \\
\mu_{SGS} &= \left(C_\nu \frac{1}{2}\overline{S}_{ij}^2 + C_\eta \overline{J}_i^2 \right)^{1/2} \Delta^2.
\end{aligned}
$$

Here Δ is the mean grid width. The three models ν_{SGS}, κ_{SGS}, η_{SGS} include constants Cν, Cκ, C_η which are often called as the Smagorinsky constants.

The three model constants are calibrated by comparing a high-resolution 3D simulation of the ballooning modes in Large Helical Device with a small viscosity, showing that the SGS viscosity can become locally considerably large. Next it is shown by LESes of two-fluid equations that a diamagnetic flow generated by the two-fluid term (Fig.1) is coupled with the ballooning modes and modify the evolution of unstable modes. Our LESes are carried out without numerical instability even though unstable GS modes grow in linear phase, and achieve nonlinear saturation. The computational cost is reduced to about 1/64 or smaller than that of a more precise simulation.

In summary, our two-fluid 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.

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[2] MIURA, H. et al., the 26th IAEA-FEC TH/P1-5 (Oct. 13-22 2016, Kyoto, Jpanan).

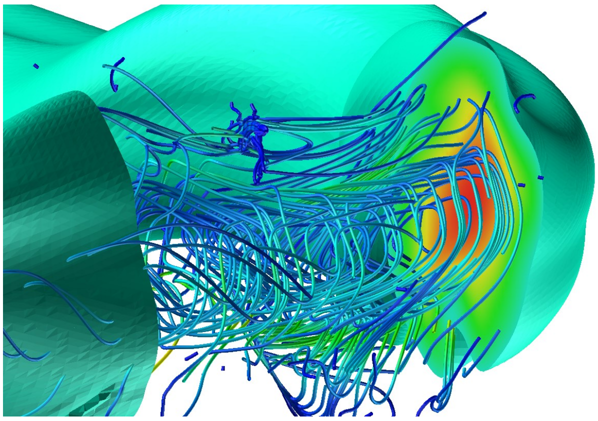

Fig.1: Diamagnetic flow generated through evolution of ballooning modes in an LES of two-fluid MHD equations.