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Development of resistive wall mode analysis code for rotating plasmas and its application to JT-60SA

回転プラズマにおける抵抗性壁モード解析コードの開発及びJT-60SAへの応用

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A new code is developed to study linear stability of resistive wall modes (RWMs) in tokamak geometry including plasma rotation. “RWMaC” modules have been developed, which solve electromagnetic dynamics in vacuum and the resistive wall. The RWMaC modules have been implemented in the MINERVA code, which solves the linearized ideal magnetohydrodynamic equations in tokamak geometry. The MINERVA/RWMaC has been benchmarked with the MARS-F code. Numerical results will be reported, which analyze the RWMs in JT-60SA plasmas.

1. Background

Unstable resistive wall modes (RWMs) limit the achievable beta value in high-beta steady-state tokamaks [1], and hence, they should be stabilized or controlled for operation of advanced tokamaks such as JT-60SA [2]. The RWMs originate from the ideal external kink modes, which can be stabilized by effect of vacuum surrounded by a wall. When the wall is sufficiently close to the plasma surface, it yields eddy currents to cancel the penetration of the magnetic field. However, the eddy current decays in the time scale defined by the wall resistivity, which results in unstable RWMs.

Theoretical [3] and experimental [4] researches have revealed that the plasma rotation is one of the most promising methods to stabilize RWMs. In rotating plasmas, there’re many physical processes that contribute to stabilization: the Alfven or slow wave continuum damping [5], dissipation [6] such as resistivity, and the kinetic resonance [7].

A linear ideal magnetohydrodynamics (MHD) code forms a basis for quantitative analysis of the above processes. Toward that end, the “RWMaC” modules have been developed to solve electromagnetic problems in vacuum regions and the resistive wall in tokamak geometry [8]. The RWMaC modules were implemented in the MARG2D code [9], which solves the modified 2D Newcomb equation, and have been benchmarked with the NMA code [10]. In this study, a new RWM code is developed by utilizing the RWMaC modules to study rotation effects on RWMs in tokamak geometry.

2. Development of new RWM code

Basic theory of the new code is briefly reviewed. Figure 1 shows the system under consideration. Axisymmetric plasma is surrounded by an axisymmetric resistive wall.

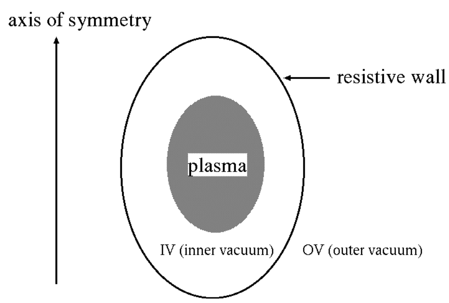

Fig.1. System under consideration.

The vacuum between the plasma surface and the wall is named inner vacuum (IV) and the vacuum outside the wall outer vacuum (OV). The energy balance in the plasma-vacuum-wall system reads $K + W_P + W_{IV} + W_{OV} + D_W = 0$, where K is the kinetic energy, W_P the potential energy including rotation, $W_{IV(OV)}$ the vacuum magnetic energy in IV (OV), and D_W the energy dissipation in the resistive wall. The energy functionals related to plasma dynamics, i.e. K and W_P, can be computed by the MINERVA code [11]. MINERVA solves the Frieman-Rotenberg equation [12] (linearized ideal MHD equations with rotation) in tokamak geometry by the initial-value approach as well as the eigenvalue problem. RWMaC modules compute the remaining energies, i.e. $W_{IV(OV)}$ and D_W by solving Maxwell's equations in vacuum regions and the diffusion equation on the resistive wall. By implementing RWMaC modules in MINERVA, it becomes possible to study the rotation effects on RWMs. The details on theory and numerical schemes will be reported in the talk.

3. Benchmark and application to JT-60SA

A benchmark effort with the MARS-F code [13] has been started. The MARS-F code solves the eigenvalue problem associated with the linearized ideal MHD equations with some additional dissipation mechanisms. The MARS-F code is now a widely-used code.

To remove errors arising from numerical computation of equilibria, an analytic Solov'ev equilibrium without rotation has been employed. It has been confirmed that the marginal wall position for the external kink modes coincides. Figure 2 shows the benchmark results of RWM growth rates for wide ranges of wall position and wall diffusion time (τ_w), which indicates the good agreement between the MINERVA and MARS-F. It should be noted that the MINERVA computed the growth rate (and real frequency) by the initial value problem as well as the eigenvalue problem.

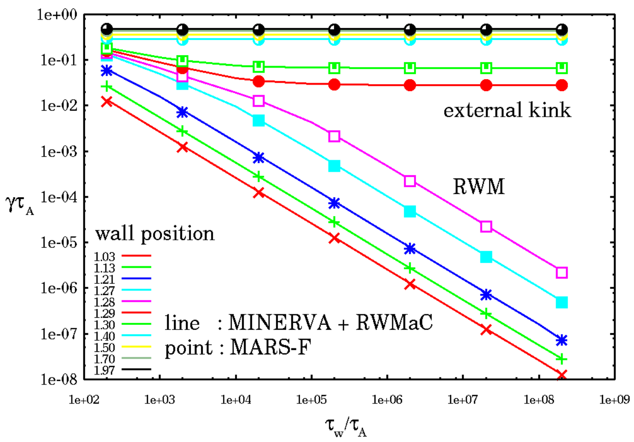

Fig.2. Benchmark results between MINERVA and MARS-F.

Here, τ_A is the Alfven transit time and wall position is defined by wall minor radius/plasma minor radius. The benchmarking effort including rotation is under progress.

One of the most critical goals of the JT-60SA tokamak is to realize the steady-state high-beta plasmas. These plasmas are prone to unstable RWMs. To study RWMs in JT-60SA, the RWMaC modules have been modified to include the JT-60SA wall shape. In the talk, the detailed numerical results will be reported for high-beta equilibria obtained in JT-60SA design study, especially focusing on the rotation effect.

4. Summary

In summary, new modules named "RWMaC" have been developed to solve the electromagnetic problems in vacuum regions and the resistive wall in tokamak geometry. The RWMaC modules have been implemented in linear ideal MHD code MINERVA. The new code has been benchmarked with the MARS-F code, which shows the good agreement for wide ranges of wall position and wall diffusion time. The new code is now being applied to the analysis of JT-60SA plasmas.

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