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Island Formation and Nonlinear Stability for Helical Plasmas Using the HINT code

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I. Introduction

Behavior of magnetic islands and breaking of magnetic surfaces in finite pressure equilibria are important issues to be studied for helical plasmas. In the LHD experiments, actually, indications of shrink/growth of magnetic islands due to finite pressure effects are observed [1]. Another interesting observation in LHD is formation of pedestal-like pressure profile [2]. The HINT code is a three-dimensional magnetohydrodynamic equilibrium code, and has been developed to study magnetic island formation in finite pressure equilibria of helical plasmas[3,4]. It has been extensively used to analyze properties of helical equilibria, such as Heliotron/Torsatron [5-7], Helias [7,8], and Heliac [9], and has revealed that the equilibrium beta limit is often determined by breaking of magnetic surfaces rather than the amount of the Shafranov shift. It has also revealed that a favorable property of the self-healing of magnetic island can occur in some cases of helical equilibria, in which the size of magnetic island shrinks as an increase in the beta value [7,8,10]. In this paper, we describe an extension of the HINT code in a couple of directions. The HINT code has been further extended to study nonlinear development of ideal/resistive unstable modes in helical plasmas. We describe observed growth of resistive ballooning type mode in an LHD-like configuration.

II. Extension of the HINT code

One extension of the code is a modification to treat coil currents existing in the computation area. So far in a HINT computation, the computation region has been carefully chosen so that coil currents were avoided form the region. This treatment had been unavoidable to relax the numerical restriction, which is called the Courant condition, caused by high speed Alfven wave due to the existence of large amplitude magnetic field near the coils. A new numerical technique has been developed to overcome the restriction. By this modification, the code can be applied for any configurations of helical plasmas more easily. As a test case, we have studied island formation in equilibria of a quasi omnigeous configuration, for which modular coil currents exist inside the computation boundary, and have confirmed the validity and usefulness of the modified code (see Fig.1). Another extension of the code is modifications to treat helical equilibria with the net toroidal current, including the neo-classical current effects [11,12], and also to treat a full-torus helical equilibria, including the effects of the n=1 local island divertor [13]. As a result of development of those modifications, the HINT code is now used to analyze behavior of magnetic islands observed in the actual experiments, such as the n=1 island in LHD.

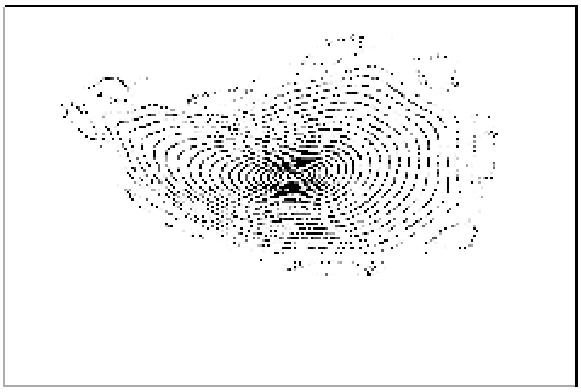

Fig.1 Computation of finite pressure equilibrium of helical plasma by using the modified HINT code, in which the coil current exists in the computational region.

III. Nonlinear Evolution of Resistive Ballooning mode in Helical Plasma

In order to study three-dimensional nonlinear behavior of a helical plasma, we have developed a new magnetohydrodynamic simulation code which solves a full set of resistive and viscous MHD equation in a helical-toroidal coordinate system. The main target is to investigate self-consistent relaxed state of plasma profiles after evolution and saturation of mild pressure-driven instabilities. Here we describe some preliminary results for an LHD-like helical plasma obtained by the code. As a first step, we execute the nonlinear computations under the condition that the so called stellarator symmetry is kept, which means that the computation is done for a half period of the helically twisted LHD configuration. Initial equilibria are obtained by the HINT code, where the magnetic axis of the vacuum field is located 17cm inside of the center of the poloidal cross section. Shown in Fig.2 is the time-evolution of the total kinetic energy for several values of the resistivity η and the viscosity μ for equilibria with $\beta(0)$=4% and 8%. Exponential growth of instabilities are observed when η is sufficiently large and μ is sufficiently small. The growth rate of the kinetic energy is almost proportional to a power of the resistivity, which is typical to a resistive instability.

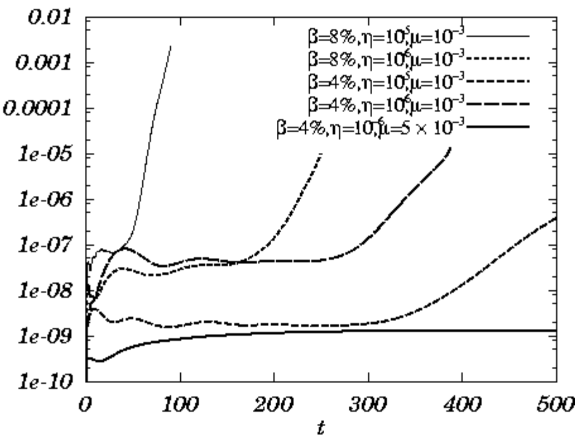

Fig.2 Time evolution of the total kinetic energy for several values of η, μ and $\beta(0)$.

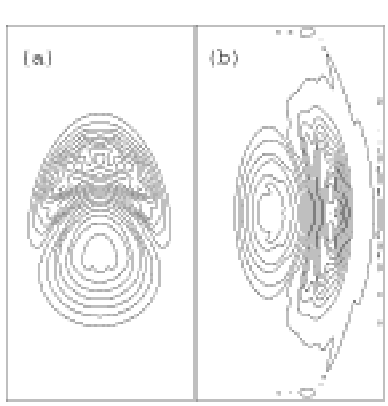

Fig.3 Contour plots of the toroidal current for two cross sections.

Contour plots of the toroidal current on two poloidal sections are shown in Fig. 3 (a) (horizontally elongated cross section) and (b) (vertically elongated cross section), for the case with $\beta(0)$=4% , η=10(-6), and μ=10(-3). Some deformation in contour lines are seen in the upper (right-hand) side of Fig.3 (a)(Fig.3(b)), which corresponds to the outer direction of the torus. The deformation is more significant on the horizontally elongated cross section (Fig.3(a)), where the curvature of the magnetic field is the worst. Those observations suggest that the exponential growth is brought by a resistive ballooning mode.

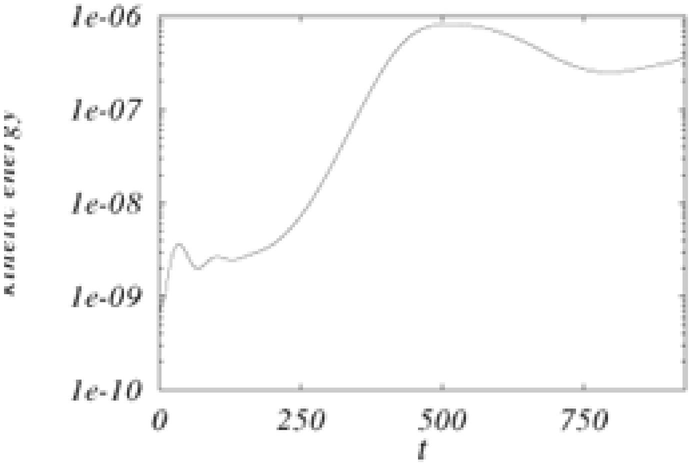

Fig. 4 Nonlinear behavior of the total kinetic energy for the case with β (0)=4%, η =3.2x10(-6), and μ =3 x 10(-3).

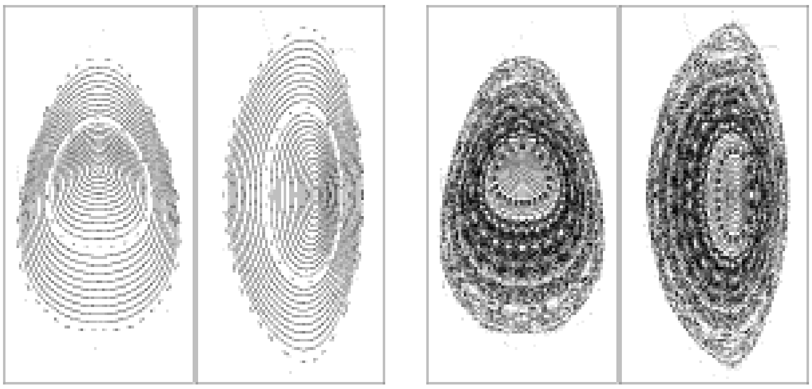

Fig.5 Poincare plots of magnetic field lines at t=0 (left) and t=420 (right).

Shown in Fig.4 is longer time-scale nonlinear behavior of the time evolution of the total kinetic energy for the case with $\beta(0)$=4% , η=3.2x10(-6), and μ=3 x 10(-3). After an exponential growth up to around t=300 τ A (τ A is the toroidal Alfven transit time), the kinetic energy saturates. Poincare plots of magnetic field lines on the two poloidal sections at t=0 and 420 are shown in Figs. 5(a) and (b), respectively. It is observed that in the nonlinear stage the central part of the plasma keeps clear closed surfaces while in the peripheral region surfaces are more or less broken although they are not completely broken and some properties of the closed surfaces still remain. Shown in Fig.6 is a bird s eyes view of the pressure profile on the horizontally elongated poloidal section. Evolution of column-like structures are observed at the peripheral part of the plasma. One-dimensional plot of the pressure profile on the two poloidal sections are shown in Fig.7. We observe that the pressure gradient at the edge region becomes steeper after the nonlinear evolution than that in the initial profile, which indicates formation of a pedestal-like structure.

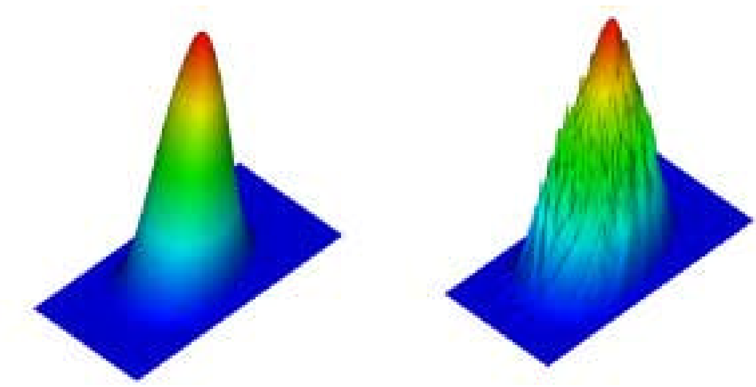

Fig.6 Bird s eyes views of the pressure profile on the horizontally elongated poloidal section at t=0 (left) and t=730 (right).

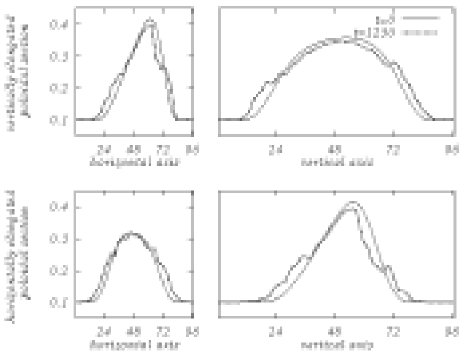

Fig.7 Pressure profile along the horizontal and vertical axes of horizontally-elongated (lower) and vertically-elongated (upper) poloidal sections. Solid lines represent the pressure profile of the initial equilibrium and dashed lines represent the plot at t=730.

IV. Conclusion

Usability of the 3D equilibrium code, HINT, is extended by the modification described in this paper. Nonlinear computations of the LHD-like configuration show formation of pedestal-like structure in the pressure profile as a result of evolution of resistive modes.

Acknowledgements

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