§17. Resistive MHD Stability Studies for LHD Configurations

Garcia, L. (Univ. Carlos III, Spain), Watanabe, K.Y.

Pressure-driven instabilities are a key feature in stellarator stability, since no net toroidal current flows in the plasma, avoiding the appearance of current-driven instabilities. Modes with high poloidal wavenumber m are usually studied using the ballooning formalism, which reduces the stability problem to finding the eigenvalue of a system of differential equations to be solved along the magnetic lines. The stellarator expansion can be applied to study the stability of modes with low toroidal wavenumber n whose variation along filed lines is slow compared with the variation of the stellarator terms. A reduced set of equations expressed in terms of the equilibrium flux coordinates was derived for those modes [1]. They are formally the same as the reduced set of MHD equations for a tokamak.

The calculation of global modes using the full three-dimensional equilibrium has been based on formulations of the ideal MHD energy principle in magnetic coordinates [2, 3]. However, these formulations cannot include the effect of resistivity and are not suitable for nonlinear calculations. In order to be able of studying the nonlinear evolution, we developed a numerical code (FAR3D), which solves the full set of resistive MHD equations [4].

For high-aspect ratio configurations with moderate β-values (of the order of the inverse aspect ratio), we can apply the method employed in Ref. [1] for the derivation of the reduced set of equations without averaging in the toroidal angle. In this way, we get a reduced set of equations using the exact three-dimensional equilibrium. In this formulation, we include linear helical couplings between mode components, which were not included in the formulation developed in Ref. [1].

The method is especially suitable for the study of LHD configurations since they verify the assumptions, and the dominant equilibrium modes are ($m = 1$, $n = 0$), and ($m = 2$, $n = 10$). The effect of the toroidal and helical couplings can be seen in Fig. 1, where the dominant component of the $n = 1$ family is shown for three different linear calculations: When only one dynamical component is included (Cylinder), when only components with $n = 1$ are included (Toroidal), and when components with $n = 1, 9, 11$ are included (Helical). The equilibrium parameters are $R_{ax} = 3.6$ m, $B_q = 100\%$, $\gamma = 1.25$, $I_p < 0$, and correspond to an experimental discharge with localized oscillations at the ($m = 2$, $n = 1$) rational surface [5]. The Lundquist number S is $8{\times}10^7$, and the growth rate increases by more than a factor of 2 from the cylindrical to the full calculation. The dominant radial magnetic field components are shown in Fig. 2. The importance of the helical couplings for the magnetic terms is clear from the Figure.

To ascertain the validity of this reduced set of equations, we have repeated the linear calculation using the full MHD equations in the pressure convection limit [1]. The results practically do not change, and are consistent with the approximations made.

We have studied the nonlinear evolution of these modes without linear helical couplings. Compared to the width of the linear component, the r.m.s. value of the radial velocity widens at saturation, as it happens in the experiment. The calculation of the nonlinear evolution including linear helical couplings is under way.

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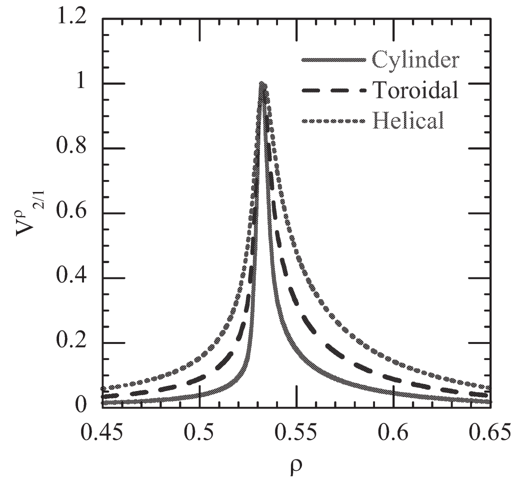

Fig.1 Comparison of the dominant component of linear eigenfunctions with no couplings, with toroidal couplings, and with toroidal and helical couplings. The LHD configuarion is described in the text.

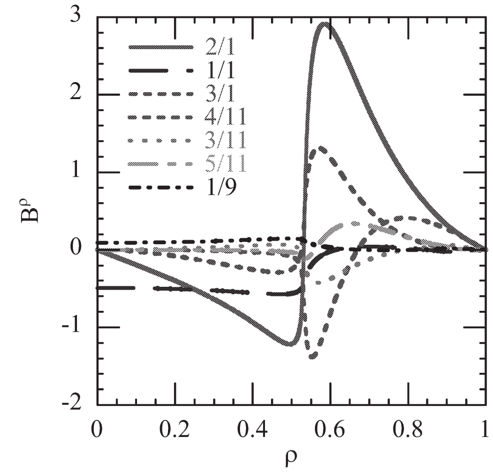

Fig.2 Dominant radial magnetic field components for the case of Fig. 1 with all the couplings included.