§1. 3D MHD Equilibrium with the Stochastic Field

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The MHD equilibrium is the basis of both most theoretical considerations and physics interpretation of the experimental results. As a standard technique to calculate the 3D MHD equilibrium, an inverse equilibrium solver VMEC[1], assuming the existence of perfect nested flux surfaces, is widely used. In such a technique, a magnetic coordinate system is directly constructed so as to satisfy the force balance, or, MHD equilibrium equation, $\vec{J} \times \vec{B} = \nabla p$. For low-β equilibrium, since the magnetic field sustains clear flux surfaces, the standard technique is acceptable. However, by nature, 3D MHD equilibrium has magnetic islands and stochastic regions in the plasma because of the absence of toroidal symmetry. For high-β equilibrium, the degradation of flux surfaces by the finite β effect is not avoidable, so that the standard technique based on the nested flux surfaces could not be directly applicable to them. On the other hand, in recent experiments, various types of 3D MHD equilibrium are obtained, namely, low-shear 3D MHD equilibrium with magnetic islands, 3D MHD equilibrium with multiple magnetic axes, 3D MHD equilibrium with zero rotational transform, two-dimensional (2D) MHD equilibrium with current hole near the magnetic axis. The standard technique based on the nested flux surfaces is not suitable in such situations. In order to analyze such MHD equilibria with magnetic islands and stochastic magnetic field, other techniques are required such as the HINT2[2] and PIES[3] codes.

The HINT2 code is one of such solvers, where a relaxation method based on the dynamic equations of the magnetic field and pressure is used. Details of the numerical scheme of the relaxation process are seen in references. HINT2 code has been applied to the study of MHD equilibrium in many helical configurations, in order to clarify the properties inherent to 3D MHD equilibrium in various types of helical systems.

As mentioned above, the HINT2 code is a powerful and user-friendly code. The demonstration of HINT2 on LHD plasmas was successful. Figure 1 shows a puncture map of magnetic field lines of an outward shifted configuration, R_{ax}=3.85m, γ=1.254, BQ=100%. The initial pressure distribution is prescribed by the function, $p = p_0(1-s)^2$. The peak beta value β_0 is about 5% and the volume averaged beta value <β> is about 2.2%. The axis shifts toward the outside of the torus. Since the magnetic shear is weak in the edge region, edge field lines are strongly ergodized. In fig. 2, profiles of the pressure P/P_0 and connection length L_C corresponding to figure 1 are plotted at the equatorial plane. Despite of changing field lines stochastically, the pressure gradient keeps in the region with long L_C. This suggests a possibility stochastic field lines with long L_C can sustain the plasma pressure.

However, in calculations of configurations with large stochastic region, the convergence problem was appeared by keeping the residual force balance, $\vec{F} = \vec{J} \times \vec{B} - \nabla p$, in the stochastic region. Since stochastic field lines are opened, the pressure gradient along the field line is remained. Thus, the residual force is not balanced. This suggests the plasma pressure in the stochastic region is not the scalar value but the tensor value. In open field lines, the inertial term $(\vec{v} \cdot \nabla \vec{v})_{||}$ and/or viscosity are required to balance to the parallel pressure gradient, $(\nabla \cdot \overleftrightarrow{P})_{||}$.

References

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2) Suzuki, Y., et al., Nucl. Fusion **46**, (2006) L19
3) Reiman, A., et al., Compt. Phys. Commnun. **43** (1986) 157

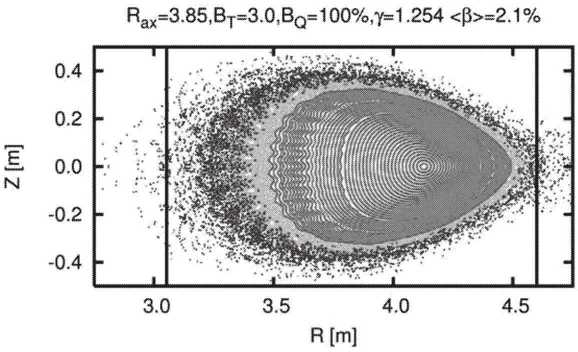

Fig.1. Puncture map of field lines of an outward shifted configuration.

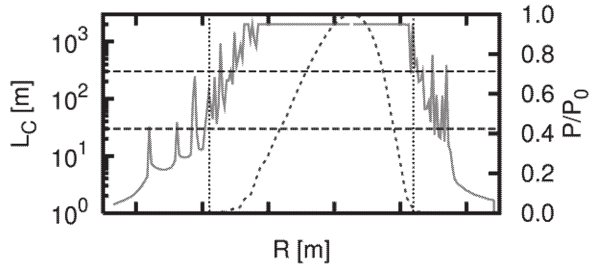

Fig.2. Profiles of the plasma pressure and connection length of field lines corresponding to fig.1.