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Anisotropic plasma MHD equilibrium Analysis in LHD
LHDにおける非等方圧力MHD平衡解析

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In anisotropic plasmas, the pressure components parallel and perpendicular to field lines are not flux surface quantities. The effects on the measured values caused by the pressure distortion from the surface average are investigated in the Large Helical Device (LHD). The MHD equilibria with the anisotropic pressure are studied using a 3D MHD equilibrium code, ANIMEC, which uses the bi-Maxwellian model as an anisotropic plasma pressure model in the 3D geometry. We study the position of magnetic axis and the magnetic flux measurements as candidates of characteristic parameter in the MHD equilibrium. As the results, we find that the position of magnetic axis is not sensitive to the distortion from the flux surface average, but the magnetic flux is sensitive to the distortion. This suggests that the magnetic diagnostics has a possibility to estimate the distortion from flux surface average.

1. Introduction

High beta plasmas in LHD experiments are generated and maintained only by tangentially injected neutral beams. Because of the long slowing down time of high energy particles in low density regimes and the small thermal pressure due to the low field, the beam pressure cannot be ignored compared with the thermal pressure and thereby expected to cause an anisotropy in the pressure with parallel component along the field lines $p_{\parallel}$ greater than $p_{\perp}$, the perpendicular component[1]. The MHD equilibrium theory with the anisotropic pressure predicts that the pressure is not the flux surface quantity. The evaluation of the magnitude of pressure distortion from the flux surface average is an important subject to identify the MHD equilibrium. Recently, a three dimensional MHD equilibrium analysis code, ANIMEC, was developed [2], in which a bi-Maxwellian model was implemented in the VMEC code to take anisotropic pressure into account. In this paper, the effects of the distortion from the flux surface average on the magnetic axis positions and the magnetic flux are investigated for $p_{\perp} > p_{\parallel}$ plasmas.

2. Pressure profile distortion from the flux surface average

The bi-Maxwellian distribution function

$$F_{\mathrm{h}}(s,\varepsilon,\mu) = N(s)\left(\frac{m_{\mathrm{h}}}{2\pi T_{\perp}(s)}\right)^{\frac{3}{2}} \times \exp\left[-m_{\mathrm{h}}\left(\frac{\mu B_{\mathrm{C}}}{T_{\perp}(s)} + \frac{|\varepsilon-\mu B_{\mathrm{C}}|}{T_{\parallel}(s)}\right)\right] \qquad (1)$$

was implemented to energetic ions in the ANIMEC code. Where s is the radial index, $N(s)$ is the density amplitude factor, ε is the kinetic energy, m_{h} is the mass of the high-energy particles, and $T_{\parallel}$ and $T_{\perp}$ are the temperatures of high energy particles in the direction parallel and perpendicular to magnetic field. The value $T_{\perp}/T_{\parallel}$ is related to the pressure anisotropy. B_{c} is a threshold field strength which prescribe the magnitude of trapped particles fraction. The trapped particles are assumed to exist in the surfaces which include smaller field than B_{c}. Fig.1 shows the magnitude of pressure profile distortion from its surface average[5]. For the case which

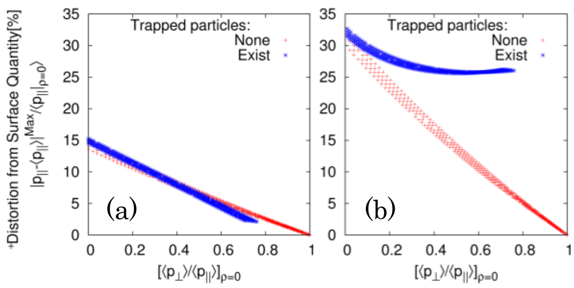

Fig.1 The maximum absolute value of the difference between the parallel pressure and its flux surface average normalized to its average value on axis (a) and the corresponding maximum absolute value for the perpendicular pressure (b) as a function of the ratio of $\langle p_{\perp}\rangle$ to $\langle p_{\parallel}\rangle$ corresponding to the strength of the anisotropy at the magnetic axis[5].

includes trapped particles, the ratio of the surface averaged pressure $p_\perp$ to $p_\parallel$ at the axis $<p_\perp>/<p_\parallel>|_{\rho=0}$ does not be unity even when $T_\perp/T_\parallel = 1$, and the difference of pressure from its averaged value remains considerable, whereas the distortion decrease as $<p_\perp>/<p_\parallel>|_{\rho=0}$ decrease in the case without trapped particle.

2. Effects of the trapped particles on the axis position and the magnetic flux

First of all, we define the equilibrium beta value which is expected to yields the equivalent magnetic axis shift to the isotropic pressure equilibria with the same beta value. From a previous study[6] with CGL formula $\mathbf{p} = p_\perp \mathbf{I} + (p_{\parallel} - p_\perp)\mathbf{nn}$ and a low β ordering, a beta value proportional to the Pfirsch-Schlüter current can be defined [5] as

$$\beta_{eq} = \frac{\frac{1}{2}\int dV\,(p_\parallel + p_\perp)}{\int dV\left(\frac{B^2}{2\mu_0}\right)} \qquad (2).$$

Fig.2 shows the axis position analyzed in

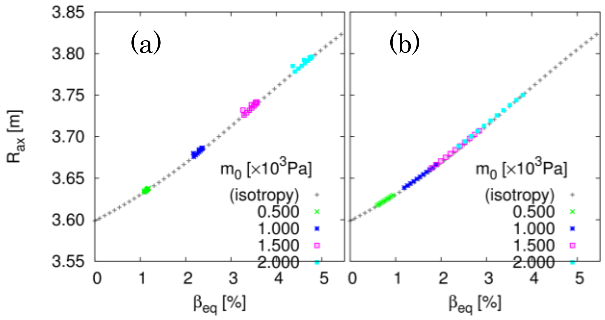

Fig.2 The dependence of the magnetic axis position obtained by a model which trapped particles does not exist(a) and exist(b). The gray points correspond to the isotropic pressure plasma axis positions which $T_\perp/T_{\parallel} = 1$ [5].

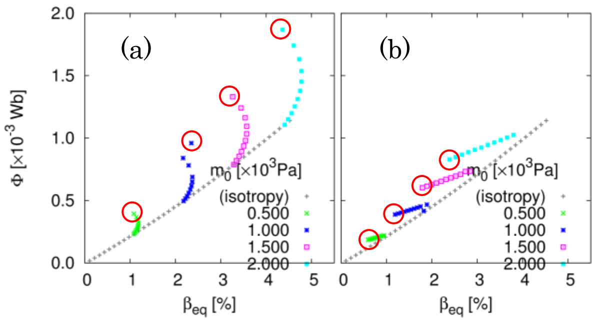

Fig.3 The dependence of the magnetic flux obtained by a model which trapped particles does not exist(a) and exist(b). The gray points correspond to the isotropic pressure plasma axis positions which $T_\perp/T_{\parallel} = 1$[5].

two models. One is the case without trapped particles and another is the case with trapped particles. All of the points in Figs.2 (a, b) nearly coincides to the isotropic case.

Fig.3 shows the estimated saddle type loop flux calculated from equilibrium current. The saddle loop is placed at the bottom of the LHD torus, and can detect the vertical field generated by Pfirsch-Schlüter current. The points housed in red circle represents the results with $T_\perp/T_\parallel = 0$. The magnetic flux varies with the trapped particles exist or not, namely the difference in the shape of velocity distribution and the value deviates from the isotropic case. The saddle loop flux seems to detect the effect of the distortion from the surface average, and therefore, the flux could be a candidate of estimating the distortion.

3. Summary

The distortion of parallel and perpendicular pressure from its surface average are estimated with $p_\parallel > p_\perp$. The distortion, particularly for $p_\perp$ was strongly affected by the presence of the trapped particles. To establish the method of identifying the pressure anisotropy and the shape of velocity distribution, the response of the magnetic axis position and the magnetic flux were examined in LHD magnetic field configurations. For the magnetic axis, the position is depending only on β_{eq}, regardless of the amount of trapped particles or the pressure anisotropy. In contrast, the magnetic flux vary in whether the trapped particles exist or not, or in other words, the difference in the velocity distribution prescribed by B_c. This result suggests that the saddle loop measurement can detect the distortion of pressure from its surface average.

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References

[1] K. Y. Watanabe, *et al.* Fusion Science and Technology **58**, 160 (2010).

[2] W. A. Cooper, *et al.* Comp. Phys. Comm. **180**, 1524 (2009).

[3] T. Yamaguchi, *et al.* Plasma Physics and Controlled Fusion **48**, L73 (2006).

[4] W. A. Cooper, *et al.* Nuclear Fusion **46**, 683(2006).

[5] Y. Asahi, *et al.* Plasma and Fusion Research **6**, 2403123 (2011).

[6] W. N. G. Hitchon, *et al.* Nuclear Fusion **23**, 383 (1983).