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Anisotropic Pressure Effects on Diamagnetic Current in a Magnetospheric Plasma Equilibrium
磁気圏型プラズマ平衡における反磁性電流に対する非等方圧力効果

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We studied effects of pressure anisotropy on magnetospheric equilibria, especially focusing on the diamagnetic current. The current has two contributions; one is from the pressure anisotropy, and the other remains in isotropic equilibria. Since the anisotropic part depends on the gradient of magnetic field rather than the pressure, it can be significant in magnetospheric configurations. If the pressure becomes large, the isotropic part changes magnetic field due to the well-known diamagnetic effect. This nonlinearity results in the change of magnetic field gradient to further increase the importance for the anisotropic part.

1. Background and Motivation

Magnetospheric plasma confinement has been studied in Ring-Trap 1(RT-1) experiment for example. Electron cyclotron heating(ECH) heats only the perpendicular direction to magnetic filed, so pressure anisotropy is important for equilibrium[1]. In the pressent paper, we study effects of pressure anisotropy on magnetospheric equilibria, epsecially focusing on the diamagnetic current.

2. Equilibrium Equation and Diamagnetic Current Including Anisotropic Pressure

Balanced equation of single fluid is

$$0 = \boldsymbol{j} \times \boldsymbol{B} - \nabla \cdot \boldsymbol{p}. \tag{1}$$

One devide this pressure into pararrel and perlendicular component to the magnetic field like $\boldsymbol{p} = p_\parallel \boldsymbol{bb} + p_\perp (I - \boldsymbol{bb})$, where $\boldsymbol{b} := \boldsymbol{B}/B$. So, one can derive the diamagnetic current including anisotropic pressure.

$$\boldsymbol{j}_\perp = \frac{1}{B^2 - \mu_0 (p_\parallel - p_\perp)} \times \left(\boldsymbol{B} \times \nabla p_\perp + \frac{p_\parallel - p_\perp}{B^2} \boldsymbol{B} \times \nabla B^2 \right) \tag{2}$$

Next, we use the Grad-Shafranov equation to determine a equilibrium state[2][3]. Three equations

$$\nabla \cdot \boldsymbol{p} = \boldsymbol{j} \times \boldsymbol{B} \tag{3}$$

$$\mu_0 \boldsymbol{j} = \nabla \times \boldsymbol{B} \tag{4}$$

$$\nabla \cdot \boldsymbol{B} = 0 \tag{5}$$

can reduce in the axisymmetric case.

$$I^*(\psi) = \sigma I \tag{6}$$

$$0 = \frac{\partial p_\parallel}{\partial \theta} + \frac{p_\perp - p_\parallel}{B} \frac{\partial B}{\partial \theta} \tag{7}$$

$$\Delta^* \psi = -\frac{\mu_0 R^2}{\sigma} \left. \frac{\partial p_\parallel}{\partial \psi} \right|_B - \frac{1}{\sigma^2} I^* I^{*\prime}(\psi) \tag{8}$$

$$-\frac{1}{\sigma} \nabla \psi \cdot \nabla \sigma \tag{9}$$

We assume the following pressure profile by using $s := (\psi - \psi_1)/(\psi_2 - \psi_1)$:

$$p_\parallel = \left(\frac{\tanh \frac{s}{L}}{s} \right)^{\alpha_1} \tanh^{\alpha_2} \left(\frac{s}{L} \right) \left(\frac{B}{B_n} \right)^{1-\lambda} \tag{10}$$

and $p_\perp = \lambda p_\parallel$, where L means the scale length and λ means the anisotropy.

We estimate gradient in the magnetic filed by

$$G := \frac{|\nabla_\perp B^2|}{B^2}. \tag{11}$$

3. Coil Size Dependence

We investigated change of the diamagnetic current in midplane($z = 0$) by chaning coil size, or gradient in the magnetic field. This lead to examination of liner effects. Figure 1 shows the radius dependence of diamagnetic current in the midplane. Figure 2 shows gradients G in the magnetic fields, and fig.3 shows ratio of the anisotropic term to the isotropic one. Coil radius become big when subscript is big in fig.1,2.

When coil size become large, both magnitude of the magnetic field and gradient of one increase. Then magnitude of the current decrease, but ratio of the anisotropic term to the isotropic one increase because the gradient become large. Therefore, anisotropic effects arise in the point which the gradient is large.

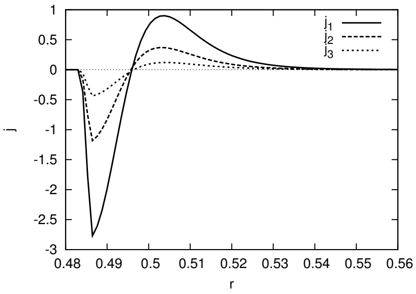

Fig.1 Diamagnetic current(Coil size dependence)

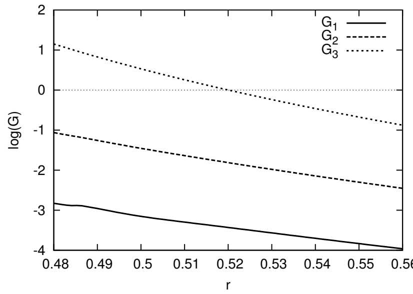

Fig.2 Coil size dependence of gradient in the magnetic field

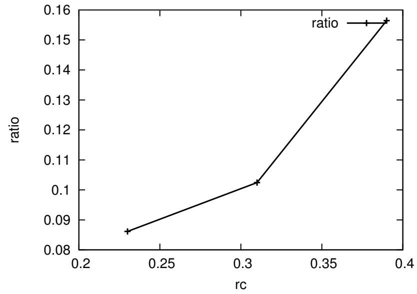

Fig.3 Ratio of the anisotropic term to the isotropic one

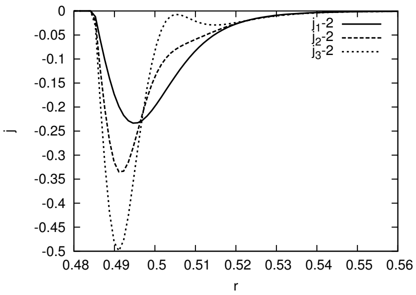

Fig.4 Anisotropic term of diamagnetic current(Pressure dependence)

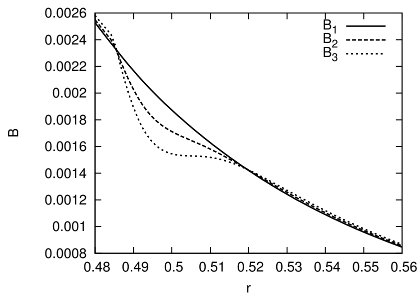

Fig.5 Magnitude of magnetic field

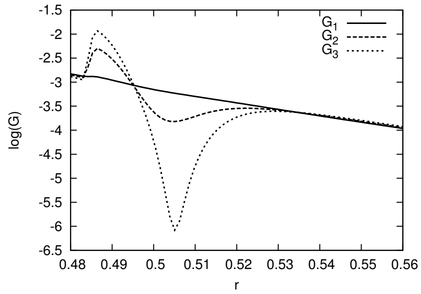

Fig.6 Pressure dependence of gradient in the magnetic field

4. Pressure Dependence

Next, we investigated change of the diamagnetic current in midplane by chaning the magnitude of pressure. This lead to examination of nonliner effects. Fig.4 shows the radius dependence of anisotropic term of diamagnetic current. Fig.5 shows the magnetic fields, and fig.6 shows gradients in the magnetic fields.

When pressure increases, magnetic field localy decreases inside the plasma. Then gradient in the magnetic field increase, and anisotropic pressure term becomes big. Thus, we found that the anisotropic pressure effects is major in high pressure.

5. Summery

We studied the anisotropic pressure effects on diamagnetic current in a magnetospheric plasma. We found that when we change a gradient in the magnetic field, anisotropic pressure effects is major in the point which the gradient is large. In high pressure, we found that the anisotropic term becomes large because of the gradient in the magnetic field.

References

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[3] D. B. Nelson G. O. Spies. Properties of magnetically confined plasma equilibria. *Phys. Fluids*, Vol. 17, No. 1879, 1974.