§7. Theoretical Modeling of Toroidal Flow Generation in Field-reversed Configurations

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The rotational instability with the toroidal mode number n=2 of a field-reversed configuration (FRC) plasma is the most often observed global instability[1]. The FRC current just after formation is primarily carried by electron current, while ions are approximately at rest. The ions, however, gradually gain angular momentum in the ion diamagnetic direction before the onset of the instability. Rotation of the FRC plasma has been often explained by selective loss of ions[2], or end-shorting[3], or both.

We have proposed another possible spin-up mechanism[4], which is direct conversion from the magnetic flux to the kinetic angular momentum as long as axisymmetry holds. Conversion to the angular momentum, however, also occurs for electrons, and it plays the electron current drive and consequently maintains the magnetic flux. Therefore, we suppose that the presence of an anomalous loss of the electron angular momentum due to an electron fluid fluctuation with higher frequency than the ion cyclotron frequency. The idea of the selective angular momentum loss of electrons comes from the current drive technique by a rotating magnetic field[5]. If the electrons' angular momentum loss is present, the poloidal magnetic flux loss could directly convert to the toroidal angular momentum of plasma ions in FRCs.

In order to investigate spatial structure of perturbation of the electron fluid in an FRC, the following wave equations of the electrostatic and vector potentials are solved.

$$\nabla^2\phi - \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} = -\frac{\rho}{\varepsilon_0}. \quad (1)$$

$$\nabla^2\mathbf{A} - \frac{1}{c^2}\frac{\partial^2\mathbf{A}}{\partial t^2} = -\frac{\mathbf{j}}{\varepsilon_0 c^2}. \quad (2)$$

Here, all the potentials above are perturbed components and have the relations with the oscillating fields in the form:

$$\mathbf{E}_1 = -\nabla\phi - \frac{\partial\mathbf{A}}{\partial t}, \quad (3)$$

$$\mathbf{B}_1 = \nabla\times\mathbf{A}. \quad (4)$$

Now, let us assume that plasma particles could not respond waves, and therefore the source terms oscillate with time and their spatial profiles do not change. Then the source terms are gives as

$$\rho = \tilde{\rho}(r,z)\exp\{i(n\theta-\omega t)\}, \quad (5)$$

$$\mathbf{j} = \tilde{\mathbf{j}}(r,z)\exp\{i(n\theta-\omega t)\}. \quad (6)$$

Amplitudes of $\tilde{\rho}(r,z)$ and $\tilde{\mathbf{j}}(r,z)$ are assumed to be proportional to the equilibrium quantities, then

$$\tilde{\rho}(r,z) = -\delta_n e n_{e0}(r,z), \quad (7)$$

$$\tilde{\mathbf{j}}(r,z) = -\delta_j \mathbf{j}(r,z). \quad (8)$$

Using the finite difference method, we find the electron fluid perturbation field as shown in Fig. 1. Here, the frequency of the perturbed field is $0.1\omega_{ce}$, where ω_{ce} is the electron cyclotron frequency of the external magnetic field.

We plan a calculation of electron orbits in this perturbed fields in order to find the loss of the angular momentum, i.e., the resistivity. We also will run an electron particle simulation to compare results to those from our analytical model.

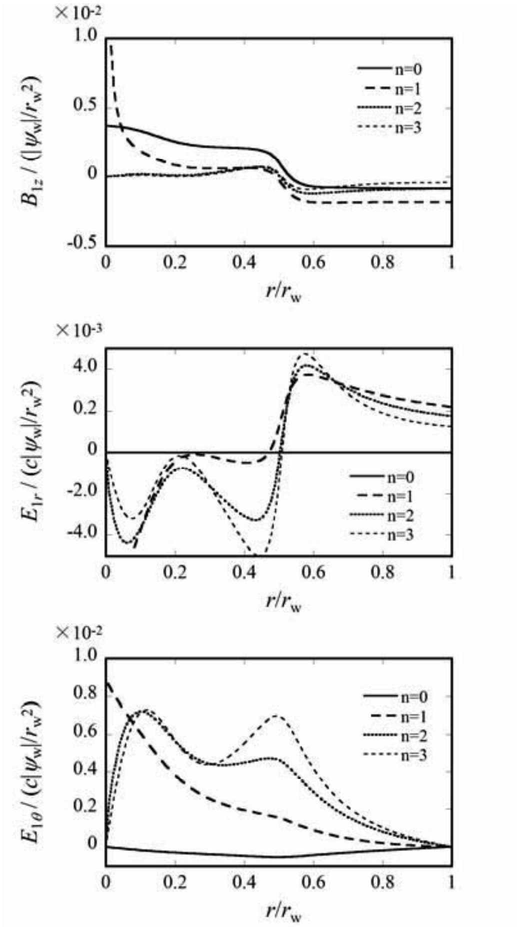

Fig. 1. The spatial profiles of the amplitude of electromagnetic wave caused by electron fluid perturbation. (Top) axial magnetic field, (middle) radial electric field, (bottom) azimuthal electric field.

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