§45. Effects of Non-axisymmetric Magnetic field on Characteristics of Axisymmetric Cusp DEC —Equilibrium Electric Field—

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In D-^{3}He fueled fusion, more than 70 % of the fusion energy is carried by charged particles. Open magnetic field lines surrounding a plasma such as a mirror system easily lead charged particles to direct energy converters, which are expected higher conversion efficiency than a conventional thermal converter with around 40 %. In the ARTEMIS design the Cusp DEC is proposed for the direct energy conversion of thermal components of plasma. Kinetic energy of thermal ion components of end loss plasma is converted to electric power by using the cusp DEC, which consists of a double cusp configuration. The main tasks of the cusp DEC are separation of electrons from ions and energy discrimination of thermal ions and high-energy ions such as fusion protons with 15 MeV in D-^{3}He fusion. Electrons are separated from ions to a first line cusp and a second cusp plays a role of energy discrimination between thermal ions and high-energy fusion products.

In order to investigate the effect of electric field, we considered the axisymmetric hollow equilibrium of the non-neutral plasma, where the densities are uniform. The ions are located at a center region, $0 \le r \le R_i$ and the electrons are cylindrically distributed, $R_i < R_{e,in} \le r \le R_{e,out}$. The momentum equation of the non-diamagnetic equilibrium of the j-th species, where the self magnetic fields are neglected, is expressed as

$$-\frac{m_j V_{j\theta}^2}{r} = q_j (E_r + V_{j\theta} B_z^0) . \qquad (1)$$

The radial electric field is obtained from the Poisson equation,

$$E_r = \frac{1}{\varepsilon_0 r} \sum_k q_k \int_0^r dr' r' n_k(r') . \qquad (2)$$

The momentum equation, Eq.(1), has the quadratic form with respect to the angular frequency $\omega_j = V_{j\theta} / r$,

$$\omega_j^2 + \sigma_j \Omega_j \omega_j + \frac{q_j E_r}{m_j r} = 0 . \qquad (3)$$

In the case of ions, the equilibrium are obtained by the rigid rotor configuration,

$$\omega_i / \omega_{ci0} = \frac{1}{2}[-1 \pm \sqrt{1 - 2n_{i0} / (\varepsilon_0 B_{z0}^2 / m_i)}] , \qquad (4)$$

where ω_{ci0} is the ion cyclotron frequency to the unperturbed axial magnetic field B_{z0}. The condition of the real rotation frequency gives the upper limit of the uniform ion density,

$$n_{i0} \le \frac{\varepsilon_0 B_{z0}^2}{2m_i} = 2.65 \times 10^{15} B_{z0,T}^2 \ (m^{-3}) , \qquad (5)$$

where $B_{z0,T}$ is the unperturbed axial magnetic field in the unit of Tesla.

For electrons, the rotation frequency is not uniform,

$$\omega_e / \omega_{ce0} = \frac{1}{2}[1 \pm \sqrt{1 - \frac{2n_{e0}}{r^2} \frac{\varepsilon_0 B_{z0}^2}{m_e} (R_i^2 - r^2 + R_{e,in}^2)}] , \qquad (6)$$

which is shown in Fig.1, where $R_{e,in} / R_i = 2.0$, $R_{e,out} / R_i = 3.0$,and $n_{e0} / (\varepsilon_0 B_{z0}^2 / m_e) = 1.0$, where $\omega_e^{\pm}$ corresponds to the sign +/- of the solution in Eq.(6). This condition satisfies the real condition of the electron angular frequency. The non-axisymmetric uniform magnetic field B_1 to the vertical direction to the axisymmetric equilibrium configuration changes the radial component of the momentum equation,

$$\omega_j^2 + \sigma_j \Omega_j \omega_j + \frac{q_j}{m_j r}(E_r + V_{jz} B_1 \sin\theta) = 0 . \qquad (7)$$

One can see that the perturbation changes the effective electric field and deform the axisymmetry. The magnitude of the effect can be estimated by

$$\frac{|V_{jz} B_1|}{E_r} \sim \frac{V_{jz}}{R_i \omega_{cj0}} \frac{B_1}{B_{z0}} \sim \frac{c_s}{R_i \omega_{cj0}} \frac{B_1}{B_{z0}} \sim \frac{B_1}{B_{z0}} , \qquad (8)$$

where $B_{z0} = 100\,\mathrm{G}$, $R_i = 1\,\mathrm{m}$ and $T_e = 10\,\mathrm{eV}$. This estimation means the change of the radial electric field is the same order of the perturbed magnetic field to the unperturbed magnetic field.

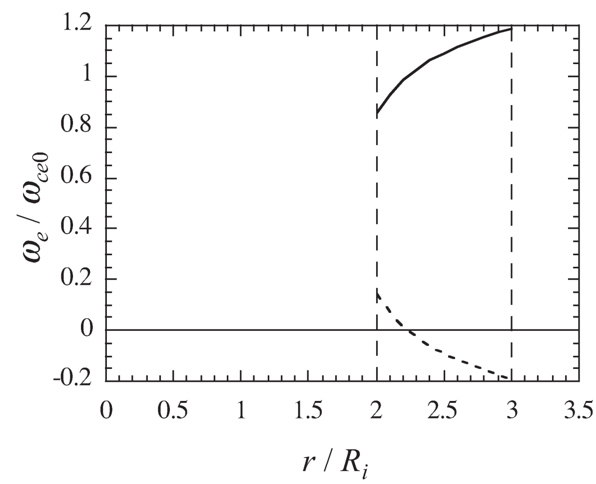

Fig. 1. Angular equilibrium frequency of electrons, which is hollow distribution with the inner and outer radius are 2.0 and 3.0, respectively