§17. Review of a Required Condition for D-^{3}He Fusion in a Field-reversed Configuration Plasma

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The D-^{3}He fusion reactor based on a field-reversed configuration plasma was designed as "ARTEMIS" more than 15 years ago [1]. Since then, new approaches such as merging formation [2], sustainment by rotating magnetic field [3], and NBI heating [4] have been introduced. Therefore, the ARTEMIS design needs to be reviewed now. By this collaborative research program, we set up our near-term goal (the energy confinement time > 1 ms and the trapped flux > 10 mWb). The condition is at least required for NBI heating and flux supply. Although NBI heating has been analyzed by several works [5, 6], flux supply has been studied little. The theoretical model to discuss the flux supply of an FRC plasma is needed to develop.

It has been thought that the presence of the beam current could augment the confinement field according to the Ampère's law, and then the flux is thought to be supplied. However, the resistive force between beam particles and electrons can cause the flux decay, when one employs the simplified Ohm's law and the Faraday's law. This suggests that the azimuthal component of electric field should be modified. Being examined the azimuthal force on the electron fluid element the thermal force

$$\mathbf{R}_{\mathrm{T}} = -\frac{3}{2}\frac{n_{\mathrm{e}}}{\omega_{\mathrm{e}}\tau_{\mathrm{e}}}\frac{\mathbf{B}}{B}\times\nabla T_{\mathrm{e}} \qquad (1)$$

can contribute to the flux supply of an axisymmetric FRC. Here, $n_{\mathrm{e}}, \omega_{\mathrm{e}}, \tau_{\mathrm{e}}, T_{\mathrm{e}}$ are the electron density, the electron cyclotron frequency, the electron collision time, and the electron temperature in Joule, respectively. When the core plasma is heated by fast ions, the electron pressure gradient enhances; it can lead the flux supply.

A tangential NBI (TBNI) as shown in Fig. 1 can suppress orbit losses of beam ions drastically than axial NBI. Then the beam ions can heat electrons; those contribute to flux supply. The midplane profiles of the flux function are shown in Fig. 2. When we neglect the electron heating, the flux decays with time as is drawn by the dotted line. On the other hand, if electron heating is present, the flux can be sustained by the effect of the thermal force. Time evolution of the maximum trapped flux is shown in Fig. 3. When the FRC plasma is heated, no decay of the trapped flux is found. Therefore, we can show successfully the possibility of flux supply by electron heating.

For a future NBI experiment, we found a difficulty is heating profile control. The peak of electron pressure should be near the field-null point in order to supply flux. The orbit calculation has been shown that even for an equilibrium FRC plasma electron heating is caused near a geometric axis; this leads to no flux supply.

On the other hand, there is an advantage of supply by the thermal force. From our result, not only NBI but also such as the electron cyclotron wave heating is also possible method to drive the diamagnetic plasma current.

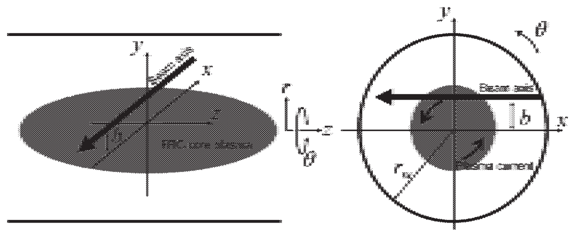

Fig. 1. Geometry of tangential neutral beam injection.

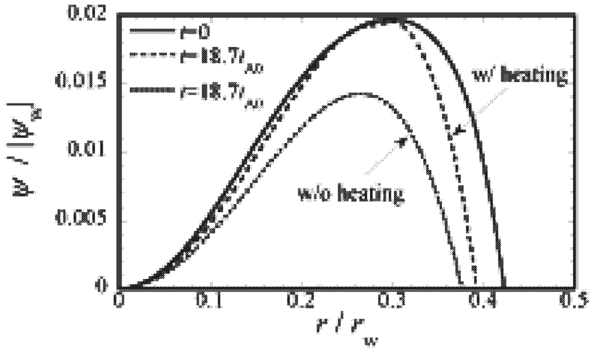

Fig. 2. The midplane (z=0) profiles of the magnetic flux function. The black solid lines indicate the initial profiles.

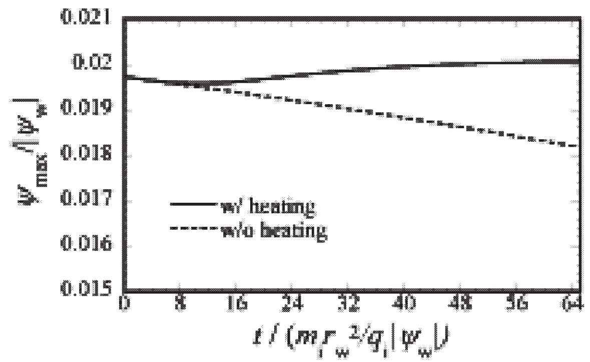

Fig. 3. Time evolution of the maximum trapped flux. The solid line shows flux supply by the electron heating. The flux decays resistively for the case of the dotted line.

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