§5. Control of LHD Type Fusion Reactor by Vertical Field Configurations and an Operation Scenario of FFHR

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i) Control of magnetic field by vertical field coils

Volume enclosed with the last closed magnetic surface, \( V_{\text{LCFS}} \), is one of the most important parameters for the performance of fusion reactors.

The helical pitch parameter (\( = \gamma \)) set up the basic structure of LHD type magnetic field configurations. To get the wide blanket space (\( = \Delta \)), the \( \gamma \) value has received a restriction (\( \gamma \lesssim 1.2 \)).

In general, \( V_{\text{LCFS}} \) increases with the inner shift of the magnetic axis \( R_{\text{AX}} \). When vertical magnetic field is restricted to minimize the leaked magnetic flux, the volume \( V_{\text{LCFS}} \) is small even for the case of inner shift \( R_{\text{AX}} \).

Suitable magnetic field configurations for FFHR has been found by optimizing the vertical magnetic field, if the minimized leaked magnetic flux is not taken into consideration.

Figure 1 shows the comparison of magnetic configurations between minimized leaked flux case and the optimized case.

Fig. 1: Relation between the magnetic axis position \( R_{\text{AX}} \) and the Magnetic flux volume \( V_{\text{LCFS}} \) and the depth of magnetic well \( U''(\Psi_{\text{AX}}) \) in the LHD. Vertical magnetic field is chosen as minimization of leaked magnetic flux or maximize the magnetic flux volume \( V_{\text{LCFS}} \).

Numerical example for the FFHR configuration for the steady state burning phase is shown in Fig. 2. Cleanfolded diverter leg, thin chaotic field line layer, large flux volume (\( V_{\text{LCFS}} \simeq 1.956 \text{m}^3 \)) are confirmed. The rotational transform of the last closed magnetic surface is sufficiently high (\( \psi_{\text{LCFS}}/2\pi \simeq 2.103 \)).

ii) Operation scenario of FFHR

A small flux volume and high beta plasma confinement is preferable to ignite the fusion plasma by small heating devices. FFHR is possible to create a magnetic well as shown in Fig. 1, by outward shifting of magnetic axes even in the vacuum configuration. The marginally stable pressure profile is shown in Fig. 3 for the outward shift (start-up phase), inward shift (steady state burning phase) and super outward shift (ash removal phase) configurations. The super outward shift configuration is characterized by disappearance of the magnetic shear.

Fig. 2: One of optimized configuration for FFHR.

Fig. 3: Marginally stable pressure profile. Start up, steady state burning and ash removal phase profiles are shown by broken, solid and chain lines, respectively.