§27. LHD-type Fusion Reactor Magnetic Configuration with Helical Coils Winding along Geodesic Line of a Torus

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In the LHD-type fusion reactor (FFHR) design studies, the balance blanket space (the most narrow space between the chaotic field lines and the inner wall of the helical coils) and plasma volume becomes an important issue. For the compatibility of the sufficient blanket space and the large plasma volume, we have studied the possibility of the D-shaped cross-section of the LCFS. For this purpose, we have analyzed numerically the magnetic configuration produced by the helical coils winding along a geodesic line of a torus, which we call the torus as "winding frame" for the helical coils.

We have formulated the geodesic winding on a toroidal surface with a variable major radius $R_c(\chi)$ and a variable minor radius $a(\chi)$.

$$\begin{aligned} r &= a(\chi)\cos\chi + R_c(\chi)\,, && (1)\\ z &= a(\chi)\sin\chi\,, && (2)\\ \chi &= \chi(\phi)\,, && (3) \end{aligned}$$

where r and z, ϕ are the standard cylindrical coordinate. The reference trajectory $\boldsymbol{r}_c$ for a helical coil is given the minimum orbit length L:

$$0 = \delta L = \delta \int_{\pi/2p}^{\pi/2p+2\pi/p} \sqrt{\left(\frac{\mathrm{d}\boldsymbol{r}_c}{\mathrm{d}\phi}\right)^2}\,\mathrm{d}\phi\,. \qquad (4)$$

The Euler equation for the geodesic line is reduced to

$$\begin{aligned} 0 &= \delta \int_{\pi/2p}^{\pi/2p+2\pi/p} \sqrt{A^2\left(\frac{\mathrm{d}\chi}{\mathrm{d}\phi}\right)^2 + B^2}\,\mathrm{d}\phi\,, && (5)\\ 0 &= \frac{\mathrm{d}^2\chi}{\mathrm{d}\phi^2} + \left(\frac{A'}{A} - 2\frac{B'}{B}\right)\left(\frac{\mathrm{d}\chi}{\mathrm{d}\phi}\right)^2 - \frac{B\,B'}{A^2}\,, && (6)\\ C &\equiv a(\chi)\sin\chi\,, && (7)\\ B &\equiv R_c(\chi) + a(\chi)\cos\chi\,, && (8)\\ A &\equiv \sqrt{\left(\frac{\mathrm{d}B}{\mathrm{d}\chi}\right)^2 + \left(\frac{\mathrm{d}C}{\mathrm{d}\chi}\right)^2}\,. && (9) \end{aligned}$$

Corresponding to the pair of the helical coils, there are two type boundary conditions,

$$\chi\left(\frac{\pi}{2p}\right) = \left\{\begin{array}{c} 0 \\ \pi \end{array}\right\},\ \chi\left(\frac{\pi}{2p} + \frac{2\pi}{p}\right) = \left\{\begin{array}{c} 0+2\pi \\ \pi+2\pi \end{array}\right\}. \qquad (10)$$

The effective value of the coil pitch parameter, γ, of the geodesic line is reduced(increased) inboard (outboard) side of the torus. Therefore, the enough space for the blanket is reserved. Moreover, because the magnetic axis is shifted to the center of the helical coils, the magnetic surface volume, V_{lcfs}, is increased, and the magnetic well is formed.

We have confirmed numerically the compatibility of the large blanket space and the large plasma volume. Formation of a weak magnetic well in the core plasma region and the high magnetic shear in the peripheral region near the LCFS are also confirmed.

Numerical results are shown in Fig.1 when the winding frame is set to a torus with circular cross-section ($a(\chi) = a_0$: constant).

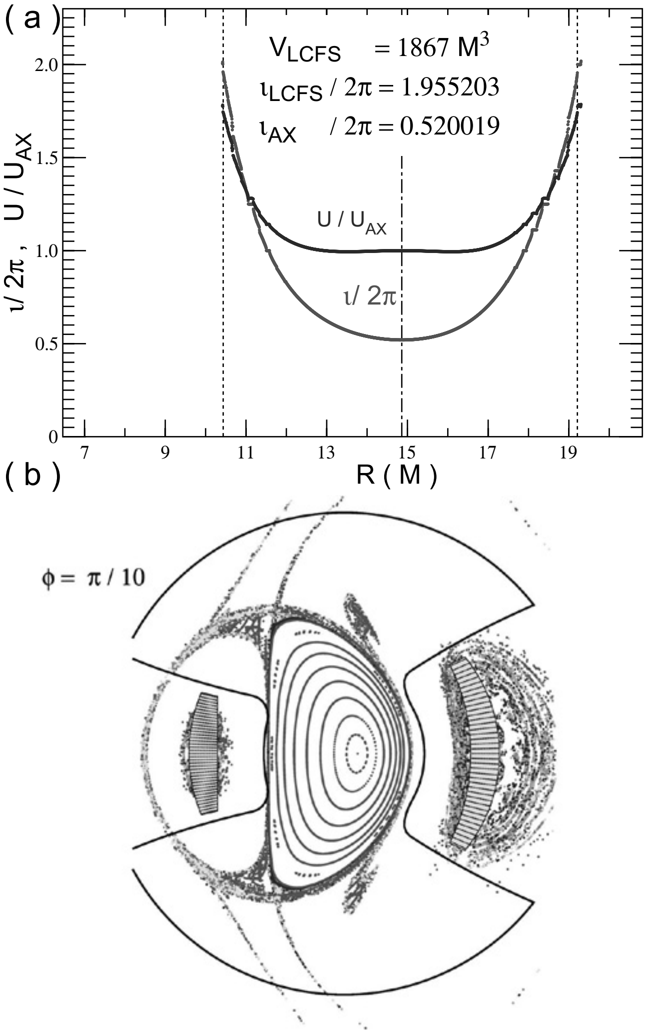

Fig. 1: (a) Distributions of the specific volume, U, and the rotational transform, $\iota/2\pi$, of line of force. (b) Structure of the magnetic surface, chaotic field line region and diverter field line. Cross-section of helical coils are also shown. ($R_c = 14$m, $a_0 = 3.36$m)

Characteristics of the magnetic surface shown in Fig.1 are preferable for a fusion reactor. But we found poor performance for 3.52MeV alpha particle confinement, when the cross-section of the winding frame is a circle (constant $a(\chi)$ case). Performance of DT alpha particle confinement is strongly improved by increase of the elongation factor of the cross-section of winding frame for the helical coils.