§2. System Design of the Helical DEMO Reactor FFHR-d1

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i) Modification of the blanket shape

After the decision of the main design parameters of FFHR-d1[1)], the detailed design of the in-vessel components (vacuum vessel (VV), blanket and divertor components) and the coil supporting structure is in progress. In the last fiscal year, a method to set the basic shape of the in-vessel components around the helical coil by mathematical formulae (polynomial of trigonometric functions of the helical-coil angle θ_c, where $\theta_c = -5\phi - 0.1 \sin 5\phi$ and ϕ is toroidal angle) on the helical-coil vertical cross-section was proposed[2)]. At this point, the shape of VV and blanket was set based on the shape of lines of magnetic force. It enables reduction of neutron flux to the divertor region and a large space for divertor components. On the other hand, total weight of in-vessel components increases and the shape is not consistent with the design of the ports for heating system. In this fiscal year, the detailed design of core plasma is in progress by the core plasma task group and the adoption of high aspect ratio configuration with helical pitch parameter $\gamma_c = 1.2$ is considered. Thus the shape of VV and blanket is modified to fit both magnetic field structure of $\gamma_c = 1.25$ and 1.2. The new poloidal and horizontal cross-sectional view are shown in Fig. 1 and 2, respectively.

ii) Consideration of plasma start-up scenario

Plasma start-up time strongly affects the start-up scenario and the design of plant equipment. In particular, in the case of helical system with a current-less plasma, the requirement on the heating system depends on the heating power amount required for its ignition access. In past study, ignition access based on feedback control of fusion power by manipulating fueling rate and external heating power was proposed using the 0-D model[3)]. To examine this result and to confirm the plasma parameters assumed in the core plasma analysis at the steady-state operation point, a calculation code to solve temporal evolution of electron density and temperature profiles was developed by utilizing the quasi-1D particle balance model[4)] in collaboration with the core plasma, the fueling and the operation control task groups. In this code, electron density is calculated by solving the diffusion equation with the spatially-constant diffusion coefficient of $D(r) = D \propto (P_{\rm abs}/\bar{n}_e)^{0.6} B^{-0.8}$. Assuming gyro-Bohm-type parameter dependence, pressure evolution can be estimated by the model that gyro-Bohm normalized pressure profile $\hat{p}(r) = p(r)/(P_{\rm abs}^{0.4} B^{0.8} n(r)^{0.6})$ relaxes to that of the extrapolation of the experimental data with a time constant of energy confinement time $\tau_{\rm E}$. Here experimental data with a peaked density profile with inward-shifted, high aspect ratio configuration ($R_{\rm ax}/R_c = 3.55/3.9, \gamma_c = 1.2$) was used.

It was found that feedback control of fusion power by manipulating fueling rate is difficult because there is time delay corresponding the time constant depends on diffusion of the density. Thus we conducted feedback control of line-averaged density instead of fusion power. Consequently, smooth ignition-access and steady-state sustainment can be achieved by a simple on-off control of the pellet injection with 10Hz repetition (Fig. 3).

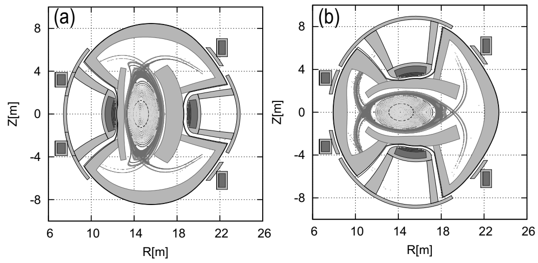

Fig. 1: Poloidal cross-sectional view of in-vessel components and supporting structure of FFHR-d1 at (a) $\phi = 0$ and (b) $\phi = \pi/10$.

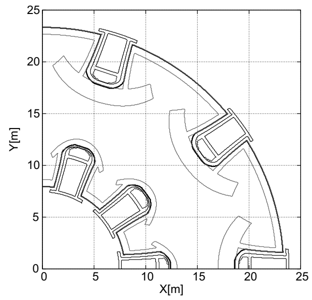

Fig. 2: Horizontal cross-sectional view of in-vessel components and supporting structure of FFHR-d1.

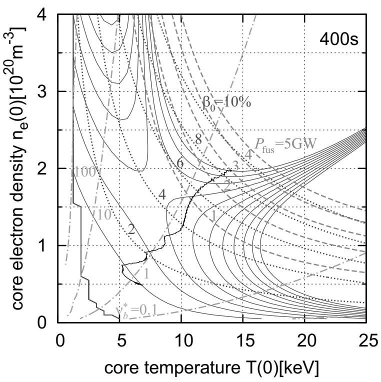

Fig. 3: Trajectory of density and temperature for an example case of ignition access scenario. The popcon plot corresponds to the final (steady-state) condition.

1) Goto, T. et al.: Plasma Fusion Res. **7** (2012) 2405084.

2) Goto, T. et al.: Annual Report of NIFS April 2011-March 2012, 234 (2012).

3) Mitarai, O. et al.: Fusion Eng. Des. **70** (2004) 247.

4) Sakamoto, R. et al.: Nucl. Fusion **52** (2012) 083006.