§3. Design Window Analysis and Core Plasma Design of a Heliotron Reactor

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i) Design point survey by a system design code

One of the critical issues in the design of LHD-type heliotron reactors is to secure sufficient space for the blanket. In the past design study, small helical pitch parameter (γ = 1.15) and outward-shifted magnetic configuration ($R_{\rm ax}/R_{\rm c}$ = 3.75/3.9) has been selected to expand the blanket space[1]. However, recent studies have clarified that the total plant capital cost does not increase so much with an increase in the reactor size when the required confinement improvement is kept constant[1]. Then a simple similar extension has been selected as a method to secure blanket space and the design study with a magnetic configuration that is consistent with LHD high-beta operation (γ = 1.2 and $R_{\rm ax}/R_{\rm c}$ = 3.6/3.9) has been carried out.

In this design study, the base design for the superconducting magnet system has been proposed using the engineering base of the ITER-TF coils. A stored magnetic energy $W_{\rm mag}$ of 120-140 GJ can be achieved with a small extension of the ITER technology[2] and the achievable maximum value is expected to be 160 GJ. Neutronics calculations have shown that a blanket system with a thickness of $\Delta \sim 1$ m under the condition of averaged neutron wall load $\Gamma_{\rm nw} \leq 1.5$ MW^2 enables the sufficient net TBR and neutron shielding[1]. To find a design window, paramtric scans have been carried out by using newly developed system design code for heliotron reactors. This system code can deal with the actual geometry of helical and poloidal coils. As for physics parameters related to the magnetic configuration, the system code utilizes the results of the detailed field line tracing calculation of vacuum equilibrium for several reference cases. The difference in the coil geometry from LHD[3] was reflected in these calculations.

Figure 1 shows the relation between $W_{\rm mag}$ and $H^{\rm LHD}$ (the required confinement improvement factor H relative to LHD which is 0.93 times ISS04v3 scaling) for design points with fusion power ∼ 3 GW. The design point that satisfies both $W_{\rm mag} \leq 160$ GJ and $\Gamma_{\rm nw} \leq 1.5$ MW/m^2 is found with volume average beta value $\langle\beta\rangle \geq 5.5$ % and $H^{\rm LHD} \geq 1.3$. The design point with the blanket space $\Delta \sim 1$ m and was selected as the candidate (shown as red star symbol in Fig. 1).

ii) Finite-beta equilibrium calculation

As mentioned above, the calculation of the system design code is based on parameters related to the magnetic surface structure of vacuum equilibrium. On the other hand, a large Shafranov shift has been observed in LHD high-beta discharges. Shrinking of the nested surface volume due to ergodization of peripheral region is also predicted by HINT code. To study this, finite-beta equilibrium calculations were carried out using the VMEC code to examine the self-consistency of the design. As shown in Fig. 2, almost the same plasma volume as the vacuum equilibrium can be obtained with the comparable plasma stored energy to the estimation by the system code (∼ 1300 MJ) for variable pressure profiles by means of adding adequate vertical field.

Consequently, it is concluded that the design of the LHD-type heliotron reactor with a sufficient fusion output for a commercial operation (∼ 3 GW) is possible with a foreseeable extrapolation of the current physics and engineering achievements.

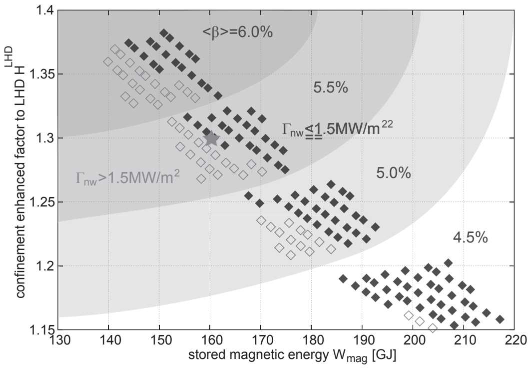

Fig. 1: The stored magnetic energy vs. the required confinement improvement factor for the design points with fusion output ∼ 3 GW.

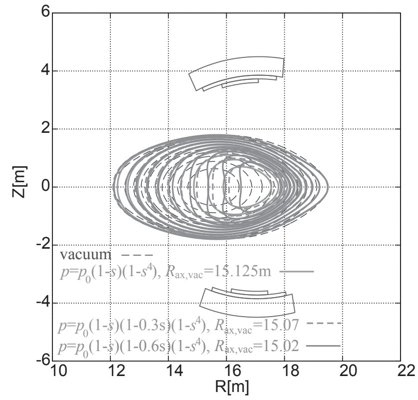

Fig. 2: Equilibirum magnetic surface structure for 3 dif6ferent pressure profiles (s: normalized toroidal flux).

1) A. Sagara *et al.*, Fusion Eng. Des. (2006) vol.81 pp.2703-2721

2) S. Imagawa *et al.*, Nucl. Fusion (2009) vol.49 075017 (7pp)

3) T. Goto *et al.*, NIFS Annual Report 2008-2009, pp.250