§2. System Design of an LHD-type Heliotron DEMO Reactor

Goto, T., Miyazawa, J., Tanaka, T., Yanagi, N., Sagara, A.

i) Development of system design code for LHD-type heliotron reactors

A helical system with a net-current-free plasma has suitable properties for a DEMO and a commercial fusion reactor. Especially, heliotron system with two continuous helical coils has achieved several remarkable achievement in the experiments in the Large Helical Device (LHD)[1]. Therefore, a design feasibility study on an LHD-type heliotron DEMO reactor is quite meaningful.

For the quantitative understanding of the relation between design parameters, a system design code for LHD-type heliotron reactors, HELIOSCOPE (Heliotron system design code for reactor performance evaluation), has been developed[2]. The most important and difficult issue is an evaluation of the shape of the magnetic surfaces. The shape of magnetic surfaces of heliotron reactors is strongly coupled to the geometry of external (helical) coils. Therefore, the parameters related to the geometric configuration of the magnetic surfaces, which are needed to evaluate plasma performance, cannot be given as input parameters but need to be obtained from an equilibrium calculation. Such an equilibrium calculation, however, is time-consuming and cannot achieve the computational speed fast enough for an application on parametric scans (less than 1 sec for one parameter set). For this reason, database of the magnetic surface configurations for various shapes of the helical coils with a fixed major radius R_c has been established separately using a field line tracing code and the 3-D equilibrium code VMEC. HELIOSCOPE refers this database and applies it to different values of R_c by a similar extension.

ii) Design window analysis for heliotron DEMO reactors Design windows of a fusion reactor is determined by balancing various design factors. In the design study of FFHR-2m2[3], which is aiming at a commercially-competitive helical fusion reactor, the following engineering constraints has been assumed: stored magnetic energy $W_{\rm mag} \leq 160$ GJ to wind helical coils based on the ITER-relevant technology, an average neutron wall load $\langle \Gamma_{\rm nw} \rangle \leq 1.5$ MW/m^2 to suppress neutron damage on blanket structural materials $<$ 100 dpa after 30 full power years (FPYs) operation with the long-life blanket concept[4], and the inboard minimum blanket thickness $\Delta_{\rm in} \geq 1.0$ m to enable a simultaneous achievement of sufficient shielding of the coils from fast neutrons and a net tritium breeding ratio ≥ 1.05. Thus, $R_c = 17$ m and $B_{\rm t,c} = 4.7$ T (an average toroidal field strength on the helical coil winding center) has been selected as a candidate design point for FFHR-2m2. This design point can be realized when a confinement improvement relative to the present LHD experiments of $H^{\rm LHD} = 1.3$ is achieved with an assumption on physics conditions: density and temperature properties as $n_e = n_{e0}\left(1-\rho^2\right)^{\alpha_n}$, $T_e = T_{e0}\left(1-\rho^2\right)^{\alpha_T}$ with $\alpha_n = 0.25$ and $\alpha_T = 1.0$, alpha heating efficiency $\eta_\alpha = 0.9$, and helium ash fraction $f_\alpha = 0.05$. However, $H^{\rm LHD}$ depends strongly on these physics conditions and the dependence does not change so much by R_c, $B_{\rm t,c}$, and a fusion power. Therefore, it is important to find a design window with a lower $H^{\rm LHD}$ to secure the design robustness.

Figure 1 shows a design window of an LHD-type heliotron reactor with the same assumption in the physics conditions as those of FFHR-2m2. It can be seen that a reduction of the blanket space by $\sim$ 20 cm can reduce $H^{\rm LHD}$ from 1.3 to ≤ 1.2 with keeping $W_{\rm mag}$. This reduction can be achieved by the use of an advanced shielding material (e.g., tungsten carbide). Since the first priority of a DEMO reactor is a demonstration of a steady-state, self-ignition plasma operation, a long-term ($\sim$ 30 FPYs) operation and a fusion output of 3 GW are not necessary conditions. Thus, the design point plotted as a circle in Fig. 1 is a possible selection as a DEMO reactor. If a higher $\langle \Gamma_{\rm nw} \rangle$ is accepted, $H^{\rm LHD}$ becomes more smaller. On the other hand, $W_{\rm mag}$ can be reduced if $H^{\rm LHD} \geq 1.3$ is achieved. The reduction of the blanket space also enables a reduction of helical coil current density or a flexible selection of a magnetic configuration (e.g., low plasma aspect ratio, etc.). Consequently, it enhances design robustness of a DEMO reactor.

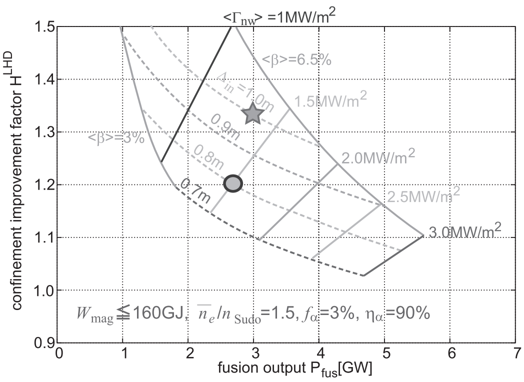

Fig. 1: The design window of an LHD-type heliotron reactor with the same physics constraints as those of FFHR-2m2 (plotted as a star symbol). The circle is a possible design point for a DEMO reactor if the inboard minimum blanket space of 80cm is acheived.

1) A. Komori *et al.*, Fusion Sci. Technol. (2010) vol. 58 pp.1-11.

2) T. Goto *et al.*, to be published in Nucl. Fusion.

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

4) A. Sagara *et al.*, Nucl. Fusion (2005) vol. 45 pp.258-263.