§4. A Conceptual Design of Helical Coils for Heliotron DEMO Plant

Imagawa, S.

The major radii of heliotron power plants are determined mainly by the minimum thickness of the blanket and the plasma minor radius required from the confinement time [1]. The minimum blanket thickness of a heliotron DEMO (H-DEMO) can be reduced by adopting excellent shield material such as WC and raising the upper limit of neutron flux in the superconducting magnets because their lifetime can be shorter than the power plants. In this study, it is set at 0.8 m by reducing the thickness of breeding layer only for the narrowest area, as shown in Fig.1. Since the area fraction of the thin blanket is 10% around, it should be possible to attain overall tritium breeding ratio more than 1.0. In addition, the self-ignition condition is not indispensable for DEMOs. The Q-value more than 20 is considered sufficient to prove the capability of reliable operation.

Figure 2 shows required magnetic fields and magnetic energy to attain the self-ignition condition or Q of 25 for a typical LHD type reactor with the improvement factor H_H of 1.2 and 1.3 with respect to the LHD. The energy confinement time is estimated with the ISS04 scaling, using γ of 1.20, β of 4% to the central toroidal field, helical coil current density of 25 A/mm^2, helium ash ratio of 5%, oxygen impurities ratio of 0.5%, and alpha particle heating ratio of 95%. Considering the experimental results in the LHD, the line density is set at 1.5 times of the Sudo limit, and the density and temperature profiles are set at $(1-\rho^2)^{0.5}$ and $1-\rho^2$, respectively, where ρ is the normalized minor radius. The required magnetic field is the lower at the more peaked profiles. The minimum blanket space Δ_b in Fig. 2 is the net thickness of the breeding and the shielding blanket. The space for thermal shield for the magnets is set at 0.1 m. In order to attain Q-value more than 25 with H_H of 1.2 with respect to the LHD and the blanket thickness more than 0.8 m, the necessary major plasma radius and magnetic energy of the H-DEMO can be reduced to 13.5 m and 80–100 GJ, respectively. The average neutron wall load to the blanket is less than 1 MW/m^2, which should be beneficial to the heat removal from the blanket.

The highest magnetic field is 11.0 T, and the current of the CIC conductor, as shown in Table 1, can be within 60 kA by adopting parallel winding in five in hand. It is lower than that of the ITER-TF coil. The average non-copper density can be increased to 400 A/mm^2 under the same criteria for ITER TF coils by grading conductors [2]. The *react and wind* method can be adopted for Nb_3Al conductors that are reacted on a bobbin with the equivalent bending radius [2]. Since the required technology for the conductor and magnet materials is comparable to that for ITER, the large magnet system can be realized with small extension of the ITER technology.

1) Sagara A. et al., *Fusion Eng. Des.* **83** (2008) 1690-1695.
2) Imagawa S. et al., *Nuclear Fusion*, **49** (2009) 075017.

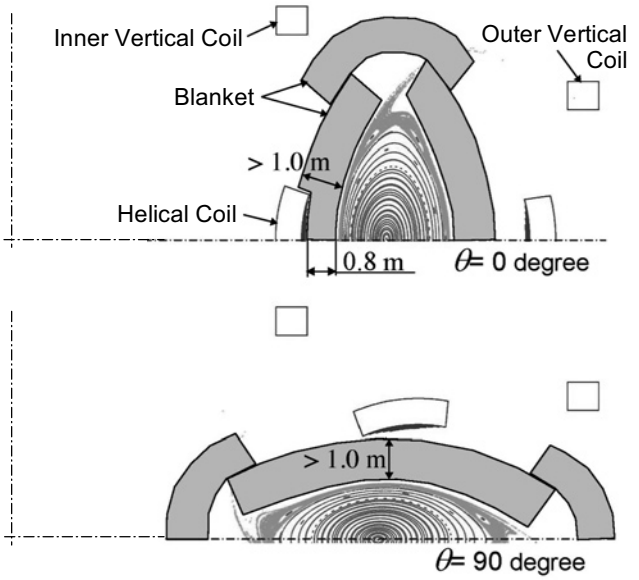

Fig. 1. A concept of blanket of H-DEMO with the minimum thickness of 0.8 m.

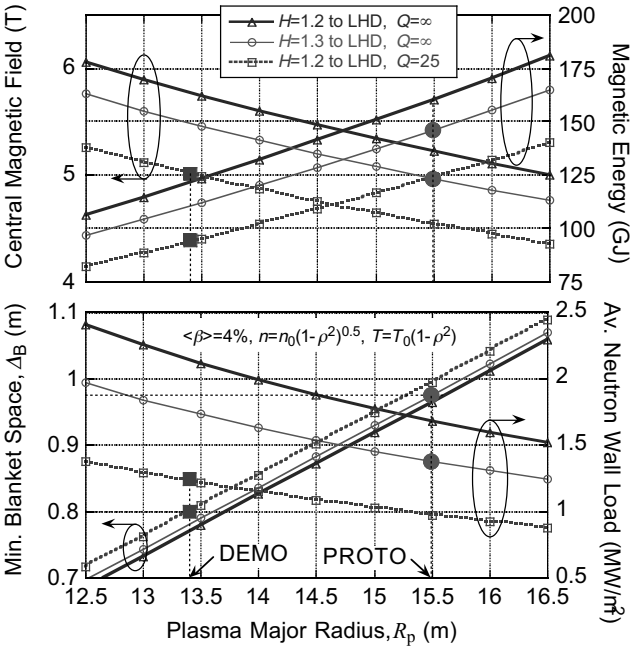

Fig. 2. Required magnetic field, magnetic energy, blanket space, and average neutron wall load of LHD-type reactor with H_H of 1.2 and 1.3 to LHD. The fusion gain $Q=\infty$ means the self ignition.

Table 1. Specification of helical coil with CIC conductors.

	H-DEMO	ITER-TF
Maximum field (T)	11.0	11.8
Conductor current (kA)	56.5	68.0
Number of parallel winding	5	1
Max. length of a cooling path (m)	500	390
Current density of winding (A/mm^2)	25	20.3
Non-Cu current density (A/mm^2)	400	273.4
Void fraction (–)	0.34	0.34
Cable outer diameter (mm)	39.4	40.2
Number of coils	2	18
Total weight of SC strands (ton)	384	351

(*1) Q=∞ (self ignition) is attained by H_H of 1.75 to LHD.