§6. Design Windows and Economic Analysis on Heliotron Reactors

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Helical reactors of LHD-types are characterized by a pair of helical coils with large major radius but moderate aspect ratio, which give us different approaches for power plants from tokamak reactors. Based on the recent experiment results of LHD and the technology-cost basis of magnets developed for LHD and ITER construction, the design window analysis has been carried out. We found that the LHD-type helical reactors have the technically and economically attractive design windows, where the major radius is increased as large as for the sufficient blanket space, but the magnetic stored energy is decreased to reasonable level because of lower magnetic field with the convenient physics basis of H factor near 1.1 and β of 5%.

For searching design windows of helical reactors and for discussing their potential as power plants, we have developed a mass-cost estimating model linked with system design code- HeliCos. The major relationships between plasma parameters and reactor parameters are identified as follows. 1) Power balance: $P_\alpha/h_\alpha = W_p / \tau_{ER} + P_r$. 2) Energy confinement scaling ISS04 and H factor: $H_f = \tau_{ER} / \tau_{E\,(ISS04)}$. 3) Basic geometry and magnet shape are similar to LHD, i.e. polarity l=2, field periods m=10, coil pitch parameter $\gamma=(m/l)/(R_c/a_c)=1.15\sim1.25$. We consider a_p, a_c (minor radius of plasma and coil) and a_{pin} (inner minimum plasma radius) are also similar to LHD inward shift plasma case. Then the major relationships between a_p, a_{pin}, the ratio of B_{max}/B_0, are given by the LHD experience depending on γ. 4) The space for blanket Δd is described with the configuration of plasma and helical coils as follow, (H: helical coil height, Δt: thermal insulation space).

$$\Delta d = a_c - (R_c - R_p) - a_{pin} - H/2 - \Delta t .$$

The design spaces of helical reactor are limited with the lower boundary of R_p given by Δd for tritium breading, the minimum B_0 for required H factor, and the upper boundary of magnetic stored energy for avoiding the difficulty of manufacturing helical coils (Fig.1).

With increasing γ the design points of helical reactors move to the larger R_p according to severe Δd constraints,

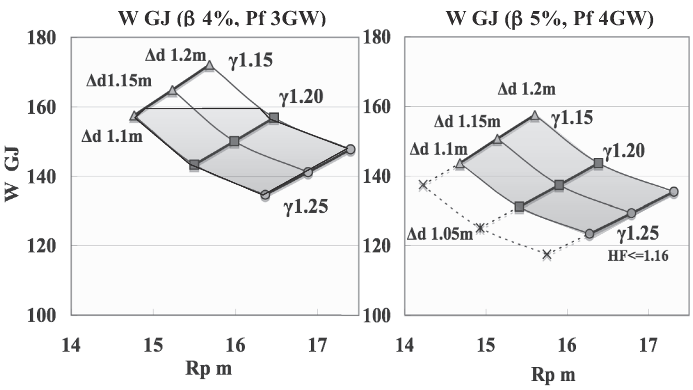

Fig.1 The design windows limited with Δd≥1.1m, H_f≤1.16, W<160GJ, depending on γ and β. H_f=1.16 means the 1.2 times value achieved in LHD experiment. $j=26A/mm^2$ is premised.

but to the smaller B_0. Then the basic design windows are shown with the constraints of Δd and H_f, and the dependence on γ such as figure 1, in the same conditions of β and fusion power P_f.

To evaluate the magnet cost with the common basis of tokamak and helical reactors, we estimated the weights and cost of magnet systems based on the cost basis of ITER and the FFHR-2m1 design [1),2)]. With increasing R_p and γ (i.e., a_p), the B_0 decreases in the same β-P_f and Δd conditions, that is why the magnetic stored energy W decreases even if in the larger coil size. These characteristics between plasma volume (R_p, γ) and B_0, and magnet cost are shown in Figure 2. The costs of blanket and shield (Cbs) are estimated basing on FFHR-2m1 blanket design studies [3)] and are increased in proportion with $R_p a_p$.

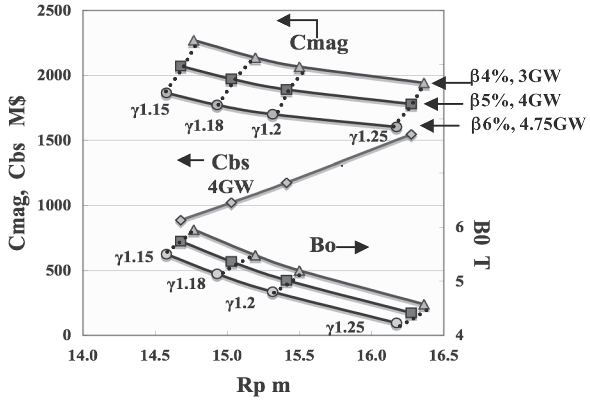

Fig. 2 The B_0, magnet cost (Cmag), and blanket Cost (Cbs) depend on R_p, γ and β. When R_p and γ increase, Cmag decreases but Cbs increases. Those plots on R_p (γ) are given with Δd=1.1m.

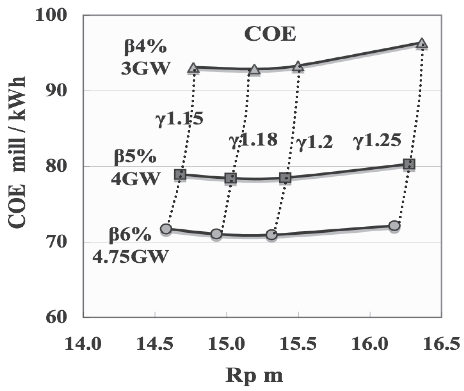

Fig.3 The COEs of helical reactors, which depend on R_p, γ and β, show the bottom as the result of the trade-off between the Cmag and Cbs (B_0 versus plasma volume).

The COEs of helical reactors shown in figure 3 suggest us that the technically and economically attractive design windows exist in the rather wide area of the large R_p (~15m), medium γ (~1.20) and β values (~5%), and the reasonable magnetic stored energy (~130 GJ).

1) Kozaki, Y. et al., Ann. Rep. NIFS (2006-2007), 270.
2) Imagawa, S. et al., Proc. the 17th International Toki Conference, Oct. 11-15, 2007.
3) Sagara, A. et al., Fusion Eng. Design, 81(2006) 2703.