§8. Scale Effects on Magnet Systems of Heliotron-Type Reactors

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Heliotron-type reactors have attractive advantages for power plants, such as no current-disruptions, no current-drive, wide space between helical coils for the maintenance of in-vessel components. One of disadvantages is a necessarily large major radius, because the larger radius will increase construction cost. However, the influence is not clear. Scale effects on superconducting magnet systems have been estimated under the conditions of a constant energy confinement time and the same aspect ratio.

The coordinate of the helical coil is shown in Fig. 1, where W and H are width and height of the coil in the cross-section. A high ratio of width to height is useful to reduce the maximum transverse field and to enlarge the blanket space, but it will bring problems for maintenance ports. The ratio of 2.0 was selected in this study as a moderate value. The current I and the pitch parameter γ of the helical coil are given by $(2\pi R_0 B_0)/(\mu_0 m)$ and $(m a_c)/(l R_c)$, respectively, where R_0, R_c, a_c, B_0, l, and m are a plasma major radius, a coil major radius, a coil minor radius, central toroidal field, a pole number, and a pitch number. Though high density of the coil current is useful to enlarge the space for blankets and for maintenance, it is restricted by cryogenic stability, mechanical strength, and the highest field. Considering a mechanical support inside the coil, it is set to 25 MA/m^2 in this study. The ratio of the highest magnetic field in the coil to B_0 depends mainly on the ratio of height of the helical coil to the minor-radius. The fitting curve is used in this study. The minor-radius hoop force F is dominant in a standard operation, and it is given by

$$F = \langle f_a \rangle \cdot a_{eq} = \langle B_T \rangle I \cdot a_c \sqrt{1+\gamma^{-2}} \qquad (1)$$

where $\langle B_T \rangle$ and a_{eq} are the transverse field averaged in the cross-section of the coil and an equivalent bending radius, respectively. Since the hoop force is supported by the tension of the structure, the necessary weight of the coil support W_{SS} is

$$W_{ss} = A_{ss} \cdot L \cdot l \cdot \rho = \frac{F}{S_m} \cdot R_c \sqrt{1+\gamma^2} \cdot l \cdot \rho \qquad (2)$$

where A_{SS}, L and ρ are the cross-sectional area, length and density of the coil support, respectively. S_m is allowable average stress.

In order to estimate scale effects on magnet systems, the energy confinement time τ_E is appropriate for the index of comparable reactors. The scaling low of ISS95 is adopted in this study. In the case that plasma heating power P per unit volume and an average electron density n_e are constant, τ_E becomes

$$\tau_E^{ISS95} = 0.079 a_p^{2.21} R_o^{0.65} P^{-0.59} \bar{n}_e^{0.51} B_0^{0.83} \iota_{2/3}^{0.4} \propto a_p^{1.03} R_o^{0.06} B_0^{0.83} \qquad (3)$$

Consequently, the necessary central toroidal field is in inverse proportion to the 1.31 power of the major radius under the conditions of the constant τ_E and a similar figure.

τ_E, n_e, and $T(0)$ are set to 1.01 s, 30.4E19 m^{-3}, and 15 keV, respectively, in this study. The improvement factor for τ_E is almost 2. The estimated results are shown in Fig. 2 for the two kinds of aspect ratios. The minimum space for blankets is subtracted by 0.1 m from the minimum gap between the helical coil and the last closed surface of the plasma for installing thermal shields. As the results, weight of the coil support is proportional to only the 0.37 power of the major radius[1]. The influence of the radius on the construction cost of the magnet system will not be strong. The smallest major radius is determined mainly by the space for blankets. The appreciated major radius will be around 15 m for a reactor similar to LHD. In order to realize more compact reactors, the lower aspect reactor with the equivalent confinement is promised.

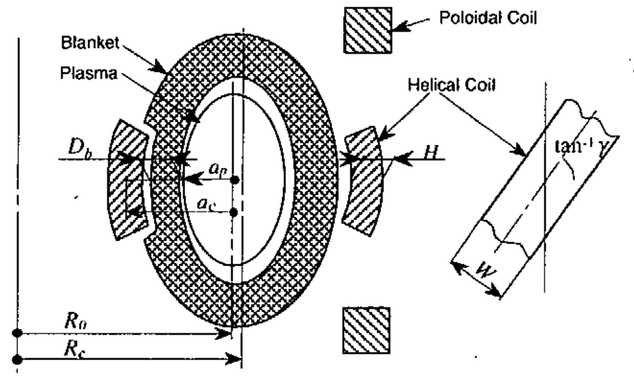

Fig. 1. A coordinate of helical coils and plasma.

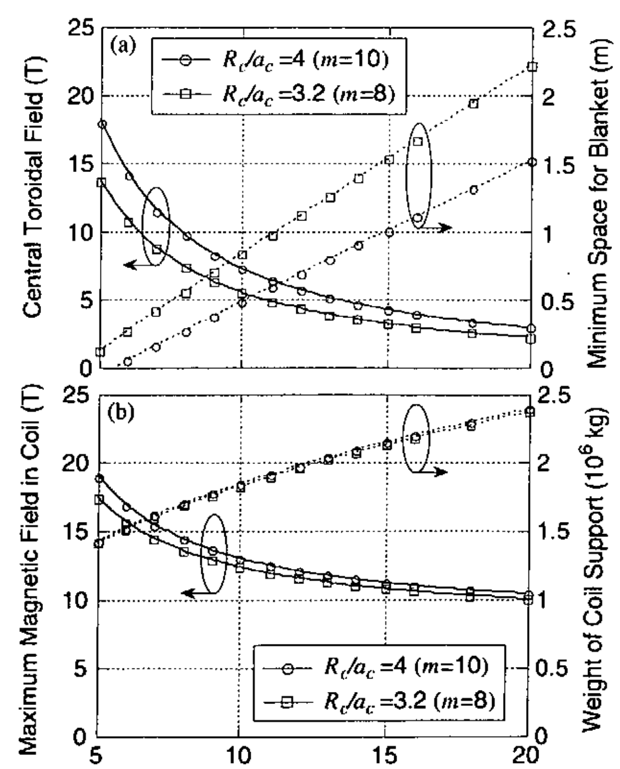

Fig. 2. Scale dependence of the central magnetic field and space for blankets (a), and the maximum magnetic field and weight of coil supports (b) under the conditions of τ_E= const., γ= 1.25, j=25 MA/m^2, W/H = 2, and S_m = 200 MPa.

Reference

1) Imagawa, S. et al.: presented at APFA03, 2003.