§70. Structural Design for Force Free Helical Reactor (FFHR)

Imagawa, S., Sagara, A., Motojima, O.

The main feature of FFHR[1] is to reduce the electromagnetic forces on helical coils in order to simplify the supporting structures on a basis of 'force free' concept. It means that integration of the electromagnetic forces in the cross section of a coil is zero, that is, the transverse magnetic field is concentric to the current-center in the coil. A magnetic field in a coil is divided into a self field B_{self} and an external field $B_{ext.}$. The former is defined as a field induced by a transport current around it, and it is intrinsically concentric. The latter is defined as an other field which is induced by loop currents of the coil and the other helical coils and poloidal coils. The 'force free' is attained by reducing the transverse component of $B_{ext.}$ into zero. In the case of helical coils, the direction of $B_{ext.}$ depends on the pitch parameter γ_c ($= m\, a_c / \ell\, R_c$, where m is the number of periodicity, a_c is the minor radius, ℓ is the number of poles, R_c is the major radius) of the coil. As the results of computer calculation, the 'force free' is performed at $\gamma_c = 0.6$–0.8 in $\ell = 2$ or 3 helical systems. If the current is continuously distributed in the poloidal section, the 'force-free' is performed at $\gamma_c = 1$.

In the 'force-free' helical coils, the maximum magnetic field becomes smaller. It is mainly determined by B_{self} that is expressed by

$$B_{self} \propto \sqrt{I \cdot j}, \qquad (1)$$

where I is the transport current of the coil, and j is the current density. If we make j small to reduce B_{self}, both the radius of the plasma and the space between the helical coils become small. We should select the suitable value.

Electromagnetic forces on helical coils have been calculated for $\ell = 2$ and 3 system. The positional distribution of the force is mainly depended on the coil pitch modulation α_C. The difference become the smallest at the suitable positive α_C. In the case of $\ell = 3$ and $j = 27$ A/mm^2, the 'force free' is satisfied at $\gamma_C = 0.76$. Since the plasma will become smaller and unstable in such low γ_C, we selected $\gamma_C = 1$. This value might not be best but moderate.

Preliminary structural design for FFHR has been carried out. In the conceptual design, FFHR has three helical coils and two pairs of poloidal coils. Since sum of electromagnetic force on all coils is balanced, all coils were supported by each other, as shown in Fig. 1. In considering the maintenance of blanket, large aperture are prepared at top and bottom region. Since electromagnetic force on the helical coils are much reduced by the 'force free' concept, the helical coils would withstand their electromagnetic forces by fixing them to cylindrical supporting structure at inner and outer mid plane. As the results of modification of fixing points of the helical coils to the supporting structure, the maximum stress intensity is reduced within 644 MPa, as shown in Table 1. This value is within the allowable stress of SUS316LN.

Table 1 Parameter of calculation and results

Parts	Young's modulus (GPa)	stress intensity (MPa)
Helical coils	200	622
Bed of HC	20	644
PC support	200	542
Poloidal coils	100	355

(note) Poisson ratio is 0.3.

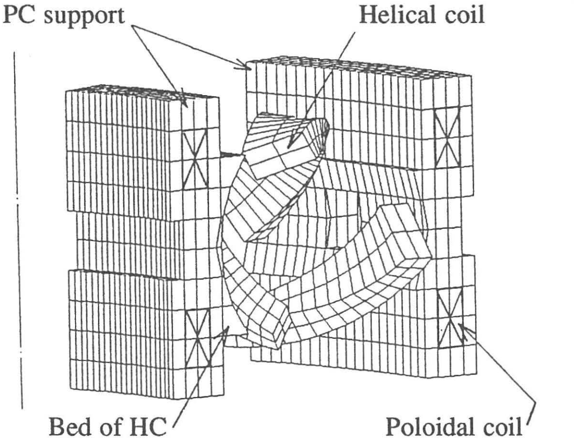

Fig. 1. Finite element model of FFHR.

References
1) A. Sagara et al., Fusion Engrg. Design, 29 (1995) 51.