§1. Magnetic Field and Force of Helical Coils for Force Free Helical Reactor (FFHR)

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The main feature of FFHR [1] is relatively small electromagnetic force on helical coils, which makes it possible to enlarge the central toroidal field or to simplify the supporting structures. In order to attain the 'force free' condition, the external transverse magnetic field in the helical coil should be small. The transverse magnetic field is very important for properties of a superconductor. The external transverse field becomes small in the 'force free' condition, and the self field becomes dominant. The self field is proportional to the square root of the coil current and the current density. Since the current is determined as the basic parameters of the helical system, the optimization of current density is important for design of the coil and the structure to gain sufficient space for the blankets.

A numerical method is necessary to calculate electromagnetic field and force of helical coils because of the complicated shape. We used the magnetic field calculation code with body-current-elements. In these calculations the number of body-current-elements was set more than 7,200 per coil to suppress the modeling error within 1%. The uniform vertical field is applied to make the vertical field zero at the major radius. The magnetic field was calculated at 20×10 points in the cross-sections by the poloidal pitch of 22.5 degree. The maximum transverse field was estimated to be the maximum in the calculated values plus the self field by one of the 20×10 segments.

A high ratio of width to height of the helical coil is useful to reduce the maximum field and to enlarge the blanket space, but it will bring problems for maintenance ports. The optimum value is determined by the total design. The ratio of 2 was selected in this study as a moderate value. As shown in Fig 1, the normalized force per unit length becomes lower with the smaller pitch parameter which is the angle of the coil to the toroidal direction. The curves are shifted in the positive y-direction with higher current density or lower aspect ratios. The maximum transverse field in the helical coil is shown in Fig. 2. It is almost proportional to the square root of the current density. Besides, it becomes gradually higher at the smaller pitch parameter due to the increase of the current. The field in the coil of the pole number of 3 is always lower than 2 because of the lower current per coil. The plasma minor radius also depends on the pitch parameter, as shown in Fig. 3. In the case of the pole number of 2, the radius becomes smaller sharply at the smaller pitch parameter to diminish at lower than 0.9. In the case of the pole number of 3, the largest value appears around 1.0.

The motional force on the helical coils is intrinsically reduced by the inclined shape, and it becomes smaller at the smaller pitch parameter or at the higher ratio of area occupied by the coils. On the other hand the plasma minor radius changes with the pitch parameter. In view of compatibility of the plasma minor radius and the blanket space, the optimum pitch parameters will be around 1.2 and 1.0 for the pole number of 2 and 3, respectively. From the viewpoint of magnets engineering, the pole number of 3 is advantageous because of smaller total force and the lower maximum field, as long as the plasma confinement is comparable.

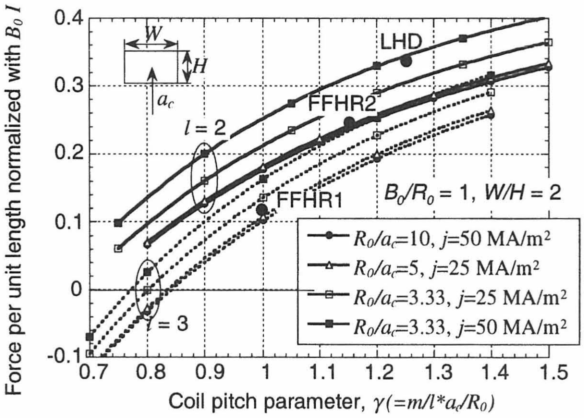

Fig. 1. The force of the helical coil normalized with $B_0 I$. B_0 is the central toroidal field, and I is the coil current.

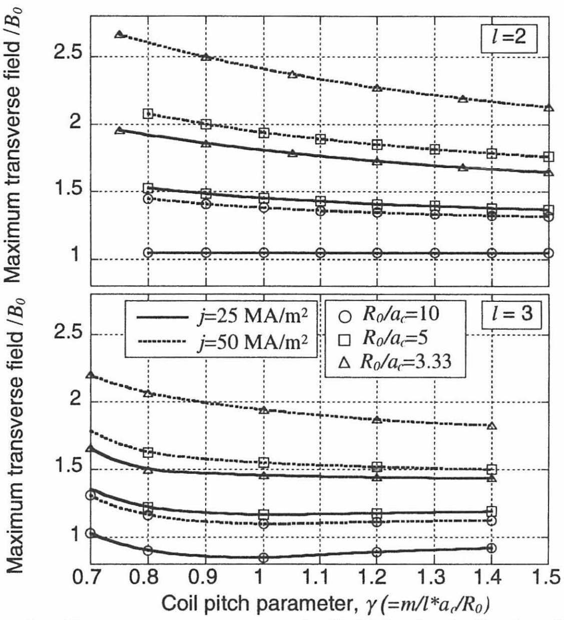

Fig. 2. The transverse magnetic field in the helical coil for the pole number of 2 and 3 with $B_0/R_0 = 1$ and $W/H = 2$.

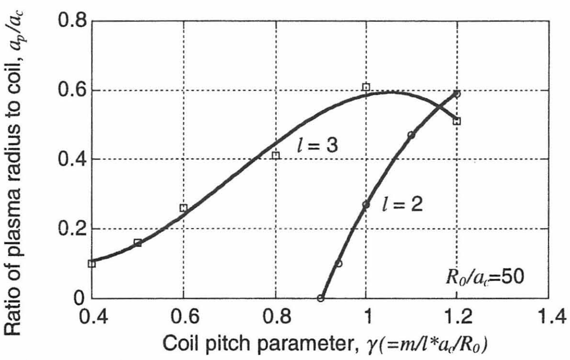

Fig. 3. The plasma radius for the pole number of 2 and 3 in the case of the aspect ratio of 50.

Reference

1) A. Sagara et al., Fusion Technology **34**, 1167 (1998).
2) A. Sagara et al., Fusion Eng. Des. **49-50**, 661 (2000).