§71. Superconducting Magnet System Design for FFHR

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The helical-type fusion reactor FFHR is a superconducting magnet system with a magnetic stored energy above 1,000 GJ and a maximum magnetic flux density of about 15 T. It consists of three helical coils, two inner vertical coils, and two outer vertical coils.

Common items for designing a superconducting magnet system are as follows;
(1) type of superconducting material,
(2) type of superconductor and cooling method,
(3) rated coil current,
(4) overall current density,
(5) winding method and coil dimension,
(6) coil protection and insulation,
(7) magnetic force and supporting structure,
(8) configuration of cryostat such as outer vessel, thermal shield, current lead, etc.,
(9) exciting method and type of power supply,
(10) helium refrigeration system.

The designed items (1, 2, 3, 4, 5) of the helical coils for FFHR are investigated based on the given values of stored energy, magnetomotive force, maximum magnetic flux density, and position of each coil.

It is well known that the rated coil current must become large according to the increase in magnetic energy storage of the magnet. The scaling law between stored energy E and rated coil current I_0 was proposed by the author based on conditions of full stability and coil protection in form of

$$I_0 \propto E^{3/7}. \qquad (1)$$

Figure 1 shows a scaling law map of rated coil currents of the many magnets tested. The 68 MJ IV-L coil for LHD was tested to the rated current of 20.8 kA in Phase-II without a quench. Three pairs of poloidal coils (IV, IS, OV) and a pair of helical coils (HC) were already assembled but not yet tested. The HC rated currents are 13.0 kA and 17.3 kA in Phase-I and Phase-II, respectively. As one helical coil for FFHR has a stored energy of about 400 GJ, the rated coil current is estimated to be 150 kA as an extrapolated value on the solid line (DC magnets) drawn by eq.(1) in Fig. 1. The broken line represents a scaling law in pulsed magnets.

Candidate materials for future 15 T helical coils are Nb_3Sn, Nb_3Al, and high temperature superconductors (HTS). Considering that FFHR will be constructed about 20 years later, Nb_3Al cable-in-conduit conductor (CICC) was chosen. CICC is suitable for mechanical strength and insulation in gigantic magnets. It is an advantage that Nb_3Al is stronger against mechanical strain than Nb_3Sn in spite of lesser production result.

We had a valuable experience that extraordinarily sophisticated winding techniques were necessary for the helical coils for LHD. Therefore, the shape of CICC for the FFHR helical coils was determined to be round. Its diameter is 66 mm at present. The overall current density is 27 A/mm^2, and the conductor current density is 44 A/mm^2. These values are fairly high compared with the tested results of many magnets, so that research and developments for current density and stability of the conductor must be performed.

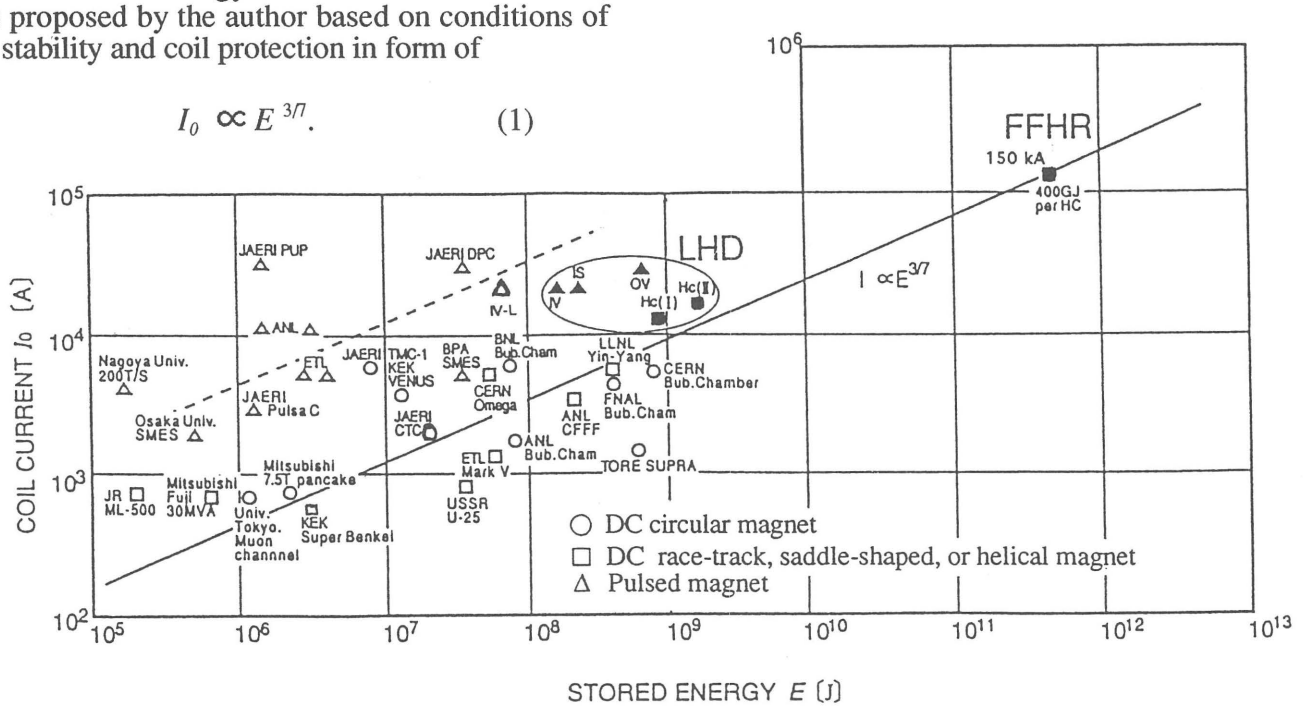

Fig. 1. Scaling law map of coil currents