§3. Conceptual Design of SC Magnets of a Helical Reactor with CIC Conductors

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Superconducting magnets for fusion reactors need high mechanical strength, high reliability, and low costs as well as sufficient current densities in the high field. Cable-in-conduit (CIC) conductors have been developed for large pulse coils, and they are adopted for all magnets of ITER. Major features of the CIC conductors are a large current up to 100 kA, high strength with thick conduits, small AC losses, and high cryogenic stability. One disadvantage is that they need circulation pumps for forced-flow cooling. The maximum length of a cooling path is about 500 m that is determined by the pressure drop for the required mass flow against the nuclear heat of 1 mW/cc. The CIC conductor will not be the best for magnets of a helical reactor that is operated with a constant current. However, technology related to CIC conductors will be strongly improved through the construction of ITER, especially in a cost and in the winding technique. Then, we study the helical winding with CIC conductors on the engineering base of ITER as a conventional option.

Main specifications of helical coils for an LHD-type reactor, FFHR2m1 are as follows: the magnet-motive force of about 50 MA, the magnetic energy of 120 to 130 GJ, a coil center line of 130 to 150 m, and average coil current density of 25 to 30 A/mm^2.[1)] Design criteria for CIC conductors based on the ITER magnets are summarized in Table 1. Since the length of the coil center line of the helical coil is five times longer than the TF coil, some ideas are necessary in addition to adopting a large current of almost 100 kA. Parallel winding is a practical solution to shorten the cooling length within 500 m. The typical design parameters of the helical coil are listed in Table 2, compared with the ITER-TF coils. It shows that the helical winding is expected to be realized with small extension of the technology for ITER.

Two types of mechanical structure are known for the CIC conductor. One is a thick conduit type, in which rectangular conductors are simply wound with being wrapped by insulating tapes. Fairly high stress is induced in the insulators by summed up forces. The other is an internal plate type, in which the conductor is wound in the grooves of the internal plate. The stress in the insulation is reduced. Besides, the force for winding is relatively small. Its disadvantage is complicated manufacturing process of the internal plates. However, its technology will be improved through ITER-TF construction. Internal plates with grooves are suite for parallel winding, because CIC conductors are just put in the grooves as shown in Fig.1. In this concept, react and wind method is preferred to use conventional insulator and to prevent huge thermal stress. Nb_3Al is a candidate for the superconducting strands of the conductor because of its good tolerance against mechanical strain. The half pitch (180 deg in poloidal) sectors of the internal plates are welded each other on site. CIC conductors are wound into the groove with insulation.

CIC conductors can be adopted for large helical windings by adopting layer winding and parallel winding method. This design is expected to be a conventional option that can be realized by small extension from the ITER technology. In order to confirm the mechanical feasibility, structural analyses is needed with considering the rigidity of the winding area.

Table 1. Design criteria for CIC conductors based on ITER-TF coils.

Items	Design criteria	ITER-TF
Max. cooling length (m)	< 500	390
Current (kA)	< 100	68
Maximum field (T)	< 13	11.8
SC current density (A/mm^2)	< 300	273
Coil current density (A/mm^2)	< 30	20.3
SC material for HC	Nb3Al (*1)	Nb3Sn

(*1) "react and wind" method can be adopted by managing strain during winding within about 0.5%.

Table 2. Specification of helical coil with CIC conductors.

	FFHR2m1-HC	ITER-TF
Maximum field (T)	13	11.8
Magnetic energy (GJ)	120	41
Conductor current (kA)	90.1	68.0
Max. length of a cooling path (m)	448	390
Number of parallel winding	5	1
Current density of winding (A/mm^2)	26.6	20.3
Cross-sectional area per turn (mm^2)	58.2x58.2	59.2x56.5
Cu ratio of strand (–)	1	1
Non-Cu current density (A/mm^2)	300	273.4
Ratio of Cu strands in area (–)	0.330	0.360
Central tube diameter (mm)	12.0	8.0
Void fraction (–)	0.34	0.34
Cable outer diameter (mm)	44.1	40.2
Conduit outer diameter (mm)	47.3	43.4
Number of coils	2	18
Total length of conductor (km)	129	82.2
Total weight of SC strands (ton)	620	351
Total weight of Cu strands (ton)	340	206
Total weight of winding (ton)	2854	1905

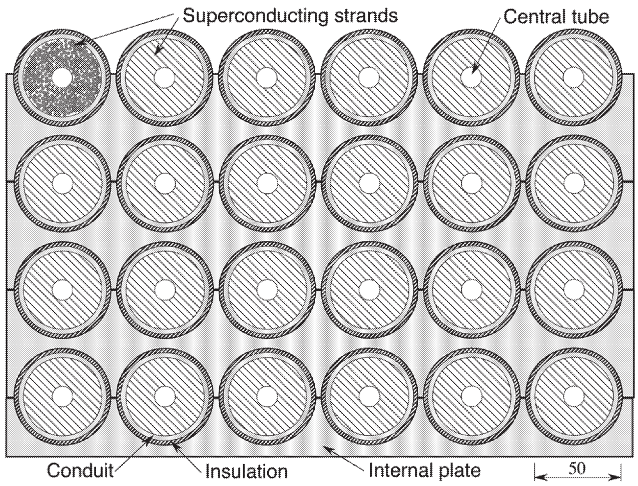

Fig. 1. Concept of helical winding with CIC conductors by five in hands.

Reference

1) A. Sagara, S. Imagawa, O. Mitarai, et al., Nuclear Fusion, 45 (2005) pp.258-263.