§25. Feasibility Study of Helical Winding with CIC Conductor for LHD-type Reactors

Imagawa, S.

A winding method is a critical issue for helical coils for helical reactors. In the case of LHD, a special winding machine was developed. The conductors from a rotating bobbin were plastically formed into the final helical shape by the shaping head at the position near the coil case. This method is not applicable to brittle high-field superconductors with react-and-wind method, because the allowable strain is in the range of 0.5% even for Nb_3Al. A candidate of winding method for Cable-in-Conduit (CIC) conductors of Nb_3Sn or Nb_3Al is as follows[1]: (1) Conductors are heated for reaction of A15 structure on a bobbin the radius of which is slightly shorter than the bending radius of the helical coil. (2) The conductors are transferred to a reel of a winding machine. The reel revolves along the helical coil as shown in Fig. 1. (3) The conductors are pulled aside by a set of winding guides and wound in grooves of the inner plate with being wrapped with glass tapes. (4) After winding the whole turns in a layer, the next inner plates are assembled.

The torsional strain by this helical winding is given by $2r\tan^{-1}\eta/(\pi a)$ where r, η, and a are the radius of the conductor, the lead angle of the helical coil and the minor radius of the helical coil, respectively. In the case of FFHR2m2, the torsional strain of the conduit is less than 0.6%[1]. Its strain is expected to be allowable for Nb_3Al strands because of the smaller torsional rigidity of the twisted strands than the conduit. This torsional strain may be allowable even for Nb_3Sn strands. Further study is needed, because the effect of torsion on superconducting properties of CIC conductors is not known.

In order to examine the concept of helical winding, a model of winding core is prepared as shown in Fig. 2. The dimension is 1/84 of the reactor design FFHR2m2, as shown in Table 1. The core is machined from two polyacetal plates, and a coil case is machined from an A1100 plate. Four V-shaped grooves of 0.5 mm depth are machined as shown in Fig. 3. The coil case is wound on the core with being bent and twisted by hand. When the terminals of the coil case are pulled for jointing, its trajectory is shifted by a few mm to the geodesic line. A stainless wire of the diameter of 0.9 mm is once wound on a bobbin of the radius of 62 mm. The bobbin is moved along the core as the wire is settled in the groove of the coil case. By being pulled by hand, the wire is settled correctly in the grooves as shown in Fig. 4. This method is feasible in principle.

Table 1. Major parameters of the helical winding model.

Items	FFHR2m2	Model	(Ratio)
Major radius (m)	16.74	0.2	(1/84)
Minor radius (m)	4.017	0.048	(1/84)
Minor radius of 1st layer (m)	3.582	0.042	(1/85)
Conductor diameter (mm)	44	0.9	(1/49)
Equivalent bending radius (m)	6.62	0.079	(1/84)
Radius of moving bobbin (m)	–	0.062	

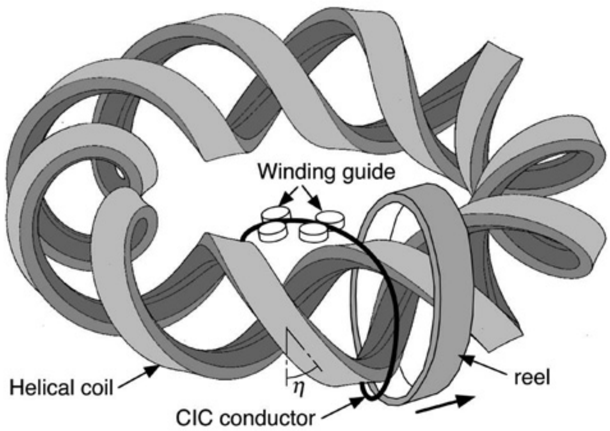

Fig. 1. Concept to wind a helical coil with CIC conductors.

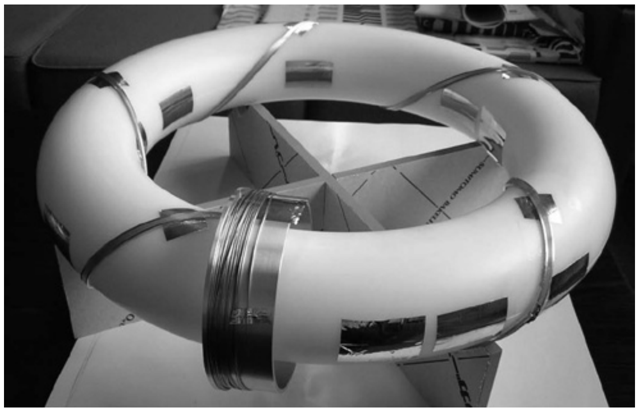
Fig. 2. Model of helical winding core on which a coil case is wound by five turns. A stainless wire corresponds to CIC conductors.

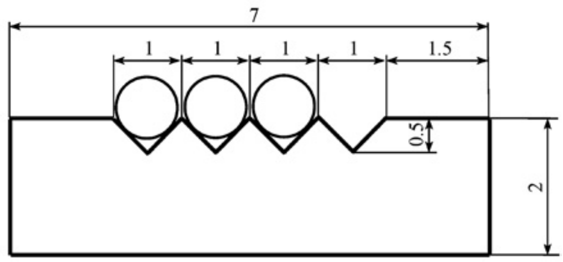

Fig. 3. Drawing of the coil case made from aluminum.

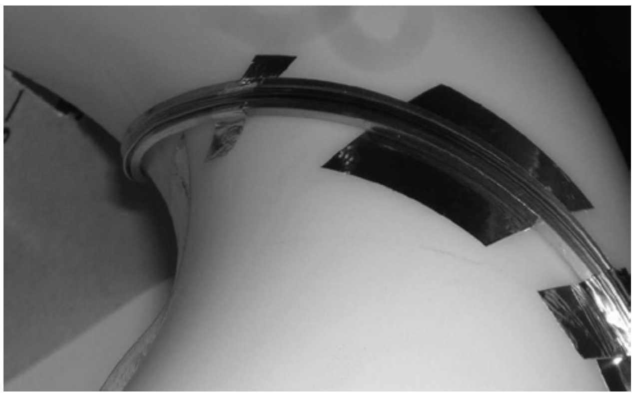
Fig. 4. The first trial of helical winding. The wire is wound in the grooves by tree turns.

1) Imagawa S. et al., *Nuclear Fusion*, **49** (2009) 075017.