§12. Feasibility Study of React-and-wind Method for Helical Coils Wound from Cable-in-conduit Conductors

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Design study on react-and-wind method for helical coils wound from cable-in-conduit (CIC) conductors has been carried out. In this concept, CIC conductors are heated for reaction of the A15 phase on a bobbin, the circumference of which is the same as the length of one pitch of the helical coil. After that, each conductor is transferred to a reel that revolves through the helical coil, as shown in Fig. 1. The conductor is wound with being pulled aside from a reel, that is, being twisted. Since the superconducting wires in the conduit are multi-stage twisted, the effect of twisting the conductor on the strain of the wires is considered to be small. Furthermore, if tension is added on the wires by twisting the conductor, the compressive strain due to thermal contraction of the wires is reduced, and the critical currents of CIC conductors can be increased with the react-and-wind method. In order to examine the effect of twisting the conductor on the strain of the wires, experimental study with a model CIC conductor has been carried out. The results show that the small tensile strain is added in the wire by twisting the conduit in the same direction as the wire twisting direction.

The torsional strain of the conduit is given by $r_{\mathrm{conduit}}\theta$ where r_{conduit} and θ are the radius of the conduit and the torsional angle per unit length. The calculated torsional strains in the conduits in the winding for several reactor designs[1)] are shown in Fig. 2. The highest torsional strain of the conduit is almost 0.7% that induces the highest tensile strain in the angle of $\pi/4$ from the longitudinal direction of the conductor. According to Mohr's stress circle, the tensile strain is zero in the longitudinal and transverse directions. Since the superconducting wires are twisted, they are inclined to the longitudinal direction of the conduit with the angle η, as shown in Fig. 3. Assuming that the wires behave as a monolithic metal, the longitudinal normal strain of the wire is given by

$$\varepsilon_{wire} = \frac{r_{wire}\theta}{2(1+\nu)}\cos\left(\frac{\pi}{2}-2\eta\right) \tag{1}$$

where r_{wire} and ν are the radius of the wire and Poisson's ratio, respectively. In reality, the strain must be reduced by slippage of the wires against the conduit.

Here, the average strain in a sub-cable is considered. The typical η of the centerline of a sub-cable is 10-15 degrees, and its radius is almost half of r_{conduit}. Then, the average strain of the sub-cable by being twisted is estimated at 1/10 of the torsional strain in the conduit from (1). In reality, the change of strain in the wires is considered to be lessened by slippage of the wires to the conduit. Therefore, the react-and-wind method is expected to be applicable for the helical coil without degradation or with slight increase of the critical current by setting the twisting direction of the Nb_3Sn wires same as the twisting direction in winding.

1) S. Imagawa, A. Sagara, and Y. Kozaki, Plasma and Fusion Research 3, S1050 (2008).

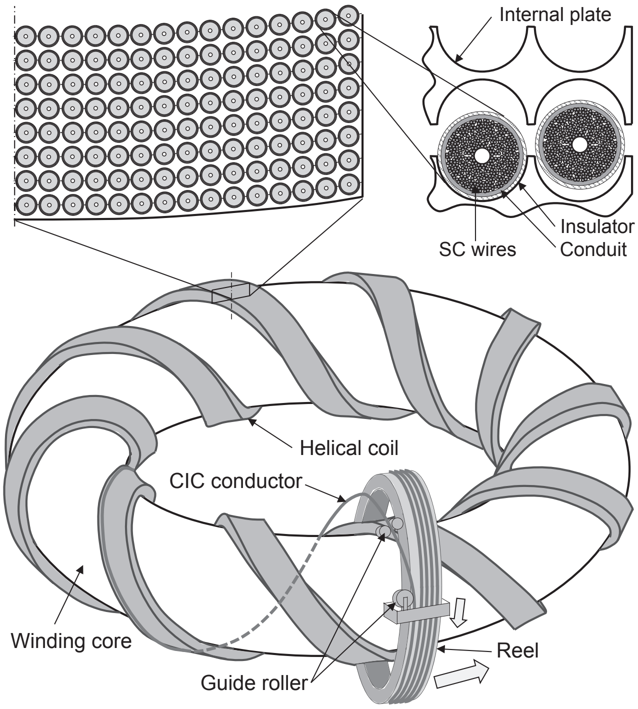

Fig. 1 A concept of winding a helical coil from CIC conductors with react-and-wind method.

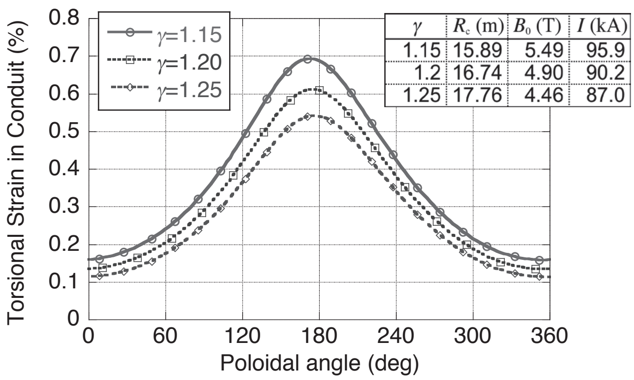

Fig. 2 Torsional strains of helical coil conductors in the winding for LHD-type helical reactors. γ, R_c, B_0, I are the coil pitch parameter, coil major radius, central field, and conductor current, respectively. The coil current density is 25 A/mm^2, and the turn number is 14×30=420.

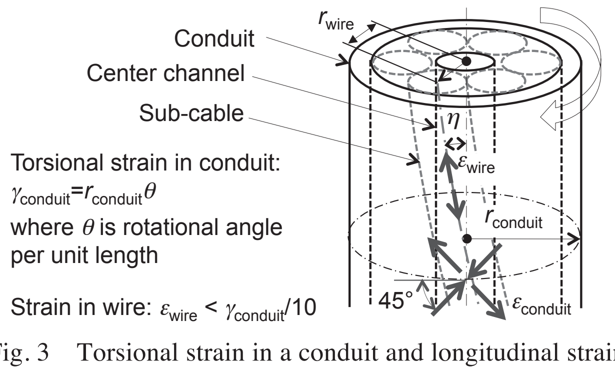

Fig. 3 Torsional strain in a conduit and longitudinal strain in wires of a CIC conductor.