§25. Progress of HTS Magnet Design and 100 kA-class Conductor Development for FFHR-d1

Yanagi, N., Hamaguchi, S., Noguchi, H., Tamura, H., Mito, T., Sagara, A.,
Terazaki, Y. (Grad. Univ. Advanced Studies),
Ito, S., Seino, Y., Hashizume, H. (Tohoku Univ.)

Conceptual design studies of the LHD-type helical fusion reactor, FFHR-d1, are progressing steadfastly.[1] The magnet system consists of a pair of continuously-wound helical coils (major radius: 15.6 m, helical pitch number: 10) and two pairs of vertical field coils. A 3 GW fusion power generation requires a toroidal magnetic field of 4.7 T with a total stored magnetic energy of 160 GJ. A conductor current of 94 kA is needed in the helical coils with a current density of 25 A/mm^2 at the maximum magnetic field of 12 T.

We select the HTS conductor as a plausible candidate owing to a number of advantages, such as high cryogenic stability, excellent mechanical rigidity, low consumption of helium resources and quickly developing wire production technology for various applications. Simple stacking of YBCO tapes is proposed to fabricate a large-current capacity conductor (Fig. 1), since formation of non-uniform current distribution among tapes (without transposition and twisting) is allowed because of high cryogenic stability, unlike using low-temperature superconducting strands. An innovative winding method is proposed for the helical coils by connecting prefabricated half-helical-pitch (length: ~15 m) HTS conductors, as shown in Fig. 2. This should drastically facilitate the in-situ fabrication procedure compared with the case of constructing a 50-m-diameter winding machine.[2,3] A bridge-type mechanical lap joint, having a staircase like structure to make a face-to-face connection of YBCO surfaces, is a viable technique.[4] To secure the mechanical strength of a joint, welding of the stainless-steel jacket is inevitable. The joint fabrication should be done automatically using an industrial robot. The conductor has internal insulation around the copper jacket. The outer stainless-steel jacket is welded between neighboring conductors, which secures high mechanical rigidity of windings. This could also skip a vacuum pressure impregnation process. The conductor surface is cooled by gas helium through cooling channels formed on the stainless-steel jacket.

A "100-kA-class" conductor sample (length: ~3 m) was fabricated using GdBCO tapes and successfully tested in a one-turn racetrack-coil.[5] The maximum current reached 100 kA at a bias magnetic field of 5.3 T and a temperature of 20 K as shown in Fig. 3. A numerical simulation, solving the magnetic field and current density profiles self-consistently among HTS tapes, shows fairly good agreement between the measured and calculated critical currents especially in the low magnetic field region.[6] The joint resistance was evaluated to be ~2 nΩ,[5] which assures that the Joule heating produced at 7,800 joints in the FFHR helical coils could be cooled by <5 MW of electricity in the cryoplant.

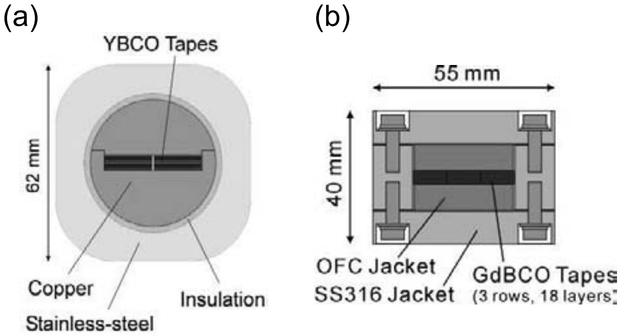

Fig. 1. Cross-sectional images of (a) the 100kA-class HTS conductor designed for the FFHR-d1 helical coils and of (b) the prototype conductor sample.

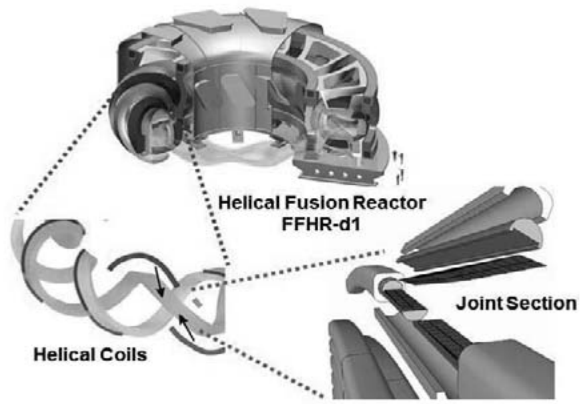

Fig. 2. Schematic illustration of "joint-winding" to be applied to the FFHR-d1 helical coils.

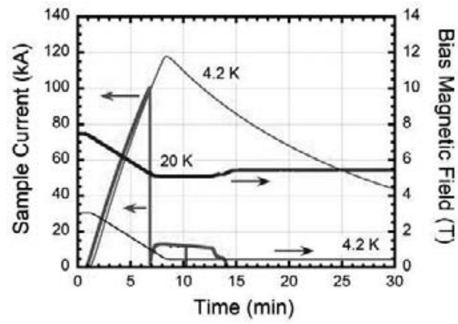

Fig. 3. Waveforms of the sample current and bias magnetic field measured for the 100 kA-class conductor sample.

1) Sagara, A. et al.: to be published in Fusion Eng. Des..
2) Hashizume, H. et al.: Fusion Eng. Des. **63** (2002) 449.
3) Yanagi, N. et al.: Plasma Fusion Res. **9** (2014) 1405013.
4) Yanagi, N. et al.: IEEE Trans. Appl. Supercond. **24** (2014) 4202805.
5) Ito, S. et al.: Plasma Fusion Res. **9** (2014) 3405086.
6) Terazaki, Y. et al.: IEEE Trans. Appl. Supercond. **24** (2014) 4801305.