§24. Progress of Magnet Design for the Helical Fusion Reactor with 100-kA HTS STARS Conductor

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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 stored magnetic energy of 160 GJ. A conductor current of 94 kA is required 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 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), which has been denoted as STARS, the abbreviation for Stacked Tapes Assembled in Rigid Structure.[2] Formation of non-uniform current distribution among tapes can be allowed because of high cryogenic stability. An innovative winding method has been proposed for the helical coils by connecting prefabricated half-helical-pitch (length: ~15 m) HTS conductors. It was recently found that the unit length could be doubled; one helical pitch of ~30 m, as shown in Fig. 2. This idea should drastically facilitate the in-situ fabrication procedure compared with the case of constructing a 50-m-diameter winding machine. 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.[3] The conductor has internal insulation around the copper jacket. A candidate of the insulation material is ceramics, but an intense R&D will be required. The outer stainless-steel jacket is welded between neighboring conductors, which secures high mechanical rigidity of windings and skips a vacuum pressure impregnation process. We propose that the conductor surface be cooled by helium gas through cooling channels formed on the stainless-steel jacket. The cooling capability should be properly evaluated in our future studies.

A "100-kA-class" conductor sample (length: ~3 m) was fabricated using GdBCO tapes and successfully tested in a one-turn racetrack-coil.[2] The maximum current reached 100 kA at a bias magnetic field of 5.3 T and a temperature of 20 K in the first experiment conducted in 2013. In 2014, we sustained 100 kA in 1 hour 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.[4] The joint resistance was evaluated to be ~2 nΩ,[3] which assures that the Joule heating produced at 3,900 joints in the FFHR helical coils could be cooled by <2.5 MW of electricity in the cryoplant.

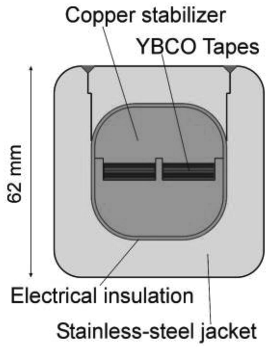

Fig. 1. Schematic cross-sectional image of the 100 kA-class HTS conductor designed for FFHR-d1.

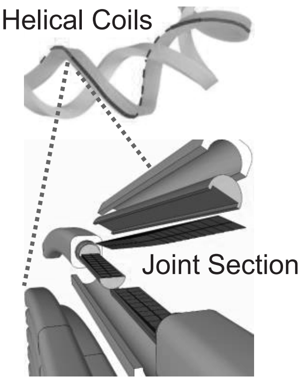

Fig. 2. Schematic illustration of the FFHR-d1 helical coils with joint-winding of the segmented HTS conductors.

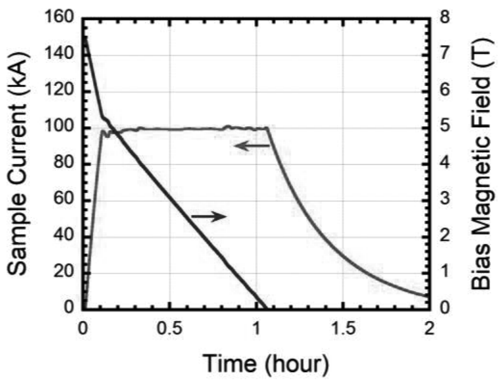

Fig. 3. Stable sample conductor current of 100 kA sustained for 1 h at 4.2 K.

1) Sagara, A. et al.: Fusion Eng. Des. 89 (2014) 2114.
2) Yanagi, N. et al.: Nucl. Fusion 55 (2015) 053021.
3) Ito, S. et al.: IEEE Trans. Appl. Supercond. **25** (2014) 4201205.
4) Terazaki, Y. et al.: IEEE Trans. Appl. Supercond. **25** (2014) 4602905.