§8. Design Progress on the High-Temperature Superconducting Coil Option for FFHR

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The engineering design of the superconducting magnet system for the heliotron-type fusion energy reactor FFHR is being conducted.[1)] The present design specifies a major radius of >15 m for the continuously wound helical coils that produce a toroidal magnetic field of ~5 T. The stored magnetic energy will reach up to 160 GJ. A current capacity of 100 kA is required for the helical coil conductor at the maximum magnetic field of ~13 T. As a counter option to the Nb$_3$Al cable-in-conduit conductor that is supposed to be the primary option for FFHR based on the ITER technology, we also propose that high-temperature superconductors (HTS) could be employed considering the quick development of the HTS wire production technology, especially for the YBCO coated-conductor. We have successfully carried out a short sample test of a 10 kA-class conductor by stacking YBCO tapes in a copper jacket.

One of the advantages of using HTS conductors is to employ an innovative winding method of the huge helical coils by connecting short-length conductors to form a continuously wound coil.[2)] Previously, we considered fabricating half-pitch segments of the entire helical coil.[3)-4)] However, we concluded that it would be very difficult to realize this concept since more than 400 turns of conductors in each coil should be joined securely and simultaneously. Moreover, the weight of each half-segment is estimated to reach several hundred tons, which must be too difficult to be prefabricated in factories and transported to the site. And thus, it seems rather difficult to pursue this option.

Consequently, we made a new proposal that instead of joining half-pitch “coil segments”, the half-pitch “conductor segments” could be joined. Figure 1(a) shows an illustrative image of this method. The helical coil casing (that installs the windings) should be first assembled by joining half-pitch segments along the entire torus. Then, the pieces of conductors, preformed into helical shapes in factories or on site, would be installed into the casings. We note that the conductor pieces could be cold tested in liquid nitrogen prior to the installation, if required. Moreover, another advantage is that it is not required to produce high-performance HTS wires over a long length. Instead, we need high-performance wires with rather short length, which must be easier to supply with lower costs.

At the joint locations between half-pitch segments, the HTS conductors are cut in step-like structures, then overlapped and joined with superconducting sides facing each other so that low-resistance joint can be formed, as shown in Fig. 1(b). The stainless-steel jacket should also be connected by welding to ensure the mechanical rigidity. We should note that a similar idea of having an intermediate joining piece for connecting two conductors was actually incorporated in the LHD helical coils with NbTi superconductors.

The joint resistance was measured for single YBCO tapes to be ~6 nΩ for a 50 mm joint length. Using this value, the overall joint resistance of a 100-kA conductor is expected to be 0.3 nΩ, consisting of 2 connections at one joint location with 100 HTS tapes, each having a 50 mm joint length. As the entire helical coils will have ~8000 joints (~400 turns of windings, 10 segments for each coil and 2 coils), this requires a ~1.5 MW increase of the refrigeration power assuming the coil operation temperature of 20 K. This is still lower than 10% of the total refrigeration power required for the conventional design with LTS coils operated at 4 K. The joint resistance of a 10-kA current capacity sample is now being measured and the result will be reported elsewhere.

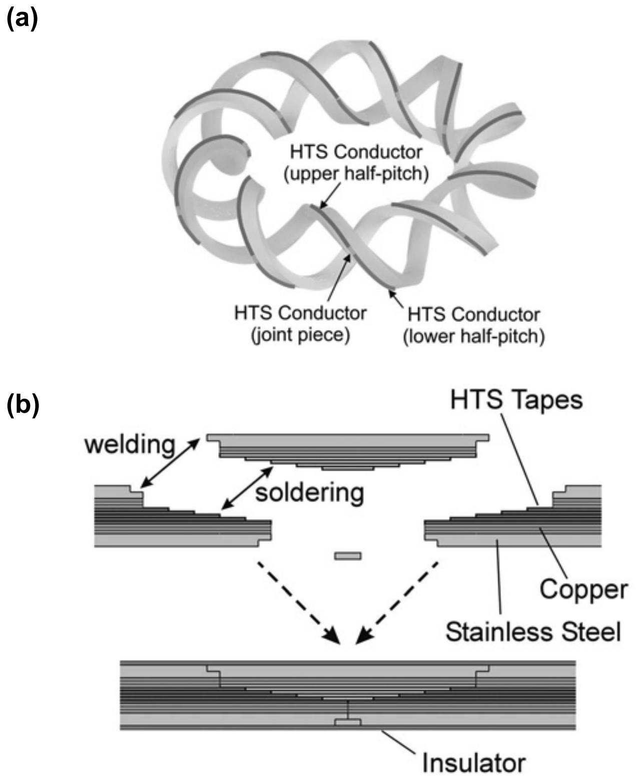

Fig. 1 (a) Segmented fabrication method of helical coils with half-pitch conductor segments. (b) Illustration of the joining method of YBCO conductors.

1) Sagara, A. et al., Fusion Eng. Des. **83** (2008) 1690.
2) Hashizume H. et al., Fus. Eng. Des. **63** (2002) 449.
3) Bansal, G. et al., Plasma Fus. Res. **3** (2008) S1049.
4) Yanagi, N. et al., Plasma Fusion Res. **5** (2010) S1026.