§17. Measurement of the Joint Resistance of Large-Current YBCO Conductors

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Conceptual design studies of the LHD-type heliotron fusion DEMO reactor FFHR-d1 are being carried out at NIFS through domestic and international collaborations. The FFHR-d1 is four times bigger than LHD and the major radius of the helical coils is 15.6 m [1]. As a counter option to the Nb_3Al cable-in-conduit conductor (CICC) that is supposed to be the primary selection for the FFHR magnet based on the ITER technology, the segmented-fabrication method using the High-Temperature Superconducting (HTS) conductors has been proposed [2, 3]. In this study, 10-kA class YBCO conductors having the joint section were fabricated. Then, the measurements of joint resistances have been carried out to verify the feasibility of the segmented fabrication of the helical coils of FFHR with the HTS option.

To make joints for the FFHR helical coils, two methods are proposed: a soldered lap joint and a mechanical lap joint. The soldered lap joint method joins conductors by applying solder and it is considered that a low joint resistance can be obtained. Whereas, the mechanical lap joint method joins conductors by applying compressive forces on the joint section temporarily and then the welding of the outer stainless-steel jacket is done. In this method, though the joint resistance may become higher, the construction process of the FFHR helical coils will be further eased.

For the 10-kA class sample with a soldered lap joint, Fig. 1 shows the measured joint voltage as a function of the sample current. In Fig. 1, the joint resistance is evaluated to be 20.2 nΩ and the contact resistivity is 109.5 nΩcm^2. Using this value, the overall joint resistance of a 100-kA class conductor is expected to be 1.1 nΩ, consisting of 2 connections at one joint location with 40 HTS tapes, each having a 50 mm joint length and the width of the tape 10 mm. As the entire helical coils will have ~8000 joints (~400 turns of windings in each coil, 10 segmented conductors for a toroidal turn and 2 coils), this requires ~5.2 MW increase of electrical power for the refrigeration system at room temperature, assuming the coil operation temperature at 20 K. This seems to be acceptable since the required electrical power for the entire FFHR refrigeration system is supposed to be ~30 MW in case of the CICC options.

For the 10-kA class sample with a mechanical lap joint, Fig. 2 shows the contact resistivity as a function of the compressive load which is expressed as the conductor thickness in the present experiment. It is found that the contact resistivity decreases as the load increases, however, the minimum value so far is observed at 4.9 μΩcm^2 (resistance: 406 nΩ). According to the previous study by A.J. Dietz et al. [4], the contact resistivity for the YBCO single tape is 200-40 nΩcm^2 by applying a pressure at 40-200 MPa. In another study by S. Ito et al. [5], the contact resistivity of a two-layer joint of BSCCO tapes is twice or three times higher than that of a single layer joint because of the misalignment of HTS tapes. Therefore, the joint resistivity measured in the present experiment can be explained by the misalignment of 14 tapes under insufficient loads. Presently, the soldered lap joint seems more feasible than the mechanical lap joint.

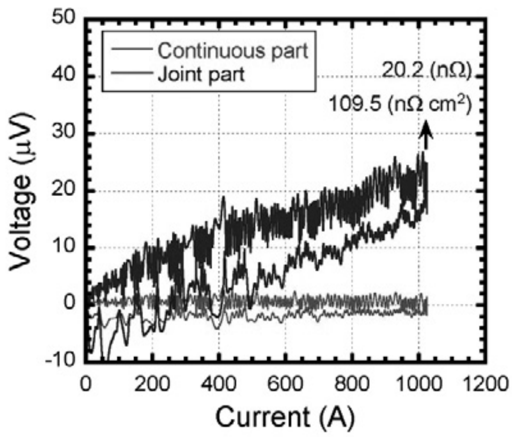

Fig. 1 Joint voltage of the 10-kA class soldered lap joint as a function of current.

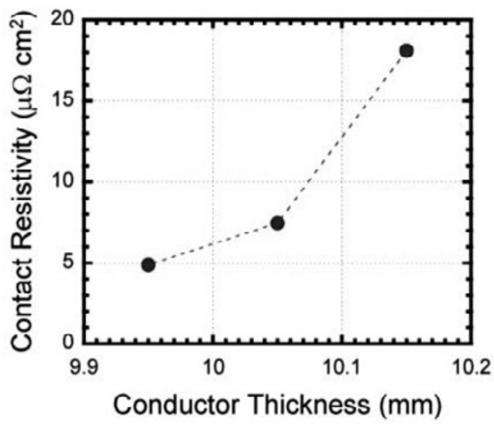

Fig. 2 Contact resistivity obtained by the 10-kA class sample in mechanical lap joint as a function of the conductor thickness.

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