27.6 T Generation Using Bi-2223/REBCO Superconducting Coils

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June 20, 2016 (STH42/HP112). We started to consider the development of a compact 1.3 GHz (30.5 T) nuclear magnetic resonance (NMR) magnet using high-temperature superconducting (HTS) coils. From the viewpoint of the magnetic field homogeneity, which is a requirement for high-resolution NMR measurements, and to allow the future opportunity of persistent current operation, we have developed, in previous projects and the ongoing one, a layer-wound HTS coil technology [1],[2],[3],[4].

Last year, as a part of a compact 800 MHz (18.8 T) class NMR development project, we fabricated a (RE)$Ba_2Cu_3O_{7-x}$ (REBCO; RE = Rare Earth) and a $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10-x}$ (Bi-2223) coils. DI-BSCCO Type HT-NX (Sumitomo Electric Industries, Ltd.) high-strength conductors [5],[4] were used for the Bi-2223 coil, and the coil was designed based on a shape for the innermost coil of an NMR magnet [3]. Both coils were layer-wound and impregnated with paraffin wax. The series-connected coils were tested in a background magnetic field of 17.2 T, generated by a 130 mm bore NbTi/Nb_3Sn outer magnet [6] cooled in a liquid helium bath. The experimental setup is shown in Figure 1. The HTS inner coils successfully produced 13 T without the background field. However, the REBCO coil showed substantial degradation in the background field, and thus we stopped charging at 25.0 T. The origin of the degradation was found to be delamination of REBCO conductors in a soldered joint. The delamination was caused by cleavage and peeling, induced by the stress concentration at the ends of the lap; the stress concentration was due to an electromagnetic force applied to the joint. In addition, we found that a conductor of the outermost layer moved and deformed in the axial direction due to axial electromagnetic force, which degraded the coil performance.

Based on these results, we improved the coil fabrication process and developed a second REBCO inner coil: as a first improvement, joints in the winding were removed, being installed on the top flange: as a second improvement, a higher number of binding layers was wound over the outermost layer of the winding, to prevent conductor motion. Thanks to these improvements, a central magnetic field of 27.6 T (285 A) was successfully achieved as shown in Figure 2. The 27.6 T value was the highest magnetic field ever achieved by all-superconducting magnets [8]. However, a gradual premature voltage appeared on a medium section of the new REBCO coil and the coil was quenched during the ramp from 27.6 T to 28 T; it resulted in a burnout of the REBCO coil.

These experiments demonstrated the feasibility of layer-wound HTS coils made from high mechanical strength conductors for super-high-field generation. We have already demonstrated effective techniques to avoid degradation due to cooling down [9]. However, it is demonstrated by these experiments that degradation due to electromagnetic forces still disturbs the performance of a REBCO coil. Therefore, to improve super-high-field HTS coil technology, we must solve that degradation problem.

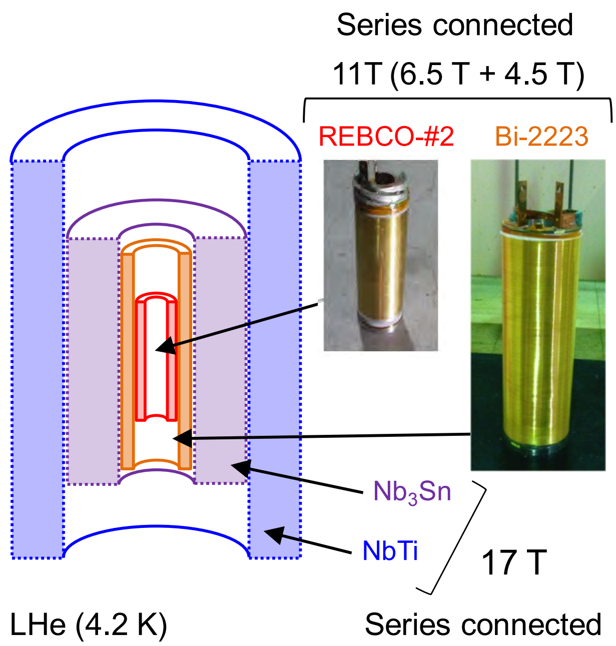

Fig. 1. Configuration of a 28 T NbTi/Nb_3Sn + Bi-2223/REBCO superconducting magnet. The REBCO coil and the Bi-2223 coil were respectively wound with Fujikura REBCO conductors [2],[3] and Sumitomo high-strength Bi-2223 conductors reinforced with Ni-alloy [5],[4].

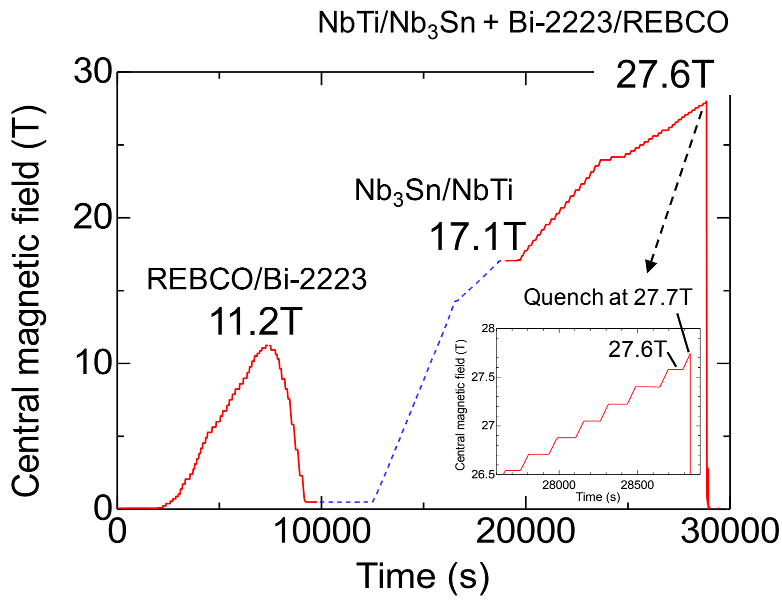

Fig. 2. Central magnetic field measured with a Hall sensor for a high field generation experiment with the new REBCO coil.

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