Present Status of the MIRAI Program; Towards a Persistent 1.3GHzNMR and DC Feeder Cables

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***Abstract*— We commenced a MIRAI Program supported by the Japan Science and Technology Agency (JST) in 2017 [1]; it comprises two development challenges focused on (a) superconducting joints between HTS conductors and a 1.3 GHz (30.5 T) persistent NMR magnet and (b) ultra-low resistive joints between HTS cables and DC superconducting joined feeder cables (e.g. 10 A) for railway systems. This lecture describes research and development progress made in the first three years of the program (2017- 2019).**

Development of a superconducting joint between HTS conductors is the first issue to be addressed in this project. Thus far, superconducting joint between GdBCO coated-conductors has been established by Sumitomo Electric Industries [2], while that for DI-BSCCO tapes was successfully developed at Aoyama-Ga uin University [3]; both are indirect joints with an intermediate HTS layer. Their joint critical currents (I_c) exceeded 100 A at 77 K in self field; the corresponding I_c at 4.2 K under 1 T is >715 A for a GdBCO joint, while >300 A for a DI-BSCCO joint. Recent studies on the field decay of a small persistent coil revealed that their joint- resistances are <10^{-13} Ω at 4.2 K, sufficient for NMR measurement. The results satisfy the specification of the superconducting joint for the 1.3 GHz NMR magnet.

Superconducting joints of HTS are a key technology to develop an NMR magnet that operates at a 1H NMR frequency of 1.3 GHz (30.5 T) in a persistent mode. The biggest technical challenge is to operate the magnet in the persistent mode, as such an NMR magnet requires several tens of superconducting joints between HTSs. Thus, we developed the first NMR magnet equipped with superconducting joints between REBCO coated conductors [2]. The temporal drift of the magnetic field showed excellent stability over 1 year after the charge to 400 MHz (9.4 T) [4]. We will discuss technical challenges for a HTS NMR magnet with HTS joints using this system as an example.

It is also a difficult challenge to achieve a field of 30.5 T, corresponding to a 1.3 GHz NMR frequency. There are two critical issues to be addressed to attain 30.5 T by using a REBCO inner coil; they are (a) coil quenches due to conductor degradation by the electromagnetic force and (b) coil damage after quench. A model magnet, comprised of a REBCO inner coil, NX-BSCCO middle coil and LTS outer coil, has been developed. The latter issue (b) was addressed by using an intra-layer no-insulation (LNI) method [5]. The magnet reached 30.5

T without quench; then it was safely protected against quench at 31 T. Further investigation is being made on the hoop stress enhancement effect due to screening currents, as a potential source of the conductor degradation described above as (a).

The Railway Technical Research Institute (RTRI) have proposed a "Next Generation DC Railway System" using HTS cables [6]. Connection of adjacent substations with additional HTS DC feeder cables may result in load leveling among substations, reduction in transmission power loss, and efficient regenerative braking. On the other hand, the typical distance between substations in an urban area is 2-5 m in Japan and the maximum available length of the unit DC cable is <500 m, limited by truck transportation. Therefore, it is clear that some joints are necessary to install a DC superconducting feeder cable that connects adjacent substations. Thus, we are developing a feasible on-site joint between unit superconducting DC feeder cables, which has an ultra-low joint resistance of the order of 10^{-8}-10^{-7} Ω. Some preliminary results will be presented at the conference.

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