Developments of RE123 insert magnet

We performed quench analysis and R&D tests of high temperature superconducting insert magnets for future high field magnet beyond 30 T using $REBa_2Cu_3O_y$ (RE123, RE: rare earth). The quench properties of the 25T cryogen-free superconducting magnet (25T-CSM) was simulated by the finite element method. We found a solution of quench protection of RE123 insert coil, which is recognized as one of serious issues of HTS magnet.

We successfully achieved a high magnetic field of 24.6 T in a 52 room temperature bore using a 25T cryogen-free superconducting magnet (25T-CSM) [1]. The 25T-CSM now operates as a user magnet at High Field Laboratory for Superconducting Materials (HFLSM) and makes a significant contribution to high field researches. Now the HFLSM in Sendai, Japan and Laboratoire National des Champs Magnétiques Intenses (LNCMI) in Grenoble, France are developing 30 T superconducting magnet. The collaboration of both laboratories focuses on the high temperature superconducting magnet technology.

The high field generation of 24.6 T of the 25T-CSM was made with the $Bi_2Sr_2Ca_2Cu_3O_y$ (Bi2223) insert. In order to develop high field superconducting magnet beyond 30 T, however, the $REBa_2Cu_3O_y$ (RE123, RE=rare earth) insert magnet should be used because its high performances of in-field critical current density and mechanical properties. The most serious problems of RE123 insert are a quench protection and a mechanical behavior of the coil under a huge electromagnetic stress. In this project, we focus on those subjects using simulation and experiments.

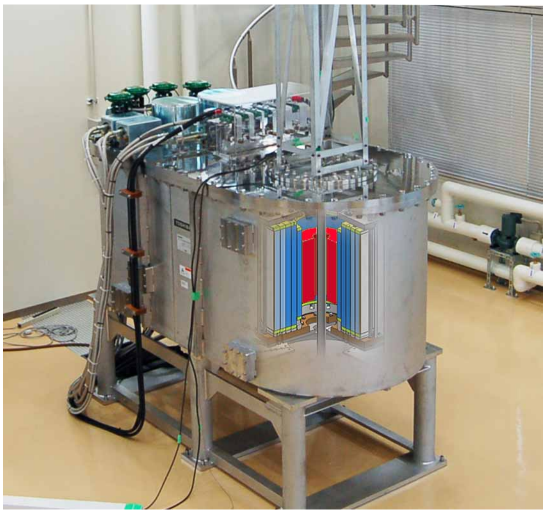


Fig. 1 Photo and coil image of 25T-CSM

Fig.1 shows the photo and coil images of the 25T-CSM. From the test of RE123 insert coil in the 25T-CSM, we confirmed that the quench protection circuit was effective at least for 6 s after the quench but the sudden drop of coil operation current took place at 6 s. Using the simulation based on the Comsol, developed at Grenoble, we succeeded in the reproduction of the quench behavior of the 25T-CSM. According to the simulation results, the temperature of a part of the RE123 insert coil reaches around 600 K at 6 s after the quench detection dumping as shown in Fig. 2. However, we found the solution to protect the coil from the damage by the simulation. It should be applied for the protection design of the 30 T-CSM.

For development of a 30T cryogen-free superconducting magnet, we made and tested a RE123 pancake coil with co-winding double-stacked RE123 tapes as shown in Fig. 3. We succeeded in the stable operation of the coil with large stress states up to 580 MPa, which is larger than 490MPa required for the 30 T-CSM. At the same time, we found that an electromagnetic coupling of double-stacked tapes influences the magnetic field and dissipation of the coil. It causes the magnetic field instability and ac losses of the coil.

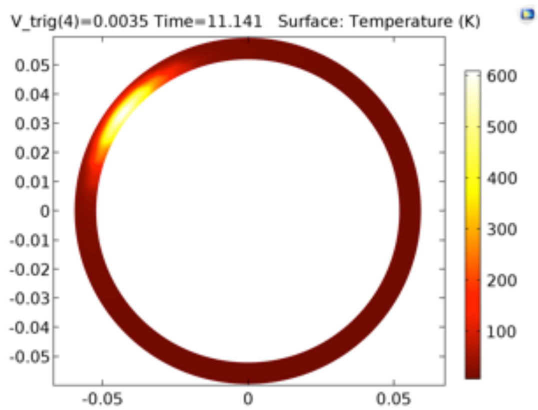
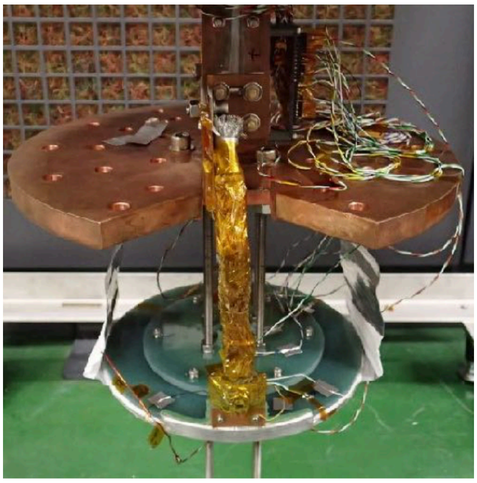


Fig. 2 Simulation result of temperature distribution in a part of RE123 insert coil of the 25T-CSM at 6s after the quench detection. The quench detection voltage is 3.25mV.



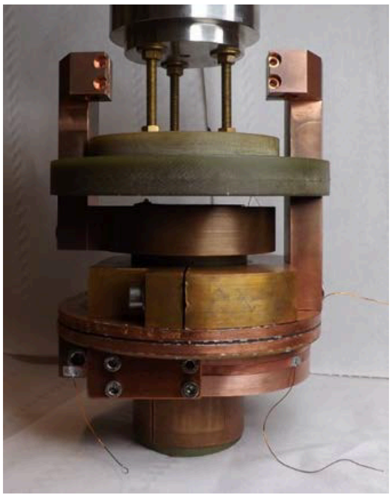


Fig. 3 Photos of (Top) double-stacked RE123 tape co-wound coil at Tohoku University and (Bottom) single tape wound RE123 coil at LNCMI.

The LNCMI performed the test of their own RE123 coil using ϕ360mm-8T-CSM at the HFLSM. It is for NUGAT project at LNCMI, which is to develop a 10 T RE123 insert coil operated in a background field of 20 T by the water cooled resistive magnet. The magnetic field of 1.3 T under the background field of 8 T was confirmed with an electromagnetic stress of 205 MPa. In particular, the coupling of the RE123 insert to the outer low temperature superconducting magnet was observed, when the outer LTS magnet quenched. We found that the induced current reaches to about 80% of operation current. The protection circuit should be designed so that the induced current in the RE123 coil is less than critical current.

The critical current density properties of RE123 tapes are also quite important for the high field magnet. We also evaluated them in detail in high magnetic fields up to 24 T. The flux pinning model of RE123 tapes with artificial pinning center (APC), which is recently used for the practical RE123 tapes, were proposed [3]. It can explain the complicated critical current density properties of RE123 with APC.

The 5th French-Japanese high field workshop (F-J WS) was held on December 17-20, 2017 at Tsukuba and Sendai. Six French and fifteen Japanese researchers attended to the workshop at this time. The important topics such as quench protection, shielding current and RE123 coil fabrication method were discussed in detail. The continuous collaboration between LNCMI, NIMS and HFLSM was confirmed for high field magnet developments using high temperature superconducting materials.

In summary, we found the quench protection method of RE123 insert coil, which is recognized as one of serious issues of HTS magnet by the simulation and experimental. The R&D RE123 insert coils were fabricated and tested under the background field of large bore superconducting magnets at HFLSM. We found the solution of quench protection of RE123 insert coil. We confirmed the international collaboration between France and Japan for high field magnet development should be continued.

References

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