MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

ID: MT26-Mon-Af-Po1.20-01

Thermal and Electrical Behaviors of an MI HTS Insert Comprised of THEVA-SuperPower Coils under High Background Magnetic Fields at 4.2 K

Jung-Bin Song[a], Xavier Chaud[a], Benjamin Borgnic[a], François Debray[a], Philippe Fazilleau[b], and Thibault Lécrevisse[b]

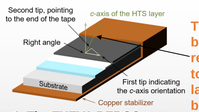
[a]LNCMI-EMFL-CNRS, Univ. Grenoble Alpes, INSA, UPS, 38032 Grenoble, France

[b]DACM, IRFU, CEA, Université Paris-Saclay, 91191 Gif sur Yvette, France

Abstract

In this study, two metal-as-insulation (MI) REBCO double-pancake (DP) coils comprised of THEVA and SuperPower REBCO single pancake (SP) coils were constructed and assembled. A sapphire plate was inserted in between the two single pancake (SP) assembled as a DP, while copper plates insulated by G10 were inserted between the DPs to enhance the cooling of the MI insert. The thermal and electrical characteristics were investigated under an applied external field in the range of 0 to 19 T at 4.2 K. The insert was pushed up to the quench at each field, such defining its real operating limit without damage. Its thermal stability was checked up to 10 A/s in self-field (SF) at 4.2 K. Characteristic resistance change, current-carrying performance, quench behavior, thermal stability of the MI insert is discussed.

REBCO tapes for coils



The c-axis of REBCO layer is tilted by approximately 30 degrees with respect to the substrate normal due to the epitaxial growth of REBCO layer on a biaxially textured MgO buffer layer

Fig. 1. The THEVA REBCO tape

Table. 1 Specifications of two REBCO tapes for test coils

Parameters		THEVA	SuperPower
Materials of superconducting layer		GdBCO	
Width; total thickness	[mm]	6; 0.145	6; 0.075
Cu stabilizer thickness (both side)	[μm]	40	20
Substrate thickness	[μm]	100	50
Measured tape I_c @ 77 K in SF.	[A]	281	262; 221
Engineering critical current density (J_e) of REBCO tapes @ 77 K	[A/mm^2]	323.0	582.2; 491.1

Winding and 77 K Test of two THEVA(TV)-SuperPower(SPo) DP coils

Metal-as-insulation (MI) winding technique

- To use self-protecting feature of no insulation (NI) winding technique
- To mitigate charging-discharging delay of NI magnet
- To reinforce mechanical strength of REBCO coils

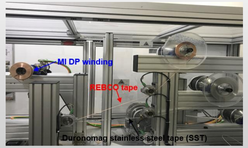
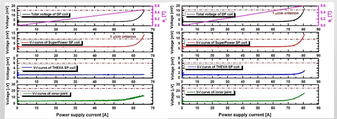


Fig. 2. MI double-pancake (DP) coil wound by LNCMI homemade HTS winding machine

Fig. 3. A photograph of the MI REBCO DP coils



(a) DP1 **(b) DP2**

Fig. 4. *V-I* curves of two DP coils at 77 K in self-field

Table. 2 Specifications of the two MI DP coils for test

Parameters		DP1	DP2
ID; OD; Height	[mm]	50; 110; 12.6	
Number of turns per SP		TV: 186; SPo: 278	
Conductor length per DP	[m]	TV: 47 ; SPo: 70	
Coil constant	[mT/A]	7.52	
Coil inductance	[mH]	16.9	
I_c of coil @ 77 K in SF.	[A]	65	80
Measuring average tension of HTS (SS)	[MPa]	98.9 (95.2)	
Inner joints of DP coils			
Average joint resistance @ 77 K in SF.	[nΩ]	10	20
I_c of joint area @ 77 K in SF.	[A]	> 80	> 80

Assembly of an MI insert

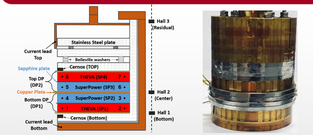


Fig. 5. Instrumentation diagram and picture of the insert

Table. 3 Specifications of the TV-SPo MI insert

Parameters		Values
Stainless steel overband turns		50
OD after overbanding	[mm]	118.5
Height of stacked DP coils	[mm]	25.2
Number of DP		2
Magnet constant	[mT/A]	14.5
Magnet inductance (L)	[mH]	58

MI insert wound with only SPo tape for previous test

Fig. 6. the MI insert for previous test [1]

Table. 4 Specifications of SPo MI insert [1]

Parameters		Values
ID; OD;	[mm]	50; 109.4
Height	[mm]	24.7 ~ 24.8
Number of DP		2
Turn per pancake		279
Total conductor length	[m]	280
Stainless steel overband turns		100
OD after SUS overband	[mm]	116.4
Magnet inductance	[H]	0.083
Magnet constant	[mT/A]	17.4

[1] J. B. Song *et al. "Construction and Test of a 7 T Metal-as-Insulation HTS Insert Under a 20 T High Background Magnetic Field at 4.2 K," IEEE Trans. Appl. Supercond.*, vol. 29, No. 5, p. 4601705, Aug. 2019.

R_c variation of the MI TV-SPo insert

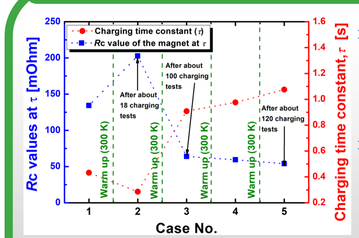


Fig. 7. R_c values of the MI insert with respect to several warm-up events.

- ***Average contact resistance (R_{ct}) value is 1 mΩ/cm² calculated by R_c=63.9 mΩ, , indicating that R_c value of the MI magnet is about 50-100 times higher than that of fully NI REBCO magnet***

- The increasing phenomenon of characteristics resistance (R_c) might be because turn-to-turn contact resistivity increased due to cryogenic work hardening of copper stabilizer under repetitive magnetic pressure load through 18 charging tests.
- The abrupt decrease of R_c value is probably because: 1) the oxide layer on surface of metal was worn-out; and 2) the surface roughness was diminished, due to repetitive magnetic pressures generated during numerous (about 100 times) charging tests.

➡ ***The R_c estimation of the magnet should be conducted periodically until R_c change is nearly constant***

Quench test of the MI TV-SPo insert under B_{ext} at 4.2 K

Current vs. B_{ext}

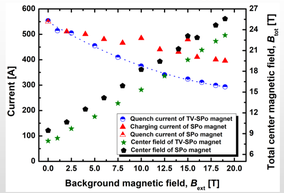
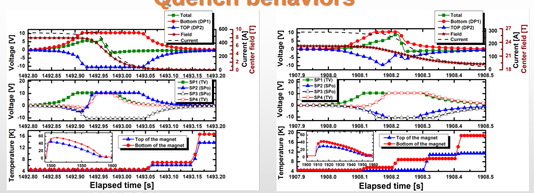


Fig. 8. Quench, charging currents and total center magnetic fields of a TV-SPo and only SPo insert under various B_{ext} at 4.2 K.

To compare the current carrying capability of the TV-SPo insert with regards to t_{ext} test results of a previous MI insert wound with only SPo tape are added to Fig.7.

Quench behaviors



(a) Self-field **(b) B_{ext}= 19 T**

Fig. 9. Quench behaviors of the MI insert

➡ **Despite above 15 quench events under B_{ext} from 0 to 19 T, the MI magnet survived without any damage, demonstrating that MI winding is self-protecting in combination with the over voltage protection of a power supply. Hence, tapes can be benchmarked efficiently without fearing burning them.**

Charging test of the MI insert under various current ramp rates

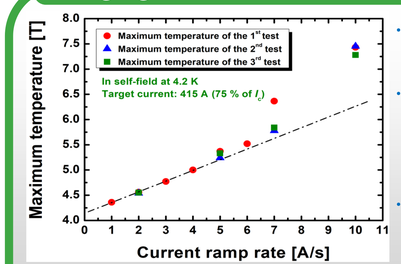


Fig. 10. Maximum temperature values of the TV-SPo insert with various ramp rates at 4.2 K in self-field.

- In the previous study, the only SPo insert without sapphire and copper plates experienced quench events at a ramp rate of 2 A/s due to poor cooling condition [1].
- Quench of the TV-SPo MI insert did not occur even at the high current ramp rate of 10 A/s.

➡ **This is probably because the sapphire and copper plates acted as a good heat exchanger between the inside of the coils and the LHe outside.**

- After charging test at 5 A/s, the T_{max} values increased faster than the ramp rates, which means that the insert cannot be reliably cooled anymore at very fast ramping rate because the amount of Joule heating generated by the increasing bypass current is greater than the cooling efficiency of the sapphire and copper plates.

The authors acknowledge the support of the LNCMI-CNRS, member of the European Magnetic Field Laboratory (EMFL), and of the French National Research Agency (ANR) through the contracts ANR-10-LABX-51-01 (Labex LANEF) and ANR-14-CE05-0005 (NOUGAT project)