Quench Behavior of a Metallic Cladding REBCO Coil Containing Copper Strips for Outer Diameter Adjustment

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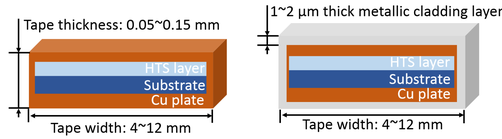
Research Background

- **Problem Definition:** Discrepancy in outer diameters of "actual" pancake coils for given designed number of turns mainly due to the manufacturing error.
- **A common approach:** Placement of metal strips in-between selected turns in pancake coil to better control the outer diameter to the designed value.
- **Technical Challenge:** Uncertainty in "fast" current sharing in the metal-strip-inserted metallic cladding (MC) no-insulation (NI) coil upon a quench, critical for the self-protecting behavior of the NI coil.
- **Demonstrate to clear the uncertainty of proposed technique:** Performance examination of the metal-strip-inserted MC-NI coil with the various quench conditions.



(a) (b)

Figure 1. Conceptual comparison between NI and MC REBCO tapes: (a) No-insulation REBCO tape, (b) Metallic cladding tape.

Specifications of the Cu Strip Inserted MC-NI Coil

Table 1. Key parameters of the Cu strip inserted MC-NI coil

Parameter	Unit	Value
Thickness of MC tape	[mm]	0.13
Width of MC tape	[mm]	4.10
Thickness of Cu strip	[mm]	0.05
Width of Cu strip	[mm]	4.00
Number of turns (MC tape)		32
# of Cu strip pieces		7
Measured inner radius of coil	[mm]	16.00
Measured outer radius of coil	[mm]	20.65
Coil height	[mm]	4.10
Estimated wire length of coil	[m]	3.68
Estimated magnet constant (B_z)	[mT/A]	1.09
Estimated critical voltage, V_c (0.1 μV/cm)	[μV]	36.82
Estimated coil inductance	[μH]	54.70
Estimated characteristic resistance, R_c[a]	[μΩ]	680.50

[a]Contact surface resistance, R_{ct}: 100 μΩ.cm²

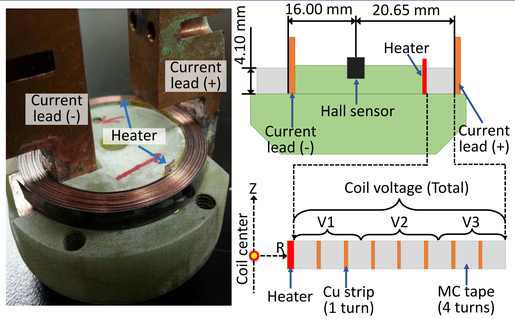


Figure 2. No-insulation test coil wound with metallic cladding REBCO tape. A total of 7 Cu strips were inserted and equally distributed within the winding.

Operation Results of the Cu Strip Inserted MC-NI Coil in LN_2

Overcurrent quench test

- MC-NI coil was operated until magnetic field drop occurred.
- J_e of MC-NI coil was ≈180.8 A/mm² (=P/S current: 107.7 A) when the magnetic field started to drop.
- Most voltage increasing was measured from 'V3' section (98.8 % of total coil voltage).

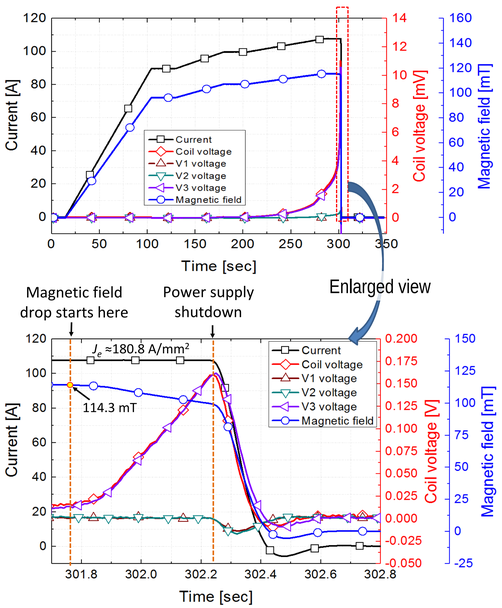


Figure 3. Voltage and magnetic field vs. time curves of the Cu strip inserted MC-NI coil during the over current quench test in a bath of liquid nitrogen at 77 K.

Critical current (I_c) measurements

- Before the overcurrent test, I_c was measured as 98.4 A (V_c: 36.6 μV).
- After the overcurrent test, the respective saturated voltage and the magnetic field were measured as 38.5 μV and 105.9 mT at the same P/S current level.

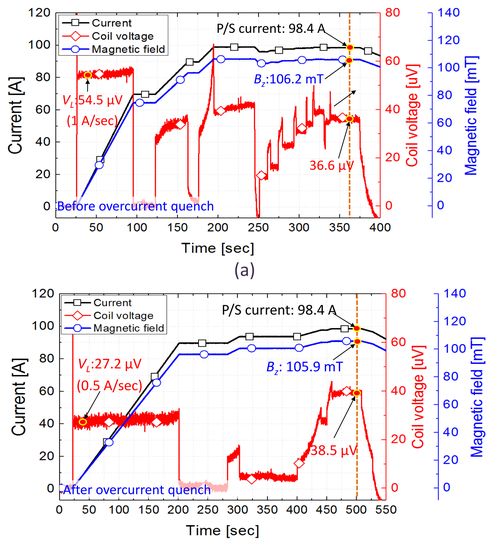


Figure 4. I_c measurement results of the Cu strip inserted MC-NI coil: (a) Before overcurrent quench, (b) After overcurrent quench.

Operation Results of the Cu Strip Inserted MC-NI Coil in LHe

Multiple quench test

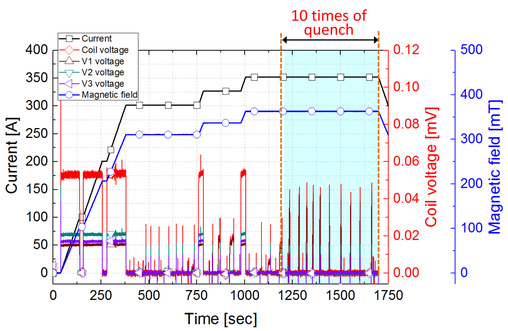


Figure 5 (a). Whole operating procedure of the Cu strip inserted MC-NI coil during the multiple quench test in a bath of liquid helium at 4.2 K.

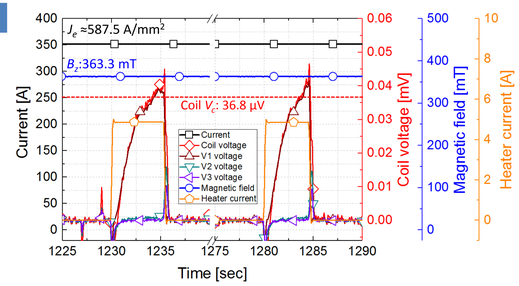


Figure 5 (b). Enlarged voltage and heater current pattern of the Cu strip inserted MC-NI coil during 2nd and 3rd quench.

- For the multiple quench test, 10 times of quenches were occurred by the operation of heater located at the coil's inner-most turn.
- The estimated resistance of the stainless heater was 0.17 mΩ at 4.2 K.
- The *Je* and the heater current to have the coil quench at 4.2 K were ≈587.5 A/mm² (=P/S current: 350 A) and 4.8 A, respectively.

Thermal runaway quench test

- The thermal runaway quench was observed at J_e = 605.2 A/mm² (=P/S current: 360 A) and I_{heater}=5 A.
- The results showed that the voltage signals were sequentially detected from V1 to V3.
- The test coil appeared to have the "current sharing" from inside to outside during the thermal runaway quench.

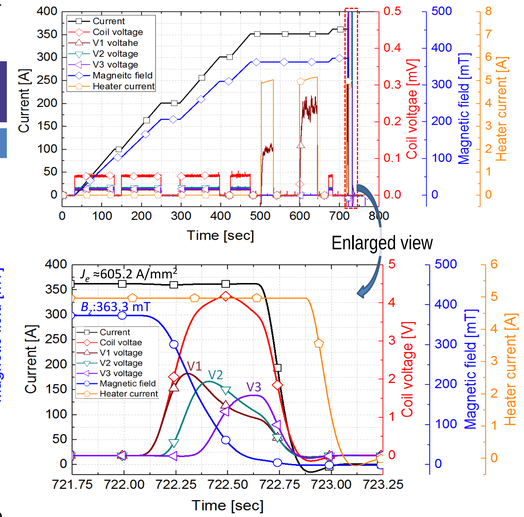


Figure 6. Quench propagation result of the Cu strip inserted MC-NI coil during the thermal runaway quench test.

Performance evaluation of Cu Strip Inserted MC-NI Coil after quench test

- Before the quench tests, the previously measured V_L and B_z were 53.3 μV and 310.9 mT, respectively (P/S current = 300 A).
- At the same charging condition, the coil's V_L and B_z were measured to be 53.0 μV and 310.5 mT after the two types of quench tests.

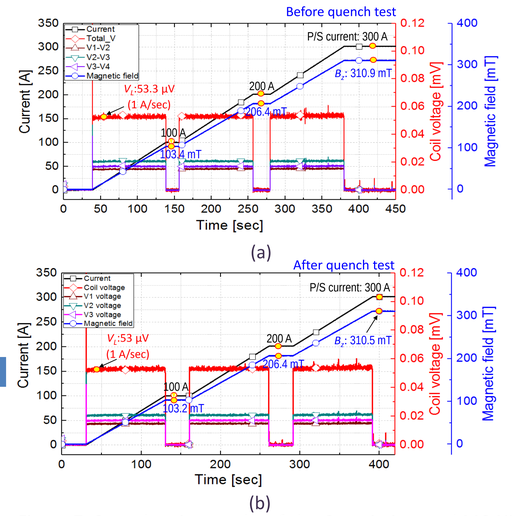


Figure 7. Step charging results of the Cu strip inserted MC-NI coil: (a) Before both quench test, (b) After both quench test.

Table 2. Rc measurement results test at 4.2 K.

Case	Condition	Ramp. rate [A/sec]	R_c [mΩ]	R_{ct} [μΩ.cm²]
1st test	Before quench test	0.50	0.34	49.96
2nd test	After multiple quench	0.50	0.55	80.82
3rd test		0.50	0.51	74.94
4th test	After thermal runaway quench	0.50	1.10	161.65

Conclusion

- From the step charging results that measured after both quench test, the difference of measured VL and Bz were less than 1 % compared with previous step charging result.
- The test coil operated normally without performance change which confirmed its self-protecting feature against the thermal runaway quenches.
- The R_c of the coil gradually increased after the multiple and thermal runaway quench tests.

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