Study of voltage dynamics in large REBCO coils: Toward the protection of 33T then 40 T REBCO inserts

REBCO Coated Conductors inserts are mandatory for very high field superconducting magnets. Yet, the number of full-size HTS inserts implemented worldwide is limited so their long-term reliability is still largely unproven. In order to acquire enough feedback to safely operate the 33 T CSM at HFLSM and its future 40 T upgraded insert, extensive tests were conducted on the existing 20 stacked-pancake coil prototype. Its mechanical behavior at low temperature under high stress was already reported. In this work the transient voltages were studied during operation at variable temperatures up to its maximum operating current. This new understanding offers additional options for the design of future REBCO insert protection systems.

The robust REBCO insert coil concept [1] chosen for the design of the future 33 T then 40 T inserts at HFLSM features fully isolated turns to limit the transient losses and to achieve fast dynamics. Protection against thermal runaway relies on early detection of dissipative behaviour thanks to sensitive voltage detection, triggering discharge in dump resistor [2].

In order for such early detection scheme to be effective, a good understanding of the transient voltage dynamics. Voltage dynamics were extensively studied in [3] with help of transient modelling. It was observed that the total coil voltage can be separated basically in three components: inductive voltage, related to the field produced by the imposed circulating current in the coil, dissipating voltage due to dynamic current redistribution in the conductor cross-section, related to the shielding and coupling current induced field, and dissipation due to local overstepping of the critical current. Only the latter is a concern for coil safety and must be discriminated from the rest.

Pick up coils having a good coupling with the REBCO coils can be used to cancel out most of the inductive voltage. The obtained "compensated coil signal" is smaller and has reduced noise while still containing the signal of interest, that is, the coil dissipative voltage due to overstepping of the critical current. However, it still retains significant transient components due to dynamic current redistribution in the conductor cross section, which is hysteretic and makes it difficult to set

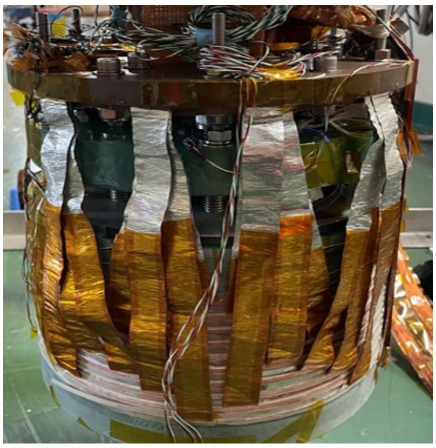

Fig. 1: 20-stacked pancake coil mounted on the cold plate of the HFLSM large bore conduction-cooled cryostat

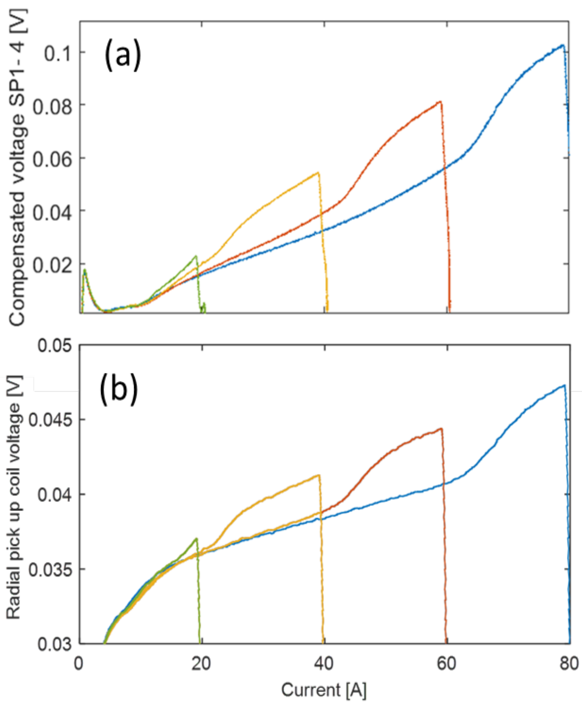

Fig. 2: Evolution of voltages during successive current ramps up to 20, 40, 60 then 80 A after initial cooling at 50 K. (a) Compensated voltage using classical axial pick up coil. (b) voltage observed on a radial pick up coil.

a simple threshold for protection purpose. This was observed during recent tests of the 20 SP coil at various temperatures, when successively ramping up the coil current to increasing targets after cooling down, as shown Fig. 2a for the compensated voltage across pancakes 1 to 4.

That hysteretic behaviour can be understood: the pick-up coil is well coupled to the REBCO coil "main" field, that is the field produced by the transport current circulating in the conductor, but do not have the same coupling with the shielding and coupling currents-induced field, whose topology is different. A correct compensation coefficient to cancel one contribution will necessarily fail to cancel the other one. In this work, an additional pick up coil was placed radially at the outer diameter, over the bottom half of the 20 pancake stack, in order to be well coupled with the shielding current induced field. The resulting pick-up coil configuration is shown Fig. 3.

The voltage over this radial pick-up coil is shown Fig. 2b to be compared to the existing compensated coil voltage Fig. 2a. The similarity in these two voltages dynamics is obvious.

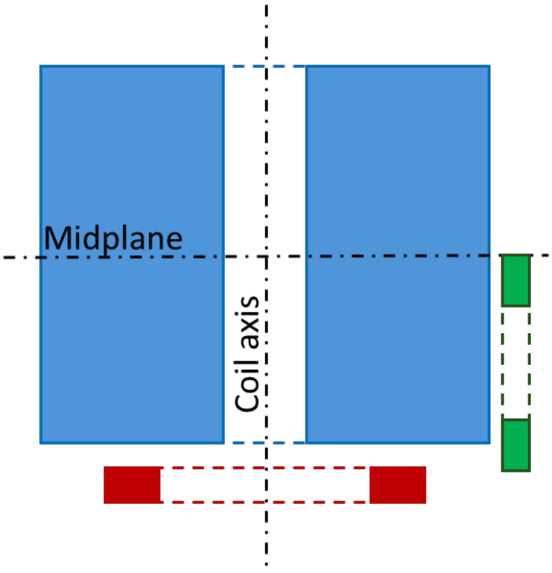

Fig. 3: Coil configuration. In blue the REBCO coil. In red the classical and already-existing pick-up coil (axial orientation). In green the additional radial pick up coil used to compensate shielding current induced field contributions.

A subtraction, performed a posteriori Fig. 4, yields a "double-compensated voltage" whose drift is much smaller, though not completely flat. The use of such double compensation would make it possible to use a simple threshold value scheme sensitive enough for quench protection of full scale REBCO insert, as the obtained signal does not vary beyond a 10 mV window.

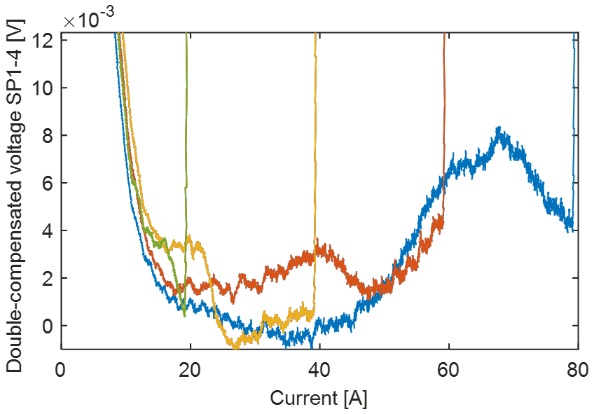

Fig. 4 Double-compensated voltage obtained by post-processed subtraction of radial pick-up coil voltage variations to the classical compensated voltage across pancakes 1 to 4 of the 20 SP REBCO coil

References

[1] S. Awaji et al., "Robust REBCO Insert Coil for Upgrade of 25 T Cryogen-Free Superconducting Magnet," IEEE Trans. Appl. Supercond., vol. 31, no. 5, Art. no. 4300105, 2021

[2] A. Badel et al., "Detection and Protection Against Quench/Local Thermal Runaway for a 30 T Cryogen-Free Magnet," IEEE Trans. Appl. Supercond., vol. 31, no. 5, Art. no. 4700705, 2021

[3] J. Vialle, A. Badel, B. Rozier and P. Tixador, "Transient voltages and energy balance in REBCO insulated magnet: experimental and numerical studies", Supercond. Sci. Technol, 34(3), 115012, 2021

[4] J. Vialle, A. Badel and P. Tixador, "12 T Insulated REBCO Magnet Used as 1 MJ SMES: Protection Strategies and Preliminary Assembly Tests," IEEE Trans. Appl. Supercond., vol. 32, no. 6, Art no. 4702307, 2022

Keywords: High magnetic field, High Tc Superconductors
Arnaud Badel, CNRS Research Associate, G2Elab / Neel Institute, Grenoble, France
E-mail: Arnaud.badel@neel.cnrs.fr