Development of mechanically and electrically reliable isolated REBCO HTS coils with high current densities

REBCO Coated Conductors inserts are now widely considered as the solution for future very high field magnets, 30 T and beyond. Yet, the number of full-size HTS inserts tested worldwide is limited, and there is a lack of data regarding their reliability. In this work the mechanical and electrical behavior of a quasi-full scale REBCO insert made of 20 stacked pancakes was modelled, and results were compared with experimental data.

A robust REBCO insert coil concept was proposed recently at HFLSM [1], in the framework of the 30 T upgrade project. Its key features can be summarized as:

- Pancake-based solenoids with epoxy impregnation, using a non-stick material in between turns to ensure conduction-cooling efficiency and improve the winding stiffness.
- Fully isolated turns to limit the transient losses and to achieve fast dynamics. In this way, the insert can be discharged in a few seconds, as fast as the outsert, limiting energy transfer from one to the other during an outsert quench [2].
- Conductor formed of two REBCO tapes co-wound so that current can be shared [3] to reduce the risk posed by local defects.
- Protection against thermal runaway by using early detection of dissipative behaviour thanks to sensitive voltage detection, triggering discharge in dump resistor [2].

That concept was developed over the years with small-scale validation coils of gradually increasing size and performance at HFLSM with contribution of Neel Institute (Grenoble) for thermal runaway detection and management. A much larger size implementation was successfully tested under 14 T background, demonstrating the practical feasibility of high performance yet reliable REBCO full-size insert coils. It consists of 20 pancakes from the 30 T upgrade project wound using 4 mm-wide Fujikura tape (inner bore 68 mm, outer bore 266 mm, total tape length 5.8 km, inductance 2.63 H). At the nominal current of 300 A, it generates more than 11 T.

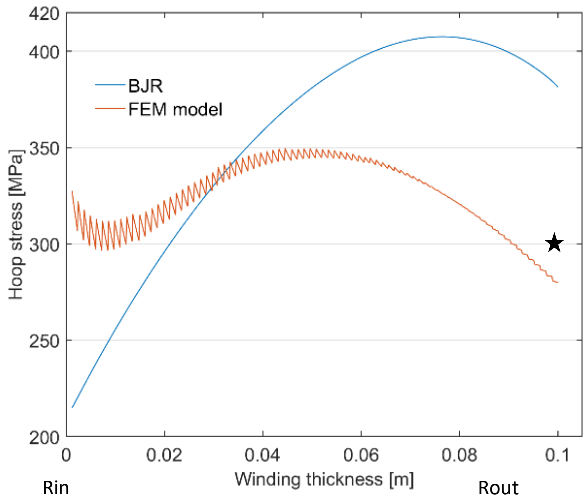

Fig. 1: Predicted Hoop Stress across the middle plane of the 20-stacked pancakes prototype at 300 A under 14 T background. Black star indicates estimated hoop stress based on strain measurement

The mechanical hoop stress was modelled using Finite Element Method, accounting for the specific structure of the edge-impregnated pancakes. The measured strain on outer diameter matches well with the value predicted by FEM, but not with the simpler “self-supporting turns” assumption (BJR formula), as shown Fig. 1. Following the FEM model, it is estimated that the circumferential elongation reached 0.25 % at maximum (corresponding to 350 MPa hoop stress), without observed degradation of the pancakes winding and their connections. In this condition (300 A under 14 T background), the centre field exceeded 25 T, with 25.25 T measured by hall sensor.

From the viewpoint of thermal runaway protection, the idea of multichannel monitoring using independent pick up coils [4] was used. The use of 5 channels monitoring 4 pancakes each offer a good sensitivity as well as to enable localization of potential weak areas. The tests were carried out at 4.2 K in LHe, so that the theoretical temperature margin was very large. No dissipative behaviour was observed, proving the good health of the windings. Yet, the acquired signals support the idea that if a dissipative area had appeared, it could have been detected early enough to prevent degradation of the windings. Indeed, Fig. 2 present the superposition of the acquired signals on one of the channels in the last minutes of the current ramp, with the predicted voltage in case of local defect using a detailed thermal runaway model as in [2]. The change of trend in case of a dissipative behaviour can clearly be identified more than 60 s before thermal runway would occur, leaving enough time to discharge the magnet safely. In recent unpublished work, this dissipative voltage detection was tested at higher temperature repeatedly without damage, further demonstrating the reliability of the robust REBCO insert coil concept.

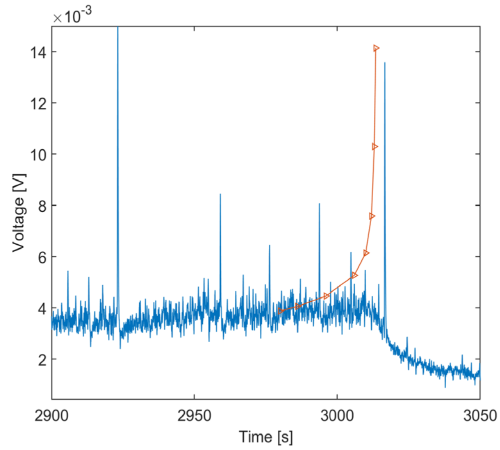

Fig. 2: Detail of the end of the current ramp reaching I=300 A under 14 T background field. In blue: experimental measurement of voltage signal using inductive compensation, across pancakes 1 to 4. In red: simulated quench behavior on a local hotspot gradually losing thermal balance for I=300 A [4].

References

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 Keywords: High magnetic field, High Tc Superconductors
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