VIEWPOINT

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Viewpoint

Small REBCO isotropic round wire (STAR): an important step from performant material to practical conductor in high field HTS magnets

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This is a viewpoint on the letter by Wenbo Luo *et al* (2018 *Supercond. Sci. Technol.* **31** 12LT01).

Development of practical high current density round wires out of REBCO tapes, for use as a single strand conductor or as a sub-element of a complex cable, may constitute a real breakthrough in magnet technology. The use of HTS materials for user-oriented high field magnets has already started for very high field (30 T range) solenoids used for laboratory measurements or for new frontier nuclear magnetic resonance beyond 1 GHz [1, 2]. The fusion community is considering HTS conductors for DEMO, while more recently, the particle accelerator community is also considering use of HTS-based superconducting magnets for the next future colliders after the Large Hadron Collider and its High-Luminosity upgrade [3, 4]. Applications of REBCO for high field magnets would be highly facilitated if the conductor used for winding were a small flexible round cable rather than highly anisotropic tapes with an aspect ratio of 100 or more. A round, basic element would make both a direct use of the wire as a conductor, or its use as sub-element of a more complex cable, like a rope or other cable geometries, easier. It would incorporate the isotropic behaviours versus magnetic field and the easy bendability in all directions typical of Bi-2212 and of Nb₃Sn, while avoiding the serious nuisance of having to make an *in situ* reaction. However, there is a pre-condition: to keep the high current density typical of the best REBCO tapes, with an engineering critical current density of $J_e \approx 400\text{--}500 \text{ A mm}^{-2}$ at 20 T.

Various cable layouts have been proposed to use REBCO tape in such a way to keep high current density. One approach is, for example, Roebel cables [5, 6], with the result not really being satisfying because this cable is highly anisotropic and some valuable HTS material is wasted during cable formation. Various forms of stacked tape cables have also been proposed but the anisotropy is always present and transposition is not always completed.

Bearing this in mind, two cable layouts have emerged with a good potential to reach high current density while giving the desired isotropic behaviour: the Conductor On Round Core (CORC[®]) [7, 8] and the Symmetric Tape Round (STAR) discussed in this paper. This layout by Luo *et al* is the subject of the most recent paper [9] published by the Selvamanickam team at the Texas Center for Superconductivity of the University of Houston, following many years of successful development and improvement of the STAR wires [10, 11].

The Houston team has been continuously improving the performance of the STAR round wire in terms of flexibility as well as in terms of critical current density. With this paper they show results that are a record in terms of absolute value of J_e at a high field and in terms of current degradation under a small

bending radius, marking a milestone in the development of REBCO round wires [12].

The paper describes results of five recently manufactured wires, of six and eight tape layers, of a length of 1 m. The main wire features are well described, as well as the cable parameters and construction techniques. Particular attention is brought to the features allowing a minimization of stress accumulation and hence current degradation. The authors carried out extensive current characterization in the self-field (s.f.) at 77 K, in a straight wire shape, and then in a curved shape on a suitable sample holder, both at 77 K s.f., and then at 4.2 K in a field up to 31 T. The possible effects of current redistribution due to the layered topology, as well as to the field direction change inside the sample would have been worth discussing. The paper shows excellent J_e results with minimal current degradation. Wire #2, cooled at the liquid helium temperature of 4.2 K, exhibits a record (for an isotropic cable) $J_e =$ of 438 A mm^{-2} under a 20 T field when bent with a curvature radius as small as 15 mm. This value is similar to what has been reported recently for the CORC [8] and enables the wire to be used for accelerator magnets of any type, like a cos ϑ layout and especially a canted cosine theta layout [13]. The paper also mentions the mechanical degradation induced with repeated current cycles and pulsed current cycles (pulsed current is used to avoid overheating), in a ‘dry’, very high current (eight layers) wire. However, the authors showed a way to drastically reduce degradation, induced by power cycling, by filling the gap between adjacent tapes with indium after the bend, supposedly via melted indium casting. The performance of both wires #4 and #5 with indium support were able to confirm $J_e = 410\text{--}440 \text{ A mm}^{-2}$ at 20 T, 4.2 K. The decay in the field is quite good, with α ranging between 0.72–0.84, which means that at 31 T the measured J_e is nearly 300 A mm^{-2} ! With a total current of 1200–1350 A at 20 T, these tapes could be effectively used as a single strand conductor for many high field magnets. The excellent robustness is shown by the fact that after seven power cycles to a critical current at 31 T, J_e remains with 1% of its original value. In addition, the dry wire #1 shows 1% repeatability with four current cycles, but the number of tape layers is limited to six, which reduces the current at 20 T to 800–950 A, with a consequent reduction of the damage induced by the Lorentz force.

These important results need to be transposed to a continuous process, enabling a length of at least 30–100 m. However, it is clear that the high potential of this STAR technology for high field magnets, as well as also for large current carrying cables for power transmission, is now fully established: an important step that will help penetration of HTS into practical applications!

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