Stacked-tape trapped-field superconducting magnets – edging ahead ?

J. H. Durrell
Department of Engineering, University of Cambridge, Trumpington St, CAMBRIDGE, CB2 1PZ

Conventional permanent magnet materials, such as NdFeB, have remanent magnetisations which are intrinsically limited to less than 1.5T. Somewhat higher fields can be achieved using Halbach arrays [1] but progress in developing higher performance materials is challenging [2]. Conversely, in a superconducting pseudo-permanent magnet the trapped magnetic field arises due to macroscopic transport currents flowing in what is essentially a single turn coil. Consequently, the maximum achievable trapped magnetic field scales with the radius of the magnet. Such pseudo-permanent superconducting trapped field magnets can exhibit trapped fields of over 17 T which have the potential to find wide applications [3].

There are two approaches to fabricating such superconducting trapped field magnets. Bulk superconductor magnets are formed from a monolith of superconducting material such as a single grain of $GdBa_2Cu_3O_7$ or pressed polycrystalline MgB_2. It is also possible to stack numerous slices of a coated conductor superconductor to form a *stacked-tape* magnet. Up to now these two approaches have offered comparable performance although, to obtain like for like trapped magnetic fields, stacked tape magnets have needed to be used at lower temperatures.

In their letter [editor to insert cross-ref] Suyama and colleagues report a trapped magnetic field of 17.89 T at 6.5 K in a stacked-tape superconducting trapped-field magnet. This exceeds the previously reported maximum value in both stacked tape (17.7 T at 8K [4]) and bulk superconductor magnets (17.6 T at 26 K [5]). Such measurements are experimentally challenging, and the modest increase in trapped field reported here should not mislead readers as to the importance of this work.

An important aspect of this work is the close attention the authors have paid to the suppression of flux jumps. While flux jumps can be helpful in the pulsed field magnetisation charging of trapped field magnets [6], in the kind of field cooled measurements described here they present a significant barrier to realising improved performance. The authors' approach to removing heat from their stack is both innovative and interesting in that they have thinned the coated conductor substrate so as to allow the introduction of a high specific heat lead thermal stabilisation layer.

It is worth noting that, aside from flux jumps, the factors limiting the performance of bulk superconductor and stacked-tape trapped-field superconducting magnets are quite different. The former are performance limited by the mechanical strength of what is a brittle ceramic material, while in the latter performance is limited by the relatively small volume of the magnet occupied by the superconducting layers. As the authors identify in this letter, if the J_e in stacked tape magnets can be improved, perhaps through further substrate thinning, significantly better performance would be expected.

It is clear, therefore, from this important work by Suyama et al. that the performance of stacked-tape superconducting magnets has now edged of their bulk-superconductor based counterparts, albeit at lower temperatures. The authors further show in their modelling that improvement in the J_e of stacked tapes by thinning could lead to trapped magnetic fields of 20 T or more. It remains to be seen as to if bulk superconductor based trapped field magnets will be able to match this magnitude of trapped field, although such a prospect has been long predicted [7].

1. Halbach, K., *Design of permanent multipole magnets with oriented rare earth cobalt material.* Nuclear Instruments and Methods, 1980. **169**(1): p. 1-10.
2. Hirosawa, S., *Permanent Magnets Beyond Nd-Dy-Fe-B.* IEEE Transactions on Magnetics, 2019. **55**(2).
3. Durrell, J.H., et al., *Bulk superconductors: a roadmap to applications.* Superconductor Science & Technology, 2018. **31**(10).
4. Patel, A., et al., *A trapped field of 17.7T in a stack of high temperature superconducting tape.* Superconductor Science & Technology, 2018. **31**(9).
5. Durrell, J.H., et al., *A trapped field of 17.6T in melt-processed, bulk Gd-Ba-Cu-O reinforced with shrink-fit steel.* Superconductor Science & Technology, 2014. **27**(8).
6. Zhou, D.F., et al., *Exploiting flux jumps for pulsed field magnetisation.* Superconductor Science & Technology, 2018. **31**(10): p. 9.
7. Tomita, M. and M. Murakami, *High-temperature superconductor bulk magnets that can trap magnetic fields of over 17 tesla at 29 K.* Nature, 2003. **421**(6922): p. 517-520.