Mon-Af-Po1.03-08 [30]

Quench Behaviour of $Bi_2Sr_2CaCu_2O_{8+x}$ Insert Coils for High Field Magnets

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Abstract

Advances in High Temperature Superconductor (HTS) technology have the potential to enable high field magnets with fields in excess of the maximum obtainable with purely Low Temperature Superconductor (LTS) magnets. HTS insert coils may be operated in the bore of a high field LTS magnet, or 'outsert', in order to enhance the overall central field. The HTS inserts are usually operated at the same low temperatures as the LTS coils as this allows a common cooling system to be used and to take advantage of the much higher critical current density of the HTS at lower temperatures. A remaining barrier to widespread commercial application of HTS insert coils in this space is adequate protection of the HTS coil during quench, where the behaviour of such coils is substantially different from that of LTS coils.

Oxford instruments (OI) is in collaboration with Bruker-OST (B-OST) and Dresden High Magnetic Field Laboratory (HLD) to design, build and test a set of HTS insert coils to be tested in the bore of the 19T 150mm LTS magnet currently in operation at Dresden. The coils are wound from B-OST round wire containing $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212). Here we discuss the challenges in design, manufacture and test of this set of coils and present experimental results of tests in background field.

Introduction

Bi-2212 is made in round wire form by B-OST, thus many of the same coil fabrication techniques can be applied as are used for LTS round wires that are not possible with flat tape form superconductors.

A series of small HTS test coils have been manufactured using B-OST Bi-2212 1.5mm round wire. Dimensions of the coils are given in Table 1. Coils A and B have been tested in 17 T and 19 T background fields. Coils C and D are wide bore coils designed and instrumented for coil hoop strain tests and are yet to be tested.

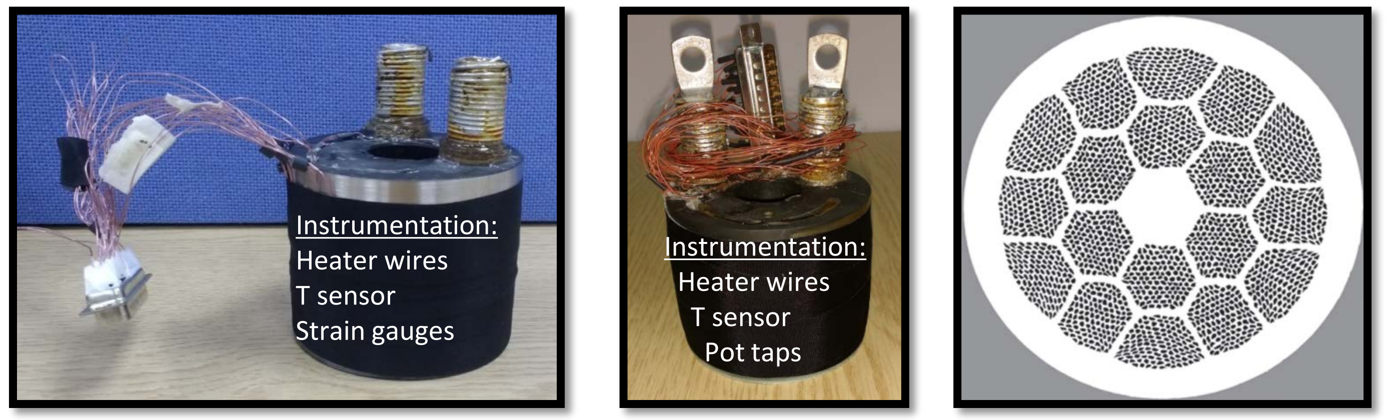

Fig. 1 Bi-2212 test coil A (left); test coil B (centre); wire cross-section (right)

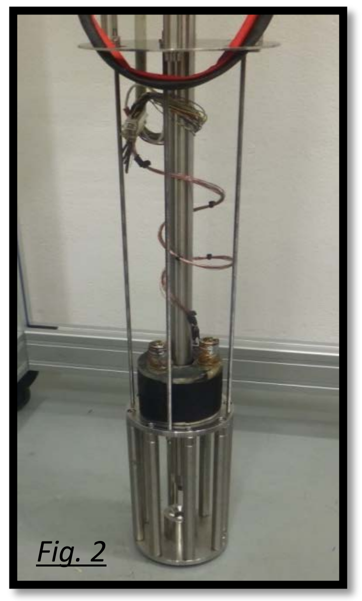

Fig. 2

Table 1 Coil	Wire diameter [mm]	Coil length [mm]	Inner radius [mm]	Outer radius [mm]	Coil layers	Heat Treatment Reaction Type
Coil A	1.5	50	14	35.7	14	Standard
Coil B	1.5	50	14	35.7	14	Over-pressure[b]
Coil C[c]	1.5	58	53	59.2	4	Standard
Coil D[c]	1.5	58	53	59.2[a]	4	Standard

[a] not including over-bind [b] Over pressure heat treated at 50 bar
[c] Coils C and D not yet tested in 19 T background.

Testing

The 19 Tesla, 150 mm bore outsert magnet system, manufactured by OI and in operation at HLD, was used to provide a background field for testing the HTS coils. Test coils were loaded into the 19T magnet on a specially designed magnet support stand (Fig.2). The coils were protected by a parallel passive shunt resistor.

Three types of testing were performed:

- Initial energisation to attempt to find critical current density (Jc) .
- Quench by continuous heating to find quench temperature (T).
- Quench by pulsed heating to find minimum quench energy (MQE).

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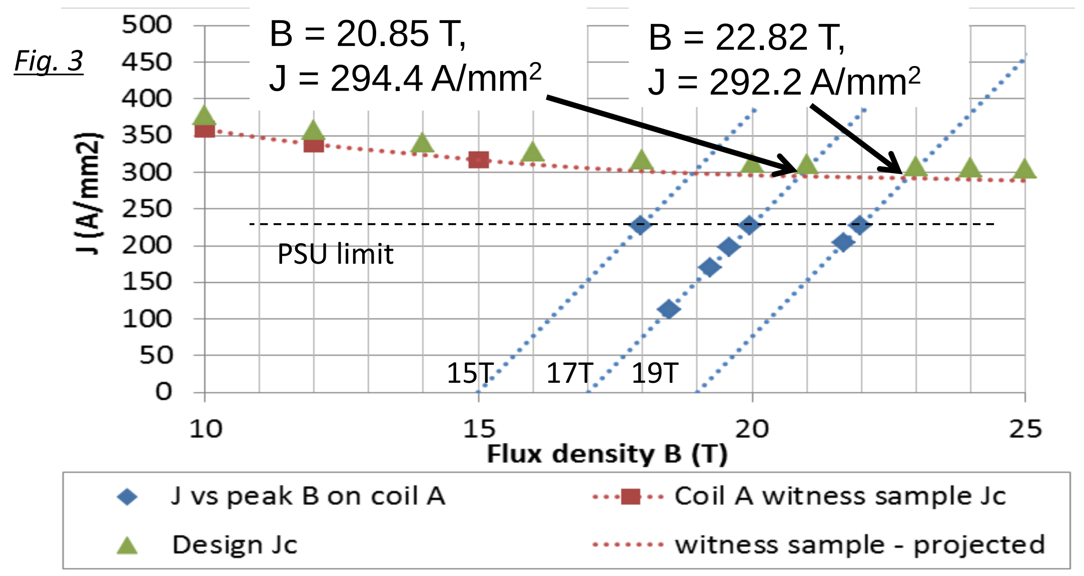


Fig. 3 shows J against peak B on HTS coil A at various test currents. Also shown are the Jc curve used for the HTS coil design and a scaled curve based on witness sample measurements. We can estimate the Jc of the coil by looking at the intersection between the Jc curve and the load lines (17 and 19T labels).

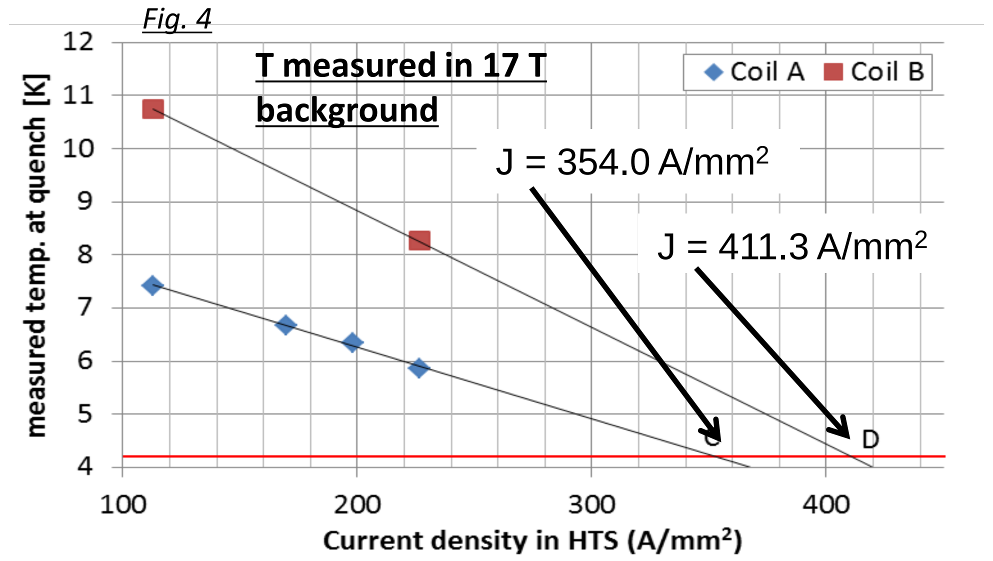
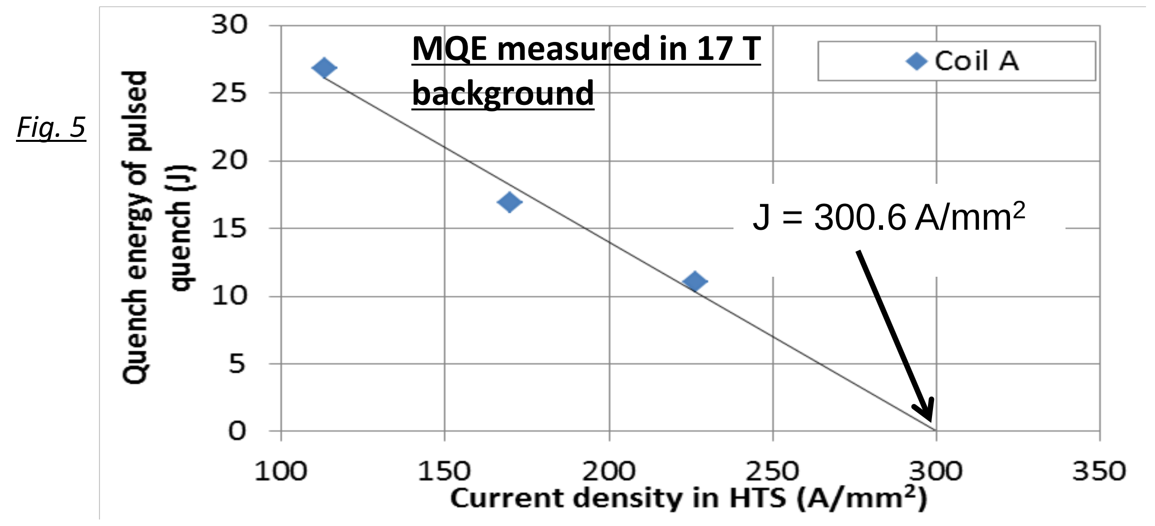


Fig. 4 shows temperature measured at quench plotted against current density for coils A and B. Temperature was raised by increasing heater voltage in steps until the HTS coil quenched, and measured by a sensor embedded into the coil surface. Assuming a linear relationship between J and T and extrapolating to T of 4.2 K gives a prediction of Jc for each coil.



In Fig. 5 the energy of heat pulse delivered to the coil heaters is plotted against current density for the Minimum Quench Energy tests on coil A. A linear extrapolation to a quench energy of zero gives an estimate of Jc of coil A of 300.6 A/mm². In reality the MQE at Jc will not be zero but a small finite value.

Table 2 Method	Coil A	Coil B
Jc curve scaled to 'as wound' data	294.4 A/mm²	-
Quench temperature	354.0 A/mm²	411.3 A/mm²
Minimum quench energy	300.6 A/mm²	-

Table 2 summarises the Jc estimates from our measurements. We think the real figure is likely close to 300 A/mm².

Conclusion and next steps

- We have demonstrated successful operation of HTS test coils in 19T background field with central field up to 21.75 T.
- We predict the Jc at 4.2 K as 300 A/mm² with standard heat treatment process, corresponding to 530 A in 1.5mm wire. Higher fields and direct measurement of the critical current are not possible due to the limit of the PSU used to drive the HTS coils.
- A new PSU of 1000 A is on order and will allow higher HTS currents.
- For HTS coils operating at higher fields the strain limit on the Bi-2212 coils and use of over binding to control strain needs to be proved. This will be explored with coils C and D which have been designed for this purpose.

Acknowledgements - Thanks to David Larbalestier, Ulf Trociewitz and colleagues at National High Magnetic Field Laboratory for providing facilities and expertise for the over-pressure heat treatment process .

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