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Comparison of DC and pulsed critical current characterisation of NbTi superconducting wires

***Abstract**. The use of pulsed magnetic fields and currents for transport critical current characterisation has many potential benefits, but introduces challenges in obtaining measurements consistent with conventional DC characterisation for some types of sample. This will be illustrated by comparative DC and pulsed critical current testing of two dissimilar NbTi conductors. The factors influencing pulsed measurements will be identified, the prospects for pulsed critical current testing assessed, and recommendations made for obtaining good agreement with DC characterisation.*

Streszczenie.** Użycie impulsowego prądu i pola magnetycznego do wyznaczania krytycznego natężenia prądu przewodów nadprzewodnikowych oferuje wiele korzyści, jednocześnie powodując trudności w interpretacji i porównaniu wyników z tradycyjnymi pomiarami prądem stałym. Na podstawie porównania wyników pomiarów prądem stałym z pomiarami impulsowymi, dla dwóch różnych przewodów NbTi, zostaną określone główne czynniki powodujące rozbieżności, a także zalecenia mogące poprawić zgodność pomiarów. **(Porównanie stałoprądowej i impulsowej metody pomiarów prądu krytycznego w przewodach nadprzewodnikowych).

Keywords: pulse measurement, critical current, niobium-titanium.
Słowa kluczowe: pomiar impulsowy, prąd krytyczny, Nb-Ti.

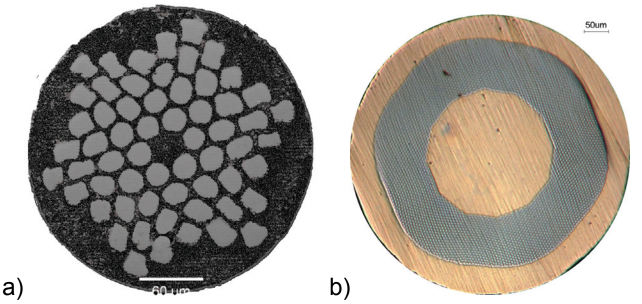
Introduction

The use of pulsed magnetic fields and transport currents for the critical current characterisation of superconducting wires has several potential benefits: in particular, large magnetic flux densities exceeding 30 T can be brought within the cost and infrastructure capabilities of typical research laboratories, and the heating associated with high current testing can be greatly reduced. However, this approach brings its own challenges in ensuring that the results are compatible with conventional direct current (DC) characterisation: the small bore diameter of a typical pulse magnet requires short samples to be used and, in combination with the need for rapid measurement, this usually results in a less sensitive electric field criterion [1,2]. Operating away from steady state conditions also introduces the possibility of time- and frequency-dependent effects, which are inconvenient for routine critical current characterisation but may be of relevance for assessing transient losses and for applications including SMES.

Experimental methods

Two contrasting multifilamentary NbTi samples were selected for investigation. To identify the discrepancies between DC and pulsed testing, their critical current behaviour was investigated using the Cryo-BI-Pulse system developed with Metis Instruments and Equipment NV (Leuven, Belgium) [3], and a comparison made to DC measurements. The first wire, from IMI, had a diameter of 0.25 mm and contained 60 NbTi filaments in a copper matrix, fig. 1(a); the second, from Luvata (OK3900), contained 3900 filaments embedded in a more resistive Cu-Mn matrix to reduce AC losses [4], with internal and external copper stabilisation, and was 0,575 mm in diameter, fig. 1(b).

To better understand the effects of sample size and configuration, both short straight samples and longer U-shaped samples were tested in the Cryo-BI-Pulse system, with the voltage measured across a length of approximately 5 mm perpendicular to the applied magnetic field in each case. The magnetic field pulse was 16,4 ms in duration, and shaped to give a broad plateau at near the maximum field. The current pulse was more sinusoidal in shape and timed to coincide with the maximum field; measurements were performed for two current pulse durations, 2.0 ms and 3.8 ms, as shown in Fig. 2. Critical currents were determined from a series of pulses in the Cryo-BI-Pulse system as described previously [1-3].



a) b)

Fig.1. Cross-sections of NbTi superconducting wires: (a) IMI wire (backscattered electron micrograph) and (b) Luvata OK3900 (optical micrograph)

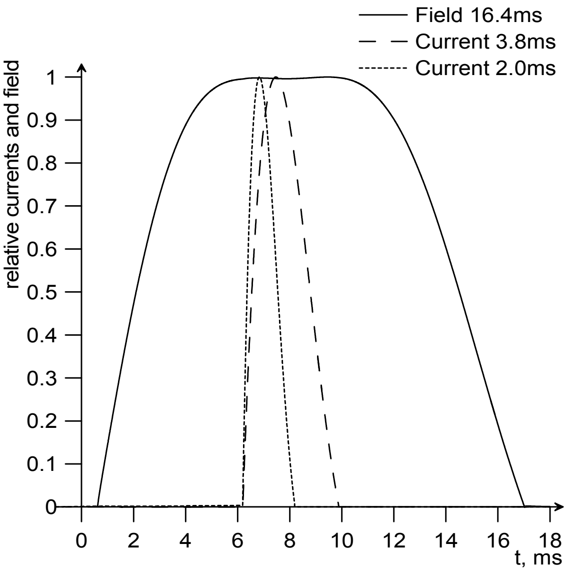


Fig.2. Shape and timing of the magnetic field and current pulses used in the Cryo-BI-Pulse system for critical current testing

Results and discussion

Very good agreement has been obtained between DC and pulse measurements of the copper-matrix IMI NbTi wire (Fig. 3) [3].

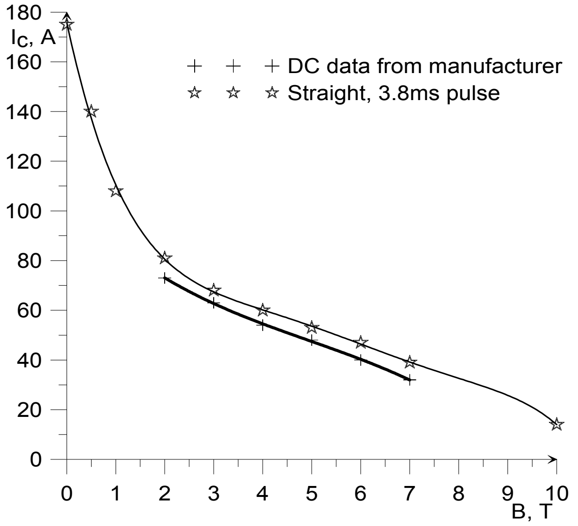


Fig.3. Transport critical current measurements for the IMI Titanium NbTi wire, by DC and pulse techniques

In contrast, the critical current of OK3900 samples measured by pulsed techniques was very much lower than the DC value: at 1 T, the apparent critical current measured on a short straight sample perpendicular to the magnetic field was more than 400 A lower than the DC critical current. Longer, U-shaped samples came closer to the DC value, but the measured critical current was still 300 A lower than for DC testing. Further measurements on samples after selective chemical etching of the copper stabilisation and Cu-Mn matrix were then performed, and the complete set of critical current values are presented in Fig. 4.

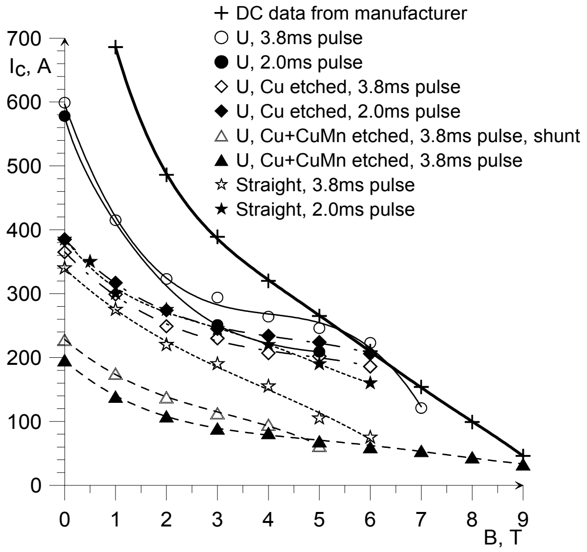


Fig.4. Critical current data for OK3900 samples, tested as short straight pieces ('straight') and U-shaped samples ('U') by DC and pulse techniques

The transition criteria applied to DC and Cryo-BI-Pulse measurements are certainly different, and might explain the small discrepancy for the IMI NbTi wire [1-2]; but this cannot explain the much larger discrepancy for OK3900, as the *n* values and sample configurations are similar for both wires.

The observation of a higher critical current for U-shaped samples than for short straight pieces suggests a contribution from ohmic heating from the current leads and contacts: the longer U-shaped samples have a greater separation between current and voltage contacts, reducing the influence of this contribution and of current transfer effects [5]. This may also explain the better agreement at higher magnetic fields, for which the critical current is lower. Heating and current transfer effects would both be expected to be more significant for the OK3900 wire than the IMI wire because of its higher critical current and lower interfilamentary electrical conductivity.

The small filament diameters in OK3900 might be expected to confer improved flux-jump and cryo-stability, but the higher thermal and electrical resistivity of the interfilamentary matrix has the opposite effect [6]. Chemical etching to remove the external copper stabilisation reduced the measured critical current, and further etching to remove the resistive Cu-Mn matrix further reduced the critical current. This was probably due to the progressively poorer stability, and confirms that differences in stabilisation can contribute to the discrepancies between DC and pulsed critical current measurements.

The effect of current pulse duration is less consistent: shorter pulses result in less heating, but also a larger rate of change of current, which may introduce transient effects. There is some evidence in Fig. 4 of reduced pulse lengths resulting in both increased and decreased critical currents, depending on the sample length and stability. Time-dependent effects and the contribution of magnetic field will be the focus of future work.

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