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Analyses and implications of *V–I* characteristic of PF insert conductor sample

R. Wesche [a,*], A. Anghel [a], P. Bruzzone [a], P. Gislon [b], L. Muzzi [b]

[a] *Centre de Recherches en Physique des Plasmas, 5232 Villigen PSI, Switzerland*
[b] *ENEA, Centro Ricerche Frascati, Via E. Fermi 45, 00044 Frascati, Rome, Italy*

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Abstract

Two short lengths of the full-size NbTi cable-in-conduit (CIC) conductor used to fabricate the ITER poloidal field coil insert were tested in the SULTAN facility. The two investigated conductors, otherwise identical, are distinguished only by the presence and absence of the last stage subcable wraps. The voltage–current (*V–I*) characteristics and the quench behaviour of the conductors with and without subcable wraps are compared. The dc performance of the conductors is limited by the occurrence of sudden take-offs above ≈35 kA in the leg with wraps and above ≈45 kA in the leg without wraps. Hall probes used to study the current distribution indicate that the better performance of the conductor without subcable wraps is closely related to the lower transverse resistance providing a more efficient current redistribution.

Keywords: Cable-in-conduit superconductors; NbTi; Quench behaviour; Voltage–current characteristic

1. Introduction

The contribution of the self-field to the total magnetic field leads to cable critical currents considerably smaller than the critical current expected from the strand data at the same background field. Moreover, the self-field causes a strong peak in the local electric field, which continuously reduces the take-off electric field until sudden take-offs occur at sufficiently high quench currents [1,2]. The threshold current for locally initiated peak-field-induced quenches depends also on the current distribution in the high-field region. In the present article, the effect of the presence or absence of subcable wraps on the current redistribution, the *V–I* characteristic and the dc performance of two, otherwise identical, conductors is discussed.

2. Experimental details

The SULTAN facility provides the possibility to test two different conductors, each forming one of the two legs of the sample, in a single experiment. In the left leg of the investigated sample, the subcables were

* Corresponding author. Tel.: +41 56 310 3592; fax: +41 56 310 3729.
E-mail address: rainer.wesche@psi.ch (R. Wesche).

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wrapped by stainless steel tapes, whereas these wraps were absent in the right leg. Arrays of Hall probes in the high-field region are available to study the current distribution in both conductor legs. A detailed description of the sample can be found elsewhere [3].

The dc performance of the conductors was tested in the field range of 4–7 T at temperatures between 5 and 7.5 K. On each leg of the sample a pair of voltage taps at 420 mm distance, placed in the high-field region, is available to detect the critical (I_c) and the quench current (I_q). In the I_c measurements, the He inlet temperature is kept constant while the current is increased, whereas for the determination of the current sharing temperature T_{cs} the current is kept constant and the He inlet temperature is increased by means of a heater. Both the I_c and the T_{cs} values are based on an electric field criterion of 0.1 μV/cm. The temperatures reported in the present work are the helium temperatures measured close to the high-field region. The measurements were performed at He mass flow rates between 4 and 10 g/s.

3. Results and discussion

3.1. Effective self-field factors

First, the cable dc performance is compared with the strand data from the strand manufacturer [4]. An effective self-field factor k_{eff} [5] is defined in such a way that $I_c^{cable}(B_{eff}) \cong N I_c^{strand}(B_{eff})$, where $B_{eff} = B_b + k_{eff} I_c$ (B_b background field, N number of strands). The peak field factor resulting from the conductor geometry taking into consideration the magnetic field generated by the return conductor is $k_p = 0.0166$ T/kA. The average effective self-field factors in the field range of 4–7 T are 0.0170 and 0.0187 T/kA for the left and the right leg, respectively. These values are slightly above the peak field factor of 0.0166 T/kA suggesting a slightly uneven current distribution in the high-field region.

The critical currents measured in both legs and those expected from the strand data for the peak magnetic field are compared in Fig. 1. In general, the measured critical currents in both conductor legs are close to the values for the peak field as expected from the effective self-field factors. However, the effective self-field factors of both conductor legs were found to increase with decreasing field. Considering only the 4 T data,

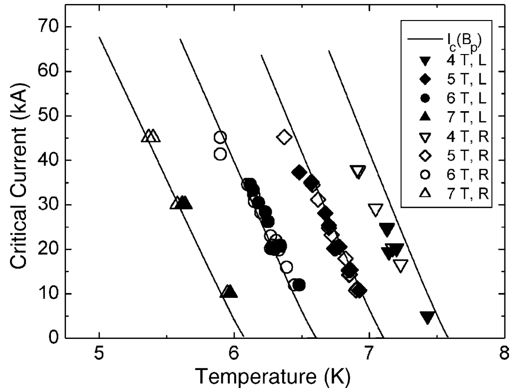

Fig. 1. Critical current as a function of temperature for the left (wraps) and the right leg (no wraps). The critical currents in both legs are close to or below the I_c expected for the peak magnetic field represented by the lines.

the effective self-field factors for the left and the right leg are 0.0277 and 0.0248 T/kA, respectively, which is reflected by the fact that the I_c values at 4 T are slightly below the peak field expectation. Because of the occurrence of sudden take-offs the I_c (see Fig. 1) could be measured only up to currents of ≈35 kA (left leg, wraps) and ≈45 kA (right leg, no wraps). Above these currents the take-off electric field falls below 0.1 μV/cm, the field criterion used to define I_c. Only the quench currents could be therefore measured at higher current levels (see Fig. 2).

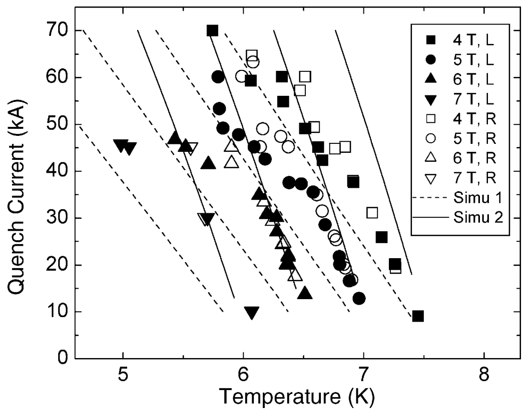

Fig. 2. Quench current as a function of the temperature for the left (wraps) and the right leg (no wraps). The measured quench currents are between the results of quench simulations for highly overloaded strands (Simu 1) and a uniform current distribution (Simu 2).