A Novel Technique for Minimum Quench Energy Measurements in Superconductors Using a Single-Mode Diode Laser

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1 Introduction

Superconducting magnets are prone to quenches, an event during which the magnet coil switches rapidly and irreversibly to the normal resistive state, thereby disrupting operation [1]. Quenches have various origins, but in compact, high-current-density coils, the origin is mostly mechanical, resulting in fairly localized (a few mm), short duration (less than 100 μs) thermal disturbances [2]. Over the years, various studies have been carried out to evaluate, both from the theoretical and the experimental points of view, the stability of superconductors against such disturbances [3-5]. The most common experimental technique is based on resistive heaters, but it has proven to be delicate and to require a great attention to sample preparation [6].

This letter introduces a new experimental technique to study the stability of superconducting multifilament composite wires against localized thermal disturbances of short durations. It relies on a single-mode diode laser coupled to an optical fiber. The release of the optical energy onto the wire surface can induce a normal resistive zone, which either propagates or recovers. Recorded voltage traces are given to demonstrate the feasibility of this new heater technique, which leads to reproducible measurements.

2 Single-mode Diode Laser and Optical Fiber

The experiment relies on a Spectra Physics, single-mode diode laser emitting at a wavelength of 807 nm and located outside the cryostat at room temperature. A laser driver supplies a maximum admissible current of 2 A, corresponding to a maximum continuous output optical power of 1.2 W. The diode is coupled to an optical fiber that is extended by another Silica-Silica fiber of the desired length (see Figure 1). It guides the light beam from the diode to the bottom of the cryostat. The tip of the optical fiber extension is customized to target the wire sample and reduce stray light (see Figure 2). It is composed of a hollow metallic needle (with an inner diameter of 300 μm) inside which the wave guide (whose core has a diameter of 100 μm) is glued.

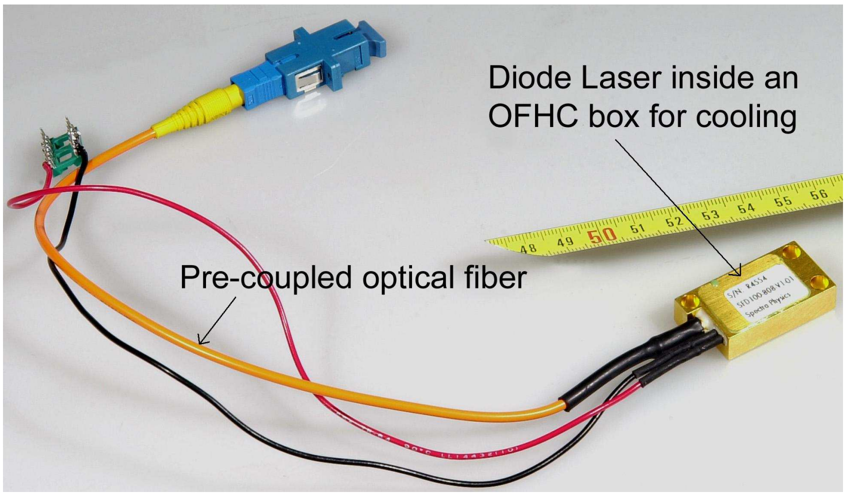

Figure 1: Single-mode diode laser of 1.2 CW coupled to an optical fiber and sealed inside an OFHC copper box (supplied by Spectra Physics).

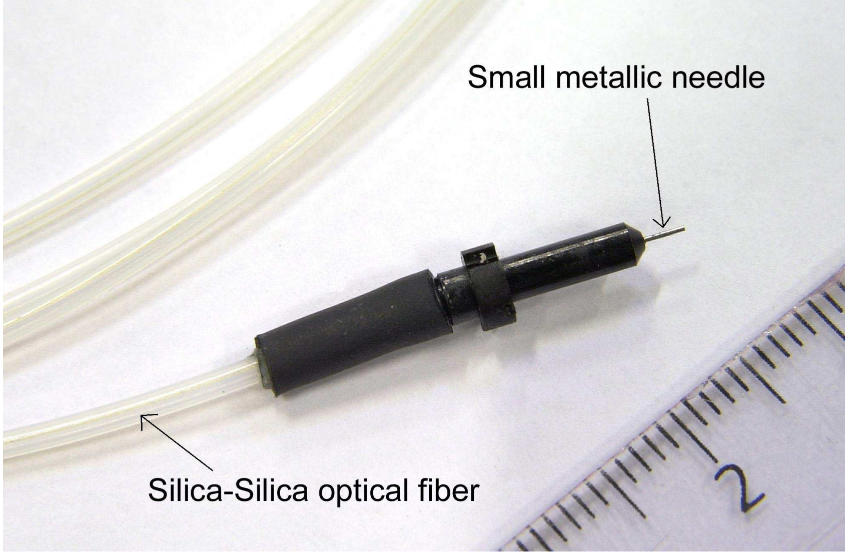

Figure 2: Customized tip of the optical fiber extension made of Ultem 1000R® into which is glued a small metallic needle to position the optical wave guide as close as possible to the sample.

2 Oxidized NbTi wire sample

The sample is an LHC-02-type, 0.82-mm-diameter, Cu/NbTi multifilament composite wire (with no tin-silver solder coating) supplied by Alstom/MSA. This wire is made of an outer copper sheath surrounding a multifilamentary zone composed of NbTi filaments embedded in a copper matrix. Following a first set of experiments carried out on a bare wire [7], it was verified that in the near infrared optical region, copper material exhibits a poor optical absorption. To improve absorption, it was decided to chemically blacken the surface of the wire sample. A mix thin layer of cupric oxide and cuprous oxide was grown on the outer copper sheath. The exceeding oxidation layer was etched using chloride acid to save for a few millimeters at the middle of the sample as shown in Figure 3.

3 Experimental setup

As illustrated on the right hand side of Figure 4, the wire sample is mounted on a U-shaped G10 sample holder. A V-shaped groove has been milled in the sample holder and two G10 pieces press the sample into the bottom of the groove to prevent wire displacement under Lorentz force. Two additional springs help tensioning the sample. As illustrated on the left hand-side of Figure 4, a metallic assembly has been especially designed to maintain the tip of the optical fiber at a distance of less than 1 mm from the wire sample. This short distance ensures that the entire cone of light coming out of the fiber strikes the wire surface.

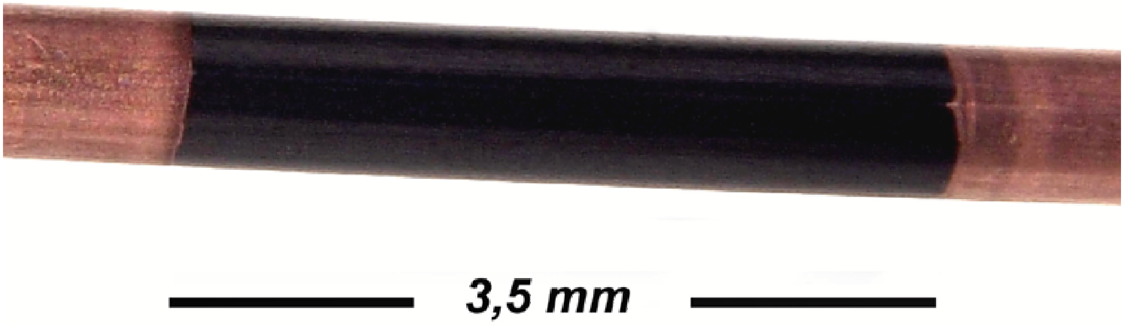

Figure 3: Oxidized Cu/NbTi wire sample. The oxidation layer, which initially covered the whole sample, was chemically etched to save for a few millimeters at the middle of the sample.

Six voltage taps have been soldered onto the wire. Voltage drop V_1 records the normal zone generation in the oxidized portion of the wire illuminated by the tip of the optical fiber, while voltage drops V_2 and V_3 are used to measure normal zone propagation velocity along the sample.

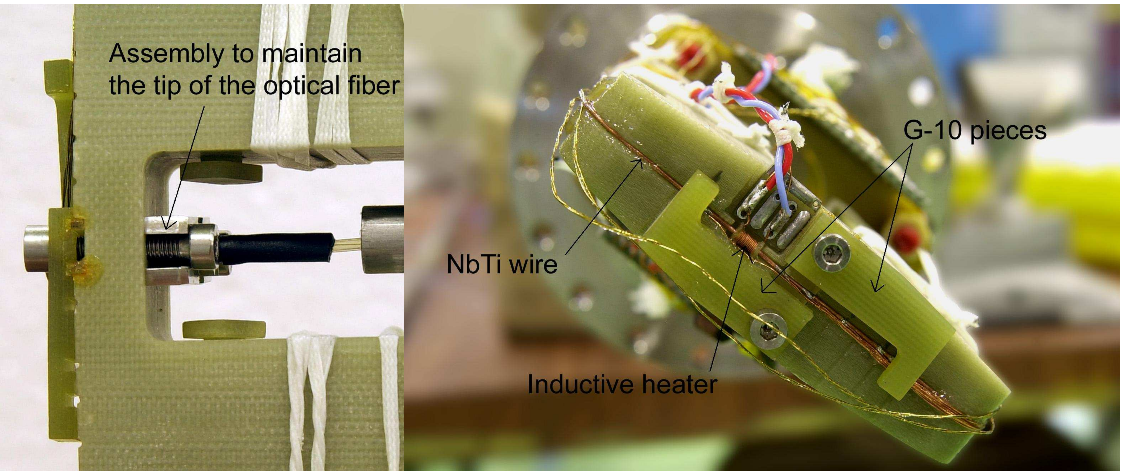

Figure 4: Experimental setup for stability measurements on superconducting wires using a single-mode Diode-Laser coupled to an optical fiber: left, maintaining of the tip of the optical fiber; right, sample holder with sample equipped. The figure shows also a small pick-up coil used as an inductive heater that is not discussed here.

4 Results

Figure 5 shows a compilation of filtered voltage traces downloaded from a digital oscilloscope for a series of shots at different input energies. The measurements were taken in pool boiling helium at ~4.2 K, in a 7 T background magnetic field (perpendicular to the wire axis), and at 285 A (corresponding to 85% of the wire critical current measured in situ). In the present experiment, the duration of the pulse current delivered to the diode laser was set to 30 μs and its amplitude was progressively increased. The diode was calibrated at room temperature by measuring its output optical power as a function of forward current. Hence, the optical energy was estimated by integrating this power over the pulse duration. After each recovery, the wire was cleansed of persistent magnetization currents by performing an intermediate quench. The voltages displayed in Figure 5 correspond to V_1 across the heated zone. When the deposited energy is not enough to trigger a full quench, the wire enters the current sharing regime but the cooling capacity of the helium cryogen is strong enough to enable a recovery of the superconducting state. However, as soon as the input energy is large enough to reach the Minimum Propagating Zone (MPZ), the heat generated by the Joule effect takes over and the sample undergoes an irreversible transition.

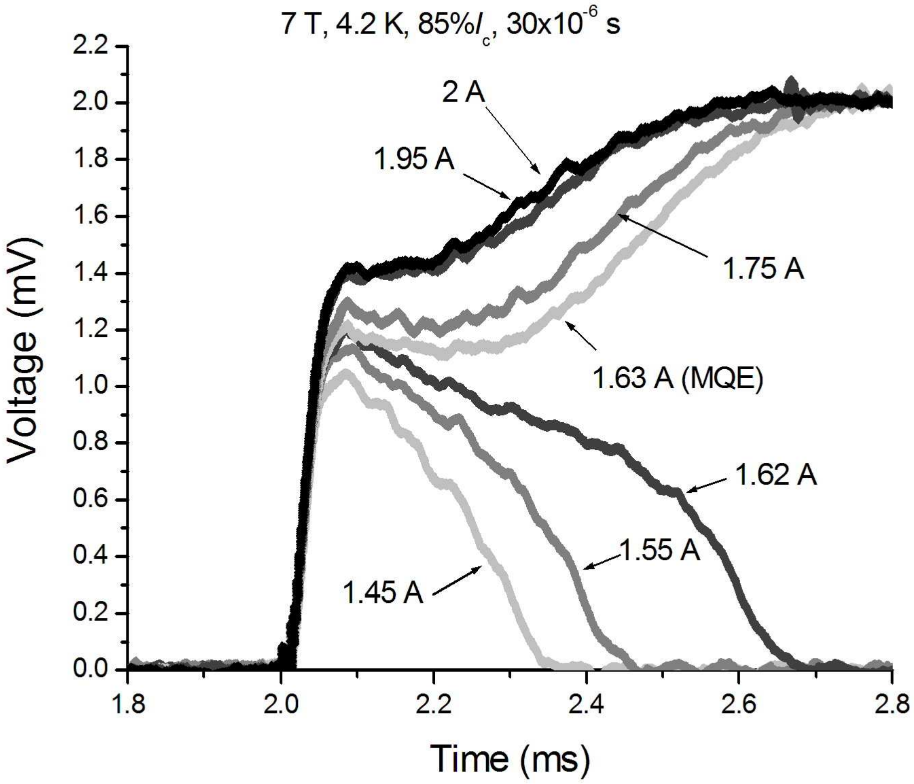

Figure 5: Transitions and recoveries observed on a 0.82-mm Cu/NbTi multifilament composite wire supplied by Alstom/MSA at 4.2 K, 7 T, and 285 A (85% of I_C). The diode laser is supplied by a pulse current, whose duration is set to 30 µs and whose amplitude is increased until a quench occurs.

Figure 6 presents a summary plot of minimum optical energies needed to trigger a quench as a function of pulse durations. These values overestimate the quench energies as a small fraction of optical power may be reflected by the wire surface. As expected, the measured energy tends toward a plateau for small pulse durations. One can point out that the long pulse energies have larger error bars. This is due to the fact that, the longer pulse, the smaller the peak current, and closer, we get to the threshold current of the diode, where the laser effect tends to disappear.

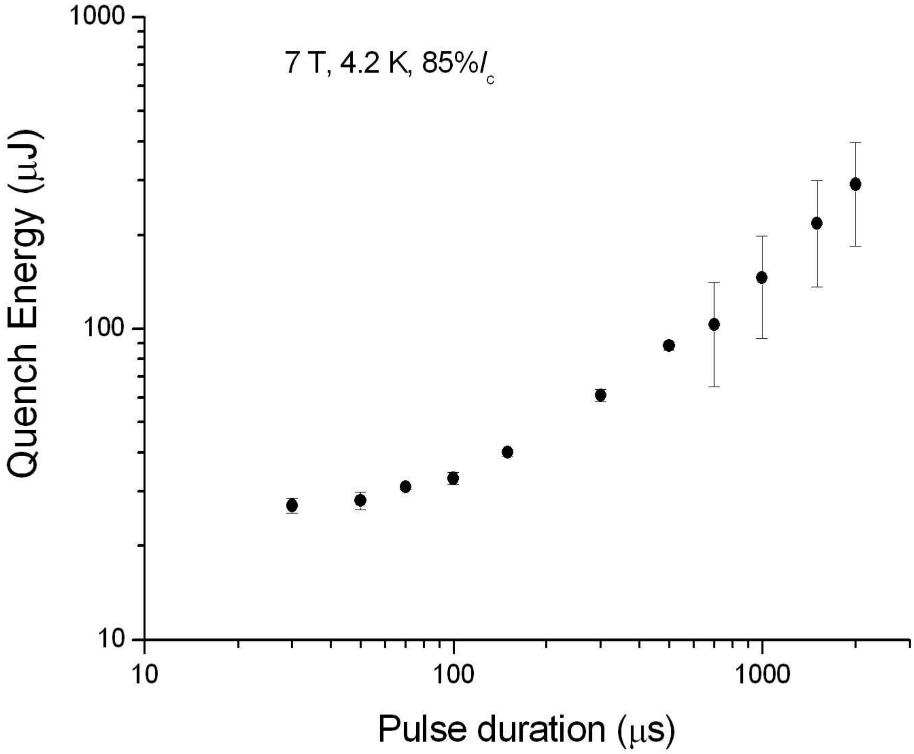

Figure 6: Minimum output optical energy to trigger a quench as a function of pulse durations.

5 Conclusion and perspectives

The feasibility of a new heating technique to induce quenches in superconductors using a single-mode diode laser coupled to an optical fiber was demonstrated. The next step is to calibrate the energy absorbed by the wire. We are planning a series of tests in a quasi-adiabatic environment plus two sets of calibrations: one using a bolometer (made up of the same copper as the wire stabilizer) and the other using the inductive heater shown in Figure 4.

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