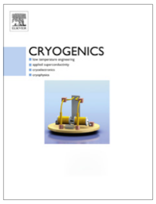
Cryogenics 79 (2016) 1–6

Contents lists available at ScienceDirect

Cryogenics

journal homepage: www.elsevier.com/locate/cryogenics



Research paper

# Forced flow He vapor cooled critical current testing facility for measurements of superconductors in a wide temperature and magnetic field range

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ARTICLE INFO

*Article history:*
Received 21 March 2016
Received in revised form 24 May 2016
Accepted 3 July 2016
Available online 9 July 2016

*Keywords:*
Superconductors
Critical current measurement
Vapor cooled

ABSTRACT

As superconducting materials find their way into applications, there is increasing need to verify their performance at operating conditions. Testing of critical current with respect to temperature and magnetic field is of particular importance. However, testing facilities covering a range of temperatures and magnetic fields can be costly, especially when considering the cooling power required in the cryogenic system in the temperature range below 65 K (inaccessible for $LN_2$). Critical currents in excess of 500 A are common for commercial samples, making the testing of such samples difficult in setups cooled via a cryocooler, moreover it often does not represent the actual cooling conditions that the sample will experience in service. This work reports the design and operation of a low-cost critical current testing facility, capable of testing samples in a temperature range of 10–65 K, with magnetic field up to 1.6 T and measuring critical currents up to 900 A with variable cooling power.

## 1. Introduction

The current a given superconductor can carry depends on a multitude of variables including temperature, magnitude of the magnetic field and its direction. These data are important when designing and optimizing conductor materials for applications, and can serve as inputs for computer models [1,2] used to validate new designs of superconducting devices.

Critical current, $I_c$, is often measured for a sample immersed in a cryogenic liquid such as liquid nitrogen (77.4 K) or liquid helium (4.2 K). Close contact with the cooling medium provides cooling for non-superconductive parts of the testing rig, i.e. current leads and sample contacts. However, for intermediate temperatures, choices of cooling system are limited. Cryocoolers are increasingly popular, but their cooling power is still fairly modest, cool-down to testing temperature can take hours and a substantial capital investment is required, making them unfeasible for smaller institutions. On the other hand, flow cryostat facilities tend to be bulky and require a magnet to be integrated into the system, increasing the cost [3,4].

We propose a new, low-cost system for critical current testing in a wide range of temperatures from 10 to 65 K and magnetic fields of up to 1.6 T, which in this case was limited by the electromagnet used. Due to the low achievable base temperature, the system is suitable for critical current measurements of materials such as $MgB_2$, rare-earth cuprates and iron-based superconductors. Samples of up to 16 cm in length can be measured. The system allows for testing of a variety of materials in a cost-effective manner. The design and construction of the critical current measurement system is outlined in Section 2, and initial data collected with the system are presented in Section 3.

## 2. Design of the critical current measurement system

The design of a critical current measurement system must take into account a number of design considerations and constraints, including cryogenic insulation and temperature control, very large current handling capability, applied magnetic field and forces on the sample and the system components due to said field. The cryogenic environment and the presence of large magnetic fields also dictates the choice of materials and components. Each of these aspects will be considered in the following subsections.

### 2.1. Overall design

A schematic outline of the system is provided in Fig. 1. The simplicity of the concept allows the system to be modular and easy to

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http://dx.doi.org/10.1016/j.cryogenics.2016.07.003
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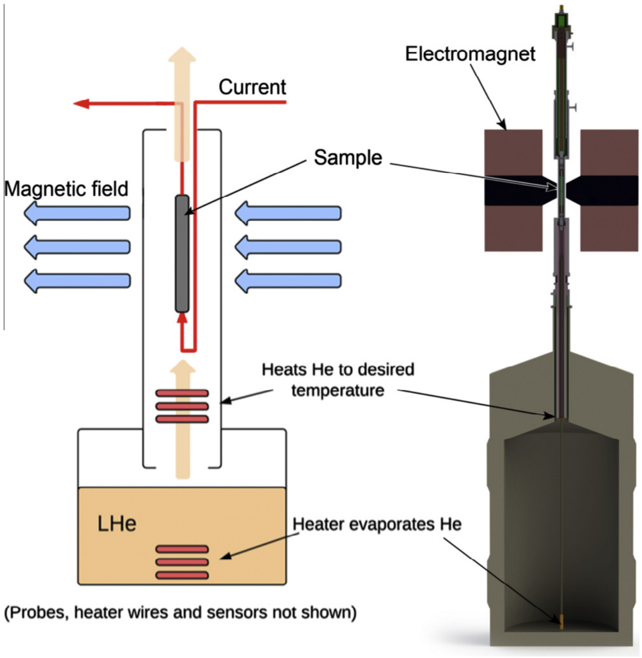

**Fig. 1.** A schematic sketch of the critical current measurement system. Probes, heater wires and sensors are not shown. Blue arrows indicate the applied magnetic field, while LHe denotes liquid helium.

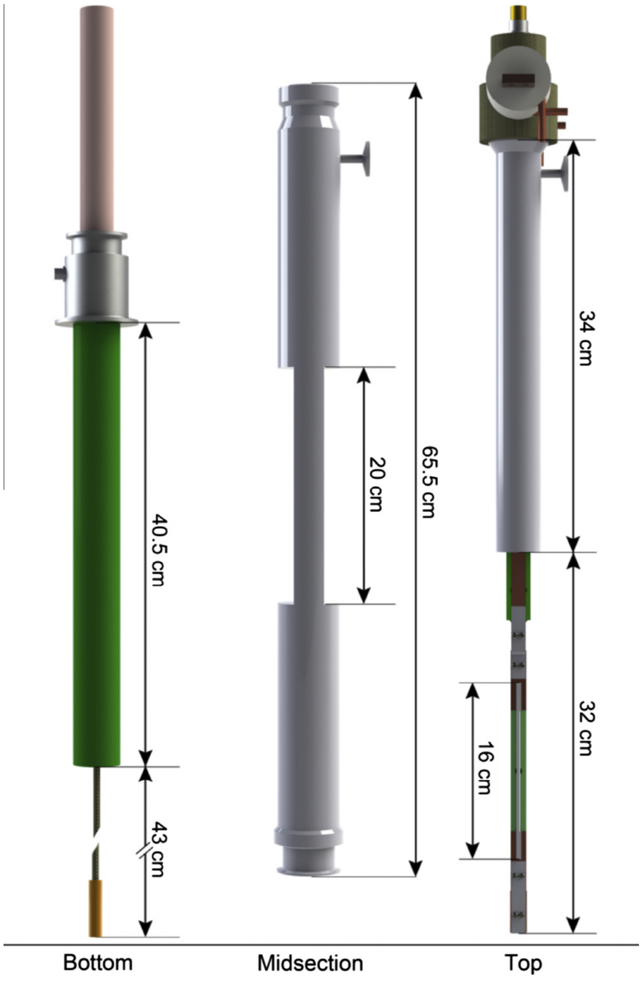

**Fig. 2.** The illustration shows the three separate parts forming the critical current testing facility, starting from the bottom-most part on the left, which inserts directly into a regular helium transfer dewar. The sample is placed on the topmost part, which slides into the midsection.

maintain. A vacuum walled sample tube is placed on the liquid helium transfer dewar, without tampering with the safety features and pressure release valves of the dewar. A heater inside the dewar is used to evaporate the helium (evaporation heater) that controls the gas flow rate of helium vapor, whilst another heater in the neck of the dewar is used to adjust the temperature of the vapor (gas heater), and hence control the sample temperature. The gas heater is controlled via a three term proportional-integral-derivative control loop (PID loop) to set the sample temperature. Having two heaters allows the helium flow rate and sample temperature to be set independently. The resulting helium boil-off can, in principle, be collected for re-liquefaction.

The magnetic field was applied externally by an electromagnet, but any other source of magnetic field can be used, e.g. a permanent magnet. In each case, fields approaching 2 T can be achieved, even without the use of superconducting magnets.

Lastly, as soon as the desired temperature is stabilized and the magnetic field applied, current is ramped through the sample until the critical current criterion is met. The procedure is repeated at multiple temperatures and magnetic field values in a sequential manner to characterize the sample with minimum liquid helium usage. At this point the system can be warmed up and another sample mounted.

### 2.2. Construction and materials used

The design of the system is modular. The system is composed of three discrete components as illustrated in Fig. 2. The bottom part inserts into the dewar and contains two heaters, whose purpose is discussed in Section 2.3.

The midsection is primarily structural. The narrow section is only 25 mm wide, allowing for the spacing of the electromagnet poles to be minimized, increasing the magnetic flux density. The whole component is vacuum-walled and contains guides for the topmost part, which holds the sample.

The topmost part holds the sample board and all of the sensors and measurement wires. Its vertical position can be adjusted, so that the sample can be centered between the electromagnet poles. Furthermore, the topmost part can be rotated about its axis to orient the sample in the magnetic field. Hence, conductor anisotropy of $I_c$ in magnetic field can be measured.

The low temperatures and high magnetic fields put constraints on the materials used in the system. Therefore, the vacuum walled parts were made out of non-magnetic stainless steel 316 with outer walls being thicker for structural rigidity (2 mm and 1 mm wall thickness for the midsection and topmost parts respectively), while the inner walls were made thinner to minimize thermal mass (less than 0.5 mm in each case). Care was taken to choose non-magnetic parts for all components near the magnetic field. The sample may experience significant forces during measurement, hence the central sample support in the topmost part was chosen to be glass-fiber/epoxy composite G10 from Tufnol due to its excellent stiffness, low thermal conductivity and excellent electrical insulation characteristics. Other parts that require non-conductive material like the cap on the topmost part were also manufactured out of Tufnol composite, but with cotton fibers due to easier machinability.

### 2.3. Cooling system and thermal insulation

The temperature is actively controlled via two heaters, made of coiled resistive Kanthal wire. Heater 1, referred to as the evapora-