Chapter 16

AC Magnetic Measurements on Superconductors: Design of a Device for Magneto-Thermal Measurements

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ABSTRACT

This work describes the design and realisation of an apparatus to measure simultaneously the AC magnetic properties and the temperature distribution on the top surface of bulk superconducting samples (up to 32 mm in diameter) in cryogenic conditions (temperature range 78-120 K). First the authors describe the experimental set-up used for simultaneous thermal and magnetic characterization of the sample. Next, the authors describe the practical considerations required for generating the large AC magnetic fields, possibly in the presence of DC fields. Then the authors present the data acquisition system allowing both temperature and magnetic data to be recorded at high a sampling rate.” The performances and limitations of the system are discussed.

1. INTRODUCTION

Superconductors are materials that exhibit zero resistance under a given temperature, called critical temperature \( T_c \). In addition to carrying lossless currents, superconductors are also characterized by several unusual and attractive magnetic properties (e.g., levitation, magnetic shielding...) that are relevant for a number of engineering applications (Campbell, 1997). The measurement of their AC magnetic properties as a function of temperature represents a well-established and powerful tool for studying their performances (Goldfarb, 1991). The AC susceptibility \( \chi \) of a superconductor can
be expressed as $\chi = \chi' - j\chi''$, where the real part ($\chi'$) represents flux exclusion due to induced shielding currents in the superconductor and the imaginary part ($\chi''$) is proportional to the magnetic losses (Gömöry, 1997). These losses may give rise to a significant temperature increase and a degradation of the superconducting properties (Yamaguchi, 2006). It is therefore desirable to measure simultaneously the AC magnetic properties and the corresponding self-heating (Fujishiro, 2006). In a previous work (Laurent, 2008), we have described an original AC susceptometer (i.e., a device for measuring AC susceptibility) suitable for measuring precisely the AC magnetic properties of large (up to 32 mm diameter) superconducting samples as a function of temperature, which is considerably larger than the size of the samples that can be accommodated in commercial devices (typically 10 mm diameter). In the present work, we describe how such an AC susceptometer can be upgraded in view of recording simultaneously the AC magnetic properties of the superconductor and the temperature at several locations on the sample surface.

This paper is organized as follows. In the first section we describe the practical considerations required for achieving simultaneous measurements of magnetic properties and of the temperature distribution along the surface of a bulk superconducting sample subjected to an AC magnetic field. In particular we describe detail the experimental precautions to be taken for precise temperature measurements in the presence of magnetic fields in the audio frequency range. The second section is devoted to the generation of magnetic fields. The performances and limitations of the magnet are measured, reported and discussed. In the third section we describe the signal conditioning (amplification and filtering) and the subsequent numerical treatment of the digitized data in order to extract precisely low DC and AC signals in a noisy environment.

2. INSTRUMENTATION OF THE SUPERCONDUCTING SAMPLE

Basically, a susceptometer consists of a magnetizing (primary) coil and two pick-up (secondary) coils wound electrically in series opposition (Nikolo, 1995). The electro-motive force (emf) induced across ideal pick-up coils (i.e., wound with the same number of turns and in identical geometries) is zero in the absence of a sample. Inserting a magnetic sample centred in one of the secondary coils results in the generation of a non-zero signal that is directly proportional to the AC magnetic susceptibility.

In the experiment described here, the classical set-up is extended to measure simultaneously (i) the temperature against the top surface of the superconducting sample and (ii) the magnetic flux density against the bottom surface of the sample, as shown in Figure 1. In the following we describe the temperature sensors and the magnetic sensors.

2.1. Temperature Sensors

The temperature sensors are used to give information on the time-evolution of the temperature distribution over the top surface of the sample (i.e., along the radius if an axial symmetry is assumed) during the application of the AC magnetic field. The temperature sensors attached to the superconductor must therefore be characterized by a small response time. In this work, thermocouples are chosen in view of their tiny size (< 1mm) and response times much smaller than 1 s. We use Type E thermocouples, i.e., chromel (90% Ni - 10% Cr) - constantan (55% Ni - 45% Cu). Type E thermocouples are characterized by a high sensitivity (68 µV/K at room temperature, ~ 28 µV/K in the 77-92 K interval) and are well suited to cryogenic use. In addition, they are non-magnetic and therefore can be used under large magnetic fields. In our set-up, thermocouples