A technique for separating the trapped vortex and current in superconducting rings

I Quelle\textsuperscript{1,3}, H González-Jorge\textsuperscript{2}, L Romaní\textsuperscript{1} and G Domarco\textsuperscript{1}

\textsuperscript{1}Dpto. Física Aplicada, Universidad de Vigo, Facultad de Ciencias, As Lagoas, 32004 Ourense. Spain
\textsuperscript{2}Dpto. de I+D, Laboratorio Oficial de Metroloxía de Galicia, Parque Tecnolóxico de Galicia, San Cibrao das Viñas s/n, 32901 Ourense. Spain

E-mail: iriaqv@uvigo.es

Abstract. In this work, a technique for separating the trapped vortices and current in YBCO superconducting rings is shown. This technique consists of heating a small part of the sample, cancelling the persistent current and keeping the vortices in the sample. Such rings are obtained from top seeding melt grown YBCO samples. To generate the persistent current in the rings an inducting technique called field cooling is used. The field is applied to the ring with a closed magnetic circuit made of an iron core and a coil. For the heating of the superconducting ring, a counter-wound coil is placed around a part of the sample. A current pass through the coil and the local heating causes the current dissipation in the superconducting ring. For magnetic field profiles in YBCO superconducting rings a Hall sensor is used, that moves at constant step on the surface of the sample.

1. Introduction
For magnetic fields between lower $H_{c1}$ and upper $H_{c2}$ critical fields, type-II superconductors are leaded to a mixed state which causes vortices penetration [1]. Under these conditions, an electric current flowing by the samples originates a thermally activated hopping of vortices between neighbouring pinning positions due to the action of Lorentz force [2]. This fact originates a decay of the current. Persistent current in superconducting rings is usually generated using a field cooling procedure [3,4].

In this work, a technique for separating the trapped vortices and the current in YBCO superconducting rings is shown. This technique consists of a counter-wound coil placed around a part of the sample for heating it, which produces the transition to the normal state of this section while the rest of the sample continues in superconducting state. The current is dissipated but the vortices are kept in the sample. For magnetic field profiles in YBCO superconducting rings a Hall sensor [5] is used, that is moved at constant step on the surface of the sample.

\textsuperscript{3} To whom any correspondence should be addressed.
2. Experimental details

Superconducting rings used were three YBCO rings (Y1, Y2 and Y3) that were obtained from top seeding melt grown superconductors. The critical temperature of the YBCO rings was approximately 92 K. These samples were purchased from the Institut für Materialphysik of Goettingen (Germany). A concentric hole was made in each sample to obtain rings. To this end, a copper-diamond drill was used [6,7]. The complete dimensions of the samples and the critical current are shown in Table 1. Critical current of the samples was measured using a contactless inductive device [8,9] at liquid nitrogen temperature.

|       | Y1    | Y2    | Y3    |
|-------|-------|-------|-------|
| $I_C$ (A) | 2200  | 4400  | 6700  |
| $R_1$ (mm) | 5.0  | 5.0   | 5.0   |
| $R_2$ (mm) | 10.5 | 12.5  | 14.0  |
| $h$ (mm)   | 8.0  | 10.0  | 10.0  |

Table 1. Main data of the samples used in this work Y1, Y2 and Y3. $I_C$ is the critical current, $R_1$ is the inner radius, $R_2$ the external radius, and $h$ the height of the rings.

Figure 1 shows the superconducting ring with counter-wound coil of constantan which was used for current dissipation. A cryogenic high vacuum grease [10] was deposited on the sample previously to situate the counter-wound coil around the superconductor, which improved the thermal conductivity between them. The coil was also isolated with polyurethane in order to avoid the contact of this one with the liquid nitrogen and concentrate all the heat dissipated in the superconductor. The resistance of the counter-wound coils of constantan assembled around the samples were measured at liquid nitrogen and 27.9 $\Omega$ for Y1, 35.3 $\Omega$ for Y2, and 22.8 $\Omega$ for Y3 were obtained as a result.

The current was induced in the YBCO superconducting rings using a field cooling procedure. The inducting technique used to produce the superconducting current consisted of the utilization of a closed magnetic circuit with a coil and an iron core [11,12]. At room temperature, a superconducting ring was assembled to an iron core. The coil was connected to a DC power supply and the core was magnetized. After then, the ring was cooled until liquid nitrogen temperature. Finally, the core was removed and a persistent current was induced in the superconductor.
The experimental procedure for separating the trapped vortices and the current in YBCO superconducting rings consists of dissipating the current using the counter-wound coil placed around a part of the sample. The current flowing through the coil produced the heating and transition to the normal state of the small superconducting section that dissipated the current but kept the vortices trapped.

The counter-wound coil of constantan was connected to another DC power supply. A Hall sensor was placed in the centre of the ring for calculating the current flowing through the superconductor, and using the law of Biot-Savart for the calculation [13]. The current flowing through the counter-wound coil was progressively increased and the Hall sensor begins to detect a magnetic field due to the dissipation of the current in the superconductor. It must be noted that the persistent current was cancelled but the vortices were kept in the sample, since the heating is performed in a localized section.

For magnetic field profiles in YBCO superconducting rings a Hall sensor was used, that was moved at constant step on the surface of the sample

3. Results

Figures 2-4 show the magnetic field profiles for current and trapped vortices in samples Y1, Y2 and Y3, respectively, with the ring parallel to the x axis. Superconducting rings walls are represented in the figures with vertical dotted lines.

First, magnetic field profiles in superconducting rings were made in samples with critical current induced, using a field cooling procedure. Secondly, the current was dissipated, using the local heating with the counter-wound coil, and magnetic field profiles were made again.

As was explained in the experimental section, the technique used for the dissipation of the current allows detecting the vortices contribution to the magnetic field and exhibits the possibility of separating the trapped vortices and the current in YBCO superconducting rings in an easy way. This technique will make possible to see the different vortices distribution in superconducting rings and to study the vortices movement, depending on the inducting procedure used.

![Figure 2. Magnetic field profiles for sample Y1. B is the magnetic field detected by the Hall probe and x the distance.](image)
4. Conclusion
In this work, a novel experimental procedure is shown to separate the vortices and the current contribution to magnetic field in ring-shaped type-II superconductors. This method is mainly based in the dissipation of the current in a small section of the sample. The critical current is achieved by using an inductive procedure. Then a part of the sample is heated to cancel the current, which is checked using a Hall sensor.

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