Physica B 194–196 (1994) 1793–1794
North-Holland

PHYSICA B

TRAPPED FLUX REDUCTION IN A SPHERICAL NIOBIUM SHELL AT 1 mG

Robert W. Brumley, Saps Buchman, and Yueming Xiao

W. W. Hansen Experimental Physics Laboratory, Stanford University, Stanford, CA 94305-4085, USA

We have developed a method to reduce flux trapped in a superconducting spherical shell. A normal spot on the shell sweeps flux lines until they close in on themselves. Using this technique the dipole moment corresponding to a trapped field of 1 mG has been reduced to about 6% of its original level.

1. INTRODUCTION

Gravity Probe B[1] is a program designed to measure rotational gravitational field effects by using cryogenic gyroscopes in Earth orbit. An important experimental requirement is to minimize the level of flux trapped in the superconducting coating of the gyroscopes. The coating is a 2.5-μm niobium film deposited on a 3.8-cm diameter quartz sphere. When slowly cooled through its transition temperature, the niobium film typically traps a density of flux quanta equivalent to a low ambient field. We attribute the lack of the Meissner effect to pinning sites in the niobium which trap the ambient field. This paper outlines the results of an experiment to reduce the level of the trapped flux using a laser annealing technique.

2. LASER ANNEALING

In 1984 Goto[2] proposed to sweep trapped magnetic flux by slowly moving a normal spot on a superconductor. The Meissner effect prevents a fluxon engulfed by the normal spot from reentering the superconducting region, thus forcing it to follow the normal region. Using this technique Geng and others[3] have demonstrated flux sweeping in a flat film. Our spherical shell geometry insures that an equal number of right-handed and left-handed flux vortices are trapped in the niobium film. We propose to eliminate trapped flux by bringing vortices of opposite helicity in close proximity to each other and thus close fluxons in on themselves.

The sphere is electrostatically suspended and cooled with helium gas at 4.2 K. Using a planar approximation of a point heat source in a thin film[4], we calculate the radius of the spot whose temperature increase is ΔT on the perimeter:

$$r(\Delta T) = \sqrt{\frac{4KD}{\pi HP}} \cdot \exp\left(-\frac{2\pi KD}{Q}\Delta T\right)$$

where Q is the power deposited in the niobium, K and D are the conductivity and thickness of the film and HP and P are the thermal conductance and pressure of the gas. The radius of the normal spot depends exponentially on the heating, making the laser power a critical experimental parameter. Figure 1 shows the calculated spot radius as a function of power absorbed in the film at two typical gas pressures. The angular velocity ω of the sphere of radius R is limited by the cooling time constant of the spot: $\omega \le rHP/\rho CDR$, where ρ and C are the density and specific heat of the film.

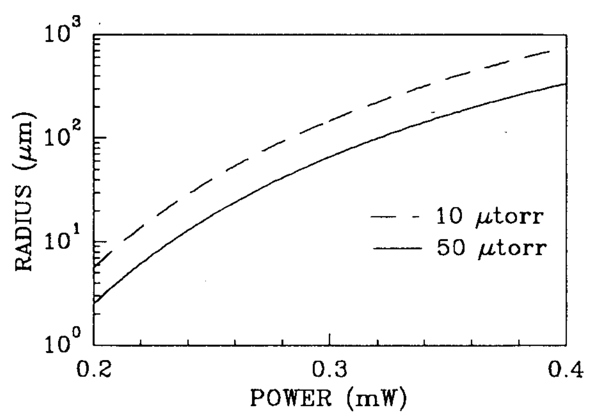

Figure 1. Hot spot radius versus power into film.

3. EXPERIMENTAL SET–UP

The experiment is performed in an ambient field of about 1 mG with 4.5 mW of 780-nm laser light coupled into an optical fiber and focused onto the

SSDI 0921-4526(93)1528-T

spinning sphere. A normal spot is thus created on the equator. Cooling is provided by helium gas at $5 \cdot 10^{-5}$ torr, while rotation and precession cause the normal spot to cover the entire surface of the sphere in less than 3 hours. From the gas pressure at which the entire sphere becomes normal, we estimate that 7% of the laser power is absorbed in the film. The calculated normal spot radius and maximum spin frequency are 50 μm and 0.5 Hz.

Figure 2 shows schematically the experimental set-up. The trapped flux couples into two superconducting loops of 3.9-cm radius arranged in the Helmholtz configuration and connected to an RF SQUID. The signal is FFT analyzed and the result recorded as harmonics of the spin frequency. Measurement of the flux determines the component of the trapped magnetic dipole moment normal to the plane of the loops. As Figure 2 indicates, neither the dipole M nor the spin axis ω will in general have any special orientation with respect to the pickup loops. However, polhoding of the trapped field and precession of the sphere will eventually bring the dipole perpendicular to the loops. Experiments with a three-axis readout system demonstrate that a single-axis readout will produce a measurement within 80% of the maximum dipole in less than 6 hours.

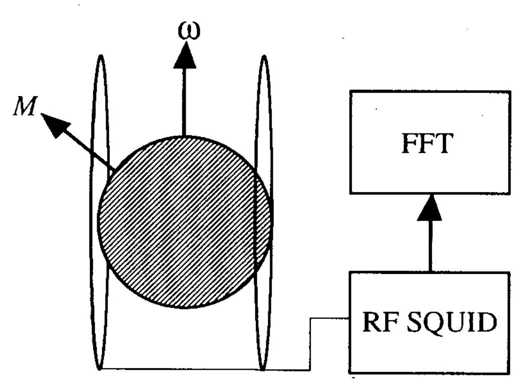

Figure 2. Schematic of the experimental set-up.

4. RESULTS AND DISCUSSION

The level of the trapped magnetic dipole was determined before and after the laser annealing process by measuring the flux through the pickup coils for 12 hours or more. The flux annealing process itself typically lasted between 3 and 12 hours. Figure 3 shows the normal component of the dipole moment as a function of time before and after the laser annealing. The maximum dipole magnitude, in units of equivalent uniform field in the sphere, is 1.0 mG from ambient field trapping, while the dipole magnitude after laser annealing is 60 μG. Thermal cycling consistently returned the superconducting shell to its initial trapped flux level. The higher-order magnetic moments are not measurable with the Helmholtz configuration.

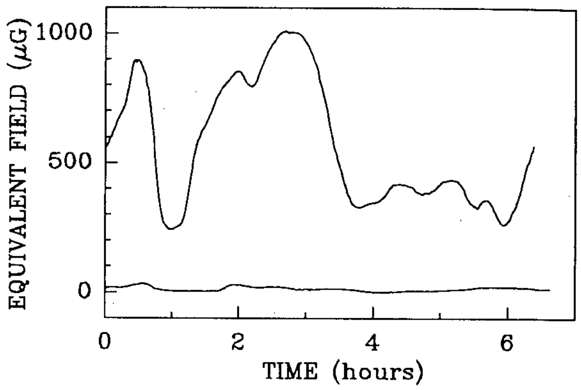

Figure 3. Evolution of trapped magnetic dipole moment before (upper trace) and after flux flushing (lower trace). Dipole magnitude expressed in units of equivalent uniform field in the sphere.

Our results indicate a reduction of the trapped flux dipole by 94%, thus providing convincing evidence of flux reduction. However, the possibility remains that some vortices were randomly re-arranged on the sphere, thus reducing the dipole moment without being eliminated. Further experiments are currently underway in a facility with an ambient field of 10^{-7} gauss and a readout system which allows for full characterization of the trapped flux evolution during laser annealing.

REFERENCES

1. J.P. Turneaure, C.W.F Everitt, B.W. Parkinson, Advances in Space Research **9**, 29 (1989).
2. E. Goto, Japanese Patent: 59-96875.
3. Q. Geng, H. Minami, K. Chihara, J. Yuyama, E. Goto, J. Appl. Phys. **72**, 2411 (1992).
4. H.S. Carslaw, J.C. Jaeger, *Conduction of Heat in Solids* (Oxford Univ. Press, Oxford, 1959).