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Simple Method for Checking the Balance of Gradiometers Used with SQUIDS

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This note describes a simples technique for detecting the degree of balance of first order gradiometers before connecting them to the SQUID. The effect of thermal cycling on this balance is given for different materiais used in the construction of the gradiometers.

Esta nota descreve uma técnica simples para detetar o grau de balanceamento de gradiômetros de primeira ordem, antes de conectá-los ao SQUID. O efeito de ciclagens térmicas neste balanceamento é dado para diferentes materiais usados na construção dos gradiômetros.

In low level magnetic detection experiments involving superconducting quantum interference devices (SQUID's) it turns out to be necessary to optimize the balance of the externa1 pair of oppositely wound sensing coils of the superconducting flux transformer, wound as a gradiometer in order to shield or discriminate against interference from distant magnetic sources.[1] Reported magnetic susceptibilities and biomagnetic fields measurements have been made using gradiometers balanced from 1.5 parts in 10^3 [2,3] down to 4 parts in 10^5.[4] To check such balancing, simple (but less precise)[5] and elaborate[4] techniques have been used with the flux transformer already connected to the SQUID.

In this note we propose a simple and quick technique to check this balancing, at room and low temperatures, before connecting the flux transformer to the SQUID, and using instruments of common use in research laboratories. The influence of thermal cycling on the balancing can be easily followed and the choice of the construction material for the former of the sensing coils optimized.

The technique is based on the symmetry and great sparial homogeneity of the axial field generated by a Helmholtz coil, in the vicinity of the central position (for an axial displacement of about 10% of the coil's radius from the central position the corresponding magnetic field variation is 1.5 parts in 10^4).

For a first order gradiometer let S_1 and S_2 be the effective horizontal areas of the two sensing coils having equal number of turns and B_1 and B_2 the magnetic induction through each coil. If we place the center of a perfectly balanced gradiometer ($S_1 = S_2$) at the central position of a Helmholtz coil excited with a sinusoidal generator, there will be no induced voltage in the gradiometer since $B_1 = B_2$. For an unbalanced gradiometer, ($S_1 \neq S_2$) the zero induced signal condition

$$S_1 B_1 = S_2 B_2$$

will only be satisfied by displacing the gradiometer a certain distance relative to the Helmholtz coil's center. Therefore the axial unbalance of the gradiometer can be checked by measuring the position of the gradiometer with respect to the center of the Helmholtz coil. We shall see that this displacement is considerable even when there is a small unbalance.

Defining the axial unbalance by $\eta = |(S_1 - S_2)/S_1|$, the zero induced signal condition for a small radius gradiometer placed along the axis of the Helmholtz coil gives

$$\eta(z) = \left| \frac{B(z+d/2) - B(z-d/2)}{B(z+d/2)} \right|$$

where $B(z)$ is the well known expression for the magnetic induction at the Helmholtz coil's axis, z is the position of the gradiometer's center where the zero signal condition is achieved and d is the gradiometer's base line (distance between the sensing coils).

The $\eta(z)$ function for a gradiometer in a Helmholtz coil of 20 cm average radius is shown in Fig.1 (curve A). A correction should beintroduced in $\eta(z)$ expression if we consider the physical dimensions of the coils. This is done by a simple integration for the following coil dimensions: 38 cm inner diameter, 42 cm outer diameter and 2 cm thick, ob-

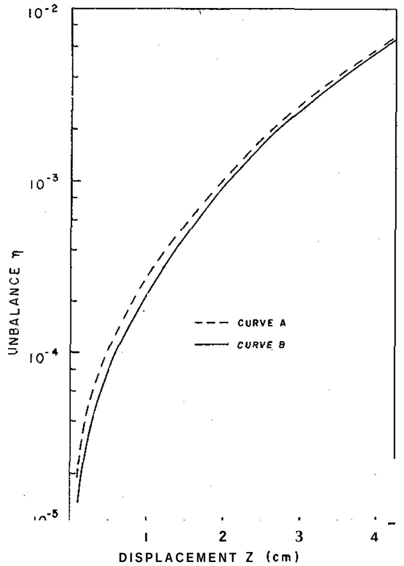

Fig.1 - Unbalance function ($\eta(z)$) versus gradiometers' axial displacement relative to the center of ideal Helmholtz coils (curve A) an with corrections due to the physical dimensions of the coils (curve B).

taining curve B in Fig.1. This curve shows the sensitivity of the method, as a displacement of 1 mm which can easily be detected, implies an unbalance of about 25 ppm. This sensitivity can be improved using Helmholtz coils of greater radius. Values shown in curve B were experimentally confirmed in the region $10^{-2} < \eta < 10^{-3}$ using intentionally unbalanced gradiometers.[6]

In our measurements we use a Helmholtz coil of 20 cm mean radius, excited by an audio frequency sinusoidal generator of 400 Hz to minimize undesired induction effects inherent to higher frequencies. The gradiometer of 2 cm diameter and with 5 turns/section is displaced by a motor coupled to a potentiometer which gives position information. The gradiometer's output is connected to a reasonable input sensitivity amplifier (P.A.R. mod. 124 Lock-in amplifier). The Dc amplifier's output and the potentiometer are connected to a X-Y recorder. As the gradiometer is moved, we obtain the output signal versus position.

A typical curve is shown in Fig. 2. We can see that a minimum is detected at a displacement from the center equal to 3.8 cm. Going back to Fig.1, we obtain the gradiometer's unbalance, which is about 0.5%. A computer generated curve was obtained for such unbalance using the calculated field profile of the Helmholtz coil, which is shown also in Fig. 2. We should emphasize that due to the easy way that currents are induced in the system, even if we attempt to avoid it, there is always a residual signal and so a minimum is found instead of a zero signal point.

One of this method's advantages is that one can have a real time observation if there are any variations in the gradiometer's balance, when it is submitted to different temperature conditions, with gradiometers wound on formers made of different materials. Some of the results we obtained are shown in Fig. 3 where the gradiometers underwent many thermal cyclings (room temperature to liquid nitrogen temperature). We see that with PVC as it underwent these cyclings, there is a degradation in its balancing; tests made with nylon tubes showed that there was also degradation but the balance returned to its original value after some hours at room temperature. As a minimum and constant unbalance is desired, we developed a flux transformer with its loops embedded in an araldite (AV-8, CIBA)[7] former. The balance remained unchanged after thermal cyclings.

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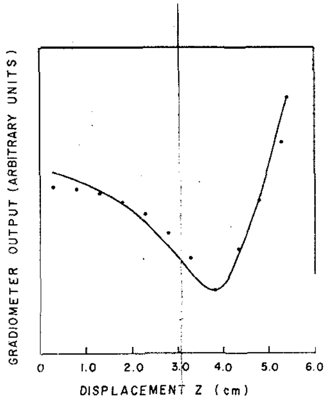

Fig.2 - Gradiometer's output signal versus axial displacement ... computer generated data, ——— experimental data.

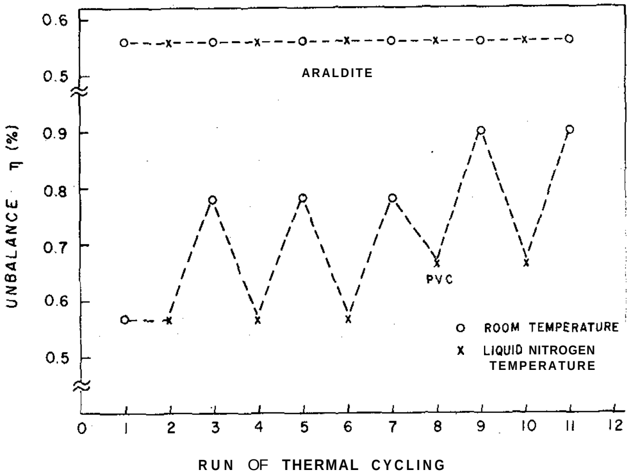

Fig.3 - Thermal cycling balance degradation characteristic of gradiometers wound on formers of PVC and Araldite.

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6. One could doubt whether there is any influence on $\eta(Z)$ due to thefact that $B(Z)$ is not radially constant in a region around the axis. Experimentally we checked this and there was not detected any influence, for a displacement equal to the gradiometer's radius.
7. Manufacturated by Ciba-Geigy Quim. S.A.