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A SIMPLE, BUT SENSITIVE MAGNETOMETER FOR USE IN HIGH MAGNETIC FIELDS

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A Simple magnetometer is described which can detect changes in the magnetic moment of a sample as small as 3×10^{-9} J/T, in applied magnetic fields up to 8 T. The sensitivity for volume-susceptibility, $\Delta\chi = 10^{-8}$ (MKSA), is better than the reported performance of conventional magnetometers.

INTRODUCTION:

In recent years much progress has been made in exploiting the high sensitivity of superconducting quantum interference devices (SQUID's) to measure the magnetic susceptibility of weakly magnetic materials and of very small magnetic samples. [1] However, the use of a SQUID as a detector leads to many complications in the measurement procedure. At the very high level of sensitivity of the SQUID, Much effort is required to control signals due to the residual (temperature-dependent) susceptibility of the construction materials, and to stabilize the applied magnetic field. Therefore, well-established techniques as the Faraday method, or vibrating sample magnetometers are still widely used.

The present investigation was mainly stimulated by the fact that attempts in our laboratory to use a vibrating sample magnetometer at the limits of its sensitivity often failed. Despite all the precautions we had taken, this seemed to be due to spurious signals caused by coupling of the vibrational energy to the pickup coils, or to parts of the cryostat. The problem can be alleviated by a decrease of the frequency of vibrations, but unless the amplitude of the vibration is substantially increased, the sensitivity is lowered, as well. [2]

Therefore, we have chosen a different approach. Our pickup circuit is a low inductance superconducting coil, and this circuit is coupled to a galvanometer which is less sensitive than a SQUID. In a preliminary study, magnetic moments as small as 10^{-8} J/T could be detected. [3] In this paper the performance is reported of a magnetometer constructed around a high field superconductive solenoid and a variable temperature cryostat insert. [4]

DESCRIPTION OF THE MAGNETOMETER:

A shielding current will flow in the superconducting circuit, proportional to the magnetic flux applied to the pickup coils, e.g. the flux due to the static applied magnetic field. The simplest way to separate the part of the signal originating in the sample from the large back-

ground is to vary the position of the sample and to detect the resulting change in the output of the galvanometer. For this purpose, it is of advantage to use a coil with gradiometer symmetry. This reduces the signal caused by the applied magnetic field. The distance of the two oppositely wound coils is chosen so that the flux sensed varies linearly with the position of the sample, near the center of the coils. In this case, the sensitivity is not proportional to the frequency of vibration, but only to the amplitude of the modulation of the position of the sample, and phase sensitive detection can be used at a suitably low frequency. Our pickup coil consisted of two one-layer coils, 30 turns each, on a 17.6 mm diameter coil-form which allowed insertion of the tail of a continuous flow cryostat for regulation of the sample temperature from 2.5 K to 300 K.

The coils are coupled to a flux-gated galvanometer [5] consisting of two small ringcores

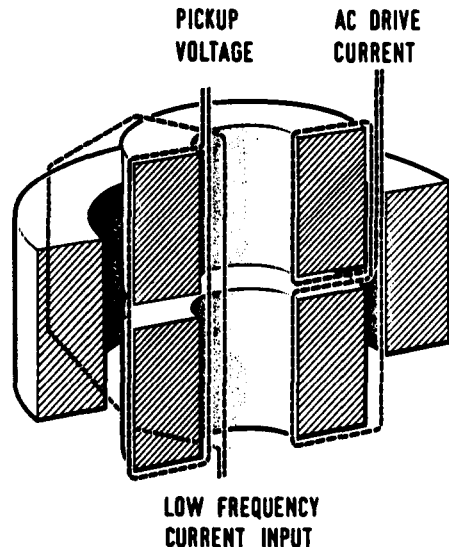


Figure 1: The ringcores of the flux-gated galvanometer and the connected circuitry.

with several layers of 0.006 mm thick high permeability tape. [6] The arrangement of the windings is illustrated in figure 1. The two ringcores are driven well into saturation by a 7.5 kHz current with 180° difference in phase. The amplitude of the second harmonic contribution to the induction voltage measured across the two ringcores is proportional to the current flowing in the low frequency input windings. Note from figure 1 that these have been wound around an extra ringcore. [6] As the flux transformer represents a large load to the galvanometer, currents are induced in this circuit that will tend to degrade the performance of the detector. Great care was taken to match the flux-gated galvanometer to the flux transformer, and it was found that inductive shielding of the pickup circuit from the galvanometer proper is most effective. Depending on the self-inductance of the pickup coil and on the amount of magnetic material in the shielding ringcore, an optimum can be found for the number of turns that should couple the signal to the galvanometer. In our case this number was as low as 4. Then, the effective inductance of the flux transformer is mainly due to the self-inductance of the pickup coils and is approximately 35 μH . Therefore, the magnetic shielding may be increased, until the effective inductance of the coupling turns is matched to the inductance of the pickup coils.

Samples can be inserted from the top of the cryostat. A very simple magnetic driving head [7] is activated from a 2 Hz oscillator and provides a modulation of the sample position with a maximum stroke of 5 mm, and a stability better than 1 part in 10^3 .

In figure 2 a schematic diagram is given of the magnetometer system. The shielding currents flowing in the flux transformer are detected by the flux-gated galvanometer. The induction voltage is fed to a phase sensitive detector (P.S.D.) which operates at the second harmonic of the frequency of the drive current. The output is fed to a low-pass filter and a feedback circuit to compensate the dc current due to the background signal and the drift therein. The same output is, furthermore, demodulated at 2 Hz and gives a signal which is proportional to the magnetic moment of the sample. The magnetometer can easily detect changes in magnetic moment of 3×10^{-9} J/T with an integration time of 30 s, provided that the 8 T superconductive magnet is operated in its persistent mode. Samples can be accommodated in a 9 mm diameter sample space. The sensitivity for volume-susceptibility achieved with the present system is an order of magnitude better than with vibrating sample magnetometers. [8]

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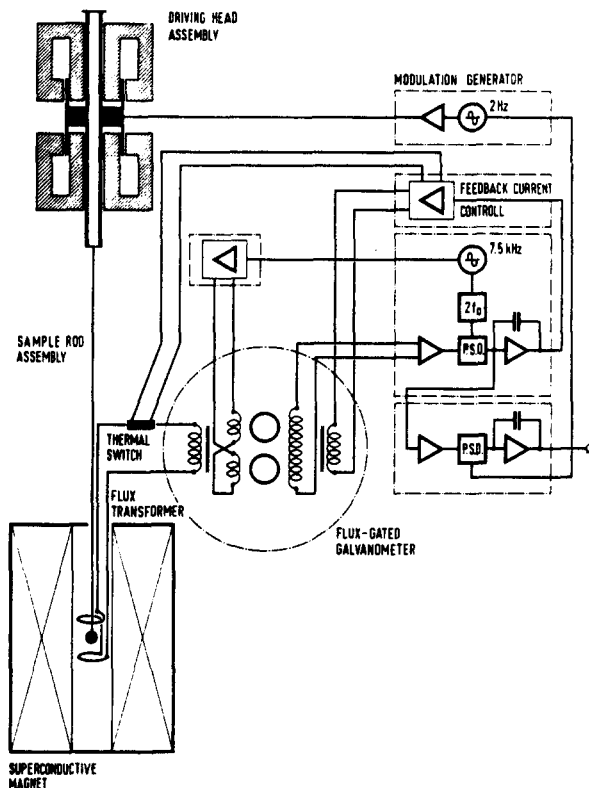


Figure 2: A schematic diagram of the magnetometer showing the superconducting pickup circuit, the driving head for the modulation of the position of the sample, the flux-gated galvanometer, and the associated electronics.

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