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CERAMIC HTSC-SQUID BASED GALVANOMETER

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Гальванометр на основе ВТСП–Сквида

Разработан функционирующий при температуре жидкого азота высокочувствительный гальванометр на основе ВТСП–Сквида, который предназначен для измерений постоянного и низкочастотного переменного тока. Чувствительность гальванометра на постоянном токе составила примерно 0.5 нА при внутреннем сопротивлении порядка 20 Ом. Энергетическое разрешение в области белого шума $2\cdot10^{-21}$ Дж/Гц.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

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Uchaikin S.V., Hiep L.H. E13-92-72

Ceramic HTSC–SQUID Based Galvanometer

A high sensitive galvanometer operating at liquid nitrogen temperature for direct and low-frequency current measurements was developed on the basis of a HTSC–SQUID. The direct current sensitivity of the galvanometer is approximately 0.5 nA at an internal resistance of about 20 Ω. Its energy resolution in the white noise region is $2\cdot10^{-21}$ J/Hz.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

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1. INTRODUCTION

Low-temperature dc-SQUIDs operating at liquid helium temperature demonstrate the highest sensitivity to magnetic field. Their creation became possible due to superconductive thin-film technology application. This technology permits one to build devices with Josephson contacts having the size of about the coherence length in a superconductor, i.e. about a thousand of Angstroms.

The situation is different with high-temperature superconductors where the coherence length is of the order of 10 Angstroms. It is not easy to build reliable contacts of a size even using the best accomplished thin film. However, intergrain contacts in HTSC ceramics have the size of the order of the coherence length [1] which fact makes it an easier task the preparation of high-temperature SQUIDs from them [2].

HTSC ceramic SQUIDs operating at liquid nitrogen temperature are the high sensitive and reliable enough devices. They are actually used for high-sensitive magnetic measurements, for instance, in taking magnetic cardiograms [3,4]. Thin-film SQUIDs on intergrain contacts have also been developed [5] but the problems of their applications have not been resolved yet.

The main problems one encounters with in ceramic HTSC-SQUIDs applications are the measured magnetic flux-to-SQUID transmission and the external magnetic noise suppression. A conventional method for transmission and effective spatial filtering, employed in low-temperature SQUID-based devices consists in the use of a superconducting flux transformer with a gradiometer and requires a thin superconducting wire which would not introduce excess noises into the measurement system. No such HTSC wire has been produced yet. Spatial filtration attained through gradiometric connection of two HTSC-magnetometers as described in [4] demands high quality electronics to be used and, thus, can be implemented only in places with a low industrial noise level.

At the same time some of HTSC-SQUIDs applications have no such problems. In electric measurements HTSC-SQUIDs can help achieve an energy resolution of up to 10^{-28}J/Hz [6], if they are screened from external magnetic fields and a signal to be measured goes via coils made of usual wire. The present work reports on the use of an HTSC-SQUID for measuring direct and low-frequency alternating currents induced by external sources.

2. SUPERCONDUCTIVE GALVANOMETERS

Low-temperature SQUID-based galvanometers have long been used for high sensitive measurements [7]. Due to high sensitivity and small internal resistance these devices were used for measurements, that were impossible to be done with other methods. For example, in one of the pioneering works in the field the volt-current characteristics of SNS-contacts were taken using a SLUG having the 10^{-9} A/Hz$^{1/2}$ sensitivity and practically zero internal resistance [8]. A matching transformer for input circuits optimization permits measuring currents at the sensitivity level of up to $8\cdot10^{-15}$A/Hz$^{1/2}$ [9].

In the "white" region the HTSC-SQUID noise is comparable with that of low-temperature SQUIDs. Thus, for alternating current measurements in white noise regions HTSC-SQUID galvanometers must have characteristics comparable with those of low-temperature SQUID-based systems without matching devices. In direct current measurements some sensitivity reduction can be observed due to a higher 1/f noise.

3. SQUID FABRICATION

The SQUID was made from a pellet of polycrystalline $Y_1Ba_2Cu_3O_{7-x}$ ceramics, synthesized following a standard procedure described in [10]. Its critical current is over 100 A/cm^2 and as a consequence the 1/f noise level is relatively low. In the 7x5x2.5 mm^3 pellet two 1mm diameter holes were drilled and a thin saw-cut was made between them. About the middle of the cut a bridge, of a few micrometers width was formed by a special knife using a microscope. The critical current of this bridge amounted to tens of microamperes and so the main parameter of the SQUID used in the galvanometer was

$$\beta=2\pi L_s I_s/\phi_0\simeq10, \qquad (1)$$

where L_s is the tank circuit inductance, I_c is the bridge critical current, ϕ_0 is the magnetic flux quantum.

4. SQUID SCREENING

It is important to shield a SQUID-based galvanometer. Double shielding is most convenient. First, external fields are suppressed with the help of a ferromagnetic screen. Then, a superconductive screen is placed inside it to provide for the optimum regime of superconductive shield cooling and to reduce the probability of magnetic flux capture by the shield at the transition to the superconducting state. For preliminary shielding the four-layer permalloy magnetic screen was used, that decreased the external magnetic field down to 10 nT. It is convenient to have the superconductive shield in the shape of cylinder with a bottom, 150 mm of height, the inner diameter of 15 mm and about 3 mm thick walls . Such a cylinder can be made from various types of

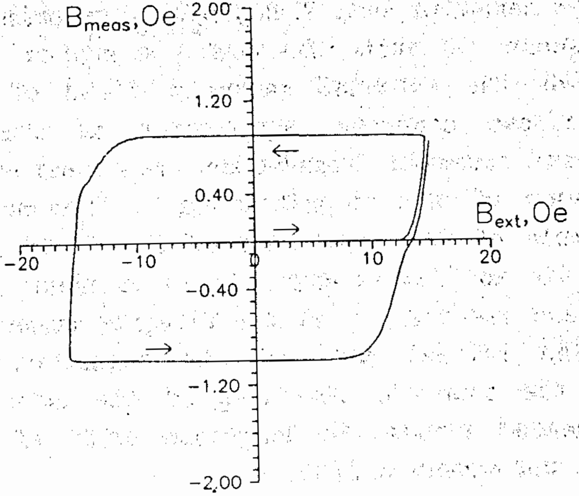

Fig. 1. The dependence of the magnetic inductance inside the shield B_{meas} versus the external magnetic field B_{ext}.

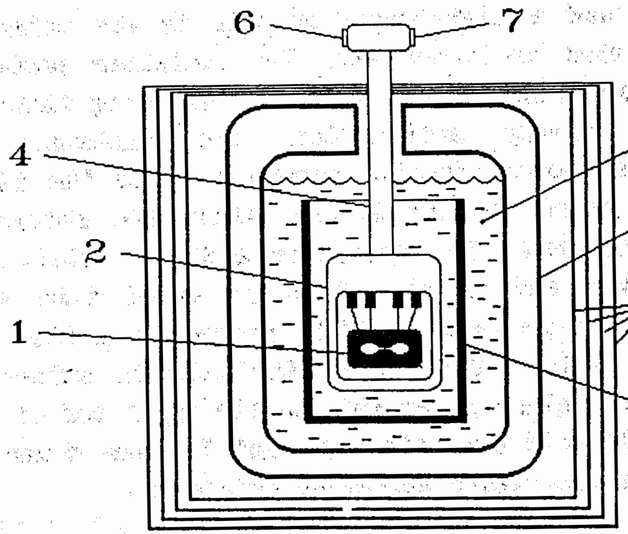

Fig.2. The system lay-out. 1.HTSC-SQUID; 2.sealed container; 3.HTSC-shield; 4. tube-holder; 5. cryostat; 6. rf-connector; 8. μ-metal shield.

superconductive ceramics but, $Y_1Ba_2Cu_3O_{7-\delta}$ ceramics with 10% Ag addition seems to suit the best. A screen from this ceramics shields the external magnetic field of up to 10 Oersted and allows complete suppression of the external noise. To prevent ceramics degradation the screen was covered with a thin layer of varnish protecting it from moisture. In fig.1 the example of the dependence of the field inside the screen versus the applied external field is shown. The field measurements were carried out with a fluxgate magnetometer. In this figure the initial part of the magnetization curve evidences for the complete shielding of the external field within experimental errors. No long-time drift of the field in this shield was observed [11].

5. SYSTEM DESIGN

The system design is illustrated in fig.2. The SQUID (1) with a measuring and a high-frequency coil in its holes is placed into a sealed container (2). The container protects the SQUID form thermo-shocks and moisture intruding that are possible during device attenuation. The container is surrounded by the superconducting screen (3) and the SQUID is placed to be nearer to its bottom, where the shielding conditions are the best. The container and the shield are fixed to the lower end of the stainless steel tube (4). Inside the tube there are a high frequency cable and connection wires. This lower end of the tube is submerged into a nitrogen fiberglass dewar (5). On the upper end of the tube there are electric connectors (6 and 7). The dewar is enveloped with the four-layer permalloy shield (8).

6. FUNCTIONAL DIAGRAM OF THE SYSTEM

The functional diagram of the system is shown in fig.3.

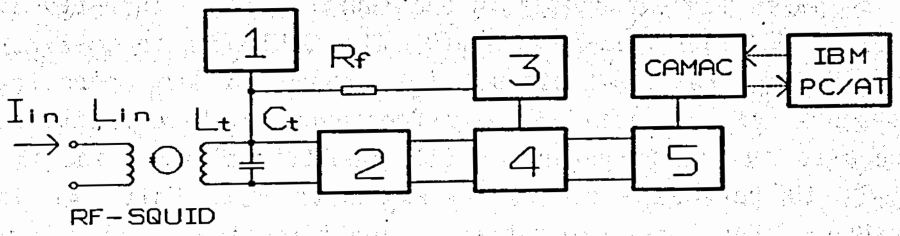

Fig.3. The functional diagram of the system. 1 - 20 MHZ generator; 2 - rf-amplifier; 3,4 - low-frequency units; 5 - ADC.

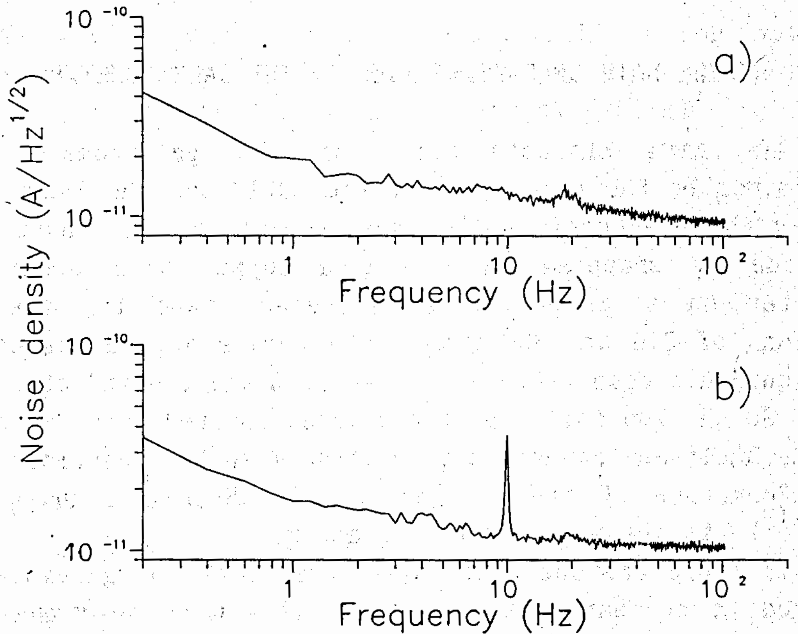

Fig.4. The spectral noise density of the galvanometer reduced to current units:

a) without external signal:

B) with external signal of 10Hz frequency and 70 pA amplitude.

The measured current passes to the input coil L_{in} inductively coupled with the two-hole SQUID. The SQUID is inductively coupled with the tank circuit $L_K C_K$ tuned to the operating frequency of 20 MHz. A high-frequency bias current is generated by the rf-generator (1). Amplification of the rf-signal is performed by the rf-amplifier (2). Unit (4) is designed for transformation, amplification and low-temperature filtration of the SQUID signal. Unit (3) generates a low-frequency bias current. This current mixed with the backfeed signal through the resistor R_{fb} passes to the $L_K C_K$ circuit. The input unit (4) signal is transformed into a digital form by the ADC (5).

7. THE MAIN CHARACTERISTICS OF THE GALVANOMETER

The main characteristics of the galvanometer are determined by the parameters of the SQUID and the input coil and by the electronic units characteristics. The input coil is made by wrapping an insulated copper wire 0.02mm in diameter on a glass 0.3 mm diameter frame to have two sections of 810 and 420 wraps. The coil's active resistance at liquid nitrogen temperature was 16 Ω and the inductance of about 90 μH. Two coil's sections were inserted into two holes in the SQUID and connected in series. Then the coefficient of transformation of the galvanometer is 30 nA/ϕ_0, where $\phi_0 = 2\cdot 10^{-15}$Wb is the magnetic flux quantum.

In fig.4 the spectral noise density of the galvanometer reduced to current units is shown. It can be seen that the spectral noise density in current units in the white noise region is approximately 10 pA/Hz$^{1/2}$. Its sensitivity to lower frequencies and to direct current is limited by a higher 1/f noise. In the direct current measurements for 10 seconds the sensitivity can be estimated to be at the level of 0.5 nA.

Reported data allow one to estimate the galvanometer energy sensitivity ε_g in the white noise region to be:

$$\varepsilon_g = S_i^2 \cdot R_K = (10\cdot 10^{-12})^2 \cdot 16 \simeq 2\cdot 10^{-21}\,\text{J/Hz}. \qquad (2)$$

8. CONCLUSIONS

One can expect a considerable improvement of the galvanometer's sensitivity using a matching superconducting current transformer [9]. Actually, until a low-noise HTSC-wire hasn't been created one could attempt to fabricate such a transformer using film technology.

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