Краткие сообщения ОИЯИ №4 [30]-88 *JINR Rapid Communications No.4 [30]-88*
УДК 538.945

SQUID OPERATING AT LIQUID NITROGEN TEMPERATURES

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A two-hole rf-squid fabricated from high-temperature superconducting yttrium-based ceramic is described. Squid operates at liquid nitrogen temperatures and demonstrates all principal features of rf-squid signal. At high frequency the noise level of the high-T_c squid is only three times as much as the corresponding level of the commercial helium rf-squid. The 1/f-noises begin from approximately 100 Hz so that at low frequencies the high-T_c squid sensitivity is by 1.5 order less than the helium squid sensitivity.

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

Сквид, работающий при азотной температуре

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Описан двухиндуктивный радиочастотный сквид, изготовленный из высокотемпературной керамики $Y_1Ba_2Cu_3O_7$. Сквид функционирует при температуре жидкого азота, проявляя все основные особенности сигнальной характеристики, присущие радиочастотному сквиду. Уровень шумов высокотемпературного сквида в диапазоне высоких частот примерно в три раза превышает соответствующий уровень низкотемпературного сквида. Шумы типа 1/f начинаются примерно от 100 Гц так, что на низких частотах чувствительность высокотемпературного сквида примерно на полтора порядка хуже чувствительности низкотемпературного сквида.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

1. Introduction

The conventional low-temperature squids are the most sensitive devices used for precision measurement of magnetic fields, magnetic field gradients, voltage and other parameters that can be transformed into magnetic ones. However, the wide practical use of such squid is limited because its operation requires liquid helium.

The high-temperature superconductors (HTS) discovery has promised to make a revolution in the measurement technique by widespread application of high sensitive squid-based devices operating at liquid nitrogen temperatures. Therefore, the efforts in creating the HTS squids were made at several laboratories of many countries. The first success in this area was the development of the so-called bulk-squid [1-4] that is a lump of HTS ceramic with rf-coil wrapped round it. The magnetic field generated by the coil destroys a number of weak links between the superconductor grains which causes the reaction similar to response of conventional rf-squid, though it is accompanied by very large noises. These noises are at the level of 10^{-9} T/Hz$^{1/2}$ that is some four orders more than low-temperature squid noises which makes this squid interesting only as a demonstration model.

The more sensitive low-temperature squids are the thin-film dc-squids[5]. Nevertheless the high-temperature thin-film squids are not created up to date. In spite of the efforts made in this area the best thin-film squids operate below 60 K with the same sensitivity as the bulk-squids[6].

To date the most widely applied are low-temperature rf-squids that combine high sensitivity (up to 10^{-13} T/Hz$^{1/2}$ in the white noise region) with reliability and ease of operation. At present there are created the HTS rf-squids operating at 78 K with sensitivity level of 10^{-11} - 10^{-12} T/Hz$^{1/2}$ [7,8].

The purpose of this paper is to describe the HTS rf-squid with sensitivity approximating to 10^{-13} T/Hz$^{1/2}$.

2. Squid Preparation

This squid was made from $Y_1Ba_2Cu_3O_7$ ceramic obtained by standard proceedings through solid-state reaction method[9]. Temperature dependence of the ceramic sample resistance measured by usual four-contact method have shown that it becomes fully superconductive at temperature about 90 K (fig. 1).

Before the last annealing this ceramic powder was pressed into pellets. In these pellets for squid preparation there were drilled holes a little more than 1 mm in diameter and there was filed a weak-junction of about 10 microns thick. In this way there were made both one-hole and two-hole squids. Approximately every fifth squid was operating well.

The squid parameters were measured on standard equipment designed for conventional low-T_c squids and fabricated by the Experimental Physics Facilities Division (EPFD) of our Institute [10]. The measurements were performed in a standard transport liquid nitrogen dewar. For elevated temperature mesurement the squid attached at the

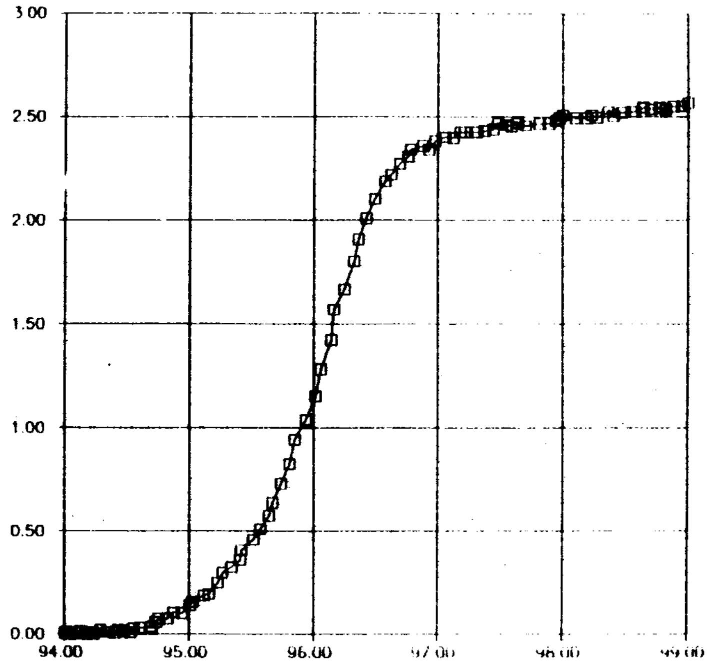

Fig. 1. Temperature dependence of yttrium-based ceramic resistance. X-axis – temperature, K. Y-axis – resistance, arbitrary units.

measurement rod was just lifted to the dewar's neck. In order to protect squid from moisture during the measurement it was placed in a sealed valve. All these proceedings have provided ceramic squid operation for several cooling-heating cycles. There was observed some degradation of the contact critical current after cycling, but such squids have lasted for 10 cycles and more. Some of the squids have operated well only at elevated temperature, its critical current at nitrogen temperature being too large.

In order to suppress the external noise influence squid in nitrogen dewar was screened by mu-metall magnetic shield that reduced earth magnetic field to 10^{-8} T and the external noise to a low enough level. However, it was observed earlier that the magnetic field within the shield had a slow drift and fluctuated, so the squid sensitivity measured in such conditions could be found lower influenced by these fluctuations.

3. Results

In order to test the squid there were measured its voltage-current characteristics first. There was as usual modulated squid pumping amplitude which gave a standard knee-picture well known for low-temperature rf-squids and permitting to optimise with the "naked eye" squid-circuit coupling. For example, fig. 2 shows 2-hole ceramic squid voltage-current characteristic received at liquid nitrogen temperature. The squid applied magnetic field modulation at optimal pumping gave the conventional "triangular pattern". This triangular signal with about $1.6 \cdot 10^{-9}$ T period and amplitude about 10 μV received in a bandwidth 1kHz at first three plateaus in a 2-hole ceramic squid at 78 K is shown in fig. 3. These measurements have shown large portion of 1/f — noises in the spectrum originating at much higher frequencies than 1/f-noises of low-temperature rf-squid. Figure 4 shows Fourier-spectrum for 2-hole ceramic rf-squid noises received at liquid nitrogen temperature (upper curve). At the same figure there is shown for comparison Fourier-spectrum of standard (made in EPFD of JINR) 2-hole helium-temperature rf-squid (lower curve). The noise measurements were carried out under different conditions: niobium squid was screened by perfect superconducting shield and ceramic one screened by mu-metal shield which could affect the measurements.

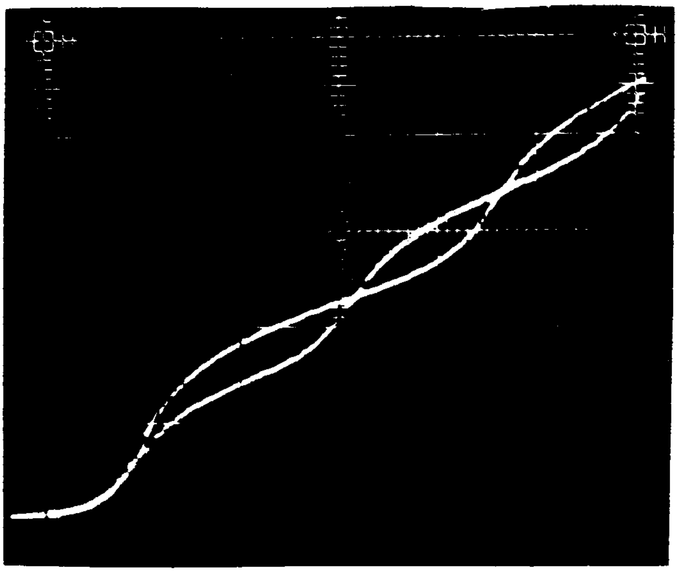

Fig. 2. Voltage-current characteristic of ceramic 2-hole rf-squid, operating at 78 K. X-axis – squid pumping amplitude. Y-axis – squid signal amplitude.

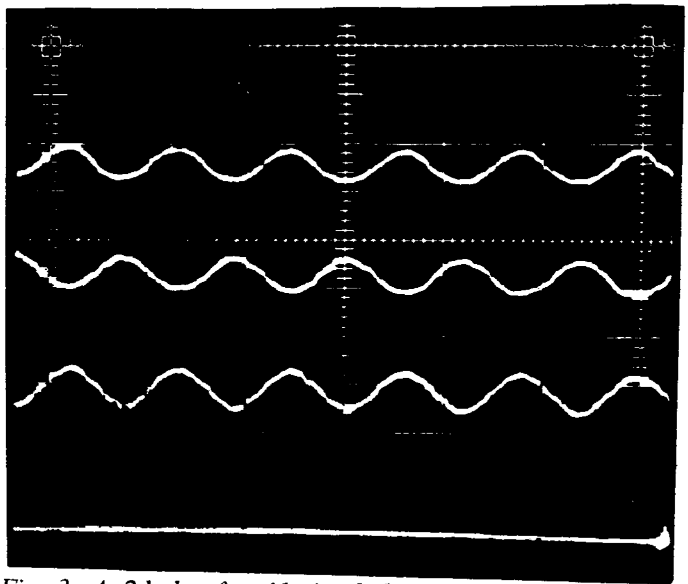

Fig. 3. A 2-hole rf-squid signal dependence on applied external magnetic field, recieved in the first 3 plateaus. Operating temperature – 78 K. Bandwith – 1KHz. X-axis – magnetic field, 3.1 nT/div. Y-axis – squid signal, 20 μV/div.

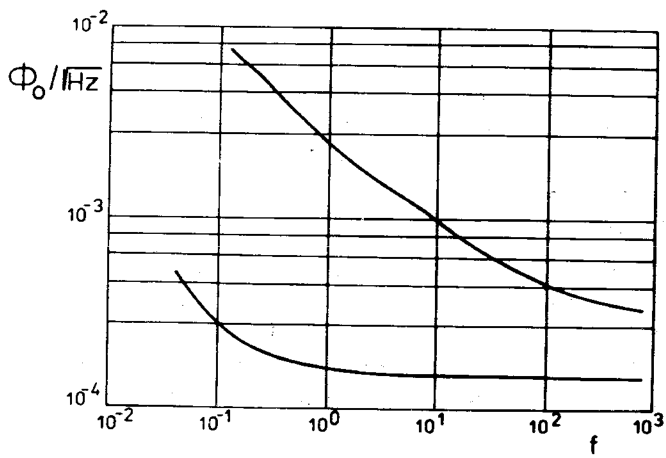

Fig. 4. Fourier-spectrum of ceramic 2-hole rf-squid at 78 K (upper curve) and of standard low-temperature 2-hole rf-squid at 4 K (lower curve). X-axis – frequency, Hz. Y-axis – noise density, $\phi_0/Hz^{1/2}$.

4. Conclusions

The ceramic squid 1/f-noises are so large because the weak-link area has probably a number of intergrain contacts switching quite at random alike the bulk-squid.

The fact that at high frequencies the ceramic squid noise level at liquid nitrogen temperatures is about $3 \cdot 10^{-4}$ flux quantum (about $5 \cdot 10^{-13}$ T/Hz$^{1/2}$) which is about rf niobium squid noise level at liquid helium temperature is not surprising, because it is well known that the white noise level of niobium squid (about 10^{-4} flux quantum) is defined by its preamplifier.

It should be noted in conclusion that despite a lower sensitivity of the described squid in comparison to its low-temperature analogue, especially at low frequencies, its development has demonstrated that the extremely sensitive HTS squid will be created in the near future. On the other hand the reported squid can be applied because of its rather high sensitivity and ease of operation, for instance, in field trial for earth magnetic field anomaly measurements. Furthermore, it seems that making use of method described above one can develope a 2-hole squid with unequal holes. Such squid can be used to handle several problems in solid-state physics and probably in magnetic cardiography.

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Received on April 26, 1988.