Low Temperature Physics/Fizika Nizkikh Temperatur, 2020, v. 46, No. 4, pp. 509–515

Transport and magnetic properties of a superconducting closed loop containing a thin-film quantum interferometer

S.I. Bondarenko, V.P. Koverya, and A.V. Krevsun

B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, 47 Nauky Ave., Kharkiv 61103, Ukraine
E-mail: bondarenko@ilt.kharkov.ua

Received October 29, 2019, published online February 28, 2020

The current in a superconducting closed loop containing a thin-film interferometer with two point contacts (two Josephson-type weak links) has been measured as a function of the transport current and external magnetic field applied to interferometer. The differences between the transport and magnetic dependences of the system under study and similar characteristics for a superconducting closed loop containing an interferometer in the form of a single pressed point contact are discussed.

Keywords: superconducting quantum interferometer, superconducting closed loop with an interferometer, critical current, magnetic field, magnetic flux quantization, diamagnetic current, transport current.

1. Introduction

The electrical and magnetic properties of superconducting double connected (in the form of a closed loop) and multi-connected structures for a long time have been the subject of the physical research [1–4]. A new stage in the study of superconducting circuits arose due to the creation of a superconducting quantum interferometer (SQI), later called a SQUID [5]. SQI along with superconducting magnets are now the most widely used among other types of superconducting devices. The processes occurring in SQI under action of the current and the magnetic field can be attributed to one of the brightest manifestations of quantum phenomena on a macroscopic scale. The study of the properties of different types of SQI and their applications is still of current interest. For instance, the transport and magnetic properties of a superconducting closed loop structure consisting of an asymmetric SQI (formed by one pressed point contact at A position) and its superconducting shunt inductance L were examined in [6–8] (see Fig. 1). In these studies, the niobium-niobium (Nb–Nb) pressed point contact (PC) at the point A had the critical current I_c of up to several tens of milliamps and was used as an asymmetric SQI (with a large asymmetry of critical currents for weak links). Quantum transport and magnetic properties are shown in Figs. 1(b),(c): the current I_1 in the superconducting closed-loop "SQI+L" as a function of the transport current I and the external magnetic field H. The magnetic

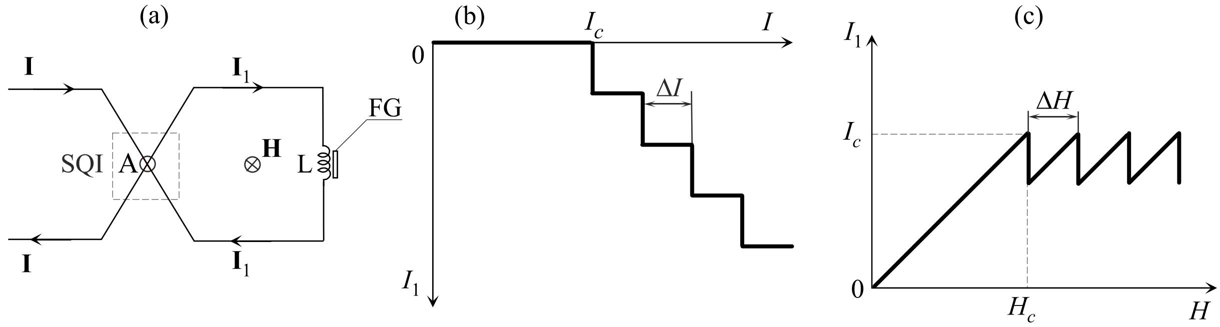

Fig. 1. (a) Scheme of a superconducting closed loop consisting of an asymmetric SQI (formed by one pressed point contact at A position) and its superconducting shunt inductance L; (b) the dependence of the current I_1 in the loop on the transport current I. For $I > I_c$ one can see the characteristic periodic current steps having a period ΔI; (c) the dependence of the diamagnetic current I_1 on the external magnetic field H applied only to the loop. For $H > H_c$ one can see the characteristic periodic current jumps having a period ΔH.

field **H** is perpendicular to the plane of the superconducting loop with shunt inductance L, while the field effect on the SQI is prevented.

In the asymmetric SQI formed by one pressed point contact, it is difficult to determine accurately the SQI quantization area and its own effective inductance L_0. In turn, this does not allow to construct a complete theory of processes in such structures. In order to solve these problems, we developed a design of a low-inductance thin-film interferometer (or SQI) with two Josephson-type weak links [9]. This design of the quantum interferometer enables accurate determination of the SQI quantization size and calculation of its inductance L_0.

The aim of this work is to study the quantum transport and magnetic properties of a superconducting closed-loop "SQI+L" containing a thin-film interferometer having two Josephson-type weak links and superconducting shunt inductance L.

2. Experiment

The scheme for incorporating a thin-film interferometer (SQI) with two Josephson-type weak links (1) and (2) in a superconducting closed loop with an inductance of $L = 10^{-6}$ H is shown in the Fig. 2(a). This inductance L actually shunts the SQI with its own very small inductance $L_0 = 10^{-13}$ H (see calculation below). The transport current I through the SQI, the current I_1 in the loop and the direction of supply to the SQI of an external magnetic field H perpendicular to the plane of the SQI loop are indicated in the scheme. A structural scheme of a thin-film SQI with two weak links formed by the method of micro-piercing the Nb_2O_5 insulator layer with a thickness of $d = 30$ nm [9] between InSn and Nb thin films is shown in Fig. 2(b) (in cross-section). The location of two weak links shown by crosses (1) and (2) is visible on top view of the thin-film interferometer in Fig. 2(c). The distance between two weak links is $l = 0.2$ mm. The width w of the upper InSn film is 1 mm. Figures 2(b),(c) also show the inputs of the transport current I to the thin-film interferometer and its connections with the shunt inductance L. Figure 2(d) shows the arrangement of the loop elements on the cryogenic insert: a thin-film SQI, a superconducting shunt inductance L (actually determining the inductance 10^{-6} H), a magnetic field detector inside of the shunt inductance in the form of a flux-gate magnetometer sensor (FG), a copper coil in the form of a solenoid to create a magnetic field H in the SQI and the scheme of the scattering magnetic field force lines of the solenoid acting on the loop.

The current I_1 in the loop is measured in a non-contact manner using a FG sensor. The sensitivity of the flux-gate magnetometer was 10^{-5} Oe. The current in the superconducting coil located on the FG detector and being part of the loop was calculated using the relation

$$I_1\,(\text{A}) = 0.14\,H\,(\text{Oe}). \qquad (1)$$

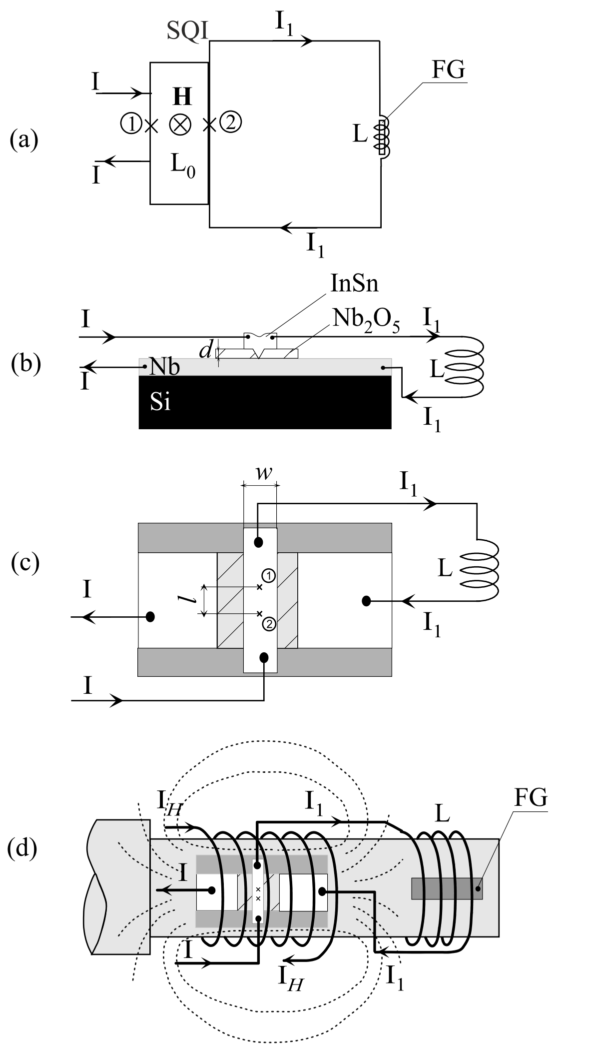

Fig. 2. (a) Electrical scheme of the superconducting closed-loop "SQI+L" containing a thin-film interferometer with two point contacts (1) and (2) (Josephson-type weak links) and superconducting shunt inductance L; (b) side view of the thin-film interferometer (cross-section) with a transport current leads included in the circuit with shunt inductance L; (c) top view of the thin-film interferometer, (d) image of the cryogenic inset design used in experiments with "SQI+L" loop.

The coefficient in the formula (1) was determined using a calibration experiment for a specific cylindrical coil of 10 turns with a diameter of 7 mm.

The magnetic field H created by the copper solenoid with the current I_H in the region of the SQI location was determined using the relationship

$$H\,(\text{Oe}) = 82\,I_H\,(\text{A}). \qquad (2)$$

The coefficient $k = 82$ was determined using the FM-20 laboratory flux-gate magnetometer when installing its sensor in the center of the solenoid with the known current I_H. The solenoid had an internal diameter of 9 mm and a length of 30 mm.

The previously obtained formulas [9] for the period of magnetic field quantization ΔH and inductance L_0 of the thin-film SQI (before it is included in the loop) allow us to calculate these quantities:

$$\Delta H = \Phi_0 / [\mu_0\, l\, (d + \lambda_{\text{Nb}} + \lambda_{\text{InSn}})], \quad (3)$$

where $\mu_0 = 4\pi\cdot 10^{-7}$ H/m, $\lambda_{\text{Nb}} + \lambda_{\text{InSn}} = 1.7\cdot 10^{-7}$ m is the total field penetration depth into the films of niobium and indium-tin alloy, l is the distance between the two point contacts (1) and (2) of the SQI. With our parameters of the thin-film SQI, we obtain the value $\Delta H \approx 0.7$ Oe. Accordingly, for L_0, we have

$$L_0 \approx \Phi_0\, [1/(10w) + 2/\pi l] / \Delta H. \quad (4)$$

For $\Delta H \approx 0.7$ Oe, after substituting the values of the SQI parameters, we obtain $L_0 \approx 10^{-13}$ H.

The transport current I and the copper solenoid current I_H were created by using two different automatic current sources. All measurements were performed with the superconducting closed loop located in a cryostat with liquid helium at the temperature of 4.2 K. The cryostat was protected from the external electromagnetic field (noise signal) using a two-layer permalloy shield.

3. Measurement results and discussion

The dependence of the current I_1 in the superconducting closed loop as a function of the transport current I is shown in Fig. 3.

The dependence $I_1(I)$ has been obtained by increasing the transport current I from 0 up to 5 mA. The kink in the dependence corresponds to the achievement by the transport current I of a critical value of $I_c \approx 3$ mA. Up to this value, the transport current flows almost completely only through the SQI, since its inductance L_0 is several orders of magnitude lower than the shunt inductance L. For $I > I_c$, a transport current higher than I_c passes into a superconducting shunt inductance L and changes linearly. In this case, the current I_1 changes without the appearance of any

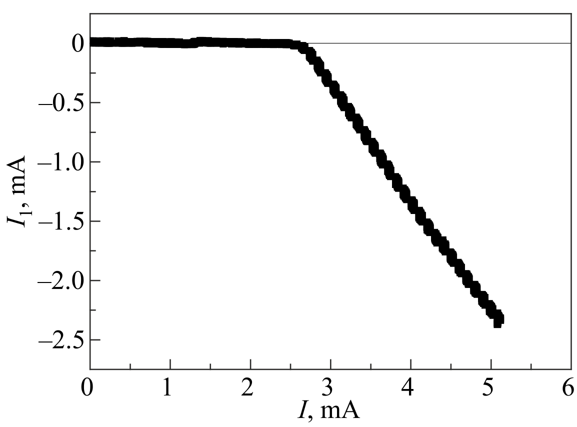

Fig. 3. The dependence of the current I_1 in the "SQI+L" loop on the transport current I.

features such as current steps detected earlier [6,7]. The form of the dependence $I_1(I)$ can be explained by the fact that this SQI has a small critical current with a small inductance. Indeed, in accordance with our calculations in [8], the condition for the formation of a flux quantum (Φ_0), in the loop of an asymmetric SQI using the transport current through it, is the fulfillment of a certain relationship between the critical currents (I_{c1} and I_{c2}) of its weak links:

$$|I_{c1} - I_{c2}|\, L_0 \geq \Phi_0 / 2. \quad (5)$$

With the opposite ratio, quantization of the magnetic flux in the SQI does not occur when the transport current reaches a critical value

$$I = I_c = I_{c1} + I_{c2}. \quad (6)$$

The transport current I exceeding the critical current I_c of the SQI flows through the shunt inductance L, forming a current I_1. Correspondingly, the $I_1(I)$ dependence does not have step features characteristic of such loops with SQIs, which have large critical currents of weak links and large asymmetry of their critical currents [6–8] (Fig. 1(a)).

An assessment (see below) of the weak links currents and their difference showed that relation (5) is not satisfied. It would seem that the answer has been obtained and this is the final solution to the question of the reason for the absence of steps in the dependence $I_1(I)$. But attention was drawn to the fact that even with an extremely high degree of asymmetry ($\alpha = 1$), achieving relation (5) is impossible for our SQI. This suggested that condition (5) is necessary, but not sufficient. It needs to be supplemented by the condition for the critical current value of the SQI:

$$I_c\, L_0 = (I_{c1} + I_{c2})\, L_0 > \Phi_0. \quad (7)$$

In the following part of this work the influence of external magnetic field H on the thin-film interferometer, which is shunted by inductance L, is investigated. In Fig. 4 the dependence of the diamagnetic current I_1 in the superconducting closed loop on the magnetic field H created by the copper solenoid at the location of the thin-film interferometer is shown. It should be noted the transport current for this experiment is absent ($I = 0$).

Some features of the obtained dependence are qualitatively similar, and some differ from the $I_1(H)$ dependence for the superconducting closed loop containing a highly asymmetric SQI with one pressed point contact (see Fig. 1(c)) [6,7], when an external field acts on the entire loop but does not directly affect the SQI. Qualitative similarity is expressed to the presence of the periodic changes of the current I_1. In this case, two main differences are visible. First, in Fig. 4 the periodic changes of I_1 exist, starting from field values close to zero and are preserved as I_1 increases with increasing field. Secondly, the form of these changes differs from the form of current modulation I_1 in Fig. 1(c), for which a spasmodic periodic current decreasing by one and the same value with increasing current I_1 is

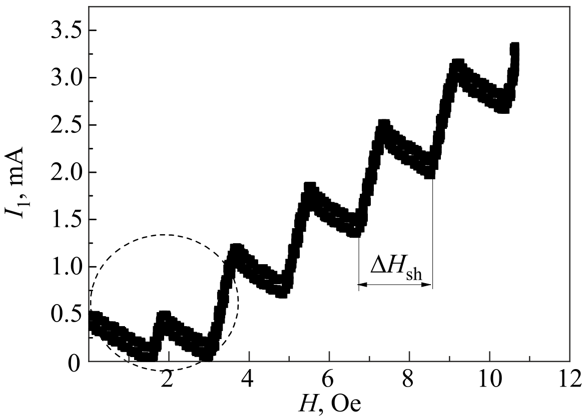

Fig. 4. The dependence of the diamagnetic current I_1 in the "SQI+L" loop on the magnetic field H created by the copper solenoid at the location of the thin-film interferometer. The main period $\Delta H_{sh} \approx 2$ Oe of the periodic current I_1 jumps is shown. The circle indicates the anomalous part of the $I_1(H)$ dependence.

typical. The position of the current jumps relative to the vertical axis I_1 does not change with increasing field.

Turning to the explanation of the experimental dependence $I_1(H)$, it is necessary to discuss the nature of the appearance of current I_1 and its periodic features under the action of the external magnetic field H. The magnetic field H of the copper solenoid acts not only on the SQI, but also on other parts of the loop (see Fig. 2(d)). If they are too far away from the solenoid, a change in its field could not generate a noticeable diamagnetic current I_1 in a closed loop. In the used loop design (with inductance $L = 10^{-6}$ H), the distance of its parts from the solenoid is several centimeters and a change in its scattering magnetic field causes the appearance of a diamagnetic current I_1 in the loop.

Measurement of the magnitude of the periods of features on the $I_1(H)$ dependence (see for more details below) shows that they indicate quantum transitions in the SQI caused by quantization in it of the magnetic flux generated by the solenoid field H. For a similar reason, quantum transitions are observed when used strongly asymmetric SQI in the form of PC in a loop with a shunt inductance L (Fig. 1(c)). The reason for creating a magnetic flux in a highly asymmetric SQI is that it is created by a diamagnetic current excited in the loop by an external magnetic field and flowing through the asymmetric SQI. In this case, by analogy with an asymmetric single-contact SQI, the following relationship between the parameters of the SQI should be fulfilled [10]:

$$2\pi\, I_c\, L_0 / \Phi_0 \geq 1, \qquad (8)$$

where, in this case, I_c is the critical current of the point contact of such SQI. According to the SQI theory [10], when a different relation

$$2\pi\, I_c\, L_0 / \Phi_0 < 1 \qquad (9)$$

is fulfilled, the quantum transitions on the dependence of the magnetic flux inside the SQI on the external magnetic flux retain periodicity, but cease to be spasmodic. In the literature on quantum interferometry, this SQI operation mode is called hysteresis-free [5]. This circumstance can explain the absence of sharp current jumps in the dependences of Fig. 4 and their transformation into the observed form of current modulation I_1. The increase in Fig. 4 of the modulated current I_1 in the loop as the field H increases, is explained by the magnetic coupling of the solenoid with both an SQI and the entire superconducting loop. Such a shift in the sequence of current jumps I_1 is not observed in Fig. 1(c), because the source of the external magnetic field, in this case, does not have an interdependent magnetic coupling with the SQI.

Now we check the fulfillment of condition (9) for our SQI. It is clear that the critical current (I_{c1} or I_{c2}) of either of the two contacts of the thin-film SQI does not exceed the critical current of the interferometer $I_c \approx 3$ mA. Substituting the values of the inductance and even the critical current of the SQI into formula (9) confirms the fulfillment of this condition, since $2\pi I_c\, L_0 / \Phi_0 \approx 0.4$.

To explain the magnitude of the period ΔH_{sh} of the observed features on the dependence $I_1(H)$, we compare their value with the period ΔH of the magnetic flux quantization in the SQI not included in the loop. As noted in Sec. 2, this period is $\Delta H \approx 0.7$ Oe. If we take into account that the magnetic field of the diamagnetic current I_1 weakens the field created by the solenoid, we can expect that for this structure the period of change of quantum states can increase. Indeed, Fig. 4 shows that this period, designated by us as the period ΔH_{sh}, is about 2 Oe and noticeably exceeds the value $\Delta H = 0.7$ Oe.

Let us return to assessing the degree of asymmetry of the thin-film interferometer. This can be done based on the modulation depth of the loop current I_1. Figure 4 shows that it is about 0.5 mA. Modulation is caused by a periodic change in the interferometer critical current under the action of the solenoid magnetic field. For the hysteresis-free quantization of the magnetic flux in the interferometer, the entry of a flux quantum into it is determined by the critical current of the weakest contact. In this regard, it can be assumed that the modulation depth is equal to the value of this critical current. This current we denote as $I_{c2} = 0.5$ mA. So the critical current of the other contact is $I_{c1} = I_c - I_{c2} = 2.5$ mA. The degree of asymmetry according to [8] is determined by the coefficient $\alpha = (I_{c1} - I_{c2})/(I_{c1} + I_{c2})$. In our case, we obtain $\alpha \approx 0.6$.

Now we discuss the anomalous region of the dependence $I_1(H)$ existing near the zero value of the magnetic field H (Fig. 4). Quasiperiodic changes in current I_1 in this region of the dependence (highlighted by a circle) have a smaller amplitude and period compared to its main region and are not generally displaced along the current axis I_1. The current I_1 of this transition region is determined by the sum of three currents: the quantum circulating current of the SQI, the diamagnetic current in the loop with a shunt inductance, and the possible frozen current in the loop associated with the history of the current state of the loop at the time of recording the dependence $I_1(H)$. Apparently, an interdependent effect of these currents on the state of the SQI arises. To clarify the cause of the anomalous region, additional experiments and the construction of a general theory of current states are needed with this new type of a current excitation in a loop with an SQI.

Concluding the discussion of features in Fig. 4, it should be noted that we also tested the possibility of influencing the current measurement I_1 (using a magnetometer) of the solenoid scattering field directly on the magnetometer sensor. For this, the superconducting loop was broken and measurements of the solenoid scattering field at the location of the magnetometer sensor were carried out. Measurements showed that the magnitude of this field is no more than a tenth of a percent of the field in the center of the solenoid where the SQI is installed. Therefore, this influence on the measurements of the dependence $I_1(H)$ can be neglected.

In conclusion, Figs. 5(a),(b) show the dependences $I_1(I)$ and $I_1(H)$ obtained when time t changes, respectively, of the transport current and magnetic field in the sequence, the schemes of which are shown in two insets (Fig. 5). The forms of similar dependences for a structure with a shunt inductance L and a strongly asymmetric SQI in the form of PC are shown for comparison in insets also. As seen in Fig. 5(a), a decreasing of the current I from +7.2 mA to a value close to zero does not cause a change of the current I_1 = –2.5 mA in the loop until the current I reverses the polarity. A further change of the transport current I to –7.2 mA leads to a linear increasing current I_1 to +4 mA. A decreasing the absolute value of current I to zero leads to a freezing of the current I_1 = +4 mA in a superconducting closed loop with a thin-film SQI.

The features of the dependence $I_1(I)$ related to the freezing of the current I_1, as one would expect, are similar (except for the absence of current steps, caused in turn by the absence of the flux quantization in the thin-film SQI) to the dependences observed when using SQI with a large asymmetry of critical currents of weak links [6,7] (see also the inset in Fig. 5(a)). In particular, it should be expected that a repeated (after freezing the current I_1 = +4 mA) increasing of the transport current from zero to +7 mA will lead to the closure of the hysteresis current dependence $I_1(I)$ (shown by a dashed line in Fig. 5(a)).

It can be seen in Fig. 5(b) that the time variation of the solenoid current according to the sequence shown in the

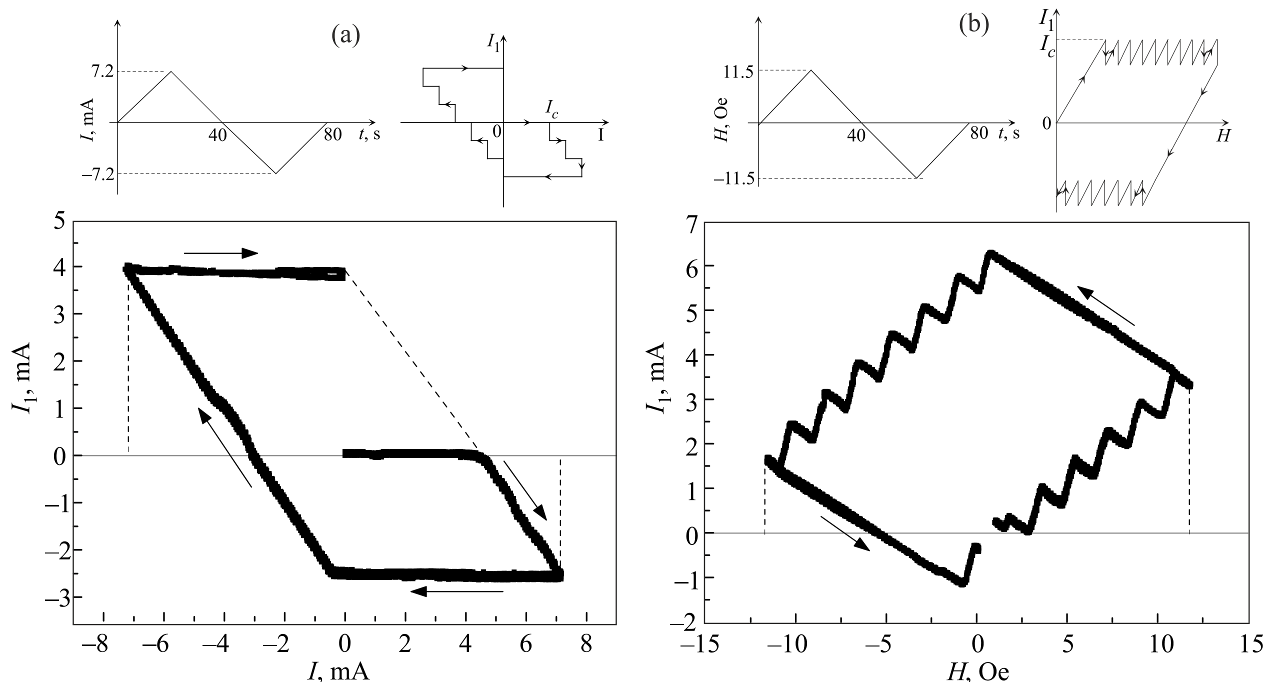

Fig. 5. Hysteretic dependences of the current I_1 on the transport current I (a) and on the magnetic field H (b), created by the solenoid at the location of the thin-film interferometer. The two insets above Fig. 5(a) show: the time sequence of the amplitude changes of the transport current $I(t)$ in this experiment (left); a typical hysteretic current dependence $I_1(I)$ observed for the "SQI+L" loop with a strongly asymmetric PC-based (single point contact) interferometer (right). Similarly the two insets above Fig. 5(b) show: the time sequence of the amplitude changes of the external magnetic field $H(t)$ acting on the interferometer and the loop (left); a typical hysteretic field dependence $I_1(H)$ observed for the "SQI+L" loop with a strongly asymmetric PC-based (single point contact) interferometer where magnetic field acting only on the loop (right).

inset in Fig. 5(b) do not lead to freezing of a noticeable current I_1 in the loop under study. In contrast, the inset of this figure shows a significant frozen current I_1, typical of a loop with a highly asymmetric SQI in the form of PC. In addition, the entire dependence in Fig. 5(b) is rotated relative to the coordinate axes H–I_1. This feature is explained by the type of its initial region (Fig. 4), formed by the simultaneous coupled action of the solenoid magnetic field on the hysteresis-free SQI and the diamagnetic current I_1 through the SQI. For more detailed clarifications of the processes of magnetic field freezing in loops with thin-film SQI with different degrees of asymmetry, additional experimental studies are required.

Conclusions

Studies of the transport properties of a superconducting closed loop containing the thin-film two-contact superconducting quantum interferometer (SQI) with low inductance $L_0 = 10^{-13}$ H and superconducting shunt inductance $L = 10^{-6}$ H have been performed. It is found that the critical value of the transport current in the loop is equal to $I_c \approx 3$ mA. It is obtained that the thin-film interferometer has an essential degree of asymmetry with $\alpha = (I_{c1} - I_{c2})/(I_{c1} + I_{c2}) \approx 0.6$. At the same time, the dependence of the current in the loop on the transport current has no quantum features (expected current steps for $I > I_c$) due to the fact that the interferometer critical current $I_c \approx$ 3 mA is not high enough. This is expressed in the fact that the additional condition on the critical current value of the SQI established in the course of our studies is not fulfilled, namely, for the appearance of periodic quantum features in the form of current steps, it is necessary that $I_c L_0 > \Phi_0$.

Studies of the magnetic properties of the loop with thin-film SQI have shown that the simultaneous action of an external magnetic field H directly on the SQI and the loop as a whole leads to the appearance of a new, previously not observed, dependence of the current $I_1(H)$. The peculiarity of this dependence is the presence of periodic modulation of current I_1, which is characteristic for quantization of magnetic flux in an SQI, but having differences in both the shape and magnitude of the period from those previously observed in the case of strongly asymmetric SQI based on pressed contacts. In this case, the solenoid magnetic field (in contrast to the magnetic field of the transport current discussed above) is sufficient for the formation of a magnetic flux in the SQI, which causes the appearance of quantum modulation of the current I_1. The difference in the modulation form (from that observed earlier in the case of a loop with a highly asymmetric SQI) is explained by the hysteresis-free regime of magnetic flux penetration into the SQI.

The increasing of the period of modulation of the loop current under the action of the solenoid magnetic field acting simultaneously on the interferometer and the loop (compared to the period of quantization of the magnetic flux not included in the loop thin-film interferometer) is explained by the diamagnetic (screening) reaction of the superconducting loop to a changing of the scattering magnetic field of the solenoid. As a result of this reaction, each specific value of the solenoid current does not correspond to the value of H calculated by the formula (2), but a smaller one. As a result, for a quantum transition, the dependence of the current in the loop on the magnetic field with a period ΔH_{sh} requires a higher current through the solenoid and a higher field value calculated by the formula (2).

For a more detailed elucidation of the features of the magnetic properties of such structures, in particular, during their magnetization reversal by the simultaneous action of a magnetic field on the SQI and the loop, additional studies using SQI with varying degrees of asymmetry are required.

In applied terms, the obtained results show the possibility of using in the discretization devices of values (in particular, linearly changing in time) of the magnetic field [8] not only asymmetric SQI with large critical currents, but also SQI with small critical currents.

1. L.V. Shubnikov and V.I. Khotkevich, *Phys. Zs. Sowjetunion* **10**, 231 (1936).
2. M. von Laue, *Theorie der Supraleitung*, Berlin, Schpringer (1949).
3. D. Schoenberg, *Superconductivity*, Izd. Inostr. Lit., Moscow (1955) [Russian translation].
4. A.C. Rose-Innes and E.H. Roderick, *Introduction to Superconductivity*, Pergamon Press, NY (1969); Mir, Moscow (1972).
5. *Superconductor Applications: SQUIDs and Mashines*, B.S. Schwartz and S. Foner (eds.), Plenum Press, N.Y. (1977).
6. V.P. Koverya, S.I. Bondarenko, A.V. Krevsun, N.M. Levchenko, and I.S. Bondarenko, *Fiz. Nizk. Temp*. **36**, 759 (2010) [*Low Temp. Phys*. **36**, 605 (2010)].
7. S.I. Bondarenko, V.P. Koverya, A.V. Krevsun, and L.V. Gnezdilova, *Fiz. Nizk. Temp*. **41**, 235 (2015) [*Low Temp. Phys*. **41**, 179 (2015)].
8. S.I. Bondarenko, V.N. Fenchenko, V.P. Koverya, and A.V. Krevsun, *Fiz. Nizk. Temp*. **45**, 1068 (2019) [*Low Temp. Phys*. **45**, 914 (2019)].
9. S.I. Bondarenko, A.V. Krevsun, E.V. Ilichev, U. Hubner, V.P. Koverya, and S.I. Link, *Fiz. Nizk. Temp*. **44**, 244 (2018) [*Low Temp. Phys*. **44**, 184 (2018)].
10. A.H. Silver and J.E. Zimmerman, *Phys. Rev*. **157**, 317 (1967).

Транспортні та магнітні властивості надпровідного замкнутого контуру, що містить тонкоплівковий квантовий інтерферометр

С.І. Бондаренко, В.П. Коверя, О.В. Кревсун

Виміряно залежності струму в надпровідному контурі, що містить тонкоплівковий интерферометр з двома точковими контактами (дві слабкі зв'язки джозефсонівського типу), від транспортного струму *I* та зовнішнього магнітного поля *H*, що діє на інтерферометр. Обговорюються відмінності між транспортною та магнітною залежностями досліджуваної системи та аналогічними характеристиками надпровідного замкнутого контуру, що містить интерферометр у вигляді притискного точкового контакту.

Ключові слова: надпровідний квантовий інтерферометр, надпровідний замкнутий контур з інтерферометром, критичний струм, магнітне поле, квантування магнітного потоку, діамагнітний струм, транспортний струм.

Транспортные и магнитные свойства сверхпроводящего замкнутого контура, содержащего тонкопленочный квантовый интерферометр

С.И. Бондаренко, В.П. Коверя, А.В. Кревсун

Измерены зависимости тока в сверхпроводящем замкнутом контуре, содержащем тонкопленочный интерферометр с двумя точечными контактами (две слабые связи джозефсоновского типа), от транспортного тока *I* и внешнего магнитного поля *H*, действующего на интерферометр. Обсуждаются различия между транспортной и магнитной зависимостями исследуемой системы и аналогичными характеристиками сверхпроводящего замкнутого контура, содержащего интерферометр в виде прижимного точечного контакта.

Ключевые слова: сверхпроводящий квантовый интерферометр, сверхпроводящий замкнутый контур с интерферометром, критический ток, магнитное поле, квантование магнитного потока, диамагнитный ток, транспортный ток.