Electrization of the superconductive windings and tori and the new type of contact potential difference

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Abstract

In the article is described the new type of contact potential difference, which appears with the flow of the current through conductors. Contact the potential difference indicated depends on the strength of current, which flows through conductor; therefore it it is possible to name a electrocurent contact potential difference. The results of investigating the electrization of the superconductive windings and tori during the introduction in them of direct currents are represented. Are represented the concept of scalar- vector potential, the assuming dependence of the scalar potential of charge on the speed, with the aid of which it is possible to explain the phenomenon of the electrization of the superconductive tori, during the introduction in them of direct currents. Are proposed the schematics of magnetometers, which make it possible to measure the magnetic fields over a wide range of their values.

The keywords: a contact potential difference, the laws of induction, scalar- vector potential, magnetometer.

1. Introduction

The first communication about the study of the electrization of the superconductive windings during the introduction in them of direct current is located in work [1]. Electric potential on such windings was measured with the aid of the electrometer with the high internal resistance, which galvanically was connected to the windings. Further studies of this phenomenon were conducted in works [2-9]. In works [6-9] for the first time it is reported that during the introduction into the superconductive tori of direct current by induction method the potential appears at the metal screen, which surrounds torus. In work [9] it is shown that the appearance of potential on the superconductive windings during the introduction in them of direct currents can be connected with the contact potential difference, which depends on the current strength. However, up to now there is no theory, which can explain the appearance of potential on the screen, which surrounds the superconductive torus.

2. Experimental study of a electrocurent contact potential difference

For the introduction of direct current into the winding was used the cooled to helium temperatures transformer with the iron core. Using as the secondary winding of transformer the superconductive winding, connected with the solenoid, it is possible without the presence of galvanic contacts to introduce current into it. The double winding was used for the purpose of the decrease of the inductance of solenoid in it. In the transformer was used ring-shaped core made of transformer steel with a cross section of 9 cm^2. The primary and secondary windings of transformer were wound by niobium-titanium wire with the copper coating and contained 150 and 10 turns respectively. Thus, transformer has a transformation ratio 15. The wire diameter composed 0.25 mm of. The secondary winding of transformer is connected in series with the solenoid with the small inductance, which is wound bifilar and contains 2448 turns of the same wire. The overall length of coil composes 910 m of. The ends of solenoid and secondary winding of transformer are welded with the aid of the laser welding. Solenoid is wound on the body from polyfluoroethylene resin. Inside and outside diameter of the winding of solenoid 35 and 90 mm of respectively, the width of the coil of 30 mm of. To the midpoint of solenoid is connected internal wiring of the coaxial, which emerges outside cryostat, the same coaxial is connected also to the screen of solenoid. The construction of solenoid is shown in Fig. 1.

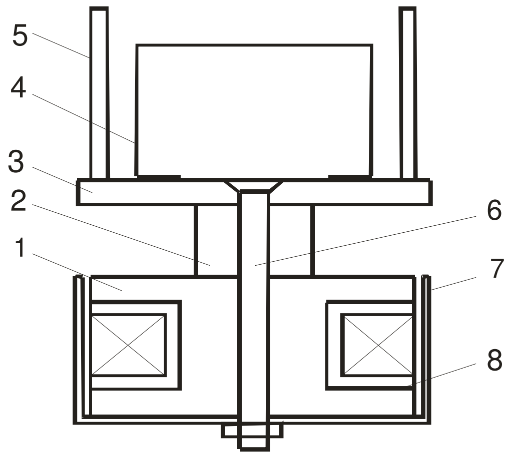

Fig. 1.   Construction of the superconductive solenoid.

by numbers in the figure are designated the following elements: 1- aluminum body, 2 - teflon bushing, 3- teflon disk, 4- clamp, 5 - counter, 6- bolt, 7- copper screen, 8 - teflon body is eighth. Solenoid is wound on teflon body 8, which is concluded in aluminum body 1. Outside solenoid is surrounded by copper screen 7, which together with body 1 is the screen of solenoid. To body 1 with the aid of bolt 6 and teflon bushing 2 is fastened teflon disk 3, on which is installed clamp 4. The turns of the secondary winding of transformer cover clamp 4, through which, without concerning it, is passed the magnetic circuit of transformer. Entire construction is attached to the transformer by means of counters 5. Transformer together with the solenoid is placed in the tank of helium cryostat.

The diagram of the connection of coaxials to the solenoid is shown in Fig. 2.

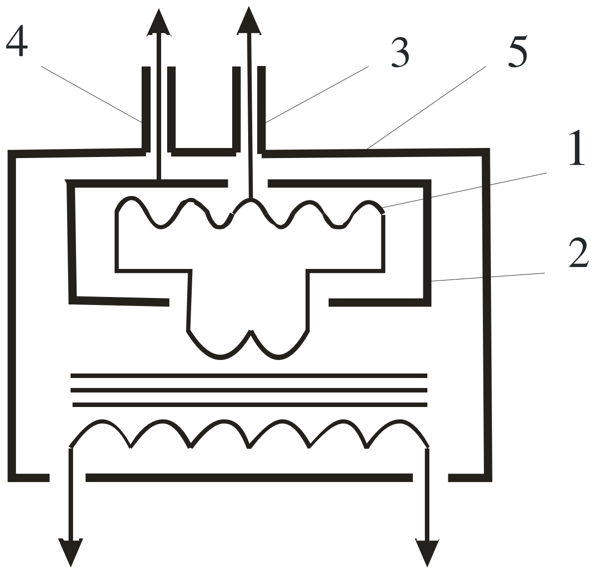

Fig. 2 Diagram of connection of solenoid and its screen with the coaxials.

By the figure are accepted the following designations: 1- solenoid, is 2nd the screen of solenoid, 3,4 - coaxials, is 5th the common screen, which the helium tank is. Resistance between the grounded elements, the screen of solenoid and solenoid itself composes not less than ~10^{14} Ohm. The elements, utilized in the construction, had the following capacities relative to the earth: the coaxial 3 - 44 pF, coaxial 4 - 27 pF, capacity screen - the earth it comprises - 34 pF, capacity screen- solenoid compose - 45 pF, as the electrometer was used by capacitive vibrating reed electrometer with a input capacitance 60 pF and a input resistance 10^{14} Ohm.

With the measurements the electrometer was connected to the solenoid with the aid of coaxial 3, and screen 2 with the aid of the coaxial I was grounded. Current into the primary winding of transformer was introduced from the source of direct current, indication of electrometer in this case they did not depend on direction of flow. With the strengths of introduced current ~9 A occurred the discharge of the indications of electrometer. This means that the current in the winding of solenoid reached its critical value, and winding converted to normal state.

The experimental dependence of a contact potential difference is shown in Fig. 3. The values of a voltage drop across figure shows with the opposite sign.

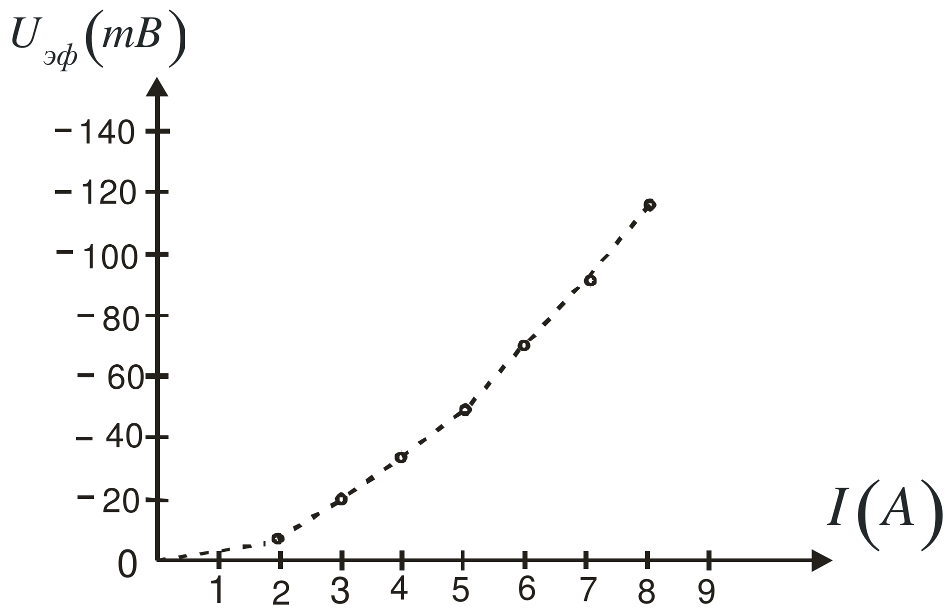

Fig. 3. Dependence of the given voltage drop across solenoid on the current in the primary winding of transformer.

Experimental data are given in the table № 1.

Table № 1

$I(A)$	1)	2	(3)	4	5	6	7	8
$I_1(A)$	15	30) of	45).	60	75	90	105	120
$H\left(\frac{A}{m}\right)\cdot 10^4$	1.91	3.82	5.73	7.64	9.55	11.5	14.6	15.3
$-U_2(mB)$	-	2	6	10.	15	21	27	35
$-U_1(mB)$	-	7	20	34	50	71	90	117
$\frac{U}{I_{эф}{}^2}\left(\frac{mB}{A}\right)$	-	1.75	2.22	2.13	2.00	1.94	1.84	1.83

In the first graph of table are given the value of current, introduced into the primary winding I. In the second graph are given the values of the current I_1 in the winding of solenoid, calculated on the basis of the value of the transformation ratio of equal to 15. In this case it is assumed that in entire range of the introduced currents the magnetization of core remains proportional to current. In the third graph are given the values of magnetic pour on the surface of the superconductive wires of winding. In the fourth graph the indications of electrometer are indicated. In the fifth graph the effective values of a potential difference are indicated. These values correspond to the value of potential between the solenoid and the screen to the connection to the screen of the total capacitance of coaxial and electrometer. In the sixth graph of table are given coefficient $k = \frac{U_{эф}}{I^2}$, which indicates the deviation of the obtained dependence on the quadratic law. The root-mean-square relative deflection of the coefficient k from its average value equal to 1.93 composes 0.13, which gives relative root-mean-square error 7%. Thus, the obtained dependence between the current and the measured value of potential is very close to the quadratic law. It is also evident from the table that with the values of current in the conductors of solenoid on the order of 120 A, the field strength on their surface reaches its critical value, which for the utilized superconductor composes 1.5x10^5 A/m, with which and is connected the discharge of the indications of electrometer with reaching of these currents. With this is connected the discharge of the indications of electrometer.

3. Electrocurent contact potential difference

A contact potential difference this is the potential difference, which appears between the located in the electrical contact conductors under the thermodynamic equilibrium conditions. As a result this between the conductors occurs the electron transfer until the Fermi levels in both conductors are made even. The established contact potential difference is equal to difference the work function of conductors, referred to the electron charge. But in the scientific literature there is no information about a contact potential difference, which occurs with the flow of the current through the superconductors.

The amount of the ponderomotive force gradient, which acts on the single square of the surface of conductor is determined by the relationship

$$F_{\square} = \frac{1}{2}\mu_0 H^2,$$

where H is magnetic field on the surface of conductor, μ_0 is magnetic permeability.

This force is applied to the moving electrons and attempts to press electronic flux. In order to balance the force indicated, near the surface of superconductor is formed the layer of the positively charged lattice (Fig. The electrostatic field of this layer balances the ponderomotoruyu force (Fig. 4).

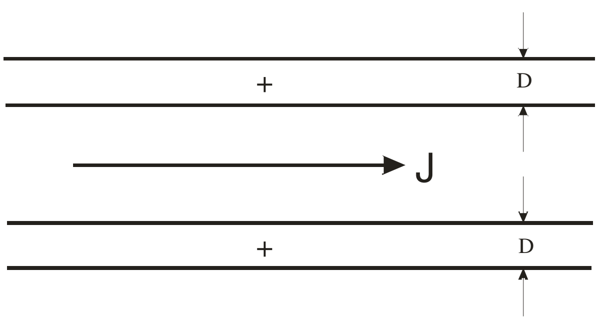

Fig. 4. Compression of the electronic flux, which flows along the conductor.

If the superconductor, along which flows the current, to lead into the contact with the normal metal, then the part of the electrons from this metal will pass to depletion layer and between the superconductor and the normal metal is formed the contact potential difference, which is proportional to the square of current. For forming the layer, depleted by electrons, the energy of magnetic field is expended, and for enumerating the contact potential difference should be made level energy of the magnetic field of electrostatic energy of depletion layer.

A contact potential difference comprises for the case of round conductor

$$\Delta\varphi = \frac{\mu_0 I^2}{2(\pi d)^2 en} \tag{3.1}$$

where I is current in the wire, d is the diameter of wire, e is the electron charge, n is electron density.

The magnetic field on its surface of superconductor, equal to specific current, can be determined from the relationship

$$H = nev\lambda,$$

where

$$\lambda = \sqrt{\frac{m}{ne^2\mu_0}}$$

is depth of penetration of magnetic field into the superconductor.

Using these relationships easy to see that the specific ponderomotive force is equal to specific kinetic energy of the electrons

$$F_{\square} = \frac{nmv^2}{2}.$$

In this case a contact potential difference is equal

$$\Delta\varphi = \frac{mv^2}{2e},$$

where m is mass of electron, v is electron velocity.

Since the potential difference in question depends on the current, which flows along the conductor, i.e. it is possible to name a electrocurent contact potential difference

4. Electrization of the superconductive windings and tori

The diagram of experiment is shown in Fig. 5. Inside the conducting screen was placed the second conducting screen, in which the superconductive torus, made from niobium, was located, and electrometer was connected by these screens. In the experiment, as external screen 1, the yoke of transformer, made from transformer steel, was used. On the central rod of yoke was located primary winding with 2, wound by niobium-titanium wire and which contains 1860 turns. Torus-shaped metal screen 3, made from copper, was located on the same rod. Torus 4, made from niobium, was located inside this screen. The outer diameter of niobium torus was 76 mm, and internal 49 mm. Transformer was placed in the tank of helium cryostat and was cooled to the helium temperature, in this case the yoke of transformer and helium tank were grounded. The current was induced during the introduction of direct current into the primary winding of transformer in the superconductive torus, and electrometer fixed the appearance between screen 3 and yoke of transformer a potential difference U . This means that the niobium torus, located inside screen 3 during the introduction into it of direct current ceases to be electrically neutral. The constant value current in the superconductive torus 1860 times exceeded the current, introduced into the primary winding of transformer.

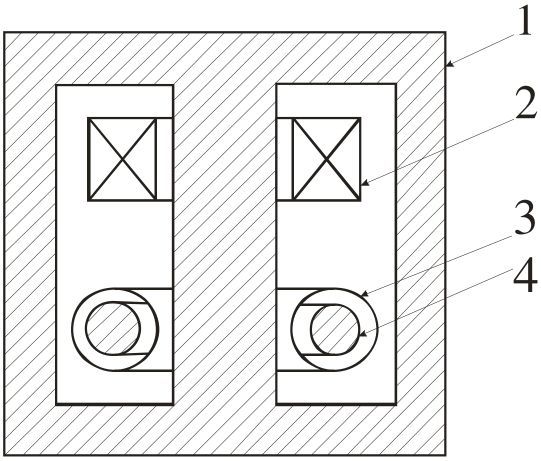

Fig. 5. Diagram of experiment with the superconductive torus.

The dependence of a potential difference U on the current I, introduced into the primary winding of transformer, it is shown in Fig. 6 .

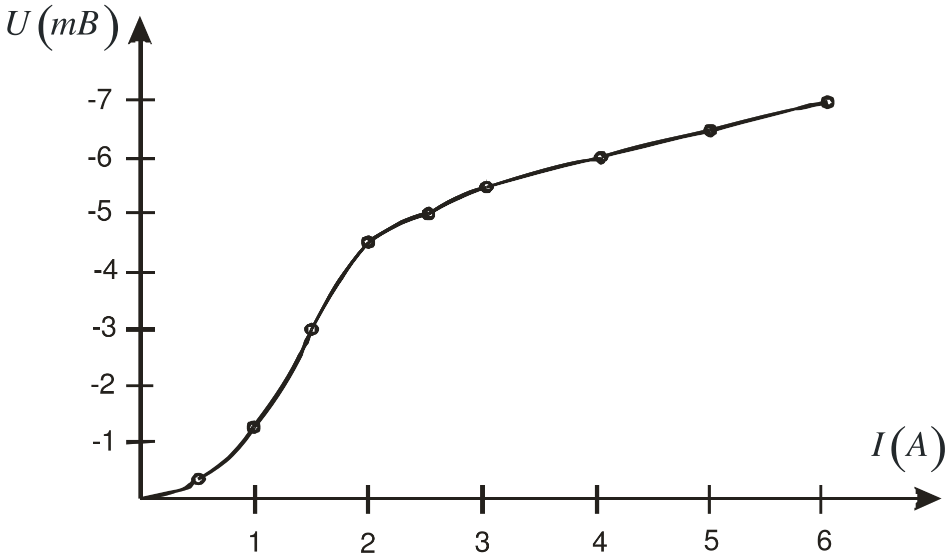

Fig. 6 . Dependence of a potential difference boundary by screen 3 by the yoke of transformer on the current, introduced into the primary winding of transformer.

The obtained values of a potential difference, in comparison with the case of the superconductive wire winding, proved to be considerably smaller, this is connected with the considerably smaller surface of torus, in comparison with the surface of wire winding. This is connected with the fact that the surface of torus considerably less than the surface of the wire of solenoid. The form of the dependence of a potential difference on the introduced current also strongly differs. Quadratic section is observed only in the very small initial section up to the values of currents into ~2 amperes, introduced into the primary winding. Further this dependence becomes practically linear with the small slope angle. The discharge of the indications of electrometer it was not observed.

In the case of wire solenoid the superconductive current is evenly distributed over the surface of wire and reaches its critical value in all its sections simultaneously.

With this is connected the simultaneous passage of the entire winding of solenoid into the normal state, with the reaching in the wire of the critical value of current.

In the case of torus the process of establishing the superconductive current on its surface occurs differently. That introduced into the direct current superconducting torus is very unevenly distributed over its surface. Maximum current densities occur on the internal surface of torus, and they are considerably less on the periphery. With this is connected the fact that the internal surfaces of torus begin to convert to normal state earlier than external. The process of passing the torus into the normal state normal phase begins to be moved from the interior of torus to the external regions. Process lasts until entire torus passes into the normal state. But why in this case up to the moment of passing the torus into the normal state does not occur the discharge of current, as it takes place in the case of wire solenoid? This niobium is connected with the fact that the superconductor of the second kind, and it does not convert abruptly to normal state. The superconductors of the second kind are had the significant region of current densities, with which it is in the mixed state. In this case inside the massive superconductor Abrikosov's vortices penetrate. The circumstance that the indications of electrometer do not have a discharge of indications, he indicates the fact that superconductive torus it is in the mixed state. In this case vortex structures also present the superconductive currents and they have an effect on the electrization of torus.

If we change direction of flow in the primary winding, then the dependence, similar to that depicted in Fig. 5, is repeated, however, it is observed strong hysteresis. This is connected with the fact that the vortices, which penetrated into the depths of the superconductor, they are attached on the stacking faults, falling into potential wells, that also leads to hysteresis.

The electrization of the superconductive windings and tori does not find the explanation of the within the framework existing electrodynamics, these results do not find explanation and within the framework the special theory of relativity. , Is the thus far only theory, which is capable of explaining the obtained results, the concept of scalar- vector potential, which assumes within the framework the conversions of Galileo the dependence of the scalar potential of charge on his speed [10-13].

5. The Scalar- vector potential of the moving charge.

The Maksvell's equation are the consequence of the laws of induction. The consequence of Maxwell's equations are the wave equations, which determine the dynamics of electrical and magnetic pour on in the free space. But in Maxwell's equations the dependence of the parameters of charge on his speed is not assumed, since with the determination of current density the steady-state value of charge is used.

For the first time the laws of induction in the symmetrical form with the use of total derivatives pour on they were represented in work [10]. These laws are written as follows:

$$\begin{aligned} \oint \vec{E}' dl' &= -\int \frac{\partial \vec{B}}{\partial t} d\vec{s} + \oint \left[\vec{v} \times \vec{B} \right] dl' \\ \oint \vec{H}' dl' &= \int \frac{\partial \vec{D}}{\partial t} d\vec{s} - \oint \left[\vec{v} \times \vec{D} \right] dl' \end{aligned} \tag{5.1}$$

or

$$\begin{aligned} rot\vec{E}' &= -\frac{\partial \vec{B}}{\partial t} + rot\left[\vec{v} \times \vec{B} \right] \\ rot\vec{H}' &= \frac{\partial \vec{D}}{dt} - rot\left[\vec{v} \times \vec{D} \right] \end{aligned} \tag{5.2}$$

.

For the constants pour on these relationships they take the form:

$$\begin{aligned} \vec{E}' &= \left[\vec{v} \times \vec{B} \right] \\ \vec{H}' &= -\left[\vec{v} \times \vec{D} \right] \end{aligned} \tag{5.3}$$

In relationships (5.1-5.3), which assume the validity of the Galiley conversions, prime and not prime values present fields and elements in moving and fixed IS respectively. It must be noted, that conversions (5.3) earlier could be obtained only from the Lorenz conversions.

The relationships (5.1-5.3), which present the laws of induction, do not give information about how arose fields in initial fixed IS. They describe only laws governing the propagation and conversion pour on in the case of motion with respect to the already existing fields.

The relationship (5.3) attest to the fact that in the case of relative motion of frame of references, between the fields $\vec{E}$ and $\vec{H}$ there is a cross coupling, i.e., motion in the fields $\vec{H}$ leads to the appearance pour on $\vec{E}$ and vice versa. From these relationships escape the additional consequences, which were for the first time examined in the work [10-12]. Outside charged rod electric field $E = \frac{g}{2\pi\varepsilon r}$ decreases like $\frac{1}{r}$ where r is the distance from the central axis of the rod, g is linear charge.

If we in parallel to the axis of rod in the field of E begin to move with the speed Δv another IS, then in it will appear the additional magnetic field of $\Delta H = \varepsilon E \Delta v$. If we now with respect to already moving IS begin to move third frame of reference with the speed Δv, then already due to the motion in the field ΔH will appear additive to the electric field $\Delta E = \mu\varepsilon E(\Delta v)^2$. This process can be continued and further, as a result of which can be obtained the number, which gives the value of the electric field $E'_v(r)$ in moving IS with reaching of the speed $v = n\Delta v$, when $\Delta v \to 0$, and $n \to \infty$. In the final analysis in moving IS the value of dynamic electric field will prove to be more than in the initial and to be determined by the relationship:

$$E'(r, v_\perp) = \frac{g ch \frac{v_\perp}{c}}{2\pi\varepsilon r} = E ch \frac{v_\perp}{c}.$$

This relationship indicates that around the straight conductor, along which flows direct current, is formed the stationary electric field

$$E(r) \simeq \frac{g v^2}{4\pi\varepsilon r c^2} \tag{5.4}$$

With obtaining of this relationship are undertaken only two first members of expansion in the series of hyperbolic cosine, and the compensating action of the positive ions of lattice is also taken into account.

Electric field of the single charge e will be determined by the relationship:

$$E'(r, v_\perp) = \frac{e ch \frac{v_\perp}{c}}{4\pi\varepsilon r^2} \quad ,$$

where $v_\perp$ is normal component of charge rate to the vector, which connects the moving charge and observation point.

Expression for the scalar potential, created by the moving charge, for this case will be written down as follows:

$$\varphi'(r, v_\perp) = \frac{e ch \frac{v_\perp}{c}}{4\pi\varepsilon r} = \varphi(r) ch \frac{v_\perp}{c}, \tag{5.5}$$

where $\varphi(r)$ is scalar potential of fixed charge. The potential $\varphi'(r, v_\perp)$ can be named scalar-vector, since it depends not only on the absolute value of charge, but also on speed and direction of its motion with respect to the observation point.

The concept of scalar-vector potential does not assume the invariance of charge with respect to the speed, therefore with its aid can be explained the electrization of the superconductive tori, when around the torus, into which is introduced direct current, appears the stationary electric field, which induces electric potential in the screen, which surrounds torus.

6 . Practical results

The electrocurent contact potential difference can be used for measuring the magnetic pour on. Schematic of the magnetometer, which uses this principle, represented in Fig. 7. The electrometer is connected to the superconductive closed loop. The magnetic flux of turn is equal

$$\Phi_{LI} = LI \tag{6.1}$$

where L is inductance of turn, I is current in the turn.

The magnetic flux of external magnetic field, the penetrating outline, are equal to field value, multiplied by the area of the outline

$$\Phi_H = HS \tag{6.2}$$

The condition follows from the law of conservation of flow in the short-circuited superconductive outlines

$$\Phi_{LI} + \Phi_H = 0 \tag{6.3}$$

From relationships (6.1-6.3) we obtain the dependence of the absolute value of current in the outline from the external magnetic field

$$I = \frac{HS}{L}$$

A contact potential difference is connected with the current, which flows along the superconductive wire, with quadratic dependence (3.1), consequently

$$\Delta\varphi = \frac{\mu_0 I^2 H^2}{2S^2 L^2 (\pi d)^2 en} \tag{6.4}$$

.

This method of measurement can be used for measuring the strong magnetic pour on, which are created with the aid of the superconducting coil electromagnets. The schematic of the magnetometer, intended for these purposes, it is shown in Fig. 7.

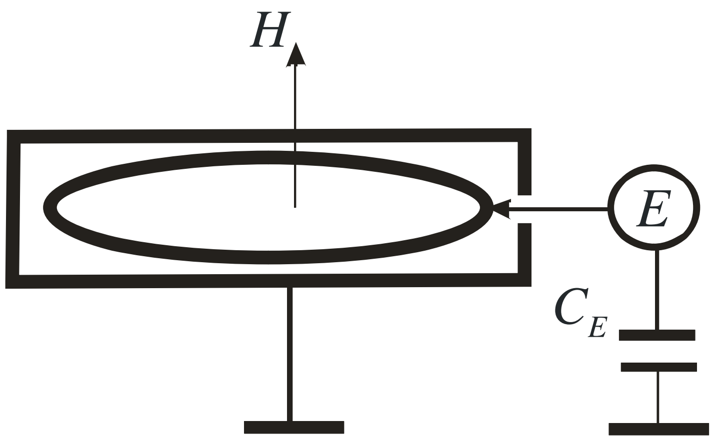

Fig. 7. Magnetometer to the superconductive outlines.

to the superconductive closed loop, surrounded by screen from the normal metal, is connected electrometer with the high input resistance. Screen is necessary for eliminating the external focusings. The capacity C_E is equal to the input capacitance of electrometer. For an increase in the sensitivity of magnetometer the capacity C_E must be considerably less than the capacity between the turn and the screen. The sensor of the magnetometer examined has small overall sizes and can be used for investigating the topology of magnetic pour on superconducting coil electromagnets.

The sensitivity of measurements can be substantially increased, if we in the superconductive outline preliminarily freeze the current I_0. Since in the outline the current is frozen, in the outline there will be its proper magnetic field, whose flow is determined by the relationship:

$$\Phi_0 = LI_0 = \int H_S dS = H_{Ev} S \tag{6.5}$$

where H_{Ev} is the average value of magnetic field in the plane of turn.

During the imposition on the outline of the external field it is added to the field of H_{EV}. In this case from the law of conservation of flow follows the condition of

$$LI + \left(H_{Ev} + H\right) S = 0 \tag{6.6}$$

From relationships (6.5) and (6.6) we obtain

$$\Delta\varphi = \frac{\mu_0 I^2 \left(H_{Ev} + H\right)^2}{2S^2 L^2 (\pi d)^2 en} = \frac{\mu_0 I^2}{2S^2 L^2 (\pi d)^2 en}\left(H_{Ev}^2 + 2H_{Ev} H + H^2\right) \tag{6.7}$$

The first term in the brackets does not depend on the measured field and with the measurements is reduced to zero. Is observed also the condition

$$2H_{Ev} H \gg H^2$$

From relationship (6.7) we obtain

$$\Delta\varphi = \frac{\mu_0 I^2 H_{Ev} H}{S^2 L^2 (\pi d)^2 en} \tag{6.8}$$

Comparing relationships (6.4) and (6.8) evident that the sensitivity of measurement increases into $K = \dfrac{2H_{Ev}}{H}$ of times. In addition to this, the scale of measurements becomes linear. The value of the coefficient K depends on the allowed values of critical magnetic pour on the superconductive closed loop and the sensitivities of the utilized electrometer it can reach the values ~ 10^5.

The schematic of magnetometer with the frozen current is shown in Fig. 8.

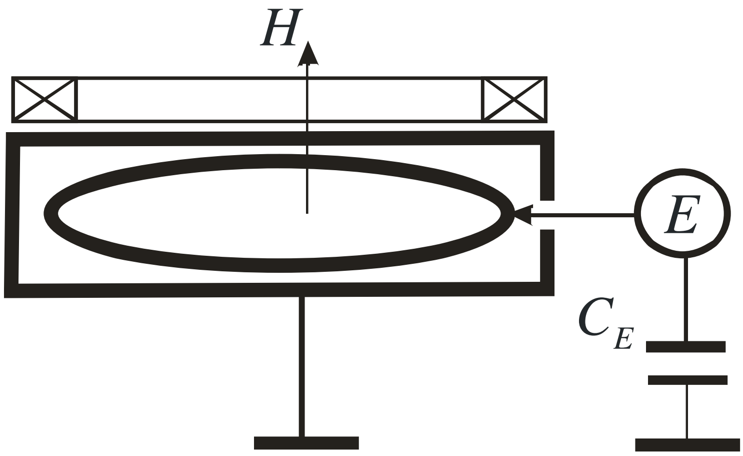

Fig. 8. The schematic of magnetometer with the frozen current.

The current in the short-circuited superconductive turn is frozen with the aid of the external solenoid, located above the screen. In the construction in question the critical magnetic field of turn must be less than in the winding of solenoid. They increase current in the solenoid until turn passes into the normal state and takes magnetic flux. After current in the solenoid will be switched off, in the turn the frozen current will remain. Its value will be somewhat lower than the critical current of turn.

With the measurements should be selected the electrometer with the minimum input capacitance, since with the measurements a contact potential difference and indication of the electrometer of E they are connected with the relationship

$$E = \frac{\Delta\varphi C_E}{C_R + C_E}$$

where C_E is the input capacitance of electrometer, C_R is capacity of the superconductive turn relative to screen.

7. Conclusion

In the article is described the new type of contact potential difference, which appears with the flow of the current through conductors. Contact the potential difference indicated depends on the strength of current, which flows through conductor; therefore it is possible to name the electrocurent contact potential difference. The results of investigating the electrization of the superconductive windings and tori during the introduction in them of direct currents are represented. Are represented the concept of scalar- vector potential, the assuming dependence of the scalar potential of charge on the speed, with the aid of which it is possible to explain the phenomenon of the electrization of the superconductive tori, during the introduction in them of direct currents. Are proposed the schematics of magnetometers, which make it possible to measure the magnetic fields over a wide range of their values.

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