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Superconductivity in the Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine

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The report contains a brief history of the superconductor's researches and their applications carried out in the Institute for Low Temperature Physics and Engineering (ILTPE) of the National Academy of Sciences of Ukraine since the ILTPE foundation in 1960. The most important results of the researches in the field of the low- and high-temperature superconductors (HTS) are stated more detailed. The experimental validation of an electromagnetic radiation of Josephson junctions; the electron pairing and existence of the distant order in the HTS; a creation of the superconducting quantum interference devices (SQUIDs) on the basis of the HTS; formation and moving of the local frozen magnetic field along the surface of the HTS; the transport properties of new Fe-based superconductors can be referred to such results.

Keywords: Superconductivity; magnetic field; energy gap; superconducting magnetic shield.

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1. Introduction

Superconductivity has been studied in the Institute for Low Temperature Physics and Engineering (ILTPE) of the National Academy of Sciences of Ukraine since 1960 when the ILTPE has been founded in Kharkov city, Ukraine (Fig. 1).

The founder of the institute was a famous scientist Academician Boris Verkin (Fig. 2).

The institute has been created by Sergey Korolev's support, who was well-known as a developer of the Soviet missile systems. That is why the first problem that should be solved by our institute was the development of the simulator of the space physical parameters: low temperatures, a vacuum, a sun radiation and the

Fig. 1. First page of the ILTPE reference book and the map of Ukraine.

Fig. 2. Boris Verkin.

electrons and protons flux in laboratory installations. It is applied to the researches of the various materials and devices of the space vehicles. One of such simulators is used now in the Harbin Polytechnic Institute.

Some other important directions apart from superconductivity that worth to be mentioned are: low temperature magnetism, thermal properties of materials and the point-contact spectroscopy (PCS) of metals. The author of the PCS method was the employee of our institute Academician Igor Yanson.

2. Weak Superconductivity

The basic direction of the works in the field of the superconductivity was finding out of an opportunity of a superconductivity application in the electronics and in the electrical technique. The Josephson effect is one of the bases of the superconducting electronics. The electromagnetic radiation of a superconducting tunnel junction of Josephson has been detected experimentally first in the world[1]

Fig. 3. I. Dmitrenko, V. Svistunov and I. Yanson.

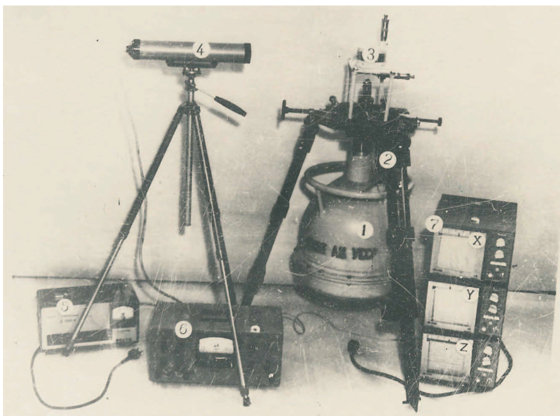

Fig. 4. Three-component SQUID–magnetometer.

by Doctors I. Yanson, I. Dmitrenko and V. Svistunov (Fig. 3); first in the former USSR the superconducting quantum interference device (SQUID)[2,3] and high sensitivity SQUID–magnetometer (Fig. 4) on the basis of the SQUIDs been developed[4–6] under the guidance of Dr. S. Bondarenko.

Three-component SQUID–magnetometer with sensitivity of 10^{-3} nT for the field of geophysical measurements and searches of the diamond tubes and iron ore has been developed and successfully applied in Eastern Siberia (Fig. 5) in 1977.

The first in the world aviation SQUID–gradiometer (Fig. 6) with sensitivity of 10^{-4} nT/m, has been created and tested for the geophysical air-magnetic investigations under the leadership of Dr. S. Bondarenko in 1984.

The first in the former USSR, the SQUID–cardiograph for the measurement of heart magnetic field, has been developed and applied in a medical clinic under the guidance of Professor I. Dmitrenko and Dr. D. Konotop.

In recent time, we have developed and investigated new SQUID-structure.[7,8] It is highly inductive ($L \sim 10^{-6}$ H), double connected superconductor (DCS) containing

Fig. 5. Geophysical measurement system of two three-component SQUID–magnetometers in Eastern Siberia.

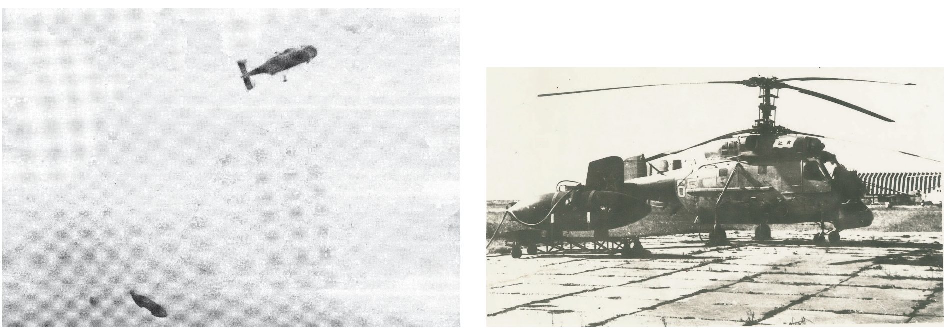

Fig. 6. Geophysical air-magnetic system on the basis of the SQUID–gradiometers.

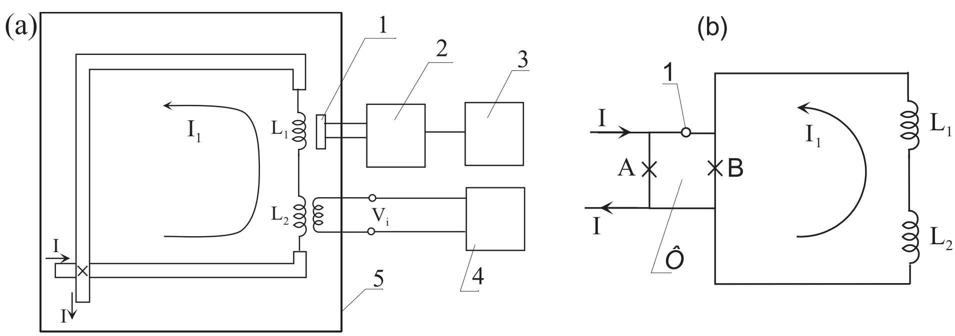

Fig. 7. (a) Scheme of the DCS with the CC-SQUID (the CC-SQUID is in the cross point x). Elements of the scheme are a fluxgate (1), an electronic amplifier (2), a recorder (3), an oscillograph (4). (b) Replacement scheme of the DCS. Elements of the scheme are two Josephson contacts (A and B) with different critical current and a counter (1) of the SQUID (1). The Φ is a magnetic flux created by a transport current I.

very low inductive ($L_0 \sim 10^{-13}$ H) SQUID in the form of niobium–niobium clamping contact (CC). In the elementary case, this structure looks like a ring with the CC-SQUID (Fig. 7).

Typical discrete dependence of a current I_1 arising in a ring on a transport current (I) through the DCS is shown in Fig. 8. This dependence reflects the periodic quantum processes occurring in the CC-SQUID at a change of a current I and its magnetic flux Φ in the SQUID.

The voltage (V_i) arising on the ring during an jump of a current δI_1 (Fig. 9) is equal to $V_i = L\delta I_1/\delta t$. It has been established that it corresponds to a value of one of the fundamental parameters of a superconductor (niobium), namely an energy

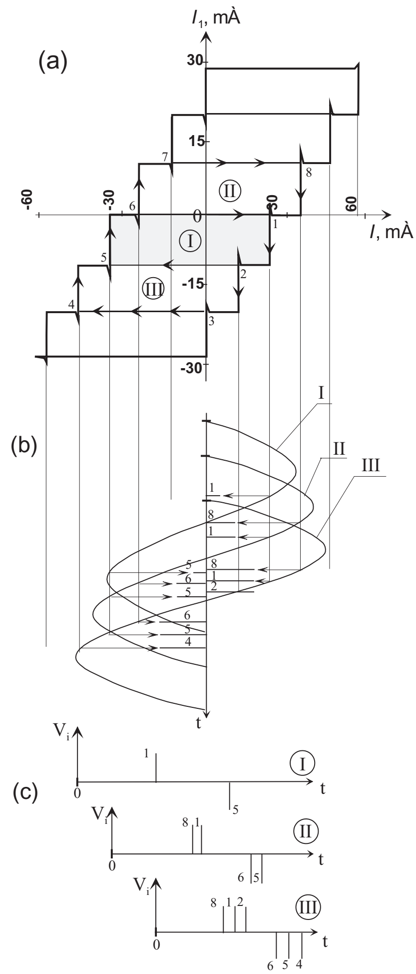

Fig. 8. Dependence of a current I_1 on a transport current I (a); one period of a alternating current I with three different amplitudes (I, II, III) at frequency 100 Hz (b); calculated dependences of the voltage V_i on time t for three amplitudes of an alternating transport current I.

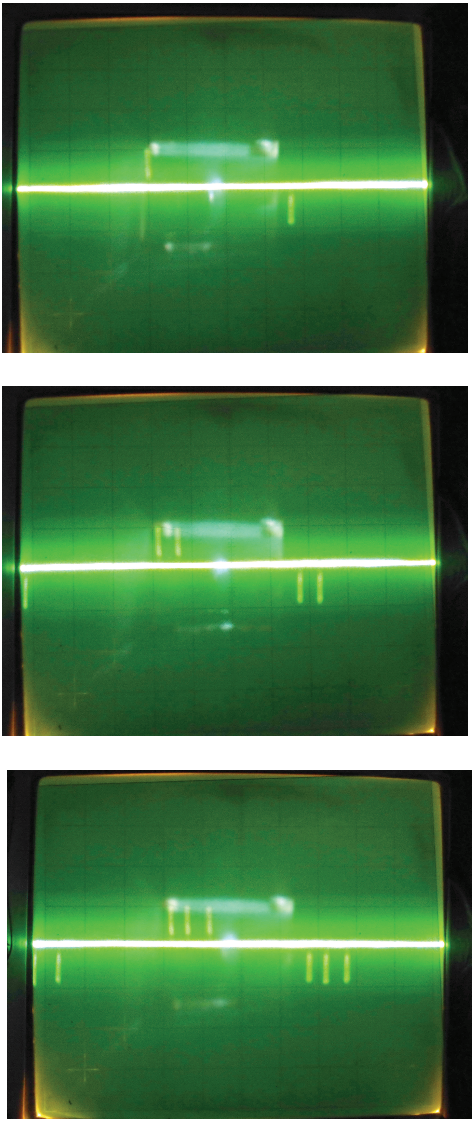

Fig. 9. Pictures of the impulses of V_i on an oscillograph screen at three different amplitudes of an alternating transport current I through the DCS.

gap (Δ):

$$V_i = \frac{2\Delta}{e}\,. \tag{1}$$

Feature of this method is a possibility of the simultaneous measurement of an impulse amplitude of a voltage (V_i) and its duration (δt). This duration has simply related to depairing time of the electrons (τ) by a ratio of inductances of the CC–

SQUID (L_0) and a big branch of the DCS ring (L):

$$\tau = \left(\frac{L_0}{L}\right) \delta t \,. \tag{2}$$

Thus, as a result, it was possible to define simultaneously Δ and τ (in our experiments $\delta t \approx 6 \times 10^{-6}$ s, $\tau_{Nb} \approx 10^{-12}$ s at $T = 4.2$ K). The given structure and method of a measurement of its parameters can be alternative to existing methods of a gap measurement and simple enough method of the τ measurement.

All the above specified researches and devices have been made with an application of traditional low temperature superconductors at working temperature of 4.2 K.

The big contribution to understand the processes of weak superconductivity has been made by physicists–theorists of ILTPE Academician Kulik and Doctors of Sciences V. Galayko and A. Svidzinsky. Theoretical researches in the field of a creation of the perspective superconducting quantum elements (qubits) for the quantum computers working at ultralow temperatures at a level 20–50 mK are being conducted now in “superconducting and mesoscopic structures” department under the guidance of Academician A. Omelyanchouk.

Finding of the high-temperature superconductors (HTS) in 1986 has necessiated to organize the study of the HTS in our institute. Experimental works in the field of the HTS have been began by us in 1987. Researches of the HTS physical properties have been carried out using the samples made in other institutes of the former Soviet Union. Received fundamental physical results of a world level have been published in the ILTPE scientific journal “Low Temperature Physics” and have been reported at the international conferences. Works in the field of the HTS applications have been directed on creation of the SQUIDs, the transformers of a magnetic flux for the SQUID-magnetometers and the sources of a frozen magnetic field, working at temperature of liquid nitrogen. In particular, the CCs have been made of the $YBa_2Cu_3O_{7-x}$ ceramics. Influence of high-frequency electromagnetic field at frequencies of $\nu = 10^{10}$ Hz at $T = 77$ K on this contact is resulted in arising the current step at voltage (V) on volt-ampere characteristic curve corresponding to a quantum relation:

$$h\nu = 2 \text{ eV} \,, \tag{3}$$

where h and $2e$ are accordingly Planck’s constant and a charge of Cooper pairs. The observable effect became the first direct proof of an existence of an electrons pairing in the HTS.[9] It was possible for us to be the first to develop the high-temperature Josephson contacts and the SQUIDs in the form of the thick-film bridges.[10] On a basis of these developments, three-channel scanning magnetic microscope (MM) was created.[11] The spatial resolution of two SQUID-channels of the microscope was equal to 1 micron at a working temperature 77 K. The resolution of the third fluxgate channel at working temperature 300 K was not worse than 100 microns (Fig. 10).

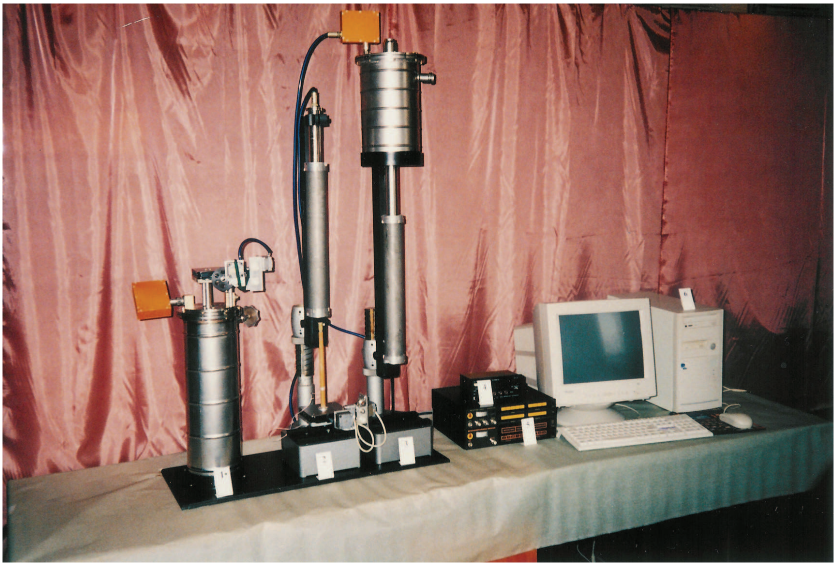

Fig. 10. External view of the MM.

(1) Measuring channel with the SQUID for the "cold" objects study.
(2) Measuring channel with the fluxgate for the "warm" objects study.
(3) Measuring channel with the SQUID for the "warm" objects study.
(4) The SQUID driving device.
(5) The SQUID and a fluxgate electronic amplifier.
(6) Personal computer.

Ten years ago, we had been offered and investigated new superconducting structure in the form of a small superconducting region of the HTS plate or thin film with local frozen magnetic field. An idea of a creation of a local external magnetic field lays in a basis of this structure and the method of a research.

A local field is formed by means of the microsolenoids located on both sides of the HTS plate at $T = 77$ K perpendicularly to its surface (Fig. 11).

Our experiments have allowed to freeze a field in the small areas of the HTS and for the first time to receive, most in direct way, the information about the local values of a critical current, a critical field, a distribution of a current in the sample, the local values of a pinning force and a viscosity of magnetic flux moving.[12–14] The method can be applied to contactless definition of an uniformity of the critical parameters of the long HTS (tapes, films, etc.).

Since 2012 we study the Fe-based superconductors. The main attention was paid to the layered Fe–Te, Fe–Se and Fe–Te–Se chalcogenides. Transport properties of these new superconductors are being studied now. Thin films Fe–Te were fabricated in the Institute of Physics of the Chinese Academy of Sciences (Beijing, Professors Lixin Cao and Yushen Xe). The films have critical temperature nearby 10 K and

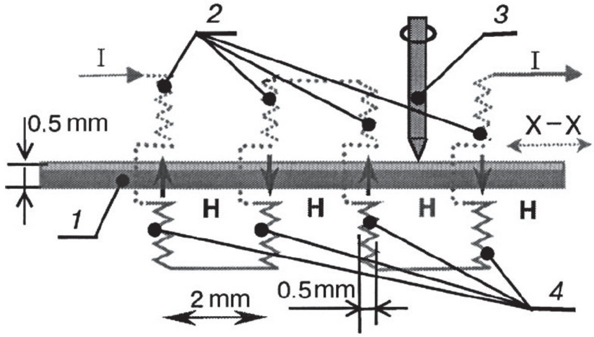

Fig. 11. Arrangement schemes of the microsolenoids (2, 4) with a current I and a fluxgate detector (3) on a surface of a HTS tape (1).

low density of a critical current (~ 10 A/cm^2) in a range of temperatures from 7 up to 2 K. Surprisingly that single crystals Fe–Te do not have superconductivity down to 2 K. The density of a critical current of the single crystals Fe–Te–Se at $T = 4.2$ K depends on a technology of their fabrication and can differ more than in 1000 times.

3. Large Scale Superconductivity

Superconducting magnetic shields (SMSs) of a great volume and the experimental samples of the superconducting electrical generators and the engines have been developed and fabricated in the ILTPE. These works were carried out with an application of the traditional low-temperature superconductors (niobium, its alloys and lead). All these devices were unique developments and had no analogues in the former USSR.

The 5 MW power generator has been developed, fabricated and tested a rotor with a superconducting winding of NbTi wire (Fig. 12). Together with the Leningrad factory "Electrosila" on the basis of this rotor first in the former USSR, the cryogenic generator for power station has been collected and successfully tested. The project of a superconducting rotor for the 300 MW generator[15] has been developed in 1989. Advantage of these machines in a comparison with the traditional non-superconducting machines was much greater than the magnetic field of the rotor windings (up to 3.7 T). It allows essentially reducing a weight and dimensions of the powerful generators and engines. Development of the generators has demanded to solve a lot of new physical and technical problems. Problems of a cryogenic heat exchange at great values of the centrifugal accelerations (at 3000 turns in a minute), the measurements of temperature distribution in a rotating superconducting winding, an input of the big current (from 100 up to 3000 A) to a rotating winding and minimization of liquid helium consumption were decided.

Our electric cryogenic motors were unipolar and had the superconducting stator windings creating a magnetic field up to 4 T. The power of the experimental motors

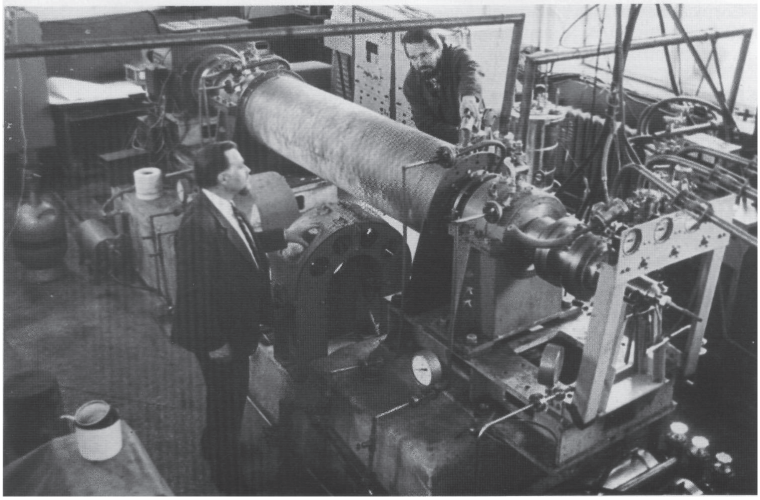

Fig. 12. External view of a superconducting rotor of an electric generator with a power of 5 MW.

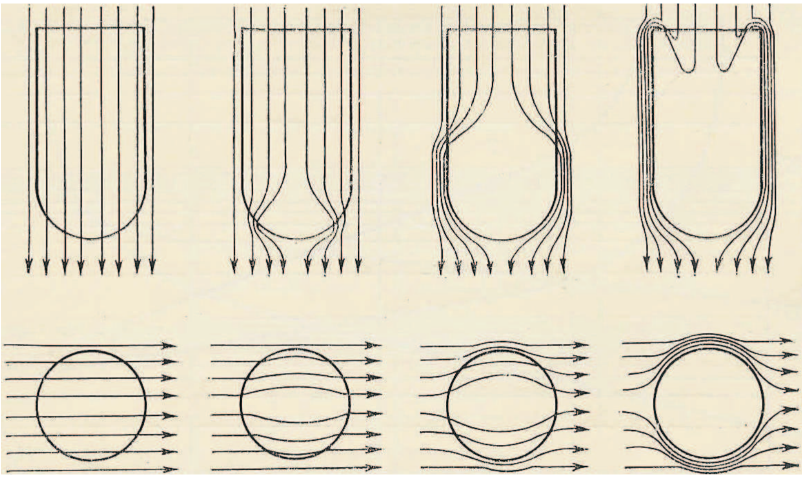

Fig. 13. Pictures of a distribution of the magnetic force lines around thin-wall cover (view from face and from above) at four different states: a superconducting state of the cover is absent in first (from the left) picture; a superconducting state is on bottom part of the cover only (second picture); a superconducting state is on the half of the cover (third picture); a superconducting state is on all cover (fourth picture). As the result, we have a region with magnetic vacuum into the cover.

with direct current was from 55 up to 132 kW. Machines can work at the engine and the generator modes.

SMSs are necessary for a calibration and a definition of sensitivity of the various modern magnetometers under industrial interferences conditions, for protection of high-sensitivity elements of the quantum computers, at researches of a magnetic

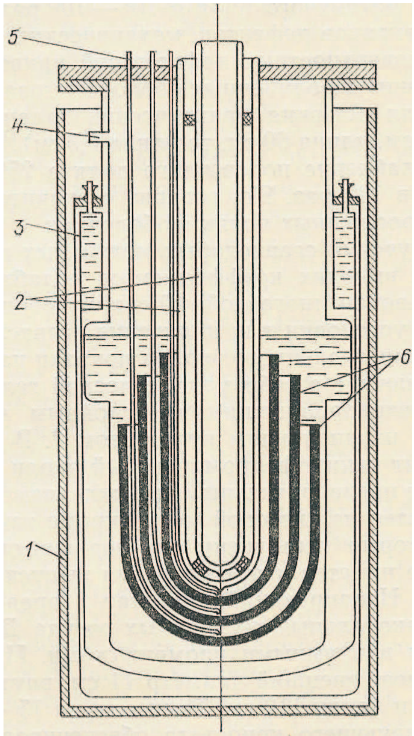

Fig. 14. Scheme of a superconducting shield with three lead covers (6). Other elements of the shield are the inner walls of a helium cryostat (1), two walls of an anticryostat with $T = 300$ K, a reservoir with liquid nitrogen (3), a reservoir with liquid helium (4) and tube for feeding helium to an external cover of the shield.

vacuum influence on the biological objects.[16] Multilayered SMS (Fig. 14) with several lead covers (diameter nearby 100 mm and length up to 600 mm) for innovative usage (Fig. 13) of the Meissner effect have been developed in the ILTPE.[17,18]

Step by step controlled transition of the covers (Fig. 14) in a superconducting state leads to step reduction of a magnetic field in an internal cover up to a level less than 10^{-9} Oe in volume more than 10^3 cm^3. This value of magnetic vacuum till now is a world record. Developed SMS are capable to decrease weak external variable magnetic fields from 10^5 up to 10^7 times in all possible range of frequencies. The working temperature of these SMS is equal 4.2 K.

Zinc two-layer SMS under the order of the company "D-wave Corporation" (Canada) for protection of detectors of a quantum computer against the electromagnetic interferences has been made by us several years ago.

4. Conclusion

Employees of the ILTPE have great experience in research of superconductivity and its application to solve for various practical problems. Experience of the frozen magnetic field research of the HTS and creations of various cryogenic sources of a magnetic field and also experience of development of the superconducting magnetometers, can be used for decision of new modern problems. In particular, it is concerned the HTS magnetic separators development for various purposes.

For successful decision of the abovementioned problems, international cooperation will be useful in including gained experience of the Chinese scientists in the development of the HTS materials with high values of a critical current density (in particular, large single crystals of the compounds on $YBa_2Cu_3O_{7-x}$ basis, and also high-quality thick films).

References

1. I. M. Dmitrenko, I. K. Yanson and V. M. Svistunov, *Pisma JETPh* **2**, 17 (1965) (in Russian).
2. I. M. Dmitrenko and S. I. Bondarenko, *Pisma JETPh* **7**, 308 (1968) (in Russian).
3. I. M. Dmitrenko, S. I. Bondarenko and T. P. Narbut, *JETPh* **57**, 1513 (1969) (in Russian).
4. S. I. Bondarenko *et al.*, *Cryogenics* **23**, 263 (1983).
5. S. I. Bondarenko, *Proc. Int. Conf. Superconducting Quantum Interference Devices and their Application (SQUID-85)* (Berlin, 1985), p. 779.
6. S. I. Bondarenko, *Collection Geophys. Equip.* **57**, 8 (1975), (in Russian).
7. V. P. Koverya *et al.*, *Low Temp. Phys.*, **36**, 605 (2010).
8. S. I. Bondarenko *et al.*, *Low Temp. Phys.* **38**, 341 (2012).
9. B. I. Verkin *et al.*, *Low Temp. Phys.* **13**, 995 (1987).
10. S. I. Bondarenko *et al.*, *Superconduct.: Phys. Chem. Tech.* **2**, 97 (1989).
11. S. I. Bondarenko *et al.*, *Physica B* **329–333**, 1512 (2003).
12. S. I. Bondarenko, A. A. Shablo and V. P. Koverya, *Low Temp. Phys.* **32**, 825 (2006).
13. S. I. Bondarenko *et al.*, *Bull. Russ. Acad. Sci.: Phys.* **71**, 1130 (2007).
14. A. A. Shablo, V. P. Koverya and S. I. Bondarenko, *Low Temp. Phys.* **36**, 137 (2010).
15. B. I. Verkin, *Cryogenic Technique* (Naukova Dumka, Kiev, 1985).
16. B. I. Verkin *et al.*, *Microbiologia* **45**, 5 (1976) (in Russian).
17. S. I. Bondarenko *et al.*, *J. Tech. Phys.* **XLV**, 124 (1975 (in Russian).
18. S. I. Bondarenko and V. I. Sheremet, *Application of Superconductivity in Magnetic Measurements* (Energoatomizdat, Leningrad, 1982), (in Russian).