Conference materials
UDC 538.945.9
DOI: https://doi.org/10.18721/JPM.161.124

Study of the anisotropy of critical currents in 2G-HTSC tapes by a non-contact method

D.S. Chikurov [1]✉, M.P. Volkov [1]

[1] Ioffe Institute, Saint-Petersburg, Russia

✉ d.chikurov@yandex.ru

Abstract. A simple and reliable method for determining the critical current of a HTSC tape is a non-contact method based on capturing the magnetic flux by a closed superconducting ring made of this tape and measuring the magnetic field in the center of the ring with a field sensor. This method also makes it possible to obtain the dependence of the critical current on the magnetic field by applying a magnetic field locally on a small section of the tape. A local magnetic field can be created using strong permanent magnets, which also makes it possible to apply the field at different angles relative to the plane of the tape and to determine the anisotropy of critical currents. Using this method, experiments were carried out on rings made of a SuperOx HTSC tape at T = 77 K and in a magnetic field up to 4 kOe. The values obtained for the anisotropy of critical currents are in good agreement with the data given by the manufacturer.

Keywords: superconductivity, HTSC, critical current, anisotropy, magnetic flux capture

Citation: Chikurov D.S., Volkov M.P., Study of the anisotropy of critical currents in 2G-HTSC tapes by a non-contact method, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (1.1) (2023) 142–145. DOI: https://doi.org/10.18721/JPM.161.124

Материалы конференции
УДК 538.945.9
DOI: https://doi.org/10.18721/JPM.161.124

Исследование анизотропии критических токов в лентах ВТСП 2 поколения бесконтактным методом

Д.С. Чикуров [1]✉, М.П. Волков [1]

[1] Физико-технический институт им. А.Ф. Иоффе РАН, Санкт-Петербург, Россия

✉ d.chikurov@yandex.ru

Аннотация. Простым и надежным методом определения критического тока ВТСП-ленты является бесконтактный метод, основанный на захвате магнитного потока замкнутым сверхпроводящим кольцом из этой ленты и измерении магнитного поля в центре кольца датчиком поля. Этот метод также позволяет получить зависимость критического тока от магнитного поля путем локального приложения магнитного поля к небольшому участку ленты. Локальное магнитное поле можно создать с помощью сильных постоянных магнитов, что также позволяет прикладывать поле под разными углами относительно плоскости ленты и определять анизотропию критических токов. С использованием этого метода были проведены эксперименты на кольцах из ВТСП-ленты SuperOx при Т = 77 K и в магнитном поле до 4 кЭ. Полученные значения анизотропии критических токов хорошо согласуются с данными производителя.

Ключевые слова: сверхпроводимость, ВТСП, критический ток, анизотропия, захват магнитного потока

Ссылка при цитировании: Чикуров Д.С., Волков М.П. Исследование анизотропии критических токов в лентах ВТСП 2 поколения бесконтактным методом // Научнотехнические ведомости СПбГПУ. Физико-математические науки. 2023. Т. 16. № 1.1. С. 142–145. DOI: https://doi.org/10.18721/JPM.161.124

Introduction

Progress in the creation of second-generation HTSC tapes has led to the industrial production of tapes with high critical currents at nitrogen temperature [1]. The tape manufacturers typically determine critical currents by measuring the magnetic field created by the current over the tape. This method makes it possible to obtain data on the homogeneity of the critical current along the length of the tape; however, the absolute values of the critical currents with this approach are not determined accurately enough due to the strong inhomogeneity of the current field near the tape. To calibrate the measuring system, it is necessary to measure periodically the critical current by the direct 4-probe method [2]. Additional difficulties arise when measuring critical currents in tapes in a large magnetic field, when a small current field is measured against the background of a large external magnetic field [3].

A convenient method for estimating critical currents and their anisotropy in HTSC tapes is a non-contact method based on the measurement of the magnetic field captured in a ring made of a tape [4]. When a magnetic flux of sufficient magnitude is created inside the ring using permanent magnets or an electromagnet and then this flux is reduced to zero, the magnetic flux created by the critical current is captured in the ring. The field of this current is measured in the center of the ring by a Hall sensor. This method makes it possible to obtain accurate values of the critical current, since the current field in the center of the ring is sufficiently homogeneous. At the same time, the anisotropy of critical currents in small fields can be measured using a system of permanent magnets. Since the critical current decreases with increasing magnetic field, it is enough to apply the field on a small section of the tape and then the critical current of the ring will be determined by the critical current of this section. For a number of technical applications, such as power lines or current limiters, it is essential to know the dependence of critical currents on a magnetic field of small magnitude (about 200 mT) when the magnetic field is oriented along and across the tape plane. The anisotropy of critical currents in HTSC tapes is connected with the significant anisotropy of the ReBCO compound itself and with the shape anisotropy, when the role of the surface is significant in the parallel orientation [5]. The relative influence of these two effects may vary from manufacturer to manufacturer, so it is important to have a simple and reliable method for estimating the magnitude and anisotropy of the critical currents of a particular HTS tape.

To avoid problems with creating a ring by soldering, one can create a ring using the following method: make a slit lengthwise of the HTSC tape, not reaching the edges of the tape, push the resulting half-width strips apart and fix the resulting ring on a light and rigid dielectric ring. Such a ring will not have weak points, as in the case of soldering or other connections, this ring will have a continuous HTS layer. By increasing the magnetic field through the superconducting ring, a current arises, which creates a flux opposite to the applied one. The magnitude of the counter magnetic flux is limited by the magnitude of ring critical current. By measuring the field at the center of the ring associated with the maximum trapped flux, we can determine critical currents with high accuracy. This method was used both to determine the critical currents and the relaxation of the critical current with time [6]. This method makes it possible also to determine the dependence of the critical current on the field applied normally or parallel to the plane of the strip. Since the critical current decreases with magnetic field increasing, it is sufficient to apply a magnetic field only on a local section of the tape, and then the total critical current will be determined by the critical current of this section. To create a local magnetic field, it is sufficient to use permanent magnets, which can be placed along or across the plane of the tape.

Materials and Methods

Experiments were carried out on rings made from SuperOx HTS tape, 4 mm wide, with the critical current value at $T = 77$ K declared by the manufacturer 170 A.

To estimate the critical current of the tape, preliminary experiments were carried out to measure the magnetization M of a square piece of tape (4×4 mm) by VSM magnetometer in a transverse field at T = 77 K. In the Bean model, there is a simple relation between the critical current and the width ΔM of the major magnetization loop [7]:

$$J_c = (3d/a)\cdot\Delta M,$$

where d is thickness, a is the side of the square, ΔM is magnetization hysteresis width. The critical current calculated from the hysteresis of the magnetization curve at H = 0 was 71 A. This value of the critical current is slightly less than the expected value 170/2=85 A. Considering that the used formula underestimates the J_c values by about 15 percent in the region of small fields [7], we obtain good agreement between the calculated and declared J_c values.

Results and Discussion

For the ring experiments in a piece of HTS tape 10 cm long, a cut was made with a diamond disk 7 cm long, not reaching the edges of the tape (Fig. 1, *b*). The magnetic flux inside the ring was introduced using a solenoid located in the center of the ring. The local magnetic field was created by two permanent NdFeB alloy magnets located opposite each other closer to the cut edge (Fig. 1, *a*). The distance between the magnets (i.e. the magnitude of the magnetic field in the gap) and the orientation of the magnetic field relative to the plane of the tape could be controlled by a mechanical device from outside the liquid nitrogen container. The measurements were carried out at liquid nitrogen temperature (T = 77 K), i.e., below the critical temperature of the HTSC (T_c = 90 K). To measure the field, a Hall sensor installed at the center of the solenoid was used.

a) *b*)

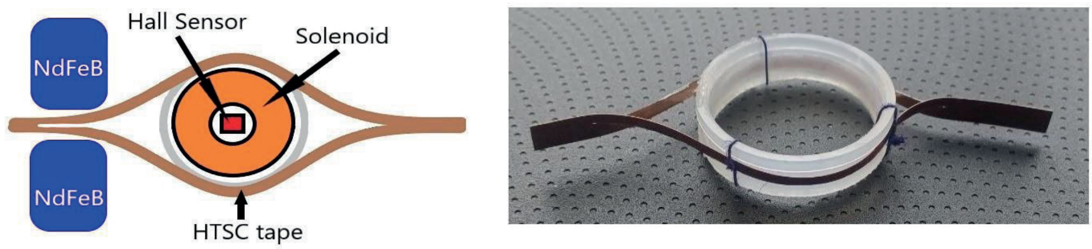

Fig. 1. Schematic representation of the design for measuring the critical current of the HTSC ring (*a*), photo of the HTSC ring (*b*)

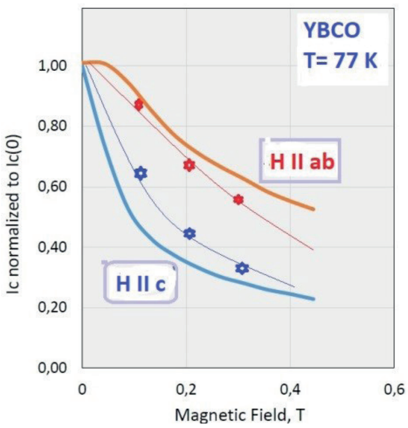

Fig. 2. Magnetic field dependence of critical current for SuperOx YBCO tape at T = 77 K. Magnetic field direction is along tape (***H*** ∥ ab) and normal to tape (***H*** ∥ c). Bold lines – data from [8], asterisks – our data obtained by non-contact method

First, the ring critical current was measured at ***H*** = 0 (without permanent magnets). It was found that, starting from a certain value of the external flux, the captured magnetic field (after the removal of the external flux) remained constant and equals to 4 mT. For the used ring with a diameter of 3 cm, this field corresponds to a current in the ring of about 100 A, that is higher than the expected value 85 A. Considering that the declared by the manufacturer J_c value is the smallest local value of the critical current of a long tape, it can be expected that in individual small pieces of the tape, the J_c values can be higher.

Using the permanent magnets the Jc values were measured at magnetic field direction along tape (***H*** ∥ ab) and normal to tape (***H*** ∥ c) (Fig. 2, asterisks) at a few magnetic fields and T = 77 K. The bold lines on Fig. 2 represent data for another SuperOx tape provided by the tape manufacturer [8]. One can see good qualitative agreement between the two datasets. Thus, the trapped magnetic flux method is an express method for measuring the dependence of the tape critical currents on the value and direction of the external magnetic field.

Conclusion

In the course of this work, the critical currents of the SuperOx HTS tape were measured by non-contact methods. The first method consisted in measuring the magnetization curve with a vibrating magnetometer and then converting the magnetization into a critical current using the equations. This method gives a discrepancy with the actual values by 15 %.

Another method of non-contact measurement of the critical current is to measure the trapped flux of a ring made from HTSC tape. The declared by the manufacturer J_c value is the smallest local value of the critical current of a long tape, it can be expected that in individual small pieces of the tape, the J_c values can be higher.

In addition, this method makes it possible to measure the anisotropy of the critical current if a magnetic field is applied locally to the section of the ring. The values obtained for the anisotropy of critical current are in good agreement with the values obtained by the manufacturer.

Acknowledgments

We thank SuperOx for providing samples of the HTSC tapes.

REFERENCES

1. **Uglietti D.,** A review of commercial high temperature superconducting materials for large magnets: From wires and tapes to cables and conductors, 2019 Supercond. Sci. Technol. 32 (5) (2019).

2. **Markelova A., Valikov A., Chepikov V., Petrzhik A., Massalimov B., Degtyarenko P., Uzkiha R., Soldatenko A., Molodyk A., Kideok Sim, Soon Hwang,** 2G HTS wire with enhanced engineering current density attained through the deposition of HTS layer with increased thickness, Progress in Superconductivity and Cryogenics 21 (4) (2019) 29–33.

3. **Li Y., Chen S., Paidpilli M., Jain R., Goel C., Selvamanickam V.,** A Reel-to-Reel Scanning Hall Probe Microscope for Characterizing Long REBCO Conductor in Magnetic Fields Up to 5 Tesla, IEEE Transactions on Applied Superconductivity 32 (4) (2022).

4. **Lee S., Kim W., Kim Y., Park S., Lee J., Hahn J., Hong G., Park I., Park C., Choi K.,** Characteristics of an HTS Pancake Coil in Persistent Current Mode Using Wind-and-Flip Winding Method, IEEE Transactions on applied superconductivity 23 (3) (2013).

5. **Zhang X., Zhong Z., Geng J., Shen B., Ma J., Li C., Zhang H., Dong Q., Coombs T.,** Study of Critical Current and n-Values of 2G HTS Tapes: Their Magnetic Field-Angular Dependence, J Supercond. Nov. Magn. 31 (2018) 3847–3854.

6. **Charles C., Paul N., George A., Jason D., Daniel J., Brian K.,** Investigation of the Relaxation of Persistent Current in Superconducting Closed Loops Made Out of YBCO Coated Conductors, IEEE Transactions on Applied Superconductivity 25 (3) (2015) 8200805.

7. **Shantsev D., Galperin Y., Johansen T.,** Thin superconducting disk with field-dependent critical current, Phys. Rev. B 61 (14) (2000) 9699–9706.

8. **Samoilenkov S.,** "Innovative coated conductors from SuperOx for power applications", EUCAS 2021, Sept 5-9, Moscow.

THE AUTHORS

CHIKUROV Daniil S.
d.chikurov@yandex.ru
ORCHID: 0000-0003-4879-0518

VOLKOV Mihail P.
m.volkov@mail.ioffe.ru

Received 26.10.2022. Approved after reviewing 14.11.2022. Accepted 15.11.2022.