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TESTS OF HTS 2G SUPERCONDUCTING TAPES USING THE LABVIEW ENVIRONMENT

Abstract

HTS 2G superconducting tapes without stabilizer are used for the construction of superconducting fault current limiters. The characteristics R =f(T) of the superconducting tape is essential for design of superconducting current limiters and analysis of their numerical models. The article presents the experimentally determined characteristics R=f(T) of the second generation superconducting tapes SF4050 and SF12050 using the LabVIEW integrated environment. The article describes the method of sample preparation and methodology of testing of HTS 2G superconducting tapes. The LabVIEW integrated environment was used for the testing, thanks to which it was possible to download, process and save measurement data.

1. INTRODUCTION

The special properties of superconductors enable the construction of electrical devices with parameters that cannot be obtained when using conventional materials. HTS 2G tapes based on yttrium have appropriate parameters for the construction of high current and high voltage limiters. In superconducting fault current limiters, the phenomenon of superconducting material retreating from the superconductive state to enter the resistive state is used as a result of exceeding the critical current value I_c (Kozak, Majka & Kwoka, 2017; Czerwiński, Jaroszyński, Majka, Kozak, & Charmas, 2016).

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Carrying out tests of HTS 2G superconducting tapes requires the use of appropriate measuring equipment and software. Often, the tests require a novel and flexible tool that enables efficient measurements, data processing, visualization and archiving of measurements and calculation results. The LabView programming environment from National Instruments seems ideal for such applications.

2. LabVIEW ENVIRONMENT

The LabVIEW programming environment (Virtual Instrument Engineering Workbench) is used in tests in industry, research and development, and wherever measurements and data analysis are performed. LabView is a graphical programming language in which icons instead of lines of code are used to create applications. Unlike textual programming languages, where instructions define the way in which a program is executed, LabView uses graphical programming of data flow between nodes and mathematical operations on data ("LabVIEW National Instruments", 2018).

LabVIEW allows one to design a graphical user interface and a source code integrated with it, also created in the graphical programming language G. The program in G language differs fundamentally from programs written in other, conventional (textual) languages, first of all, in the fact that it does not include variables in the explicit form, and the program is structured by the data flow. It also forces the sequence of actions: the specified function (component) of the program will be executed only when all required data will be delivered to it.

The LabView applications are called "virtual instruments" due to their similarity to physical measuring devices, such as oscilloscopes or meters. They consist of two basic components: the front panel and the block diagram, an example of which is shown in Figure 1. The front panel is the user interface. Here, the programmer can place input elements – used to enter data, application operation parameters, such as numerical inputs, knobs, sliders, buttons, and output elements – used to present the results of the application operation, such as numerical outputs, indicators modeled on analog meters ("LabVIEW National Instruments", 2018).

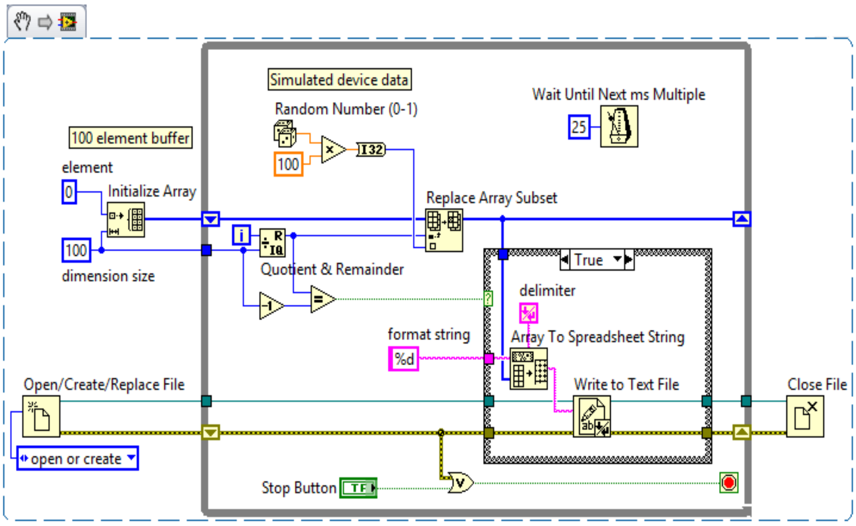

Fig. 1. Example of the program in the LabVIEW environment ("LabVIEW National Instruments", 2018)

3. HTS 2G SUPERCONDUCTING TAPES

The second generation superconducting tapes are made in thin-film technology. They consist of a number of layers from which one can distinguish: the substrate layer, stabilizer layer, buffer layers and the superconductor layer. The structure of the 2G Superconducting tape manufactured by SuperPower is shown in Figure 2.

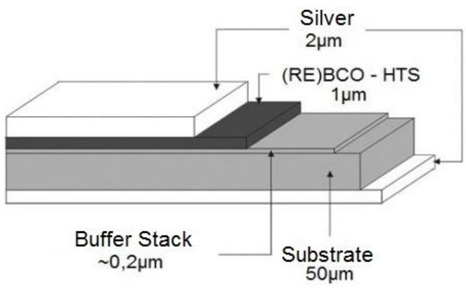

Fig. 2. Structure of HTS 2G superconducting tape without copper stabilizer ("SuperPower Inc.", 2018)

Currently, HTS 2G superconducting tapes are manufactured without stabilizer and with copper stabilizer with 2 mm, 3 mm, 4 mm widths (Fig. 3a), 6 mm and 12 mm (Fig. 3b), substrate thicknesses of 50 μm and 100 μm with a silver layer of 2 μm to 4,5 μm ("SuperPower Inc.", 2018).

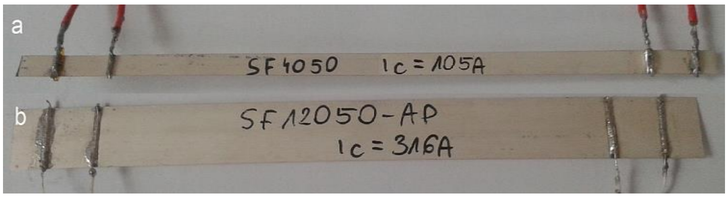

Fig. 3. SuperPower HTS 2G SF4050 superconducting tapes without copper stabilizer with 4mm (a) and 12mm width (b)

The basic parameters of SF type tapes produced by SuperPower are shown in Table 1.

Tab. 1. The parameters of the SF4050 and SF12050 tapes (SuperPower Inc., 2018)

Tape HTS 2G	SF4050	SF12050
Tape Width	4 mm	12 mm
Total Wire Thickness	55 μm	55 μm
HTS YBCO Layer Thickness	1 μm	1 μm
Silver Overlayer Thickness (upper/lower)	2.0/1.8 μm	2.0/1.8 μm
Substrate (Hastelloy C276) Thickness	50 μm	50 μm
Critical Bend Diameter in Tension	11 mm	11 mm
Critical Current $I_{C\,(77,4\,K)}$	105 A	316 A
Critical Temperature T_C	~92 K	~92 K

The HTS 2G superconducting tapes are used in such devices in which traditional conductors are replaced with superconducting equivalents. These include: cables, transformers or motors, and devices that do not have equivalents in the form of conventional conductors. The second group of devices in which the HTS 2G superconducting tapes are used include, among others, superconducting electromagnets, superconducting fault current limiters SFCL, generators (Kozak & Majka, 2014; Naeckel & Noe, 2014; Kozak, Majka, Janowski, Kozak, Wojtasiewicz & Kondratowicz-Kucewicz, 2011).

At operational currents, the current in the superconducting tape is smaller than the critical current I_C of the tape. In the superconductive state, the current flows in the layer of the superconductor YBCO with the omission of other layers. During a fault, the value of the current in the tape exceeds the value of the critical current I_C several times. The superconductor goes to the resistive state and the current in the tape flows mainly through the silver layer (about 80–90%) and the substrate. During a fault, the superconducting tape starts heating up very quickly, which is why the tape should have high resistance in a resistive state and a suitable thermal capacity. During a fault, the temperature and resistance of the tape increases, and therefore the experimental determination of its characteristics R=f(T) is necessary.

4. TEST OF HTS 2G SUPERCONDUCTING TAPES USING THE LabVIEW ENVIRONMENT

Tests of resistance in the temperature function *R*=f(*T*) were performed for two types of HTS 2G superconducting tapes: SF4050 and SF12050. The characteristics *R*=f(*T*) were determined using the four-wire method using current (I–, I +) and voltage (V–, V +) leads to measure voltages spaced at 100 mm (Fig. 4). The tape sample holder was made of a glass-epoxy composite to which two copper flat bars insulated with 50 μm thick polyimide tape are fixed. After turning the holder, the superconducting tape adheres on both sides to the flat bars; the sample is electrically insulated, and its temperature is measured by the LakeShore Cryotronics CERNOX sensor placed in a hole made in one of the copper flat bars. The test leads are soldered to the superconducting tape sample by means of a hot air soldering tool with the Sn62Pb36Ag2 alloy at 210 ºC.

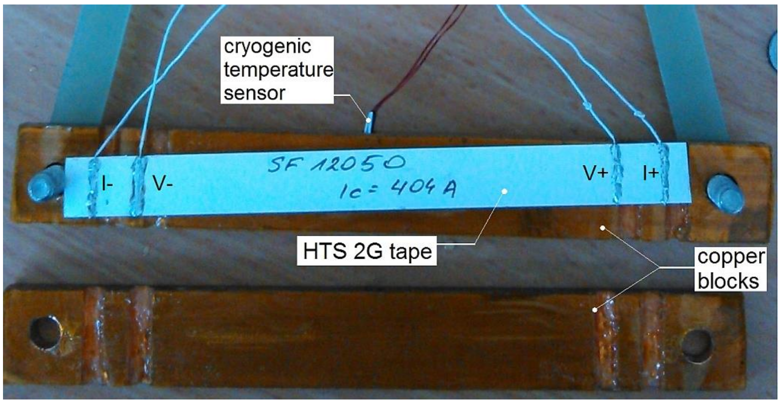

Fig. 4. HTS 2G tape sample in the holder

To carry out measurements and determine the characteristics *R*=f(*T*) of HTS 2G SF4050 and SF12050 superconducting tapes, a laboratory measuring system was built (Fig. 4). The measuring system consists of a computer with software written in the LabVIEV environment, the Lake Shore Temperature Monitor 218 temperature meter with a CERNOX cryogenic temperature sensor, NI USB-6343 measuring card, liquid nitrogen cryostat, HTS 2G tape sample holder. Communication between the temperature meter and the computer is carried out via the GPIB port using the GPIB-USB-HS + converter. To measure the current (voltage on the shunt) and the voltage on the tape sample, two analog inputs of the USB-6343 card were used (Fig. 5). Measurement of the superconductor tape resistance is carried out every 0.1 K for 50 ms, in order not to additionally heat the sample with 100 mA.

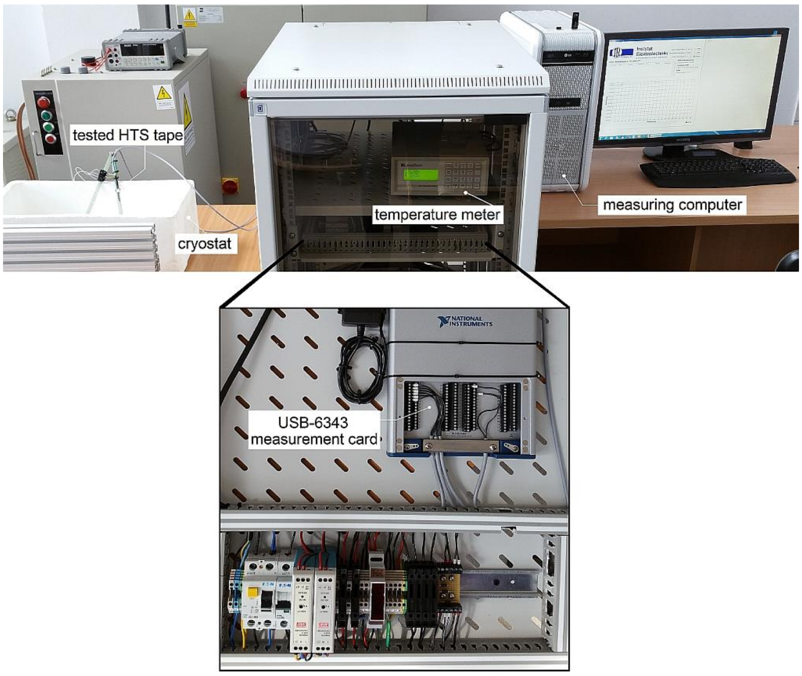

Fig. 5. Laboratory measurement system (own study)

4.1. Test of the characteristics *R*=f(*T*)

Measurement of the characteristics *R*=f(*T*) of the tape was made in the measurement system shown in Figure 5. After cooling the holder with the sample of the superconducting tape in a liquid nitrogen bath to 77.4 K (Fig. 6) the handle was removed from the cryostat.

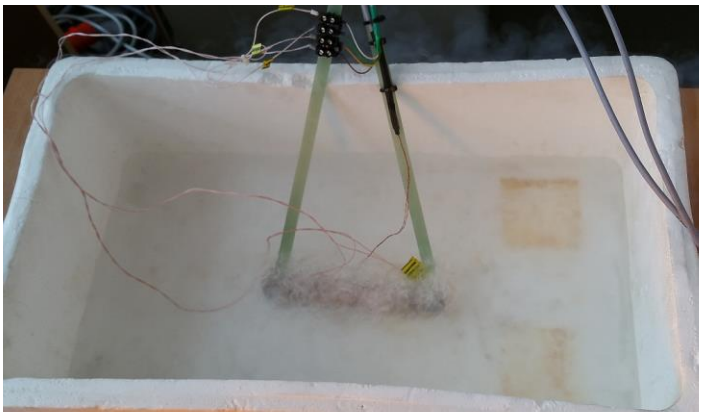

Fig. 6. Sample of HTS 2G tape placed in the holder during cooling in liquid nitrogen

During the slow heating, the results of the measurements are recorded in the temperature range 77 K – 300 K. For the registration of measurements, IEl RT program was written in the LabView environment (Fig. 7). The program allows one to read the temperature from the LakeShore Temperature monitor 218 through the GPIB port, control the relay, and save to * .xls file of all registered parameters.

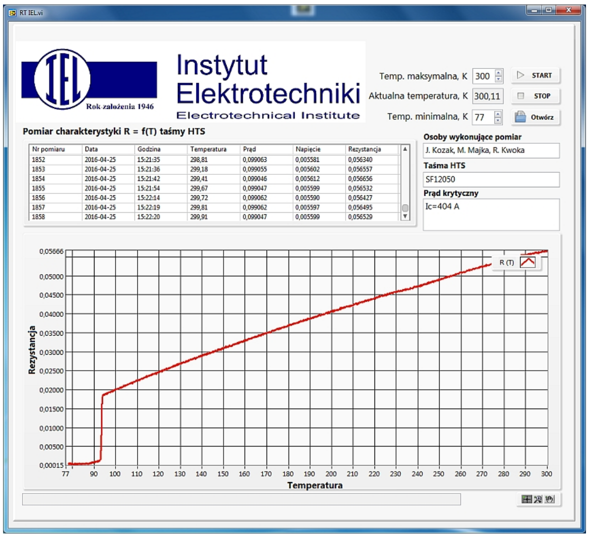

Fig. 7. Determining the characteristics *R*=f(*T*) for HTS 2G SF12050 tape using the LabView environment

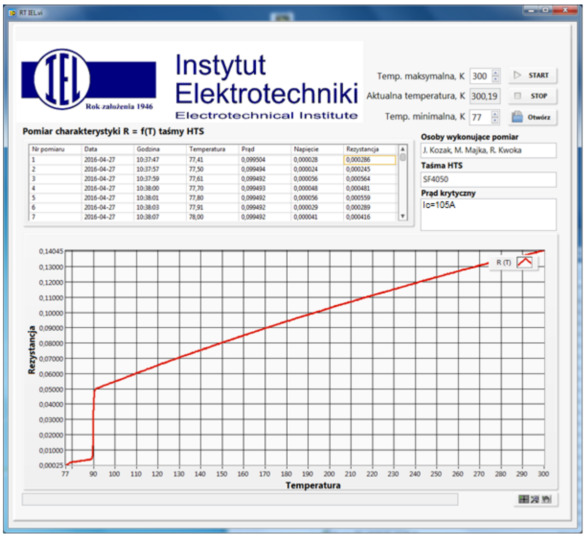

Fig. 8. Determining the characteristics *R*=f(*T*) for HTS 2G SF4050 tape using the LabView environment

The graph (Fig. 9) presents the obtained characteristics R=f(T) of the tested superconducting tapes. The resistance of both tapes measured at 77,4 K is equal to zero.

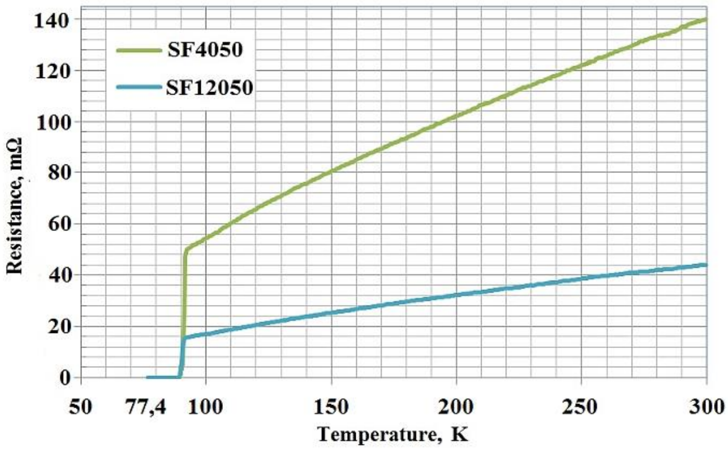

Fig. 9. List of test results concerning characteristics *R*=f(*T*)

The graph shows the characteristic transition of the superconductor from the superconductive state to the resistive state at the critical temperature T_C. SF12050 tape has approximately three times lower resistance than SF4050 tape after exceeding T_C. In the calculation of windings in superconducting fault current limiters, both the resistance of the tape and thermal capacity are taken into account. These parameters make it possible to calculate the tape temperature during a fault.

3. CONCLUSIONS

The article presents the experimentally determined characteristics R=f(T) of the second generation superconducting tapes (SF4050 and SF12050) without copper stabilizer. The tests were carried out in the temperature range from 77,4 to 300 K. The article presents a method of preparing samples of superconducting tapes for testing, a measurement method and a way of making measurements. The integrated LabVIEW environment was applied as a tool using the graphical programming language G. Consequently, it was possible to construct virtual devices intended for data collection, processing, analysis, visualization, and for process and measurement control. The experimentally determined characteristics R=f(T) are necessary for the design of superconducting current limiters and the analysis of their numerical models.

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