energies

Article

Study on Recovery Time of Conduction-Cooled Resistive Superconducting Fault Current Limiter

Janusz Kozak

Faculty of Electrical Engineering and Computer Science, Department of Electrical Engineering and Superconducting Technology, Lublin University of Technology, 38A Nadbystrzycka St., 20-618 Lublin, Poland; j.kozak@pollub.pl

Abstract: This paper presents the influence of superconducting tape insulation on the recovery time of superconducting fault current limiters. The analysis is based on the experimental results of short-circuit tests. The reduction in the thermal and dynamic effects of the passage of a fault current can be achieved by limiting the short-circuit time and the value of the surge current. An ideal fault current limiter is required to have almost zero impedance at operating currents and significant impedance at fault conditions. A superconducting fault current limiter (SFCL) meets these requirements under certain conditions. The recovery time—a very important parameter—shows the ability of the limiter to return to the superconducting state to be ready to limit the subsequent short circuit. The experimental results show that the recovery time can be significantly reduced with the application of thin-film insulation and an appropriate design of the conduction cooling of the HTS tape.

Keywords: superconducting fault current limiter; recovery time; superconducting tape; short circuit

check for updates

Citation: Kozak, J. Study on Recovery Time of Conduction-Cooled Resistive Superconducting Fault Current Limiter. *Energies* **2024**, *17*, 3350. https://doi.org/10.3390/en17133350

Academic Editors: Andrea Mariscotti and Zheng Xu

Received: 27 May 2024
Revised: 28 June 2024
Accepted: 5 July 2024
Published: 8 July 2024

Copyright: © 2024 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

A limitation of both the short-circuit time and the value of the maximum initial fault current reduces the thermal and dynamic effects of the passage of a fault current. The use of devices that limit the value of a fault current can reduce the required short-circuit capacity of the entire system. However, the chosen means of fault current limitation must meet power quality standards. An ideal fault current limiter would have substantial impedance in fault conditions and zero impedance at operating currents. These requirements are met by a superconducting fault current limiter (SFCL). An increase in current caused by the occurrence of a fault current causes the superconducting material to go from the superconducting state to the resistive state. This increases the impedance of the short-circuit loop, allowing the fault current value to decrease [1]. A significant body of literature exists on the study and improvement of the performance of different types of short-circuit current limiters. Numerous papers have addressed the topic of inductive-type fault current limiters [2–6]. To enhance their performance and reduce their size, a novel approach to saturated-core fault current limiters has been proposed [7–9]. Resistive fault current limiters are also employed for the rapid limitation of short-circuit currents in HVDC transmission systems [10]. To meet the demand for reclosing, fast recovery is essential [11].

2. The Expectations toward the Limiter

2.1. Installation

In order for the superconducting fault current limiter to be widely installed in the existing substations, it should be as small as a circuit breaker and air cooled. The SFCL is a cryogenic device that requires a cryogenic cooling system. Unlike liquid nitrogen cooling, air cooling and the electrical power supply required for the correct operation of the SFCL are relatively straightforward to install in substations. The liquid-nitrogen-cooled limiter necessitates frequent replenishment of nitrogen and a special design to permit rapid removal of nitrogen vapours in the event of a short circuit. Such an installation occupies a considerable amount of space and entails significant modifications. The use of contact cryocoolers to cool the limiter effectively eliminates the need for a liquid nitrogen cooling installation.

2.2. Operation

The limiter is expected to operate reliably and to be invisible in the network at rated currents. A voltage drop across the limiter, which occurs mainly at the current feedthroughs, should be as low as possible. Regardless of how the limiter windings are cooled, with liquid nitrogen or by contact cooling, the cooling system must remove heat from the cryostat during rated operation. Power dissipation in the current feedthroughs is a function of the temperature difference, the resistance of the feedthroughs and the current. To maintain a stable temperature of the contact-cooled superconducting windings at varying current levels, a cryocooler with a temperature controller must be used. The transition from the superconducting state to the resistive state should be automatic and repeatable at the same adjustable current value. During rated operation, the superconducting windings, like the rest of the components, are kept at cryogenic temperature. During a short circuit, a sudden rise in temperature causes the high-temperature superconducting tape to expand while the other components remain cold. This results in mechanical stresses that can damage the HTS tape or cause permanent degradation of its critical current. To prevent the stresses from exceeding the permissible values, it is necessary to limit the maximum temperature of the HTS tape during short-circuiting by reducing the short-circuit time with a fast circuit breaker and by reducing the thermal resistance between the HTS tape and the cold mass. A short-circuit current also creates dynamic forces on the superconducting windings. These forces can cause winding sweep and damage to the electrical insulation.

2.3. Short Circuit

It is recommended that a superconducting fault current limiter should limit a surge current in less than 1 ms in order to significantly reduce the dynamic and thermal impact of the short-circuit current before opening the circuit breaker contacts. The contact-cooled resistive limiter can achieve a short time of 0.6 ms, which has been experimentally confirmed [1]. Once a short circuit has been cleared, the limiter should revert to its superconducting state, thus ensuring readiness for reclosure.

2.4. Recovery

Should the critical value of the current be exceeded, the superconductor will become resistive and will heat up at an accelerated rate. An increase in temperature will result in an increase in resistance and subsequent limitation of the current. In order to return the limiter to the superconducting state, it is necessary to switch off the current through the circuit breaker and to cool the superconductor as rapidly as possible. The recovery time of the limiter should be as short as possible. The recovery time is contingent upon the speed with which the circuit breaker disconnects the current and the efficacy of the cooling system. Additionally, the recovery time is influenced by the thermal conductivity of the structural elements and the insulation of the superconductor. The liquid-nitrogen-cooled limiter comprises fully submerged windings [12]. A sudden temperature rise causes the nitrogen to evaporate in the immediate vicinity of the HTS tape. The pressure generated within the cryostat facilitates the escape of nitrogen vapours through the apertures in the cryostat cover at a high rate of speed. The superconducting tape, whose temperature is approximately 200 K higher than that of liquid nitrogen, is subject to challenging conditions with regard to heat dissipation. It takes time for the nitrogen vapours to dissipate and for the superconducting windings to cool down. However, the design of the contact-cooled limiter ensures a faster cooling of the superconductor.

2.5. Reliability

The superconducting fault current limiter is expected to operate reliably in order to protect power system elements against the dynamic and thermal effects of fault currents. The SFCL is a self-triggering device and does not require an external current monitoring and tripping system. The limiter responds immediately when the critical current value is exceeded. It is imperative that the limiter is operated in conjunction with a circuit breaker that will switch off the limited short-circuit current, thus protecting the windings of the limiter from overheating and irreparable damage. This circuit breaker must be controlled by a system that monitors the rate of current rise. In the case of a circuit with a superconducting fault current limiter, the circuit breaker should be selected taking into account the short-circuit current but already limited. In the case of a contact-cooled superconducting current limiter, which was tested successfully in the accredited Switchgear and Controlgear Testing Laboratory of the Electrotechnical Institute in Warsaw, the SFCL effectively limited the peak value of a fault current by more than 40 times (from 81 kA to 1.9 kA) within 0.6 ms [1]. Reliable operation of the superconducting short-circuit current limiter can be achieved by appropriately selecting the parameters of the circuit breaker trip circuit.

2.6. Maintenance

It is also desirable that the superconducting fault current limiter should be maintenance-free. Liquid nitrogen cooling requires a regular supply of liquid nitrogen, at least several times a year, depending on the capacity of the liquid nitrogen tank. The use of additional cryocoolers in the liquid nitrogen system allows the frequency of liquid nitrogen replenishment to be reduced. Gifford-McMahon cryocoolers should normally be serviced every 10,000 h. A maintenance-free cooling system can be achieved by utilising single-stage CryoTel cryocoolers with a mean time to failure of over 200,000 h [13]. Contact cooling of the superconductor eliminates the need for liquid nitrogen, while air cooling of the cryocoolers simplifies the overall design of the limiter. The cryocooler head is responsible for removing the heat reaching the interior of the cryostat through radiation and thermal conduction. Additionally, it removes the heat from the superconducting windings generated due to AC losses and Joule losses which result from current flow through the current leads. The dependability of the limiter is contingent upon the dependability of the cooling system.

3. The Concept of the Fast Recovery SFCL

Among the many superconducting fault current limiter designs, the contact-cooled resistive superconducting fault current limiter appears to be the most attractive. Liquid-cooled limiters, in which HTS tape is insulated with Kapton to provide adequate electrical insulation, are fast but have a long recovery time [12]. The superconducting fault current limiter described in paper [12] is cooled with liquid nitrogen. In that design, the superconducting windings are made of HTS tape wrapped with polyimide tape. The turns of the windings are wound one on top of the other. The thermal conductivity of the HTS tape insulation is too low to allow rapid cooling in liquid nitrogen after a short-circuit current has been switched off [12]. An SFCL of similar design cooled with liquid nitrogen has windings made of HTS tape, which are insulated with a single layer of polyimide tape during winding. The temperature of the HTS windings rises up to 260 K during a short circuit. The recovery time depends on the temperature of the tape and takes about 27 s after a 100 ms short circuit.

3.1. Reduction in the Recovery Time

A reduction in cooling time can be achieved by using a winding design that avoids HTS-to-HTS tape heat transfer. Direct heat transfer from the HTS tape through the insulator to the coolant or to the cold mass allows the recovery time to be reduced. Thermal conductivity depends on the thickness of the insulator, the insulator material and the contact between the HTS tape and the insulator. The limiter described in [1] consists of two coils and internal and external cooling plates. This design ensures a recovery time of less than

2 s. The recovery time can be reduced to less than one second by using a fast circuit breaker to reduce the limitation time from 80 ms to 10 ms [14].

3.2. Concept

The concept of the fast recovery superconducting fault current limiter is to involve the use of the anodised aluminium alloy to accelerate the heat transfer from the HTS tape to the cold mass. The aluminium alloy block, which ensures appropriate heat capacity and electrical resistance through a thin layer achieved in the anodising process, can shorten the recovery time. The idea behind the proposed solution is to reduce the thermal resistance between the superconducting tape and the cold mass. This is so that, after a short circuit, the temperature of the superconducting tape reaches its pre-short-circuit value as quickly as possible. There are many insulating materials that can provide good insulating properties, but not all are suitable for cryogenic temperatures. On the one hand, the insulation thickness of superconducting tape has a positive effect on the breakdown voltage; on the other hand, it increases the thermal resistance. Using a single layer of insulation and reducing the thickness improve the thermal conductivity conditions. Constructing a superconducting fault current limiter using very thin single-layer insulation can be technically very difficult. The superconducting tape may move slightly during cooling due to the different expansion of the materials used in the construction of the SFCL. Also, the HTS tape may move during a short circuit as a result of dynamic forces and a rapid temperature rise. Small displacements of the superconducting tape can cause degradation of the insulation and result in electrical breakdown. The concept presented here uses durable but thin insulation to provide good thermal conductivity between the HTS tape and the aluminium blocks in order to ensure adequate heat capacity. It also uses a second insulation to provide the required breakdown voltage between the anodised sectioned aluminium blocks and the cold mass. The aluminium anodising process ensures a durable insulating film thickness in the order of micrometers. The thickness of the obtained anode layer on aluminium depends on the anodising time. A suitable insulation layer can, therefore, be produced easily and accurately. Three sets of square insulated aluminium profiles were prepared for measurement purposes. The first set was insulated with double polyamide tape, the second set was insulated with single polyamide tape, and the third set was anodised to a coating thickness of 30 µm. The aluminium blocks insulated in this way were placed on both sides of the HTS tape and pressed with a force of approximately 500 N.

4. Measurement Setup

4.1. Sample

Sample blocks were made of 6060 aluminium alloy, anodised in the sulphuric acid process Type II to a thickness of 30 micrometres. Anodising is a conversion coating that transforms aluminium on the surface of components into aluminium oxide. The overall thickness of the coating formed is 67 percent penetration in the substrate and 33 percent growth over the original dimension of the part. For comparison, identical non-anodised blocks were prepared with polyimide tape insulator 50 and were 100 micrometres in thickness. A current is applied between the copper blocks $I+$ and $I-$. The voltage on the HTS tape is measured over the length of 200 mm as shown in Figure 1. The upper and lower copper blocks are bolted together to ensure good electrical contact with the HTS tape positioned between them.

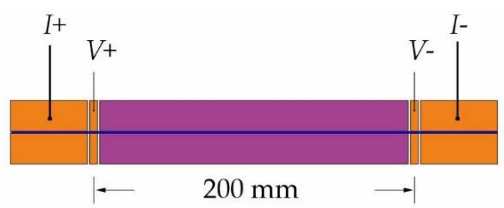

Figure 1. Side view of the HTS tape between anodised aluminium blocks.

Figure 2 shows a cross-section of the sample. The HTS tape is sandwiched between two thin-walled anodised profiles with a square cross-section of 20 mm × 20 mm and a wall thickness of 0.8 mm. A clamping force of 500 N was applied to ensure good thermal contact.

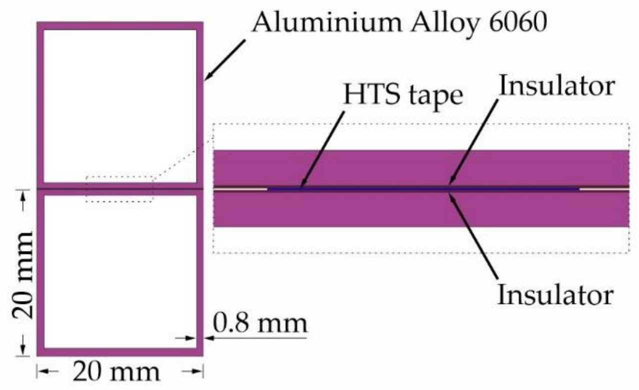

Figure 2. A cross-sectional view of the HTS tape between anodised aluminium blocks.

The first sample, shown in Figure 3, consists of HTS tape and two non-anodised profiles insulated with double Kapton tape. The next sample consists of HTS tape and two non-anodised profiles insulated with single Kapton tape. The third sample is an HTS tape sandwiched between two anodised aluminium profiles.

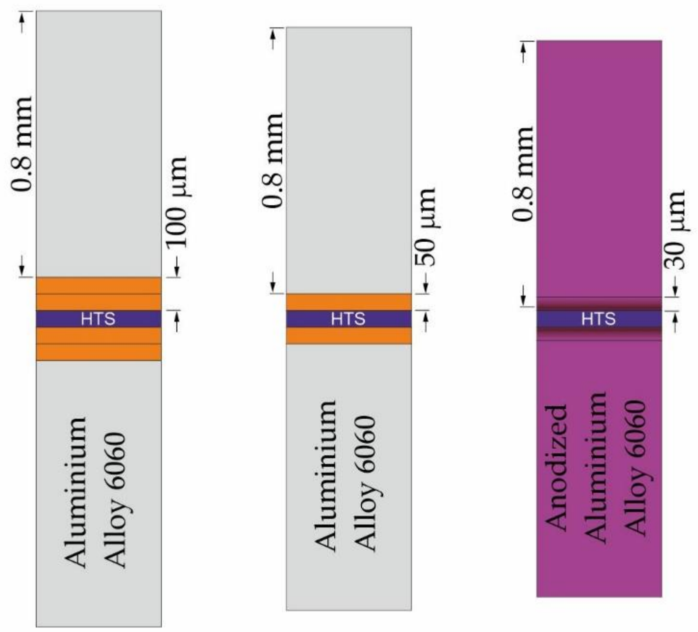

Figure 3. A comparison of three samples with different HTS tape insulators.

4.2. Test Setup

The test was performed on a short sample of 2G SF4050 HTS tape [15]. The current in the circuit and the voltage on the tape were measured using differential probes connected to the USB-6343 card shown in Figure 4.

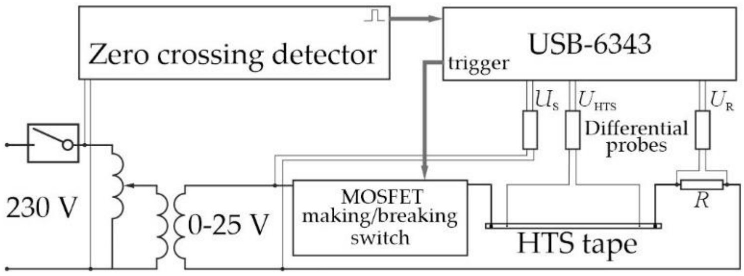

Figure 4. A scheme of the circuit.

The resistance of the HTS tape during a short circuit is measured by measuring the voltage across the HTS tape (U_{HTS}) and the voltage across the *R* shunt. It is possible to measure the resistance before the short circuit and after the short circuit has been switched off by means of an additional resistor connected in parallel with the connection switch. The additional resistor causes a small current to flow, which has little effect on the heating of the HTS tape but makes it possible to measure the voltage across it. An autotransformer positioned before the step-down transformer allows precise adjustment and setting of appropriate U_S supply voltage. The zero-crossing detector allows accurate detection of the zero-crossing of the supply voltage and the generation of a logic signal in the form of a short rectangular pulse. The switch consists of a diode bridge and MOSFET transistors. A trigger signal from the USB-6343 multifunction card via an optocoupler allows the switch to be quickly switched on and off. In the circuit shown, short-circuit currents of up to 700 A can be measured.

The laboratory setup shown in Figure 5 consists of a sample holder, a power supply and a computer with software. The sample holder is equipped with current terminals and voltage terminals. The voltage clamps are located on the interior and allow the measurement of the voltage of the HTS tape over a distance of 0.2 m. The current clamps on the exterior of the HTS tape holder are supplied with power via 50 mm^2 copper wires. Furthermore, a shunt is incorporated into the circuit in series, which is marked R in the diagram and serves to measure the current. The power supply system, comprising the components illustrated in Figure 5, is housed within the grey enclosure.

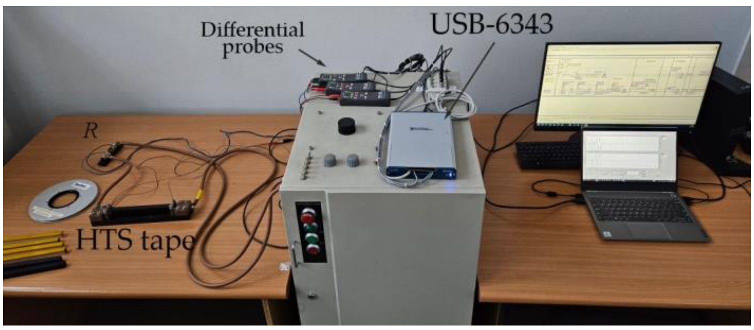

Figure 5. Laboratory test bench for recovery time.

The software written in LabView 21.0 (Figure 6) enables the short-circuit parameters to be set. Zero crossing detection, short duration and number of consecutive shorts are realised by software and hardware consisting of step-down transformers and a MOSFET connection switch.

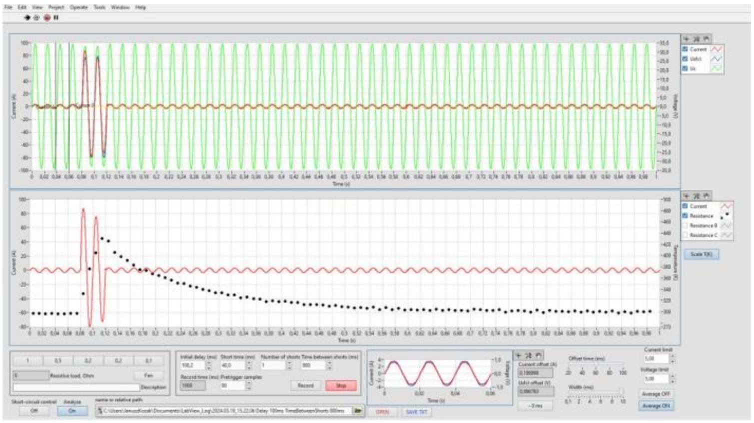

Figure 6. Software developed in LabView.

Figure 6 depicts the front panel of the software. The software enables the user to control the short-circuit system and to save measurements to a file, as well as to read measurements from the file. The measured current and voltage waveforms are displayed in the top graph. The graph at the bottom shows a short-circuit current waveform and the averaged resistance values during a short circuit. Below the bottom graph, there are elements for setting the parameters of the short-circuit system, including load resistance value, short-circuit delay time, short-circuit time, time between consecutive short circuits, acquisition time and number of short circuits. The path to the file is at the very bottom of the screenshot.

5. Measurement Results

The 2G SF4050 superconducting tape from SuperPower was utilised in the measurements. This superconducting tape is 4 mm in width and approximately 50 µm in thickness. The tests were performed for a temperature range of 300–430 K. This range partly overlaps with the operating range of the SFCL and is sufficient to compare the effect of superconductor insulation on the cooling rate. The small sample results presented in the paper will form the basis for the development and construction of a medium voltage limiter, which will be tested in a short-circuit laboratory as previous designs [1,12].

Figure 7a illustrates the waveforms of the current I in the measurement circuit, the supply voltage U_S and the voltage on the HTS tape U_{HTS}, before, during and after a short circuit. A short circuit commences when the current passes through zero and persists for 40 ms. Figure 7b depicts the waveforms of the current and the instantaneous resistance values calculated as U_{HTS}/I. Figure 7c depicts the current and instantaneous resistance waveforms without the values calculated when the current passes through zero. Figure 7d presents the waveforms of current and the averaged resistance values calculated every 10 ms. Figure 7e illustrates the current waveforms and the averaged temperature values calculated every 10 ms.

Figure 8 presents a comparison of the temperature of the HTS tape during and after the short circuit, plotted for four different supply voltages of the short circuit system. Prior to the short circuit, the temperature of the HTS tape is approximately 300 K. During the short circuit, the temperature rises rapidly. The dots on the graph represent the average temperature values, which are recorded every 10 ms. The rapid rise in temperature of the HTS tape results in a rapid reduction in the short-circuit current. The highest temperature and the fastest temperature rise were obtained for the highest value of voltage per metre of the tape. Therefore, in order to ensure that the limiter is ready for the next short circuit, it is important to make the return time of the SFCL after the short circuit has been removed as short as possible.

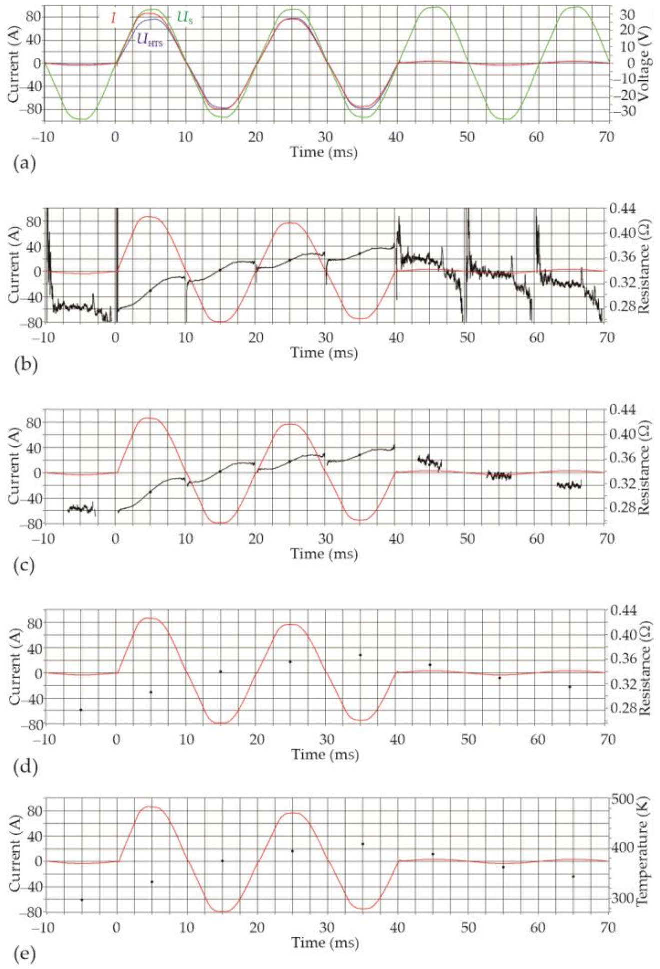

Figure 7. Measurement results: (**a**) current and voltage measured on HTS tape, (**b**) HTS tape resistance calculated during short circuit, (**c**) HTS tape filtered resistance course, (**d**) average resistance values calculated every 10 ms and (**e**) average resistance values of HTS tape converted to temperature.

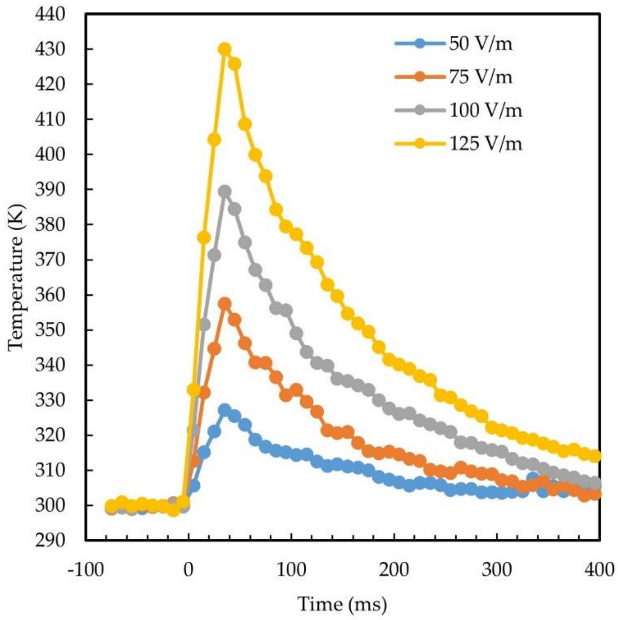

Figure 8. A comparison of the temperature of HTS tape sandwiched between aluminium profiles insulated with double Kapton tape (100 μm) during a short circuit lasting 40 ms for different values of electric field strength.

The incorporation of thicker insulation has a beneficial impact on the breakdown voltage between the HTS tape and the aluminium profile. However, the recovery time for both 100 µm-thick (Figure 8) and 50 µm-thick (Figure 9) insulation is prolonged, despite the tape being heated to the same temperature.

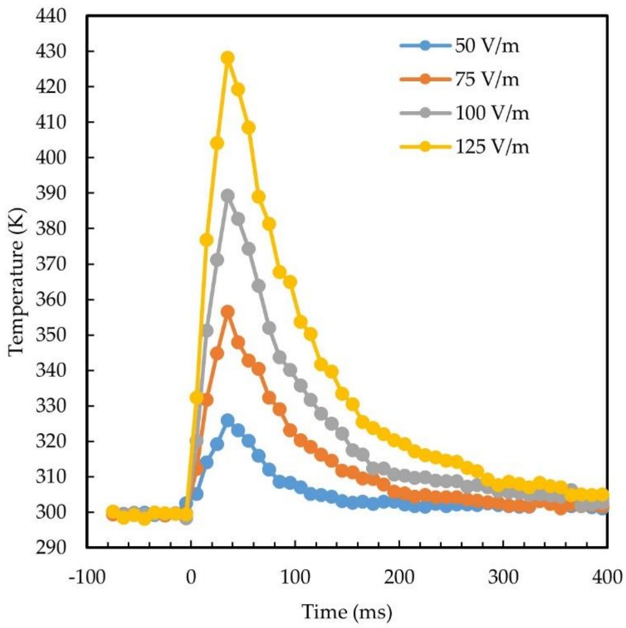

Figure 9. A comparison of the temperature of HTS tape sandwiched between aluminum profiles insulated with single Kapton tape (50 µm) during a short circuit lasting 40 ms for different values of electric field strength.

It can be observed that thinner insulation provides a shorter recovery time. Figure 10 illustrates the HTS tape temperature values recorded for aluminium profiles with a thin insulating layer (30 µm) obtained by anodising. It can be noted that although the insulating layer obtained by anodising does not possess the same insulating properties as Kapton, it can be obtained permanently and in practically any thickness below 30 µm. The electrical insulation of HTS tape can be enhanced by separating the anodised parts that adhere directly to the HTS tape and then insulating them from the grounded cold mass using Kapton tape. This solution provides good thermal conductivity and a short recovery time without affecting the breakdown voltage value.

Figure 11 shows a comparison of the temperature of the HTS tape during a short-circuit test for three insulation thicknesses at an electric field strength of 125 V/m for the HTS tape. A short circuit lasts from 0 ms to 40 ms and at the beginning of the short circuit, the characteristics coincide because the current is limited equally for the polyimide insulation and the anodised layer. During a short circuit, the temperature of the HTS tape rises to 430 K when polyimide insulation is used in both 50 µm and 100 µm thicknesses. In contrast, if anodised aluminium is used, the maximum temperature is lower and reaches approximately 410 K. Table 1 presents the heating and cooling times of the HTS tape during a short circuit for the tested insulations.

Table 1. Heating and cooling time of the superconducting tape during the short-circuit test at 125 V/m.

Insulator	Heating (310 K–410 K)	Cooling (410 K–310 K)
Kapton 100 µm	29 ms	400 ms
Kapton 50 µm	29 ms	240 ms
Anodised 30 µm	37 ms	170 ms

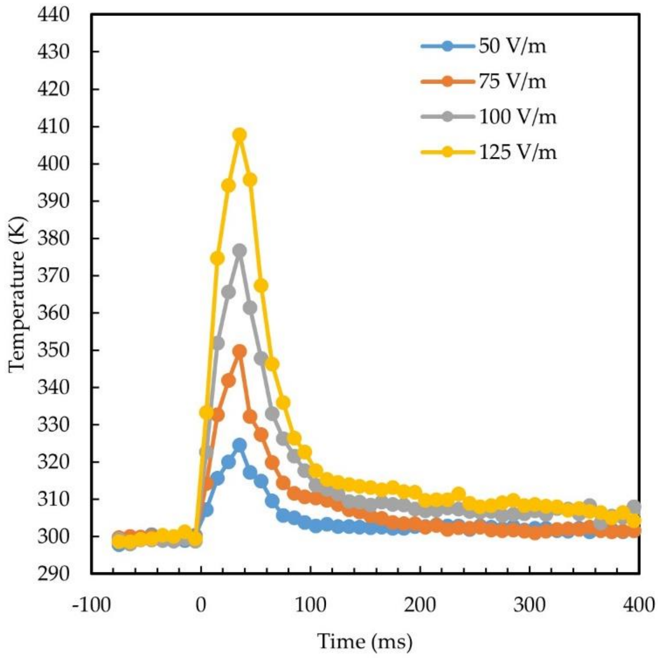

Figure 10. A comparison of the temperature of HTS tape sandwiched between anodized (30 μm) aluminum profiles, during a short circuit lasting 40 ms for different values of electric field strength.

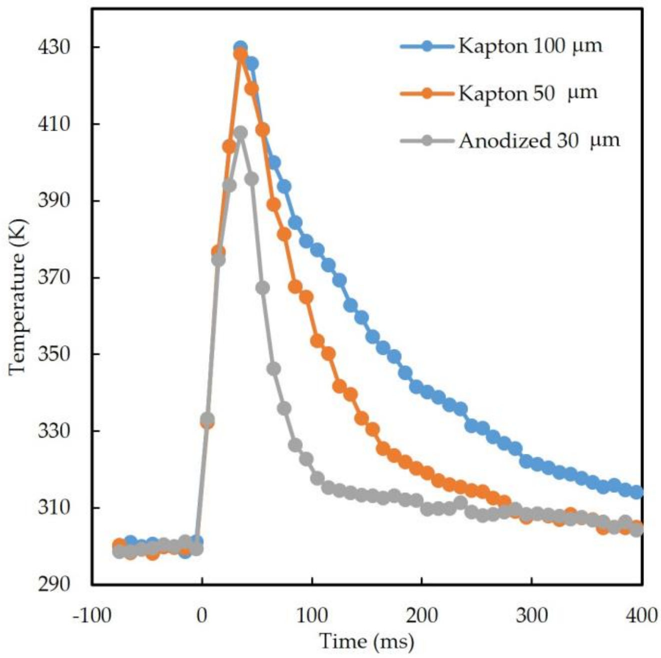

Figure 11. A comparison of the temperature of HTS tape during a short-circuit test at an electric field strength of 125 V/m for HTS tape.

In the event of a short circuit, the temperature of the superconductor rises rapidly, with the energy of the surge current heating the superconducting tape to 430 K in 29 ms for both 50 μm- and 100 μm-thick insulation due to the high thermal resistance. In the case of anodised aluminium, the effect of the lower thermal resistance is more pronounced, with the temperature reaching a lower value.

6. Discussion

The anodised aluminium provides the fastest cooling of the HTS tape following the termination of a short circuit. A comparison of the temperature drop rate by 100 K, from

410 K to 310 K, for all cases reveals that for an insulation thickness of 100 µm, the time required is approximately 400 ms, for an insulation thickness of 50 µm, it is 240 ms, while for an insulation thickness of 30 µm, it is only 170 ms. Furthermore, the initial 50 K drop takes only 25 ms for the aluminium with a 30 µm anodised layer, while for the insulation of 50 µm and 100 µm, it takes 45 ms and 90 ms, respectively. When dissipating heat from the superconducting tape through the insulation to a component with a much lower temperature, good contact is also important. Even when employing a single-layer insulation, two contact surfaces are present. In contrast, anodised aluminium affords only a single contact surface. The interface thermal resistance plays a key role in heat conduction between two materials. The interface thermal resistance is determined by phonon density-of-states overlapping, group velocity and bonding [16].

This paper describes the research carried out to improve an important parameter of a superconducting fault current limiter. Tests were carried out to reduce the recovery time of the superconducting fault current limiter to its rated operation. The return of a superconducting tape to the superconducting state after a short circuit is switched off depends on the type and thickness of the used insulation. In order to achieve this, insulation made of polyimide tape and a thin layer of anodised aluminium were compared.

7. Conclusions

The use of the insulation proposed in this paper, i.e., a thin layer of anodised aluminium, allowed the recovery time of the superconducting fault current limiter to be greatly reduced without adversely affecting the rate of temperature rise and the limiter's performance during the limitation of short-circuit current. The thickness of the anodic layer produced on the aluminium surface can be appropriately selected over a wide range, which is of great significance in the design of an SFCL with a very short recovery time. Based on these tests, a contact-cooled limiter will be built and subjected to short-circuit testing in an accredited short-circuit laboratory, as with previous designs.

Funding: This research was funded by the Lublin University of Technology, grant number FD-20/EE-2/408.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Kozak, J. Forces and Stresses in the Windings of a Superconducting Fault Current Limiter. *Energies* **2022**, *15*, 6519. [CrossRef]
2. Naeckel, O.; Noe, M. Design and Test of an Air Coil Superconducting Fault Current Limiter Demonstrator. *IEEE Trans. Appl. Supercond.* **2013**, *24*, 5601605. [CrossRef]
3. Kvitkovic, J.; Pamidi, S.V.; Graber, L.; Chiocchio, T.; Steurer, M.; Usoskin, A. AC loss and magnetic shielding measurements on 2G HTS inductive fault current limiter prototype modules. *IEEE Trans. Appl. Supercond.* **2014**, *24*, 5600604. [CrossRef]
4. Heydari, H.; Sharifi, R. Three-Dimensional Pareto-Optimal Design of Inductive Superconducting Fault Current Limiters. *IEEE Trans. Appl. Supercond.* **2010**, *20*, 2301–2311. [CrossRef]
5. Wang, C.; Hong, W.; Lu, J.; Li, B.; Xin, Y.; Li, W.; Yang, T.; Zhang, Y. Experiment Studies of a DC Inductive Superconducting Fault Current Limiter with Energy Dissipation Capability. *IEEE Trans. Appl. Supercond.* **2024**, *34*, 5600505. [CrossRef]
6. Chen, Y.; Wang, Z.; Shen, B.; Wang, B.; Sheng, J. Optimization of Inductive Superconducting Fault Current Limiter for Distribution Networks. *IEEE Trans. Appl. Supercond.* **2021**, *31*, 5603705. [CrossRef]
7. Yuan, J.; Ye, C.; Zhou, H.; Liu, J.; Zheng, Y.; Dong, W.; Ni, Z.; Wei, L. A Compact Saturated Core Fault Current Limiter Magnetically Integrated with Decoupling Windings. *IEEE Trans. Power Deliv.* **2023**, *38*, 2711–2723. [CrossRef]
8. Lei, H.; Gui, J.; Johnson, B. Impact of Saturated Iron Core Superconducting Fault Current Limiters on Traveling-Wave-Based Protection. *IEEE Trans. Appl. Supercond.* **2023**, *33*, 5601308. [CrossRef]
9. Zhang, Z.; Yuan, J.; Hong, Y.; Chen, H.; Zou, C.; Zhou, H. Hybrid Multifunctional Saturated-Core Fault Current Limiter. *IEEE Trans. Power Deliv.* **2022**, *37*, 4690–4699. [CrossRef]
10. Prakash Reddy, S.R.; Kar, S.; Rajashekara, K. Resistive SFCL Integrated Ultrafast DC Hybrid Circuit Breaker for Subsea HVDC Transmission Systems. *IEEE Trans. Ind. Appl.* **2022**, *58*, 5977–5986.
11. Li, L.; Song, M.; Zhang, Q.; Xiang, B.; Yuan, Z.; Tang, Z.; Liu, Z.; Geng, Y.; Wang, J. Effects of Lamination Thickness on Recovery Characteristics of a Variable Resistance SFCL. *IEEE Trans. Appl. Supercond.* **2024**, *34*, 5600405. [CrossRef]
12. Kozak, J.; Majka, M.; Kozak, S.; Janowski, T. Design and Tests of Coreless Inductive Superconducting Fault Current Limiter. *IEEE Trans. Appl. Supercond.* **2012**, *22*, 5601804. [CrossRef]

13. CryoTel Cryocooles. Available online: https://www.sunpowerinc.com/products/stirling-cryocoolers/cryotel-cryocoolers (accessed on 15 May 2024).
14. Kozak, S. Superconducting Surge Current Limiter. *Energies* **2021**, *14*, 6944. [CrossRef]
15. SuperPower. Available online: https://www.superpower-inc.com/specification.aspx (accessed on 15 May 2024).
16. Ishibe, T.; Okuhata, R.; Kaneko, T.; Yoshiya, M.; Nakashima, S.; Ishida, A.; Nakamura, Y. Heat transport through propagon-phonon interaction in epitaxial amorphous-crystalline multilayers. *Commun. Phys.* **2021**, *4*, 153. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.