回転機用高温超電導バルクに対するパルス着磁の研究

[課程博士・論文博士共通]

博士学位論文内容要旨
Abstract

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論文題目 Title	Study of pulsed-field magnetization of high-temperature superconducting bulk for rotating machines (回転機用高温超電導バルクに対するパルス着磁の研究)		

High-temperature superconducting (HTS) bulk rotating machines are appealing due to their increased power density over permanent magnet synchronous machines. However, the magnetization process of the superconducting bulks before use is a major barrier to the adoption of these superconducting machines. The most common techniques of magnetization are quasi-static processes. They have the advantage of trapping strong magnetic fields in the HTS bulk but require the use of expensive superconducting magnets to apply the magnetic field. Pulsed-field magnetization (PFM) is another magnetizing process that consists of applying a strong magnetic field for a short duration, generally less than one second. The time needed by PFM techniques is considerably reduced compared to quasi-static techniques. It allows the use of copper coils to generate the applied magnetic field rather than superconducting coils, thereby decreasing the cost and size of the magnetizing system. The major drawback of this technique is the reduced trapped magnetic field compared to quasi-static techniques, especially at low temperatures.

The waveform-controlled pulsed magnetization with negative feedback (WCPM-NFB) is an advanced magnetization technique based on PFM and developed to increase the trapped magnetic flux density by modifying the waveform of the applied field. This technique has previously been tested in our laboratory at 77 K, the temperature of liquid nitrogen, and 70 K. It showed great improvements over the passive PFM technique. The next objective is to improve the magnetization process of superconducting bulks for their use in superconducting rotating machines. The goal of this research is to be able to trap a strong magnetic field inside superconducting bulks in a single pulse and therefore make this technique suitable for the practical use of superconducting machines using HTS bulks as field poles. This research is divided into three chapters.

Chapter 1 concerns the test and study of the WCPM-NFB technique at a lower temperature than previously tested. The use of PFM techniques at low temperatures is difficult due to the theoretically high applied magnetic flux density required to fully enter the bulk and because of the augmented heat generation caused by the motion of the flux vortices inside the bulk during the magnetization. Therefore, other techniques such as multi-pulse, and multi-temperature PFM processes have been developed. However, the increased magnetization time reduces the main advantage of PFM. Thus, the first experiment was done to try to magnetize a GdBaCuO HTS bulk using a single pulse, at 60 K. This experiment showed that with the right parameters for the control by the WCPM-NFB, it was possible to magnetize the bulk over 2 T at 60 K. Moreover, the positioning of the Hall sensor to determine the target required for negative feedback was shown to have an impact on the waveform control and the results. It has also been found that the WCPM-NFB technique could reduce the flux jump's rising rate in the center during the flux jump. A lower rising rate leads to a reduced maximum temperature in the growth sector boundary and higher trapped magnetic flux density in the center.

The numerical simulation of superconducting bulk magnetization has increased in popularity in recent years, and despite the absence of commercially available software for modeling superconductors, various numerical techniques, models, and formulations have been developed. The numerical simulation of the WCPM-NFB technique is shown in chapter 2. The goal was to have a better understanding of the magnetization

process, by visualizing the repartition of the heat generation and current density. The magnetization system has been modeled to simulate the behavior of the bulk during the magnetization with the WCPM-NFB technique. This includes a model of the electrical circuit of the pulse magnetizing power supply, the electromagnetic model of magnetizing coils, and the thermal and electromagnetic model of the superconducting bulk. The numerical simulation of the system allowed us to compare a passive PFM technique with the WCPM-NFB technique. According to the model, and similarly to the experimental results, the WCPM-NFB technique resulted in an improvement in the trapped magnetic flux density due to reduced heat generation.

In chapter 3, the WCPM-NFB technique was used experimentally at a low temperature of 50 K, the upper operating temperature of the axial-gap superconducting motor, and it displayed some improvement over the passive PFM. However, it was originally expected that the trapped flux density could be further increased. We suspected that this limitation came from the control target set before the flux jump that was incompatible with the significant change in the magnetic and thermal conditions following the flux jump. The WCPM-NFB technique has therefore been modified, by enabling the change of the control targets during the pulse. The control of the applied magnetic flux density can be adjusted depending on the magnetic conditions inside the HTS bulk before and after the flux jump. This advanced magnetization technique has been experimented with at 50 K, and it resulted in a significant improvement over the previous WCPM-NFB technique. It is therefore possible to magnetize the bulk in a single pulse, at a relatively low temperature, up to 3.17 T. Previously, similar results at this temperature had been obtained only by using multi-pulse or multi-temperature processes.

In summary, during this research, an improved magnetization technique has been developed, using PFM technology, for the magnetization of HTS bulks. This technique can trap strong magnetic fields in the HTS bulk field pole, making it suitable for its use in superconducting rotating machines. The use of this technique would mean that the magnetization process is no longer the main obstacle to the adoption of such superconducting machines in practical applications.