

OPEN ACCESS

Pulsed Field Waveforms for Magnetization of HTS Gd-Ba-Cu-O Bulk Magnets

To cite this article: T Ida *et al* 2006 *J. Phys.: Conf. Ser.* **43** 539

View the [article online](#) for updates and enhancements.

You may also like

- [Materials preparation and magnetization of Gd-Ba-Cu-O bulk high-temperature superconductors](#)
Tetsuya Ida, Zhi Li, Difan Zhou *et al.*
- [Significant improvement of trapped flux in bulk Gd-Ba-Cu-O grains fabricated by a modified top-seeded melt growth process](#)
Difan Zhou, Shogo Hara, Beizhan Li *et al.*
- [Processing of high-performance Gd-Ba-Cu-O bulk superconductor with Ag addition](#)
S Nariki, N Sakai and M Murakami



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Pulsed Field Waveforms for Magnetization of HTS Gd-Ba-Cu-O Bulk Magnets

T Ida^{1,2}, H Matsuzaki², E Morita², H Sakashita¹, T Harada¹,
H Ogata², Y Kimura², M Miki³, M Kitano³ and M Izumi²

¹ Department of Electronic Control Engineering, Hiroshima National College of Maritime Technology, 4272-1, Higashino, Ohsakikamijima-cho, Toyota-gun, Hiroshima 725-0231, Japan

² Department of Marine Electronics and Mechanical Engineering, Tokyo University of Marine Science and Technology, 2-1-6, Etchu-jima, Koto-ku, Tokyo 135-8533, Japan

³ Kitano Seiki Co. Ltd., 7-13-7, Chuo, Ohta-ku, Tokyo 143-0024, Japan

E-mail: ida@hiroshima-cmt.ac.jp

Abstract.

Progress in pulse magnetization technique for high-temperature superconductor bulks of melt-textured RE-Ba-Cu-O with large diameter is important for the realization of power applications. We studied the pulsed power source and pulsed field waveforms to enhance to improve the magnetization properties for Gd-Ba-Cu-O bulk. The risetime and duration of pulse waveform effectively varied distribution of magnetic flux.

1. Introduction

For advanced industrial power applications, we are interested in motion of magnetic flux in the melt-textured RE-Ba-Cu-O (RE is a rare earth elements) high-temperature superconductors (HTSs), which have strong pinning effect [1]. It is difficult to use cooled HTS bulk which is magnetized by field cooling (FC) method to the general industrial applications. In-situ magnetization technique with a pulsed copper coil is a prerequisite for the rotating electrical machinery use of HTS bulk as cryo-permanent magnets [2, 3].

In our previous works, a melt-textured Gd-Ba-Cu-O bulk was magnetized from the pulse, which is passively formed by pulse generator with RLC circuit loads. With intensifying the pulsed-field, the trapped flux density was distorted and decreased by the heating which originated in transient flux motion [4]. The shielding characteristics together with the temperature increase of the HTS bulk for magnetic flux motion must be overcome in order to have enough magnetization in utilization [5]. The sharp pulse to be generated from RLC caused magnetic flux motion for variation of rapid magnetic flux density. In the present study, we applied a large current pulse, which enables us to realize a variety of pulse width and risetime in order to trap large magnetic flux density in HTS bulk.

2. Pulse generator

In many HTS bulk magnet applications, it is necessary that a pulsed field magnetic generator is used to generate electronic impulses with large energy. The dB/dt as flux motion is related

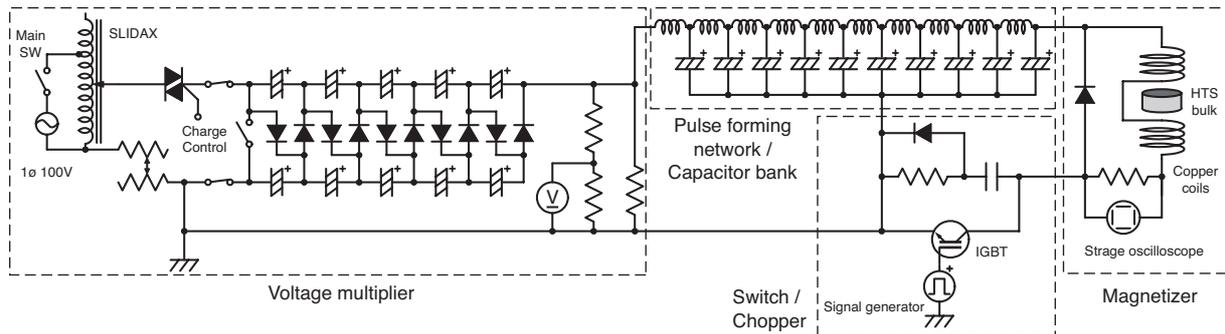


Figure 1. Pulse generator with pulsed copper coils. The Cockcroft-Walton voltage multiplier generate maximum 1.5 kV DC. The capacitor is the same as 5 mF in each mesh and the inductor is chose $0 \mu\text{H}$, $73.5 \mu\text{H}$ or $400 \mu\text{H}$ in PFN.

to dI/dt of current flowing through magnetization coil. The condition dI/dt is set by the series RLC circuit loads for constructing pulse generator.

We designed the pulse generator as shown in Fig. 1, because "wide top" waveform control was required for dB/dt variation and convergence of strong magnetic field. The Cockcroft-Walton voltage multiplier works out to maximum 1.5 kV DC from 100 V AC (RMS). Pulse Forming Network (PFN) are usually comprised of a number of capacitors and inductors arranged so that the discharge pulses from the capacitors are spaced in time, resulting in a rectangular or trapezoidal current pulse with a relatively wide top. The maximum energy accumulated in the capacitor of the PFN and the voltage multiplier is 32.8 kJ.

Energy stored in a capacitor bank of the PFN and the voltage multiplier is switched to the pulsed copper coils through the insulated gate bipolar transistor (IGBT). For waveform control, the IGBT is used as the chopper, which accomplishes the on-off control of current flowing from the capacitor bank to a couple of vortex pulsed coils.

3. Experiment

Melt growth method Gd-Ba-Cu-O bulk sample ($\text{GdBa}_2\text{Cu}_3\text{O}_{6.9}$ 70.9 wt %, $\text{Gd}_2\text{BaCuO}_5$ 19.2 wt %, Ag 9.4 wt %, Pt 0.5 wt %) was fabricated by Nippon Steel Co. Ltd. The dimensions of the sample is 60 mm diameter and 19 mm thick. By using the static magnetic field in FC mode at liquid nitrogen temperature, we obtained the maximum trapped flux density of 1.38, T with a conical distribution on the sample surface.

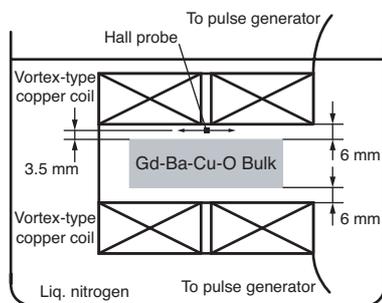


Figure 2. A schematic diagram of pulsed copper coils and superconducting bulk.

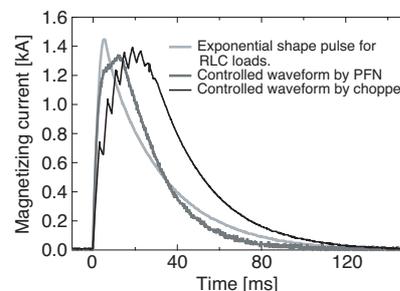


Figure 3. Magnetizing current of EDS pulse for RLC loads, trapezoidal pulse for PFN and controlled waveform pulse for IGBT chopper.

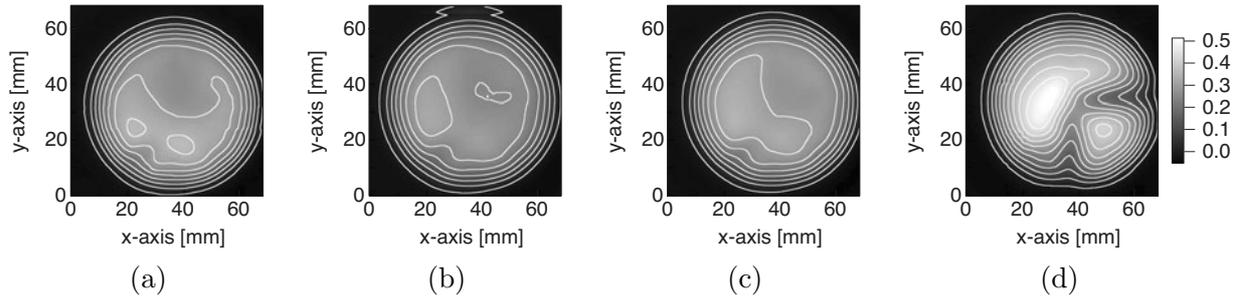


Figure 4. Trapped magnetic flux density distribution by (a) EDS pulse, (b) trapezoidal pulse, (c) controlled waveform pulse and (d) strong trapezoidal pulse.

For pulsed field magnetization, the bulk sample was sandwiched in between two vortex-type coils with inductance of 1.3 mH. A couple of vortex-type copper coil applies the field with conical distribution associated with the maximum flux density along the centre axis of the sample. The geometry of the pulsed magnetization is shown in Fig. 2. Trapped flux density was measured by scanning a Hall probe 3.5 mm above the sample surface. The detailed outline of the pulsed magnetization was reported in reference [4].

4. Results and discussions

We magnetized bulk by using each of three type of pulse waveform. The transient response of pulse current system is shown in Fig. 3. We made three peak of magnetization pulse current even with roughly 1.4 kA as 5.4 T. The voltage multiplier was passively generated with the exponential decaying shape (EDS) pulse depending on RLC loads. Figure 4(a) shows the trapped magnetic flux density distribution which was magnetized by the single EDS pulse with 1.46 kA peak current and 3.3 ms risetime. The truncated cone distribution above the bulk surface allows that more magnetic flux can be trapped because there is not large flux density peak.

We formed magnetization pulse current on trapezoid by the PFN with $73.5 \mu\text{H}/5 \text{ mF}$ at 8-stage and $400 \mu\text{H}/5 \text{ mF}$ at final 2-stage. Because the peak current is 1.34 kA, the integral value of the PFN pulse current is 95% of the EDS pulse. The substantial risetime of the waveform was set to 3.6 ms which is almost same risetime as the EDS pulse. However, the PFN pulse has longer duration than the EDS pulse with strong magnetic field region. Figure 4(b) shows the trapped flux distribution by PFN pulse, which is almost same distribution by the EDS pulse.

The PFN pulse which increased peak current in 1.5 kA with same as risetime got the magnetic flux density distribution in Fig. 4(d). This peak current is near to peak current of the EDS pulse, but the trapped flux distribution shows a trace of two peak rather than deviation from the conical shape around the top [4]. The maximum flux density peak located along the growth sector boundaries (GSBs) which are the diagonal lines in the distribution graph. This profile shows that external large magnetic flux penetrated [6, 7]. The transient magnetic flux motion in strong magnetic field region may be cause of this variation.

Figure 4(c) shows the trapped magnetic flux distribution for controlled waveform pulse current by using IGBT chopper, which is shown by black line in Fig. 3. The switch condition was $t_{\text{on}} = 2 \text{ ms}$ and $t_{\text{off}} = 1.39 \text{ ms}$ at 59% duty factor including $t_{\text{on}} = 3.05 \text{ ms}$ and $t_{\text{off}} = 1.39 \text{ ms}$ of the first time. The hysteresis of magnetization coil by counter electromotive force changed chopping wave to continuous wave. The fundamental pulse has slow risetime of 14 ms. The magnetic flux distribution by the chopper pulse is same as profile by the EDS pulse (Fig. 4(a)). The electrostatic energy of 2.53 kJ in the capacitor bank with chopper is larger than the energy of 1.92 kJ from the voltage multiplier. Waveform control by the chopper does not have extra power loss. We guess that there will be not the intense transient flux motion at the EDS pulse and the chopper pulse magnetization.

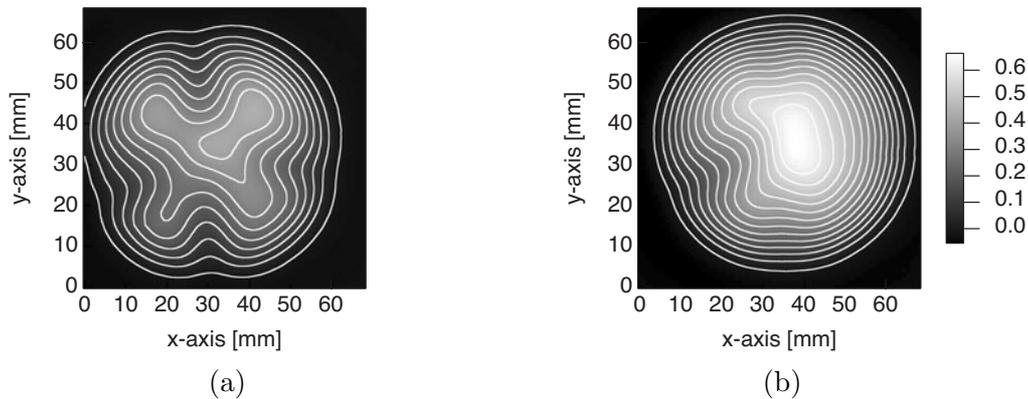


Figure 5. Trapped magnetic flux density distribution by (a) EDS pulse and (b) controlled waveform pulse with switch condition of $t_{\text{on}} = 1.96$ ms and $t_{\text{off}} = 1.88$ ms ($t_{\text{on}} = 3.08$ ms and $t_{\text{off}} = 1.88$ ms of the first time).

Consequently, we compared trapped flux density distributions by the EDS pulse and the chopper pulse, as shown in Fig. 5. The pulse of the same energy of 3.71 kJ formed by only RLC loads and chopper. The peak current was 1.88 kA and 1.68 kA, respectively. Risettime of the EDS pulse and the controlled fundamental pulse by the chopper are 7.5 ms and 11.8 ms for 51% duty factor. For the EDS pulse, the sample trapped four flux peaks which located along the GSBs, as this shown in Fig. 5(a). Figure 5(b) evidently shows that the sample trapped a single peak magnetic flux at the central region for controlled pulse current by the chopper. The maximum field density was 0.44 T and 0.66 T for EDS pulse and controlled waveform pulse, respectively. Therefore, the forming wide top pulse with slow risetime was effectively magnetizing and we got a conical flux distribution. The bulk trapped total flux of $812 \mu\text{Wb}$ which increased to 140% of EDS pulse as $562 \mu\text{Wb}$. The difference occurred for suppression of flux variation by pulse waveforms.

5. Conclusion

Pulsed magnetization for single controlled waveform is a necessary technique to magnetize HTS samples in electrical rotating machinery. For the practical pulse forming techniques, bulk trapped magnetic flux effectively to realize a variety of pulse width, risetime and duration of strong magnetic field region. The formed excessive magnetic pulse magnetized Gd-Ba-Cu-O bulk strongly with well-dressed distribution. In near future, controlled waveform pulse with decreasing magnetic flux motion will be used for HTS power application of synchronous motor, efficiently.

References

- [1] Tomita M and Murakami M 2000 *Supercond. Sci. Technol.* **13** 722
- [2] Matsuzaki H, Kimura Y, Ohtani I, Izumi M, Ida T, Akita Y, Sugimoto H, Miki M and Kitano M 2005 *IEEE Trans. Appl. Supercond.* **15** 2222
- [3] Itoh Y, Yanagi Y, Yoshikawa M, Oka T, Harada S, Sakakibara T, Yamada Y and Mizutani U 1995 *Jpn. J. Appl. Phys.* **34** 5574
- [4] Ida T, Matsuzaki H, Akita Y, Izumi M, Sugimoto H, Hondou Y, Kimura Y, Sakai N, Nariki S, Hirabayashi I, Miki M, Murakami M and Kitano M 2004 *Physica C* **412-414** 638
- [5] Sander M, Sutter U, Adam M and Klaser M 2002 *Supercond. Sci. Technol.* **15** 748
- [6] Surzhenko A B, Schauroth S, Lizkendorf D, Zeisberger M, Habisreuther T and Gawalek W 2001 *Supercond. Sci. Technol.* **14** 770
- [7] Ikuta H, Ishihara H, Yanagi Y, Itoh Y and Mizutani U 2002 *Supercond. Sci. Technol.* **15** 606