## APP3-1

# Effectiveness of Filter Inductor of Rectifier Transformer Flux Pump in Energizing Multi-Stacked No-Insulation REBCO Pancake Coils

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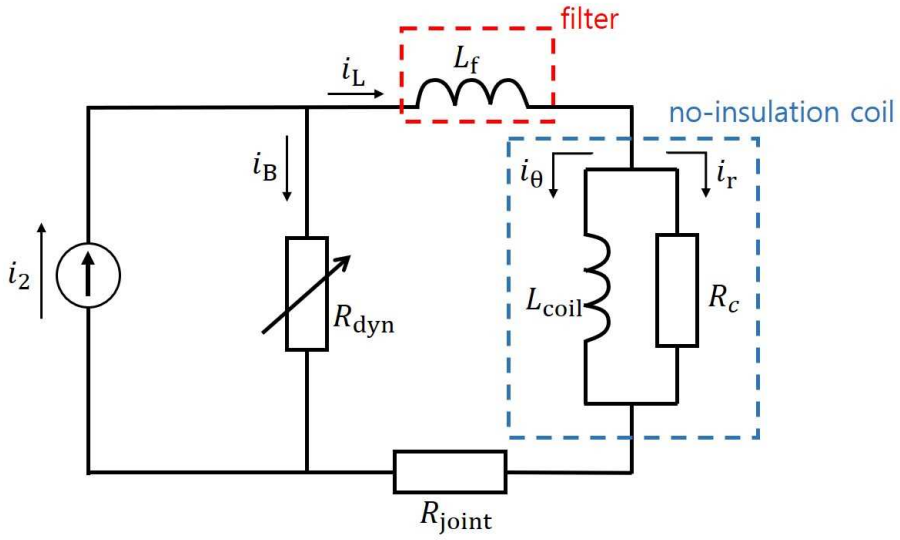
In recent years, strong field high-temperature superconducting (HTS) magnets are required in many applications, such as magnetic resonance imaging (MRI), nuclear magnetic resonance (NMR), particle accelerators, and so on. Also, they are applicable to rotors of highly efficient motors. For such applications, one attractive magnet-energizing method is a flux pump. A flux pump effectively increases a current flowing in closed loop made of superconducting wires without a large amount of heat penetration. When a current reaches to an arbitrary value, it is easy to switch to a persistent current mode (PCM), which needs no more power to retain the current. Recently it was reported that a flux pump of rectifier transformer type [1] could energize a REBCO magnet with no-insulation (NI) winding technique. Figure 1 shows the equivalent circuit model of rectifier transformer type flux pump (RTTFP) to energize a single NI REBCO pancake coil [1]. The variable resistance $R_{dyn}$ works as a superconducting switch by the resistance change between the superconducting and normal state. The current increases when the switch turns off, otherwise the current is remained. The RTTFP performance was validated in experiments [1]. It was also reported that a filtering inductance improved the charging performance of a single NI REBCO pancake coil. That is, the amount of charged current increases and the charging speed is accelerated by using the filter inductor.

As a next development step, a practical application must be considered. Toward a practical application, some NI REBCO pancake coil must be stacked to generate a high magnetic field, however the stacked NI pancake coil has a large inductance. Therefore, the effectiveness of a filter inductor for multi-stacked NI pancake coils with a large inductance must be investigated further. We have extended the equivalent circuit model of Fig. 1 to multi-stacked NI REBCO pancake coils by connecting the equivalent circuit of NI pancake coils in series. We will check what is the best inductance for multi-stacked NI pancake coils by numerical simulation. The effectiveness of filter inductor will also be discussed.

[1] J. Ma, et al., “Charging performance improvement of flux pumping for HTS no-insulated coil,” Appl. Supercond. Conf., 2018.




Keywords: charging performance, filter inductor, flux pump, no-insulation REEBCO pancake coil

## APP3-2

# Experimental investigation of switching to normal state of CC-tapes under the action of magnetic field pulses

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In this work, we studied the behavior of CC-tapes under the action of magnetic field pulses: a transition to a normal state was observed in case of application of external magnetic field pulses to tapes loaded with transport current. The data obtained allow us to solve the problems associated with the development of high-speed switching devices based on high-temperature superconductors designed for operation in superconducting energy storage devices, energy distribution and transmission systems, current limiters, and new types of modern transport.

In this work, experimental studies of the behavior of CC-tapes under the action of pulses of an external magnetic field were carried out. The studies were carried out on samples of 4 mm wide CC-tapes manufactured by SuperOx. To reduce the value of transport critical current of the tape, bridges of various widths were made by laser cutting. During the experiment, a transport current of various values was applied to the superconducting bridge. The transport current values were close in value to the critical current of the bridge. After that, a magnetic field pulses were applied parallel to the tape plane. The influence of such parameters as the value of the initial transport current, the amplitude and duration of the magnetic field pulse on the transition of the CC-tapes to the normal state and the return to the initial superconducting state was studied. The measurements were carried out both in liquid nitrogen and during cooling using a cryocooler. The effect of temperature on the transition to a normal state was studied in the range of 30 to 80 K.

At certain pulse parameters, damage to the superconducting layer of CC-tapes was observed. The distribution of the damaged zone was observed, and the degradation of the superconducting properties of CC-tapes was assessed by studying the samples using Hall magnetometry and magnetooptics.

The analysis of experimental data and the conclusions of this work can be useful for practical application in the development of high-speed switching devices based on CC-tapes.

The work is supported by the Russian Foundation for Basic Research under the grant 17-29-10024.

Keywords: CC-tape, Magnetic field pulses

# APP3-3

## Switching processes in 2G HTS tape under magnetic field and short current pulses

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This report presents the results of studying switching processes in HTS tapes under pulsed loads. Investigation was performed on pulses of various amplitudes from 0.9 to 5 values of the critical current at a constant current. The minimum rise time of the front is 800 ns, the pulse width is from 1 to 200 μs. The current pulses were combined with a magnetic field parallel to the wide side of the HTS tape. Stable current flow on amplitudes up to 4 times the critical current without degradation of the superconductor is shown, as well as the influence of the magnetic field on the stability of the characteristics during pulse current switching. Regimes of transition instability and current oscillations at a constant pulse load were founded. A model for describing the observed features is proposed.
HTS tapes from three manufacturers were investigated: AmericanSuperconductor, SuperPower, SuperOx. The current - voltage characteristics of the samples were preliminarily measured and the critical currents of superconductors at a direct current were determined.
A pulsed current source and an automated experimental test bench were designed and manufactured for the study. The measurements were carried out by the four-contact method, the amplitude of the current was determined by the voltage on a calibrated shunt.
The measurements were carried out in liquid nitrogen. Two series of measurements were performed: with a characteristic time of current rise up to 3 ms (long pulses) and up to 1.5 μs (short pulses). On long pulses, a significant effect of thermal processes in the superconductor and metal layers of the tape on the switching process, arising of thermal instabilities and degradation of the HTSC ribbon was found. On short pulses there is no such effect. This is primarily due to the fact that the hot spot does not have time to develop and does not lead to an increase in the temperature of the superconductor above 3 degrees from the boiling point of nitrogen and the boiling crisis does not develop.
Based on the model of dynamic resistance in the flow regime, a qualitative explanation of the results was given. The velocity of motion of the vortices during short pulses and the coupling coefficient of the HTS film and the stabilizing tape layer are calculated.
The research was done under support of Russian Foundation for Basic Research (grant 17-29-10024).

Keywords: 2G HTS tapes, switching, superconducting key, short pulses

## APP3-4

# Electromagnetic and Mechanical Properties of Two-ply REBCO Tape double Pancake Coils

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We have succeeded in operating a 25 T cryogen-free superconducting magnet (25T-CSM), which consists of LTS outsert coils and Bi2223 insert pancake coils [1]. As a next step, an upgrading design of 25T-CSM is considered by replacing the Bi2223 insert coils with REBCO coils, since REBCO tapes have better mechanical and in-field critical current properties. In this design, co-winding of two REBCO tapes is a key technology to increase the current density in the coil. We investigate electromagnetic and mechanical properties of two-ply REBCO double pancake coils with and without a co-wound Hastelloy tape for reinforcement. The coils were fabricated with a Fujikura REBCO tape that had a dimension of 4 mm width and 0.1 mm thickness, and a Hastelloy tape of 0.05 mm thickness. The inner diameter of the coils was 100 mm, and the outer diameters were 188 and 169 mm for with and without the co-winding Hastelloy tape, respectively. The coil voltages and strains were measured at 4.2 K under a background field of 11 T by using a 360 mm room temperature bore superconducting magnet at the HFLSM, IMR Tohoku University. The maximum hoop stress in the coil without a Hastelloy tape was estimated to be about 540 MPa by using the *BJR* relation for 700 A and 11 T. The maximum strains on the outermost winding were approximately 0.25-0.39% at the operation current of 700 A. For the case of the Hastelloy co-wound coil the stress was induced up to the almost same level, and the strains on the innermost winding as well as on the outermost winding were obtained. In the presentation, the *IV* properties and the strains as a function of operating current for the both coils including the results under the self field will be reported and discuss about the results.

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[1] S. Awaji *et al.*, *Supercond. Sci. Technol.* **30** (2017) 065001.

Keywords: Two-ply REBCO tape pancake coil, Hoop stress

## APP3-5

# Investigation of current distribution in an HTS twisted stacked-tape cable conductor by self-field measurements

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Various large current-carrying conductors composed of REBCO tapes have been proposed in recent years for high current applications such as magnets and power transmissions. As one of the conductors, a twisted stacked-tape cable (TSTC) is being developed at the Massachusetts Institute of Technology [1,2]. The TSTC conductor is composed of stacked REBCO tapes which are twisted along the longitudinal direction of the stacked tapes. The stacked REBCO tapes are immersed with a solder, and are imbedded in a copper former. Therefore, current transfer between REBCO tapes occurs easily when applying current in the TSTC conductor. In this study, self-field measurements of the TSTC conductor were conducted in order to investigate current distribution in the conductor. As a test sample, a 650 mm diameter single turn coil of a TSTC conductor was utilized. The current distribution in the TSTC conductor is discussed by using analytical models with the measured self-fields around the conductor.

[1] M. Takayasu, L. Chiesa, L. Bromberg, J. Minervini, HTS twisted stacked-tape cable conductor, Supercond. Sci. Technol. 25 (2012) 014011.
[2] M. Takayasu, L. Chiesa, N. Allen, J. Minervini, Present Status and Recent Developments of the Twisted Stacked-Tape Cable Conductor, IEEE Transactions on Applied Superconductivity, Vol. 26, No. 2 (2016) 6400210.

Keywords: REBCO tapes, twisted stacked-tape cable (TSTC), self-field measurements

## APP3-6

# Numerical Simulation of a Hybrid Trapped Field Magnet Lens (HTFML) Magnetized by Pulsed Fields

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Our group has proposed a concept of the hybrid trapped field magnetic lens (HTFML) consisting of a trapped field magnet (TFM) cylinder and a bulk magnetic lens [1, 2]. A magnetic field, trapped by a TFM cylinder, is concentrated by a bulk magnetic lens inside the TFM cylinder under the magnetizing process, in which the zero-field cooled magnetization (ZFCM) and field-cooled magnetization (FCM) are combined. As a result, the HTFML can continuously generate a magnetic field higher than the external field, $B_{bg}$. Using numerical simulations, a concentrated magnetic field, $B_c$, of 4.73 T was expected for $B_{bg}$ = 3 T at 20 K using $MgB_2$ cylinder and GdBaCuO lens, and $B_c$ = 13.49 T for $B_{bg}$ = 10 T at 20 K using GdBaCuO cylinder and GdBaCuO lens [1]. Recently, we have experimentally confirmed the HTFML effect using an $MgB_2$ cylinder and GdBaCuO lens, for which $B_c$ = 3.65 T was achieved for $B_{bg}$ = 2 T at 20 K. To magnetize superconducting bulks, a pulsed field magnetization (PFM) is attractive for practical applications because of an inexpensive and mobile experimental setup with no need for a superconducting magnet [3]. In the present study, the HTFML effect is numerically investigated using GdBaCuO cylinder and GdBaCuO lens during PFM for the first time. A three dimensional numerical model is constructed, in which the TFM cylinder (40 mm in inner diameter ID, 60 mm in outer diameter OD, 20 mm in height H) and magnetic lens with thin slits (10 mm in ID, 30 mm in OD, 10 mm in H) are set on the cold stage of a refrigerator. The concentrated magnetic field at the center of the lens bore and the temperature rise of the bulks are investigated. The possibility of the HTFML device magnetized by PFM is discussed.

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[2] S. Namba et al., IEEE Trans. Appl. Supercond. 21 (2019) 6801605
[3] M. D. Ainslie, H. Fujishiro, Supercond. Sci. Technol. 28 (2015) 053002

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Keywords: hybrid trapped field magnet lens, pulsed field magnetization, superconducting bulk, magnetic lens