AP1-1-INV

Portable high-field magnet systems using bulk high-temperature superconductors

*Mark D Ainslie[1], Yeekin Tsui[1], Dominic A Moseley[1], Anthony R Dennis[1], Hiroyuki Fujishiro[2], Vito Cientanni[1], Ewan Laidlaw[1], Keshav Manju[1], Devendra K Namburi[1], Yunhua Shi[1], David A Cardwell[1], John H Durrell[1]

University of Cambridge, UK[1]
Iwate University, Japan[2]

Bulk high-temperature superconductors can be used, when cooled to cryogenic temperatures, as super-strength, stable permanent magnets capable of generating fields of several Tesla. This makes them attractive for a number of engineering applications that rely on high magnetic fields, including compact and energy-efficient motors/generators with unprecedented power densities, magnetic separation and compact and portable magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) systems.
In this presentation, we report our recent developments in portable high-field magnet systems using bulk high-temperature superconductors, including: 1) cryogenic system design that emphasises flexibility and portability, but with operating temperatures down to around 50 K or lower, 2) a compact pulsed field magnetisation (PFM) system, including pulse waveform control and the exploitation of flux jumps during the PFM process, and 3) solenoid- and split-type magnetising coil options.

Keywords: Bulk high-temperature superconductors, Portable magnet system, Large scale applications

AP1-2-INV

A Hybrid Trapped Field Magnet Lens (HTFML): concept and experimental realization

*Hiroyuki Fujishiro[1], Sora Namba[1], Tomoyuki Naito[1], Mark D. Ainslie[2], Keita Takahashi[1], Difan Zhou[3], Yousuke Yanagi[4]

Department of Physical Science and Materials Engineering, Iwate University[1]
Bulk Superconductivity Group, Department of Engineering, University of Cambridge[2]
Department of Physics, Shanghai University[3]
IMRA Material R&D Co., Ltd[4]

The concept of a Hybrid Trapped Field Magnet Lens (HTFML) is described, which exploits two different characteristics of type-II superconductors: the “vortex pinning effect” of an outer superconducting bulk cylinder, which acts as a trapped field magnet (TFM) using field-cooled magnetization (FCM), combined with the “diamagnetic shielding effect” of an inner bulk magnetic lens using zero-field cooled magnetization (ZFCM) [1]. The HTFML can reliably generate a concentrated magnetic field in the center of the lens that is higher than the trapped field from both the cylindrical bulk TFM and the external magnetizing field, even after the externally applied field decreases to zero. We predicted numerically a concentrated field of B_c= 4.73 T under an external magnetizing field of B_{app}= 3.0 T using an MgB_2TFM cylinder and GdBaCuO lens design with a single cooling stage, and a B_c= 13.5 T under an external magnetizing field of B_{app}= 10 T using an all-GdBaCuO cylinder and lens design using independent temperature control of each part [1]. In this presentation, we report the experimental verification of the HTFML using the MgB_2TFM cylinder and GdBaCuO lens design. Using an optimised lens design [2], a maximum concentrated magnetic field of B_c= 3.55 T was achieved experimentally at the central bore of the HTFML after removing an applied field of B_{app}= 2.0 T at T_s= 20 K. The HTFML effect is also reported using the all-GdBaCuO cylinder and lens design at 77 K. The HTFML device could prove useful to enhance the magnetic field for bulk NMR/MRI systems and to achieve a locally higher magnetic gradient for magnetic separation applications.

References
[1] K. Takahashi, H. Fujishiro and M. D. Ainslie, Supercond. Sci. Technol. **31** (2018) 044005.
[2] S. Namba, H. Fujishiro, M. D. Ainslie, K. Takahashi, T. Naito, Devendra K. Namburi, and Difan Zhou, IEEE Trans. Appl. Supercond. **29** (2019) 6801605.

Acknowledgements
This research is supported by Adaptable and Seamless Technology transfer Program through Target-driven R&D (A-STEP) from Japan Science and Technology Agency (JST), Grant No. VP30218088419 and by JSPS KAKENHI Grant No. 19K05240. M. D. Ainslie would like to acknowledge financial support from an Engineering and Physical Sciences Research Council (EPSRC) Early Career Fellowship, EP/P020313/1.

Keywords: A Hybrid Trapped Field Magnet Lens , experimental realization, vortex pinning effect, diamagnetic shielding effect

AP1-3

Upgrade of 25T cryogen-free superconducting magnet to 30T at HFLSM

*Satoshi Awaji[1], Arnaud Badel[1], Tatsunori Okada[1], Kohki Takahashi[1], Hiroshi Miyazaki[2], Satoshi Hanai[2], Sigeru Ioka[2], Shinji Fujita[1,3], Shogo Muto[3], Yasuhiro Iijima[3], Masanori Daibo[3], Kazuhiro Kajikawa[4]

Institute for Materials Research, Tohoku University[1]
Toshiba Energy System & Solutions Corporation[2]
Fujikura Ltd.[3]
Kyusyu University[4]

The 25T cryogen-free superconducting magnet (CSM) with high strength Bi2223 insert and CuNb/Nb_3Sn Rutherford cable coils is operated as a user magnet at High Field Laboratory for Superconducting materials (HFLSM) sine 2016 [1]. Now we plan an upgrade of the 25T-CSM with replacing the Bi2223 insert coil with the REBCO one. Thanks for good mechanical and in-field J_c properties of REBCO tapes, we can design the 16T REBCO insert under the background field of 14 T, in spite of some limitations such as coil space, operation current and cooling capacity. We propose two bundle (two-ply) REBCO tape winding in order to increase the space current density with a good reliability of REBCO coil. The design study is performed based on the REBCO tapes with the artificial pinning center (APC). In addition, the effects of two REBCO tape coupling on the AC losses and magnetic field should be investigated. We performed some R&D studies with the two-ply REBCO pancake coils under the electro-magnetic stress. The R&D studies and the primitive design of REBCO insert will be presented.

This work was supported by JSPS KAKENHI Grant Number 18H05248.

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

Keywords: REBCO, Cryogen-free superconducting magnet, electromagnetic force

AP1-4

Field and Voltage transient behavior in REBCO HTS coils using single tape or two bundled tapes: Comparison between Experiment and Modelling

*Arnaud Badel[1], Julien Vialle[2], Kohki Takahashi[1], Blandine Rozier[2], Tatsunori Okada[1], Satoshi Awaji[1]

Tohoku University, Japan[1]
Université Grenoble Alpes[2]

The development of practical REBCO HTS coils (Rare-EarthBiCaCuO High Temperature Superconductor) for very high field face two issues. The first is destructive thermal runaway induced by local dissipative zones, and the second is dynamic field homogeneity. These two problems are due to the specificities of REBCO Coated Conductors. They have significant critical current variations along the length which engender local dissipative zones with slow propagation, and their wide and thin tape structure enable the development of large shielding current loops. The first issue, thermal runaway, may be solved by using a non-insulation or partial insulation technique. These techniques however affect negatively the second issue as shielding current loops may appear both in the tape surface and across coil turns. We observed, as other groups, that an early detection of dissipating voltages makes it possible to discharge isolated coils before a dangerous thermal runaway can occur. However, the dissipating voltage that must be detected is very low, comparable in amplitude to the transient voltage due to magneto-electric effects. These must thus be understood and considered in the detection scheme.
We report results obtained on pancakes wound with single 12 mm tape, in terms of transient voltages and magnetic field evolution. They are compared with simulation results obtained using a recently developed model. It shows that these transient behaviors can be accurately predicted by the model and that transient voltage measurement can be a good tool to study shielding current variations.
Even though early detection makes the practical use of isolated REBCO coils possible, the maximum operating current remains limited by the weakest conductor defect. We investigated the possibility of using two co-wound tapes to average the tapes properties. Results obtained on pancakes wound with such conductors are reported both in terms of transient voltages and field evolution. The behavior is qualitatively similar to single tape pancakes, with comparatively weaker hysteresis.
Simulation results obtained using various simplifying assumptions for the conductor structure are presented for comparison, showing the interest of the two bundled concept and the need for further model refinement to represent accurately such conductors.

Keywords: REBCO coil, Field homogeneity, Very high field

AP2-1-INV

Superconducting motors for aircraft propulsion: the Advanced Superconducting Motor Experimental Demonstrator project

Francesco Grilli[1], Tara Benkel[1], Jens Hänisch[1], Mayraluna Lao[1], Thomas Reis[2], Eva Berberich[2], Simon Wolfstädter[2], Christian Schneider[2], Pail Miller[3], Chloe Palmer[3], Bartek Glowacki[4], Vicente Climente-Alarcon[4], Anis Smara[4], Lukasz Tomkow[4], Johannes Teigelkötter[5], Alexander Stock[5], Johannes Büdel[5], Loïc Jeunesse[6], Martin Staempflin[6], Guillaume Delautre[6], Baptiste Zimmermann[6], Ruud van der Woude[7], Ana Perez[7], Sergey Samoilenkov[8], Alexander Molodyk[8], Enric Pardo[9], Milan Kapolka[9], Huo Li[9], Anang Dadhich[9]

Karlsruhe Institute of Technology[1]
Oswald Elektromotoren[2]
Rolls Royce[3]
University of Cambridge[4]
Hochschule für angewandte Wissenschaften Aschaffenburg[5]
Air Liquide[6]
Demaco[7]
SuperOx[8]
Instituite of Electrical Engineering Bratislava[9]

The European Union-funded ASuMED project started in May 2017 with the purpose of demonstrating the benefits of a new, fully superconducting motor for reaching the targets established by the FLIGHT2050 plan. The project aims at a motor power density of 20 kW/kg using a high-temperature superconducting (HTS) stator. The rotor will use HTS stacks operating like permanent magnets. A highly efficient cryostat for the motor combined with an integrated cryogenic cooling system and associated power converter will be used. This presentation will provide a general overview of the prototype that is currently being built and tested soon.
The motor design was decided by using an analytical calculation tool for multicriterial optimization and by following the specifications provided by Rolls Royce. The stator integrates the cryogenic cooling circuit into the superconducting winding system while using less than 10% of the stator space for the complete cooling supply system. The winding structure is also the flux generator for magnetizing the superconducting rotor.
The AC losses in the stator were evaluated with aptly developed numerical models which incorporate the angular field dependence of the critical current of the superconducting tapes, derived from measurements with fields up to 6 T.
Advanced numerical modeling was used to calculate the magnetization of the tape stacks of the rotor, optimize their design, and study the effects of cross-field demagnetization on the trapped field.
For the inverters, a “Dual-Two-Level” topology, consisting of two classical Two-Level inverters placed on each ends of the windings, was chosen. For such a topology, all ends of the motor windings need to be open and therefore are not connected in the standard star configuration.
The rotor cryostat design is particularly challenging because of the cryogenic operating temperatures, the cooling requirements and the rotating parts, which include a rotary seal. A number of alternatives based on different heat transfer mechanisms were analysed, showing that a forced convection based system using gaseous helium is the optimal solution for the rotor cryostat.
Airborne cryocooler systems were investigated, and their mass was found to be compatible with an airborne application thanks to the use of light heat exchangers and an optimized cycle.

Keywords: Superconducting motors, Aircraft propulsion, HTS coated conductors, AC losses

AP2-2-INV

S Design and test of a superconducting generator for aircraft application

*Jean LEVEQUE[1], Alexandre COLLE[1], Thierry LUBIN[1], Sabrina AYAT[2], Olivier GOSSELIN[2]

GREEN Lab - University of Lorraine[1]
SAFRAN TECH, Magny-les-Hameaux[2]

More electric or all-electric aircraft are seen as a viable solution for improving efficiency, reliability, maintenance in compliance with environmental commitments. This is why many concepts have been developed for a progressive electrification of aircraft with generators, motors and secondary functions as flight control. The benefits of electrification are significant and include: noise reduction, greenhouse gas emissions, pollutants and energy consumption.
For the reasons mentioned above, the aircraft manufacturers wish to develop an aircraft using electric or hybrid energy. Progress in the field of electric motors for the propulsion of cars or ships is a first technological approach for aeronautics. In addition, the technology of YBCO superconducting tapes and pellets is now ripe and ready to be used for aeronautical applications.

In this paper, we present a new topology of superconducting machine. The inductor of the actuator is composed with two superconducting and a classical elements. The first one is a large superconducting coil producing an axial magnetizing field. The second element is a set of superconducting pellets placed inside of the superconducting coil. These pellets shields the magnetizing with the diamagnetic response of the superconducting materials. The magnetic flus density is then modulate between a low value near a pellet and a high value elsewhere. The last part of the machine is two classical armature windings made with copper wire. These windings are placed on both sides of the superconducting system. In this way, we built an axial flux machine. The designed nominal power is 50 kW at 5000 rpm and an operating temperature of 30 K. The cryogenic cooling is provided by a circulation of helium under pressure. No-load, short circuit and load tests have been carried out and extrapolation to a 1 MW machine is in progress.

Acknowledgement: This work is supported by “Direction Générale de l’Armement” and the company SAFRAN Tech.

Keywords: Superconducting motor

AP2-3

Electromagnetic Analysis of Fully Superconducting Motor for Electric Aircraft

*John Voccio[1], Quinn Voccio[1]

Wentworth Institute of Technology[1]

In order to reduce carbon emissions, there is considerable interest in all-electric aircraft for transportation. Fully superconductor motors will be required to meet the high specific weight requirements, which are > 13 kW/kg for the NASA N3-X plane. This paper summarizes the results of electrogmagnetic analysis generated using the FEMM magnetics code, along with the Lua scripting language, to determine the optimum motor configuration. For AC loss considerations, the analysis assumes Bi-2212 stator windings and both iron-tooth and air-core designs are considered.

Keywords: Superconductor, Motor, Optimization, AC Loss

AP3-1-INV

Large Scale HTS Systems and Value Propositions

*Tabea Arndt[1,2]

Siemens AG, Germany[1]
Karlsruhe Institute of Technology KIT, Germany[2]

In the past years, demonstrators of large scale HTS systems have been successfully installed in dedicated sites and sometimes even in the field for long term operation.
Nevertheless, there is no market or steady demand established yet.
In this presentation, the technical benefits of selected HTS devices are sketched and some prospects on the near-future technical challenges are presented.
In addition, in the context of "outreach", we will try to formulate a suitable value proposition for stakeholders to support the efforts to prepare a demand in power technology.

Keywords: HTS, power technology, value proposition, market

AP3-2

Development of a 20kV/400A Resistive Type DC Superconducting Fault Current Limiting Module

*Tao Ma[1], Shaotao Dai[1], Yuan Cai[2], Lei Hu[1], Bangzhu Wang[1], Teng Zhang[1]

School of Electrical Engineering, Beijing Jiaotong University[1]
Suzhou New Material Research Institute[2]

Resistive type superconducting fault current limiter (SFCL) is one of the most promising SFCLs for HVDC systems. The resistance of SFCL is almost zero with the negligible influence on the system in normal operation. The increased impedance makes the current decreasing to levels below the breaker limit during a fault situation, which can effectively reduce the fault current in the DC system. Within a collaboration of Beijing Jiaotong University and Samri, one resistive type SFCL for the ±20kV Nano-Substation has been designed and manufactured. The active part of the SFCL module consists of 8 solenoids made of 14mm wide steel-stabilized YBCO conductor supplied by Samri, and is housed in a cryostat operated at normal state liquid nitrogen. The 8 solenoids are parallel assembled, and the windings of the neighbouring solenoids are series connected. The rated operation current is 400A, and the prospected limiting resistance if 9 Ω. By using of the SFCL, the maximum fault curren could be reduced to about 2.1 kA.

Keywords: Fault current limiter, YBCO tape, DC power grid

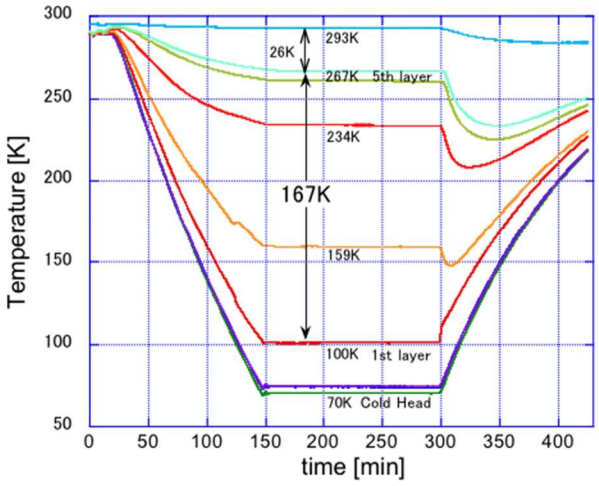
AP3-3

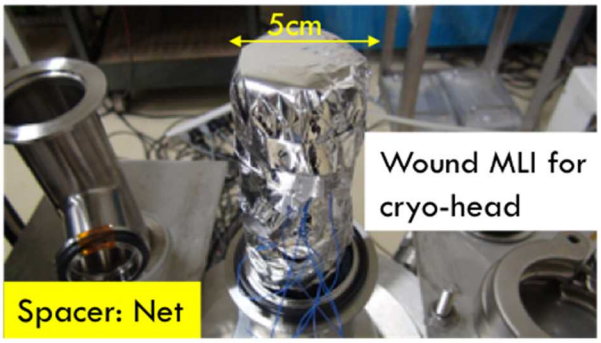
Heat leak of cryogenic pipe for superconducting dc power transmission line

*Sataro Yamaguchi[1], Masae Kanda[1], Yury Ivanov[1]

Chubu University[1]

Main loss of the superconducting DC power transmission line (SCDC) comes from the heat leak of the cryogenic pipe because of no internal heat generation in the dc cable. It should be minimized to realize the high performance of SCDC. The major process of the heat leak is the heat transfer through the multi-layer insulation (MLI) and the second process is the thermal conduction of the support leg of the inner pipe. The MLI is made from the multi-layers of the aluminum-coated thin film with the spacer, and the support leg is made of the glass-fiber-reinforced plastic (G-FRP). The aluminum layer reflects the infrared light highly to reduce the heat transfer by radiation, and the spacer prevents the direct contact with the aluminum-coated thin films, and therefore it can reduce the heat transfer by the thermal conduction. Therefore, the weight of the MLI should be light to realize the thermal transfer of the spacer. We tested various types of MLI to find the optimum MLI structure. Unfortunately, computer simulation would not be effective for the MLI to estimate the heat leak. Usually, the measurement of the heat leak is not easy in an actual cryogenic pipe and we need a long time and a relatively large instrument to evaluate the heat leak. But there are several candidates of the structure of MLI. In these meanings, we could not find the optimum structure of the MLI for SCDC. To find the optimum MLI, we started to test three small samples of the MLI supplied from Kaneka Corp., and did not measure the heat leak directly, and measured the temperature of the MLI. Since the weight of the MLI is very light (several grams to ~15 gram per square meters), and therefore its heat capacity is quite low. To measure the temperature of the MLI, we used the 50-micron meters thermocouple (TC) and attached it carefully. To analyze the experimental data, we also adopt an analytical model of heat transfer [1]. This model can estimate the emissivity of the aluminum surface thermally, and its value accorded with the measurement value by the optical method. We summarize the results of the experiments and analysis, and finally, we will able to reduce the heat leaks of the cryogenic pipe to half of the Ishikari project [2].





[1] R. Byron Bird et al, Transport Phenomena, p. 447, 1960, John Willey & Sons, Inc.
[2] H. Watanabe et al, *IEEE Trans. Applied Supercond.* Vol. 27, No. 4, 5400205.

Keywords: cryogenic pipe, heat leak, thermal analysis, multi-layer insulation

AP3-4-INV

Development of Test Device for Aluminum Metal Melting by Induction Heating Using DC HTS Coils

*Satoshi Fukui[1], Jun Ogawa[1], Tomonori Watanabe[2], Shigeo Nagaya[2], Mitsuho Furuse[3]

Niigata University[1]
Chubu Electric Power Co., Inc.[2]
National Institute of Advanced Industrial Science and Technology[3]

Aluminum die-casting technology is widely applied for the production of industrial parts such as automotive parts, since it can produce large amount of complex parts in short time with high dimensional accuracy. In industrial aluminum casting factories, there are following problems to be solved:

- Low efficiency of the gas heating main furnace. Continuous energy consumption in the hold furnace to keep aluminum in molten condition.
- Conveyance of melted aluminum to hold furnace which leads accident risks such as falling-down and sudden drop off of vessel.
- Suppression of aluminum dross (aluminum oxide) which is produced around the surface of melted aluminum due to gradual reaction with air in the hold furnace. Aluminum dross degrades quality of die-casting production and it finally becomes waste.

If an aluminum melting device that can melt necessary amount of aluminum within a short time only when it becomes necessary (called just-in-time melting) can be developed, the melted aluminum material can be directly supplied to die-casting machines. The gas heating furnaces with low efficiency can be disused and the conveyance of melted aluminum also can be abolished. Therefore, in large scale aluminum die-casting factories, the just-in-time aluminum melting devices are required. To realize them, it is necessary to develop a high efficient and high speed aluminum melting technology. We have focused on the application of the induction heating using DC HTS coils to aluminum melting and have been investigating the possibility of aluminum melting. Fig. 1 shows the schematic illustration of our proposed induction heating device using HTS coils for aluminum melting. The aluminum materials are rotated in DC high magnetic field generated by HTS coils and the large eddy current joule heat induced in the aluminum material. In our former study [1], we have reported that 0.77 kg aluminum material can be melted by induction heating in DC magnetic field of 0.4-1.0 T. The results reported in [1] indicate that the induction heating with DC HTS coils can apply to aluminum melting. In this study to extend our former study [1], the 1/5 scale test device for aluminum melting by the induction heating using REBCO HTS coils are designed using the numerical electromagnetic and thermal analysis. In the paper, the design and fabrication process of the test device is reported.

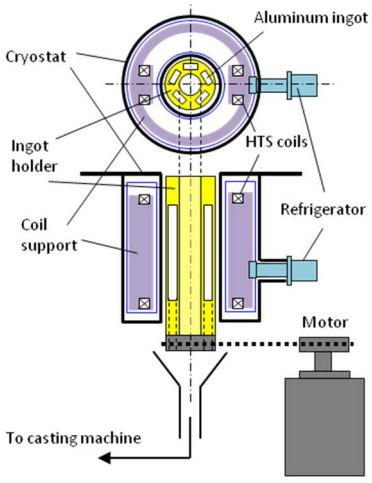


Fig. 1. Schematic illustration of proposed induction heating device for aluminum melting using DC HTS coils.

[1] T. Watanabe, S. Nagaya, N. Hirano, S. Fukui, "Elemental Development of Metal Melting by Electromagnetic Induction Heating Using Superconductor Coils", IEEE Trans. Appl. Supercond., Vol.26, Art. ID 3700504, 2016.

Keywords: Induction heating, HTS coil, Aluminum melting

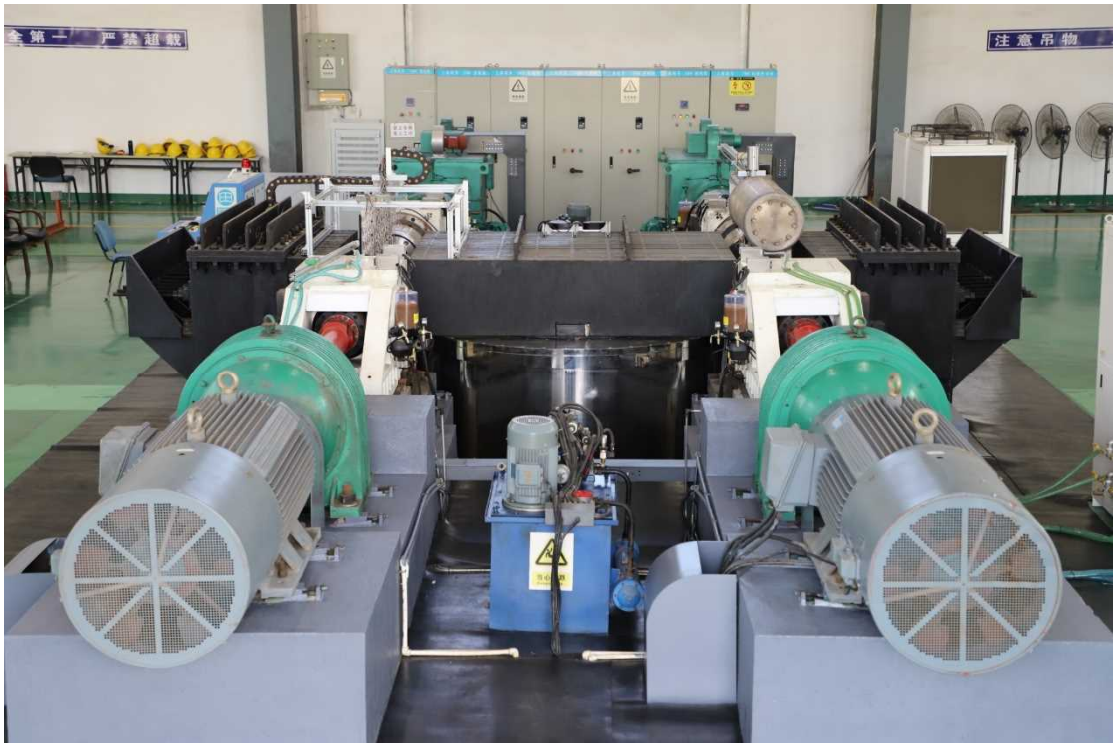
AP3-5

Development of the 1 MW Superconducting Induction Heater

*Shaotao Dai[1], Tao Ma[1], Zhiyong Hong[3], Guozhong Jiang[2], Lei Hu[1], Chao Li[4], Bangzhu Wang[1], Teng Zhang[1]

School of Electrical Engineering, Beijing Jiaotong University[1]
Jiangxi Lianchuang Optoelectronic Technology Co., Ltd.[2]
Shanghai Superconductor Technology Co., Ltd.[3]
Western Superconducting Technologies Co., Ltd.[4]

The 1 MW HTS induction heater has been developed for the non-ferrous metal industry where the HTS coil is used to generate a static magnetic field. The HTS magnet is made of YBCO conductor produced by Shanghai Superconductor, and the prospected operating temperature is about 25 K. The size of Aluminium billet was set to 446 mm of the diameter and 1500 mm of length, and the heating power of was determined to be 1000 kW with over 80% of system efficiency. The conduction-cooled HTS magnet consists of three solenoid coils wound with 18 km YBCO conductor. The inner and outer diameters of the YBCO magnet are Φ1960 mm and Φ2009 mm, respectively. The magnet system is cooled by two AL325 cryo-refrigerators. According to the testing results at an operation current of 130 A, the temperature of the HTS coils and the thermal shield are less than 20 K and 70 K, respectively, while are much better than the expected value.



Keywords: Induction heater, Superconducting magnet, YBCO

AP4-1-INV

Conductor for MRI magnets

*Michael Parizh[1]

GE Global Research[1]

Magnetic Resonance Imaging, MRI, is a powerful medical diagnostic tool and the largest commercial application of superconductivity. MRI magnet design is determined by competing requirements including functional performance, patient comfort, ease of siting in a hospital, minimum acquisition and lifecycle cost. The increased center field, maximized uniformity volume, minimized field decay and stray field, magnet compactness, optimized refrigeration, improved manufacturability, reliability and serviceability drive the magnet requirements. We consider the conductor requirements for commercial MRI magnets while avoiding links to a specific magnet configuration. MgB2, ReBCO and BSCCO conductors are evaluated. From a technical point of view, none of the HTS or MgB2 conductors meet all of the requirements to commercial MRI magnets at the moment. The following conductor features shall be developed or improved:

· Conductors specifically designed for MRI applications, with form-fit-and-function which can be readily integrated into present MRI topology with minimum modifications

· Conductors with improved quench characteristics, i.e. the conductor ability to carry significant currents without damage in the resistive state

· Insulation which is compatible with manufacturing and refrigeration technologies

· A dramatic increase in production and long-length quality control, including large-volume conductor manufacturing technology.

The in-situ MgB2 conductor is, perhaps, the closest to commercial requirements while still needs significant and lengthy developments including development of a stabilized conductor, conductor that does not require processing after winding, reliable long-length conductor.

Conductor technology is not the only issue in introduction of HTS / MgB2 conductor in commercial MRI magnets. Volume-production technologies shall be developed including efficient winding, reliable quench protection, superconducting joints, thermal switches that are compatible with HTS / MgB2 and can operate at elevated temperature, refrigeration technologies.

Keywords: MRI, Magnetic Resonance Imaging, NbTi conductor

AP4-2-INV

Development of A Half Size 3T REBCO Superconducting Magnet for MRI

*Shoichi Yokoyama[1]

Mitsubishi Electric Corp.[1]

Research and development for the practical application of a medical-use magnetic resonance imaging system (MRI) superconducting magnet that requires without liquid helium started as the New Energy and Industrial Technology Development Organization's (NEDO) supported project in fiscal 2016. Development of a liquid helium-free medical MRI superconducting magnet is desired. Another purpose is to reduce the size and weight of high magnetic field magnets. By using the high temperature superconducting coil, it is possible to make the 3T magnet as shape, weight, leakage magnetic field as 1.5T magnet. In this project, we are developing a half size active shield-type 3T REBCO coil for MRI. This magnet has active shield coils with a maximum diameter of 1200 mm, and the room bore diameter is 480 mm. This magnet is one of the largest in the world as a magnet using a REBCO wire with an accumulated energy of 1.6 MJ at the rated magnetic field. It is a magnet system with magnetic field uniformity and magnetic field stability necessary for imaging. In this paper, we report the half-size active shield-type 3T coil and the cooling system that can reduce the initial cooling time.

Acknowledgement
This research received grants and support from NEDO "development of an HTS magnet system with highly stable magnetic field" as part of the "promotion technology development for HTS practical application."

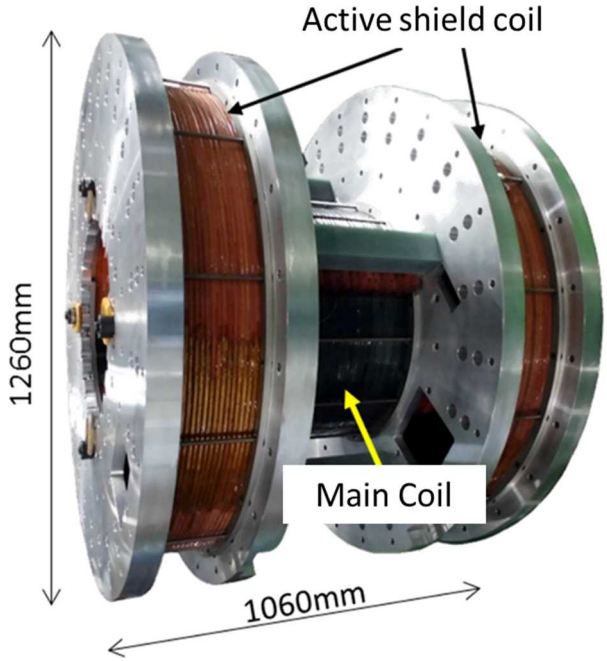


Fig.1 Photograph of half-size REBCO superconducting coil for MRI with active shield coils.

Keywords: Superconducting magnet, MRI, Liquid helium free, REBCO coil, field stability, field uniformity

AP4-3-INV

A Quench of an 800-MHz HTS Insert (H800)

*Yukikazu Iwasa[1], Dongkeun Park[1], Juan Bascuñàn[1], Philip C. Michael[2]

Francis Bitter Magnet Laboratory/Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge MA 02139[1]
Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge MA 02139[2]

An 800-MHz HTS insert (H800), together with a 500-MHz LTS NMR magnet (L500), constitutes the MIT 1.3-GHz high-resolution LTS/HTS NMR magnet (1.3G). The H800, composed of 3-nested coils, each a stack of no-insulation REBCO double-pancake coils, was designed to generate at 4.2 K and 251.3 A a center field of 18.3 T (= 18.8 T -0.5 T), where 0.5 T is an estimated field by screening current. In 2018, we operated H800 in a bath of liquid helium at 4.2 K: ~5 min after its power supply had reached 251.3 A, H800 quenched. When it quenched, its measured center field was 17.9 T, corresponding to a computed (from 18.3 T and 17.9 T) azimuthal (field-generating) current of 245.8 A. This talk begins with a brief history of the MIT 1.3G program that began in 2000, and then proceeds to focus on H800. Topics include: 1) the H800's charging history when it quenched; 2) a likely quench cause; 3) consequences seen in H800 after quench. The talk concludes with a brief description of key design features in H800N, a new 800-MHz insert, introduced in light of lessons learned from the H800.

Work supported by the National Institute of General Medical Sciences of the National Institutes of Health under R01GM114834.

Keywords: High-temperature superconducting magnet, REBCO double-pancake coils, 1.3-GHz high-resolution LTS/HTS NMR magn, Magnet quench

AP5-1-INV

Shingal Project ; The 1st Commercial Application of 23 kV HTS Power Cable System in Korea

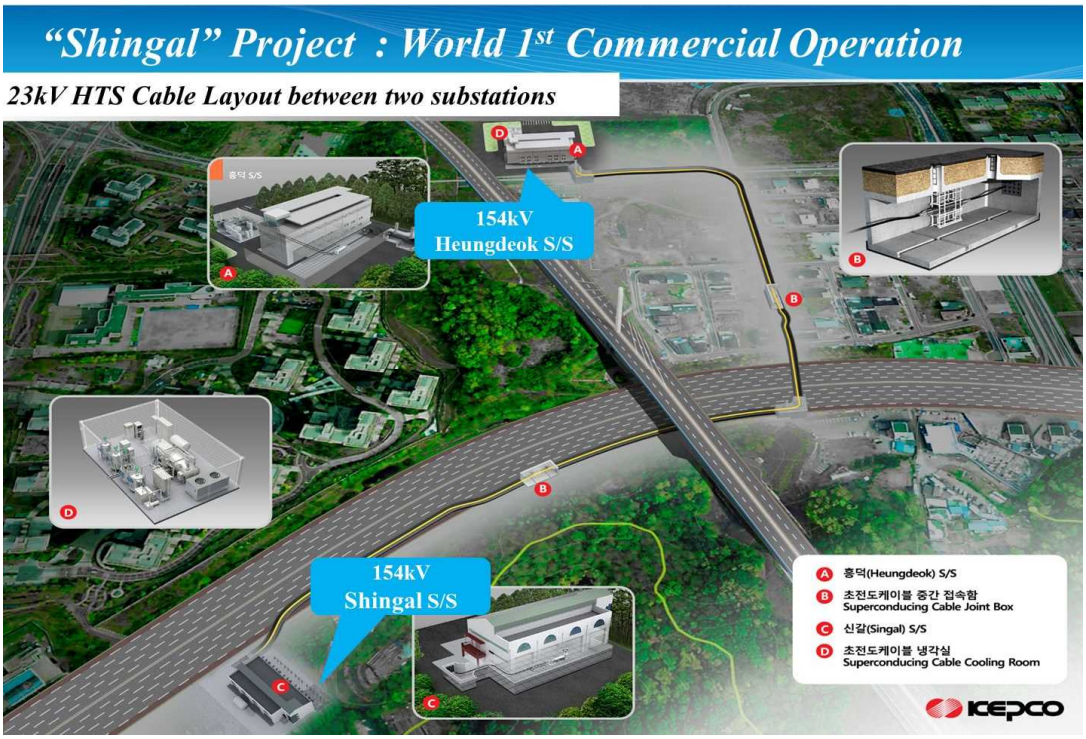
*Chulhyu Lee[1], Hyukchan Son[1], Cheol-hwi Ryu[2]

Korea Electric Power Corp. S. Korea[1]
LS Cable & System Ltd. S. Korea[2]

High temperature superconducting (HTS) cables have the advantage of being able to transmit much more power than that of the same size cable. Therefore, it is expected that HTS cables will be able to replace conventional XLPE transmission cables or multiple distribution cables and, consequently, will have the effect of enhancing reliability or minimizing substation construction. Based on a couple of successful demonstration projects of R&D, KEPCO, Korea's only electric utility, implemented a plan to put 23 kV HTS power cables into actual power system and use them for commercial operation, which was the birth of Shingal Project.

Shingal project was to connect the secondary buses of the two 154 kV substations Shingal and Heungdeok with a 23 kV HTS power cable. It consists of AC 23kV HTS cable system with the capacity of 50 MVA composed of 1 km long cable embedded with HTS tapes, 2 sets of normal joint and 2 sets of termination. The 23 kV HTS cable with a return pipe was installed along with existing cable conduits. It started its commercial operation successfully from July, 2019.

After the successful commercial operation of Shingal project, KEPCO is developing other projects in order to apply not only 23 kV superconducting cables but also 154 kV superconducting cables to real power system, such as Onsu project, Munsan project, etc. These projects will be introduced in this conference.



AP5-2-INV

ComEd superconductor cable project in Chicago and vision for the technology

*Daniel P Brotzman[1], Jim Maguire[2]

ComEd[1]
AMSC[2]

This presentation will cover at a high level the newly announced project in Chicago that will install a permanent in-grid superconducting cable. This low voltage cable will be the first permanent installation in the United States using the 2nd generation High Temperature Superconducting ("HTS") technology. Additionally, I will highlight a plan for future deployment of the HTS technology within Chicago. I will also share the vision that I see for the technology deployment and highlight some applications and challenges that the technology needs to overcome to increase the commercialization position of the technology.

Keywords: Chicago Project

AP6-0-INV

Efficient cryogenic cooling methods for HTS (High Temperature Superconductor) applications; from stationary cooler to moving HTS coils

*Sangkwon Jeong[1], Bokeum Kim[1]

Cryogenic Engineering Laboratory, Department of Mechanical Engineering, KAIST (Korea Advanced Institute of Science and Technology), Daejeon, Republic of Korea[1]

An HTS system typically requires cryogenic temperature which is much lower than the critical temperature of the superconductor for its normal operation. In the case of modern applications of HTS coils, this demanded temperature is passively determined by not only the cryocooler as a cooling source but also the thermal connection mechanism between the cryocooler and the target HTS system. Regardless of HTS applications, an efficient thermal communication is, therefore, very important to reduce unnecessary temperature difference between cooling source and target and the resultant parasitic entropy load of the cryocooler. In many cases, the real cooling load is insignificant unless the superconducting coil is operating in a ramping or ac (alternating current) mode with relatively large current. The virtual cooling load which is originated from thermal conduction or radiation heat leak from room-temperature environment frequently becomes the dominant factor to determine the size of the cryocooler. This paper addresses rather peculiar thermal bridging issue for moving HTS system. Instead of utilizing stationary cryocooler and implementing a complex configuration of thermal communication to take heat from the moving HTS coil, an innovative on-board cryocooler concept is introduced and systematic conduction-cooling is proved to be possible for superconducting rotor. Due to the bulkiness and inherent inefficiency, GM or JT cryocooler is not appropriate for on-board cryocooler. If the magnitude of heat generation and parasitic heat leak is manageable as in this example, a two-stage Stirling cryocooler or Stirling-type pulse tube refrigerator shall be readily applicable for this purpose. The first stage is used for thermal anchoring and the second stage is for cooling HTS coil. As demonstrated in this paper, a close collaboration with adequate communication between cryocooler developer and superconductivity community can produce genuinely competitive application of HTS system.

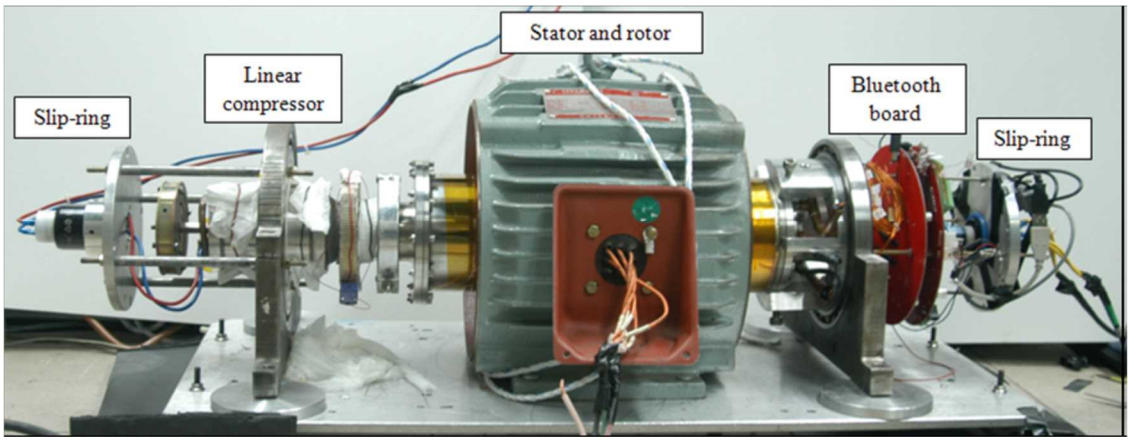


Fig. Superconducting rotor with onboard cryocooler

Keywords: Cryocooler, Entopy load, HTS coil, Parasitic heat leak, Thermal anchoring

AP6-1-INV

Superconducting Power Generators for Offshore Wind Turbines

Quan Li[1], Kevin Kails[1], Jacky Hong[1]

University of Edinburgh[1]

Offshore wind turbines, far away in the ocean, require light and compact power generators that can be easily shipped and installed. Superconducting power generators are a perfect option, which significantly reduce the mass of wind turbines and consequently result in substantial cost saving for installation and maintenance. However, excessive amount of superconductors are required that make superconducting power generators suffer from high cost and cooling and reliability issues. This presentation will introduce our latest research on an improved design of stackable superconducting power generators with a stationary superconducting field winding. This new design enables further mass reduction based on mechanical optimization of the rotation mechanism. Its stackable structure benefits on-site installation due to the flexible small modules that can be easily transported. We will also present our research work on the reliability of superconductors for offshore wind turbines. The change of superconductors after several cooling processes will be clearly demonstrated, which gains new knowledge essential to developing reliable superconducting power generators. This work is supported by the UK Research Council, under collaboration with Scottish Microelectronics Centre and Centre for Science at Extreme Conditions.

Keywords: superconducting power generator, wind turbine, mass reduction, reliability

AP6-2-INV

EcoSwing – Development, test, installation, and commissioning of a 3 MW superconducting wind power generator

*Markus Bauer[1]

THEVA Dünnschichttechnik GmbH[1]

In the EU funded EcoSwing project the world's first large-size superconducting lightweight multi megawatt wind turbine generator was designed, built and tested in a real wind turbine.

In order to realize this generator a technology to produce high quality HTS coils for reliable industrial use was developed and successfully qualified. Due to the high magnetic fields generated by the superconducting coils in the rotor a decrease of diameter from 5.4 m to 4 m and corresponding weight reduction was achieved.

In 2018 the generator was first tested in a nacelle test rig on ground and then installed on an existing wind turbine with 128 m rotor diameter in a demanding coastal site in Western Denmark. There, the previously installed PM direct drive generator was replaced with the much smaller superconducting EcoSwing generator. During commissioning early 2019 in total 650 h of operation were achieved and power up to 3 MW was delivered to the grid. Electromagnetic characteristics were met or even exceeded expectations. Cooling of the rotor was reproducible demonstrating the reliable performance of the cryocoolers.

An overview on the design, manufacture, and operation will be given, and main design features will be explained with a special focus on the superconducting coils and cryocooling.

Acknowledgements:
EcoSwing has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 656024.

Keywords: HTS coils, wind turbine generator

AP6-3-INV

Current Status and Future Expectation of HTS Rotating Machines in Korea

*Minwon Park[1]

Changwon National University[1]

Recently, many researchers have been actively researching superconducting rotating machines, in particular, superconducting generators for wind turbines and superconducting motors for propulsion aircraft. In Korea, research on the superconducting rotating machines has been ongoing. In the case of the superconducting motor, much attention has recently been paid to localization of electric propulsion systems for aircraft. Research on the superconducting motors for propulsion aircraft using liquid hydrogen has been conducted. In this paper, the world and Korea R & D trends of superconducting motors were discussed.

In the case of the superconducting generator, a large-scale floating offshore wind turbine with a superconducting wind power generator was suggested to achieve the renewable energy target which is 20% renewable energy achievement by 2030 in Korea. This paper introduces a new wind project for developing 10 MW class high-temperature superconducting (HTS) magnet, test facility, offshore floating system, and network connection technologies sponsored by Korea Electric Power Corporation. First step is a design of a 10 MW floating offshore wind power system with the superconducting generator. The design process of the 10 MW superconducting generator are developed, and the modeling method for the large-scale wind farm is suggested using real time simulator. Second step is the detail design of the 10 MW floating platform in which the floating system of the wind power system is designed considering the superconducting generator. Algorithms for control systems of the superconducting wind farm are developed. Korean type large scale floating offshore wind power system platform is suggested in the last-step. The fabricated superconducting pole is tested using a performance evaluation device. The mechanical stress and electric characteristics by Lorenz force are analyzed, and economic analysis result of the floating offshore wind power system is provided. As a result, we will discuss the possibility of large scale floating offshore wind power system, and Korean type large scale floating offshore wind power system platform with the HTS wind power generator will be proposed.

Keywords: Aircraft, HTS generator, HTS motor, Rotating machine, Wind turbine

AP6-4

Development of Hydrogen Supply and Exhaust System for Liquid Hydrogen Cooled Superconducting Rotating Machine

*Yasuyuki Shirai[1], Yoshiki Iwami[1], Shintaro Hara[1], Taito Matsumoto[1], Masahiro Shiotsu[1], Hiroaki Kobayashi[2], Yoshihiro Naruo[2], Satoshi Nonaka[2], Yoshifumi Inatani[2], Hirokazu Hirai[3], Seiichiro Yoshinaga[4], Teiichi Tanaka[5]

Kyoto university[1]
JAXA[2]
Taiyo Nippon Sanso, Ltd.[3]
IHI[4]
National Institute of Technology, Kumamoto College[5]

Superconducting generator has been developed with NbTi superconducting field winding cooled by liquid helium, but not yet commercialized.Superconducting motor and wind generator has been recently developed using BSCCO or REBCO wires which are mainly cooled by liquid nitrogen or refrigerator.

On the other hand, hydrogen based energy infrastructure is now promoted and liquid hydrogen is becoming an important energy carrier.We proposed to utilize liquid hydrogen as a coolant for superconducting generator.The superconducting generator can improve the power system stability and hence promote the introduction of renewable energies to the power system.Liquid hydrogen immersed cooling is preferable for rotor field winding of middle or large capacity commercial generator.

Experimental facility for the development of hydrogen supply and exhaust system for the hydrogen cooled rotor was introduced as one of the important component technology.

Keywords: liquid hydrogen, superconducting generator, cooling system

AP7-1-INV

Dynamo-type HTS Flux Pumps: Physics and Applications

*Chris W. Bumby[1], Andres E. Pantoja[1], Ratu C. Mataira[1], Mark D. Ainslie[2], Zhenan Jiang[1], Rodney A. Badcock[1]

Robinson Research Institute, Victoria University of Wellington, New Zealand[1]
Bulk Superconductivity Group, Department of Engineering, University of Cambridge, UK[2]

HTS magnet coils require large DC currents to be continuously injected from an external supply which is conventionally achieved using metallic current leads which penetrate the cryogenic envelope. These leads impose a significant heat load on the cryogenic system, due to both resistive dissipation and heat conduction. The resulting cooling-power requirements constrain the design of the overall magnet system, increasing system cost, footprint and weight. A preferred solution would be to eliminate the metal current leads entirely, and this talk will discuss a novel superconducting device which can achieve this goal - the HTS dynamo.

HTS dynamos are a type of superconducting flux pump. These unusual devices induce a DC current to flow around a closed superconducting circuit, formed between a magnet coil and the flux pump. During operation these devices output a small 'time-averaged' DC voltage, which is sufficient to overcome resistive losses incurred at normal-conducting soldered joints in the circuit. As a result a 'quasi-persistent' DC current can be maintained within the superconducting coil.

The HTS dynamo is topologically identical to a conventional ac alternator. It employs a permanent magnet rotor to apply a rotating magnetic field to a thin film of superconductor, such as a ReBCO coated conductor wire. In the normal-conducting state, the time-averaged DC output voltage from this device is zero, as expected from Faraday's law. But when cooled into the superconducting state, the output voltage is observed to now include a non-zero DC component, which acts to continuously inject current into a series-connected inductance (such as an HTS magnet coil). To understand this somewhat counter-intuitive experimental result, we present results from both experiment and finite element modelling. These illustrate the important role played by eddy currents in the HTS tape which experience a non-linear resistivity, and give rise to partial rectification of the AC emf. Building on this understanding, we have now developed improved dynamo designs, which are capable of injecting currents of >1 kA into a closed HTS circuit. We will conclude by discussing some potential applications of HTS dynamos in the excitation of high-current high-field magnet systems.

Keywords: Superconducting Flux Pumps, HTS Dynamo, Quasi-persistent Current, Finite Element Model

AP7-2-INV

Dynamic resistance in REBCO coated conductors

Zhenan Jiang[1], Chris W. Bumby[1], Rodney A. Badcock[1]

Victoria University of Wellington[1]

Dynamic resistance occurs in a superconducting wire carrying a DC transport current whilst exposed to AC magnetic field. REBCO-based coated conductors are steadily becoming the mainstream wire choice for HTS power applications. The HTS field coils in rotating machines, are exposed to an alternating ripple field while carrying DC current and dynamic resistance generated in this process adds to heat load to the cooling system. Dynamic resistance also plays a key role in HTS flux pumps, where it sets a limit for the maximum achievable output current from the flux pump. Although there have been some experimental results in dynamic resistance in REBCO wires, an analytical expression which can fully describe dynamic resistance in REBCO conductors (a 'superconducting strip') has not previously been validated.

Here, we review our recent research into dynamic resistance in REBCO wires exposed to applied AC magnetic fields with arbitrary angular orientations, and at different operating temperatures. We show that these experimental results can be fully described using two different analytical expressions for threshold magnetic field for the coated conductors. At low transport currents (($I_t/I_{c0} \leq 0.2$, where I_t is DC current level and I_{c0} is self-field critical current of the wire), Mikitik and Brandt's expression shows good agreement with experiment. At higher currents ($I_t/I_{c0} > 0.2$), an alternative expression based on the effective penetration magnetic field obtained from Brandt and Indenbom's analytical magnetization losses. We also show that a non-uniform critical current distribution at the edges of coated conductors plays an important role, and that at different field angles the dynamic resistance is dominated by the perpendicular magnetic field component, with negligible contribution from the parallel component. Dynamic resistance measurements at different temperatures show that dynamic resistance follows the predicted dependence on critical current density (which has been measured at each operating temperature).

This work now provides a clear foundation for the understanding of dynamic resistance in coated conductor wires, and has validated equations which predict the magnitude of this often neglected source of AC loss.

Keywords: HTS REBCO coated conductors, Dynamic resistance

AP7-3

Quench Analysis of the DEMO CS1 Coil

Aleksandra Dembkowska[1], *Monika Lewandowska[1], Xabier Sarasola[2], Kamil Sedlak[2]

West Pomeranian University of Technology, Szczecin, Poland[1]
École Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-5232 Villigen PSI, Switzerland[2]

The European DEMOnstration Fusion Power Plant (EU-DEMO) is being designed as an intermediary stage between the ITER experimental reactor and future commercial fusion power plants. The EU-DEMO is based on the tokamak concept with a fully superconducting magnet system. The Central Solenoid (CS) coil of the EU-DEMO will consist of five modules, namely CSU3, CSU2, CS1, CSL2 and CSL3, located vertically one above the other. The central CS1 module will be subjected to the most demanding operating conditions (the highest magnetic field and mechanical loads). Two concepts of the CS1 winding pack (WP) are being designed by CEA IRFM (France) and EPFL-SPC, (Switzerland) teams. The pancake wound WP proposed by CEA is based on Wind & React Nb_3Sn Cable-in-Conduit Conductor, whereas the hybrid WP developed by EPFL-SPC consist of 10 sub-coils, layer-wound using: HTS (RE-123), React & Wind Nb_3Sn and NbTi conductors in the high, medium and low field sections, respectively. Each design iteration undergoes comprehensive electromagnetic, mechanical and thermal-hydraulic analyses aimed at verification if it fulfills the design performance criteria. Our present work is focused on the quench analysis of all the hybrid CS1 sub-coils, aimed at the assessment of the maximum hot-spot temperature. The analysis, based on the iteration of the hybrid design proposed in 2017, is performed using the THEA CryoSoft code. We assume that quench is initiated at the beginning of premagnetization phase and include in our model the realistic magnetic field distribution along each conductor computed with 2D axi-symmetrical finite element model in ANSYS. We study the effect of taking into account heat transfer between neighboring turns and heat generation due to AC losses during the fast discharge on the value of the hot spot temperature.

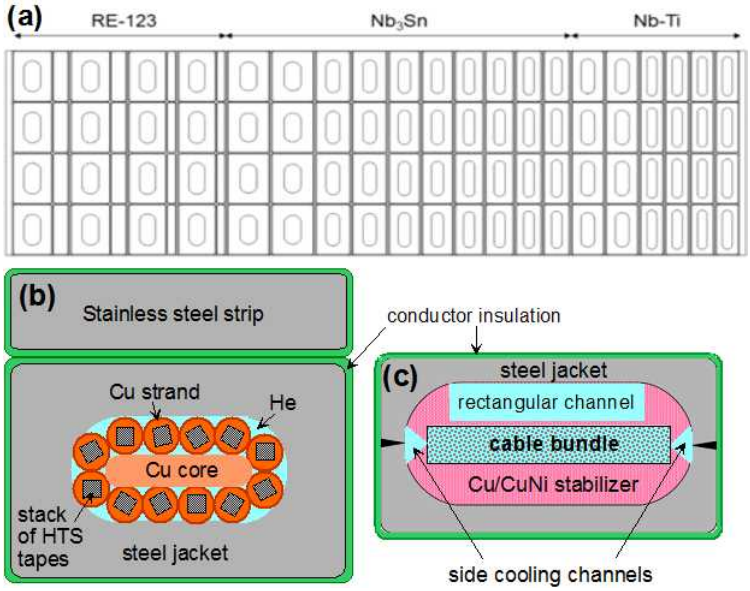


Fig. (a) Layout of the four conductor rows in the CS1 winding pack and schematic cross section of the (b) HTS and (c) LTS conductor.

Acknowledgement
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.
This scientific work was partly supported by Polish Ministry of Science and Higher Education within the framework of the scientific financial resources in the years 2018-2019 allocated for the realization of the international co-financed project.

Keywords: EU-DEMO, CS coil, CS1 module, quench, hot-spot temperature

AP7-4

The world's largest superconducting magnetic bearing for cosmic microwave background polarization experiments

*Yuki Sakurai[1], Peter Ashton[1,2,3], Akito Kusaka[3,4,5,6], Charles Hill[2,3], Kenji Kiuchi[4], Nobuhiko Katayama[1], Osamu Tajima[7]

Kavli Institute for The Physics and Mathematics of The Universe (WPI), The University of Tokyo, Japan[1]
Department of Physics, University of California, Berkeley, USA[2]
Physics Division, Lawrence Berkeley National Laboratory, USA[3]
Department of Physics, The University of Tokyo, Japan[4]
Kavli Institute for the Physics and Mathematics of the Universe (WPI), Berkeley Satellite, The University of California, Berkeley, USA[5]
Research Center for the Early Universe, School of Science, The University of Tokyo, Japan[6]
Department of Physics, Kyoto University, Japan[7]

We describe the design of a large-diameter superconducting magnetic bearing (SMB) employed in a continuously rotating cryogenic half-wave plate (CHWP) polarization modulator for cosmic microwave background (CMB) polarization experiments. A precise measurement of the CMB polarization will enable improved constraints on cosmic inflation, which describes a rapid expansion of the early universe. The CHWP system is a key instrument for suppressing 1/f contamination (mainly due to atmospheric noise) and mitigating systematic uncertainties that arise when differencing orthogonal polarization detectors. To ensure a sufficient field of view and to reduce thermal emission from the modulator, the CHWP must have a clear-aperture diameter of > 500 mm and must operate at cryogenic temperatures. We have developed an SMB with an inner diameter of 550 mm, which is the largest used in CMB polarization experiments to date. Here we present the design of the SMB and its mechanical and thermal performance.

Keywords: Superconducting Magnetic Bearing, Polarization Modulator, Cosmic Microwave Background, Cosmic inflation

APP1-2

One-dimensional quench analyses combined with quench experiments of conduction-cooled RE-123 coated conductors

*Xijie Luo[1], Satoru Inoue[1], Naoyuki Amemiya[1]

Kyoto University, Japan[1]

We have been accumulating data of quench experiments using short-pieces of conduction-cooled coated conductors. We aim to clarify the conditions for successful quench detection and protection of conduction-cooled magnets. The short turnaround time of such an experiment allows us to accumulate data at various operating conditions, but it cannot completely simulate circumstances in real magnets. The transverse thermal conduction cannot be simulated, because one side of our sample is attached to a GFRP sample holder, and another side is exposed to vacuum. A limited length of a short sample may affect quench propagation, because both ends are attached to current terminals, which are copper blocks with large heat capacity. We combined one-dimensional quench analyses with quench experiments to study the influence of such restrictions of short-sample experiments.

Our quench analysis model was formulated with the one-dimension heat conduction equation, in which the following factors were considered: the local and transient thermal disturbance inducing quench; the heat conduction along the conductor; Joule heat generation based on the current-sharing model; the transverse cooling (heat conduction to adjacent turns etc.) by using a simplified model. To consider the transverse cooling, we attached a GFRP piece with a certain thickness, which increased entire heat capacity and conducted heat through its thickness, to the sample coated conductor. The temperature of the outer side of this GFRP piece was assumed to be the operating (initial) temperature. The thickness of this GFRP piece was used as a parameter to fit the calculated longitudinal voltage distribution to the measured one. To consider the limited length of the short sample, the length of coated conductor in the model is limited, and the temperature at two ends is constant, same as operating (initial) temperature.

Keywords: Coated conductor, Conduction-cooled, Protection, Quench

APP1-3

A Study on Temperature Distribution Measurement for a No-Insulation HTS Coil with Encapsulated Optical Fiber Based on Raman-Scattering Technology

*Yingying Lv[1], Junjie Jiang[1], Longbiao Wang[1], Zhuyong Li[1], Zhiyong Hong[1]

Department of Electrical Engineering, Shanghai Jiao Tong University, No.800 Dongchuan Road, Minhang District, Shanghai, 200240, China[1]

In high temperature superconducting (HTS) applications, especially for HTS magnets, quench detection before burning out is very difficult, and it is considered as a key issue. As a potential candidate method, the technology based on optical fibers is proposed in recent years, and some progress is shown in HTS quench detection. However, the combination methods between optical fibers and HTS tapes in present study are inapplicable to HTS applications using long length tapes. In this paper, we proposed a novel HTS tape with two encapsulated optical fibers along the two sides to make good contact between the optical fibers and HTS tapes. To verify the feasibility of temperature distribution measurement for this novel HTS tape, a no-insulation coil is fabricated, and also a DTS system based on interrogating Raman-scattering is prepared. The structure of this novel HTS tape is introduced in this paper. Besides, critical currents of the novel HTS tape before and after winding are tested. Moreover, temperature distribution of the no-insulation HTS coil in air and in liquid nitrogen is measured. More specification of the no-insulation coil and the experiment results are presented and discussed in this study.

Keywords: optical fiber, DTS system, temperature distribution, HTS tapes

APP1-4

Substrate Temperature Dependence of AC Loss in BHO-doped SmBCO films

*Hiroki Kato[1], Yuji Tsuchiya[1], Yusuke Ichino[1], Yutaka Yoshida[1]

Nagoya University, Japan[1]

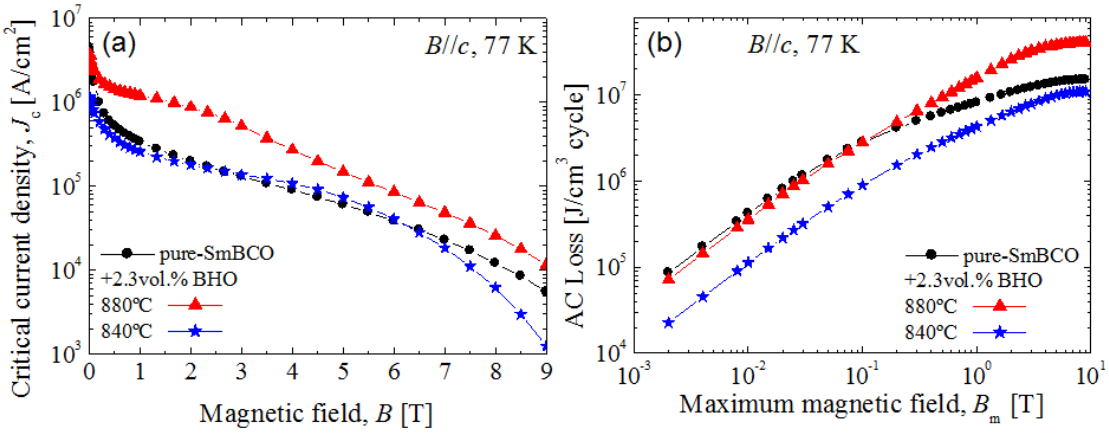
REBCO have been studied to be applied to rotating machines for airplanes, generators, and so on[1]. For these applications, it is necessary to improve their transport properties and reduce their AC losses. There are various ways to reduce their AC losses such as a laser scribing[2], a transposed parallel conductor[3], and so on. We focused on a magnetic field dependence of critical current density J_c in low field. That was because the less J_c in the field below an operating field was, the less AC loss was. In this study, we fabricated REBCO films which were introduced impurities into and controlled them. In results, their AC losses decreased.

Pure and BHO-doped SmBCO films were fabricated on IBAD-MgO buffered metallic substrates by using the PLD method. The BHO content was 2.3vol.%. The substrate temperatures T_s were changed from 840°C to 880°C. Magnetic field dependence of J_c in the films was measured at 77 K and at fields of 0-9 T. Magnetic field amplitude dependence of AC losses in the films was estimated from the magnetic field dependence of J_c.

Figs.1(a) and (b) showed magnetic field dependence of J_c and magnetic field amplitude dependence of AC losses at 77 K and $B//c$ in pure and BHO-doped SmBCO films fabricated in various T_s. As a result, the AC loss in the BHO-doped film of T_s = 880°C was lower than one in the pure film in low fields, although the in-field J_c in the BHO-doped film was higher than one in the pure film. That was because that the J_c in self-field in the BHO-doped film was lower than one in the pure film. In addition, J_c in the BHO-doped film of T_s = 840°C was almost the same as one in the pure film but the AC loss in the BHO-doped film was lower than one in the pure film at fields of 0-9 T. In particular, the AC loss at 1 T was about half. We will discuss transport properties and AC losses in BHO-doped SmBCO films fabricated in lower T_s with various BHO contents.

This work was partly supported by JSPS (19K22154), JST-ALCA, and JST-A-STEP. The metal substrates were provided from AIST.

[1] G. Snitchler *et al.*: IEEE Trans. Appl. Supercond. **15** (2005) 2206-2209.
[2] K. Suzuki *et al.*: Supercond. Sci. Technol. **20** (2007) 822-826.
[3] S. Oki *et al.*: IEEE Trans. Appl. Supercond. **28** (2018) 8201005.



Keywords: High Temperature Superconductivity, AC Loss, Artificial pinning centers, BaMO3

APP1-5

AC loss calculations of superferric magnets using HTS coils wound with stacked coated conductors and wound with CORCÒ wires

*Masahiro Yasunaga[1], Yang Li[1], Yusuke Sogabe[1], Yasuhiro Fuwa[2], Yoshihiro Ishi[1], Naoyuki Amemiya[1]

Kyoto University, Japan[1]
J-PARC, Japan[2]

In order to reduce the electricity consumption of rapid cycling synchrotrons (RCSs), we consider to apply superferric magnets using HTS coils to them. Because magnets for RCSs are required to generate time-dependent magnetic fields, the reduction of ac losses is one of the important issues when using HTS coils for superferric magnets for RCSs. When we consider to wound HTS coils for superferric magnets with single conductors, there are several problems such as mechanical strength of single conductors and large inductance of HTS coils. Using assembled HTS conductors is one of the solutions of these problems, and we focused on stacked coated conductors and Conductor on Round Core (CORCÒ) wires [1].
In the analyses of superferric magnets for RCSs using HTS coils wound with stacked coated conductors, we use the method same as we developed before [2] with assumption that all coated conductors carry same current. In the case of HTS coils wound with CORCÒ wires, we approximate the one part of HTS coils as an infinitely-long CORCÒ wire exposed to the external magnetic field assumed to be uniform along the CORCÒ wire. In order to get this external magnetic field, we calculate the magnetic field in the one part of HTS coils which generated by magnetized iron yokes and current in the other parts of HTS coils. Then, we carry out the three-dimensional electromagnetic field analysis to calculate ac losses of an infinitely-long CORCÒ wires exposed to external magnetic fields and carrying current.
We design the superferric magnets using HTS coils wound with stacked coated conductors and wound with CORCÒ wires which generate magnetic field of about 1.4T in the beam region, and calculate ac losses of those magnets. The magnets are operated at frequency of 100 Hz, and temperature of 65-70 K. The ac loss distributions in the HTS coils of those magnets are compared and discussed based on magnetic field and current density distributions in the HTS coils. Influence of the CORCÒ wire's three-dimensional geometry on the ac loss is discussed.

This work was supported in part by the Ministry of Education, Culture, Sports, Science and Technology under the Innovative Nuclear Research and Development Program.

[1] D. C. van der Laan, et al., Supercond. Sci. Technol., **25**, 045005, 2015
[2] Y. Sogabe, et al., IEEE Trans. Appl. Supercond., **29**, 5900505, 2019

Keywords: Rapid cycling synchrotron, Accelerator magnet, Assembled HTS conductor, AC loss

APP1-6

Theoretical Evaluation of AC Losses and Screening-Current-Induced Fields in HTS Insert for High Field Magnet

*Hiroki Yokoyama[1], Botao Zhu[1], Kazuhiro Kajikawa[1], Satoshi Awaji[2], Arnaud Badel[2], Kohki Takahashi[2], Tatsunori Okada[2]

Department of Electrical and Electronic Engineering, Kyushu University, Japan[1]
High Field Laboratory for Superconducting Materials, Tohoku University, Japan[2]

AC losses and screening-current-induced fields (SCFs) in a high temperature superconducting (HTS) insert for high field magnet are evaluated theoretically. The HTS insert is composed of stacked pancake coils, which are wound using two-ply conductors, where the superconducting-layer sides of two rare-earth-based coated conductors are attached to each other without electrical insulation. The theoretical formulas of AC loss and SCF in the two-ply conductor are derived for the simultaneous applications of a transport current and an external magnetic field parallel to its broad face. The obtained formulas consist of three terms, the contributions from the external field, transport current and gap between the superconducting layers. In order to evaluate the influence of the radial component of applied magnetic field on the magnetization in pancake coil, the electromagnetic-field distribution of stacked two-ply conductors exposed to only the external field is calculated numerically by means of a two-dimensional finite element method. The AC losses in the two-ply conductors a little far from the ends of stacked conductors can almost be reproduced with the theoretical formula as a result of the magnetic interaction between the conductors. By taking into account the magnetic-field profile in the HTS insert and the magnetic-field dependency of critical current density in the coated conductor, the AC losses and SCFs are estimated using the theoretical formulas for monotonical increase in a central field up to 25.5 T in 60 minutes in combination with low temperature superconducting outsert coils. In the case where the gap between the superconducting layers is 40 μm, the parallel-field loss becomes 17 W in maximum at about 10 minutes, which could be cooled by using prepared cryocoolers, after that, it monotonically decreases due to the decrease in the critical current density. The SCFs produced by the axial magnetic moments in two-ply conductor windings of the HTS inserts are positive, and it might be expected that the center fields in the high field magnets become a little larger than the design value.

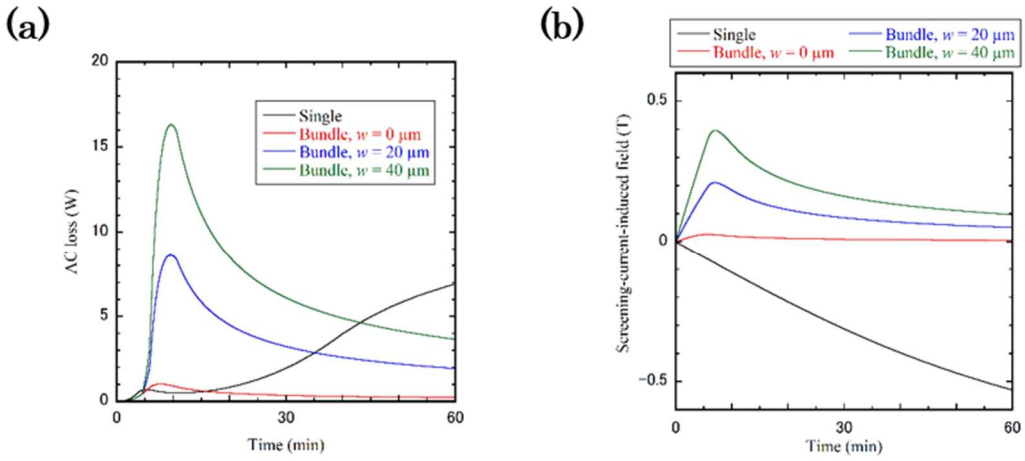


Fig. (a) AC losses in HTS inserts, (b) SCFs in HTS inserts

Keywords: High field magnet, HTS coil, AC loss, Screening-current-induced field

APP1-7

Finite Element Analysis of Electromagnetic Responses in Pancake Coils for High Field Magnet Wound Using Two-ply Conductors

*Botao Zhu[1], Hiroki Yokoyama[1], Kazuhiro Kajikawa[1], Satoshi Awaji[2], Arnaud Badel[2], Kohki Takahashi[2], Tatsunori Okada[2]

Department Of Electrical And Electronic Engineering, Kyushu University, Japan[1]
High Field Laboratory For Superconducting Materials, Tohoku University, Japan[2]

AC losses in stacked conductors exposed to external magnetic fields are numerically evaluated by means of a two-dimensional finite element method formulated using a self-magnetic field due to currents induced in an analysis region [1]. Fig. (a) shows the schematic illustration of two-dimensional numerical analysis model. The conductor is composed of two-ply tapes, in which the flat face close to a superconducting layer in one coated conductor is attached to that for the other coated conductor without electrical insulation to improve the thermal stability. The copper layer is sandwiched by two superconducting layers in the conductor. The external magnetic fields are increased monotonically from zero so as to simulate the electromagnetic responses in several typical parts inside a pancake coil for high field magnet. In order to understand only the geometrical effects on the AC losses, it is assumed that the transport property of superconductor can be expressed by the Bean model, in which the critical current density is independent of the local magnetic field. The influences of the numbers of bundle conductors, the gaps between superconducting layers and the angles of applied magnetic fields on the AC losses are investigated numerically. Fig. (b) shows the numerical results of AC losses in eleven conductors stacked at even intervals.

This work was supported by JSPS KAKENHI Grant Number JP18H05248.

[1] K. Kajikawa et al.: IEEE Trans. Appl. Supercond. 13 (2003) 3630.

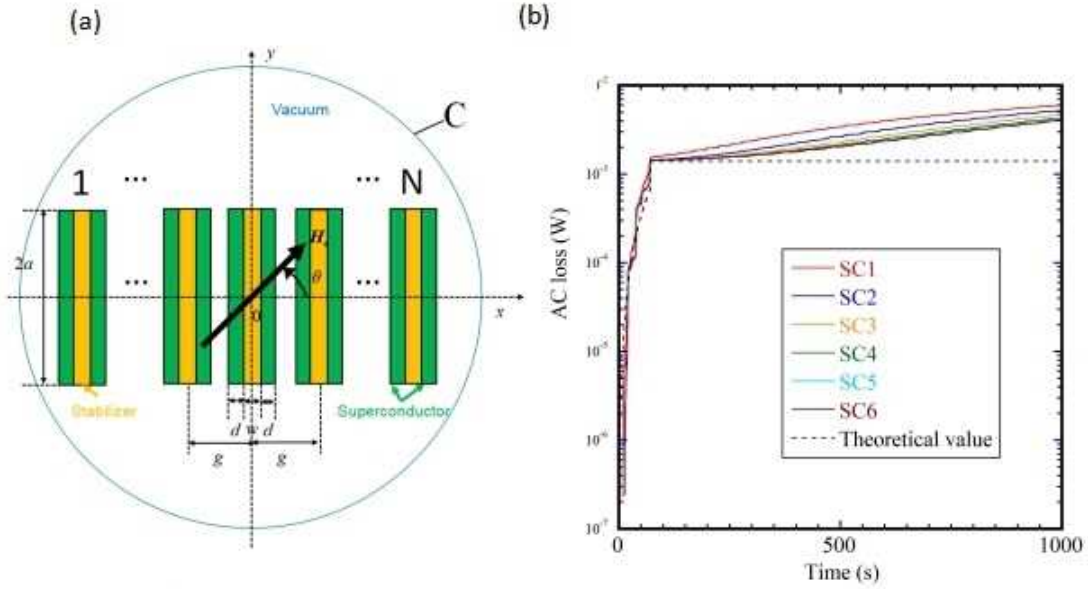


Fig. (a) Two-dimensional numerical analysis model, (b) numerical results of AC losses in stacked

Keywords: AC loss, Finite element method, Magnetic interaction, Pancake coil

APP2-1

Novel Performance for WLTC Operation Mode of 50kW Fully Superconducting Motor Drive System

*Masaya Okuno[1], Taketsune Nakamura[1]

Kyoto University, Japan[1]

Our group has been developing a high temperature superconducting motor, which has been expected for the applications of next-generation transportation equipment, e.g., train, bus, etc. Our motor is so-called High Temperature Superconducting Induction/Synchronous Motor (HTS-ISM). So far, the 20 kW class prototype, which consists of BSCCO rotor and copper stator, has already been developed and shown its excellent characteristics based on experiments and analysis. Furthermore, the 50 kW class HTS-ISM prototype, in which both the rotor and the stator are made of BSCCO superconducting tapes, has been fabricated, and various characteristics have been evaluated.
In order to realize a practical HTS-ISM drive system, not only the HTS-ISM but also peripheral devices such as an inverter and a refrigerator must be investigated. Furthermore, it is really important to study the cooling characteristics during drive conditions.
In this paper, we developed a multidisciplinary analysis method which combines the nonlinear voltage equation, the motion equation and the thermal equivalent circuit. Then, we carried out the so-called World-wide harmonized Light duty driving Test Cycle (WLTC) rotation test for the 50 kW class fully HTS-ISM. The WLTC is a newly adopted global harmonized driving test cycle which is used to measure the fuel consumption and CO2 emissions. It was shown that the nonlinear resistance of HTS stator winding should be considered in the voltage equation to express the exact performance of the HTS-ISM. It was also clarified that the heat generation of the motor is absorbed into the heat capacity of the motor body after the temperature of the rotor bar as well as the stator coil rise instantaneously, due to the large starting current. Furthermore, we successfully calculated the electric power consumption of the 50 kW class drive system and showed that our system possesses high efficiency even we consider the power consumption of cryocooler.

Acknowledgements:
This work has been supported by Japan Science and Technology Agency under the program of Advanced Low Carbon Technology Research and Development Program (JST-ALCA) in Japan.

Keywords: HTS-ISM, Fully superconducting motor, Multiphysics, WLTC

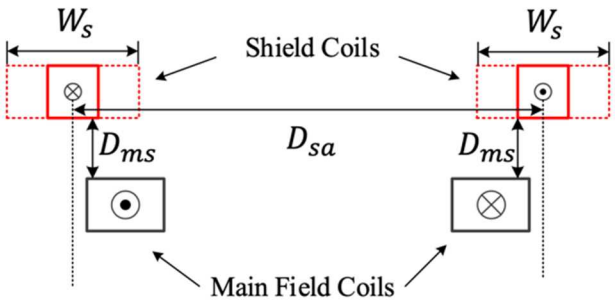
APP2-2

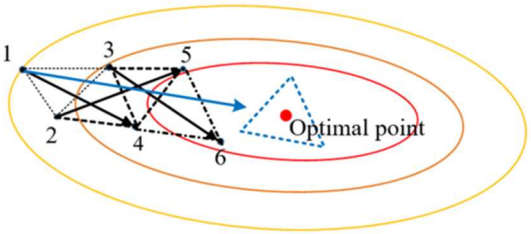
Optimal Design of Air-Core Superconducting Generator Using Simplex Method

Je-Min O[1], Gang-Hyeon Jang[2], Jung-In Lee[2], Tae-Kyoung Bang[2], Kiruba S. Haran[3], *Han-Wook Cho[1]

Dept. of Electrical, Electronics, and Comm. Eng. Edu., Chungnam National University, Daejeon, S. Korea[1]
Dept. of Electrical Engineering, Chungnam National University, Daejeon, S. Korea.[2]
Dept. of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urbana, U.S.[3]

Superconducting(SC) machines have been proposed and demonstrated for several high-power-density applications such as wind turbines, electric aircraft, and ship propulsion by using superconducting wires that can carry more than 100 times the current of conventional copper conductors [1][2]. Especially, fully air-core SC topologies have been considered as an option to achieve very high power density with unit weight of machines. In this paper, 10-MW 3000-rpm class active shield SC-generator which consists of rotating armature is proposed. Fig. 1 shows 1-pole analysis model with key parameters. Simplex method is useful optimization technique for finding the minimum or maximum value of the objective function by using reflection, contraction, and expansion. Fig. 2 shows the simplex method briefly. Initial simplex is formed of point 1, 2, 3. By comparing the objective function values at the points of the simplex, one of them (for example point 1) is reflected to point 4. Now 2nd simplex consists of point 2, 3, 4. It moves to the simplex having the optimal point gradually. In the full paper, the optimal design results by using Simplex method will be presented in detail.





Keywords: Optimal design, Air-core, Simplex method, active shield

APP3-1

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

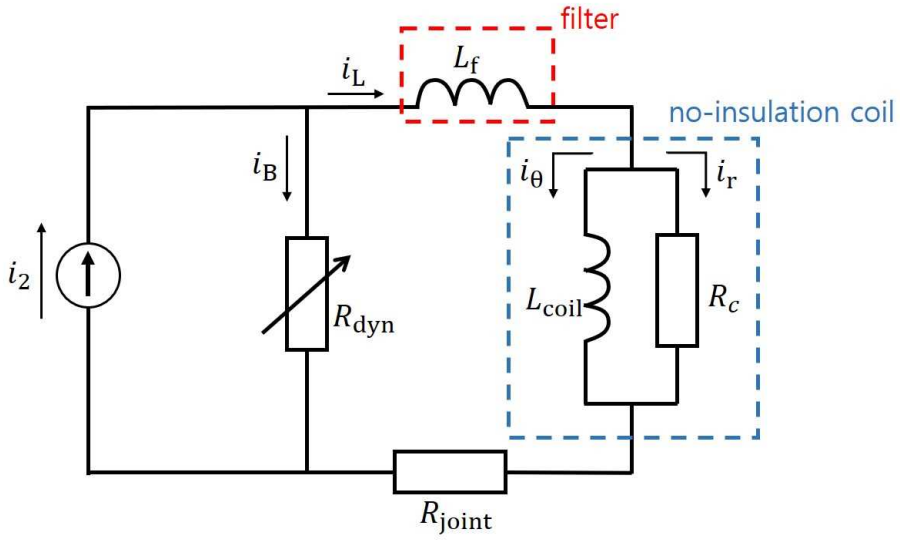
*Takanobu Mato[1], Thomas Kurauchi[1], So Noguchi[1]

Hokkaido University, Japan[1]

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

*Maxim Osipov[1], Sergey Pokrovskii[1], Dmitriy Abin[1], Irina Anishenko[1], Igor Rudnev[1]

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Russia[1]

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

*Irina V Anischenko[1], Sergei V Pokrovskii[1], Dmitry A Abin[1], Maxim A Osipov[1], Igor A Rudnev[1]

NRNU MEPHI[1]

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

*Kohki Takahashi[1], Tatsunori Okada[1], Arnaud Badel[1], Satoshi Awaji[1], Hiroshi Miyazaki[2], Satoshi Hanai[2], Shigeru Ioka[2]

Institute for Materials Research, Tohoku University, Japan[1]
Toshiba Energy Systems & Solutions Corporation, Japan[2]

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.

This work was supported by JSPS KAKENHI Grant Number 18H05248.

[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

*Tetsuhiro Obana[1], Yoshiro Terazaki[1], Nagato Yanagi[1], Shinji Hamaguchi[1], Hirotaka Chikaraishi[1], Makoto Takayasu[2]

NIFS[1]
MIT[2]

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

*Motoki Shinden[1], Sora Namba[1], Tatsuya Hirano[1], Hiroyuki Fujishiro[1], Tomoyuki Naito[1], Mark D. Ainslie[2]

Department of Physical Science and Materials Engineering, Faculty of Science and Engineering, Iwate University, 4-3-5 Ueda, Morioka 020-8551, Japan[1]
Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, United Kingdom[2]

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.

[1] K. Takahashi et al., Supercond. Sci. Technol. 31 (2018) 044005
[2] S. Namba et al., IEEE Trans. Appl. Supercond. 21 (2019) 6801605
[3] M. D. Ainslie, H. Fujishiro, Supercond. Sci. Technol. 28 (2015) 053002

Acknowledgements
This research is supported by Adaptable and Seamless Technology transfer Program through Target-driven R&D (A-STEP) from Japan Science and Technology Agency (JST), Grant No. VP30218088419 and by JSPS KAKENHI Grant No. 19K05240. M. D. Ainslie would like to acknowledge financial support from an Engineering and Physical Sciences Research Council (EPSRC) Early Career Fellowship, EP/P020313/1.

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

APP4-1

Estimation of Machine Parameters in Superconducting Transformer using Differential Evolution

*Tomohiro Yonenaka[1], Tatsuki Muraoka[1], Yuto Ichiki[1], Edmund Soji Otabe[1], Yoshitaka Tokunaga[2]

Kyushu Institute of Technology Japan[1]
Okayama Prefectural University Japan[2]

When a transformer is energized in the power system, an exciting inrush current occurs, which affects the power quality, such as unnecessary operation of the protective relay and malfunction of the control device. In order to grasp and solve these problems, it is necessary to analyze the waveform at the time of occurrence of the inrush current under several conditions. It is believed that the same problem is applied to superconducting transformers. In previous researches, we used Genetic Algorithm (GA) to estimate the machine parameters of superconducting transformers from excited inrush current. In this study, the estimation technique was further developed using Differential Evolution (DE).

As a result of estimation by DE, the calculation time is reduced to 1/10, the evaluation value representing the difference between the estimated value and the measured value is reduced to about half, and the estimation accuracy is improved, compared to GA.

Fig. (1) shows the measured value and the estimated values of the waveform of the excitation inrush current. It can be seen that the estimation result of DE is closer to the measured value.

The influence of differences in parameters was investigated on the DE estimation results. Fig. (2) shows the changes in the evaluation values for various CR and F, where CR is the crossover ratio and F is the scaling factor, respectively. As the CR is larger, crossover takes place actively to search a wide range, so it is easier to find an optimal solution and the evaluation value becomes smaller. As the F is small, the search range is narrow and the evaluation value is large. On the other hand, if it is large, detailed search can not be performed near the optimum solution, and the evaluation value becomes large. As described above, it is important to set parameters such as the CR and the F appropriately for estimation using DE. In this estimation, the CR was 1.0 and the F was 0.6 for best results.

This work was partly supported by JSPS KAKENHI Grant Number 19H00771.

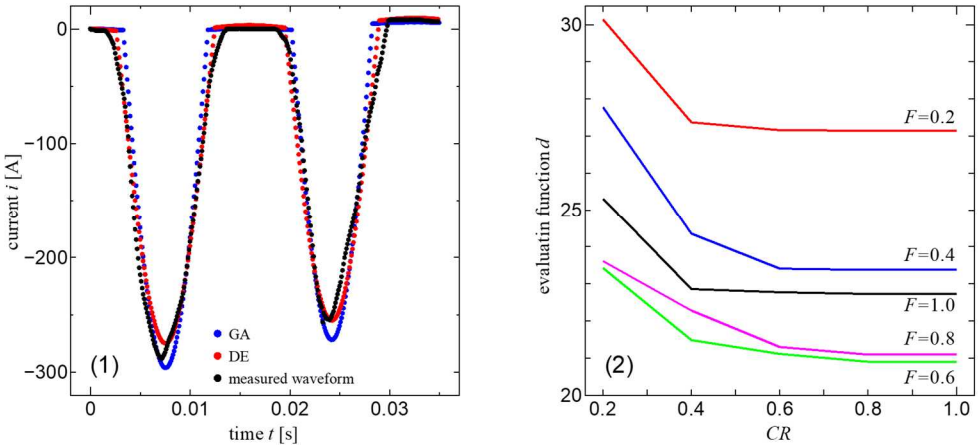


Fig. (1) Inrush current waveform calculated by GA and DE, (2) Values of the d at various CR and F

Keywords: Superconducting Transformer, Machine Parameter, Algorithm, Differential Evolution

APP4-2

Development of a High Temperature Superconducting Transformer for a 1 kA - 1 kHz Class Compact Power Supply

*Takahito Yamanishi[1], Nozomu Nanato[1], Masaya Okamoto[1]

Okayama University(Japan)[1]

Development of a High Temperature Superconducting Transformer for a 1 kA - 1 kHz Class Compact Power Supply

*T. Yamanishi, N. Nanato, M. Okamoto

Okayama University

We have been developing a compact power supply with a single-phase high temperature superconducting (HTS) transformer [1-3]. Our goal is to develop the variable voltage variable frequency power supply with a rated frequency of 1 kHz and rated current of 1 kA. We have achieved 1 kHz-850 A class HTS transformer so far [4]. The transformer had some leakage inductance and therefore the maximum output current was limited to 850 A. In this presentation, we report an HTS transformer with less leakage inductance based on the structural study of the transformer and the 1 kHz-1 kA class power supply. In addition, we will report a protection system for normal transitions in the 1 kHz-1 kA class HTS transformer.

[1] N Nanato, S Tanaka and S Tenkumo, Study on a Magnetic Flux Detection Coil for Detection of Normal Transitions in a Hybrid Single-phase Bi2223 Superconducting Transformer by the Active Power Method, Journal of Physics: Conference Series, Vol. 1054, 012070 (2018)
[2] N Nanato, T Ono, T Adachi and T Yamanishi, Protection System for Normal Transitions in a Single-phase Bi2223 Full Superconducting Transformer by the Active Power Method under Flowing Currents of Various Frequencies, Journal of Physics: Conference Series, Vol. 1054, 012068 (2018)
[3] N Nanato, N Kishi, Y Tanaka and M Kondo, Basic study for a large AC current supply with a single phase air-core Bi2223 high temperature superconducting transformer, Journal of Physics: Conference Series, Vol. 871, 012101 (2017)
[4] T Adachi, N Nanato, T Yamanishi, Development of Single-phase Bi2223 High Temperature Superconducting Transformer with Protection System for High Frequency and Large Current Source, Journal of Physics: Conference Series (in press)

Keywords: HTS transformer, Leakage inductance, Large AC current source, Normal transitions

APP4-3

Basic Study for an Air-core Hybrid Bi2223 High Temperature Superconducting Transformer for a Compact Current Source and its Protection System for Normal Transitions

*Shota Tenkumo[1], Nozomu Nanato[1], Kouki Matsuda[1]

Okayama University. of Japan[1]

A compact current source for supplying large AC current is useful for measuring current transport characteristics of HTS sample tapes. We focus on small weight and volume of a high temperature superconducting (HTS) transformer and have studied and presented the source with an HTS transformer [1-3]. The source outputs large current from its secondary coil by supplying small current to the primary coil. In order to reduce the weight and volume much more, we have been trying to develop an air-core hybrid Bi2223 HTS transformer. The transformer has a primary copper coil, a secondary HTS coil and no iron core [2, 3]. In this presentation, we will firstly report the structure of the transformer and characteristics of the large output current. The hybrid transformer needs a protection system for normal transitions in the secondary HTS coil for safe operation. Secondly, we will propose an appropriate protection system for the hybrid and air-core transformer. This work was supported by JSPS KAKENHI Grant Number 18K04080.

Keywords: current source, large AC current, HTS transformer, protection system

APP4-4

Comparison of several types of fault current limiter introduction into frequency converters of Shinkansen

*Takahiro Akahori[1], Yutaka Terao[1], Hiroyuki Ohsaki[1]

The University of Tokyo[1]

The Tokaido Shinkansen travels through both 50 Hz and 60 Hz electric power system regions, and the trains run on 60 Hz. Therefore, the Tokaido Shinkansen has equipped frequency converters to convert electric power from 50 Hz into 60 Hz in eastern area of Japan. There are two types of frequency converters, rotary frequency converters (RFCs) and electronic frequency converters (EFCs). RFCs have mainly been used and, recent years, the replacement from RFCs into EFCs is progressing, due to merits in maintenance. However, the EFCs have no overcurrent (such as fault current) tolerance and this problem has to be solved to replace all the RFCs into the EFCs. One of the solutions is introduction of fault current limiters (FCLs).

There are various types of FCLs, such as resistive type, saturated iron-core type, bridge type and so on, and each of those has different advantages and disadvantages. The FCLs for frequency converters of Tokaido Shinkansen have to reduce fault current less than 2.2 p.u. And this low allowable current brings difficulties for FCLs to protect EFCs. Therefore, there is a need to discuss which type of FCLs is suitable for this severe condition.

In this research, the Shinkansen systems which equipped various types of FCLs for EFCs were analyzed by using Psim. And fault current reduction effect, size, loss, fail safe and recovery time of each FCLs were compared.

The resistive type is smaller in size, lower loss and fail safe. However, it cannot reduce fault current less than the maximum allowable current and its recovery time is long. The bridge type can reduce fault current less than the maximum allowable current and its recovery time is short. However it tends to be bigger, larger loss and lower fail safe.

Keywords: Frequency converter, Fault current limiter, Superconductivity

APP4-5

Electromagnetic and Thermal Coupled Analysis of an SFCL REBCO Coil Immersed in Liquid Nitrogen Considering Boiling Phenomenon

*Kezhen Qian[1], Yutaka Terao[2], Hiroyuki Ohsaki[2]

Graduate School of Engineering, The University of Tokyo, Japan[1]
Graduate School of Frontier Sciences, The University of Tokyo, Japan[2]

A resistive type SFCL using REBCO tapes has shown high potential in limiting fault currents rapidly and improving the power system reliability. Temperature during and after the limiting operation is a key parameter when designing a SFCL, because the superconductor is sensitive to high temperature [1]. A detailed thermal analysis is helpful to study the transient distribution of the temperature. However, it is still a subject to precisely simulate the transient characteristics of coolant, which cannot be neglected and plays an important role in recovering from normal state to superconducting state [2].
In this paper, we have developed a 3D electromagnetic and thermal coupled FEM analysis model to study the transient characteristics of an SFCL REBCO coil immersed in liquid nitrogen. A thin-plate approximation and coordinate transformation (from cylindrical coordinate system to orthogonal coordinate system) is utilized to conduct the electromagnetic analysis of REBCO coils in 2D calculation space which have 3D structures. The governing electromagnetic equation is given by $\nabla\times(\rho\nabla\times\boldsymbol{T})=-\partial\boldsymbol{B}/\mathrm{dt}$ ($\boldsymbol{T}$: current vector potential; ρ: electric resistivity; $\boldsymbol{B}$: magnetic flux density), where $\boldsymbol{T}$ is defined by $\boldsymbol{J}=\nabla\times\boldsymbol{T}$ ($\boldsymbol{J}$: current density). In thermal analysis, the 3D structure of REBCO coil is modeled and the temperature rise is calculated under the condition of Joule heating, heat conduction, heat transfer, and cooling characteristics of liquid nitrogen. Moreover, the boiling phenomenon of nitrogen and hysteresis in the heat transfer coefficient are approximately modeled in this work. With this analysis model, we studied the transient temperature distribution and recovery of REBCO coils with the cooling of liquid nitrogen that considers the influence of boiling hysteresis phenomenon.

References

[1] Tixador P, et al, *IEEE Transactions on Applied Superconductivity* **28** 1–5, 2018
[2] Zubko V, et al, *IOP Conf. Ser.: Mater. Sci. Eng.* **502** 012178, 2019

Keywords: superconducting fault current limiter, finite element method, coated conductor, electromagnetic and thermal analysis

APP4-6

An Approach to Development of the HTS Magnet for SMES at JINR

Hamlet Khodzhibagiyan[1], Valeriy Drobin[1], Gennadiy Dorofeev[1], Victor Karpinskiy[1], Alexandr Shurygin[1], *Mikhail Novikov[1], Dmitriy Kashaev[1], Maxim Zaslavskiy[1], George Kachlishvili[1]

Laboratory of High Energy Physics, Joint Institute for Nuclear Research, Dubna, Moscow Region, Russia[1]

Particle accelerator complex NICA comprises Booster and Nuclotron accelerators which dipole magnets operate at pulse mode in opposite phase with a period of about 4 seconds. Summary energy of Booster and Nuclotron dipoles will vary from 1 to 2.6 MJ during the period. NICA power supply system can be significantly improved by Superconducting Magnetic Energy Storage (SMES) application that will help to move the energy back and force between Booster and Nuclotron. The useful energy at this SMES must be about 1.6 MJ so the maximum total SMES energy should be 3-5 MJ. SMES with this energy should have several Tesla magnetic fields to keep a reasonable size. SMES operating current can be not less than Booster and Nuclotron dipoles currents so it might be 10-12 kA. It is better to make such a SMES magnet from an HTS cable for the sake of stability at 6-7 T 4 s pulse mode. SMES magnet is planned to be wound as a short solenoid (Brooks coil) of cables optimized for several coaxial sections. HTS cables with a helical structure similar to well-known CORC cables are under the development at JINR. The HTS cabling technology is based on the same principle as nuclotron type cable manufacturing technology. HTS tapes, cables and magnets experimental study and testing methods are being developed on the base of the existing test facility at LHEP. JINR is also going to develop high field fast cycling dipole magnets for accelerators of HTS cables of the same type.

Keywords: supeconducting magnetic energy storage, high temperature superconductor, superconducting cable, fast cycling magnets

APP4-7

Theoretical and experimental investigation of R&W and W&R SMES coils wound with large-scale MgB2 Rutherford cables operated around liquid hydrogen temperature

*Moeto Hira[1], Tsuyoshi Yagai[1], Tomoaki Takao[1], Naoki Hirano[2], Takakazu Shintomi[6], Yasuhiro Makida[6], Toshihiro Komagome[3], Taiki Onji[4], Atsushi Ishihara[4], Masaru Tomita[4], Makoto Tsuda[5], Takataro Hamajima[5]

Science and Applied Technology, Sophia University, Tokyo, Japan[1]
NIFS, Toki, Japan[2]
Mayekawa MFG, Moriya, Japan[3]
Railway Technical Research Institute, Kunitachi, Japan[4]
Tohoku University, Sendai, Japan[5]
KEK, Tsukuba, Japan[6]

We have been developed the system called Advanced Superconducting Power Conditioning System (ASPCS) composed of Superconducting Magnetic Energy Storage (SMES), fuel cell and water electrolyzer for effective use of renewable energy such as wind and solar power generation. The SMES coils are wound with superconducting cables with large current capacities of kiloamperes (kA). We have been investigating about the SMES coil using large-scale Rutherford-type conductors made of commercially-available MgB_2 wires. The MgB_2 wires has critical temperature above boiling temperature of hydrogen, showing enough critical current (I_C) for practical application in self field of energy storage devices. Due to strain sensitivity even before heat treatment for MgB_2 production, the design for large-scale Rutherford cables both in wind and react (W&R), react and wind (R&W) method applied to coil fabrication has to be done cautiously to prevent the degradation of the I_C by optimizing design parameters such as twist pitch and cable compaction. Especially for the R&W method using heat-treated wires, other factors like handling during coil production process which might affect the conductor and coil I_C should be also considered. To evaluate the applied strains during manufacturing process, we conducted theoretical investigation on strains applied to individual filaments caused by wire-bending. We developed a test coil designed for R&W method based on analyzing those factors and the result of experiment. Furthermore, we have measured the coil I_C-B-T characteristic, which will be compared to those of other test coil made with W&R method.

Keywords: MgB2, SMES, Rutherford cable, Ic-B-T characteristic

APP4-8

Heat leak measurement of the cryogenic pipe for the superconducting power transmission at different surface temperatures

*Hirofumi Watanabe[1], Toru Takeuchi[1], Katsuya Miyake[1], Satarou Yamaguchi[1]

Chubu University[1]

Heat leak of the cryogenic pipe constituting a transmission line of the superconducting power transmission is one of the key characteristics, because it affects the efficiency of the transmission strongly. Since the heat leak is mainly caused by the radiative and conductive heat transfers, it depends on the surface temperature of the cryogenic pipe, which can vary with the changes of atmospheric temperature, weather, and direct sunlight hours. Thus, the heat leak can depend on the environmental conditions, where the transmission lines are installed.

We have measured the heat leak of the cryogenic pipes for the superconducting power transmission in the wide range of their surface temperatures to investigate the effect of the temperature variation and to obtain data for the installations of cables in different places with different environmental conditions. The cryogenic pipe used for the measurement was a 12 m long test pipe, which was the same type of the cryogenic pipe used in the Ishikari project [1]. This cryogenic pipe contains two inner pipes within an outer pipe. One of two inner pipes is for the installation of the cable and another is used to return the liquid nitrogen for circulation. The measurement was performed with the boil-off method. The obtained data was compared with the results obtained during the cooling tests of the actual transmission lines in the Ishikari project [2,3,4]. The heat leak characteristics of the cryogenic pipe will be discussed based on the results.

[1] H. Watanabe et al., Physics Procedia 67 (2015) 239-44
[2] H. Watanabe et al., IOP Conf. Ser.: Mater. Sci. Eng. 171 (2017) 012116.
[3] H. Watanabe et al., IEEE Trans. Appl. Supercond. 27 (2017) 5400205
[4] H. Watanabe et al., J. Phys. Conf. Ser. 1054 (2018) 012076

Keywords: Heat leak, Cryogenic pipe, Superconducting power transmission

APP5-1

Magneto-Archimedes levitation of metals by optimized ferromagnetic cylinder arrays in magnetic fields

*Daiki Yamamoto[1], Yuto Tagawa[1], Osuke Miura[1]

Electrical Engineering and Computer Science, Graduate School of Systems Design, Tokyo Metropolitan University, Japan[1]

We have studied magnetic levitation properties for metals by magneto-Archimedes effect under a high magnetic field gradient. Magneto-Archimedes effect is a phenomenon that materials levitate at a particular position in a paramagnetic medium by applying magnetic field gradient due to the difference of magnetic susceptibility and density between the medium and the materials. In order to enhance the magnetic force factor BdB/dz in a vertical direction, a ferromagnetic cylinder and an array of the cylinders were set into the room temperature bore of a 10 T superconducting magnet. We optimized the shape and the arrangement of the ferromagnetic cylinders to increase the magnetic force. The maximum BdB/dz achieved the high value of over -1600 T^2/m which was about 4 times larger than that without ferromagnetic materials. However, the problem remains that $BdBdz$ only increases just above the ferromagnetic cylinder. We succeeded in solving the problem by using the ferromagnetic cylinder array. The magnetic levitation properties for several kinds of metals in manganese chloride aqueous solution as a paramagnetic medium were studied. Each metal levitated at different height in relatively low magnetic fields. The ferromagnetic cylinder array made the metal grains and powders levitate uniformly in a horizontal direction. That proposes a new magnetic separator for valuable resource recovery from solid mixture in relatively low magnetic fields.

Keywords: magneto-Archimedes, metals, ferromagnetic cylinder array

APP5-2

Localization and Mapping for HTS Maglev Test Vehicle Based on Visual SLAM

Yi Li[1], Zigang Deng[2]

School of Information Science and Technology, Southwest Jiaotong University, Chengdu 611756, China[1]
Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China[2]

Real-time position information is the future development of high-temperature superconducting (HTS) maglev test system toward intelligence. However, due to the design parameters, drift, magnetic field interference of the system, traditional methods are difficult to maintain real-time performance when the positioning system is simplified. In navigation, mapping and odometry for indoor and outdoor environment, visual simultaneous localization and mapping (Visual SLAM) is the computational problem that constructs a map of an unknown environment and keeping track of real-time location simultaneously by visual sensors. In order to explore the accuracy and robustness of the visual SALM method under the HTS maglev test system, this paper focuses on the different behaviors of multi-sensor fusion SLAM method and monocular SLAM method in the measurement environment. Compared to the monocular SLAM with only a single camera, the multi-sensor fused SLAM method using cameras, IMU and active IR detector is more robust in low-texture and high-frequency texture environments. This method can improve the feature matching precision of the system and provide powerful guarantee for real-time positioning and mapping. On this basis, this work comes strong support for evaluating the driving characteristics of maglev vehicles at different speeds, and offers a fresh idea for the positioning method of rail transit experimental system.

Keywords: SLAM, Multi-sensor data fusion, Localization, High-temperature superconducting maglev

APP5-3

Active Vibration Control of Secondary Suspension Based on High-Temperature Superconducting Maglev System

Qingshu LI[1], Zigang DENG[1], Haitao LI[1]

Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China[1]

High-temperature superconducting (HTS) maglev vehicle system is a kind of self-stable levitation mode which is characteristic of flux pinning of non-ideal type II superconductor, has the outstanding advantages of simple and reliable principle, environmentally friendly and so on. But in HTS maglev vehicle system, the levitation force of the YBCO bulk over a NdFeB guideway is oscillated by the fluctuant external magnetic field, which is easily transmitted to the car body to affect the running comfort. This paper starts with the active vibration absorber of the secondary suspension system of HTS maglev, the electromagnetic linear actuator was applied based on active vibration control. The magnetic force of the electromagnetic linear actuator was controlled to increase the damping of suspension system thus improve the comfort of the maglev system. The experimental platform of active vibration absorber is built, which is composed of four electromagnetic linear actuators and a suspension frame, the electromagnetic linear actuators are placed in four corners of the frame above the four HTS maglev dewars respectively. The magnitude of the electromagnetic force is controlled through AC current to counteract the vibration from the track, the mathematical model of absorber system was built, digital PID control was used to the design of the controller to realize the control of the magnetic force. Then, the designed active vibration absorber of the secondary suspension system was validated under different speed levitation height and field cooling height (FCH). The result of the experiment indicates that the electromagnetic linear actuator will reduce the vibration of magnetic levitation vehicle caused by the fluctuant external magnetic field efficiently. With this method, it can greatly improve the stability of the system and help us to achieve more comfortable.

Keywords: high-temperature superconducting maglev, active vibration control, electromagnetic linear actuator, Simulink simulation

APP5-4

Dynamic modeling of bulk superconductors with different E-J relationships for high temperature superconducting Maglev systems

Ye Hong[1], Jun Zheng[1], Zhichuan Huang[1], Hengpei Liao[1]

Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, P. R. China[1]

Three ***E-J*** relationships describing the electromagnetic behavior of the high-temperature superconducting (HTS) bulk over a permanent magnet guideway (PMG) are discussed in this paper. They are the power law model (PLM), the flux flow and creep model (FFCM), and the flux flow model (FFM). With the aid of the finite element software COMSOL Multiphysics, these models were successfully established combining with the AC/DC module and the Heat Transfer module. The irregularity of the surface of the real PMG is considered in the modeling by applying a small-amplitude vertical vibration function to the guideway which is built as a geometric entity. In view of the application of high-speed HTS magnetic levitation (Maglev) system, compared with the experimental data, the dynamic response of the levitation force, the temperature distribution and the current density distribution of the HTS bulk under different vibration frequencies was analyzed. This work can provide a reference for the modeling of the dynamic response of the electromagnetic-thermo-force characteristics of the HTS Maglev system.

Keywords: high temperature superconducting bulk, power law model, flux flow model, flux flow and creep model

APP5-5

Simulation Study on Maglev Performance of High Temperature Superconductors in Low Pressure Environment

*Weifeng Zhang[1], Zigang Deng[1], Yu Liu[2]

Southwest Jiaotong University, China[1]
CRRC Tangshan Co., Ltd., China[2]

High temperature superconducting Maglev evacuated tube transport (HTS Maglev ETT) system has significant potential for rail transit applications, due to the advantages of self-stable levitation, no contact friction and low air resistance, which combines HTS Maglev and ETT technology. It is necessary to study how the Maglev performance of high temperature superconductors (HTSCs) will change in low pressure environment. In this paper, the applicability of the Power Law Model (PLM) and Flux Flow and Creep Model (FFCM) is compared when studying the Maglev performance related to air pressure, as well as different J_c-T models. The simulation model applicable to analyze the Maglev performance of HTSCs in different pressure environment is established. This simulation demonstrates the beneficial effect of low pressure environment on the Maglev performance of HTSCs, and provides an effective approach for HTS Maglev simulation in further lower pressure and low temperature environment.

Keywords: high temperature superconductors, maglev performance, simulation model, low pressure environment

APP5-6

Load characteristics of contactless bearing based on HTSC tape

*Igor Rudnev[1], Maxsim Osipov[1], Aleksander Starikovskii[1], Dmitriy Abin[1], Irina Anischenko[1], Sergey Pokrovsrii[1]

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia[1]

By now there are many studies aimed to finding of possibility for using of novel superconducting flexible tapes in magneto-levitation systems instead bulk high temperature superconducting materials. In this report we present design and results of investigations of superconducting magnetic bearing on the base of HTSC flexible tapes. The bearing consists of a cooled by liquid nitrogen cylindrical stator and concentrically placed rotor. The HTSC tape with 12 mm width and 150 cm length is wound on the cooling stator in a few layers as a pancake. The rotor consists of a simple set of permanent magnets. The magnetizations of adjacent layers have opposite directions. We tested the bearings with various configurations of superconducting windings which differ in numbers of pancakes and number of tape layers in one pancake. The loading characteristics, i.e. dependencies of axial and radial levitation force components on displacements were measured. We compared the obtained dependencies with the values of the levitation force for stacks of HTSC tapes in a similar configuration of permanent magnets and found a good agreement for both cases.

Keywords: HTSC, Flexible tapes , Levitation, Bearing

APP5-7

Moddeling of thrust magnetic bearings for levitation systems

*Sergei Pokrovskii[1], Irina Anischenko[1], Igor Rudnev[1]

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Russia[1]

Currently, the main construction material for levitation bearings and suspensions are bulk high temperature superconducting samples. But bulk HTS has several drawbacks such as brittleness, the complexity of sample preparation, when samples of desired shape are needed. Also critical current density of the bulk samples is significantly less than it for the HTS tapes. Thus, an alternative way to construct levitation systems is to use HTS tapes stacks that has high strength, simplicity of thermal stabilization and the ability to vary the geometric parameters of the stack Special attention is paid to the HTS magnetic bearings development in various technical applications, such as gas-turbine installations, electric motors, high-speed rotor systems, where the magnetic bearing is one of the main components determining technical characteristics and durability. The complexity of this type magnetic systems need to take into account the superconducting materials properties in gradient magnetic fields. Therefore, using the special software taking into account the features of the three-dimensional magnetic system and sharply non-linear hysteresis materials properties is necessary. This work presents the complex results of the FEM H-formulation modeling of the thrust magnetic bearing based on 2G HTS tapes, which consist of HTS stator and PMs rotor. In view of the required size production problem, ring PMs magnetized radially replacing with sectoral PMs, as well as cubic PMs, were proposed and justified. Load characteristics and losses in the system for various bearing configurations were obtained. In this work we present a computational model for a magnetic levitation system based on the second generation HTS tapes GdBa2Cu3O7-x. In our the model we have used the magnetic and transport characteristics of industrial superconductors and also took into account the thermal properties of each layer of high-temperature superconducting tape and the features of the layered structure of whole stack. The numerical simulation was performed using the finite element method. We compared the simulation data with the experimental results and got good agreement of results.
This work was supported by Russian Science Foundation (project 17-19-01527)

Keywords: levitation, bearing, HTS, moddeling