Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13 Shinonome Koto-ku, Tokyo 135-0062, Japan Tel:+81-3-3536-7283, Fax:+81-3-3536-7318

Contents:

Top of Superconductivity Web21

Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13 Shinonome, Koto-ku, Tokyo 135-0062, Japan
Tel: +81-3-3536-7283 Fax: +81-3-3536-7318
Top of Superconductivity Web21: http://www.istec.or.jp/Web21/index-E.html

This work was subsidized by the Japan Keirin Association using promotion funds from KEIRIN RACE
http://ringring-keirin.jp

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Force-free torque and longitudinal magnetic field effect

Teruo Matsushita, Professor
Graduate School of Computer Science and Systems Engineering
Kyushu Institute of Technology

When an electric current is passed through a superconductor in a normal transverse magnetic field, Lorentz force is exerted on the inner magnetic flux and this force is expressed as the restoring force to eliminate the strain of magnetic flux such as unevenness and bending, or as magnetic pressure and line tension. In the case of longitudinal magnetic field, on the other hand, in which an electric current is passed through a straight superconducting wire or tape in a parallel magnetic field, it is empirically known that force-free state ($J \times B=0$, where J is current density), in which magnetic flux and electric current are locally parallel to each other, is obtained. In this state, the magnetic field has strain as shown in Figure 1 (force-free strain). It is presumed from the example of Lorentz force that restoring torque (force-free torque) to release the strain is exerted. Actually, this torque can be obtained by calculating the energy increase when force-free strain is virtually introduced using Maxwell theory. That is, this energy is obtained by calculating the induced electric field and the Poynting vector on the surface when the strain is introduced. Torque density is given by the rate of change of the energy density relative to the angle of surface magnetic field.

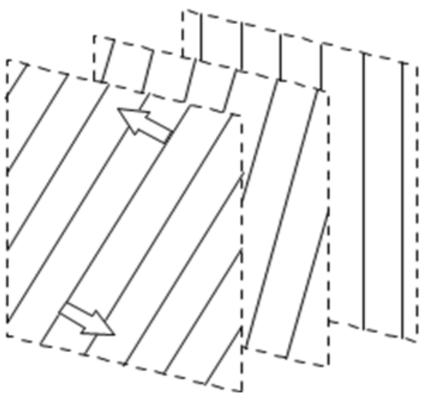


Fig. 1 Distortion of magnetic structure under force-free state and force-free torque that alleviates the distortion

Although the existence of this torque has not been recognized, this is one of the basic rules derived from Maxwell theory like Coulomb force and Lorentz force, which has been dormant for one hundred and tens of years since the theory of electricity and magnetism was formulated.

The reason why force-free torque is not known is that it cannot be directly observed like Lorentz force. This is firstly because the electric current flows straight through the shortest passage in normal conductors such as metals for which Ohm' law stands so that force-free state does not appear as shown in Figure 1. Secondly, since the force-free state developed in a superconducting material is an internal force and internal forces negate each other resulting in zero. Therefore, verification of the existence of force-free torque that cannot be directly observed can be done only indirectly through the explanation of electromagnetic phenomenon caused by the torque. The electromagnetic phenomenon is longitudinal magnetic-field effect.

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Electromagnetic phenomena that occur when an electric current is passed through a superconducting wire or tape in a longitudinal magnetic field is collectively called longitudinal magnetic-field effect, and the following facts are known: critical current density significantly increases compared with the case of transverse magnetic field, magnetization in the longitudinal direction becomes paramagnetic due to the electric current, Josephson equation relating to induction field, $E=B\times v$, does not stands (v is the velocity of magnetic flux), surface electric field structure including negative field region is observed in resistive state in which the electric current exceeds the critical value. The paramagnetic effect is explained by the force-free model supported by Josephson theory. For this reason, it is assumed that the force-free state is essentially a stable state without pinning, and the critical current density has been thought to be determined by the threshold value of magnetic flux cutting proposed to explain the deviation from Josephson equation.

However, the critical current density actually depends on the pinning strength as under the transverse magnetic field, and it is expected that the critical current density becomes zero without pinning. This prediction agrees with the force-free prediction, which suggests that Josephson theory has a problem. As a matter of fact, the gauge of vector potential assumed in the theory is denied by the test results and it is concluded that electrical current has to be zero in the equilibrium state without stabilization by pinning.

Thus, it is concluded that the critical current density in a longitudinal magnetic field is given by the balance between force-free torque and pinning torque, which corresponds to the force balance in transverse magnetic field. This condition explains the experimental results that the critical current density depends on the strength of magnetic flux pinning strength also in longitudinal magnetic field. Figure 2 shows the experimental results indicating that the critical current density is proportional to pinning torque, and the straight line shows theoretical prediction, where f_p, N_p, d_p stands for elementary pinning force, number density, and average interval of pinning centers respectively.

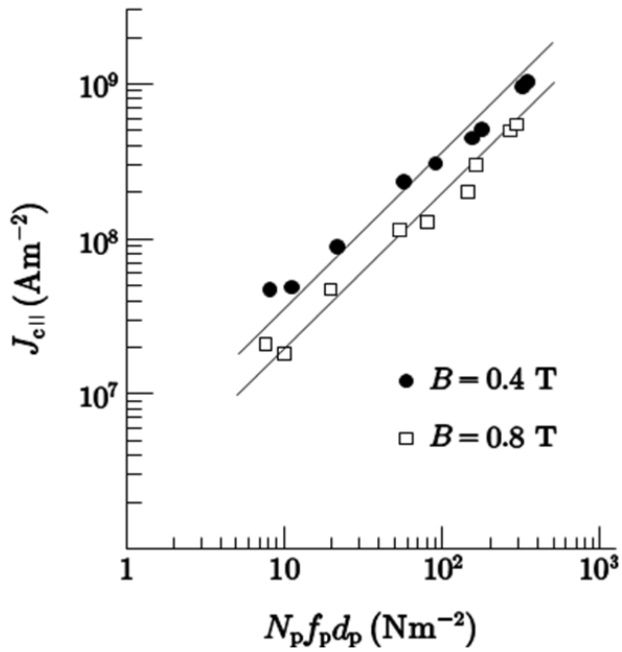


Fig. 2 Relationship between the critical current density of Pb-Bi samples in longitudinal magnetic field and pinning function (Straight line indicates theoretical prediction.)

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Then, rotational solution of magnetic flux velocity is introduced from the continuous equations of magnetic flux in the quasi-static process of force-free state to move in from the surface by passing electric current in a longitudinal magnetic field, and it was shown that the rotation is caused by the force-free torque that exceeds the pinning torque. It was also shown that the Josephson's equation, $E=B\times v$, does not stand when the rotation of magnetic flux occurs. Furthermore, surface electric field structure is explained assuming spiral magnetic flux flow as the steady movement of magnetic flux generated by force-free torque in a dynamic condition in which resistance is produced.

As described above, longitudinal magnetic-field effect is explained from the viewpoints of force-free torque and rotational movement of magnetic flux induced by it, in all of statically balance condition, quasi-static condition, and dynamic condition, so that the existence of force-free torque is indirectly proved.

The basis of the application of this phenomenon is to utilize the fact that the critical current density increases in longitudinal magnetic field. What is important here is to develop appropriate superconducting wire materials and basic research is required for obtaining eminent characteristics because the critical current density is determined by a principle different from traditional principle. What is required next is to study the possibility of application of such eminent wire materials and it is expected that new ideas of application are brought about in addition to the applications to high magnetic field and electric power transport that are now under consideration.

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

What's New in the World of Superconductivity (August, 2009)

Akihiko Tsutai, Director
International Affairs Division, ISTEC

Award

Air Force Office of Scientific Research (August 19, 2009)

Dr. Paul Barnes, a researcher at the U.S. Air Force Research Lab (AFRL), has won the 2009 Science, Technology, Engineering and Mathematics (STEM) award for his outstanding achievements in the field of superconducting materials. Barnes has been exploring new and innovative methods of fabricating advanced superconductors using nanotechnology. Dr. Alan Garscadden, chief scientist of the AFRL Propulsion Directorate, commented, "The AFRL Propulsion Directorate is proud to have Dr. Barnes leading the way in the invention and application of superconductors for improvement of current and next-generation weapon systems."

Source:
"Air Force Research Lab scientist wins award for groundbreaking research"
Air Force Office of Scientific Research press release (August 19, 2009)
http://www.wpafb.af.mil/news/story.asp?id=123163582

Power

Zenergy Power plc (August 3, 2009)

Zenergy Power plc has completed the first set of 28 superconducting coils required for the construction of a full-scale superconducting electricity generator. The generator will be the main component in a 1.7-MW hydropower generator to be installed in a commercial hydropower station belonging to E.ON Wasserkraft GmbH in early 2010. Once installed, the generator will supply electricity to more than 3,000 local homes. The completion of the superconducting coils is of particular significance in that it demonstrates Zenergy Power's ability to scale production in a consistent, uniform, high-quality, and reliable manner. The completed coils have been tested and shipped to Converteam UK Ltd., who will begin the final construction work on the full-scale machine.

Source:
"Coil Delivery for Superconducting Renewable Energy Generator"
Zenergy Power plc press release (August 3, 2009)
http://www.zenergypower.com/images/press_releases/2009/2009-08-03-Coil-Delivery-for-Superconducting-Generator.pdf

Zenergy Power plc (August 5, 2009)

Zenergy Power plc has announced that its German subsidiary has received additional government funding (€400,000) for ongoing work on the development of its patented low-cost production techniques for the mass-production of second generation HTS wire. Specifically, the funding will be used to develop advanced layering techniques to support and accelerate the ongoing second-generation wire development program. Zenergy's 'all-chemical' production approach is anticipated to significantly reduce the cost of HTS wire, facilitating the supply of highly efficient superconducting generators to the global renewable energy market. Such applications could dramatically reduce the cost of producing renewable energy.

Source:
"Development Grant for 2G wires"
Zenergy Power plc press release (August 5, 2009)
http://www.zenergypower.com/images/press_releases/2009/2009-08-05-Development-Grant-for-2G-wires.pdf

SuperPower, Inc. (August 18, 2009)

SuperPower Inc. has reported its latest achievements and world-record performances at the 2009 U. S. Department of Energy's Annual Peer Review of Superconductivity for Electrical Systems. A number of significant new achievements in product performance, length, production improvements and enhanced product configurations were reported; these milestones are closely associated with the DOE's goal of encouraging the development of second-generation HTS wire to meet the specifications required for the modernization of the electric power grid and the enhancement of the reliability and security of the energy infrastructure.

First, SuperPower has obtained a new world record wire performance, breaking its own previous world record. The new record consists of a 1,065-meter-long wire capable of carrying a minimum current of 282 amperes, resulting in a record wire performance of 300,330 amp-meters. The previous world record was for a 1,030-meter-long wire capable of carrying 227 amperes, resulting in a wire performance of 233,810 amp-meters.

SuperPower also reported that it has reorganized its organization to emphasize technology development and manufacturing. Arthur P. Kazanjian, general manager of SuperPower, explained, "Until last year SuperPower's technology development and manufacturing operations were integrated in Schenectady with long length, high throughput and yield issues being managed by the technology group. We recognized that our rapidly growing customer orders needed a routine manufacturing operation directed by manufacturing engineers. Likewise, the strong advances needed in technology for high performance wires, highly efficient processes and advanced wire architectures remained critical for the commercialization of 2G wire… [As a result] we have consolidated SuperPower's technology development operations in Houston, thus enabling our total focus on manufacturing in Schenectady…"

Several technical advances were also reported, the most important being a consistent two and one-half times improvement in in-field performance with a high uniformity. Dr. Venkat Selvamanickam, Chief Technology Advisor at SuperPower, reported, "Over a wire length of 300 m, 28 percent retention in critical current was achieved in a field of 1 T at 77 K… Additionally, this level of performance was found to be uniform within three percent over long wire lengths. This achievement enabled SuperPower to demonstrate coils which generated a magnetic field of 2.5 T at 65 K, exceeding the FY09 Annual Performance Target of 2 T established by the DOE in the effort to maintain progress in achieving increasingly powerful coils for electric power applications such as transformers and motors." Additional technical improvements reported by SuperPower included high-efficiency processes and new wire architectures designed to meet specific customer requirements.

A new magnet coil constructed using standard production SuperPower® 2G HTS wire with a

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Superconductivity
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

world-record performance of 10.4 T when cooled with liquid helium to 4.2 T (self-field) was also reported. When this same coil was tested at 4.2 K in a background magnetic field of 19.89 T, a magnetic field of 27.4 T was achieved; this represents yet another world record. When cooled with liquid nitrogen to 77 K, the coil achieved a record of 1.38 T; when cooled to 65 K, it produced a magnetic field of 4.6 T in a background field of 3 T. David Larbalestier, chief materials scientist at the National High Magnetic Field Laboratory at Florida State University (where the magnet was tested), commented, “We are now confident that this conductor technology can be used to construct an all-superconducting magnet with fields in excess of 30 T. This is a huge gain over niobium-based superconducting magnets that are only operational to 23.5 T.”

Regarding the progress of the Superconducting Fault Current Limiter (SFCL) program, Juan-Carlos Llambes, senior high voltage engineer at SuperPower, stated, “Although SuperPower has scaled back its efforts in the development of a superconducting fault current limiter to focus solely on the core technology 2G HTS-based device modules, we are pleased to report that during the past year we have been able to optimize the configuration to a more compact module design and have determined that it is scaleable to both distribution and transmission levels with the number of modules used to be based on the voltage and current requirements of the specific applications. ”

Kazanjian concluded by commenting, “Along with the unmatched progress we have made in wire performance over the past year, our market penetration has moved ahead as well. We have built a good base of customers around the world and regularly produce and ship wire for application to devices in the areas of energy, alternative energy, transportation, healthcare, military, science and research. We are proud to be making progress on the three fronts of technology development, manufacturing and marketing and believe that this excellence is what will keep us at the forefront in the implementation of this revolutionary technology.”

Source:
“SuperPower Reports Latest Achievements at 2009 U. S. Department of Energy Peer Review”
SuperPower Inc. press release (August 18, 2009)
http://www.superpower-inc.com/content/superpower-reports-latest-achievements-2009-u-s-department-energy-peer-review

American Superconductor Corporation (August 18, 2009)

American Superconductor Corporation (AMSC) has received an initial order for 17 sets of wind turbine electrical systems, including AMSC’s proprietary PowerModule™ power converters, from Hyundai Heavy Industries Co. Ltd. (HHI, Korea). The electrical systems will be used in the 1.65-MW doubly fed induction wind turbines that HHI is producing under a license from AMSC Windtec™. HHI also has a contract with AMSC Windtec for a 2-MW doubly fed wind turbine design, and its marketing and sales rights for both wind turbines encompasses most countries worldwide including those in North America. Young N. Kim, Senior Executive Vice President and COO, HHI Electro Electric Systems, commented, “…HHI has been able to produce its first wind turbine less than a year after licensing the design from AMSC Windtec. We are pleased to announce that our renewable energy business is now entering an exciting new phase with the commencement of volume wind turbine production for the global market.” AMSC expects to ship the initial set of electrical systems by the end of January 2010. AMSC founder and Chief Executive Officer Greg Yurek added, “As expected, HHI has moved swiftly through the prototype phase and into volume production. We are confident that HHI’s aggressive business plan and global reputation for manufacturing excellence will enable them to be a key player in the wind power market. With production set to begin in their new wind turbine factory in Gunsan, South Korea this fall, we look forward to receiving additional

orders from HHI as they ramp up from their initial production platform.
Source:
"Hyundai Heavy Industries Orders Initial Wind Turbine Electrical Systems from AMSC"
American Superconductor Corporation press release (August 18, 2009)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1321825&highlight

American Superconductor Corporation (August 26, 2009)

American Superconductor Corporation (AMSC) has received a second order for a D-VAR system to meet the dynamic reactive compensation requirements of the Chinese power grid. The device will be deployed at the Guanting Wind Farm (near Beijing) by the China National Machinery Industry Complete Engineering Corporation (CMCEC), a large state-owned enterprise. AMSC expects to deliver the device by the end of 2009. Upon completion, the Guanting Wind Farm will provide 150 MW of wind power to the local power grid.

In addition, AMSC announced that the CMCEC would act as AMSC's second-channel partner for sales in the Chinese power grid market.
Source:
"AMSC Receives Second D-VAR® Order for Chinese Power Grid"
American Superconductor Corporation press release (August 26, 2009)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1324456&highlight

Magnet

SCI Engineered Materials, Inc. (August 18, 2009)

SCI Engineered Materials, Inc. has been awarded a two-year Phase II Small Business Innovation Research (SBIR) contract entitled, "Homogenous BSCCO-2212 Round Wires for Very High Field Magnet". The contract will enable SCI to continue its efforts to develop BSCCO-2212 wires with a high J_c performance. Such wires are needed for new-generation magnets being developed for high-energy physics experiments. While SCI applied for approximately US $650,000, the final amount of the award is subject to the completion of negotiations with U.S. Department of Energy.
Source:
"SCI Engineered Materials, Inc. Awarded Phase II Research Contract"
SCI Engineered Materials, Inc. press release (August 18, 2009)
http://www.sciengineeredmaterials.com/investors/ne/news/scia081809.htm

Medical

Varian Medical Systems (August 20, 2009)

Varian Medical Systems has been selected to equip a new proton therapy center in Sweden. The contract covers an estimated $60 million in products, including the superconducting cyclotron, beam line, and treatment room gantries as well as information management and treatment planning software. The center represents the first proton therapy center to be built in Sweden and is scheduled to open in 2013. Varian President and CEO Tim Guertin commented, "We are honored to be selected for this important project following a competitive bidding process and a thorough review of our proton therapy technology by

numerous experts from across Sweden's radiation oncology community. This will be our first full installation for managing, planning, and delivering proton therapy, which we believe will be a powerful weapon in the battle to cure cancer. This award is a major milestone for the Varian Particle Therapy business."
Source:
"Varian Medical Systems Selected for New Proton Therapy Center in Sweden"
Varian Medical Systems press release (August 20, 2009)
http://varian.mediaroom.com/index.php?s=43&item=699

Cryogenic System

Oxford Instruments (August 5, 2009)

Oxford Instruments has delivered the world's first integrated Cryofree® dilution refrigerator with a 12-T superconducting magnet. The system utilizes only a single pulse tube refrigerator and does not require any liquid helium for cooling purposes. Temperatures can be controlled from below 10 mK to 30 K at magnetic fields as high as 12 T without requiring any external manipulation of the sample environment—a key feature for neutron scattering experiments. Over the last six months, Oxford Instruments has gained considerable experience in the production of Cryofree dilution refrigerators and has shipped more than twenty systems during this time period.
Source:
"Innovative Cryogen-free instruments"
Oxford Instruments press release (August 5, 2009)
http://www.oxford-instruments.com/news/Pages/news.aspx

Oxford Instruments (August 5, 2009)

Oxford Instruments NanoScience has developed a recondensing dewar, the IntegraTMAC, that reduces the amount of liquid helium consumed by Oxford Instruments' low temperature inserts and superconducting magnets. The recondensing dewar enables existing equipment to be retained, minimizing the disruption of experiments. Five dewars have already been shipped. Professor Rimberg of Dartmouth College commented, "The IntegraAC provided us with the option of using either of our existing dilution refrigerators with a recondensing cyrostat rather than purchasing entirely new systems. It has also completely changed our approach to sample screening. Since the cryostat is always cold, costs associated with cooling a sample are minimized. Even more importantly, the Integra AC has cut helium consumption for our largest cryostat by 80%, allowing us to stay cold longer and make the most of our limited liquid helium budget".
Source:
"The cool alternative to liquid helium"
Oxford Instruments press release (August 5, 2009)
http://www.oxford-instruments.com/news/Pages/news.aspx

Quantum Computer

University of California at Santa Barbara (August 11, 2009)

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Researchers at the University of California at Santa Barbara have produced a new type of superconducting circuit that behaves quantum mechanically and has as many as five levels of energy (instead of the two energy levels present in a qubit). The term for such a circuit is "qudit", where the 'd' refers to the number of energy levels (in the present case, d equals 5). Lead researcher Matthew Neeley explained, "Because it [the circuit] has more energy levels, the physics of a qudit is richer than for just a single qubit. This allows us to explore certain aspects of quantum mechanics that go beyond what can be observed with a qubit… Most research to date has focused on qubit systems, but we hope our experimental demonstration will motivate more effort on qudits, as an addition to the quantum information processing toolbox." The group's achievement was reported in the August 7 issue of *Science*.

Source:
"Experiments at UCSB push quantum mechanics to higher levels"
University of California at Santa Barbara press release (August 11, 2009)
http://www.ia.ucsb.edu/pa/display.aspx?pkey=2068

Communication

Superconductor Technologies Inc. (August 6, 2009)

Superconductor Technologies Inc. (STI) has reported their financial results for the second quarter ending June 27, 2009. Total net revenues for the second quarter were US $2.6 million, compared with $2.9 million for the same quarter in the previous fiscal year. Net commercial product revenue for the second quarter was $1.8 million, compared with $1.3 million for the same period in the previous fiscal year. Government and other contract revenue totaled $854,000, compared with $1.6 million for the same quarter in the previous fiscal year. Jeff Quiram, STI's president and chief executive officer, commented, "Commercial product revenue and backlog increased sequentially as the market continued to stabilize in the second quarter. We are pleased to see this trend is continuing into the third quarter as well. In addition, our government revenues are beginning to increase as we start delivering on the $4.1 million U.S. Air Force contract announced late in the first quarter." Net loss for the second quarter was $4.1 million, compared with $3.3 million for the same period in the previous fiscal year. As of June 27, 2009, STI had $13.2 million in cash and cash equivalents and a commercial product backlog of $873,000, compared with $12,000 at the end of the same quarter in the previous fiscal year. Also during the second quarter, STI received net proceeds of $10.5 million from a registered direct offering.

Source:
"Superconductor Technologies Inc. Reports Second Quarter 2009 Results"
Superconductor Technologies Inc. press release (August 6, 2009)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1317741&highlight

Accelerator

CERN (August 6, 2009)

CERN has announced that the Large Hadron Collider (LHC) will operate at an initial energy level of 3.5 TeV per beam when the device restarts in November of this year. The announcement was made following the completion of all tests of the machine's high-current electrical connections, which confirmed that no further repairs are needed for the device to be operated safely. An energy level of 3.5 TeV was selected because this level will enable the LHC operators to gain experience operating the machine safely while enabling a new discovery region for experiments. The first high-energy data should be available a few weeks after the injection of the first beam. Once a significant data sample has been collected, the energy level will be increased to 5 TeV per beam. The injection of lead ions is scheduled to begin at the end of 2010. Thereafter, the LHC will shut down and work will begin to upgrade the machine to enable an energy level of 7 TeV per beam.

Source:
"LHC to run at 3.5 TeV for early part of 2009-2010 run rising later"
CERN press release (August 6, 2009)
http://press.web.cern.ch/press/PressReleases/Releases2009/PR13.09E.html

Lawrence Berkeley National Laboratory (August 19, 2009)

The Lawrence Berkeley National Laboratory has received US $11.3 million in funding through the American Recovery and Reinvestment Act. The funding will be used to upgrade the facilities at Berkeley Lab's Advanced Light Source (ALS), one of the world's brightest sources of ultraviolet and soft x-ray beams. Part of this funding ($2 million) will be used to construct and install an elliptically polarizing undulator to provide a new source of femtosecond x-ray pulses for studying dynamics. This upgrade will effectively double the capacity of the existing ultrafast measurement facility by enabling both soft and hard x-ray beams to operate simultaneously, enabling new research on complex materials including superconductors. In addition, $1.5 million will be used to develop a unique superconducting magnet for an x-ray scattering beam line. This new beam line will enable experiments that should lead to novel insights into the structure of engineered magnetic nanostructures and other materials.

Source:
"Berkeley Lab's Advanced Light Source Receives $11.3 Million To Enable New Types Of Scientific Inquiry"
Lawrence Berkeley National Laboratory (August 19, 2009)
http://newscenter.lbl.gov/press-releases/2009/08/19/als-arra-funding/

Basic

Brookhaven National Laboratory (August 2, 2009)

Researchers at the U.S. Department of Energy's Brookhaven National Laboratory have succeeded in growing crystals of a high-temperature superconductor (BSCCO) that are large enough to directly measure the magnetic properties of these materials. The crystals were grown using a special technique and two furnaces operated continuously for two years. Measurements of the magnetic properties of the resulting crystals (performed using neutron scattering spectrometry) have cast considerable doubt on some of the assumptions that have been commonly made in understanding the role that magnetism plays in the ability of high-temperature superconductors to carry currents with no resistance. Physicist Guangyong Xu explains, "The calculations based on the material's electronic properties—which change dramatically as the material is cooled and transitions from its electrically resistive state to become a superconductor—predicted there would be a similar large change in magnetic characteristics below the transition temperature (T_c). But our direct measurements of the magnetic properties showed surprisingly little change. This implies that the model the theorists have been using to describe these magnetic properties is incomplete. It could be that

the magnetism somehow drives the electronic structure, rather than the other way around—or that something underlying both magnetism and electronic structure influences both but in different ways." Specifically, the magnetic measurements showed that some of the magnetic characteristics of the original "parent" compound (an insulator) persist after the material has become a superconductor, suggesting that some electrons move as waves to carry the current while others remain in relatively fixed positions to produce the magnetism. The group's results were published online by *Nature Physics* on August 2.
Source:
Magnetic Measurements Question Assumptions About High-Tc Superconductors"
Brookhaven National Laboratory press release (August 2, 2009)
http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=989

University of British Columbia (August 19, 2009)

Researchers at the University of British Columbia (Canada) have provided compelling evidence that challenges single-band Hubbard physics—a model that has been used to predict and calculate the behavior of high-temperature superconductors. Lead researcher Darren Peets explains, "Single-band Hubbard physics has been used for 20 years to predict how superconducting cuprate materials accommodate the 'holes' left by electron removal. But now it looks like the approaches that underpin a large fraction of the theoretical work in the field just don't work across all the ranges of superconductivity we can study. The part of the cuprates' superconducting phase diagram we looked at could exhibit less-bizarre behavior, or we could be seeing completely new physics, but in either case the usual theoretical approaches do not work here." The new evidence was obtained by 'overdoping' a crystal cuprate superconductor past its optimal range; such materials are difficult to produce and very rarely studied. While the Hubbard model explains electron behavior in materials with conventional levels of doping, it does not explain the observed behavior when additional electrons are removed. Using tunable-energy x-rays, the researchers observed that the electron holes were accommodated in a fundamentally different manner and that the interactions among the holes already in the material changed completely. The group's findings were published in the August 19 edition of *Physical Review Letters.*
Source:
"UBC research pokes holes in Hubbard model"
University of British Columbia press release (August 19, 2009)
http://www.science.ubc.ca/news/303

Stanford Linear Accelerator Center (August 20, 2009)

Researchers at the Stanford Institute for Materials and Energy Science (SIMES), a joint institute of the Stanford Linear Accelerator Center and Stanford University, have produced a hydrogen-rich alloy that could provide insight into the properties of metallic hydrogen. Previous studies have suggested that pure silane, which contains an atom of silicon bound to four atoms of hydrogen, metallizes at pressures far lower than those required to produce metallic hydrogen. The goal of the SIMES group was to study the properties of alloys composed of mixtures of hydrogen and silane: one alloy contained equal parts hydrogen and silane, and another contained an abundance of hydrogen in a five-to-one ratio. These samples were then squeezed in a diamond anvil cell, which generates pressures in excess of 6 gigapascals. The researchers found that the samples solidified at much lower pressures than would be required for hydrogen alone, with the hydrogen-rich alloy forming a solid that was more than 99% hydrogen. Although the amount of silane in this sample was minimal, it had a dramatic effect on hydrogen-hydrogen interactions. This finding is significant because it may help to advance our understanding of the properties of atoms in hydrogen alloys. The group's findings were published in the August 17 issue of the *Proceedings of the National Academy of Sciences*.

Source:
"Hydrogen-rich Material Promises Advances in Energy Transmission, Fuel Storage"
Stanford Linear Accelerator Center press release (August 20, 2009)
http://today.slac.stanford.edu/feature/2009/silane.asp

Dartmouth College (August 21, 2009)

Dartmouth researchers have proposed a new method for reproducing a black hole on a quantum scale in the laboratory. The method would enable a better understanding of Hawking radiation—the photons emitted by black holes (as proposed by Stephen Hawking 35 years ago). The researchers propose that a magnetic field-pulsed microwave transmission line containing an array of superconducting quantum interference devices (SQUIDs) would not only reproduce physics analogous to that of a radiating black hole, but would do so in a system where high energy and quantum mechanical properties are well understood and can be directly controlled. One of the paper's authors, Miles Blencowe, added, "We can also manipulate the strength of the applied magnetic field so that the SQUID array can be used to probe black hole radiation beyond what was considered by Hawking…In addition to being able to study analogue quantum gravity effects, the new, SQUID-based proposal may be a more straightforward method [compared with previous proposals for recreating a black hole] to detect the Hawking radiation." The group's theories were published in the August 20 issue of *Physical Review Letters*.

Source:
"Dartmouth researchers propose new way to reproduce a black hole"
Dartmouth College press release (August 21, 2009)
http://www.dartmouth.edu/~news/releases/2009/08/21a.html

Brookhaven National Laboratory (August 27, 2009)

Researchers at the U.S. Department of Energy's Brookhaven National Laboratory and Japanese collaborators have shown, for the first time, that the spectroscopic "fingerprint" of high-temperature superconductors remains intact well above the critical temperature. These findings confirm that the specific conditions necessary for superconductivity to exist at warmer temperatures do indeed exist. Lead physicist Seamus Davis commented, "The spectroscopic 'fingerprint' confirms that, at these higher temperatures, electrons are pairing up as they must in a superconductor, but for some reason they are not cooperating coherently to carry current." Previous studies have indirectly indicated that the higher temperature "parent" state of cuprate superconductors might represent a "quantum phase incoherent" superconductor—a state in which electron pairs exist but do not flow coherently as they do below the transition temperature. By modifying a spectroscopic imaging scanning tunneling microscopy method to improve the signal-to-noise ratio and averaging measurements made over a period of up to 10 days, the scientists were able to obtain definitive results showing that the characteristic spectroscopic signature does not change when the material is warmed from its superconducting state up to temperatures of at least 55 K, which is 1.5 times the transition temperature. The existence of a phase-incoherent superconducting state seems to be the only feasible explanation for this phenomenon. The group's results were published in the August 28 edition of *Science*.

Source:

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

"Scientists detect 'fingerprint' of high-temp superconductivity above transition temperature"
Brookhaven National Laboratory press release (August 27, 2009)
http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=994

(Published in a Japanese version in the October 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Current status of refrigeration/cold energy technology - Progress in Refrigeration/ cooling technology Using Superconducting Equipment -

Shigeru Yoshida
Cryogenic Development Group
Taiyo Nippon Sanso Corporation

High-temperature superconducting equipment has entered the stage of application research and much effort is being given to the development of refrigerators. Figure shows the comparison between the performance of refrigerators used for cooling the high-temperature superconducting power equipment and that of conventional refrigerators.

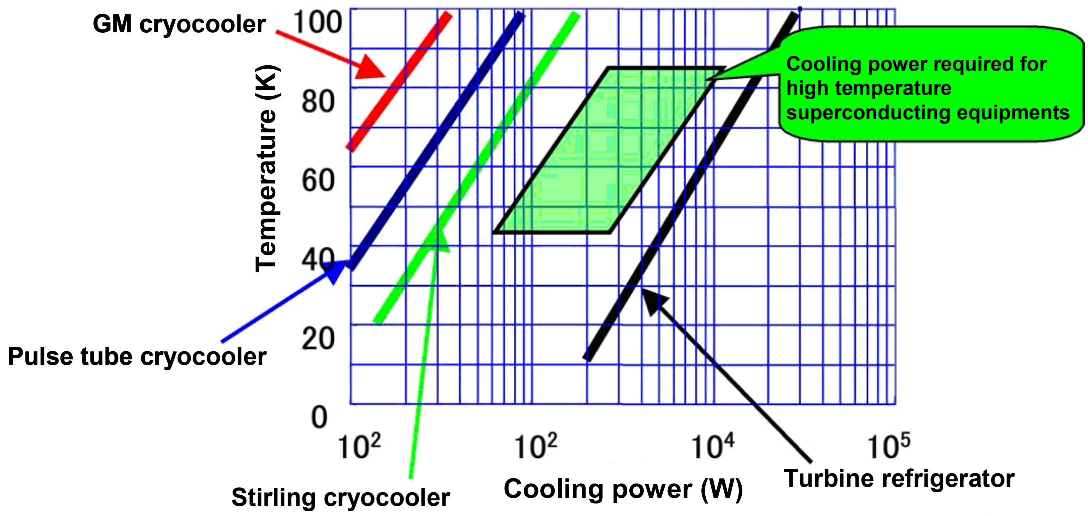


Fig. Cooling power of refrigerators

As seen from the Figure, required temperature range is about 40 K to 80 K and cooling power is 2 kW to 10 kW (at 80 K). The cooling power of compact cryocoolers available in the present market is 1 kW (at 80 K) or less, and normally requires maintenance work about once a year because the structure has rubbing parts.

On the other hand, the expansion turbine system is used for the large-size cryogenic refrigerator for an air separation plant and helium liquefier, which has proved to have sufficient cooling power and durability. However, the cooling power of the latter is too much. Therefore, in order to develop a refrigerator suitable for this range, a prototype expansion turbine refrigerator was made using neon gas as the working medium. The prototype refrigerator achieved a cooling power of 2 kW(at 70 K) with a neon gas flow rate of 1,200 Nm^3/hr and a system pressure of 2 MPa/1 MPa. While the prototype refrigerator is equipped with an expansion turbine, a conventional reciprocating compressor with a rubbing part is used. Thus, the prototype refrigerator is not yet a sufficient refrigerator that can be used for practical cooling of superconducting equipment from the viewpoints of both maintenance and efficiency. Therefore, improvement of efficiency of

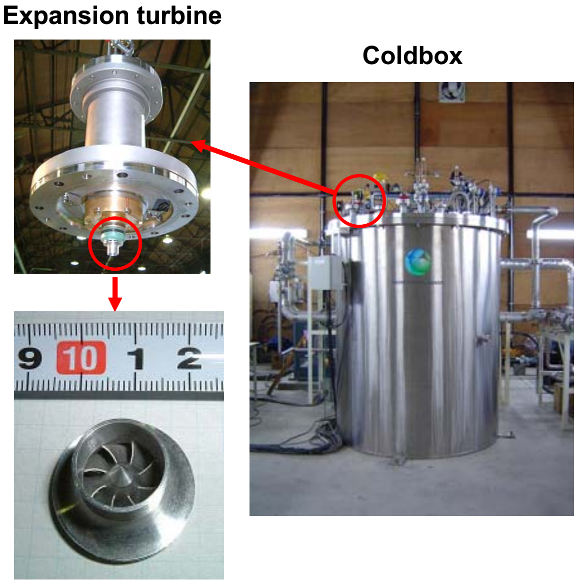
Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Superconductivity
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

the expansion turbine and development of the compact turbo compressor aiming at the upgrade of performance efficiency and realization of maintenance-free refrigerators are the next issue to be solved. Since there are no rubbing parts in neither of the turbo compressor and the expansion turbine, a maintenance-free refrigerator can be realized. Furthermore, since the compact turbo compressor occupies a smaller installation space compared with refrigerators using a conventional reciprocating compressor or screw type compressor, compactness required for refrigerators of superconducting equipments is realized.

Coefficient of Performance (COP; cooling power/power consumption) is an index that shows the performance of refrigerator, which is a very important value because it is directly related with the economy of superconducting equipment usage. COP of the prototype refrigerator is about 0.05 at 80 K and it is an important target of development of the refrigerator to increase the value as high as possible. In the expansion turbine refrigerator, COP becomes maximized at the expansion ratio of about 2. Morever, simulation of refrigeration process using actual neon gas proved that the maximum COP is obtained at 1 MPa/0.5 MPa of the system pressure. Therefore, it is now under investigation to develop a refrigerator equipped with a compact turbo compressor and expansion turbine in a low pressure system (1 MPa/0.5 MPa).

Among other elementary components, the heat exchanger occupies large volume in the cold box of turbine refrigerator. Therefore, optimization of heat exchanger is an important factor in the downsizing of refrigerator. To solve this problem, dimensions of the heat exchanger are being investigated by a refrigeration process simulator. It is another important issue how to take out the cold energy from the developed refrigerator and transfer to the superconducting equipment being cooled. Research on cooling systems including the use of subcooled liquid nitrogen as the cooling medium and direct cooling by thermal conduction is considered to be important in the future.

Prototype expansion turbine neon cryocooler



(Published in a Japanese version in the June 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Present status of cryocooling/cold energy technology - Present status of continuous adiabatic demagnetization refrigerator (cADR) -

Takenori Numazawa
National Institute for Materials Science
Peter Shirron
Goddard Space Flight Center, NASA

Adiabatic demagnetization refrigeration (ADR) is widely known as a method to generate cryogenic and ultra-low temperatures. The continuous ADR explained here is an old yet new refrigeration technology whose basic concept has been verified in the last ten years. ADR generates cold energy utilizing the change in magnetic entropy of magnetic substance caused by magnetic field. The magnetic substance is installed in a magnet and the endothermic and exothermic stages are connected to magnetic substance through thermal switch so that a high-efficiency Carnot cycle is driven with the changes in magnetic field and ON/OFF of thermal switch. However, since the four stages of magnetization and demagnetization under adiabatic or isothermal condition are carried out sequentially in the Carnot cycle by ADR, cold and hot stages are not executed simultaneously so that it is difficult to keep the temperature of the cold stage constant through the whole refrigeration cycle. Such intermittence of refrigeration at cold the stage is a significant bottle neck for experiments such as generation of superfluid helium and solid helium in which the temperature must be kept constant. In other words, conventional ADR is not a cryocooler but only a cooler that keeps the low temperature for a certain period of time.

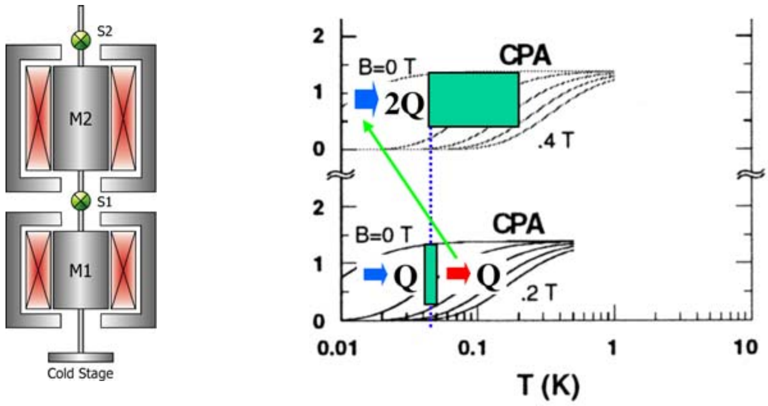


Fig. 1 Schematic diagram of continuous ADR: Figure on the left shows the constitution of two ADR's. Figure on the right shows the Carnot cycles on the entropy diagram of corresponding magnetic material (CPA). Magnetic material unit M1 generates constant temperature and M2 absorbs the exhaust heat from M1. Carnot cycle of M1 is used only for passing the heat.

Continuous ADR has been devised to eliminate the intermittency, making ADR a true cryocooler. Peter Shirron of NASA / Gadoord devised a cycle in which two ADR units operate the Carnot cycle with shifting half period each other so that the magnetized heat from the ADR that generates low temperature is absorbed without delay by ADR on the high temperature side through demagnetization. In this case, the

ADR on the low temperature side plays a role of heat buffer for maintaining the constant temperature and is used only for passing the heat. When multiple stages of such ADR are combined, each cycle is driven independently for a short period, contributing to significant decrease in magnetic field and mass of magnetic material (see Figure 1).

Prototype continuous ADR developed by NASA achieved absorption temperature of 60 mK, heat exhaust temperature of 4.2 K, Carnot efficiency of 45 % or higher, refrigeration capacity of 10 μW, and temperature stability of ±10 μK. Subsequently, National Institute for Materials Science developed a continuous ADR for space experiment in cooperation with NASA and JAXA (see Figure 2 and Photo 1). This ADR adopted a newly developed magnetic material ($GdLiF_4$) and its refrigerating cycle was shortened to within 30 minutes in order to increase the refrigeration capacity up to 100 μW (100 mK) aiming at broader utility. In this ADR system, liquid helium is not required because of using a conduction cooled GM-refrigerator, and compact size with light weight is achieved with diameter of cryostat including ADR of 45 cm, height of 90 cm, and total mass of less than 60 kg.

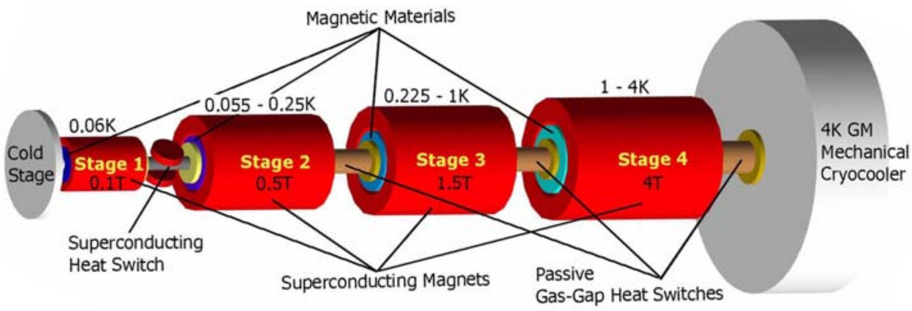


Fig. 2 Schematic diagram of 4-stage continuous ADR at NIMS: The ADR consists of magnetic material, a superconducting magnet, and thermal switch and exhaust heat of ADR is transferred to GM cryocooler.

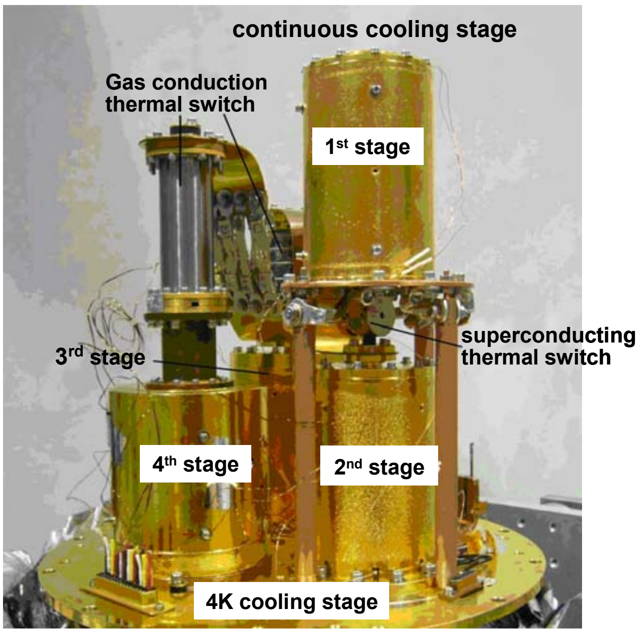


Photo 1 4-stage continuous ADR: Optimally arranged main part of actual ADR, which is encased in a space of 30 cm diameter and 35 cm height.

As described above, the continuous ADR has entered practical use stage from demonstration stage and has been developed to a technology that can compete with a dilution cryocooler. However, there are problems characteristic to ADR including the following two: (1) complexity due to the combination of four stages of ADR with independent Carnot cycles, which are driven simultaneously and by sophisticated software; (2) the ADR unit on the high temperature stages cannot keep constant temperature so that it cannot be used as thermal anchor, which is significant obstacle for experiments in which heat capacity is relatively large and heat penetration must be taken into account. It is difficult for an ADR to substitute a dilution cryocooler immediately, since the problem may be resolved soon. It seems that ADR will prevail segregating the market with conventional cryocoolers.

(Published in a Japanese version in the June 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Present status of cryocooling/cold energy technology - Present status of development of a dilution refrigerator using pulse tube cryocooler -

Tohru Hata, Professor
Graduate School of Science
Osaka City University

There are three methods for obtaining temperatures of 1 K or lower as follows. The first is a helium-3 cryostat in which liquid helium 3 is depressurized to obtain a low temperature, but the lowest obtainable temperature is 0.3 K. The second is an adiabatic demagnetization method in which magnetic salt is magnetized in a magnetic field, and then adiabatically demagnetized to obtain a low temperature. This method once disappeared due to the appearance of dilution refrigerator, but is spotlighted now as a cryocooler is used in the space station because of the downsizing and weight saving without using a pump as well as the fact that it can be used in a weightless state. The third is a dilution refrigerator, which is widely used for physical measurements because low temperatures down to mK can be obtained continuously. However, this method is rarely used for other purposes. The greatest problem is that the equipment is large-sized and requires periodical replenishing of liquid helium, and, furthermore, operation procedure is so complicated that unskilled operators cannot handle it. As a new method that solves the problems of the third method, there are high expectations for dilution refrigerator, using a pulse tube cryocooler instead of liquid helium.

From the aspect of helium free, Uhlig of Germany fabricated a dilution refrigerator, using a GM cryocooler, but it did not draw much attention. The reason for this seems to have been the large size of the equipment and the fact that a GM cryocooler generates large vibrations. Recently, however, temperature less than 3 K has been obtained using a pulse tube cryocooler that generates little vibration and downsized products have been commercialized in the U.S.A. In the past few years, the products have been placed on the market in England, France, Netherlands, and Finland. Osaka City University has also succeeded in developing a compact dilution refrigerator, of the pulse tube type as a JST project jointly with Iwatani Industrial Gases Corp (photo).

The left half is pulse tube cryocooler and the right half is dilution refrigerator. The length of dilution refrigerator, from the top flange is about 80 cm.

Basically, a dilution refrigerator is operated by liquefying a gas mixture of helium 3 and helium 4. Since helium 4 becomes superfluid at 2 K or lower remaining in the cryostat, only helium 3 circulates between room temperature and low temperature, which requires helium 3 circulating from room temperature to be liquefied.

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Normal dilution refrigerator, using liquid helium generates 3 K by introducing the liquid helium into 1 K pot and depressurizing it to liquefy helium 3 gas. In a pulse tube cryocooler, on the other hand, since the temperature is still 3 K, helium 3 gas is liquefied by Joule-Thomson expansion from 3 K. This is the largest difference between the liquid helium type and pulse tube type. We were also worried about how to appropriately cool the helium 3 gas coming from the room temperature, but the results were easier than expected and we could obtain about 50 mK in the first trial. This success can be attributed to our experience in fabricating a dilution refrigerator, of the top level in the world by ourselves. However, troubles are encountered frequently in developmental work, and we experienced several instances of trouble such as a slowdown in cooling and disturbance in the liquefaction of gas mixture when we moved the facilities after successful trials. It was revealed later that two points; vacuum for a thermal isolation and radiation were the very basics for the low temperature generation.

The dilution refrigerator, developed this time does not need liquid nitrogen because an internal 50 K trap is provided to remove the gas impurities. We automated the operation and found that the operation is astonishingly easy compared with the operation of ordinal dilution refrigerators using liquid helium, which was fabricated and operated by ourselves. We believe that ordinal dilution refrigerators will be replaced with this type of dilution refrigerators except special cases. Unfortunately, the price is still very high due to development cost at present but mass production and depletion of helium resources will accelerate the popularization of this type in near future. The scope of application is limited to physical measurement at present, it is expected that application is expanded to the area of analytical instruments using superconducting sensors for its high sensitivity and high resolution.

Finally, the cryocooler is compared with several commercialized dilution refrigerator. When the dilution refrigerators, are operating normally, all the dilution refrigerators including ours similarly achieve the cooling power of 200 μW at 100 mK and lowest temperature of 10 mK. The difference is in pre-cooling systems, which include use of liquid nitrogen, use of separate circulation line, use of heat exchange gas, and use of hydrogen thermal switch, each of which has advantages and disadvantages. In any case, the cooling time is about a day and here is a room for improvement and it is expected that the cooling time will be reduced to about half a day in the future. As to automation, there is no other dilution refrigerator fully automated requiring no nitrogen gas like ours and most of others still require liquid nitrogen and are only semiautomatic. This means that future improvement is needed. The point is how to realize maintenance-free dilution refrigerator, so that unskilled workers can operate the equipment. As a matter of fact, failure due to low temperature leakage is observed in commercial dilution refrigerators.

Ultra low temperature Group, Graduate School of Science, Osaka City University
URL : http://www.sci.osaka-cu.ac.jp/phys/ult/

(Published in a Japanese version in the June 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Present status of cryocooling/cold energy technology - Present status of the development of magnetic cryocooler for hydrogen liquefaction -

Koichi Matsumoto, Associate Professor
Graduate School of Science and Engineering
Kanazawa University

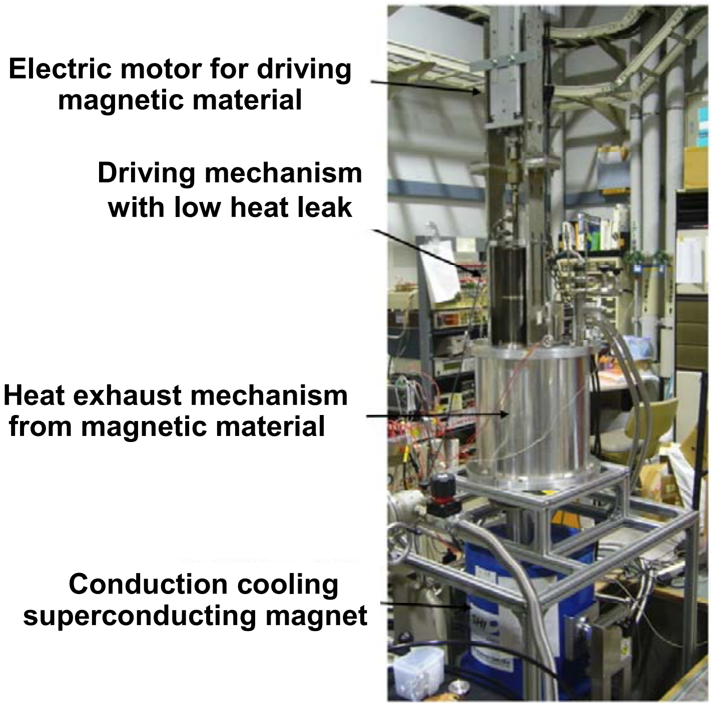
Hydrogen is receiving attention as clean energy as a result of commercialization of fuel cells. The work required for producing compressed hydrogen of about 700 atmospheres is comparable to that required for hydrogen liquefaction and so liquid hydrogen is advantageous in large-scale storage and transportation from the viewpoint of energy density. However, the efficiency of present hydrogen liquefaction by gas expansion is as low as between 30 and 40 % of that by ideal thermal cycle and improvement in the efficiency of liquefier is essential for the utilization of liquid hydrogen.

The basic principle of magnetic cryocooling is that the temperature of magnetic material changes when magnetic field in which the magnetic material is placed varies. This phenomenon is called the magnetocaloric effect. The magnetic cryocooling has been used for generating very-low temperatures in the field of low-temperature physics for a long time, and recently, research aiming at practical application at various temperatures including room temperature has become very active. Characteristics of hydrogen liquefiers by magnetic cryocooling are: (1) high efficiency by reversible cycle is possible in principle; (2) downsizing using high density magnetic material; (3) high pressure hydrogen compressor is not required and (4) high reliability. On the other hand, technical point for the realization of magnetic cryocooling is generation of magnetic field of several tesla. Recently, as a result of progress in application research on superconducting magnets cooled by cryocoolers and high-temperature superconductivity, generation of high magnetic field without liquid helium has become possible so that practical application of magnetic cryocooling to hydrogen liquefaction is being sought.

Research on magnetic cryocooler aiming at hydrogen liquefaction has been fully in progress since the 1990's. CryoFuel conducted investigation of economic potential and element research including magnetic material as part of "International cooperation in research and development of clean energy system with particular emphasis on hydrogen (We-Net)" project. It was reported that the construction cost of magnetic cryocooler is 30 % that of a gas expansion cryocooler and it is possible to obtain a high liquefaction efficiency of 60%. Research on magnetic materials is very active worldwide and in Japan research on new magnetic material utilizing first order phase transition and that on rare earth nitride is being conducted by Tohoku University and Osaka University respectively. For cryocooler systems, Mitsubishi Heavy Industry succeeded in hydrogen liquefaction with static magnetic cryocooler using pulse superconducting magnet. Recently, the research group of National Institute for Materials Science and Kanazawa University is undertaking research on both magnetic materials and cryocooler system as a NEDO project. They developed a practical prototype of a magnetic cryocooler of operating Carnot cycle using garnet-based magnetic material and a superconducting magnet directly cooled by the cryocooler shown in the Photo, and succeeded in hydrogen liquefaction. Furthermore, research on development of metallic magnetic materials used in high temperature region and a pre-cooling magnetic cryocooler of hydrogen gas with a regenerative

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Superconductivity
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

thermal cycle (AMR) is being undertaken. Victoria University of Canada is trying to expand the research from room temperature magnetic cryocooling to hydrogen liquefaction temperature.



Magnetic material driving type magnetic cryocooler using superconducting magnet directly cooled by cryocooler
(Research group of National Institute for Materials Science and Kanazawa University)

Although research on magnetic cryocooling for hydrogen liquefaction is making progress, problems such as hydrogenation of magnetic materials and improvement in efficiency of regenerative thermal cycle are to be solved and further demonstration research is also required.

(Published in a Japanese version in the June 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Present status of cryocooling/cold energy technology - Superconducting microgrid initiative that utilizes liquid hydrogen cold energy -

Takataro Hamashima, Professor
Department of Electrical and Communication Engineering
Graduate School of Engineering, Tohoku University

The explosive increase of the worldwide population and rapid development of the global economy are drastically increasing energy consumption causing serious environmental problems. To solve these problems, effective utilization of renewable energy friendly to environment for energy generation and the renewable hydrogen energy cycle, which is limitlessly storable, are effective. It is also indispensable to highly utilize electrical energy in order to maintain and develop sophisticated industry and high standard of living and so highly-efficient and energy saving electrical systems for generation, transmission, storage, and consumption are demanded. In particular, superconducting technology is an ace for the technology. The liquid hydrogen cooling superconducting system in which both superconducting technology and hydrogen are combined is considered to be an important technology for the next generation.

Table 1 shows the characteristics of coolants including liquid hydrogen. Since the latent heat of vaporization of liquid hydrogen (LH_2) is larger than that of liquid helium (LHe), the former can maintain the superconducting state stably. Since the viscosity is lower than that of liquid nitrogen (LN_2), it is advantageous for long-distance transportation. In addition, since the reciprocal of coefficient of performance of the reverse Carnot cycle is about one-fifth that of LHe, it requires less pumping motor power. Furthermore, it can be stored as secondary energy, which has excellent feature no other coolant has.

Table 1 Comparison of liquid hydrogen with liquid helium and liquid nitrogen

		LH_2	LHe	LN_2
Boiling point	K	20.3	4.2	77.3
Latent heat of vaporization	kJ/kg	443.0	20.4	198.6
Viscosity	μPa-s	12.5	3.2	142.9
Heat quantity	MJ/kg	114.9	----	----
Reciprocal of coefficient of performance of reverse Carnot cycle		13.8	70.4	3.8

When hydrogen is stored as a liquid with high storage density in LH_2 tank and used as the coolant for superconducting equipment, it has a great advantage that liquefying power for cooling is saved. Microgrid is an example that utilizes these advantages and an environmentally-friendly next-generation electrical power system aiming at sustainable society. Figure 1 shows the circuit diagram. Left middle of the figure is the renewable energy source such as wind turbine generator (WT) and photo voltaic generator (PV) and lower part is the storage and generation devices that store excessive energy and compensate deficient energy, which consist of quick-response access-oriented storages and capacity-oriented storages that store large amounts of energy and generate electric power. Since renewable energy fluctuates inherently, the output is

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

divided into average value portion and fluctuation portion, and the average power is supplied by fuel cell generator using hydrogen (FC) or capacity-oriented storage equipment that stores hydrogen produced through electrolysis, and quick fluctuation is supplied by superconducting energy storage system (SMES) which has high efficiency and enables instantaneous input and output of large amount of power so that energy utilization is optimized. The stored hydrogen is liquefied with liquefier to store a large volume of hydrogen and at the same time, the cold energy is used for cooling of SMES and superconducting cables, and, furthermore, hybrid power combined with electrical power and hydrogen energy is transported. All in all, transmission efficiency is significantly improved. The full line in the figure shows electricity flow and the thin line shows control signal flow, and the broken line shows the flow of hydrogen.

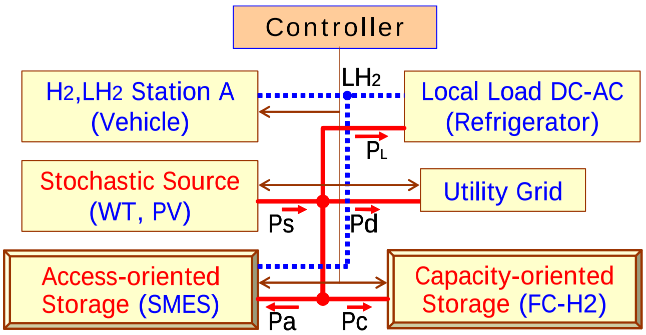


Fig. 1 Circuit diagram of the next-generation superconducting microgrid

In the actual operation, predictive control is required because a capacitive power generator such as fuel cell requires lead time before reaching full operation. Since the error of prediction for average power in one minute using a Kalman filter is expected to be within about 10 %, the optimum power control becomes possible by supplying averaged deficiency power by FC generator and the fluctuation portion by SMES with ms response when the output of natural energy power is insufficient compared with demanded power as shown in Figure 2, which enables the realization of the next-generation hydrogen cooled superconducting microgrid system.

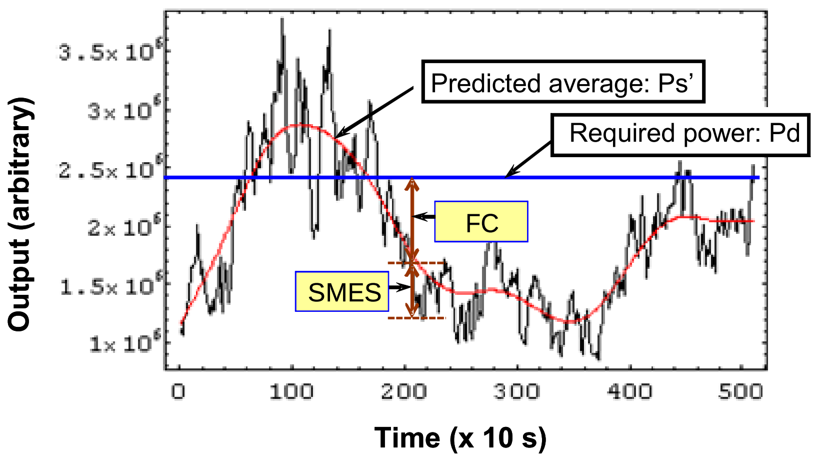


Fig. 2 Decomposition of natural energy and concept of control algorithm for storage generator

(Published in a Japanese version in the June 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Guide for superconducting products - compact cryocooler
- companies are introduced in the order of Japanese alphabet -

Stirling cryocooler

〇Peltier/cryocooler Group, L&E Product Planning Department, Aisin Seiki Co., Ltd.
―Pulse tube cryocooler
―Stirling cryocooler
Tel: 0566-24-8860
Fax: 0566-24-8859
Contact personnel: Kondo

〇Smach Co., Ltd.
―Cryocooler
Tel: 06-6949-6955
Fax: 06-6949-6965
e-mail: kawahara.s@jp.panasonic.com
Contact personnel: Kawahara

Gifford-McMahon (GM) cryocooler

〇Peltier/cryocooler Group, L&E Product Planning Department, Aisin Seiki Co., Ltd.
―Pulse tube cryocooler
―GM cryocooler
Tel: 0566-24-8860
Fax: 0566-24-8859
Contact personnel: Kondo

〇Low Temperature Equipment Division, Iwatani Industrial Gases Corp.
―4 KGM cryocooler
―1K cryocooler (LHe free-type)
―Pulse tube cryocooler
Tel: 03-5405-5795
Fax: 03-5405-5985
Contact personnel: Kenji Morita

〇Ultralow Temperature Field, Sales Development Division, Industrial Gases, Taiyo Nippon Sanso Corporation
Tel: 03-5788-8610
Fax: 03-5788-8709

Modified Solvay cryocooler

〇Low Temperature Equipment Division, Iwatani Industrial Gases Corp.
Tel: 03-5405-5795
Fax: 03-5405-5985
Contact personnel: Kenji Morita

Dilution cryocooler

〇Superconducting Business Division, Oxford Instruments
Tel: 03-5245-3261
Fax: 03-5245-4477
E-mail:supercon.jp@oxinst.com

〇Ultralow Temperature Field, Sales Development Division, Industrial Gases, Taiyo Nippon Sanso Corporation
—Dilution cryocooler
—No-coolant dilution cryocooler
—^{3}He cryocooler
Tel: 03-5788-8610
Fax: 03-5788-8709

〇Scientific System Division, Nippon Automatic Control Co.
Tel: 03-5434-1600
Fax: 03-5434-1630
e-mail:nacc-c@naccjp.com

Adiabatic demagnetization cryocooler

〇Scientific System Division Nippon Automatic Control Co.
Tel: 03-5434-1600
Fax: 03-5434-1630
e-mail:nacc-c@naccjp.com

Subcooled liquid nitrogen circulation system

〇Ultralow Temperature Field, Sales Development Division, Industrial Gases, Taiyo Nippon Sanso Corporation
Tel: 03-5788-8610
Fax: 03-5788-8709

(Editorial Office: Yasuzo Tanaka)

(Published in a Japanese version in the June 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009
- Forum on Superconductivity Technology Trends 2009 -

Masaharu Saeki, Director
Public Relations Division, ISTEC

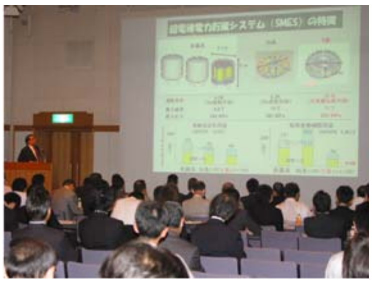
ISTEC held a Forum on Superconductivity Technology Trends 2009 on May 25th (Mon) at the Toshi Center Hotel in Tokyo. About 170 people from industry, government, academia and the general public participated and discussed earnestly after reports on results, problems and trends in superconducting technology development aiming at industrialization.

Ryoji Doi, Director of Research and Development Division, Industrial Science and Technology Policy and Environment Bureau, Ministry of Economy, Trade and Industry and Hideki Fukuda, Manager of New Energy Technology Development Department of New Energy and Industrial Technology Development Organization (NEDO) delivered congratulatory speeches to the following effects. “Research and development of superconducting technology has been conducted in cooperation between Japan and the U.S.A. since the time when ISTEC was established. The results of both Fundamental Superconducting Application Technologies Project and SMES project were highly appreciated and ended in 2007 with the activities having been passed on to the Technological Development of Yttrium-based Superconducting Power Equipment Project. Practical application is the field is what Japan is good at and they encouraged ISTEC and business people who participated in the meeting saying that they were hoping that the people would exert efforts aiming at realization of practical power equipment in 2020 by winning out severe competition with overseas competitors

Lecture by Director General Shiohara

In the keynote lecture titled “Development of Basic Technology for Yttrium-based Superconducting Power Equipment,” Yuh Shiohara, Director General of SRL/ISTEC, explained the outline and significance of the project sponsored by NEDO, “Technological Development of Yttrium-based Superconducting Power Equipment,” and emphasized that application of superconducting power equipment contributes to significant reduction in CO_2 responding to the increasing worldwide concern about the environment and energy.

Teruo Izumi, Director of Superconducting Tapes & Wires Division SRL/ISTEC delivered a speech titled “Development of fabrication process of yttrium-based superconducting wires for power equipment application” and reported the newest results of high-performance long-length wires, low cost long length wires, and very-low cost wires which were developed in the application basis project. Also he reported on the importance of wire development in the yttrium-based superconducting power equipment development projects that has been newly started based on preceding research and development of application to equipment and latest results of research and future tasks.



A scene of conference

Kaname Matsumoto of Kyushu Institute of Technology delivered a speech titled “Yttrium-based wires with vortex pinning aiming at high J_c-B characteristics,” and introduced the basic concept of the introduction of the vortex pinning for the improvement of yttrium-based wires and empirical results of pinning site introduction, visualization by simulation, and future design.

Noboru Fujiwara, Director of Electric Power Equipment Division, SRL/ISTEC, delivered a report titled “Status of technical development of yttrium-based superconducting power equipment” and explained the present status of development of SMES (power storage), superconducting cable and superconducting transformer.

Kazuhiko Hayashi of Sumitomo Electric Industries, Ltd. made a report titled “Development and application of Bi-based superconducting wires at Sumitomo Electric Industries, Ltd.” and explained that applications to various high-temperature superconducting cable projects have started by improving the performance and mechanical characteristics of Bi-based high-temperature superconducting wires. He also introduced the present status of application exploitation expecting downsizing and energy saving effects for superconducting motors for ships and automobiles.

Mutsuo Hidaka, Manager of Low Temperature Superconducting Devices Division, SRL/ISTEC, made a report titled “ New evolution of development of Nb-based superconducting devices,” and explained that superconducting wires SFQ using niobium, which is easiest to fabricate and most stable among the superconducting materials, is the ultimate energy saving device and compact systems are already being developed. He added that these systems have performance that exceeds conventional technology and it is important to find appropriate field applications that effectively utilize the advantages.

Hiroyuki Kayano of Toshiba Corp. gave a lecture titled “Development of superconducting filter system for the next-generation weather radar.” It is expected that occupied bandwidth of adjacent 5 GHz weather radar is narrowed in order to ensure the number of frequency ranges to deal with the explosively increasing use of wireless LAN, etc. To address the situation, it is essential to narrow the bandwidth of transmission spectra and to reduce the spurious transmission. He reported that he could realized this by developing superconducting filter using a resonator with the surface resistance of high temperature superconductor and high unloaded Q value.

Keiich Tanabe, Deputy Director General and Director of Advanced Material & Physics Division, SRL/ISTEC made a report titled “Development of fabrication and evaluation technologies for low AC-loss yttrium-based wires,” regarding the present status and results of the development of thin wire fabrication technology aiming at the reduction of AC loss of yttrium-based wires used for power equipment and the and the progress in the evaluation technology and future problems.

Ken Nagashima of the Railway Technical Research Institute explained the technical development of a superconducting bulk body applied to the support bearing for a railway flywheel electric storage device in his report titled “Development of high-temperature superconducting bulk body magnetic bearing for a flywheel.” He reported that a large load capacity per unit area more than 10 times that of conventional system is obtained and downsizing of the equipment is expected.

Yasuzo Tanaka, Director of Standardization Affairs Division, ISTEC, pointed out that if we are flattering ourselves that Japan is an advanced country in superconducting technology with excellent advanced technologies, the country may become a Galapagos Island, ignoring the threats of foreign countries in his report titled “Past and

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

future of international standardization of superconductors." To breakthrough such a situation, it is essential to cultivate technical capabilities (intellectual property) and proceed with international standardization. Fortunately, Japan is a secretary country of IEC/TC90 (Superconductivity) and in an advantageous position for international standardization of superconductors and he solicited for understanding of and cooperation for international standardization.

As the summary lecture titled "Application to power devices and oxide superconductors," Tanzo Nitta of Meisei University forecasted that the use of electrical energy would increase due to the characteristics of present electrical system as the ultimate energy for high efficiency and carbon reduction in the future society, and suggested the fields of generation, transformation, transmission, and distribution of electricity in which superconducting devices are utilized.

The first step of practical use based on steady progress in research and development in various fields of superconductivity has been already taken and the significance and the importance of cooperation among industry, government, and academia were recognized anew in the conference.

(Published in a Japanese version in the June 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Keynote lecture-Materials and Power Applications of Coated Conductors-

Yuh Shiohara
Director General, SRL/ISTEC

It has been recognized that yttrium-based superconducting tapes (coated conductors) have significant advantages compared with other superconducting wires in future cost, superconducting characteristics in magnetic fields, and AC losses. A national project of five years from 2008 to 2012 is currently underway, in which technologies of three superconducting power devices; Superconducting Magnetic Energy Storage system (2 GJ-class SMES for electric grid stabilization), superconducting power cable (66 kV/5 kA large-current cable and 275 kV/3 kA high voltage cable) and a superconducting transformer (66 kV/6.9kV 20 MVA class distribution transformer) are being developed aiming at introduction and dissemination at around 2020. Technical development of these fabrication processes for low-cost, high-performance tapes as well as standardization of superconducting power devices are promoted. In this review session, “Materials and Power Applications of Coated Conductors” supported by New Energy and Industrial Technology Development Organization (NEDO) is reviewed. It was also explained that it is important to reduce the emission of carbon dioxide (CO_2) by utilizing superconducting technologies.

Development of yttrium-based superconducting magnetic energy storage system

On the premise that a large amount of electricity is supplied stably to the urban areas using superconducting power equipments, flexible operation with effective power control is aimed by installing SMES in an electric power station to solve the problems such as voltage fluctuation due to long-distance power transmission and step-out of generator. Targeting the development of 2 GJ (about 555 kWh) -class SMES, effectiveness of element coils of 20 MJ-class SMES is being verified. Up to now, from the viewpoint of mechanical strength, which is important for a high-magnetic field (about 11 T) SMES, hoop stresses are being tested and a conceptional design of a 20 K conduction cooling coil system and a 2 GJ/100 MW-class toroid type SMES has been finished.

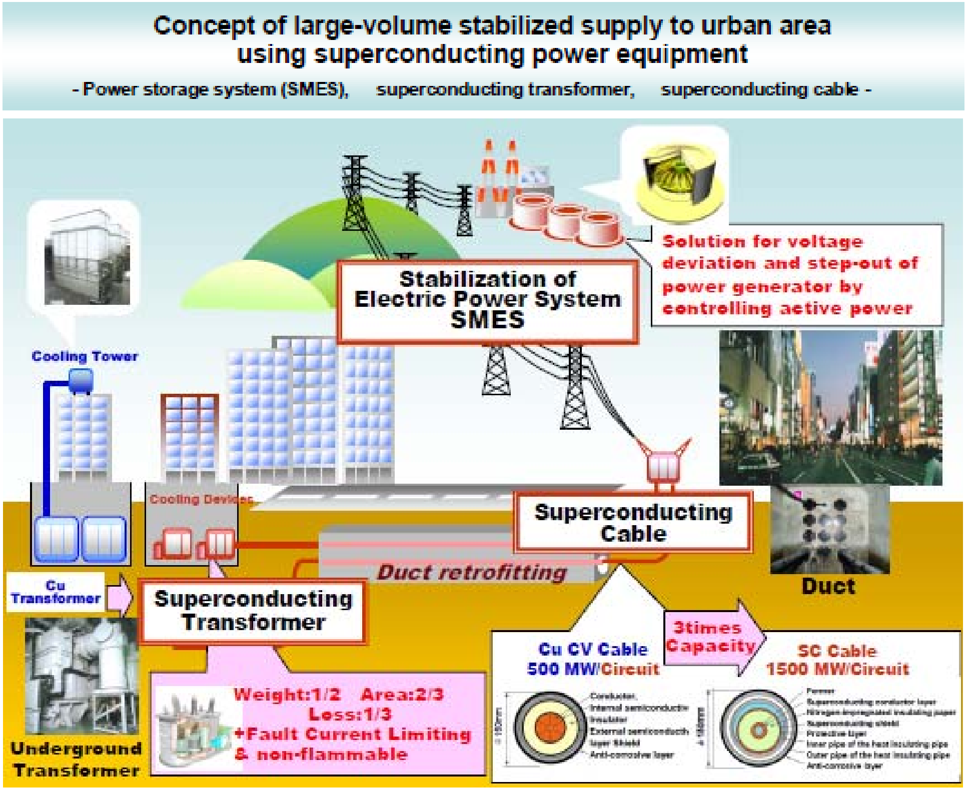
Development of power cable

Development of 66 kV/5 kA large-current cable and 275 kV/3 kA superconducting high-voltage cable is targeted from the viewpoint that scale-up by superconducting cables utilizing the existing conduit lines for the stable supply of large-scale electric power to the urban areas is efficient. For example, replacement of conventional POF cable (154 kVx900 A class x3 lines) with YBCO cable (66 kVx5-6 kA class x1 line) not only provides energy saving and reduction in CO_2 but also enables to provide compact large-amount electrical power transmission, by reducing the transmission losses. In order to reduce AC losses, which is important in the development of compact superconducting cables, the cable design applying characteristics of yttrium-based tapes and reduction of AC losses in a 1-m class cable conductor were successfully achieved and results that promising reduction of AC losses have been attained by technologies of wound spirally on the copper former to reduce the losses and obtain cables with a precise circular cross-section shape making use of flexibility of 2 mm wide thin wires and 10 mm wide wires. In addition, current capacity has been successfully increased by increasing the number of layers of the superconducting tapes. Furthermore, methods for cooling the conductor assuming that insulating layers between conductors and shielding layers becomes thicker in the design of the high-voltage cable, and it was confirmed by simulation that there is no problem in a steady state cooling of either solid or hollow tubes.

Development of superconducting transformer

Application of superconducting technology to transformers enables downsizing (1/2 weight and 2/3 installation area), high efficiency, and flame resistance. The reduction in AC losses of coils, which is an important basic technology in the development of superconducting transformer, has been verified by the grooving (scribing) of tapes and Japanese original winding technology. Further, detailed development of the basic technologies is being carried out including critical current characteristics, bending strain characteristics, and a transposed winding technology together with a copper layer for stabilization. In addition, a creative research and development in which a fault current limiting function is added to the transformer is being developed and a coil to verify the transforming function and the current limiting function with a four-coil structure provided with auxiliary winding to primary and secondary windings has been designed and fabricated. And experiments are going to be made to develop a transformer provided with a current limiting function of several hundred kVA class.

Development of yttrium-based high-temperature superconducting tapes



Recently, yttrium-based superconducting tapes are closing in on Bi-based wires as shown by reported result, I_c x L =350 A x 500 m (Fujikura). Because of the four distinguished characteristics of yttrium-based tapes (1. future low cost, 2. high critical current density in magnetic field, 3. high mechanical strength, and 4.

low AC loss after grooving treatment), competition in the yttrium-based coated conductor development is pretty keen worldwide, particularly in Japan and the U.S.A. In "Development of basic technology for the superconductor application project, phase II" ended the year before last with technologies aiming at champion data in critical current, length and magnetic effects of the tapes developed. In the current project, coated conductors are being developed that will meet the specifications including cost when various superconducting power devices are introduced and disseminated in 2020.

Future policy

" Materials and Power Applications of Coated Conductors" started last year and superconducting magnetic energy storage system, superconducting power cable, and superconducting transformer as well as coated conductors required for these devices are being developed. In addition, superconducting high-efficiency transmission is selected in Japan's for "Cool Earth Energy Innovation Technology Plan" and it is expected to reduce the present transmission losses of about 5 % to one-third in practical applications of superconducting transmission using yttrium-based assumingly after 2020.

Acknowledgement

This paper includes the research results obtained as a part of "Materials and Power Applications of Coated Conductors" supported by New Energy and Industrial Technology Development Organization (NEDO).

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

超電導 Web21
Superconductivity

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Development of fabrication process for coated conductors suitable for power devices -

Teruo Izumi, Director
Superconducting Tapes & Wires Division, SRL/ISTEC

While Y-based superconducting tapes (coated conductors) have large expectations compared with Bi-based superconducting tapes since they have advantages from the viewpoints of cost, characteristics in magnetic field, mechanical strength and low AC loss, it is necessary to realize the crystal grains alignment in three dimensions, which is technically difficult so that time is required for the development. Therefore, Japan has been addressing the challenge with concerted efforts combining Japanese capabilities of industries, government, and academia.

In the "Collaborative Research and Development of Fundamental Technologies for Superconducting Applications" project, conducted for 10 years from 1998 being led by ISTEC (International Superconductivity Technology Center), Japanese electrical power and wire companies, and universities cooperated in the development of process and large-scale facilities by developing materials and high-speed fabrication technologies for metallic substrate, oxide buffer layer, and superconducting layer of coated conductors, which have a lamellar structure. While wires of several meters were the best of our ability, wires exceeding 500 m with high critical current higher than 300 A were produced with multiple processes at the end of project. The activities of the project have been leading the world always fiercely competing with the U.S.A.

Succeeding the results of the above-mentioned project, "Materials and Power Applications of Coated Conductors," which is a project aiming at power device development using coated conductors, started in 2008. In this project, three electric devices, "Superconducting Magnetic Energy Storage system (SMES)," "superconducting power cable" and "superconducting transformer" are selected and full-scale development work is scheduled. Another main theme is "development of coated conductors for superconducting power devices." Although it is supposed to use the tapes available at the end of "Basic technology for application project" for the above-mentioned devices in 2020 when the introduction and dissemination of the devices are assumed, not only specifications of higher level are required for length and characteristics (for example, 500 m-500 A or higher), such properties as characteristics in magnetic field, mechanical strength, uniformity and workability required for reducing AC loss that satisfy the requirements of each device must be provided. Furthermore, to realize the dissemination of these devices, the cost of tapes has to be extremely low ¥3/Am). In this project, therefore, development of tapes aims at providing tapes that satisfy specifications required by the above-mentioned devices in future at low cost. Specifically, the following five sub themes are selected and research and development has started.

① Degradation of properties,
② High I_c under magnetic field (I_c),
③ low AC loss,

④ high-strength and high engineering critical current density (J_e),
and
⑤ low cost and high yield.

About one year has passed since the start of the project and several results have been already obtained. In the tapes for which superconducting layers are formed using the pulsed laser deposition (PLD) method, whose problem has been its cost, tapes with high characteristics of 448 A or higher can be fabricated now at 15 m/h and low cost by changing the material for ion beam assisted deposition (IBAD) from Gd-Zr-O to MgO, which enables reduction in thickness and high speed and optimizing laser conditions of PLD, as well as the development of technology that enables film formation in the plume. For metal organic deposition (MOD) process, in which introduction of artificial pinning has been considered to be difficult, highly uniform characteristics have been realized regardless of the angular dependence of the applied magnetic field by replacing part of Y with Gd to uniformly distribute $BaZrO_3$ particles. Furthermore, there is progress in the technology to improve uniformity required for reducing AC loss, and, in scribing technology, 30 m-3 split tapes whose insulation between filaments is maintained while superconducting characteristics are kept have been successfully fabricated by shallow YAG radiation and two chemical etching treatments.

Successively, we aim at achieving intermediate and final goals set to the end of FY 2010 and FY 2012 in order to establish the fabrication technology for tapes required for electric devices using coated conductors at the time of introduction and dissemination.

Acknowledgement
Results of research introduced in this paper are part of the work sponsored by New Energy and Industrial Technology Development Organization (NEDO).

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

超電導 Web21 Superconductivity

Superconductivity Web21

Published by International Superconductivity Technology Center

1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Development of technology for introducing pinning center aiming at high J_c-B characteristics -

Kaname Matsumoto, Professor
Materials Science, Graduate School of Engineering
Kyushu Institute of Technology

There is a worldwide trend that fossil fuel usage is reduced as much as possible by replacing with more efficient electrical power for an energy source and a movement to build a new society by large-scale investment in energy and environmental industries has been started inside and outside of the Japan. It is expected that superconducting materials with zero resistance will play an important role in the 21st century in which electrical technologies will lead society. In particular, the high-temperature superconductor whose resistance becomes zero in low-cost liquid nitrogen is competent materials for various electrical applications.

An important technology for this purpose is how to control the maximum current J_c. Recently, a technology has been developed that drastically increases J_c in high magnetic field at about 77 K by introducing crystal defects in YBCO high temperature superconductor controlling nanostructure to strongly pin the quantized vortices. The crystal defect introduced into the crystal is called artificial pinning center (APC). In the artificial pinning, the distribution and density of crystal defects are designed and introduced into the thin film so that the maximum J_c is obtained. The crystal defects used for the artificial pinning center are classified according to dimensionality into linear defects such as dislocation and columnar defects (one-dimensional artificial pinning center), planar defects (two-dimensional artificial pinning center) such as dislocation array at small angle grain boundary and large precipitates surface and granular defects (three-dimensional artificial pinning center) such as precipitates or heterogeneous phase with a length equal to coherence length or longer.

What the author and colleagues did first for the proof of principle was substrate surface modification method using PLD and Y_2O_3 nano-island, and one-dimensional high-density artificial pinning centers of dislocations, etc. were introduced into YBCO thin film with Y_2O_3 nano-island on the substrate as the starting point. It was confirmed that as the density of nano-islands increases, J_c in the magnetic field (B//c) at 77 K increases severalfold. At the same time, a group of U.S.A. tested to introduce fine particles into YBCO thin film by switching target method and mixing target method, and obtained J_c severalfold that of pure YBCO film in both methods.

After the above-mentioned research results, many studies on the artificial pinning center were started. At present, experiments to introduce many nanorods of 5 – 10 nm diameters into YBCO and GdBCO thin films using mixed target of $BaZrO_3$ and $BaSnO_3$ are being conducted. These nanorods are introduced parallel to the c-axis and work as one-dimensional pinning centers. By using nanorods, J_c reaches 1 MA/cm^2 (77 K, 2 T, B//c). Although the mechanism of nanorod formation has not been clarified, it is a very interesting theme from the viewpoint of material science. While most of these studies on artificial pinning center use PLD, it has been found that nanorods are also introduced by MOCVD. As for two-dimensional artificial pinning center, anti-phase boundary (APB) and small inclination grain boundary have been tried,

Superconductivity Web21

Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

but only a few tests have been made. There are several patterns for three-dimensional pinning centers. One method is to introduce nano particles as artificial pinning center into thin film, which is formed by simultaneous deposition of material, which does not form nonorods, such as Y_2O_3 and YBCO using PLD. By this method, nano particles of 10 – 20 nm can be introduced into the film as artificial pinning center in high density. To introduce nano particles, MOCVD and TFA-MOD can be also used in addition to PLD. The dependency of J_c characteristics on temperature and magnetic field is quite different from that of nano rods, and it is expected that research on the detailed comparison of these methods will make progress.

Recently, the irreversible magnetic field of YBCO thin film at 77 K has reached 10 T or higher by using an artificial pinning center and practical Nb-Ti wire used at 4.2 K with values exceeding J_c has been reported. Therefore, it is expected that high performance wires with characteristics comparable with those of Nb-Ti wires at 77 K is realized by introducing an artificial pinning center into high-temperature superconducting wires using YBCO and GdBCO, which opens the road to the application of superconducting power equipment at 77 K.

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Present status of technical development of yttrium-based superconducting power equipment -

Noboru Fujiwara, Director
Electric Power Equipment Division, SRL/ISTEC

As a result of "Research and development of basic technology for application of superconductors, phase II" (hereinafter referred to as "Application basis"), yttrium-based wires having performance of 300 A/cm-500 m have been developed. In this paler, progress and results of "Development of technology for yttrium-based superconducting power equipment" based on the yttrium wires are reported.

SMES

Technology for SMES of 2 GJ class installed on the power station side is being developed as a measure for the stabilization when a failure occurs in a long-distance transmission line of an electric power system.

Based on the results of "Application basis," a coil with 12 double pancake coils having an inner diameter of 100 mm made of 10 mm wide IBAD-MOCVD wires arranged in toroid shape was fabricated and charge and discharge were successfully performed (Figure 1). In this project, development of constitution technology of compact coil for high magnetic field, large current, development of technology for high efficiency coil conduction cooling, and verification of SMES system model are being implemented. Evaluation test of combination of element model coil for SMES of 20 MJ class targeting 2 GJ class will be also carried out.

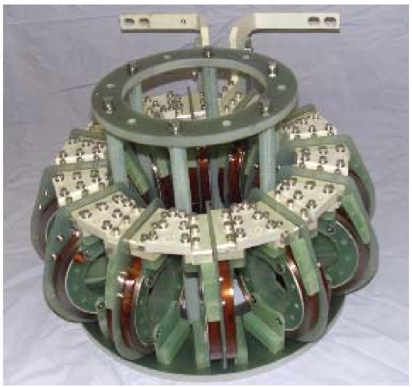


Fig. 1 Appearance of toroid-shape coil using IBAD-MOCVD wires

Power cable

Technology for 66 kV-5 kA large current cable and 275 kV-3 kA high voltage cable that enables compact and large volume transmission is being developed.

For the large current cable, a prototype cable core using 2 mm wide clad substrate-PLD wire was made and evaluated. The above-mentioned 165 wires were assembled in six layers as the conductor and 149 wires were assembled in three layers as the shield; and a prototype of single cable core of 1 m (Figure 2) was formed. Critical currents of I_c=7300 A and I_c=5800 were obtained for conductor layer and shield layer respectively.

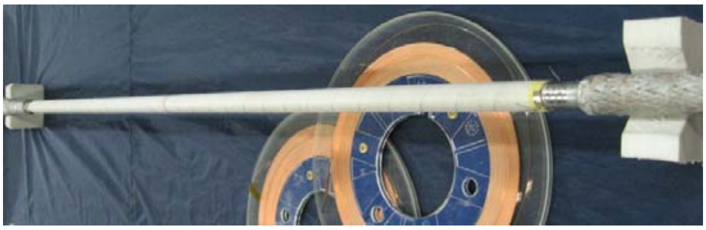


Fig. 2 Appearance of cable core using clad substrate-PLD wire

In the development of high voltage cable, a two-layer conductor of about 1 m using 4.5 mm wide

IBAD-MOD wires (Figure 3) was fabricated. The 4.5 mm wide wire was slit in the center for easier fitting to the former. This conductor achieved I_c=4554 A and AC loss of 0.01 W/m-phase at 1 kA. Reduction of AC loss is an important point for the development of superconducting power cable. To reduce the AC loss generated in the cable, it is necessary to evaluate the effects of not only load factor I_p/I_c, but also wire width, gap between wires, flexibility and roundness of wires, interval between layers, and cable design will be performed based on the above-mentioned results.

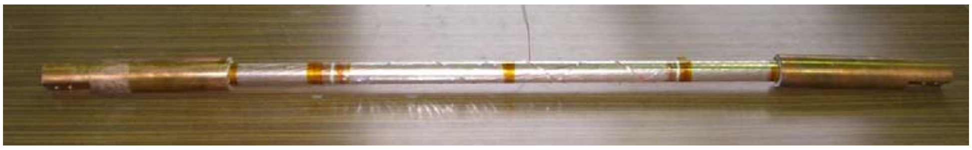


Fig. 3 Appearance of conductor using IBAD-MOD wire

Transformer

Technology for 66/6 kV 20 MVA class power transformers featuring compactness, high efficiency, and noncombustibility is being developed.

Technology for winding with low AC loss when a large current is passed and strength t endures the short circuit current is being developed. A model coil was fabricated using 5 mm wide IBAD-PLD wire (Figure 4) and over current test corresponding to short circuit current of 20 MVA was conducted using this coil to verify the critical current characteristics and the effect of protective measure by stabilizing copper. In addition, soundness against bending strain of 0.3-1.0% simulating the strain generated by coiling was confirmed to check the I_c deterioration due to edgewise bending strain.

Furthermore, in the development of a fault current limiting function, the model of four-winding structure provided with auxiliary windings was designed and made for verification of basic characteristics.

Fig. 4 Appearance of model coil using IBAD-PLD wire

Acknowledgement

The results introduced in this paper are based on the research sponsored by New Energy and Industrial Technology Development Organization (NEDO).

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Development and application of Bi-based wires at Sumitomo Electric Industries, Ltd. -

Kazuhiko Hayashi, Deputy General Manager
Superconductivity & Energy Technology Department
Sumitomo Electric Industries, LTD.

Sumitomo Electric Industries has been consistently pursuing the development of wire fabrication and application since the discovery of Bi-based high temperature superconductors in 1988. This paper reports the progress of wire fabrication, future prospect and present status of development of application of Bi-based wires. Here, Bi-based wires refer to Bi-based 2223 wires with a critical temperature exceeding 110 K.

1. Bi-based wires

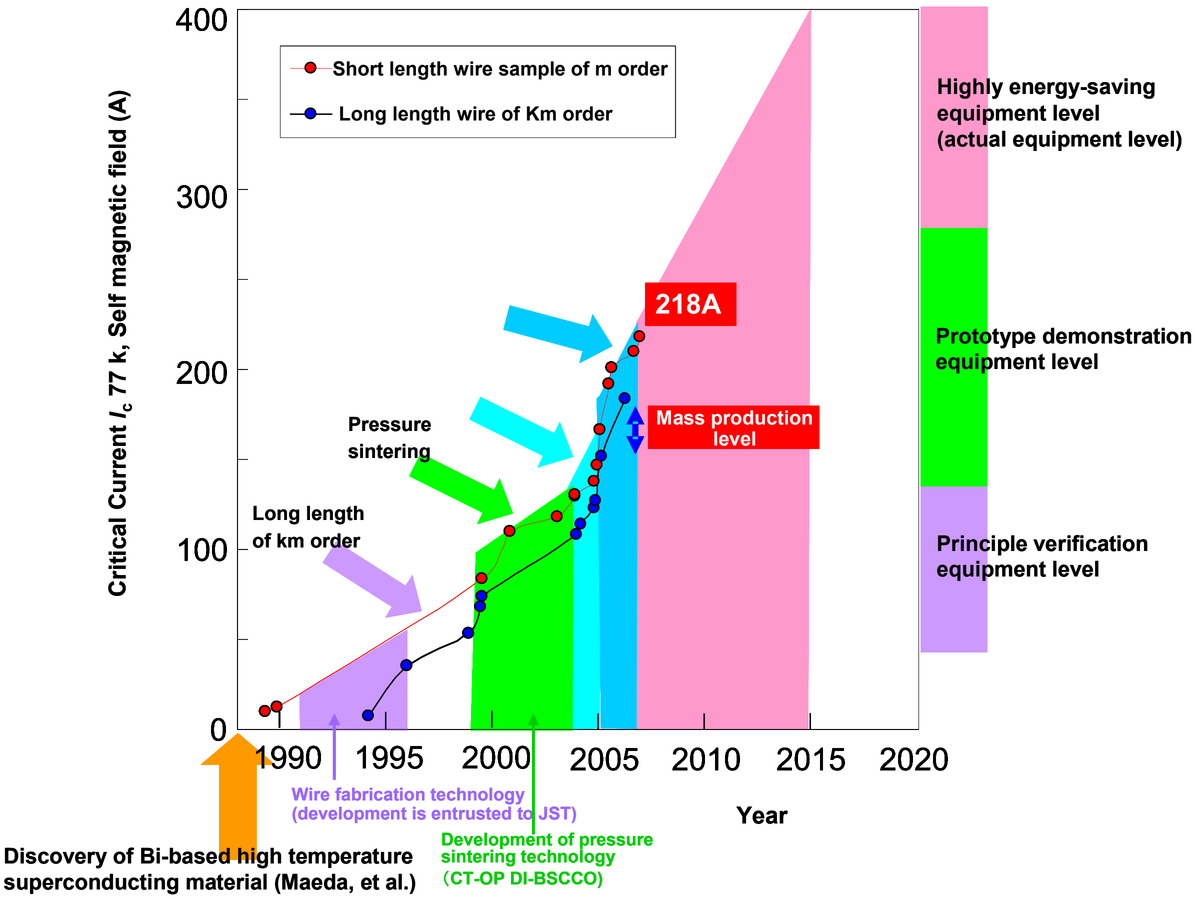


Fig. 1 Improvement in performance of Bi-based high temperature superconducting wires

High temperature superconducting wire of $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ (Bi2223) is produced by PIT (Powder In

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Tube) method, in which a metal pipe filled with raw powder materials is fabricated by composite process and the internal powders are sintered. The wire has a tape shape about 4.3 mm wide and 0.23 mm thick. To provide flexibility, the ceramic superconducting filament has a multi-filamentary structure covered with silver or silver alloy.

Figure 1 shows the history of improvement of critical current of Bi-based wires. In the initial stage up to 1995, the basis for PIT method in which the wire is fabricated by composite fabrication with silver was established and trial production of wires of 1 km class was implemented. Since then optimization of fabrication process made steady progress and the critical current of standard size reached 100 A at liquid nitrogen temperature and under a self magnetic field. The reason for the significant progress in wire fabrication was that that overpressure sintering process was developed. Due to the overpressure sintering, Bi-based wires reached to the level of industrial products because the overpressure sintering increased production yield drastically by reducing local defects and critical current and mechanical strength were significantly improved. After that, there has been a progress in fabrication process and optimization of fabrication conditions so that the critical current reached 218 A in short samples and long-length wires in km order with a critical current of 160-180 A can be supplied in a large volume at industrial level.

From the evaluation of orientation of wires using high intensity X-rays of Spring-8, average disturbance of orientation of wires with a critical current of 210 A was found to be about 6º and it is predicted that the critical current will reach 300 A if the value is improved to 4º. Furthermore, microscopic evaluation of wires indicates that 4 to 5 fold critical current exists locally and so there is a room for the critical current characteristic to be significantly improved by expanding the high critical current density region.

2. Present status of development of applications of Bi-based wires

Table 1 shows present status of applied products of Bi-based wires. In the medical field, MRI has become popular by using superconducting technology and compact MRI (portable, for encephalography) using Bi-based wire is being developed. For the treatment of cancer, it is being studied how to apply superconductivity to a proton/heavy particle accelerator, which will enable downsizing of building requiring a radiation shield and significant reduction in construction cost.

In the electric power field, application of cables is making progress worldwide and there are several examples that actually connected to commercial systems including Albany U.S.A. In Japan too, Tokyo Electric Power Co., Mayekawa Mfg. Co., Ltd. and Sumitomo Electric Industries are planning to implement an in - grid test at the Asahi Substation for the first time in Japan as part of verification project for superconducting cable sponsored by NEDO. As a new application of cables, direct current cables for applications such as transmission and distribution of renewable energy including solar battery and feeder cable for railway are being investigated and it is expected that the merit of application of superconductors with no AC loss is utilized.

In the application to motors, which consume 70 % of total electricity consumption, application to motors for ship propulsion systems was first studied in various world countries and a motor of 400 kW applicable to inland vessels was developed in Japan. For ground transportation equipment, a prototype superconducting electric vehicle has been developed and driving with passengers is being tested. Energy saving effect was evaluated for route buses, which has high utilization rate and frequently starts and stops, and energy saving of 13 % (improvement of 13 % in travel distance for the same batter capacity) is expected compared with a conventional electric vehicle.

Table 1 Present status of development of superconducting equipment

Application	Description	Low loss	Compactness	Lightweight	Large torque	High magnetic field	High precision	Quietness	Maintainability	Stability	Total economic efficiency	Remarks
MRI (medical)	High magnetic field generator	○				○			○	◎	○	Portable (GE), encephalography (JST, Kyoto University)
NMR	Ultra-high magnetic field generator	○				◎					○	High performance type (>1GHz)
Accelerator for medical application	Proton/heavy particle accelerator			○						○		Gantry, synchrotron
Cable (AC and DC)	Large amount of electricity with small diameter and low loss	◎	○							○	◎	Electric power company, U.S.A. government project, combination with natural energy, railway
Transformer	For Shinkansen bullet train		○	◎								Weight saving is the supreme issue, necessity for reduction in AC loss.
	For electric power	◎	○								○	For underground substation, etc.
Current limiter	Suppression of accidental current	○								○	○	Saturable core (Bi), S-N transition type (2G)
SMES	Magnetic energy storage	○				◎						Compensation for instantaneous under voltage, compensation for load fluctuation
Motors for ships	Reduction of propulsion resistance by downsizing	◎	◎	◎	◎			◎	○	◎	◎	Industrial-academic cooperation, development of 400 kW equipment
Aircraft propulsion	Weight saving and utilization of fuel cell power	○	○	◎				○			◎	U.S. Air Force
Solidification control of molten metal	Convection control in high magnetic field	○				◎				○		Next generation large scale single crystal furnace, production of iron and steel
Machine tool	Gearless, high precision and higher maintainability due to large torque			○	○		◎		◎			Stable fabrication of ultra-high precision products
Magnetic separation	Medicines, purification of waste water	○				◎				○	○	Being used in paper factories
Automobile	Large torque and low loss of driving motor	◎	◎	◎	◎						◎	Significantly effective for liquid hydrogen fuel
Wind power generator	Simplification of nacelle structure		○	◎	○			○			○	Weight saving and quietness

3. Future prospect

For high temperature superconducting equipment to overwhelm conventional technology and disseminate, it is considered to be essential to realize a wire price of ¥10/Am (cost for equipment manufacturer) in the application field where the competition is with copper wire application, and ¥5/Am in the field where the competition is with low temperature superconductors for MRI, etc. (critical current: 77 K converted to self magnetic field). From the prospect of critical current performance and production cost, wire cost of this level is probable for Bi-based wires so that we will make research and development in this field extensively together with the development of new application fields.

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009
- New evolution in development of Nb-based superconducting device -

Mutsuo Hidaka, Director,
Low Temperature Superconducting Device Division, SRL/ISTEC

International Superconductivity Technology Center (ISTEC) is developing devices using niobium as the superconducting material. The reason why niobium is selected from many superconducting materials is that niobium is an elemental metal, the superconductor can be fabricated only by a low temperature process because epitaxial growth is not required, forming of high quality Josephson junction is established and conventional equipment used for semiconductor processing can be used, which means that niobium superconducting device is the easiest to develop among all the superconductors. It is another significant reason that device characteristics are stable and variation with time is negligibly-small.

ISTEC is developing a digital device called a single flux quantum (SFQ) circuit. SFQ circuit uses the minimum unit of quantized magnetic flux that appears only in superconductors as the information media and the state in which one SFQ exists in superconducting ring is defined as "1" and the state in which no SFQ exists in superconducting ring is defined as "0." Josephson junction is used as the gate that inputs and outputs SFQ to and from the superconducting ring.

The most eminent characteristic of SFQ circuit is that the high speed exceeding 100 GHz consists with power consumption as low as 0.1 μW per gate, which enables the realization of large scale integrated circuit that operates at high speed. The switch for network router is an example of effective application of the SFQ circuit. In NEDO's "Superconductors Network Device Project", which was carried out until 2006, ISTEC engaged in developing SFQ switch and succeeded in an experiment in which moving images are transferred avoiding the collision of packet by connecting four PC's with SFQ switch. The power consumption of the SFQ router with a processing capacity of 100 Tb/s class was calculated based on this technology and the result indicated that energy efficiency five-times that of the limit of semiconductor router is obtainable. Furthermore, an SFQ circuit of the energy saving type can improve the efficiency by an order of magnitude.

In the process of developing large scale SFQ circuits including SFQ switch, technologies for design, processing, and packaging have been accumulated and what was impossible five years ago has become possible now. However, in order to realize a large scale SFQ system, still more resources and time are required so that the demand for early realization of this technology has not been met. On the other hand, it is possible to put a superconducting small scale system to practical use relatively early with the present technology. For this purpose, systems using small scale superconducting devices are being developed.

In the "Development of Next-Generation High-Efficiency Network Device Technology Project" of NEDO, ISTEC is developing a superconducting real time oscilloscope that can observe even single events of high speed optical communication signals. In this development, the key components are an AD converter (ADC) utilizing the high speed of SFQ circuit and high speed optical input to superconducting circuit cooled by a cryocooler. So far, optical input of 40 Gb/s and ADC operation according to the design have been successfully achieved. It is scheduled from now on to realize a superconducting ADC that exceeds the limit of semiconductor ADC by increasing the Josephson junction critical current density as well as to develop a

Superconductivity
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

system in which a superconducting ADC is provided to a compact cryocooler.

ISTEC is developing a pulse-driven Josephson signal source that can be used for an AC voltage standard in cooperation with the National Institute of Advanced Industrial Science and Technology (AIST). This is to realize AC voltage standard utilizing the quantum effect of Josephson junction that has never existed. An experiment in which AC of arbitrary waveform was successfully generated by mounting the superconductor device designed by the AIST to a cryocooler provided with optical input fabricated by ISTEC was successfully conducted. It is expected that the system can be applied not only to AC voltage standard but also to wide range of uses including various signal sources and calibration equipment for ADC, etc.

Yoshikawa/Yamanashi Laboratory of Yokohama National University indicated that a high speed physical random number generation circuit can be created using a very simple SFQ circuit called a comparator. Different from pseudo-random numbers based on an algorithm, physical random numbers are unpredictable because the numbers are generated based on natural phenomena, which enhance the safety of cryptography. Yokohama National University, using SFQ circuit, succeeded in generating physical random numbers satisfying the criteria of NIST with 1,000 times faster than the speed of a semiconductor physical random number generating circuit.

As explained above, not only the compact superconducting system becomes available in near future but also the performance of the SFQ technology surpasses by far the conventional ones. Therefore, it is important to find appropriate applications that enjoy these advantages.

Part of this paper is excerpts from the results of “Superconductors Network Device Project” and “Development of Next-Generation High-Efficiency Network Device Technology Project” sponsored by New Energy and Industrial Technology Development Organization (NEDO). Appreciation is also expressed to Dr, Kaneko of the National Institute of Advanced Industrial Science and Technology and Professor Yamanashi of Yokohama National University for providing materials.

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Development of filter system for next-generation weather radar -

Hiroyuki Kayano
Functional Materials Laboratory, Corporate Research & Development Center
Toshiba Corp.

Recently, the use of devices utilizing radiowave, such as digital TV, cell phones and wireless LAN, has been expanding and expectations for future high speed communication are growing. In order to meet such expectations, it is important to utilize the limited frequency resources effectively and secure an appropriate radiowave utilization environment. In particular, efficient utilization of 5 GHz band wireless LAN is urgent because demand for the band is explosively increasing. Toshiba has been conducting research and development on narrowing of the neighboring weather radar band assuming the expansion of frequency band of 5 GHz wireless LAN. This paper reports the development of narrow band filter for receiving required for the narrow band operation of system[1), 2)].

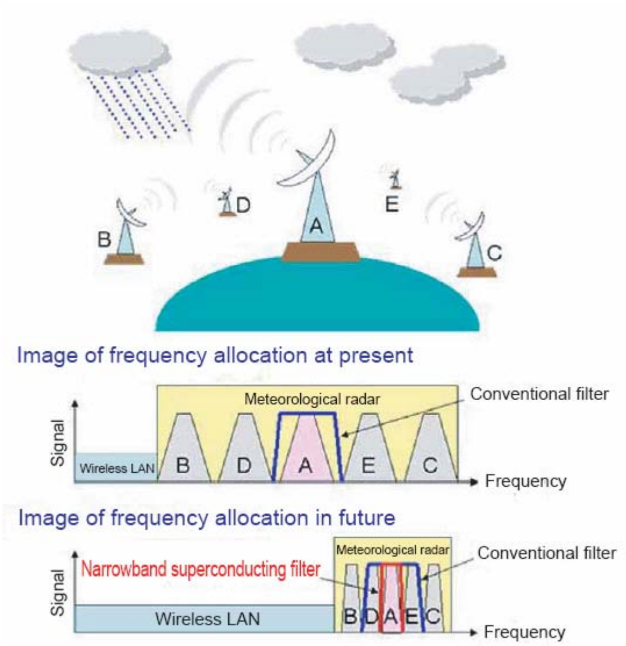


Fig. 1 Meteorological radar and frequency allocation

As shown in Figure 1, the present situation in which signals are allocated on the frequency axis in high density causes interference because signals from other weather radar in the neighboring area enter the receiver or deterioration of receiving sensitivity because spurious transmission enters the neighboring signal. To solve these problems, narrow-band transmitting and receiving filters are required. However, in the past, it was difficult to provide narrow-band filter because the loss of conventional filters made of metal conductors (e.g. copper) was large. Therefore, narrow-band filter using superconductors whose loss in high frequency range is expected to be as low as 1/100 or less compared with metal conductor. Especially in transmitting filter, since the power of passing signal is large, it is a problem for superconductors that have critical current density characteristics. To realize high electric power resistance required for weather radar, hybrid filter using cavity resonator with high power handling capability and superconducting resonator with low loss in narrow-band was developed[3)]. Figure 2 shows schematic operation principle of the filter. The hybrid filter has a structure that large power is bypassed and only spurious of small power is passed through the superconducting resonator so that steep characteristics and high power handling capability characteristics are achieved simultaneously. Figure 3 shows the photo of appearance of developed filter unit. The unit is 19-inch rack mount type and the size is 15 U. The fractional band-width of the transmitting and receiving filters is as low as 0.075%. For the receiving filter, neighboring signal suppression is 30 dB. In addition, operation at 3.5 kW

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

was demonstrated for transmitting filter and spurious was suppressed to 1/10 or lower. This filter is expected to provide four times larger frequency utilization efficiency.

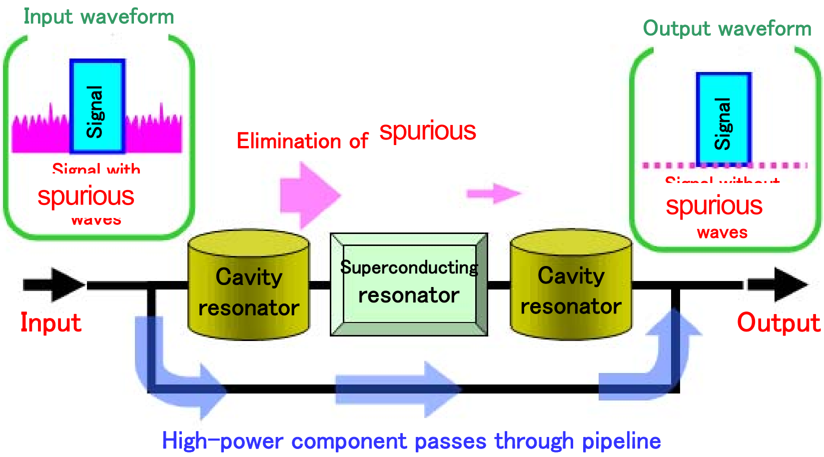


Fig. 2 Hybrid filter operating principle

Fig. 3 Filter system unit for next-generation weather radar

This research was supported by the Ministry of Internal Affairs and Communications, JAPAN.

References

1) Kayano, Hashimoto, "Development of superconducting radar for weather radar," Superconductivity Web21, Feb. 2008.
2) Shiokawa, *et al.*, "Development of superconducting radar for weather radar," IEICE Technical report, SCI2008-14, MW2008-14, pp.75-80, Apr. 2008.

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Development of fabrication and evaluation technologies for yttrium-based wires with low AC loss -

Keiichi Tanabe,
Deputy Director General, SRL/ISTEC

Among the power devices being developed in the "Technological Development of Yttrium-based Superconducting Power Equipment" project, so-called M-PACC project, started in 2008 being sponsored by NEDO, reduction of AC loss of cables and transformers is one of the important targets. In the case of cables, since the direction of magnetic field generated by the current is in the circumferential direction of the former, it is possible to reduce the AC loss by winding the yttrium-based wires fabricated in narrow strip about 2-mm wide with perfect roundness around the former as much as possible so that the magnetic field is not exerted in the perpendicular direction. On the other hand, in the case of transformers in which solenoid coil is used, there exists magnetic field exerted in the vertical direction of the wire at a position close to coil end. Since the hysteresis loss generated by the magnetic flux coming in and going out between the edge of wire and the center accounts for the most part of the loss of superconducting wire placed in the vertical AC magnetic field, the loss can be reduced by 1/N by scribing the superconducting layer of the wire to split into N-filaments. In the yttrium-based wires, since the intermediate buffer layer is insulator, the resistance between the filaments is supposed to be very high if the scribing is ideally implemented. However, if the residue of normal conductor remains between the filaments, coupling loss is generated by the current passing between the filaments. This coupling loss cannot be ignored compared with hysteresis loss when the wire becomes long.

For the scribing technology in which multi-filament wires are formed by scribing yttrium-based wires, mechanical fabrication, laser scribing, and etching methods have been proposed. ISTEC has succeeded in obtaining high inter-filament resistance by combining laser scribing and chemical etching in the precedent NEDO's project. The fabricated wire 3–5-m long and 5-mm wide was split into five filaments and a 19-layer solenoid coil was fabricated using original winding method at Kyushu Electric Power Company and it was shown that the AC loss was reduced by 1/5 compared with the coil without scribing. To develop the transformer of 2 MVA class to be shown in the present project, wires 5-mm wide and 300-m long at the most split into 3 filaments are required and the total required length is about 10 km. ISTEC is now developing the technology to stably fabricate such a large amount of multi-filamentary wires. For the future commercialized transformers, more sophisticated technology to split the 5-mm wide wire into five to ten filaments is required. ISTEC is now developing a technology to fabricate wires having uniform characteristics in longitudinal direction and lateral direction and to process fine wires in which defects generation and deterioration of critical current (I_c) is suppressed as part of the present projects.

In 2008, laser scribing process and chemical etching process were improved. Specifically, filaments having very sharp end face were successfully fabricated within 1/10 of the time required for conventional processing by scribing with lower laser strength, which suppresses the dross generation due to meting of Hastelloy substrate and using etching solutions suitable for silver (Ag) stabilizing layer and superconducting

超電導 Web21
Superconductivity
Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

layer, respectively. In addition, reel-to-reel continuous etching equipment was developed to process wires 30-m long and 5-mm wide split into three filaments, and the rate of decrease of I_c due to fabrication to less than 3 %. Furthermore, the resistance between the filaments was 100 kΩ per 30 m, which is sufficient for transformer application. This process is applicable to long wires. On the other hand, in order to fabricate long wire filament with high yield, it is effective to evaluate I_c and defects in the longitudinal direction and lateral direction before and after the fabrication and to repair the wire as needed. Although the Hall sensor method that was used only for non-contact evaluation of I_c in the longitudinal direction, a method for the evaluation in the lateral direction has been developed this year, which shows the possibility to estimate the I_c distribution among filaments. Regarding the defect distribution evaluation equipment by eddy current using SQUID magnetic censor array developed in the precedent project, it has been reported that not only positions where I_c is deteriorated but also various defects including delamination and short-circuit between filaments can be detected. Furthermore, high speed evaluation of 80 m/h became possible by improving the cooling method for wire. Utilizing these improved fabrication processes and evaluation technology, establishment of fabrication technology for wires 100-m long split into three filaments and wires 50-m long and split into five filaments are the targets for this year.

The research reported in this paper was conducted as part of "Technological Development of Yttrium-based Superconducting Power Equipment" sponsored by New Energy and Industrial Technology Development Organization (NEDO).

(Published in a Japanese version in the July 2009 issue of Superconductivity Web 21)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Development of magnetic bearings using high-temperature bulk superconductors for flywheel -

Ken Nagashima, Laboratory Head
Cryogenic Systems Laboratory, Maglev Systems Technology Division
Railway Technical Research Institute

Power storage facilities for railway contribute to energy saving through regenerative energy recycling and peak cut, some of which are being actually applied. Superconducting flywheel power storage equipment that stores electric power as rotational energy by rotating heavy objects generates less loss accompanying the rotation and enjoys easier maintenance compared with flywheel equipment using mechanical bearings because the former has no contact part. There have been some examples of development of power storage facilities using superconducting bulk bearing in Japan, USA, and Germany. All of these examples use bearings prepared by combining permanent magnets and bulk superconductors, which has an advantage that the system is completely non-contact stable levitation that does not require controlling by using the pinning center effect of the bulk superconductors. However, there is a limit (about 0.5 T) for generated magnetic field as long as a permanent magnet is used and the maximum force density (electromagnetic force supported by unit area of bulk superconductors) is 100 kN/m^2 at most. In order to store a large amount of energy, it is natural to rotate heavy objects. On the other hand, when high magnetic field is applied, force density increases as the square of the magnetic field. For example, when superconducting coil is used as the magnetic flux source instead of permanent magnet as shown in Figure 1, the problem will be solved. Figure 2 shows an image of flywheel power storage facility using superconducting magnetic bearing in the combination of bulk superconductors and superconducting coils. Although this constitution has several problems such as the loss in the rotation of bulk superconductors and cooling method of bulk superconductors, there is a possibility that force density is innovatively increased.

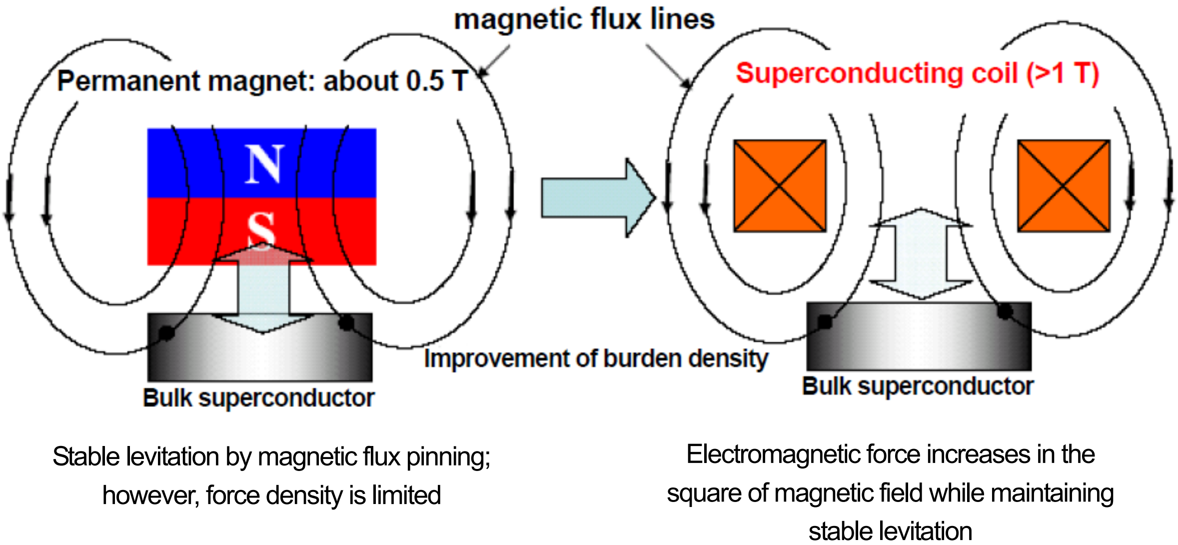


Fig. 1 Schematic diagram for bearing using bulk superconductors and superconducting coils

超電導 Web21
Superconductivity
Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

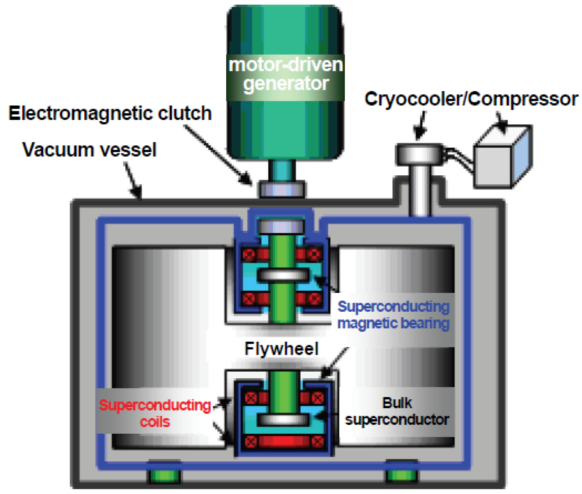


Fig. 2 Flywheel electric power storage facility
using bulk superconductors and superconducting coils (image)

For the magnetic bearing consisting of two superconducting components, it is a problem to cool the bulk body on the rotating side. To make the present experiment easier, bulk superconductors immersed in liquid nitrogen are placed on the rotating side and superconducting coils are placed on the stationary side to form a thrust bearing. The target specification is: load capacity is 10 kN as static load, thrust load is 5 kN, and the maximum rotational speed is 3000 rpm

Table 1 shows the specifications for material, shape, and cooling method for testing superconducting magnetic bearing. Schematic diagram of testing superconducting magnetic bearing is shown in Figure 3. Gadolinium-barium-copper-oxygen (Gd-Ba-Cu-O) was selected as the bulk superconductor because of the excellent critical current characteristics in magnetic field at the liquid nitrogen temperature (77 K). The Dewar for rotating test is an adiabatic cold box holding liquid nitrogen in which bulk superconductors are immersed and the Dewar itself comprises a part of the axis of rotation. Two coils are arranged in the developed superconducting magnet and cusp magnetic field is generated by exiting the different poles. The magnetic field weakens in the space between the coils and the rate of the change of magnetic field is increased so that the electromagnetic force is effectively exerted on bulk superconductors being held at the liquid nitrogen temperature. Room temperature space (room temperature bore) passes through the cryostat (low temperature vessel), and the adiabatic liquid nitrogen cold box (dewar for rotating test) holding bulk superconductors comprising a part of rotational axis is placed in the bore to construct the bearing.

Table 1 Specification for superconducting magnetic bearing for test

Rotor		Stator	
Bulk supeconductor		Superconducting Magnet	
Material	Gd-Ba-Cu-O	Wire	Nb-Ti
Shape	Disk Φ 60 mm x t 20 mm 2 pieces double-decked	Shape	Room temperature bore Φ 120 mm Cusp magnetic field Magnetic flux density 5 T (Max)
Cooling method	Liquid nitrogen (77 K)	Cooling method	Direct cooling by cryocooler (4 K)

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

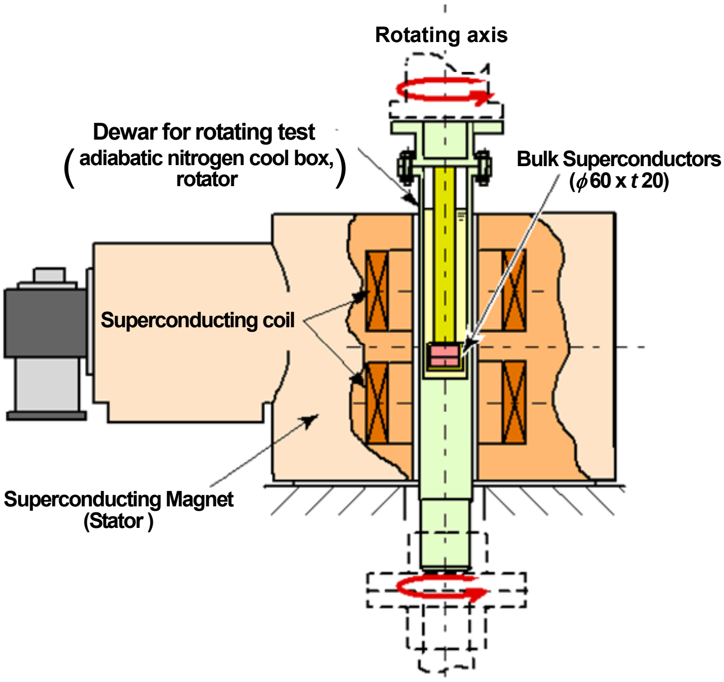


Fig. 3 Superconducting magnetic bearing for test

After sufficiently cooling bulk superconductors by zero magnetic field cooling (cooling without applying magnetic field), superconducting magnet is excited and the generated levitation force was measured. Figure 4 shows the comparison between predicted electromagnetic force (results of electromagnetic force analysis) and the measurements of electromagnetic force (experimental results). Both values agree well and electromagnetic force of vertical load capacity limit 10 kN was generated at 78 % of rated output of superconducting magnet. The load capacity of the superconducting magnetic bearing for test developed in this project corresponds to 10 times or more that of load capacity per unit area (about 100 kN/m^2) of the conventional thrust type superconducting bearing consisting of bulk superconductors cooled by liquid nitrogen and permanent magnets.

Furthermore, experimental equipment in which rotating body of 500 kg is supported with the superconducting magnetic bearing for test and rotated was fabricated and the operating characteristics of magnetic bearing consisting of two superconducting systems were investigated under thrust load. The results show that no significant reduction in electromagnetic force was observed in a test at the maximum speed of 3000 rpm and the levitation position was maintained stably. Although the bearing has resilience characteristics in the radial direction, since

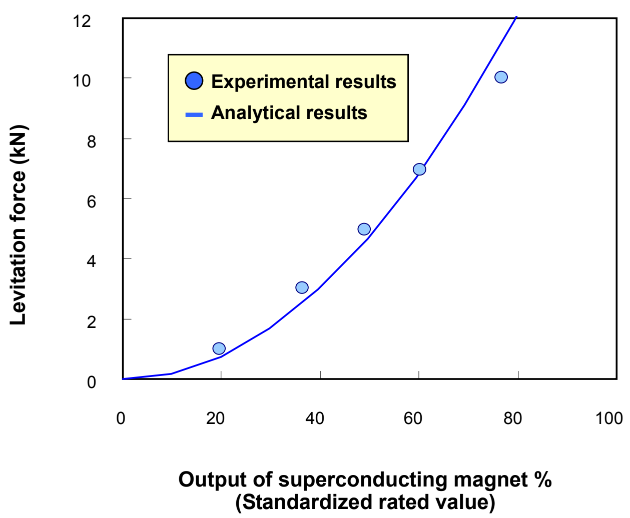


Fig. 4 Relationship between output of superconducting magnet and generated levitation force

the power is insufficient mechanical radial bearing was used concurrently for the safety during high-speed rotation.

The bearing capacity will be increased in the future aiming at the realization of energy capacity at a commercial level. Furthermore, it is scheduled to investigate the application to radial bearing and develop technologies for cooling method for the superconductors placed on the rotating body side and peripheral elemental devices. Niobium-titanium (Nb-Ti) wires were used for the superconducting coil in the present experiment considering the current cost, high temperature-superconducting wires will be used to reduce the power consumption for the cooling of the equipment in the future. Furthermore, it is targeted to construct a strong magnetic bearing structure by enhancing the magnetic coupling by holding bulk superconductors and superconducting coils in the same vacuum vessel as shown in Figure 2. This work was financially supported by the Japanese Ministry of Land, Infrastructure, Transport and Tourism.

Reference URL：
http://www.rtri.or.jp/rd/openpublic/rd77/CS/cs_1.6.html

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Past and future of the international standardization of superconductivity -

Yasuzo Tanaka, Director
Standardization Affairs Division, ISTEC

1. Introduction

The international society is developing continuously by concentrating the wisdom of mankind. In particular, advanced technologies, including superconductivity have the possibility to dramatically develop the international society. In order to utilize the superconducting technology for the development of international society, it is considered to be important to ensure the intellectual property related to superconducting technologies as well as to internationally standardize recent superconducting technologies. This paper, describes the necessity, history, and future of international standardization of superconductivity.

2. International standardization of superconductivity in the past

In the 1970s, superconductivity technology entered commercial stage as laboratory equipment using niobium-titanium alloy superconducting wires. In the 1980s magnetic resonance imaging (MRI) rapidly became popular as diagnosis equipment and now the MRI market accounts for 80 % or more of international superconductivity market of ¥560 billion. With such a background of market, international standardization of superconductivity started as International Electrotechnical Commission (IEC)/TC90 (Superconductivity) in 1989. With the excellent superconducting technological capabilities as background, Japan has been leading the international standardization of superconductivity as the secretary country of IEC/TC90 since 1989. In this period, 14 IEC standards in total for electrotechnical vocabulary relating to superconductivity and test methods have been published, and 14 JIS standards corresponding to the 14 IEC standards have been also published.

3. Necessity of internal standardization of superconductivity

In the field of superconductivity technology, in addition to niobium-titanium alloy and niobium-3-tin (Sn) compound, which are Japan’s specialty, bismuth (Bi)-based and yttrium(Y)-based superconductivity technologies have been added in the 1990s. In the year 2000 international competition in the development of superconductivity technology and its application technology has been intensified. Stagnation of Japanese superconductivity technology in such an international competition will cause the delay of progress in superconductivity technology making Japan the Galapagos Islands of superconductivity. To avoid such a situation, it is important to secure the intellectual property relating to high temperature technology as well as to emphasize international standardization of superconductivity technology. In particular, it is necessary to enhance product standards that provide the basis for production and marketing in addition to standardization of terms related to superconductivity and test methods for basic characteristics. Therefore, it may not be an exaggeration to say that Japan can avoid becoming the Galapagos Islands only by taking initiative in promoting international standardization as the secretary country of IEC/TC90.

4. Future international standardization of superconductivity

International standardization of superconductivity is divided broadly into the electric power category related to large current and strong magnetic field and the electronic device category related to weak signals and information. The power category includes international standardization of current lead, which is under deliberation, superconducting wires and superconducting power cables whose international standardization started in 2008, and superconducting magnetic energy storage system (SMES) and superconducting transformers whose market is anticipated to be formed around 2020. In the device category, the present target of international standardization is superconducting sensor, which is a device for relatively small scale systems such as diagnosis equipment, measuring instruments, and inspection equipment rather than sophisticated digital systems taking the fact that the market development is rather slow compared with the power category into consideration. For both categories, it is essential to take the following three points into consideration in the international standardization. First, it is like replacing the pieces of jigsaw puzzle with superconductivity pieces to introduce the superconducting technology into the technological system extending throughout the international society. While it is obvious that superconductivity technology is superior to the conventional technology, superconductivity technology must be accepted by the conventional technological system by ensuring the conformity with the peripheral technologies, establishing global consensus of people concerned, ensuring conformity with applied area and system, and making the economic appropriateness clear. Second, in addition to usability and economic potential, dignity is required for superconductivity technology that responses to diversified social needs speedily and conforms to environmental and safety issues. Finally, international standardization must be systematically maintained by revising, eliminating, and enhancing flexibly because the superconductivity technology is constantly advancing and market needs and social needs varies in diversified way.

5. Conclusion

In the history of international standardization of more than 100 years, that of superconductivity is only 20 years. Therefore, for the superconductivity technology to promote industrialization related to superconductivity and contribute to international society, not only the understanding of concerned parties, which forms the basis of international agreement but also further understanding in international standardization and cooperation of the party concerned of peripheral technologies are required.

This paper is based on the research conducted as part of “Development of technology for yttrium-based superconducting power equipment” sponsored by New Energy and Industrial Technology Development Organization (NEDO).

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center

1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Articles: Forum on Superconductivity Technology Trends 2009 - Key-note lecture – Applied superconductivity to power system apparatus and oxide superconductivity -

Tanzo Nitta, Professor
Department of Electrical and Electronics System Engineering
Faculty of Science and Engineering, Meisei University

1. Introduction

Let us examine future energy consumption. Further energy saving and lower carbon society must be tried. The solution seems to lie in further use of electricity at final stage of energy consumption. On power generation, further use of nuclear power and regenerable energy must be carried out. Thus, the generation of electric energy by many kinds of energy sources is being promoted and the consumption of electrical energy is going to be more than twice of now. Electric power systems match the generation and consumption (utilization) of electric energy. In addition to the above mentioned background, it is necessary to find a solution for the construction and operation of the future electric power systems that enables effective utilization of the present systems.

2. Power system apparatuses and application of superconductivity

The present main power system apparatuses are electric generators at power stations, switches and transformers at substations, and transmission and distribution lines that connect these stations. Let us consider whether the abovementioned subjects are solved by using superconducting apparatuses for these facilities. General characteristics of superconducting ones are downsizing, weight reduction, and high efficiency as well as constant temperature. This constant temperature prolongs the equipment life. The following are additional characteristics of superconducting apparatuses other than those described above.

a. Power stations

Electrical equipment in power station consists of electric generators, transformers, and bus that connects the former two devices. As is well known, superconducting generators contribute to the improvement of power systems by higher supply capacity of reactive power, higher power system stability, etc. Effectiveness of superconducting transformer should be further investigated. Since the terminal voltage of the bus cannot be increased, a large current exceeding 20 kA flows through the bus, which means that application of superconductivity gives various advantages.

b. Substations

Electric power substation consists of lightning arrestors, switch gears, and transformers. It is difficult to apply superconducting equipment to other than transformers. The introduction of superconducting fault current limiter, which is not a switch device, will significantly contribute to increasing the capacity of existing electric systems.

c. Transmission and distribution lines

Superconducting transmission and distribution lines have a line constant comparable with overhead transmission line, which is a desirable characteristic that conventional cables do not have.

Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

3. Conclusion

By applying superconductivity to part of existing power systems, higher performance systems can be constructed and operated. Oxide superconducting wires develop characteristics that metal superconductors do not have by exploiting their characteristics and have the possibility to easily solve the abovementioned future subjects of power systems.

(Published in a Japanese version in the July 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Trend in diagnosis/inspection technology using SQUID - Present status of metal resources exploration tool (SQUITEM) using high-temperature superconducting magnetometer -

Eiichi Arai, Deputy Director
Metals Exploitation Department, Metals Strategy and Exploitation Unit
Japan Oil, Gas and Metals National Corporation

1. Introduction

Japan Oil, Gas and Metals National Corporation (JOGMEC) developed an electromagnetic exploration tool (SQUITEM) using high-temperature SQUID in the five year period from 2001 to 2005 to improve exploration depth of electromagnetic exploration, which is frequently used for metal resources exploration. JOGMEC is now using SQUITEM for metal resources exploration implemented by JOGMEC. In this paper, the outline of SQUITEM and the examples of metal resources exploration using SQUITEM are introduced.

2. Outline of SQUITEM

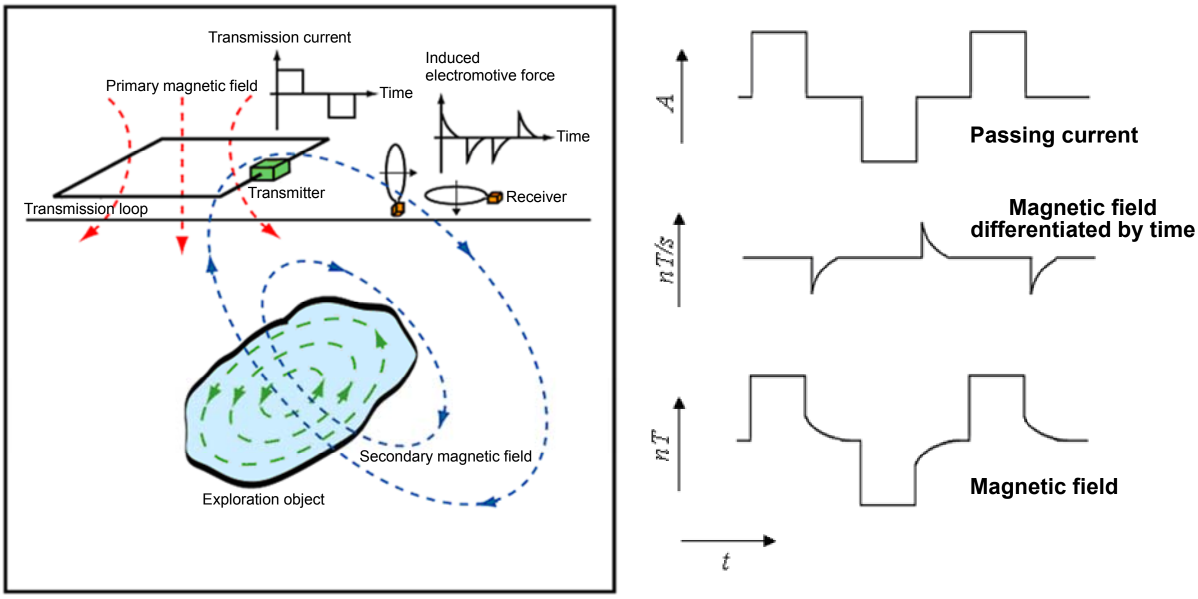


Fig. 1 Explanation of electromagnetic exploration

In electromagnetic exploration (time domain electromagnetic exploration), a transmission loop is installed on the ground to generate electromagnetic field as the media for investigating the distribution of underground specific resistance, and alternating direct current with on-off period is passed through the loop (Figure1). When the current passed through the transmission loop installed on the ground is suddenly turned off, according to the law of electromagnetic induction, a current with a magnitude equal to the current flowing through the loop is generated on the ground surface directly under the loop to object the change in the magnetic field flowing until then. While this induced current attenuates due to the specific resistance of

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

the ground, new induced current is generated in the ground so that the change in induced current is objected. This process is repeated so that a phenomenon called smoke ring is generated as if the induced current propagates deep into the ground. Since the induced current attenuates according to the specific resistance in the propagation path, underground specific resistance distribution can be studied by measuring the magnetic field generated by the induced current or the magnetic field differentiated by time. The diffusion depth that expresses the depth of maximum amplitude of electromagnetic field diffusing in the direction of the depth at time *t*, ($d=\sqrt{2t\rho/\mu}$) (ρ: underground specific resistance, μ: underground permeability) is assumed to be the indication of exploration depth measured at time t. Since the induced current penetrates deep into the underground, as the time elapsed as seen from the equation for diffusion depth, specific resistance distribution in deep part is obtained by measuring for longer time.

Although electromagnetic exploration is widely used for detecting the position of metal ore deposit or accompanying ore showing (such as alteration zone by argillation), electromagnetic exploration with deep exploration depth is required as the metal ore deposit gets deeper these days. What is attracting attention instead of conventional measuring the magnetic field differentiated by time using induction coil magnetometer is a method for measuring magnetic field using a magnetometer that directly measures the magnetic field. Since magnetic field attenuates with time more slowly than magnetic field differentiated by time, data can be taken for a longer time (deeper depth) than conventional method that uses magnetic field differentiated by time. SQUID is suitable for magnetic sensor used for electromagnetic exploration tool for metal resources exploration because of extremely low noise level compared with other magnetic sensors, sufficiently broad frequency bandwidth, which is suitable for the exploration depth of metal resources exploration, and its directionality.

SQUITEM consists of notebook PC for controlling measurement, A/D converter, controller, power source, and SQUID magnetometer (Figure 2). The frequency band of SQUITEM is DC 100 kHz and noise level of SQUID magnetometer in the magnetic shielding is about 100 fT/$\sqrt{\text{Hz}}$.

Fig. 2 Entire view of SQUITEM (No. 2 equipment)

3. Example of application of SQUITEM to metal resources exploration

SQUITEM was used for zinc exploration in Australia in 2006. The investigation was made in the precincts of Broken Hill Mine (lead, zinc, silver deposit) in the west part of New South Wales. Broken Hill Mine, which is one of the representative mineral deposits in Australia, is a stratabound sulfide deposit with country rock of sedimentary rock. The ore is made mainly of galena and zinc blend accompanied by copper pyrite and pyrrhotite. In the exploration, JOGMEC assumed the Broken Hill type as the exploration target, and SQUITEM was used to detect low resistance, which is the characteristic of Broken Hill deposit. The size of transmission loop was 200 m × 200 m and magnetic field was measured at the center of the transmission loop (measuring point). Measuring interval was 100 m but data was obtained at intervals of 50 m in hopeful areas.

Figure 3 shows profile curves by conventional electromagnetic exploration tool and SQUITEM. The profile curve is drawn by plotting measured values and measuring pints for measuring time. The abscissa axis is measuring point and the ordinate axis is measured value. It is seen in both SQUITEM and conventional equipment that a peak showing the existence of low resistance in underground appears in the area between 6464500N and 6465200N. Since the peak between 6464500N and 6464800N appears at an early time, it is indicated that the low resistance exists in a shallow part. On the other hand, since the peak in the range between 6464800N and 6465200N appears at a later time, it is indicated that the low resistance exists at a deep part. While profile curve obtained by conventional equipment showing the deep low resistance is disordered, reliable curve is obtained by SQUITEM. This fact indicates that SQUITEM has deeper exploration depth than conventional equipment.

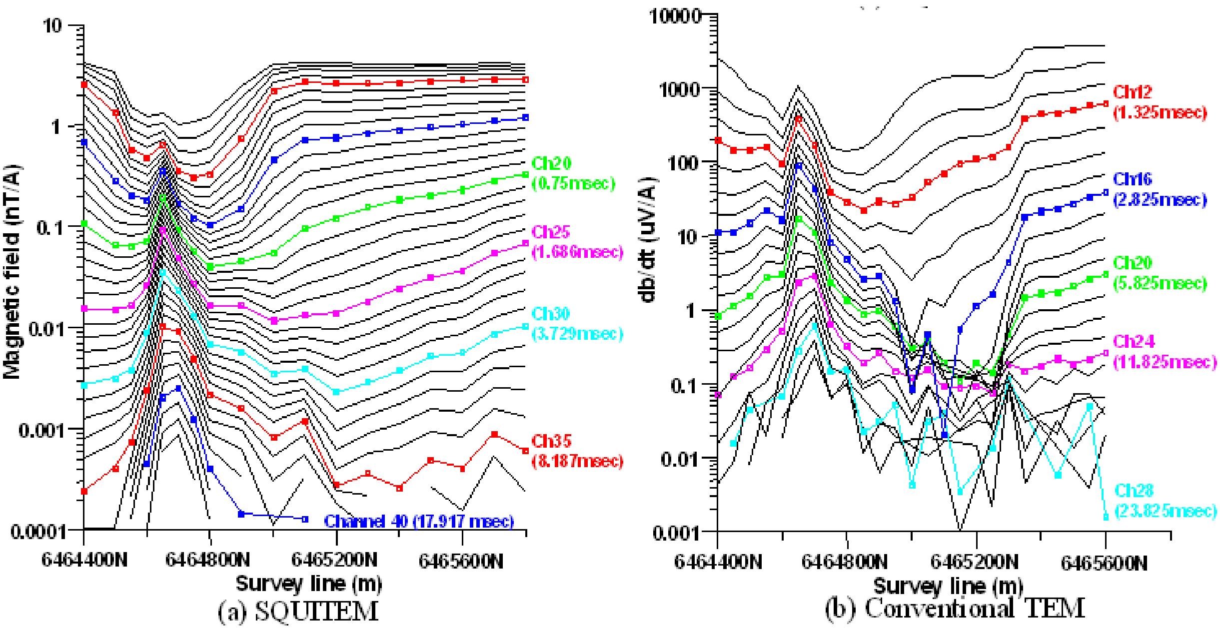


Fig. 3 Profile curves of SQUITEM (left) and conventional equipment (right)

Figure 4 shows the results of inversion relative to underground specific resistance (specific resistance distribution in underground) obtained by conventional equipment and SQUITEM. In the range between 6464500N and 6464800N where low specific resistance was predicted by profile curves obtained by both conventional equipment and SQUITEM, low specific resistance was obtained by the analysis of both

SQUITEM and conventional equipment. However, in the range between 6464800N and 6465200N, deep low specific resistance is reproduced by SQUITEM, but low specific resistance and high specific resistance are irregularly reproduced being mixed by conventional equipment. Two boring were drilled into the blind low specific resistance gently sloping to the right, which was indicated by the specific inversion of SQUITEM. Large amount of sulfide ore mainly consisting of pyrrhotite was captured at the depths between 250 and 260 m and depth of 343 m in the left side boring, and at the depth between 318 and 320 m and the depth between 350 and 360 m in the right side boring. These positions conform to those obtained by the analysis of low specific resistance data obtained by SQUITEM.

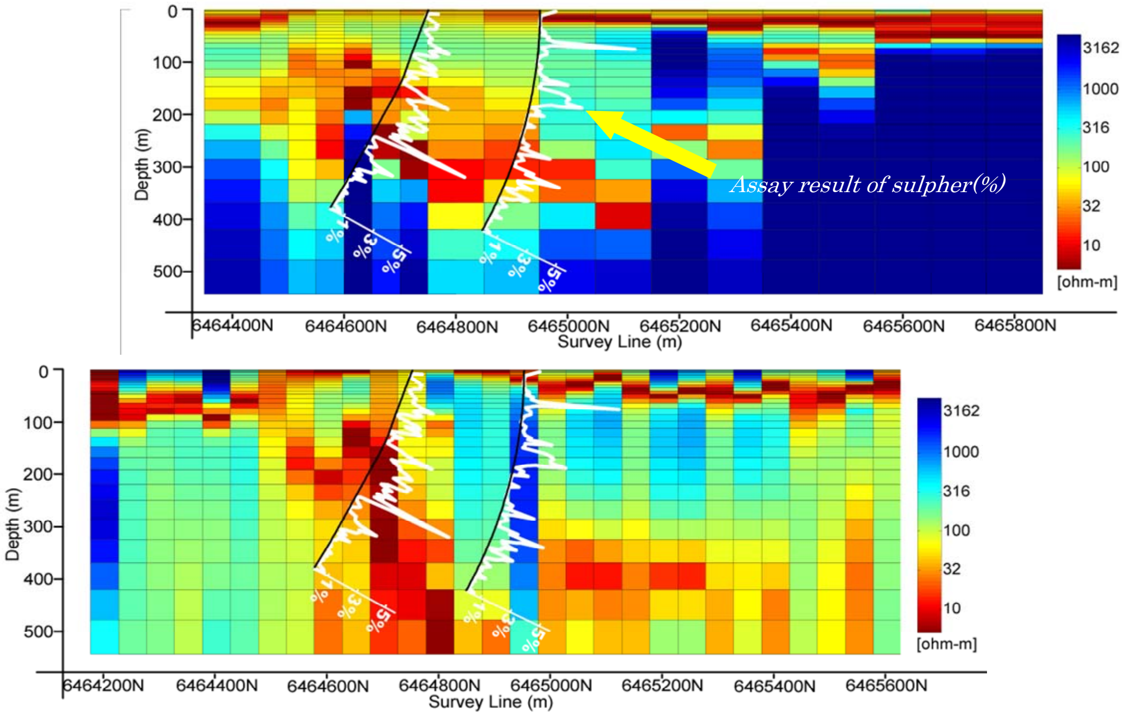


Fig. 4 Results of inversion of specific resistance obtained by SQUITEM (top) and conventional equipment (bottom)

4. Conclusion

In order to increase the exploration depth of electromagnetic exploration equipment widely used for metal resources exploration, JOGMEC developed SQUITEM using high-temperature SQUID as the magnetic sensor, and is using for the metal resources exploration implemented by JOGMEC. Since metal ore deposits are getting deep recently as mentioned at the beginning, development of electric and electromagnetic exploration technology that can be used in the region where the deposit is covered by low specific resistance layer is strongly desired. SQUITEM is the electromagnetic exploration equipment that realizes the request. We hope that the further application of SQUITEM to metal resources exploration implemented by JOGMEC contributes to the improvement of effectiveness and the success rate of exploration.

(Published in a Japanese version in the August 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Trend in diagnosis/inspection technology using SQUID - Present status of robotized mobile HTS-SQUID non-destructive inspection equipment -

Yoshimi Hatsukade, associate professor
Ecological Engineering
Toyohashi University of Technology

At present, SQUID magnetic sensor using high-temperature superconducting material (mainly $YBa_2Cu_3O_{7-x}$) is being used for applications such as magnet cardiogram and inspection of magnetic foreign materials utilizing the ultrahigh sensitivity. Furthermore, applications to immunological test and non-destructive test of materials and structures are being investigated. However, HTS-SQUID generally has a structure having bicrystal Josephson junctions prepared by depositing single layer high-temperature superconducting film on the bicrystal $SrTiO_3$ substrate. Therefore, it has a problem that the operation becomes unstable due to magnetic flux trap or magnetic flux jump even in a magnetic field smaller than 1 μT. This means that SQUID cannot be applied to active non-destructive test in which measurement is implemented by adding magnetic field without magnetic shielding.

Toyohashi University of Technology, therefore, developed an active noise cancelling technology that creates low magnetic field so that magnetic trap or magnetic jump does not occur when conventional HTS-SQUID gradiometer (gradient meter) with bicrystal Josephson junction is moved in an environment without magnetic shielding (Figure 1). A feedback circuit was developed and used to generate a space in which environmental magnetic noise is always reduced using flux-gate magnetometer, which operates stably even when magnetic noise of several tens of μT exists in the environment, and compensating coil. By installing HTS-SQUID gradiometer in this low magnetic field space, HTS-SQUID was successfully operated stably and transferred at the speed of 100 mm/s using a robot arm that generates magnetic noise of several μT.

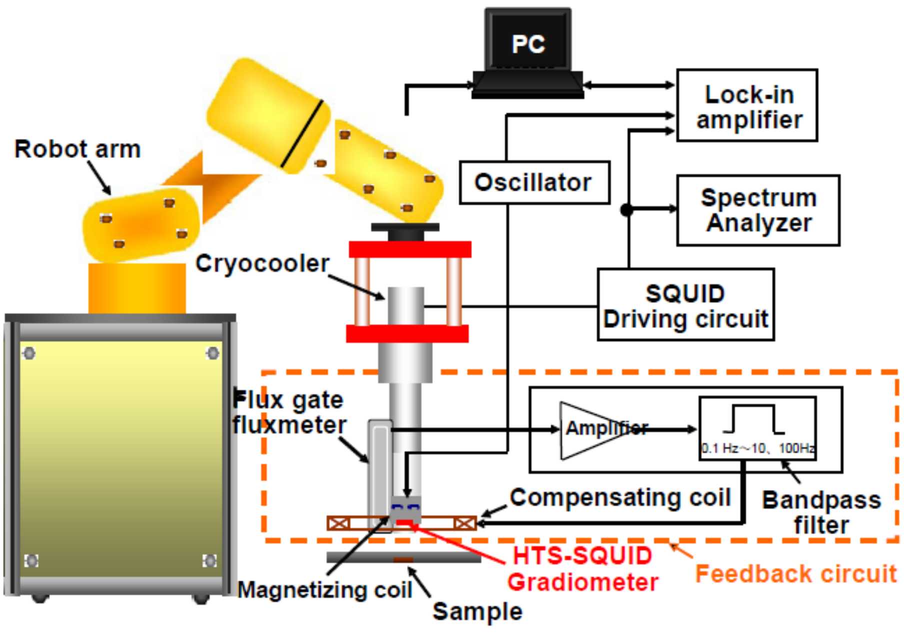


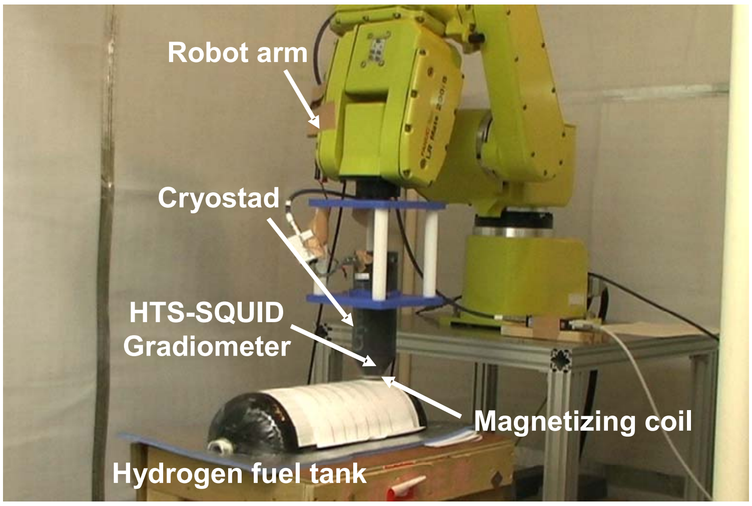
Fig. 1 Robotized SQUID non-destructive inspection equipment using the active noise cancelling technology

Fall, 2009 Date of Issue: October 15, 2009
超電導 Web21 Superconductivity
Superconductivity Web21
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Recently, Superconductivity Research Laboratory (SRL/ISTEC) has developed stacked HTS-SQUID using ramp-edge type Josephson junctions. In this SQUID, SmBCO and La-ErBCO with T_c of 87 K or more are used for the upper and lower films that compose ramp-edge junction. The maximum value of field modulation voltage, which indicates the performance of the developed SQUID was as large as 50 μV and excellent low noise characteristics (white noise level: 6 $\mu\phi_0/Hz^{1/2}$) was obtained when the equipment was cooled and used without magnetic shielding.

Stability of HTS-SQUID gradiometer having such ramp-edge type junctions was evaluated at the Toyohashi University of Technology. The equipment operates stably in an AC magnetic field of 1.5 mT, which is four to five orders larger than conventional HTS-SQUID gradiometer using bicrystal junctions, showing an excellent magnetic field robustness The reason for this high magnetic field robustness seems that firstly, no critical current-limiting crystal boundary junction exists in the pickup coil of ramp-edge type, which exists in that of bicrystal-type; secondly, magnetic trap and magnetic jump are suppressed in the SQUID ring with ramp-edge junctions because of the sandwich structure consisting of superconducting thin films covering the upper and lower sides of the barrier surfaces of the junctions. This robustness contributes to the excellent easy handling of the equipment because elimination of the trapped magnetic flux is rarely required even when ferromagnetic metals with residual magnetization are brought close to HTS-SQUID in unshielded environment.

At the Toyohashi University of Technology, we developed non-destructive inspection equipment, in which the HTS-SQUID gradiometer mounted on compact cryostat and integrated with a robot arm is movable in three dimensions (Figure 2, left). Due to the excellent magnetic field robustness of the ramp-edge type SQUID gradiometer, this equipment can move the SQUID in three-dimensions without using special magnetic shield technology at a speed of several tens of mm/s. This equipment was used for testing the detection of internal defects of hydrogen fuel tank mounted on the next-generation fuel car, and the effectiveness was verified. In this test, three-dimensional scanning was conducted with the SQUID along the cylindrical curved surface around the tank while low frequency exciting magnetic field of amplitude about 20 μT and 1 kHz was generated in the double-D type exciting coil installed directly below the SQUID. In the test, magnetic response to the crack with length of about 10 mm, which was generated within the tank by repeated high pressure, was successfully detected (Figure 2, right).



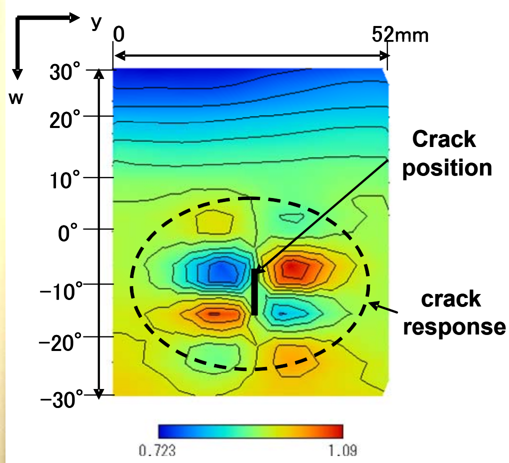


Fig. 2 Robotized SQUID non-destructive inspection equipment for inspecting hydrogen fuel tank(left) and result of crack detection (right)

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Thus, the mobilization of HTS-SQUID, which has been impossible under non-magnetic shielding environment, has become possible using a robot, which will result in the expansion of the range of objects, including advanced structures such as fuel tank. Therefore, it is expected that magnetic sensors and practical non-destructive inspection equipment for industrial use will be commercialized.

(Published in a Japanese version in the August 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Trend in diagnosis/inspection technology using SQUID
- Diagnose technology for railway rail by SQUID -

Yoshiki Miyazaki, Researcher
Cryogenic Systems Laboratory, Maglev Systems Technology Division
Railway Technical Research Institute

Railway rail often suffers from the generation of hard and brittle thermal transformation structure called white etching layer or white layer due to slipping and sliding of the wheels at the time of starting and braking of the vehicle. Micro cracks are expected to develop around the white layer and the developed Micro cracks may cause rail damage such as the separation of tread surface. The white layer is considered to cause such damage to the rail, and it is required to clarify the relationship between the white layer and cracks and damage.

http://www.rtri.or.jp/rd/openpublic/rd45/kouzou/research08/index.html

At present, white layers are observed intermittently by measuring the hardness and visual inspection but there is no measure to inspect continuously. Information on the continuous distribution of white layers will provide effective measures to investigate the correspondence between railway section information and generation status of white layers.

In this research, non-destructive inspection of white layers using superconducting quantum interference device (SQUID) is being studied, and it has been reported that white layer actually generated on the rail by the travel of trains can be detected using the SQUID (Superconductivity Web21, August 2008). Figure 1 shows the measuring circuit. The principle of this method is the eddy current technique, in which when the eddy current distribution generated in the specimen by two exciting coils becomes inhomogeneous at the defective point of the specimen the difference is measured by the SQUID as the magnetic field generated by the eddy current.

Figure 2 shows the results of measurement of white layer generated in actual rail. Circled domains A and B are corresponding to the white layer in Figure 2. Signals at these domains are strengthened compared with those at other domains. So, white layers well conform to the measuring signals. It seems that the change in the signal corresponds to the change in physical properties (magnetic permeability and specific resistance) due to the change in structure (martensitic transformation)

http://www.rtri.or.jp/rd/openpublic/rd77/CS/cs_1.7.html

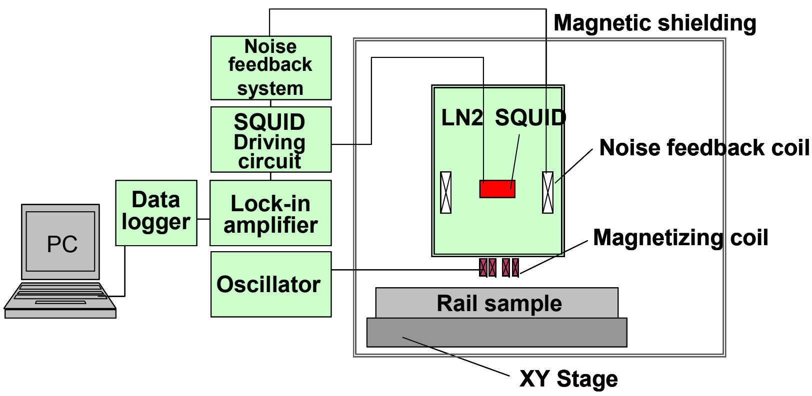
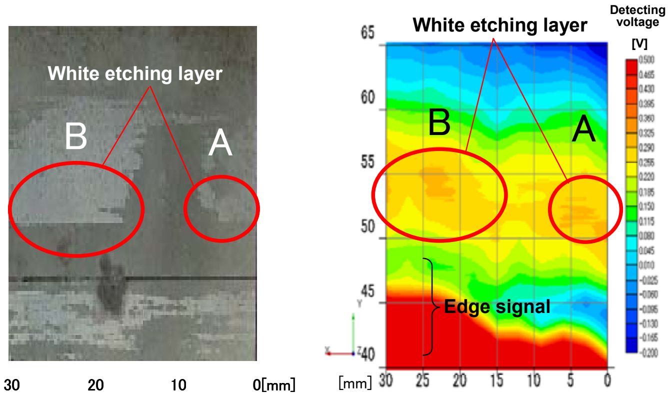


Fig. 1 Measuring circuit

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318



Measuring sample (actual rail)

Two-dimensional contour diagram for induced magnetic-field intensity

Fig. 2 Measurement results of white layer

In the measuring circuit in Figure 1, magnetic noise is prevented using magnetic shielding and the rail is demagnetized to reduce the residual magnetism since the rail being measured is ferromagnetic. To remove the effect of residual magnetism that cannot be completely eliminated from the rail, the low frequency signal of the SQUID output is fed back to the noise feedback coil in order to compensate the noise.

However, measuring rails in the field is difficult to construct a system that covers whole rail with shielding, and pretreatment such as the demagnetization of the rail is undesirable because the inspection time is prolonged. Therefore, the circuit was improved as shown in Figure 3 for the field measurement. Only the detection probe comprising the bridge circuit is brought close to the rail and the SQUID obtains the signal from impute coil. In this system, the SQUID can be placed away from the rail and completely shielded from magnetic noise so that the measuring system becomes stable without being affected by the residual magnetization. Furthermore, the feedback circuit was stabilized by adding a signal phase compensator. Thus, the noise resistance was improved by about 30–40 dB providing a measuring system that is resistant to noise.

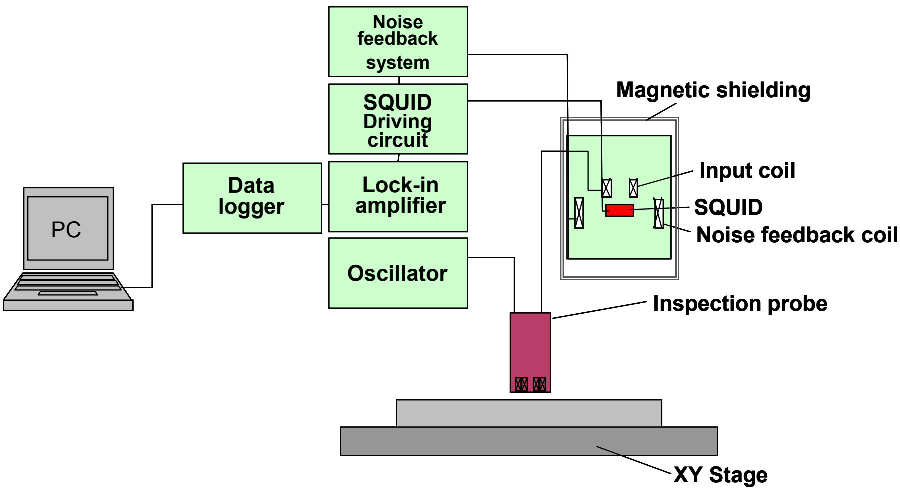


Fig. 3 Improved measuring circuit

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Test piece of the artificial white layer 4-mm wide and 5-μm thick prepared by laser processing was placed on X-Y stage and the inspection probe was placed so that the distance from the test piece was 1 mm. While the inspection probe is fixed, X-Y stage was moved at a speed of 5 mm/s relative to the artificial white layer for measuring by the abovementioned measuring system. The eddy current signal was obtained as the SQUID output and the phase difference between the signal and exciting signal was compared with lock-in amplifier. Figure 4 shows the results of phase difference measurements. It is seen that phase difference is clearly obtained when the probe passes by the position of the artificial white layer. Now auto-measuring equipment that runs at a speed of 5 mm/sec ~70 mm/sec on the rail with stepping motor has been made and field test is being made.

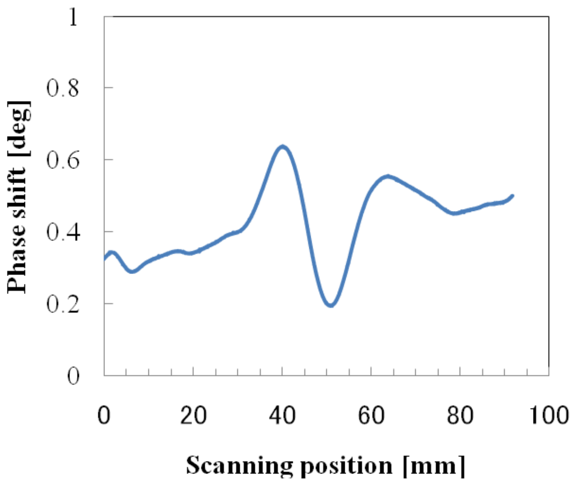


Fig. 4 Measurement results of test piece of the artificial white layer

(Published in a Japanese version in the August 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Trend in diagnosis/inspection technology using SQUID - Present status of Magnetoencephalograph -

Kunio Kazami
MEG Gr. Development Team, Bioanalytical Center
Yokogawa Electric Corporation

Information is transferred by electrical activity of nerve cells in the brain. This electrical activity generates electric current inside and outside of the nerve cells. Since the intracellular current due to excitatory synaptic potential is relatively large current and has long duration, it is considered to be the main source of the generation of magnetic field (neuromagnetic field) (Figure 1). Although neuromagnetic field is extremely weak (10^{-12}~10^{-13} Tesla, less than one-billionth of geomagnetism), it can be measured by magnetoencephalograph (MEG) (Figure 2).

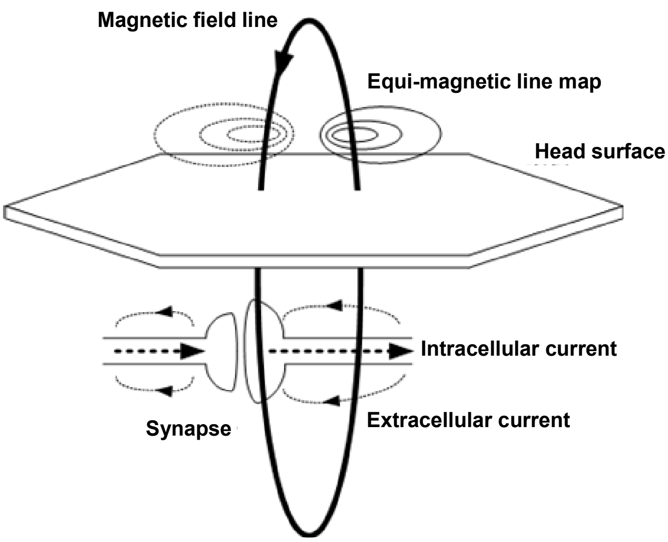


Fig. 1 Mechanism of the generation of neuromagnetic field

MEG has SQUID fluxmeter, which is a superconducting device with a sensitivity of 10^{-14} Tesla or less and includes a dewar filled with helium inside. Neuromagnetic field is measured by inserting the head of the examinee into the concave portion of the dewar. Since extremely weak magnetic field is measured, measures against noise such as installation of dewar in a magnetic shielding room are required.

Since the magnetic permeability of brain and cerebral fluid is almost equal to the space permeability, neuromagnetic measurement is rarely affected by body tissue so that brain activities are captured with high spatial resolution. In addition to the quick response of SQUID fluxmeter, the completely non-penetrating characteristic attracts the attention in brain function diagnosis and brain science research

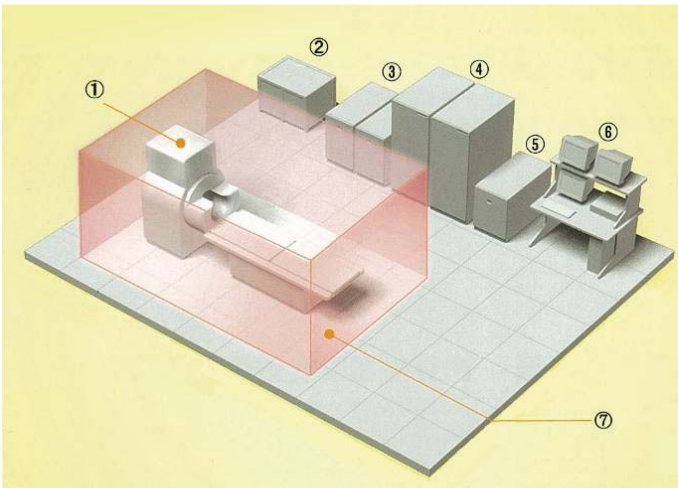


Fig. 2 Biomagnetism measuring device (① Dewar, ② Electronics part, ③ DC power source, ④Computer for recording, ⑤ AC power source, ⑥Computer for control, and ⑦ Magnetic shielded chamber)

Recently, it is desired to establish diagnosis using MEG in wide range of applications, including dementia including Alzheimer's, developmental disorder of infant (autism

Fall, 2009 Date of Issue: October 15, 2009
Superconductivity Web21
Superconductivity
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

disorder), and cerebral ischemia. For this reason, new analysis technology for MEG data and noise reduction methods for easier handling are being developed. In addition, multi-modality with functional images such as brain waves and functional magnetic resonance imaging (fMRI) is attracting attention for the purpose of capturing from various angles. Figure 3 shows an example of magnetoencephalographic analysis using spacial filter method, which is attracting attention recently. This is a projection of MRI image assuming the active positions based on the magnetoencephalographic data of auditory evoked magnetic field (AEF) due to click sound to the left ear, which showed that both right and left auditory areas become active by the sound stimulation to the left ear. Furthermore, helium recovery system has been developed to reduce the operation cost, which was the problem for the practical application of MEG for a long time and the equipment is being commercially used so that the expansion of use in the medical field is expected.

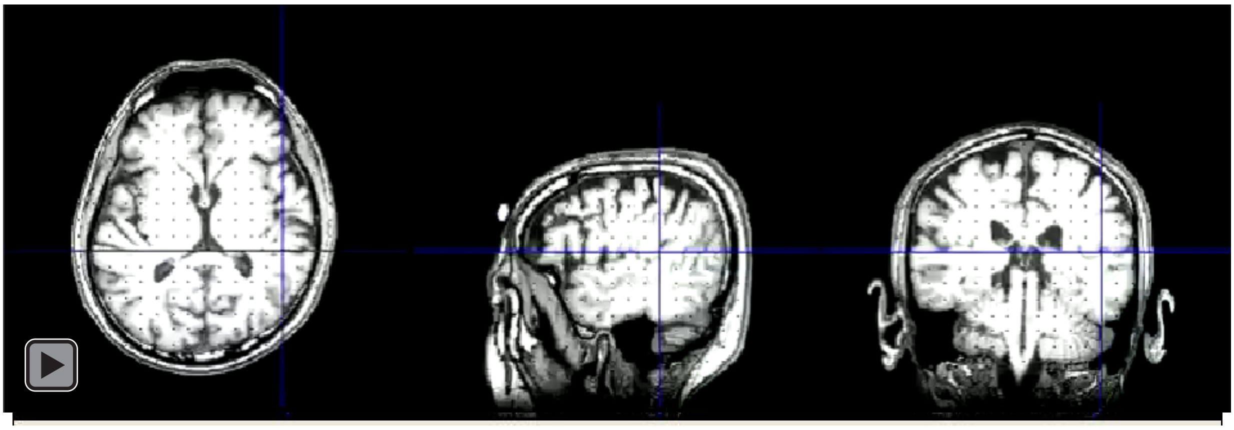


Fig. 3 Examples of signal source estimation for magnetoencephalographic data of auditory evoked magnetic field (AEF) using sLORETAspace filter (animated image)

(When the animated image does not move, please download QuickTime.)
http://www.apple.com/jp/quicktime/download/index.html

(Published in a Japanese version in the August 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

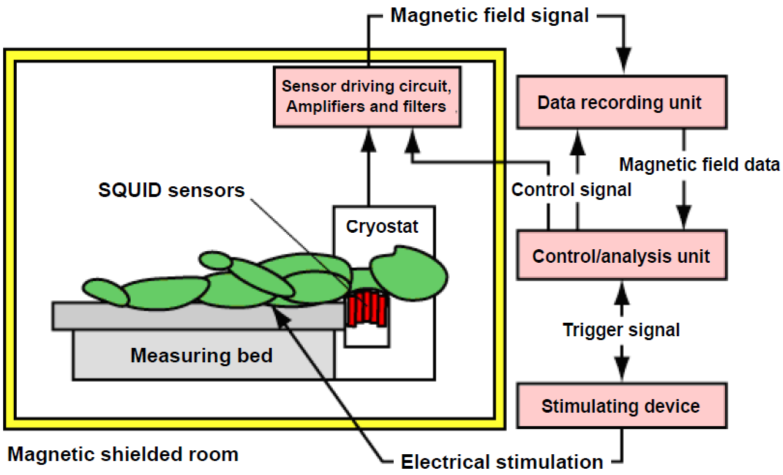
Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Feature Article: Trend in diagnosis/inspection technology using SQUID - Progress in technology for the measurement of spinal cord evoked magnetic field by SQUID magnetometers -

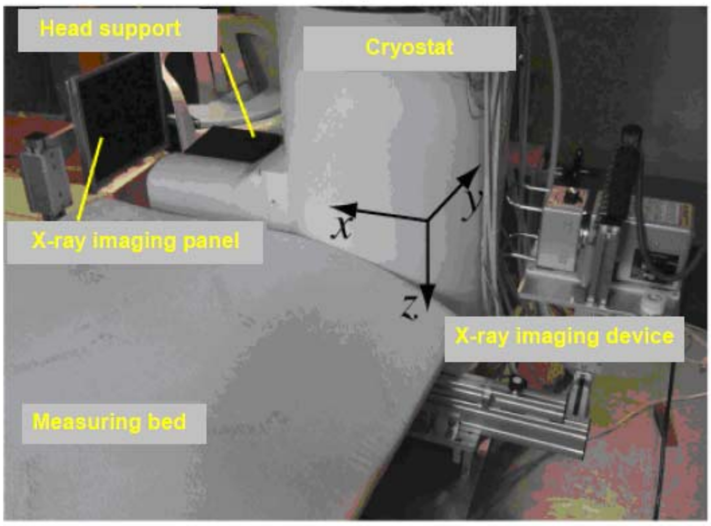
Yoshiaki Adachi, Associate Professor
Applied Electronics Laboratory
Kanazawa Institute of Technology

Magnetoencephalograph, which detects the weak magnetic field accompanying the brain nervous activities with SQUID magnetometers arranged around the head to observe the cerebral activities, is being used for research on brain functions, diagnosis of epilepsy at medical institutions, pre-surgery mapping, etc. for a long time since the commercialization of the equipment. We are developing a device that detects the weak magnetic field accompanying nervous activities of spinal cord at the cervical region to investigate the functions of the spinal cord. Many symptoms such as paralysis and numbness are caused by injurious compression and the causes can be clarified non-invasively by magnetic field measurement. The measurement of magnetic field evoked by the spinal cord is significantly attracting expectation and concern in the field of orthopedic surgery and neurology since such examination has not been possible.

Figure 1 (a) shows the configuration of the measuring system of magnetic field evoked by spinal cord. A new cryostat with a special shape has been developed so that the cervical region of the patient lying on his/her back is inspected from the backside. The cryostat has a structure in which the sensor holder protrudes from the side of the cylindrical main body. The sensor array is arranged along the upper surface of the sensor holder, and the patient places the



(a)



(b)

Fig. 1 System configuration (a) and appearance (b) backside of neck on the surface so that the magnetic field strength that can be detected stably. The source of spiral cord magnetic field is positioned 60–70-mm deep from the body surface, and the strength of magnetic field detected outside the body is 10 fT or less. For this reason, the distance between low temperature and room temperature is set 7 mm or less so that the sensor approaches the magnetic field source as close as possible. Since the measuring area at the neck is narrower than that at the brain and heart, vector SQUID gradiometers[1),2)] are used so that sufficient information on magnetic field is collected from a narrow observation area. Figure 1 (b) shows the appearance of the system.

The developed measuring system was applied to healthy test subjects to measure the spinal cord magnetic field. The evoked magnetic field was measured at the neck by stimulating the peripheral nerve at the left wrist of a test subject lying on the back with repeated current pulse. An example of magnetic field distribution is shown in Figure 2 and Animated image 1. Characteristic magnetic field distribution pattern appears about 10 ms after the stimulation. As shown by the arrows in Figure 3, the magnetic field distribution pattern includes a component toward the head along the spinal cord.

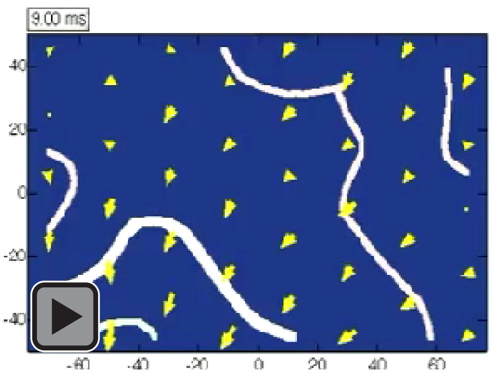
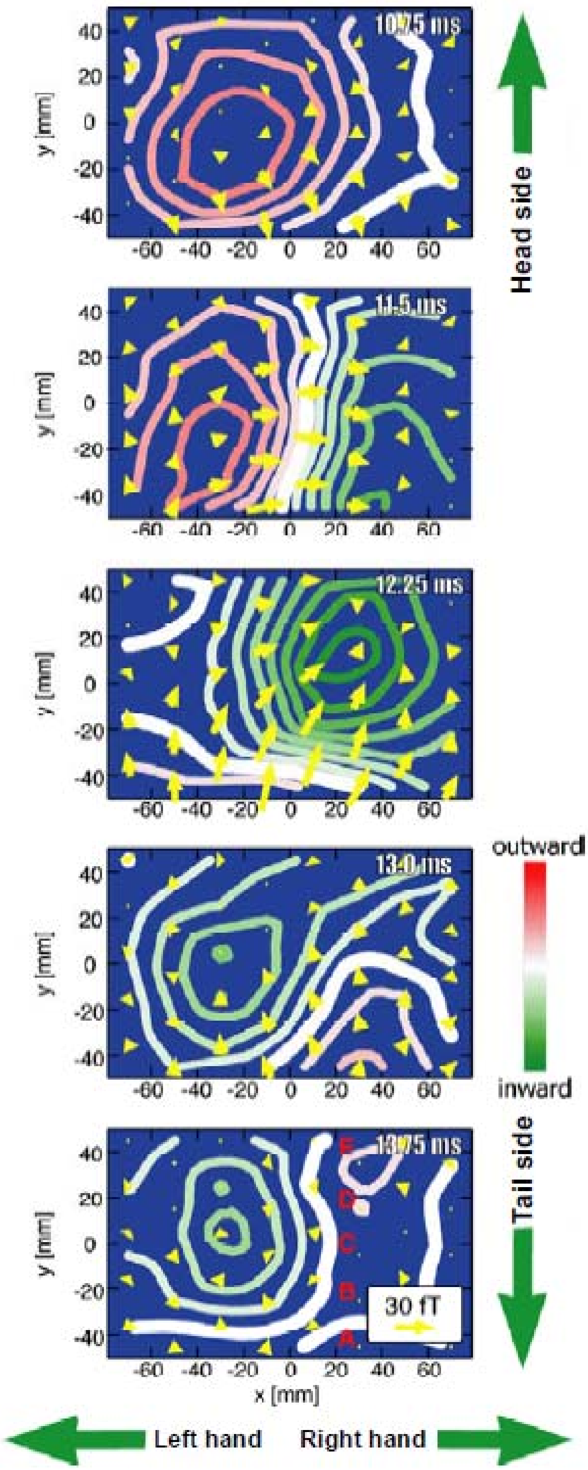


Fig. 2 Animated image 1
Example of measurement of peripheral nerve stimulated spinal cord evoked magnetic field (Animated image)
(When the animated image does not move, please download QuickTime.)
http://www.apple.com/jp/quicktime/download/index.html



The developed prototype is now installed at Section of Orthopedic and Spinal Surgery of Tokyo Medical and Dental University. More than 100 patients have been tested and effective data on diagnosis have been obtained for 90 % of them. The practical value of the measuring system has been verified. We would like to complete the commercialization of spinal cord evoked magnetic field measuring equipment as the third pillar of SQUID biomagnetic measurement following the magnetoencephalography and magnetocardiography.

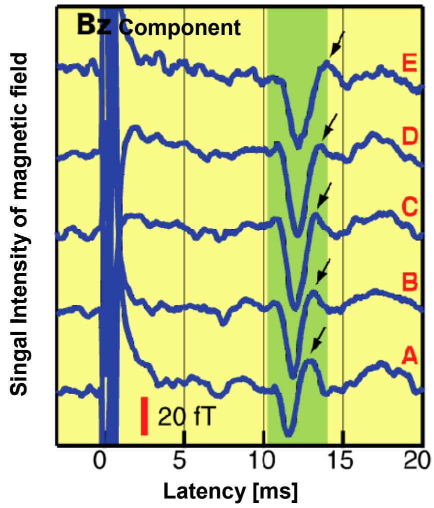


Fig. 3 Waveform of spinal cord evoked magnetic field signal

Magnetic field signal, Sensor driving circuit, Amplification, Filter circuit, Data recording unit, Control/analysis unit, Stimulating device, Electrical stimulation, SQUID fluxmeter array, Cryogenic vessel, Measuring bed, Control signal, Magnetic field data, Trigger signal, Magnetic shielded camber, Head fixing table, X-ray imaging panel, and X-ray imaging device

Reference :

1) A. Kandori *et al*., "A vector fetal magnetocardiogram system with high sensitivity", Rev. Sci. Instrum., vol. 70, pp. 4702-4705, 1999.

2) Y. Adachi *et al*., "Three dimensionally configured SQUID vector gradiometer for biomagnetic measurement", Supercond. Sci. Technol., vol. 16, pp. 1442-1446, 2003.

(Published in a Japanese version in the August 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Fall, 2009 Date of Issue: October 15, 2009

Superconductivity Web21

Superconductivity

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan T el: +81-3-3536-7283, Fax: +81-3-3536-7318

Patent information

Ichiro Nagano, Associate Director
Planning & Management Division, SRL/ISTEC

Published Unexamined Patents in the 1st Quarter of Fiscal 2009.

The following are ISTEC's patents published from April through June 2009. For more information, access the homepage of Japan Patent Office and visit the Industrial Property Digital Library (IPDL).

1) Publication number 2009-111306 "Electronic d evice with Josephson junction and the method of manufacturing the same"

This patent relates to a method to manufacture Josephson junctions with small dispersion in characteristics on the same substrate. This patent suppresses the deviation of critical current, which depends on the status of the connection of niobium electrodes, i.e. the pattern from the design value so that large-scale, high-performance Josephson junction LSI is produced.

It is necessary for highly integrated electronic devices that the dispersion of characteristics of constituent elements is restricted within a certain range. For Josephson devices, a manufacturing process that limits the dispersion of critical current at the Josephson junction within the permissible range is required.
In the past, one of the largest factors that arises the dispersion was considered to be the etching so that the plasma etching technology that have been investigated as a measure to reduce the wide dispersion of critical current. However, a phenomenon in which only a few junctions significantly deviate from the average critical current value has been reported in certain literatures, which is now considered to be a more serious problem for realizing large-scale integrated circuit.

The inventors of the patent observed and investigated the latter phenomenon and found that the basic reason for the dispersion of critical current was the generation of local concentration difference in the element due to the incorporation of hydrogen into the niobium electrode material. Since the superconductivity characteristics of niobium electrode vary with hydrogen content, the fluctuation of contaminant hydrogen directly causes the fluctuation of superconducting critical current. The concentration of contaminant hydrogen depends not only on the film-formation equipment and the status of use but also on other processing conditions and the status of niobium electrode connection (pattern dependency) because hydrogen may be absorbed into or emitted from the niobium electrodes, which makes the process very complex and appear complicated.

While hydrogen migrates in niobium at room temperature, it can rarely migrate in aluminum, molybdenum, tungsten, their nitride, and niobium nitride. However, hydrogen migrates easily in palladium, platinum, and titanium. Utilizing this characteristic, it is possible to take measures to homogenize hydrogen concentration in niobium.

Figure 1 shows an example of the cross-sectional drawing of superconducting Josephson device to which the present invention is effectively applied. 1 is silicon substrate, 2 is insulation film of thermally

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

oxidized silicon, and 3 is insulation films for each layer formed by SiO_2 using sputtering, Nb (indicated by Nb_{11}, Nb_{31}, etc., in Figure 1) is niobium layer of superconducting interconnection, Al_2O_3 is aluminum oxide layer, and Mo is molybdenum layer.

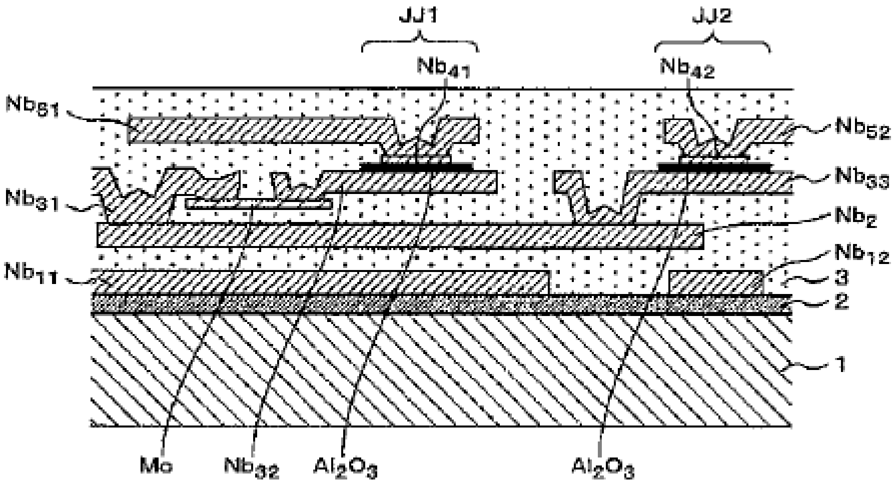


Fig. 1 Cross-sectional drawing of superconducting Josephson device

(Published in a Japanese version in the August 2009 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21