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Contents:

超電導 Web21 Superconductivity

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Standardization Activities

- Topics in August

  Masato Murakami, Vice-President of Shibaura Institute of Technology, received Chairperson Award of IEC-APC

- Topics in September

  The 8th panel discussion on the international standardization of superconductivity technology

Top of Superconductivity Web21

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Top of Superconductivity Web21: http://www.istec.or.jp/Web21/ Web21-E.html

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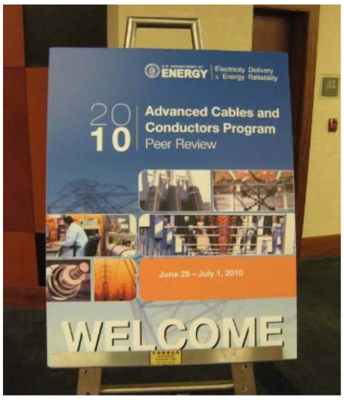
DOE Peer Review 2010 (June 29 – July 1, 2010)

Makoto Yamamoto
Planning & Management Division
SRL/ ISTEC



Welcome board

Advanced Cables and Conductors Program Peer Review, hosted by United States Department of Energy (DOE), was held for three days from June 29 to July 1 at The Westin Alexandria, where the same conference was held last year. Although the Peer Review is held once a year in Washington DC between the end of July and the beginning of August, it was held about one month earlier this year.

In the Peer Review, the results of research and development in the past one year in the field of HTS, which is funded by DOE, are reported, and future plans are proposed, the evaluation of which is reflected in budgeting of future research plans.

Participants of 141 registered for the Peer Review and total number of reports for the sessions were 31, which were somewhat fewer than those in the last year.

As in the case of last year, three sessions—"2nd GENERATION WIRE SESSION," "STRATEGIC RESEARCH SESSION," and "SUPERCONDUCTIVITY APPLICATIONS SESSION"—were held separately in parallel.

The following are outlines of the three sessions.

In "2nd GENERATION WIRE SESSION," SuperPower reported that the technical cooperation with the University of Houston was arranged, and the effects of Y: Gd ratio on the characteristics in the magnetic field other than "length + I_c" were studied. It was also reported that the improvement of I_c in the magnetic field using long sample was attempted so that the characteristics at 3 T was increased from 14–15 A to 20 A. AMSC reported that the characteristics was improved by using clad substrate for decreasing the FM loss. It was also reported that about 460 A/cm-width (short sample) was obtained by improving I_c of single coating with increased single-coated film.

In "STRATEGIC RESEARCH SESSION," ORNL reported on the mechanical strength of the wire developed by them in which a superconducting layer is formed around Al_2O_3 single crystal wire. The wire material has a Young's modulus 1.5 times higher than that of hastelloy (310 GPa) and a very high fracture strength of 1508 MPa and is promising as a wire material. The film-forming technology that is attracting attention as a substrate planarizing technology in which a bed layer is formed by MOD, Ra < 2 nm was achieved for 4-layer film formed on non-polished hastelloy, and high-speed film forming at 60 m/h also succeeded. LANL reported several achievements in IBAD and peripheral technology, and a new idea about in-plane oriented crystal growth mechanism was proposed.

In "SUPERCONDUCTIVITY APPLICATIONS SESSION," reports were presented on HTS power cable, fault current limiter, transformer, etc.

Relating to power cable, AMSC, Nexans, and Air Liquide reported on the operation status of single-core cable (600 m, 138 kV, 2.4 kA) of LIPA Holbrook Substation in Long Island, New York, and development status of the cables using Y-based wires. Southwire and ORNL reported on the operation status of Tri-axial cable (200 m, 13.2 kV, 3 kA) of Bixby Substation of AEP in Columbus, Ohio, and the termination of funding by DOE. As to the plan to install Tri-axial cable (1.76 km, 13.8 kV, 2 kA) between Labarre Substation and

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Metairie Substation of Entergy in New Orleans, Louisiana, it was reported that the installation was canceled, and the project was delayed due to the slowing of increase in the demand for supply on the planned site. Information on the progress in the Tri-axial cable (300 m, 13.8 kV, 4 kA) using Y-based wires of Project Hydra , which is planned in Manhattan, New York sponsored by Department of Holmeland Security (DHS) was not given this time.

Regarding fault current limiter, Zenergy proposed a plan to install 3-phase FCL of 138 kV at Tidd Substation of AEP in Brilliant, Ohio. AEP has already agreed to host the installation of FCL, and the operation is aimed to start in 2012. AMSC, Siemens, Nexans, and SCE reported on the present status and research and development plan for 3-phase FCL system of 115 kV–138 kV which is planned to be installed and operated at a substation of SCE. At present, the development is focused on the fabrication and testing of a single-phase to validate FCL system design.

As for transformers, ORNL and WES explained the outline of a transformer of 28 MVA -70.5 kV/12.47 kV provided with FCL which is scheduled to be installed at MacArthur Substation of SCE in Irvine, California as a smart grid regional demonstration project. It is scheduled to start conceptual design and wire development.

Scene of conference room (first day)

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Top of Superconductivity Web21

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Accomplishment report session of NEDO on technical development of new energies 2010

New Energy and Industrial Technology Development Organization (NEDO) held Accomplishment report session of NEDO on technical development of new energies 2010, at Tokyo International Forum from July 27 (Tue) to July 28 (Wed). The poster session for superconductivity was held between 13:40–15:00 on July 27 (Tue) and the oral session was held between 15:00–16:00 on the same day.

In the oral session, the following reports were presented on the three projects of "Technological development of Y-based superconducting power equipment," "High-temperature superconductor cable verification project," and "Development of Y-based composite material for light weight motors with high performance."

Scene of lecture by Yuh Shiohara

Yuh Shiohara, Director General, SRL/ISETEC, gave a lecture titled "Contribution of the technical development of superconductivity to environment and energy - Technological development of Y-based superconducting power equipment." He pointed out that the superconductivity technology is important for the reduction of CO_2 and reported on the latest accomplishments of SMES, superconducting power cable, superconducting transformer, and Y-based superconducting wire, which are being developed under this project.

In the lecture entitled "High-temperature superconductor cable verification project," Tsukushi Hara, fellow of Tokyo Electric Power Company, reported on the merits of high-temperature superconducting cable, the outline of the project of "three-phase" Bi-based superconductivity power cable of 66 kV, 200 MVA, progress in advance verification (long-term rated current-voltage loading test) of 30-m cable, and future development for commercialization.

Scene of lecture by Tsukushi Hara

Teruo Izumi, special researcher of Industrial Superconductivity Technology Research Association (ISTERA), commented, in his lecture titled "Development of Y-based composite material for light weight motors with high performance (Rare metal substitute materials development project)," on the possibility of electromagnet using Y-based superconducting wires in stead of Nd-Fe-B permanent magnet containing Dy, and introduced the long Y-based superconducting wires longer than 1 km, improvement of raw material yield ratio making use of laser CVD and YAG laser PLD, and downsizing of umbrella-type coil.

In the poster session, the following results were reported as the accomplishments of the three projects of "Technological development of Y-based superconducting power equipment," "High-temperature superconductor cable verification project," "Development of Y-based composite material for light weight motors with high performance." Furthermore, products of Y-based superconducting wires and superconducting cables were exhibited and opinions were exchanged actively.

Relating to the project of "Technological development of Y-based superconducting power equipment ," in the poster session, Chubu Electric Power Co. reported on "Research and development of superconducting electric power storage system (SMES)," Kyushu Electric Power Co. reported on "Development of

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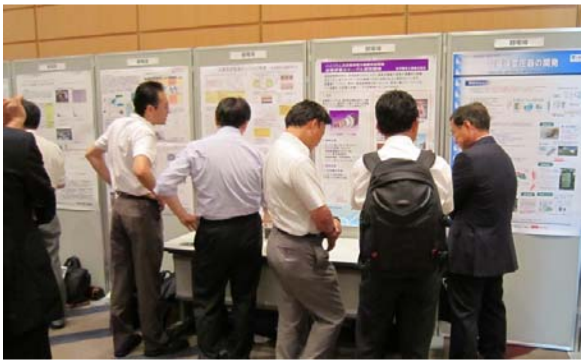
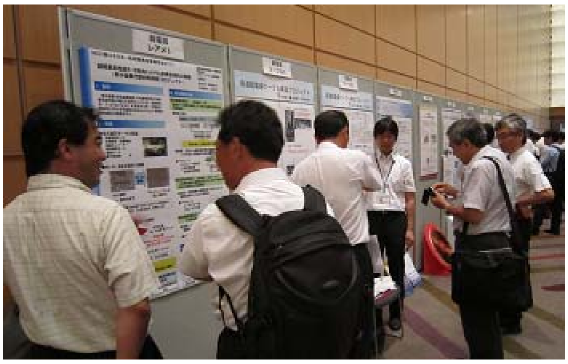
superconducting transformers," Taiyo Nippon Sanso Corporation reported on "Technical development of cooling system," Furukawa Electric Co. reported on "Research and development of superconducting cables," Sumitomo Electric Industries Ltd. reported on "development of large-current superconducting cables," Mayekawa Mfg. Co. reported on "Cooling technology using slash nitrogen," ISTEC reported on "Technical development of Y-based superconducting power equipments," Fujikura Ltd. reported on "Technical development of stable manufacturing of superconducting wires for transformers," Showa Electric Wire and Cable Co. reported on "Next-generation Y-based superconducting wire developed by Showa Electric Wire and Cable Co.," and Fine Ceramics Center reported on "Three-dimensional analysis of MOD-$YBa_2CuO_3O_y$ superconducting layers using FIB-SEM dual beam."

Relating to the project of "High-temperature superconductor cable verification project," Tokyo Electric Power Company, Sumitomo Electric Industries Ltd., and Mayekawa Mfg. Co. reported on the results of verification test for 30-m cable as a latest achievement in the development of three-phase cable of 250-m class using Bi-based superconducting wires.

Relating to the project of "Development of Y-based composite material for light weight motors with high performance," ISTERA (ISTEC, Fujikura Ltd., and Showa Electric Wire and Cable), Tohoku University, Waseda University, Nagoya University, and Kyushu University reported on the progress of the development of long superconducting wire exceeding 1 km, the technical development for improving efficiency utilizing laser CVD and YAG laser PLD, and the development of elemental technology for rotating equipments.





Scenery of poster session

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011
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Technical development of the world's first HTS power tansformer using Y-based superconducting wire

- Verification of short-circuit performance and current limiting function using transformer winding - Significant progress toward practical use and new functional advancement of HTS transformers

Hidemi Hayashi, Group Leader
Power Storage Engineering Group, Research Laboratory
Kyushu Electric Power Co., Inc.

Kyushu Electric Power Co. is working on superconductivity technology as the one that provides flexible measures to cope with the impact on electric power system due to the increase in electricity demand and the introduction of renewable energy and to contribute to the low-carbon society. In particular, HTS transformers are being developed. Recently, a HTS power transformer using Y-based superconducting wire (GdBCO, etc.) (after this ; Y-based transformer) was developed for the first time in the "Development of Y-based transformer," a part of the "Technical development of Y-based HTS power equipments[1)]" relegated by New Energy and Industrial Technology Development Organization (NEDO) in cooperation with Kyushu University, International Superconductivity Technology Center, Fujikura Ltd., and SWCC Showa Cable Systems Co. Using the transformer, the short-circuit performance as well as the limiting function[2)], which is a new function of HTS transformers, was verified for the first time in the world.

The use of superconducting wires makes transformers smaller and more efficient. In particular, early commercialization of Y-based transformers is desired since its critical current is large and it enables loss reduction using thin wires and lower cost in the future. Especially in distribution transformers (66/6.9 kV-20 MVA), the weight of the Y-based transformers is expected to be reduced by 1/2 and volume by 2/3, and loss by 1/6 compared to the conventional oil-immersed transformers.

The results of the test promise a significant advancement in practical use the commercialization of Y-based transformer,Y-based transformers with a hope for the practical use of "Y-based transformer provided with fault current limiting (after this ; FCL) function[3)]," which enables to suppress the accident current and is effective for lowering and suppressing the momentary voltage drop.

1. Verification of short-circuit performance of Y-based superconducting transformer

The short-circuit performance of the Y-based transformer, (400 kVA) that endures short-circuit current that occurs accidently in electric power system, and the strong electromagnetic force accompanied by the large short-circuit current was verified. As the measures for the transformer to cope with the short-circuit occurrence, the following elements were uniquely adopted: ① the capacity was set to 400 kVA (about 1/50 of the practical transformer), which corresponds to the minimum capacity that can be verified using 20 MVA commercial transformer, and the short-circuit current and electromagnetic force were set to 398 A, which is comparable to those of commercial transformer; ② the original stabilized layer consisting of silver and copper was applied to the Y-based wires; ③ original transposition (wires are aligned alternately) was applied to the (three-layer) secondary wire winding to homogenize the current (Fig. 1).
The voltage (primary/secondary) and current of the practical transformer were 66 kV/6.9 kV and 175 A/1674 A, respectively, and the wire consisted of 3 pieces/24 pieces. The voltage and current of the HTS

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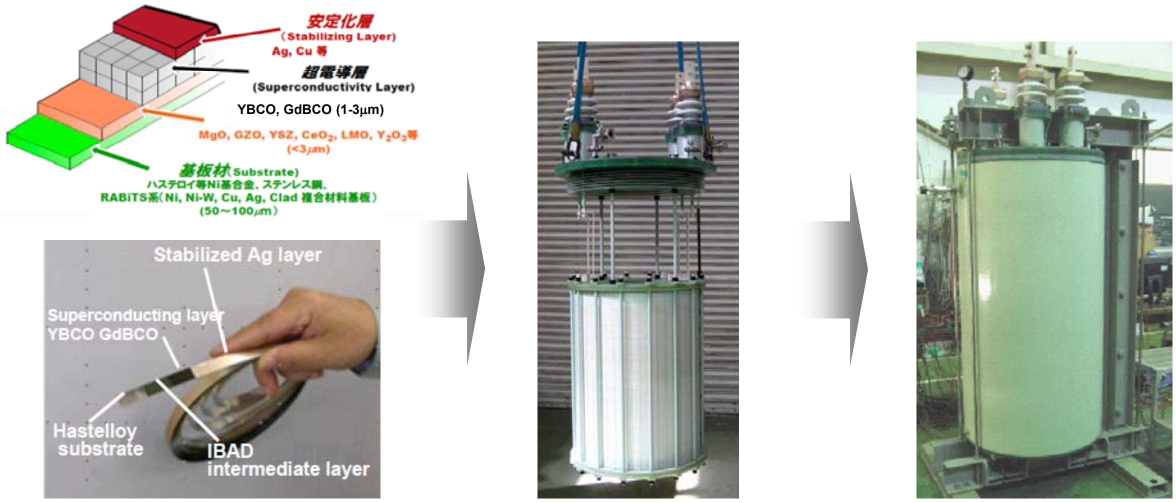
transformer was 6.9 kV/2.3 kV and 58 A/174 A, respectively, and the wire consisted of 1 piece/24 piece.



Y-based superconducting wire

Appearance of winding wire
(φ565 mm, H810 mm)

Appearance of transformer
(inside is cooled by liquid nitrogen)
(φ738 mm, H 2300 mm)

Fig. 1 Y-based superconducting transformer (400 kVA)

To verify the technical measures for short-circuit, short-circuit test was conducted by cooling the transformer to subcool-liquid-nitrogen temperature (−207°C) and applying a voltage of 6.9 kV for 0.2 s. A desired result was obtained at a short circuit current of 1040 A (about 6 times the rated current of 174 A) (Fig.2). The values of the impedance measured before and after the tests were comparable with each other, which confirmed that the winding was sound after the test (Fig.3).

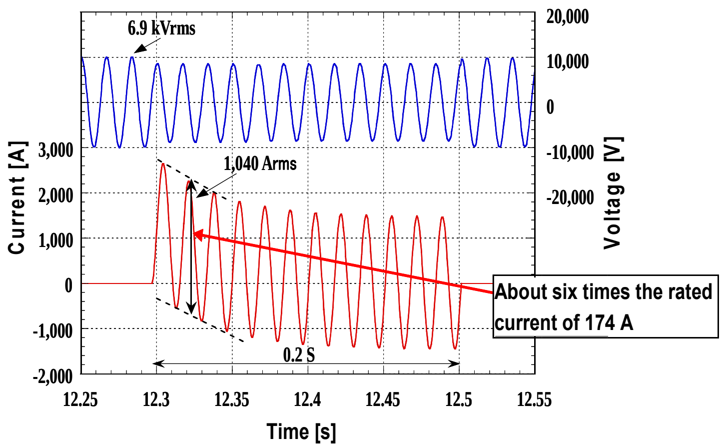


Fig.2 The results of the short-circuit test

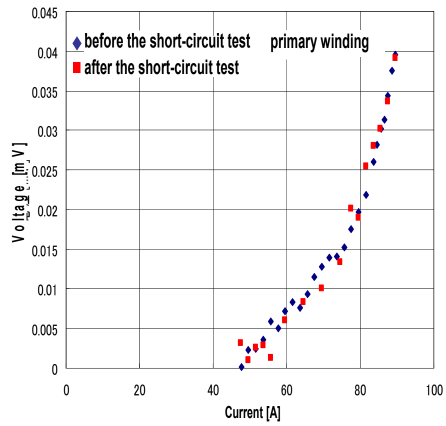


Fig. 3 The winding characteristics before and after the short-circuit test

2. Verification of fault current limiting function (new function) of Y-based small transformer

Current limiting function, which is a new function of the HTS transformer, was verified using a winding of the Y-based transformer (10 kVA) provided with a FCL function. Although the transformer is normally used as a conventional transformer, it was verified that it exhibits a function as a FCL that suppresses the accident

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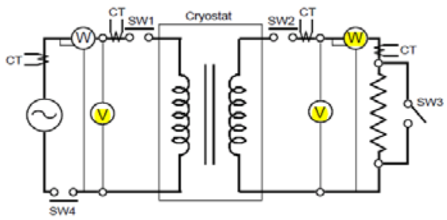
current and voltage drops because of the instantaneous transformation of the superconducting winding wires into a normal conductor (current resistance occurs) as a result of the accident current (large current).

The elements of the FCL technology are: ① the transformer endures short-circuit load in accident while it normally acts as a transformer; ② the mechanism in which accident current is suppressed by the transformation of the superconducting winding wire of the transformer to normal conductor (generation of resistance) was theoretically analyzed, and the winding condition was uniquely applied. The specifications of the transformer are: voltage (primary/secondary) is 400 V/400 V, current is 25 A/25 A, and winding wire is six layers × 50 turns (Fig.4).



Constitution of transformer
(including test circuit)

Appearance of transformer
(φ200 mm、H250 mm)

Fig. 4 Y-based small transformer with FCL function

In the verification test of FCL function, the following items were confirmed: ① normal operating characteristics as a transformer; ② the FCL performance that suppress the short-circuit current to 1/30 (1200 A→43 A) and momentary voltage drop (Fig. 5); ③ the position of transformation to normal conducting increases in proportion to voltage so that the adjustment of FCL effect is possible.

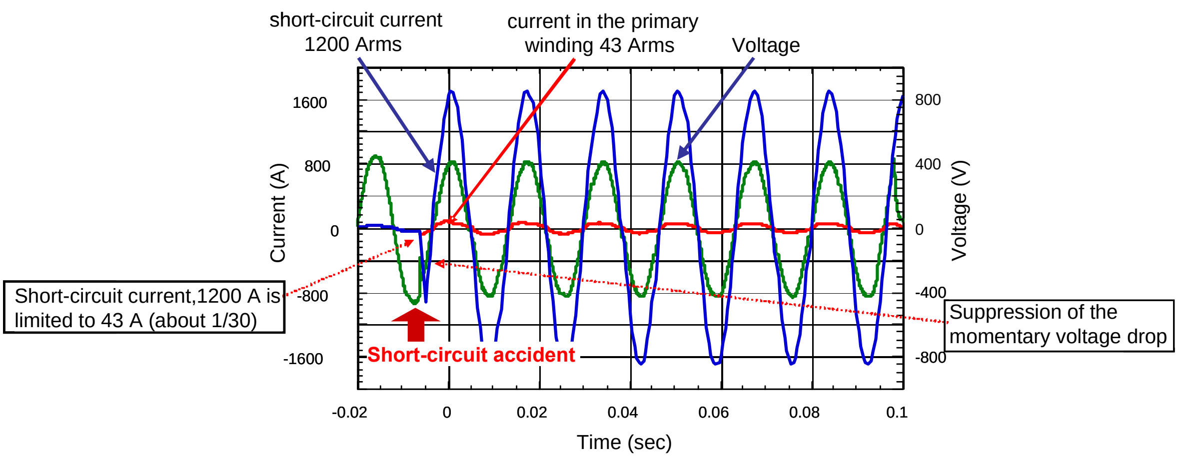


Fig. 5 Test results of current limiting function

Early commercialization of the 20 MVA class superconducting distribution transformers is aimed at by steadily bringing forward the present project through the development and verification of 2 MVA superconducting transformer systems.

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1) "Technical development of Y-based superconducting transformers," part of "Technical development of the yttrium-based superconducting electric power devices" (FY 2008 to FY 2012: part of "Technical development of Y-based superconducting transformer," which is an NEDO subsidy project funded by the Agency for Natural Resources and Energy) is being implemented by Kyushu Electric Co. in cooperation with Kyushu University, International Superconductivity Industrial Technology Center, Fujikura Ltd., and SWCC Showa Cable Systems Co. The development of an elementary technology is proceeding smoothly, and an intermediate assessment has been conducted this month. The plan of the project was published in the November 2009 issue of Web21, and the progress status will be published in November 2010 issue.

2) "Current limiting function" is a function that suppresses the current before the short-circuit accident current in an electric power system reaches the maximum (within 4 ms) (it is also possible to suppress momentary voltage drops), and provides significant effect on the suppression of the short-circuit capacity in an electric power system including transformers (also economically advantageous if measures for electrical, mechanical, and thermal stresses are alleviated). Because existing technology cannot provide such a "current limiter," superconducting current limiters are being developed desperately all over the world.

3) "Superconducting transformer provided with current limiting function" is a transformer that utilizes the superconducting winding wire of superconducting transformer as a current limiter. Downsizing is realized by using the components for dual purposes rather than using separately, thereby resulting in better efficiency and cooling performance. There have been no successful developments so far.

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Top of Superconductivity Web21

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Discovery of a new phenomenon in AC loss of Y-based superconducting wire

Masataka Iwakuma, Associate Professor
Research Institute of Superconductor Science and Systems
Kyushu University

International Superconductivity Technology Center and Kyushu University are jointly promoting the research and development of Y-based superconducting wires in "Technical development of yttrium-based superconducting power devices" a project relegated by New Energy and Industrial Technology Development Organization (NEDO). In the course of this research and development, it was found for the first time that the hysteresis loss (major component of AC loss) decreases significantly deviating from the conventional theory. This discovery brought about fundamental changes in the guideline for reducing the loss in Y-based superconducting wire based on the existing theory. Old guidelines are replaced with a new guideline for the development of material science so that the innovation will be brought about in the application development of various superconducting technologies.

In the past, the development of the Y-based superconducting wires, the thinning of the wire (making to filament) was the only solution for the reduction of AC loss because hysteresis loss increases in return when the critical current density is increased to improve the characteristics. The new phenomenon that has been found recently indicates that the phenomenon develops remarkably when the improvement of the wire characteristic (critical current density and uniformity) is attempted with the hysteresis loss being reduced, which is just opposite of the past concept.

Fig.1 and Fig.2 show the magnetization curves of GdBCO tape wire at 64 K as an example of the measurement of the newly found phenomenon. Fig. 1 shows magnetization curves when magnetic fields are applied at 90°, 60°, 45°, 30°, and 15° to the tape surface. The characteristics of these curves are zero-magnetization when the magnetic field is decreased from the positive and negative peaks and the abrupt drop in magnetization when the direction of the magnetic field is changed. Fig. 2 show magnetization curves under magnetic field biased at 15° to the tape surface and the zero magnetization becomes prominent as the biased magnetic field is increased.

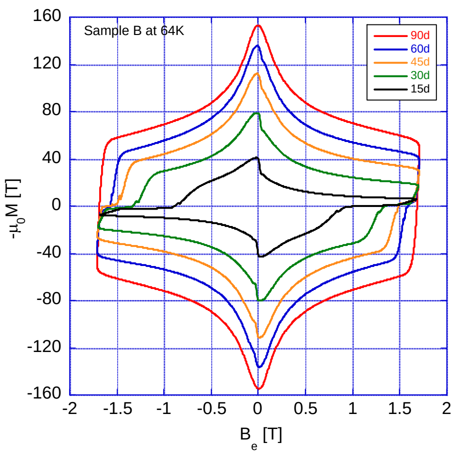

Fig. 1 Magnetizing curve of GdBCO tape wire at 64 K (the magnetic fields are applied at 90°, 60°, 45°, 30°, and15° to the tape surface)

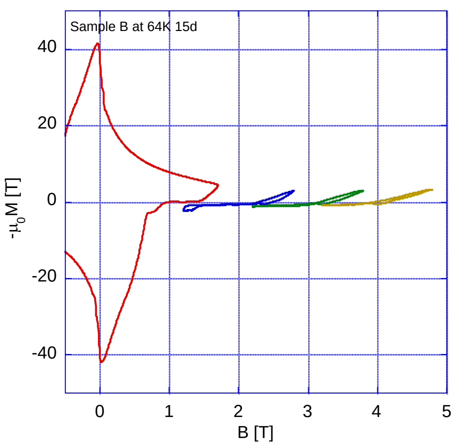

Fig.2 Magnetizing curve of GdBCO tape wire at 64 K (1 in a biased magnetic field based at 15° to the tape surface)

The discovery indicates that not only electrical devices such as generators, motor, transformers, SMES (superconducting magnetic energy storage) systems, and cables, but also medical devices, including MRI and heavy particle accelerators for cancer treatment as well as NMR for the analysis of macromolecule structure, can be realized using Y-based superconducting wires easily at low cost.

(Published in a Japanese version in the October 2010 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

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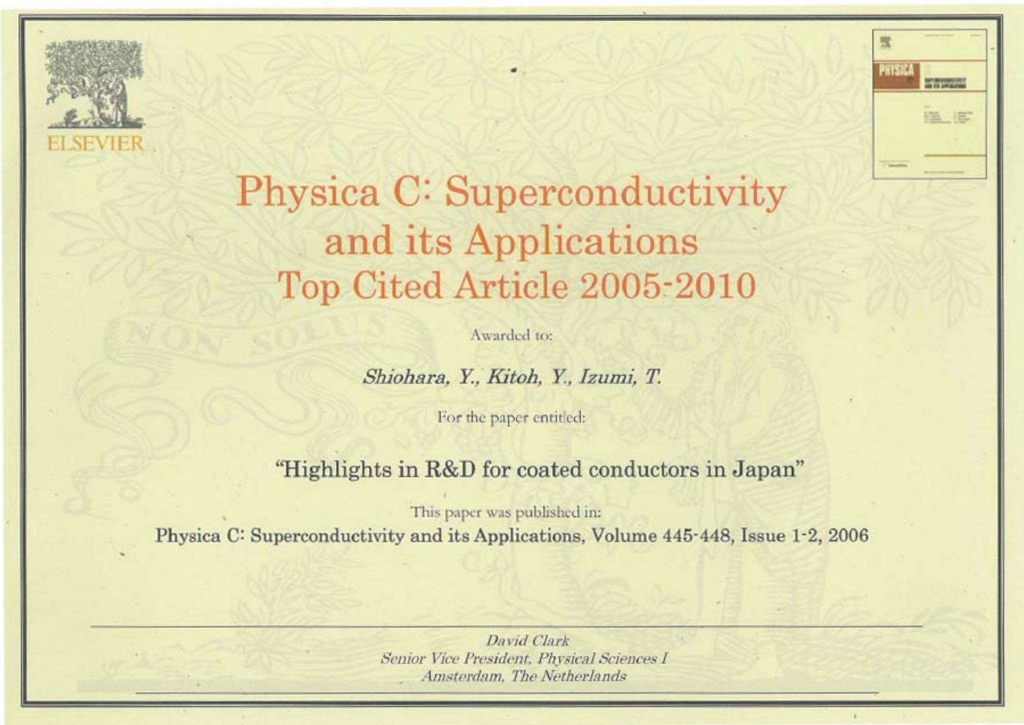
"Physica C: Superconductivity and its Applications Top Cited Article 2005-2010" was awarded

Yuh Shiohara (Director General, Superconductivity Research Laboratory, International Superconductivity Technology Center) received the "Physica C: Superconductivity and its Applications Top Cited Article 2005-2010" award from Elsevier for his dissertation* presented as an invited lecture at the 18th International Superconductivity Symposium (ISS2005).



Top Cited Certificate

* Title: "Highlights in R&D for coated conductors in Japan" (Physica C: Superconductivity and its Applications, Volume 445-448, Issue 1~2, 2006)
Coauthors: Yutaka Kito (currently in Tokyo Electric Power Co.), Teruo Izumi (Director, Superconducting Tapes & Wires Division, Superconductivity Research Laboratory, International Superconductivity Technology Center)

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Top of Superconductivity Web21

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Report on the 19th International Superconductivity Industry Summit (ISIS-19)

Akihiko Tsutai, Director
International Affairs Division, ISTEC

Yuh Shiohara, Director General of SRL, giving a lecture at ISIS-19

The 19th International Superconductivity Industry Summit (ISIS-19) was held at Sestri Levante, Italy from October 5 (Tue) to 6 (Wed), 2010. About 50 people participated in the conference from Japan, USA, Europe, New Zealand, and Korea. Sestri Levante is located in the suburbs of Genoa, and it takes about one hour from Genoa by train. Columbus Superconductors SpA, manufacturer of MgB_2 and ASG Superconductors SpA, famous for magnet for accelerators, are based in Genoa.

In this conference, Korea sought for an official member status of the ISIS, and their request was approved unanimously by all the member countries. As a result, the number of ISIS official members has become five−Japan, USA, Europe, New Zealand, and Korea.

The theme of the conference was "Enabling Sustainable Solutions." Following the opening address, keynote lectures were given by representatives of ISIS members. Consecutively, the present status and future aspects of superconductivity projects, the challenges for commercialization and the international cooperation were discussed and views exchanged. From Japan, Dr. Yuh Shiohara, General Director of Superconductivity Research Laboratory, delivered a keynote lecture on Japan's superconductor technology development toward full-fledged commercialization. As for the present status and future plan of Japanese individual development program, Tsukushi Hara, fellow of Tokyo Electric Power Company explained the demonstration project for high-temperature superconducting cable; Takeshi Okuma, Director of Electric Power Equipment Division, SRL, explained the development of Y-based electric power devices; Teruo Izumi, Special Researcher of Industrial Superconductivity Technology Research Association (Director, Superconducting Tapes & Wires Division, SRL) explained the development of Y-based superconducting wires. Keiich Tanabe, Director of Technical Research Division, Industrial Superconductivity Technology Research Association (Deputy Director General of SRL) introduced superconductor related international cooperation in Japan. Although the role of superconductor technology in the US smart grid is still not fully made clear yet, superconducting power devices such as superconducting cable, superconducting current limiter, and superconducting transformer are now being recognized as equipments for the smart grid, and their development is promoted with the subsidy from US government. The development of SMES has also been restarted. In addition, demonstration projects for superconducting cables and superconducting current

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limiters are under way. Tres Amigas project, planned and funded solely by private sector, was started last year, aiming at the commercialization of DC superconducting cable. In the field of large-scale wind generation, the applicability of superconductor technology is being examined, taking its advantage into account. Y-based wires are expected to be used for these superconducting equipments. American Superconductors Corporation and SuperPower Inc. are in charge of the development and manufacturing technology of the Y-based wires in cooperation with US government organizations such as DOE national laboratories. In the field of electronics, the development and commercialization of superconducting circuits and superconducting filters is under way. In Europe, development for MgB_2 wires and its applications including superconducting magnets are being actively carried out. In the field of HTS, development and commercialization are promoted in the application areas that include motors, generators, and induction heaters. In New Zealand, superconducting magnets are actively developed and commercialized. In addition, the development of Roebel cable aiming at electric power applications including superconducting transformers is vigorously carried out. In Korea, while DAPAS (Development of the Advanced Power system by Applied Superconductivity technologies) project, which was started in 2001, has reached the last phase, new GENI project, led by Korean Electric Power Corporation, has been started. Thus, Korea is accelerating the commercialization of high-temperature superconductor technology.

The important point of discussion in the conference was how to manage international cooperation under the challenges toward the expansion of commercialization. In order to realize the full-fledged commercialization of the high-temperature superconductor technology, there remain issues that need to be solved, including how to make the market demand-pull. It is important to obtain users' trust and confidence by steadily advancing the development and demonstration programs under way so that the advantages of superconducting devices are clearly visualized. There was an opinion in the conference that it would be necessary to show values of superconductor technology explicitly and listen to users' voices sincerely. While the competition in the development of superconductor technology is keen among countries worldwide, international cooperation might be necessary in the areas which are considered to be possible and useful. Actually, firms and organizations in Europe and New Zealand are taking part in some of the superconductivity projects of USA. In the past, a Japanese firm participated in a superconducting cable project of USA. Since this summit is different from the usual academic conferences, functioning as a place where the executives and technical leaders of business and research organizations exchange opinions, the author hopes that the discussion at the ISIS would continue to be fruitful and useful for all the member countries in the future. Having received Korea as a new member, it is expected that the summit grows further and international discussions are further expanded.

The next conference will be held in Korea in 2011.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

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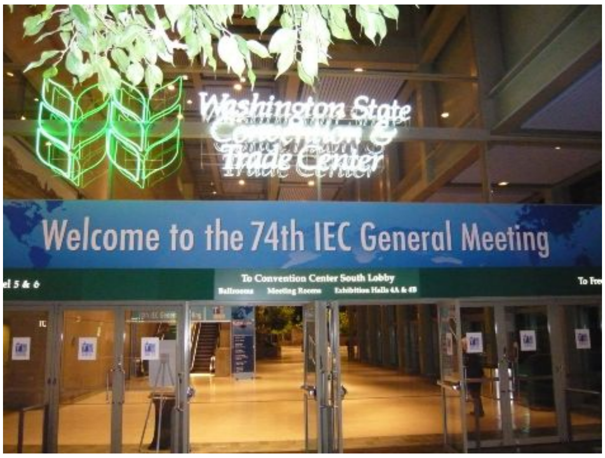
IEC/TC90 Conference at Seattle, USA

Masahiro Okuda,
Managing Director, ISTEC,
Secretariat of IEC/TC90 Domestic Committee



Entrance of the 74th General Meeting

The International Electrotechnical Commission (IEC), an international organization which develops and publishes international standards relating to electrical and electronic technology, held its 74th General Meeting at the Washington State Convention & Trade Center in Seattle, USA from October 11 to 15, 2010. Along with the General Meeting, some 90(scheduled) IEC`s technical committees (TCs) and subcommittees (SCs) also met in Seattle. Among them, TC90, working in the area of superconductivity, had nine working group (WG) meetings to review preparations for revising existing standards and setting up new ones, and a mini symposium to discuss new initiatives towards further standardization, both on October 11 and 12, followed by the TC90 plenary meeting on October 13.

This report outlines a couple of highlights of the TC90 plenary meeting. TC90 was organized in August 1989, as one of the TCs of IEC to develop international standards relating to superconducting materials and devices. The technical committee meets once every two year, and the last meeting took place in Berlin in June 2008. At present 11 P-members, who have the voting right, participate in the committee, where Japan acts as the Secretariat.

The TC90 plenary meeting of October 13, 2010 was joined by five countries—Japan, USA, Germany, China and Korea, chaired by Dr. L. Goodrich (USA) with Dr. K. Sato (Japan) as the secretary. The IEC Central Office also participated in the meeting. The highlights of this meeting are as follows:

- Progress with establishment and revision of IEC standards of superconductivity

  TC90 discussed progress with WGs' preparations for establishment and revision of standards, following the reports from WG conveners. Fifteen IEC standards of superconductivity has been to date published on terminology, definition, and testing & measuring methods, among which as the latest one the standard on current leads was in June 2010. Five standards at present are being prepared for publishing. After published, IEC standards are regularly reviewed and revised where needed. TC90 now has 12 WGs to prepare for such establishment and revision with experts from member countries.

  TC90 also confirmed the stability date of the following edition of each published standard In line with the management policy of IEC.

- Cooperation with other international organizations

  It was reported that CIGRE (International Council on Large Electric Systems) had set up WG B1.31 on standardization of superconducting cables in January 2010, where the testing methods were being investigated. TC90 discussed how to promote cooperation with CIGRE, and with IEC/TC20, which is responsible for standardization of power cables.

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The recent activities of TWA16 (superconducting materials) of VAMAS (Versailles Project on Advanced Materials and Standards) were also reported.

Scene of IEC/TC90 meeting

・ New initiatives for further standardization of superconductivity

The activities of Ad-hoc Group 3, which was set up at the Berlin meeting in order to investigate general requirements for superconducting wires, particularly the workshop in Berkley, USA on October 8 and 9, just before this meeting, was reported. TC90 approved of preparing for a New Work Item Proposal (NP) on this issue, which was to be followed by official voting and establishment of a new WG.

In addition, preparations for NPs on testing method for bending critical current of Bi wires and for measuring method for residual resistance of Nb were also approved.

TC90 also agreed to set up an Ad-hoc Group on standardization of superconducting sensors. Inquiry would be made to participating countries for dispatching specialists to this Ad-hoc Group.

TC90 adjourned the meeting with agreement to meet in China in two years.

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Top of Superconductivity Web21

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What's New in the World of Superconductivity (November, 2010)

Akihiko Tsutai, Director
International Affairs Division, ISTEC

Power

American Superconductor Corporation (November 2, 2010)

American Superconductor Corporation (AMSC) has reported their financial results for the second quarter of fiscal year 2010, ending September 30, 2010. Total revenues for the second quarter increased by 36 % to U.S. $101.5 million, compared with $74.7 million for the same quarter in the previous fiscal year. The gross margin for the quarter was 40.7 %, compared with 38.9 % for the same quarter in the previous fiscal year. Net income for the quarter totaled $10.0 million, compared with $4.3 million for the same period in the previous fiscal year. The non-GAAP income was $14.6 million, compared with $8.7 million for the same period in the previous fiscal year. Greg Yurek, AMSC's founder and chief executive officer, commented, "In the second quarter - our fifteenth consecutive quarter of sequential revenue growth - we generated new quarterly records for both gross margin and earnings. In recent weeks, we have achieved a number of additional successes that we believe will enable us to extend our strong track record of profitable growth well beyond fiscal 2010. We strengthened our position in the renewable energy and power grid sectors by making a strategic investment in advanced wind turbine blade manufacturer Blade Dynamics Ltd., and we introduced our new SolarTie™ Grid Interconnection Solution. Most importantly, the second fiscal quarter marked the 'Coming of Age' for high temperature superconductors as we booked a three million meter order for our Amperium™ wire - the largest order for high temperature superconductor wire in history." As of September 30, 2010, the company had cash, cash equivalents, marketable securities, and restricted cash totaling $131.2 million and a reported backlog of approximately $956 million. The company has increased its fiscal 2010 financial forecast for revenues (now $430 million to $440 million), net income (now $44.0 million to $46.5 million), and non-GAAP net income (now $60.5 million to $63.0 million).
Source:
"AMSC Reports Second Quarter Fiscal Year 2010 Financial Results"
American Superconductor Corporation press release (November 2, 2010)
http://www.amsc.com/pdf/Q210%20Press%20Release%20-%20Final.pdf

American Superconductor Corporation (November 11, 2010)

American Superconductor Corporation (AMSC) has announced that a public offering of 4.6 million shares of common stock will be priced at US $35.50 per share. AMSC has also granted the underwriters a 30-day option to purchase up to an additional 690,000 shares of common stock to cover over allotments, if any. AMSC expects that the net proceeds from the offering will amount to $155.1 million or $178.4 million if the underwriters exercise the over-allotment option in full, after the deduction of underwriting discounts and commissions and the estimated offering expenses. The offering is expected to close on or around November 16, 2010.
Source:
"American Superconductor Announces Pricing of Common Stock Offering"

American Superconductor Corporation press release (November 11, 2010)
http://www.amsc.com/pdf/AMSC%20Pricing%20Press%20Release%201110.pdf

American Superconductor Corporation (November 23, 2010)

American Superconductor Corporation (AMSC) has selected LS Cable Ltd. (Korea) and Nexans (France) as the superconductor power cable subcontractors for the Tres Amigas SuperStation. The first-of-its-kind power transmission hub will be located in New Mexico, USA, and will link the three primary electric transmission grids in the United States. Both LS Cable and Nexans will use AMSC's Amperium™ wire to manufacture the superconductor cables required for the project. Phil Harris, founder and chief executive officer of Tres Amigas, commented, " We are delighted that AMSC has chosen to work with two of the world's largest and most respected cable manufacturers for this project of national importance." Upon completion, the transmission hub will allow the transfer of thousands of megawatts of power among the three power grids, enabling the faster adoption of renewable energy and increasing the reliability of the U.S. power grid.
Source:
"American Superconductor Selects Cable Subcontractors for Tres Amigas SuperStation"
American Superconductor Corporation press release (November 23, 2010)
http://www.amsc.com/pdf/Tres%20Amigas%20Cable%20Subs%20(23Nov2010)%20-%20Final.pdf

Communication

Superconductor Technologies Inc. (November 10, 2010)

Superconductor Technologies Inc. (STI) has reported its financial results for the third quarter of the fiscal year, ending October 2, 2010. Total net revenues for the third quarter amounted to $2.0 million, compared with $4.3 million for the same quarter in the previous fiscal year. Net commercial product revenues totaled $1.8 million, compared with $3.0 million for the same period in the previous fiscal year. Government and other contract revenues totaled $144,000, compared with $1.3 million for the same period in the previous fiscal year. The net loss for the third quarter was $3.4 million, compared with $1.8 million for the same period in the previous fiscal year. Jeff Quiram, STI's president and chief executive officer, commented, "… we continue to see conservative spending by our large carrier customers on performance enhancement solutions for their existing networks… We also successfully completed the SURF 2 development program for the United States government and have re-assigned those technical resources to our 2G HTS wire initiative. Our future focus is creating shareholder value by utilizing our HTS expertise to capture a significant share of the global market for 2G HTS wire in existing and emerging power transmission and generation applications." As of October 2, 2010, STI had $9.4 million in working capital, including cash and cash equivalents. During the quarter, STI received $5.2 million from an underwritten offering of cash stock; shortly after the end of the quarter, the company received an additional $830,000 in net proceeds from the exercise of an over-allotment option related to that offering. The commercial product backlog at the end of the third quarter was $106,000, compared with $95,000 for the same period in the previous fiscal year.
Source:
"Superconductor Technologies Inc. Reports Third Quarter 2010 Results"
Superconductor Technologies Inc. (November 10, 2010)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1494459&highlight

Accelerator

CERN (November 4, 2010)

CERN announced the successful conclusion of the first operation run of the LHC, with all the objectives for the first year of proton physics research at 7 TeV having been achieved. Regarding the research accomplished to date, Rolf Heuer, Director General of CERN, commented, "This shows that the objective we set ourselves for this year was realistic, but tough, and it's very gratifying to see it achieved in such fine style. It's a testimony to the excellent design of the machine as well as to the hard work that has gone in to making it succeed. It bodes well for our targets for 2011."

During the remainder of the 2010, the LHC will move into a new phase of operation in which lead ions will be accelerated and collided in the machine for the first time. The main research goal for 2011 will be to collect enough data (one inverse femtobarn) to make significant advances across a broad frontier of physics. The LHC is scheduled to accelerate lead ions until December 6, after which time a technical stop for maintenance will occur. Operation of the collider will resume in February, with operation continuing throughout 2011.

Source:
"The LHC enters a new phase"
CERN press release (November 4, 2010)
http://press.web.cern.ch/press/PressReleases/Releases2010/PR20.10E.html

CERN (November 8, 2010)

CERN announced that the transition from protons to lead ions has been completed after only four days of work: first collisions were recorded on November 7, and stable operating conditions were achieved on November 8. Rolf Heuer, Director General of CERN, commented, "The speed of the transition to lead ions is a sign of the maturity of the LHC. The machine is running like clockwork after just a few months of routine operation." Switching from protons to lead ions required a complete re-establishment of the operating parameters—from source to collision. The energy level of the circulating lead ions (287 TeV per beam) is much higher than that for protons, and a period of careful adjustments was required before lining up opposing beams for collision and confirming the establishment of the stable beams required for nominal data collection. Three experiments (ALICE, ATLAS, and CMS) requiring the collision of lead ions will now be able to commence.

Source:
"CERN completes transition to lead-ion running at the LHC"
CERN press release (November 8, 2010)
http://press.web.cern.ch/press/PressReleases/Releases2010/PR21.10E.html

Basic

Princeton University (November 2, 2010)

Researchers at Princeton University have observed a new material—a crystal called a topological superconductor—with part superconductor, part metal characteristics. At very low temperatures, the interior of the crystal behaves like a normal superconductor; however, the surface simultaneously remains metallic. The findings have important implications for the development of next-generation electronics, including energy-efficient quantum computers with the ability to identify errors in calculation as they occur and to resist them during processing. L. Andrew Wray, the first author of the paper, explained, "These highly unusual superconductors are the most ideal nurseries to create and manipulate Majorana fermions, which could be used to do quantum computing in a fault-resistant way. And because the particles would exist on a superconductor, it could be possible to manipulate them in low power-consumption devices that are not only 'green,' but also immune to the overheating problems that befall current silicon-based electronics." The group's research has been published in *Nature Physics*.

Source:
"Unique duality: Princeton-led team discovers 'exotic' superconductor with metallic surface"
Princeton University press release (November 2, 2010)
http://www.princeton.edu/main/news/archive/S28/87/21S83/index.xml

University of Minnesota (November 10, 2010)

Researchers at the University of Minnesota in collaboration with international colleagues from Germany, France, and China have reported the discovery of a novel type of magnetic wave involving oxygen atoms. The researchers bombarded copper-oxide crystals with an intense neutron beam; by measuring how the magnetic neutrons are scattered after colliding with the crystals, the group was able to identify the presence of unusual magnetic waves involving oxygen atoms. The findings are fundamental in nature, but might eventually lead to an improvement of superconducting wires and their use in national electrical grids. The group's results have been published in *Nature* and have been highlighted in *Science* as well. The study's lead author is Dr. Martin Greven, an associate professor in the School of Physics and Astronomy, College of Science and Engineering, University of Minnesota.

Source:
"University of Minnesota leads team in discovery of novel type of magnetic wave"
University of Minnesota press release (November 10, 2010)
http://www1.umn.edu/news/news-releases/2010/UR_CONTENT_272043.html

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

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Feature Articles: Latest trend in the application of SQUID - Development of evaluation system for high-temperature superconducting coated conductors using HTS-SQUID

Tsunehiro Hato, Chief Researcher
Electronic Devices Division, SRL/ISTEC

HTS-SQUID is advantageous in handling and maintenance because it is operated at the liquid nitrogen temperature, and positioned between LTS-SQUID, which has a magnetic sensitivity of less than 10 fT, and fluxgate magnetic sensor, the sensitivity of which is inferior by three orders or more, but does not require cooling. To find the advantage of HTS-SQUID in application, it is necessary to improve the sensitivity.

We obtained high-sensitivity HTS-SQUID by applying the multi-layer structure processing technology[1] with four superconducting layers and four intermediate insulating layers at maximum that has been developed by us, and multi-channeled gradiometer array was successfully developed. Using the SQUID gradiometer array, we succeeded in completing a non-destructive evaluation system for high-temperature superconducting coated conductors[2),3)].

Fig.1 shows a SQUID gradiometer using the multi-layer technology. It has features that there is a freedom in layout when fabricating multi-channel SQUIDs since ramp edge junction is used, and that it endures high magnetic field. Furthermore, mutual interference with adjacent gradiometer is suppressed because the feedback coil is positioned on the pickup coil.

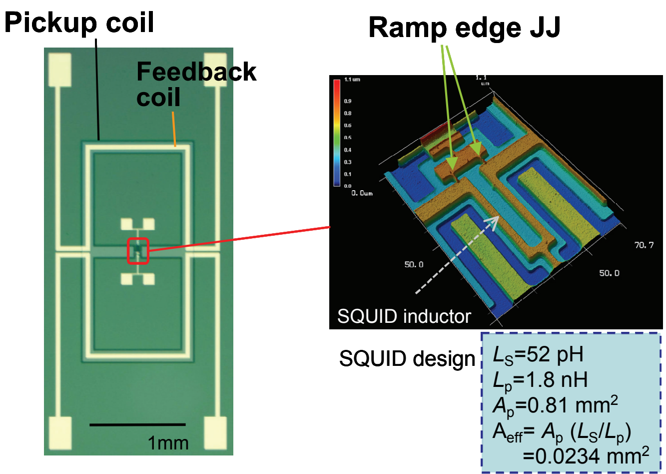

Fig.1 SQUID gradiometer using multi-layer technology

Fig.2 shows a non-destructive evaluation system for high-temperature superconducting coated conductor in which five channels of the gradiometers are used as the high-sensitivity sensors for eddy-current non-destructive evaluation devices. This equipment is actually being used as a tool to support the development of coated conductors. The equipment is made up so that the measurement is made while the coated conductor is passed between reels with a diameter of 480 mm to measure a wire of 500 m. In the superconducting coated conductor, Y-based superconducting layer is placed on the hastelloy substrate via buffer layers of insulator, and the top is covered with Ag stabilizing layer. To detect the defects in the superconducting layer, it is required to cool the conductors to superconducting temperature. Coated conductors are cooled by thermal contact in the cooling stage connected to two refrigerators and auxiliary cooling mechanism cooled by liquid nitrogen while being passed. Induced current caused by the induction coil under the SQUID mainly passes through the superconducting layers. This induced current flows bypassing the defects in the superconducting layer, and gradient of the vertical element of the magnetic field is detected by using the SQUID. The system is realized without magnetic shield by using a gradiometer. The maximum measuring speed is 80 m/h that is limited by the cooling speed. The heat shielding technology developed by the low-temperature probe and the sampler system is utilized. Assuming to apply to power devices, the 5 mm-wide coated conductors are striated into 5 filamentary lines of 1 mm width to reduce AC loss. To detect the defects speedily in each filament of the conductor, five gradiometers with a width of 1 mm are installed. Fig.3 shows an example of the measurements before and after striating the conductor into five filaments. It is shown that the defects due to delamination and short-circuiting between filaments are newly detected. Types of defects can be identified to a certain extent by the waveform, and automatic recovery function from lock-off and automatic tallying function for defects by setting threshold value are provided to effectively evaluate long coated conductors.

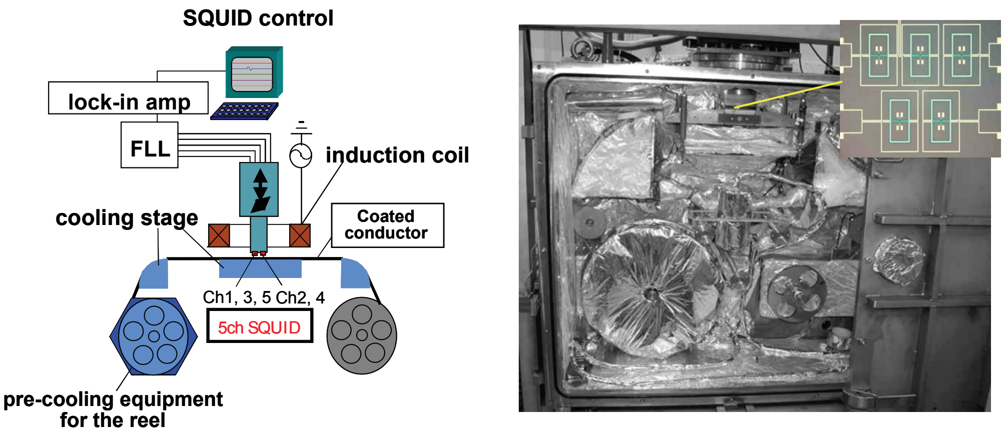

Fig.2 System constitution and photographs of the inside of the vacuum chamber and the gradiometer array

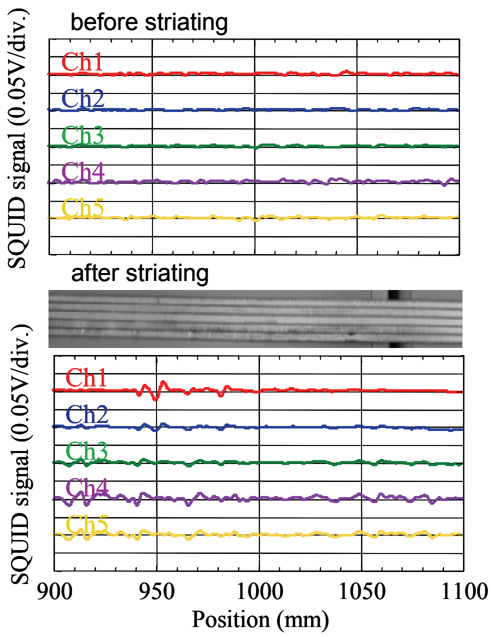

Fig. 3 Example of the superconducting tape evaluation.

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Reference:

1) K. Tanabe *et al.*, "Advances in High-T_c single flux quantum device", IEICE Trans. Electron., vol.E91-C, p.280, 2008.
2) T. Hato *et al.*, "NDE of coated-conductor using HTS SQUID array", Physica C 469 (2009) 1630-1633.
3) T. Hato *et al.*, "Non-Destructive Testing of YBCO Coated-conductor by Multi-Channel HTS SQUID Gradiometers", IEEE Trans. Appl. Supercond., vol. 19, no. 3, pp. 804-807, June 2009.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

Superconductivity Web21

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Feature Articles: Latest trend in the application of SQUID - Development of non-destructive inspection system with the application of orthogonal DC/AC magnetic field measurement using HTS-SQUID

Keiji Tsukada, Professor
Graduate School of Natural Science and Technology
Okayama University

In the conventional non-destructive inspection using magnetism, a high-frequency magnetic field of several kHz or more is applied to the object, and the magnetic field generated in the object is measured. This method is limited to the measurement of the surface of the object because of the skin depth effect. For this reason, low-frequency measurement that enables the measurement of deep part or whole part of the object is now being pursued actively. The magnetic field generated in the object is not limited to the secondary magnetic field generated in metals. There is a magnetic field due to the magnetic property of the material. Magnetic properties of materials include ferromagnetism, paramagnetism, and diamagnetism. In the defect inspection of the ferromagnetic materials such as steel, it is found that not only defects such as cracks but also metal fatigue before the generation of the defects can be detected by a small change in permeability. It has also become possible to measure moisture in the grains and soil making use of very small magnetization in diamagnetism. As described above, the use of low-frequency and high sensitivity have become important in non-destructive inspection using magnetism. In the measurement of magnetic characteristics, larger signals can be obtained by increasing the applied magnetic field. However, in HTS-SQUID, the downsizing of which is expected, noise increases due to magnetic flux trap when the applied magnetic field is increased, and hence, it is necessary to improve the magnetic field resistance characteristics. To solve this problem, a system was developed as shown in the figure, in which SQUID and detecting coil are separated, the detecting coil is so arranged that the directions of magnetic component detected by the coil and applied magnetic field component are at right angles to each other, and fine tuning function is provided. Obtaining the true magnetic component from the object was made possible by developing an analytical method to eliminate the residual applied magnetic field component. A SQUID with high resistance to the applied magnetic field is being developed at present, and it is expected that a high-precision-compact-measuring system for magnetic characteristics that has not been existed will be realizes.

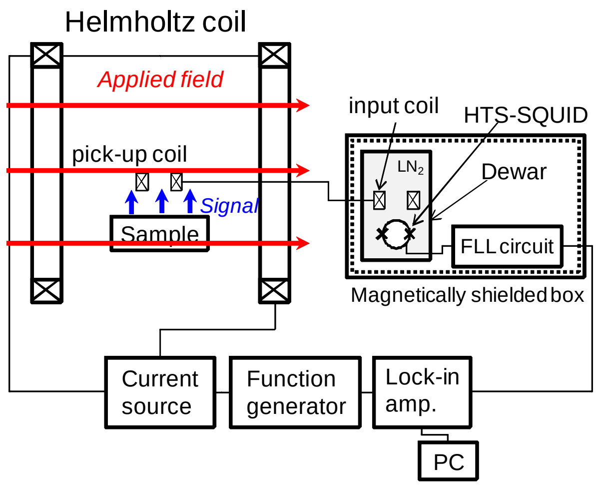

Fig. Non-destructive inspection the system of orthogonally applied magnetic field type using HTS-SQUID

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011
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Feature articles: Latest trend in the application of SQUID
- Development of HTS-SQUID Magnetic contaminant detection system

Saburo Tanaka, Proffessor
Department of Environmental and Life Sciences
Toyohashi University of Technology

We are developing a superconducting magnetic SQUID sensor with high sensitivity for demonstration, which enables us to detect extremely small magnetic contaminants of 50 μm in commercial products. This level of sensitivity has been impossible by using conventional technologies so far. It is known that inclusion of around 100μm metal contaminant within such high-tech products as ceramic packages deteriorates product reliabilities. As for Lithium-ion batteries, many spontaneous combustion accidents of notebook PCs occurred in 2006. Reportedly, it is highly possible that fine metal fragments entering into the products during manufacturing process could cause the accidents. While Nickel metal hydride batteries with high power capacity are used in hybrid cars including "Toyota Prius" at present, possibility to adopt Lithium-ion batteries which can make the volume of the battery half are investigated. However, its reliability remains to be the important issue. It is also known that fine metal contaminants could cause cracks of ceramic packages after sintering and/or their stress ruptures during use. Since there is no existing technology that can be utilized in the ceramic package production line with a speed of 30 m/min or more, the method using magnetic SQUID sensor with superconductivity technology is considered to be very promising for this purpose. We are developing an industrial SQUID inspection equipment to detect contaminants with a support from Hamamatsu/Higashi-Mikawa Area Knowledge Cluster Creation Project 2008-2011(Phase 2), sponsored by Ministry of Education, Culture, Sports, Science and Technology.

The important feature of the equipment is a newly developed cryostat equipped with a special device to magnify the magnetic signal from magnetic contaminants. As shown in Fig.1, two planar high-temperature superconducting gradiometers are installed on the sapphire rod located at the tip of the cryostat which can make the distance between SQUID sensor and the target contaminants decreased up to 1 to 2 mm.

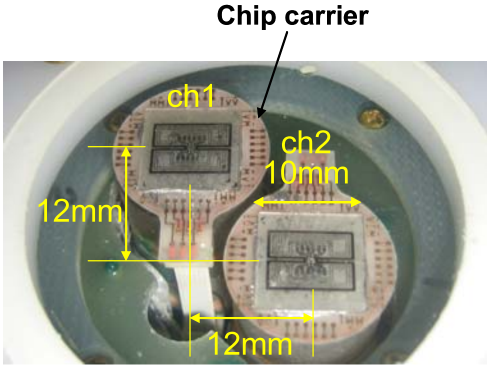

Fig.1 Close-up view of the cryostat fore-end

Fig.2 shows an appearance of the prototype system. The system consists of permanent magnets, SQUID gradiometers inside high-permeability magnetic shield cylinder, and two belt conveyors. The size is approximately W2000 mm × D700 mm × H1350 mm, and the touch panel for the operation and display is separately installed.

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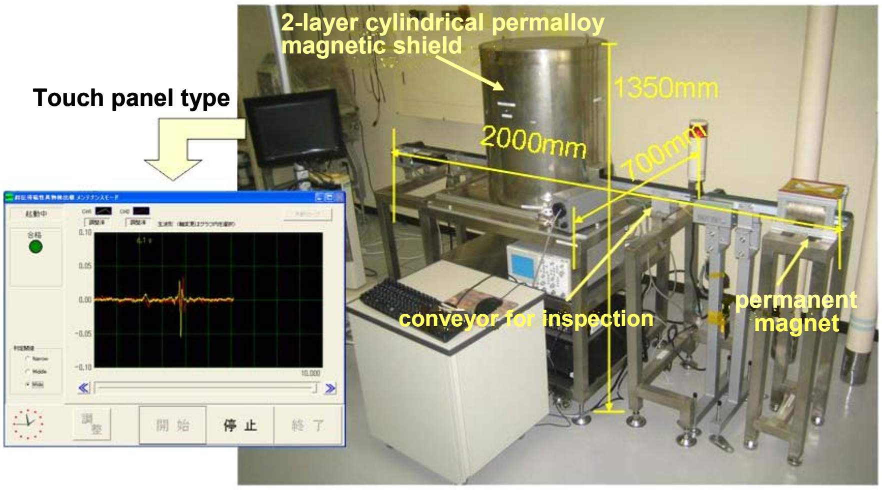

Fig.2 View of the high T_c SQUID Detection system

Tested steel balls (S50C) with different diameters of Φ40 μm, Φ50 μm and Φ75 μm were prepared to evaluate how small magnetic contaminants can be detected by using this prototype system. The generated signal was detected when the steel balls passed through under the gradiometer ch1 with distance of about 3 mm. Two SQUIDs were located at the diagonal positions, respectively, as shown in Fig.3. The smallest detectable size was estimated from the relationship between the output signal strength from ch1 and the sizes of contaminants. Fig.4 shows the signals from the steel balls. Although the magnetic signal becomes smaller as the diameter of the steel ball decreases, it is demonstrated that the device maintains enough sensitivity even when the diameter of the contaminant is 40 μm.

We are planning to further develop the multi-channel equipment for wider applications toward its commercialization.

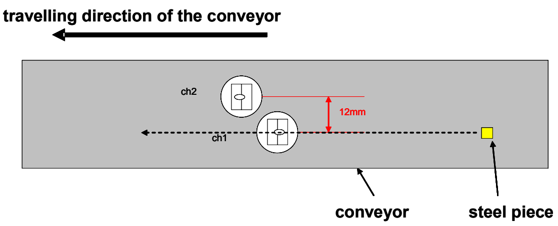

Fig. 3 Top view of detecting section

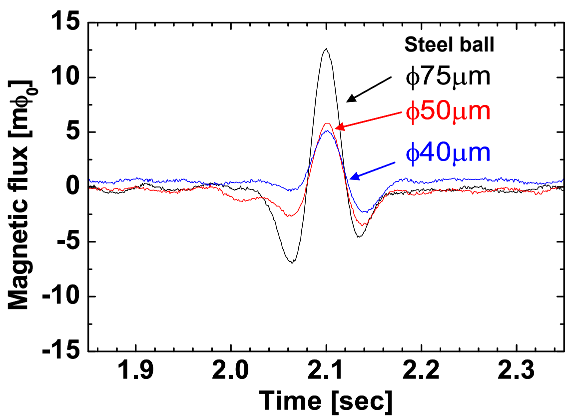

Fig. 4 Time trace of the signals from test steel balls

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Top of Superconductivity Web21

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Feature articles: Latest trend in the application of SQUID - Development of STM-SQUID microscope

Hideo Itozaki, Professor
Graduate School of Engineering Science
Osaka University

One of the applications of SQUIDs is the magnetic microscope. Since the miniaturization of magnetic materials and magnetic devices including the densification of magnetic hard discs, the development of nano-magnetic beads, and the progress in spintronics, the fine observation of magnetic structure has become necessary for evaluating these magnetic materials. Even the when magnetic flux density is large, the volume of magnetic flux decreases when the structure is miniaturized so that the development of a magnetic microscope is required in order to pick up the minute magnetic flux.

A SQUID microscope has been developed using a minute SQUID loop or minute pickup loop as the sensor head with a resolution of several μm to several tens of μm, and has been used for the observation of an image printed with magnetic ink and magnetic flux generated in a superconducting material.

Osaka University and NIMS (National Institute for Material Science) have developed a magnetic measurement method, in which a sharp needle with a high permeability is used as the sensor head for scanning the sample surface and SQUID is placed at the root opposite to the head to improve the space resolution of the SQUID microscope. As a result, the observation of micron size was achieved, and fine materials such as magnetic toner were successfully observed. One important factor that determines the resolution performance is how to set the needle as close to the sample material as possible. Since the needle easily deforms if it touches the sample, micron order is the limit when the needle is moved toward the sample while optically observing the head of the needle. This means that the limit of the spacial resolution of the needle type head is micron scale, and a new technology that controls the distance between the needle head and the sample to nano order was required.

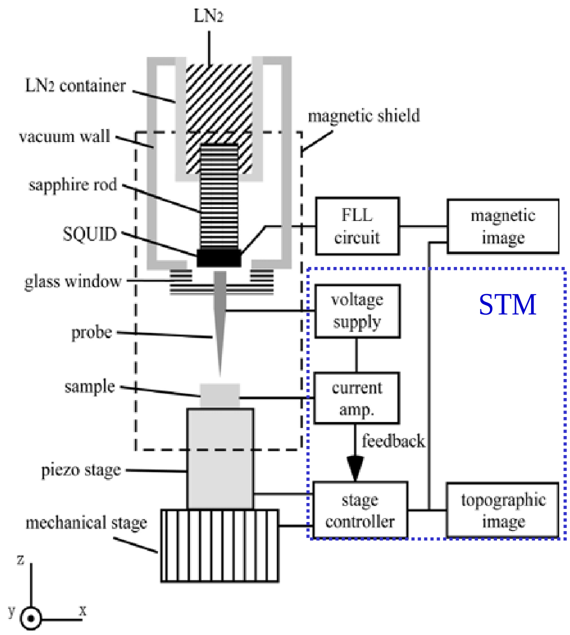

Fig.1 Schematic diagram of STM-SQUID microscope

A STM-SQUID microscope was developed as a solution to this problem (Fig.1). A bias voltage is applied between the needle head and the sample. The head is brought closer to the sample and the current is kept constant while the sample is scanned. Thus, it is made possible to keep the distance between the needle head and the sample surface at a constant value at a nano scale. This is a STM (scanning tunnelling microscope) itself. By observing the magnetic field with the SQUID installed at the root of the needle, it is possible to observe the magnetic field around the needle head. Therefore the surface morphology and magnetic image can be obtained simultaneously. Thus, the spacial resolution of the SQUID has been remarkably improved. Fig.2 shows the image of the magnetic structure of a hard disc. The magnetic structure can be clearly observed.

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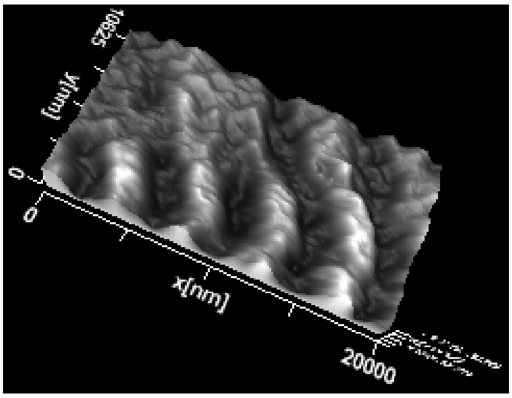

Fig.2 Magnetic image of the hard disk observed by STM-SQUID microscope

A MFM (magnetic force microscope) is a magnetic microscopes with a high spacial resolution and is used to obtain magnetic observation with high resolution using together with AFM (atomic force microscope). Since MFMs use miniature magnet as the sensor head utilizing magnetic force with the sample for measurement, it is affected by the atomic force near the surface so that the surface condition has significant effects in rough samples. Since STM-SQUID, on the other hand, observes the magnetism itself, uneven surface have no effect, and the observation of minute magnetic field is possible even in rough samples.

As described above, the STM-SQUID microscope has been developed as a magnetic microscope having an excellent special resolution that has never been obtained, and it is expected that it will be useful for the observation of various magnetic materials.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

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Feature articles: Latest trend in the application of SQUID - Development of liquid phase immunological test system using magnetic marker

Keiji Enpuku, Professor
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Kyushu University

In the medical tests such as blood test, it is generally called immunological test to detect biomaterials such as protein due to disease and bacillus using antigen-antibody reaction. In these tests, type and volume of the biomaterials are detected using test antibody that selectively combines with the biomaterial (antigen). The antibody is marked with a marker and the binding reaction is detected by measuring the signal from the marker. Although optical tests using optical markers are adopted at present, the magnetic test using the magnetic markers of nanometer size is attracting attention as a substitute for the optical test.

The magnetic test has two significant features that optical test does not have. One is that the magnetic markers can be assumed to be fine magnets, and the signal is a vector quantity with magnitude and direction. By combining this property with the Brown rotational motion, the test in liquid phase without washing process is made possible. The washing process is indispensable for optical method. Since the "washing process" requires much labor and time, elimination of this process enables quick tests. The other feature is that non-transmitting materials can be tested, and testing with whole blood and diagnosis in the body is being investigated.

Fig.1 shows schematic diagram of the liquid phase immunological test that we are developing. Fixing antibody is set on the surface of the polymer particles of about a micrometer, to which antigen combines. After combining, the magnetic markers for detection are fed and a part of markers combine, forming bound markers, and others remain as unbound (free) markers. While the free markers exhibit high speed Brown rotation, the bound markers rarely rotate. As a result, the magnetic characteristics of the two greatly differ so that they can be identified without using the "washing process."

Fig.2 is an example of detecting a protein called IgE using this method. The abscissa axis stands for the volume of IgE, and the ordinate axis stands for the magnetic signal detected by SQUID. The figure shows that there is a good correlation between the volume of IgE and the detected signals, which indicates that detection at attomole level is possible. The results of the solid-phase detection using normal "washing process" are shown for reference. It is seen that the same results are obtained by the two methods.

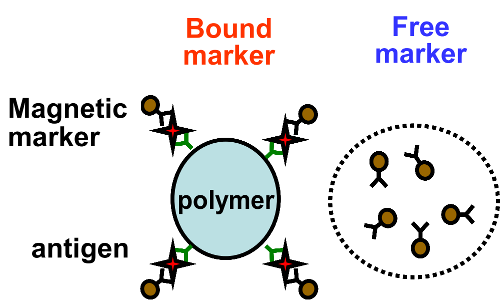

Fig.1 Liquid immunological test using solid polymer beads

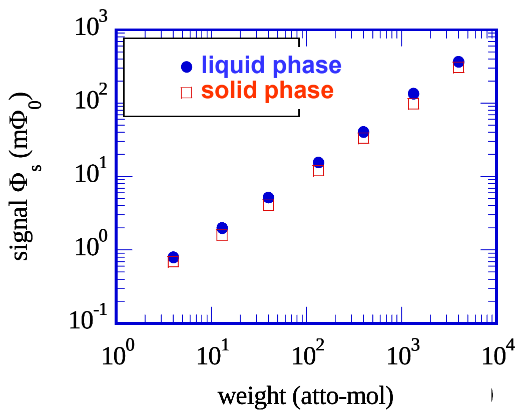

Fig.2 Detection of protein (IgE)

This research was conducted in cooperation between Nagasaki International University and Advanced Research Laboratory of Hitachi Ltd.

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Top of Superconductivity Web21

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Superconductivity Web21

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Feature articles: Latest trend in the application of SQUID
- Development of high critical temperature SQUID system for handheld magnetocardiogram measurement

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Superconducting Quantum Interference Device (SQUID) magnetometer operated at liquid helium temperature is widely used in the bio-magnetic instrumentation. For clinical applications of bio-magnetic measurement, however, it is required to develop equipments that can be handled more easily. It is strongly hoped to develop equipment that can operate by hands, such as a stethoscope, without using liquid helium and without using magnetically shielded room (MSR). As a first step, we developed a handheld SQUID magnetometer and actually measured the magnetocardiogram to confirm the possibility of the application of using the equipment.

Fig.1 shows the developed handheld SQUID magnetometer. High critical temperature SQUID that can be used by cooling with liquid nitrogen was used. The SQUID has a non-differential type magnetic sensitivity area (0.8 mm^2) with a magnetic field sensitivity of 2.7 nT/Φ_0. The device is equipped with a small sized vacuum bottle that can be held in hand as the dewar. Since the magnetocardiogram is quite small signal compared to geomagnetism and environment noises, wide dynamic range is required for the situation when operations by hands or outside MSR. We developed FLL systems[1),2),3)] that were used a simple hardware to obtain a wide dynamic range.

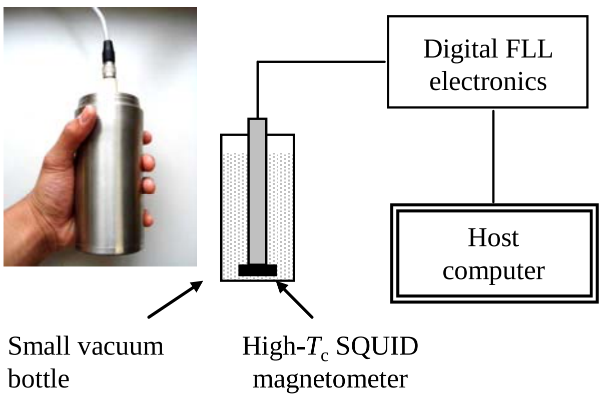

Fig.1 Outline of the handheld SQUID magnetic fluxmeter

We demonstrated two examples of magnetocardiogram measurements with developed handheld SQUID magnetometer. First, magnetocardiogram signal was measured using this system with the small cryostat held by a hand about 2 cm apart from subject's chest in MSR. Fig.2 shows the picture of measurement and measured waveforms (magnetocardiogram waveforms), and analyzed magnetocardiogram waveform by a band pass filter for 5–40 Hz and 15 times averaging. Although the magnetic field fluctuation of about 10 nT was caused by the vibration of the hand holding the dewar, it was confirmed that this SQUID magnetometer could maintain steady operation by virtue of its large dynamic range. Second, the dewar was set on a table in a laboratory outside MSR, to measure magnetocardiogram. Fig.3 shows the picture of measurement, measured waveforms (magnetocardiogram waveforms), and analyzed magnetocardiogram waveform by a low pass filter of 40 Hz and 63 times averaging (1-minute measurement). Although the power line noise at 50 Hz was mainly seen about 3 nT_{pp}, the SQUID magnetometer operated steadily and magnetocardiograms were obtained.

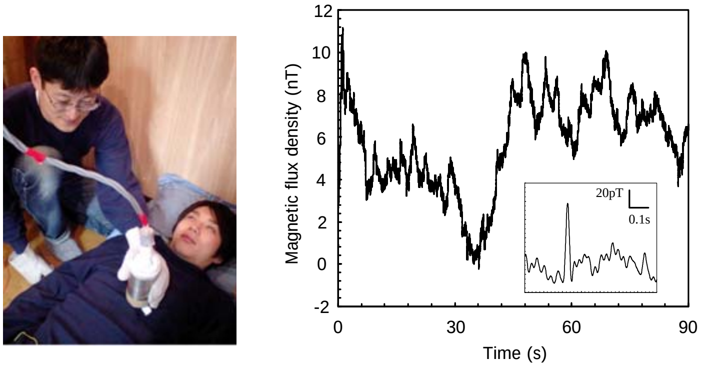

Fig.2 Magnetocardiograms measured with handheld dewar in MSR

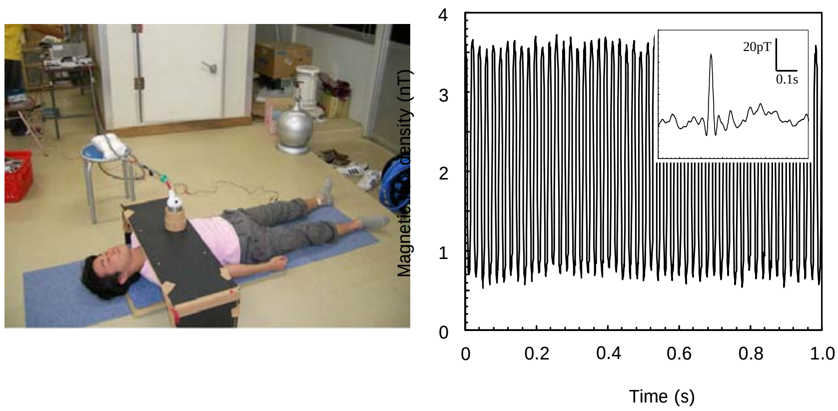

Fig.3 Magnetocardiograms measured with dewar placed on a table outside MSR

A handheld SQUID magnetometer for magnetocardiogram using high critical temperature SQUID was developed. The prototype handheld SQUID magnetometer enabled the measurement of magnetocardiograms with the cryostat held by a hand in MSR and with outside MSR. However, clinical application of biomagnetic measurements needs much higher noise performance.

References:

1) Daisuke Oyama, Koichiro Kobayashi, Masato Yoshizawa, Takayuki Shimizu, Kenji Nakai, Yoshinori Uchikawa: Development of digital FLL system for SQUID using double counter method, Journal of the Magnetics Society of Japan,
2) D. Oyama, K. Kobayashi, M. Yoshizawa, Y. Uchikawa : Development of Digital FLL System for SQUID Using Double Counter Method, IEEE Trans. Magnetics, Vol.42, No.10, 3539-3541, 2006.
3) D. Oyama, K. Kobayashi, M. Yoshizawa, Y. Uchikawa: Mobile High-T_c SQUID System for MCG Measurement, IEEE Trans. Applied Superconductivity, Vol.19, Issue 3, Part 1, June 2009 Page(s):871 - 873.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

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Feature articles: Latest trend in the application of SQUID
- Present status of the development of SQUID magnetospinography system

Yoshiaki Adachi, Associate Professor
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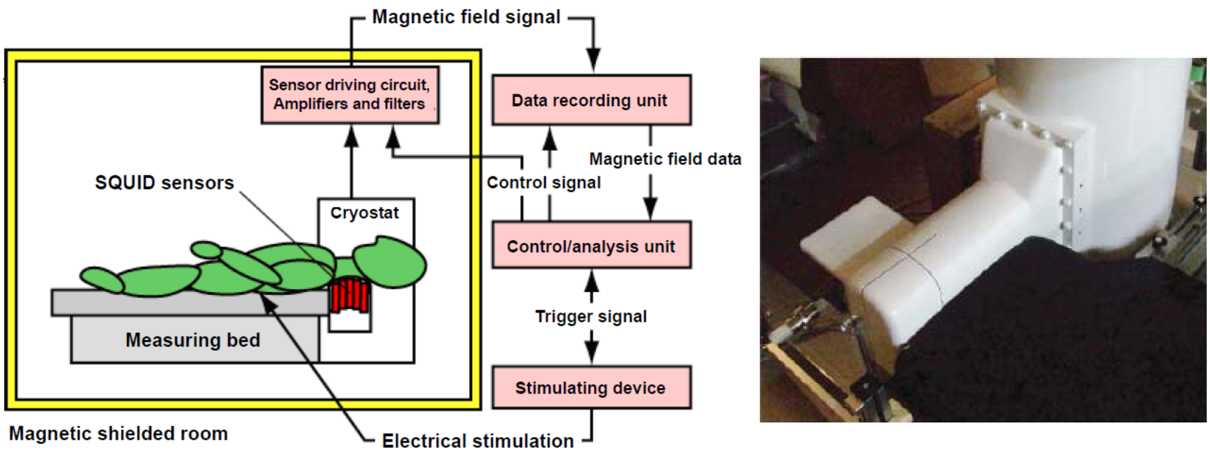
Kanazawa Institute of Technology

We are developing a device to study the function of spinal cord by detecting faint magnetic field generated by the nervous activity in spinal cord. Many cases of paralysis and numbness in limbs are caused by injurious compression in spinal cord and it is often difficult to make a correct diagnosis based only on conventional neurological observation and morphological image information such as MRI and X-ray CT. It has become possible to obtain imaging of spinal cord function using Magnetospinography (MSG) developed by us for the observation of the activity of spinal nerve without invasion, which will contribute to the diagnosis of damaged region of spinal cord.

Fig. 1 shows the constitution of magnetospinography equipment and its photograph of appearance. A special cryostat was developed[1] so that the test is implemented from the backside of the subject lying on the back. The sensor holding a part of the cryostat is protruding from the side of the cylindrical main vessel, and the LTS-SQUID magnetometer array is laid out along the upper surface of the sensor holding part. Although the magnetic field generated from the cervical spinal cord has been mainly measured so far, it has become possible to apply to other parts such as lumbar since a new cryostat with extended protruding part has been developed.

The prototype device is installed at orthopedic section of Tokyo Medical and Dental University and the verification tests of magnetospinography are being conducted for sound subjects and patients with damaged a spinal cord waiting for surgery. The prototype device is equipped with vector SQUID gradiometric magnetometers are arranged at 5 × 8 = 40 positions in a matrix-like arrangement so that the magnetic field distribution in a region of 90 mm × 140 mm is detected at a time. By taking a cervical X-ray image on the measuring site, a morphological image that shows the relative position between the cervical vertebra of the subject and the sensor is acquired.



(a) (b)

Fig. 1 Constitution of magnetospinography device (a) and appearance (b)

In cooperation with Tokyo Metropolitan University, software that enables visualizing the transition of the current distribution around the spinal cord by applying magnetic field source analysis algorism based on the measured magnetic field data and X-ray image data was developed. This enables users at the clinical site to take functional images of spinal cord relatively easily[2,3]. Fig. 2 shows an example of spinal cord functional imaging in which the current distribution reconstructed by applying magnetic field source analysis based on the spatial filter method to the detected spinal cord magnetic field distribution is superimposed to the cervical X-ray images. It is confirmed that the nervous signals go up along the spinal cord.

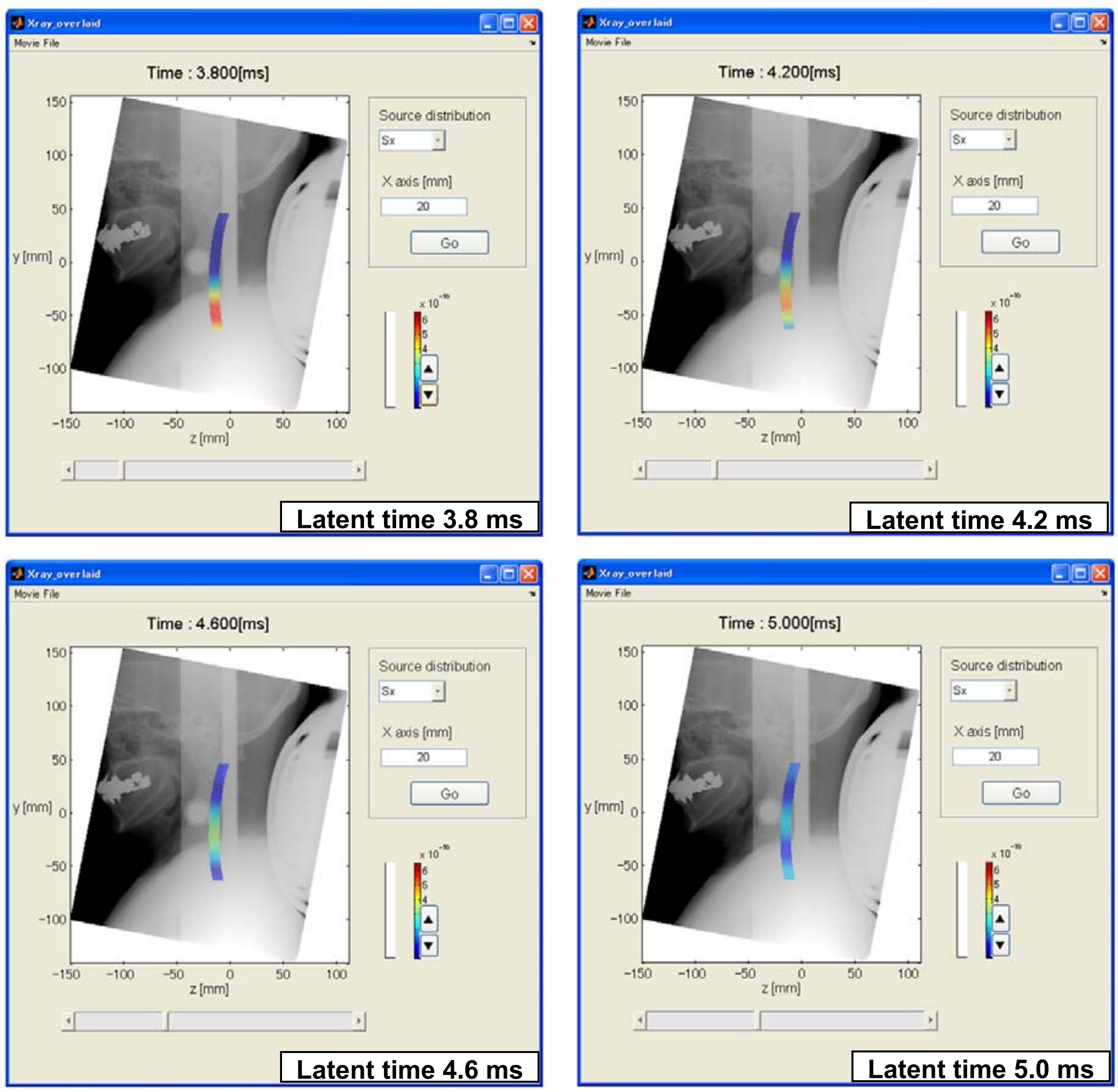


Fig. 2 Example of magnetospinography imaging (cited from Reference 3)

As described above, magnetospinography has become a system that works in clinical practice. To disseminate the magnetospinography to wider applications, research and development to reduce the cost for introduction and running cost and the development of magnetic field source analysis suitable for spinal cord magnetic field will be continued.

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Reference:

1) Y. Adachi, *et al.* “A SQUID System for Measurement of Spinal Cord Evoked Field of Supine Subjects”, IEEE Trans Applied Superconductivity, 19, 861-865, 2009.
2) T. Sato *et al*, “Functional Imaging of Spinal Cord Electric Activity from Its Evoked Magnetic Field”, IEEE Trans Biomedical Engineering, 56, 2452-2460, 2009.
3) Tomoya Sato *et al,* “Development of spinal cord functional imaging software”, Japanese Journal of Clinical Neurophysiology, 37, 123-129, 2009.

(Published in a Japanese version in the August 2010 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011
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Feature articles: Superconducting digital device
- Trend in superconducting digital device

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The worldwide trend in superconducting digital device is the reduction in power consumption. In USA, the investigation of Exa scale computer (floating-point arithmetic is made 10^{18} times in a minute) has started in order to increase the operation speed of the Peta scale computer (floating-point arithmetic is made 10^{15} times in a minute) by 1000 times. If the Exa scale computer is made up using conventional technology, however, the power consumption goes up to 3000 MW by simple calculation, which corresponds to the total power generated by a large-scale power plant. Therefore, a new innovative technology to reduce the power consumption is required to realize the Exa scale computer. This means that an innovative new technology is required for the realization of the Exa scale computer. Since it is possible for integrated circuits using superconducting devise to reduce power consumption by 1,000 times compared to the CMOS circuits, it has a potential to significantly reduce the power consumption of the high-end information equipments even if the energy required for the cooling process is taken into account.

The power consumption of normal single flux quantum (SFQ) is broadly divided into static power consumption consumed by bias resistance and the dynamic power consumption consumed when SFQ pulse passes through the junction (see Fig.1). In normal SFQ circuit, the static power consumption is about 20 times than that of the dynamic power consumption. Since the power efficiency (volume of operation per 1 W) of the SFQ circuit is sufficiently high compared to CMOS circuit, research on increasing the power efficiency of the SFQ circuit has not been so active. However, with the interface circuit for quantum computer and application to the high-end computer of Exa scale in view, research aiming at significant improvement in the power efficiency of SFQ circuit compared to the CMOS circuit has become active recently centered mainly in USA,

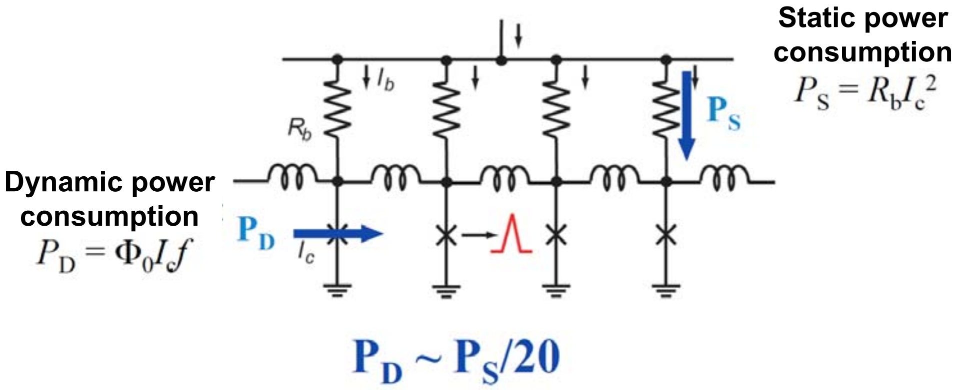

Fig.1 The power consumption of conventional single flux quantum (SFQ) circuit, consisting of static power consumption consumed by the bias circuit and the dynamic power consumption consumed by the Josephson junction itself.

One of the methods to reduce static power consumption is the LR bias method developed by the author and his group. In this method, the power consumed in the bias circuit is reduced by replacing the resistance of the current bias circuit with inductance and minute resistance. By this method, the static power consumption is reduced to a level that is comparable with the dynamic power consumption.

Herr and his group of Northrop Grumman proposed a new circuit called Reciprocal Quantum Logic (RQL). In this circuit, each gate is driven by an AC power source so that the static power consumption is completely eliminated. Corresponding to the rising up and falling down of the AC power current, the output junction of each gate is switched twice by $+2\pi$ and -2π respectively so that the net volume of magnetic flux is conserved. In RQL, since many logical gates are driven in a series by a superconducting transformer, it has a feature that the bias current of the total circuit is reduced.

Kirichenko and his group of Hypres proposed a circuit called Energy-Efficient RSFQ (ERSFQ), in which the resistance of the current bias circuit of the SFQ circuit is replaced by Josephson junction. When the SFQ pulse passes through each gate, automatic switching occurs at the junction of the bias circuit as if to compensate it. This reduces the power consumption in the bias circuit to the level of dynamic power consumption at logical gate. Furthermore, since ERSFQ is prepared by replacing the current bias circuit in the conventional SFQ circuit, it is advantageous in that existing asset is utilized.

The above-mentioned methods are attempts to reduce the static power consumption of the circuit and the total power consumption is reduced to about twice the static power consumption of the logical gate. On the other hand, there are proposals to reduce the dynamic power consumption itself of the circuit.

Semenov and his group of Stony Brook University proposed a logical gate that enables reversible calculation using a special SQUID called negative inductance SQUID (n SQUID) in which the two inductances in the SQUID loop are joined in reversed polarity. It is said that the dynamic power consumption of the circuit is reduced to the level of thermal noise.

The author and coworkers are proposing Adiabatic Quantum Flux Parametron (A-QFP). This circuit reduces the dynamic power consumption to the level of thermal noise by operating QFP slowly and adiabatically.

As described above, the superconducting digital circuit technology is now attracting attention as a technology that reduces the power consumption of the integrated circuits to one thousandth to one millionth of the CMOS circuit. The progress in the future is really attracting attention.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

Superconductivity Web21

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Feature Articles: Superconducting digital device - Fabrication of asymmetric nanobridge and application to rectifier circuit

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Nagoya University

Since the advanced process in which the number of Nb layers was increased from four to nine was established by Superconductivity Research Laboratory (ISTEC-SRL), the integration density of single flux quantum (SFQ) was increased by four-fold, and the operating frequency is approaching 100 GHz. It is expected that the SFQ integrated circuit that consists of 100,000 or more Josephson junctions is realized soon. The problem here is the method to supply power source to the SFQ circuit. The SFQ circuit is driven by a DC power source. Although the power consumption is only about 10 mW for a circuit consisting of 100,000 Josephson junctions, the current goes up to several amperes. If the DC current is supplied directly from the power-source circuit at ambient temperature, the power consumption in the power-source circuit cancels out the power saving in the SFQ circuit. This is because the output impedance of the power-source circuit is greater than the load impedance, which is the input impedance of the power source of the SFQ circuit. One method to avoid this is the impedance transformation using a transformer. To constitute a power-source circuit for the SFQ circuit, the diode voltage generated in the circuit should be under 1 mV. However, since such a diode does not exist, this method has been neglected. Taking the final form of use into consideration, large current capacity, high speed that keeps pace with the microwave frequency, and small occupying area are required in addition.

We proposed a high-temperature superconducting asymmetric nanobridge as a diode that satisfies these conditions and conducting operation verification. The nanobridge is a fine wire whose width is less than the magnetic field penetration length, and it functions as a nanogate that allows one vortex to pass at a time. It operates faster as the wire becomes thinner and a higher voltage is generated. Fig.1 shows the photograph of a microscopic asymmetric nanobridge fabricated by using $YBa_2Cu_3O_y$ thin film. The width of the bridge is 100 nm. A new fabrication method that repairs damage was used, and the barrier height (surface barrier) felt when the vortex enters the nanobridge was made different on the both sides by obtaining an asymmetric configuration. By doing so, the position at which the vortex enters is fixed. In Fig.1, the position is shown at the constricted part on the right-hand side. By applying external DC magnetic field B_e, orientation and running direction of the vortex are decided. This fact is confirmed by the phenomenon in which the critical current in the positive direction and that in the negative direction differ on the Current-Voltage (*I*-*V*) characteristic and is called as the ratchet effect. In the experiments in which the wire width and film thickness were changed, the critical current was within the range of 2 mA to 12 mA when magnetic field was not applied, and the maximum decreasing rate in the positive direction was 16 % at maximum (the increasing rate in the negative direction was the same) when magnetic field is

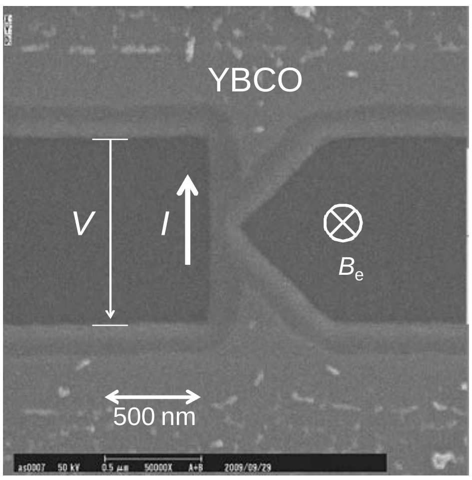

Fig.1 Electron microscope photograph of an asymmetric nanobridge

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applied.

Obviously, in order to use it as a diode for the above-mentioned rectification, it is necessary to make the decreasing rate of the critical current to almost 100 %. To realize this, it seems to be effective to construct the asymmetric nanobridge by parallel array accompanied by small loops, and we are carrying forward this research. Since the ratchet effect is an effect that cannot be obtained by Josephson junctions, we intend to develop the application of this effect in a positive manner.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

Superconductivity Web21

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Feature Article: Superconducting digital device
- Reduction in the power consumption of superconducting single flux quantum (SFQ) by improving fabrication process

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Low Temperature Superconducting Device Laboratory
SRL/ISTEC

The superconducting single flux quantum (SFQ) circuit is a device that achieves high speed and low power consumption at the same time, which no other technology can realize. However, in the recent pursuit for lower power consumption, still more reduction in power consumption is required. In addition, it is said that the power consumption of the present SFQ circuit is too high when used as the periphery circuit of superconducting detector or quantum bit and the reduction in the power consumption is strongly required. This paper discusses the reduction of SFQ circuit power consumption from the viewpoint of the fabrication process of the Nb integrated circuit.

The power consumption P of the SFQ circuit is expressed by the following equation:

$$P=N(\alpha f\Phi_0 I_c+I_b^2R_b) \quad (1)$$

Here, N is the number of Josephson junctions (JJ), α is the switching probability, f is the operating frequency, Φ_0 is the value of SFQ (2.07×10^{-15} Wb), I_c is the critical current value of JJ, I_b is the bias current, and R_b is the bias resistance. Let me point out that equation (1) is a rough estimation because JJs with different values of I_c exist in the actual SFQ circuit, and one bias line does not necessarily corresponds to one JJ. The first term stands for the dynamic power consumption consumed every time SFQ passes through JJ. The second term is the power consumption consumed by the bias resistance for distributing bias current to each JJ, which is static power consumption constantly consumed regardless of the SFQ circuit operation. By substituting $\alpha = 0.5$, $I_c = 0.2$ mA, $I_b = 0.14$ mA (70% of I_c), $R_b = 18\ \Omega$, which are the typical values of the present SFQ circuit in equation (1), the power consumption at f = 40 GHz is estimated to be approximately 360 mW even in a large-scale SFQ circuit of N = 1 million. This value is significantly less than that of other devices such as CMOS. As for the ratio between the dynamic power consumption and static power consumption under this condition, the static power consumption is larger by 40-fold or more. When the operating frequency is decreased, the ratio still increases remarkably.

Equation (1) shows that it is necessary to reduce the values of I_c and R_b in order to further reduce the power consumption of SFQ. The value of I_c is determined by the condition that the minimum value is sufficiently large compared to the thermal noise. Since the thermal noise is about 0.2 μA at 4.2 K, at which the Nb devices are operated, the minimum value of I_c is set to 0.1 mA, which is 500 times larger than the thermal noise. However, there is still room to reduce the value and the operation of the SFQ circuit will not be affected much even when the minimum I_c is set to 0.02 mA, which corresponds to one-hundredth of thermal noise. Since the operation speed of the SFQ circuit reduces if the critical current density of JJ is decreased, it is necessary to reduce I_c by reducing the area of JJ. To reduce the area of JJ, improvement in the fine fabrication technology and fabricating technology such as the connection of miniature JJ and upper-wiring is necessary. Furthermore, it is necessary to keep the value of LI_c, product of I_c and the inductance of the superconducting ring L, constant in the SFQ circuit so that L must be increased as I_c decreases. To avoid the direct increase in circuit area due to the increase in L, improvement in the fabrication to increase the value of *L* per unit length is effective.

R_b has the role to prevent the current reflected at the time of switching of JJ from entering other JJs through the bias line. Therefore, it is possible to reduce the high frequency current from entering other JJs by inserting a large inductance into the bias line. Although a small amount of R_b has to be actually retained to a certain extent, reduction by 90% is very possible. However, relatively large inductance must be used, and significant increase in the circuit area is an issue of concern. To solve this problem, the multi-layer structure developed by ISTEC seems to be effective. Ten layers of Nb have been successfully formed so far, which makes it possible to suppress the increase in the circuit area by forming the inductance for the bias line in the layers different from those of the SFQ circuit.

By reducing the values of I_c and R_b by 1/5 and 1/10, respectively, the power consumption of the above-mentioned SFQ circuit with a million JJs operating at 40 GHz is reduced by 1/120 to 3 mW. Since the static power consumption is remarkably reduced by 1/250, the impact is significant in the low-operation-speed area, where the static power consumption is dominant. In the case of operating speed of 10 GHz, for example, the power consumption is 1.8 mW, which is about 1/200.

Research on low power consumption SFQ circuit is being conducted actively not only in Japan but also in Europe and USA, and several new circuit structures have been proposed. However, as described in this paper, it is also possible to significantly reduce the power consumption of the SFQ circuit by improving the fabrication process of conventional circuit structures without bothering the operation speed and integration level.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011
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Feature Articles: Superconducting digital device
- Development of an optical IF module in 1550 nm band for SFQ circuit operation

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Because the superconducting single flux quantum (SFQ) logic circuit operates at high speed with low power consumption, it is expected to be used in various applications including network devices. Since the SFQ circuit operates at a very low temperature, its packaging technology into the refrigerator including input/output (I/O) signal link is a key technology for a practical application. Although the packaging technology to refrigerators has progressed in these several years[1)], the limit of electrical signal bandwidth in I/O link and thermal load to the refrigerator through a large number of coaxial cables have become a critical issue. Therefore, the optical interface using optical fiber having sufficiently wide signal transmission band and very low thermal conductivity is attracting attention. Hashimoto *et al* of Superconductivity Research Laboratory (SRL/ISTEC) and his group demonstrated the optical signal input to the SFQ circuit using commercial photo diode (PD) in the communication wavelength band 1550 nm[2)]. However, there has been no research and development of the optical interface in which multi-channel optical input for the use of ultra-low temperature operation.

National Institute of Information and Communication Technology is developing optical input module, shown in Fig.1[3)]. PD and superconducting microstrip line are integrated on multi-tip module (MCM) carrier and the SFQ circuit is connected with the MCM carrier by flip-chip bonding. By integrating many PDs on the MCM carrier, compact implementation of multi-channel signal inputs can be achieved in the limited packaging space of the refrigerator. We used metal-semiconductor-metal (MSM) PD which allows high-speed response and easy access by optical fiber due to its planar structure. The $In_{0.53}Ga_{0.47}As/InP$ epitaxial wafer, which has a gap wavelength suitable for the detection of 1550 nm band optical signals, was used as the MCM carrier.

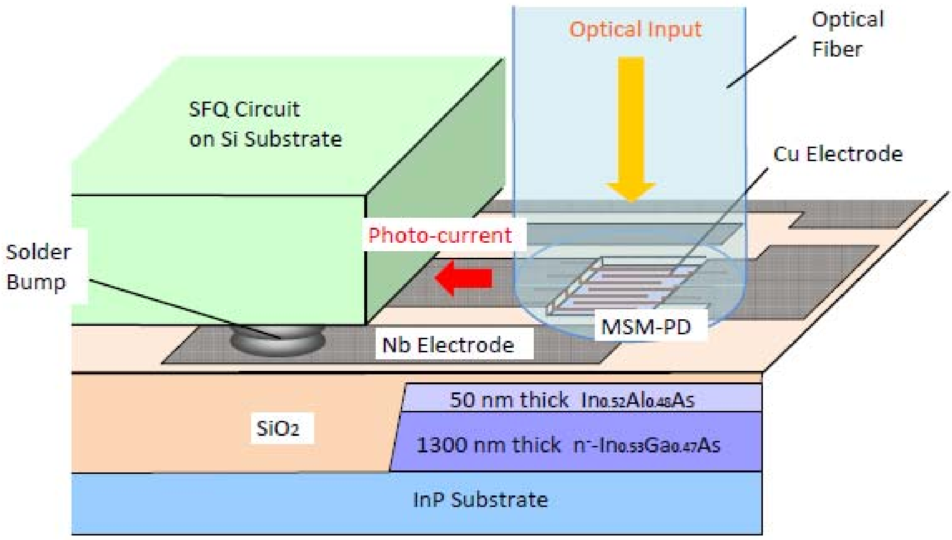

Fig. 1 The schematic diagram of a 1550 nm optical IF module

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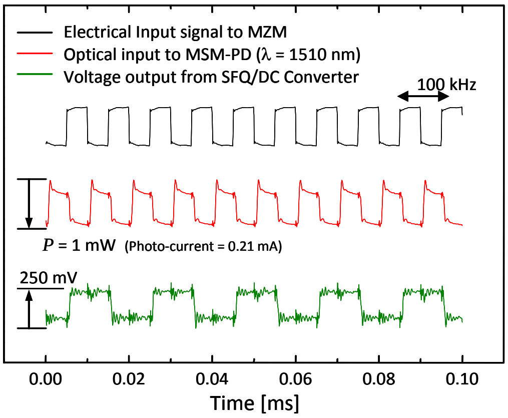
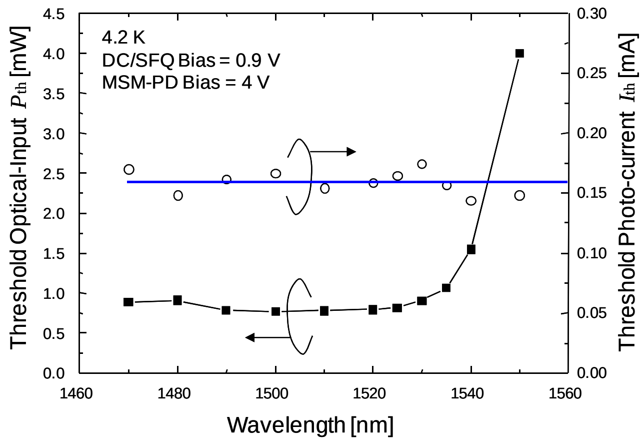
Fig.2 shows the results of the functional test of the fabricated optical module. As shown in Fig.2 (a), the successful conversion of the rectangular optical pulses with a repetition frequency of 100 kHz to SFQ pulses was confirmed. Fig.2 (b) shows the optical-wavelength dependence of the optical input amplitude (not the average power, but the peak amplitude of the optical pulse) required for the generation of the SFQ pulse. Although the optical amplitude required for the generation of the SFQ pulse was about 0.75 mW, up to the optical wavelength of 1530 nm, the optical amplitude drastically increased above 1530 nm. This is because the optical sensitivity of MSM-PD at 4 K rapidly decreases at a wavelength of 1530 nm or longer. To improve the optical sensitivity at ultra-low temperature at 1530 nm or longer wavelength, $In_{0.56}Ga_{0.44}As$ with increased in content was tested, in which the optical sensitivity at 1530 nm or longer significantly increased. Thus it was confirmed that the optical sensitivity of 0.1 A/W can be achieved in the whole area of C band (1530 nm–1570 nm) in DWDM (Dense Wavelengths Division Multiplexing) optical transmission. The power consumption of the PD is expected to be 0.5 mW or lower and we are considering a device with 50-fold or more advantage based on the heat inflow of 25 mW per coaxial cable. The refrigerating system for the high speed test of the fabricated optical input module is being constructed at present.



(a) Output waveform for rectangular optical input



(b) Wavelength dependency of the optical pulse required for the generation of SFQ pulse

Fig. 2 The results of the functional test of optical IF module, an output waveform for rectangular optical input

Reference:

1) Y. Hashimoto, S, Yorozu, T. Miyazaki, Y. Kameda, H. Suzuki, and N. Yoshikawa, IEEE Trans. Appl. Supercond., 17, 546 (2007).
2) Y. Hashimoto, H, Suzuki, M. Maruyama, K. Fujiwara, and M. Hidaka, Electron. Lett., 45, 87 (2009).
3) S. Shinada, H. Terai, N. Wada, and Z. Wang, Appl. Phys. Lett. 96, 182504 (2010).

(Published in a Japanese version in the October 2010 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

Superconductivity Web21

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Feature Articles: Superconducting digital device
- Integration of single flux quantum circuit and optical waveguide

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By combining single flux quantum (SFQ) circuit that provides information processing at high speed and ultra-low power consumption with an optical circuit that enables ultra-high speed, and low power consumption interconnection, a basic technology can be constructed for a high performance information processing system that can handle future explosive increase in the information processing volume.

Fig.1 shows a diagram of the superconducting integrated optical circuit combining these technologies. The optical signal entering the integrated optical circuit from optical fiber is processed by an optical device such as wavelength demultiplexer, and distributed to each SFQ chip using an optical waveguide. The optical signal is converted to electrical signal by opto-electro (O-E) converter and input into the SFQ chip. This technology that combines the advantages of the optical circuit and the superconducting circuit is expected to become a basic technology for future optical router and supercomputer.

In the past, diversified low-loss, multi-functional optical devices have been developed using silicon optical integrated circuit technology. Although a dedicated silicon processing is usually used for the optical integrated circuit, we used a superconducting integrated circuit process, which is an approach different from the conventional method, for the fabrication of the optical waveguide.

The left-hand-side diagram in Fig.2 shows the metal-clad optical waveguides of different lengths fabricated using the standard Nb process (STD2) of ISTEC. The optical waveguide consists of a lower Nb clad, a SiO_2 core, and an upper clad of air. The thickness of SiO_2 core is 1.2 μm. These layers were stacked using three insulating inter-layers (thickness: 3 μm, 0.4 μm, and 0.5 μm each).

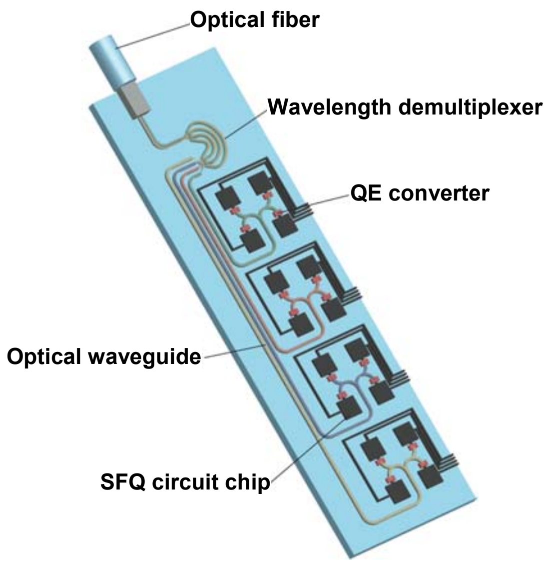

Fig.1 Image of superconducting optical integrated circuit

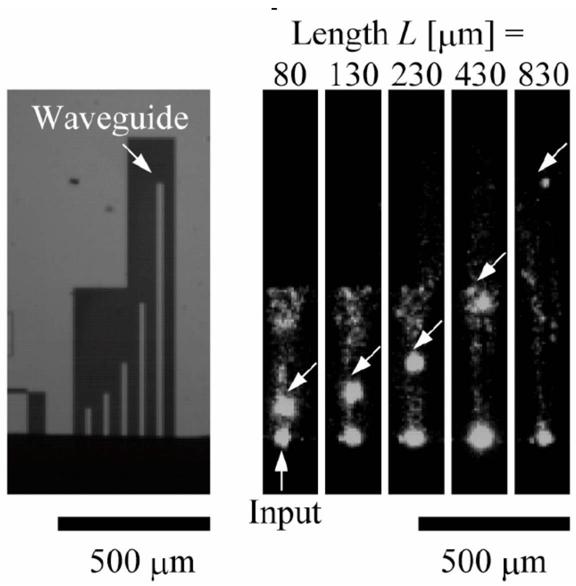

Fig. 2 Metal clad optical waveguide fabricated by using the superconducting integrated circuit process (left-hand side), and the scene of optical propagation in the metal-clad optical waveguide (right-hand side). The way in which the light entering at the bottom of the waveguide moves upward in the waveguide is clearly seen.

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The right-hand side-diagram in Fig.2 shows the propagation characteristics of the metal-clad optical waveguide, which was made by using the superconducting integrated circuit process. The way in which the light entering at the bottom of the waveguide moves upward in the waveguide is clearly seen. The size of the optical spot indicates the size of the optical output, and the optical output decreases as the length of the optical waveguide increases. From the results of the experiment, the propagation loss per unit length of the metal-clad optical waveguide was estimated to be 16 dB/mm. This propagation loss is greater than that of an optical waveguide made of Si core and SiO_2 clad. This is because the refraction index of Nb has an imaginary part. However, an optical waveguide up to about 1 mm long is sufficiently usable and applications such as optical signal input to the superconducting devices are expected.

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Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

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Feature Articles: Superconducting power device
- Trend in the development of superconducting power device

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The research and development of the superconducting power devices in Japan is mainly conducted under NEDO projects supported by the Ministry of Economy, Trade and Industry. At present, the "Technological Development of Y-based Superconducting Power Equipment (M-PACC : Material & Power Applications of Coated Conductors)" project (FY2008 to FY2012) and "High-temperature Superconductor Cable Verification Project" (FY2007 to FY2012) in which Bi-based superconducting wires are used are under way.

The basis of the M-PACC project is to develop a process technology for fabricating the Y-based superconducting wires and the development toward the commercialization of superconducting magnetic energy storage (SMES) system, cables, and transformers using these Y-based superconducting wires is also being promoted.

In "High-temperature Superconductor Cable Verification Project" the construction of a cable system integrating the technologies for cables using the Bi-based superconducting wires and refrigeration is aimed at, and a verification test using actual 66 kV electric power system to verify not only a cable system, but the comprehensive reliability of the total system including operation and maintenance is planned.

In USA, the research and development of the superconducting power devices is being conducted, supported mainly by Department of Energy (DOE), and demonstration programs including the verification of cables using the Bi-based superconducting cables have been conducted. Furthermore, a program on cable and current limiter was carried out in the new superconducting power device project (SPI Project) sponsored by DOE, and the demonstration test of the superconducting devices developed in this program is being verified by using actual electric power system. Last year, the promotion of a program for superconducting transformers provided with a current limiting function as part of technical development related to smart grid was announced in November, and a three-year project for developing SMES of 3.4 MJ using the Y-based superconducting wire was started.

In European research and development of superconducting power devices, projects sponsored by European Union (EU) or governments, and the projects promoted by private companies are mixed up. In the European Commission's 6th Framework Program (FP6), the trial production of the Y-based superconducting cable and functional verification project (Super 3C) were implemented. Under the present 7th Framework Program (FP7), a demonstration project for the Y-based superconducting current limiter (ECCOFLOW) started in January 2010. Furthermore, European companies such as Siemens, Nexans, and Zenergy are conducting research and development by taking part in the above-mentioned development program in USA for cable and current limiter.

Other than USA and Europe, as described above, development is being accelerated in China, Korea, and New Zealand. In Korea, in particular, the superconducting power devices including the cables, transformers, and high-temperature superconducting wires under the 10-year DAPAS program that started in 2001 assisted by the government are being developed. Korea Electro-technology Research Institute (KERI) and private SuNAM are in charge of the development, and SMES using the Y-based superconducting wires is being developed in parallel. In addition, 5-year GENI program funded by Korea Electric Power Corporation (KEPCO) started in 2009, in which the cable and current limiter using the

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Y-based superconducting wire are being developed, and the demonstration test using an actual electric power system is scheduled in 2011.

This paper introduced the outline of the trend in the recent superconducting power devices in Japan and outside Japan. In the following reports, the person in charge of each project will explain the status of development of the superconducting power devices (SMES, power cable, and transformer) in Japan.

(Published in a Japanese version in the November 2010 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

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Feature Articles: Superconducting power device -Technical development of SMES

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Among the power devices using superconductivity technology, SMES, different from other devices such as power cable and transformer, is a device that applies the intrinsic feature of superconductivity. Since the function and applications are not only a simple replacement of the conventional devices but also its function as an energy buffer is indispensable in enhancing the diversity and flexibility of the electric power network, and it is one of the key technologies for the protection of the global environment.

Until now, the technical development of SMES was focused on the control system of electric power network and metallic superconductors have been successfully used for the compensation of momentary voltage drop, which is the only commercialized superconducting power device.

However, the superconducting devices, not only SMES, are special devices that require ultra-low temperature, and there are restrictions relating to not only the cost but also the operation and maintenance. Therefore, further technical innovation is required to realize the widespread applications.

High-temperature superconductors, YBCO superconductors in particular, have excellent magnetic field characteristics, and provide SMES with advantageous high-magnetic field at a low cost with a high performance. In addition, since the substrates with high-mechanical strength can be used for the wire, it solves the problem of a high-hoop stress in the coil for obtaining a high-magnetic field.

Following Japan, USA and Korea are developing the compact high-magnetic-field SMES utilizing the high mechanical strength of the YBCO-coated superconducting wires. In all the three projects of Japan, USA, and Korea, the basic structure of the SMES coil is a high-magnetic-field type of toroidal arrangement, and the structure and constitution are in common with the one that has been developed in Japan. This seems to indicate that the constitution is the best way to make the most of the characteristics of the present YBCO-coated wires such as the angle dependency and wire shape.

The function required for the superconducting in SMES is the capacity that can store as much magnetic energy as possible. Since the energy storage density of SMES is less as compared to the other electric–power-storage technology, high-magnetic field is effective for higher storage density and downsizing. The downsizing of the superconducting devices leads to low load on the cooling system, which further leads to significant cost reduction including running cost.

For the dissemination of the superconducting devices including SMES, not only the technical progress but also the function and benefit of the device must overweigh the cost. Particularly, the merit of the cost is required. If these conditions are not met, there may be a possibility for the commercialization in special areas, but widespread applications are impossible.

While the advantage of SMES has been the large output that can be easily realized compared to energy storage, the use of the YBCO-coated superconducting wire enables large capacity under high-magnetic field. However, the number of wires required in the system increases significantly. There remaining matters of research about the YBCO-coated superconducting wire and the cost are not satisfactory yet. Furthermore, the reduction in the wire cost (¥/Am) by increasing the apparent value of I_c taking A/m as index may not be actually reflected in the device cost.

The development of the devices and the development of the wires are two sides of the same coin. In other countries, wires are going to be commercialized by mass production so that the development of the devices is accelerated. From now on, it is necessary to promote the evaluation of feasible technology and the cost on an industrial basis—not simply technical possibility or characteristics.

The NEDO project that started in 2008 is generally divided into two stages. In three years of the first stage, the technology for constructing high strength, high-hoop stress coil making use of the wire strength, which is the feature of the SMES coil system, and the technology for constructing the conduction cooling system are developed; in the second stage, the characteristics of the conduction cooling SMES coil is evaluated in order to confirm the marginal performance (such as durability and reliability) of the coils using the YBCO-coated superconducting wires aiming at the development of large-capacity SMES for the control of the electric power system of 2 GJ class in the future.

Although the target of the development of high-strength, high-hoop-stress coil was 600 MPa, which is twice more than the yield strength of the conventional metallic coils, a value of 854 MPa has been obtained in the verification test (Fig.1). It is now scheduled to study the effects of wire structure and constitution on the coil performance in order to optimize the coil structure. Furthermore, a cooling system partially using gas cooling piping was constructed (Fig.2), and a high-thermal conduction cooling system that enables the heat flow ratio of 21 W/m^2 at 20 K was successfully developed. The value of 21 W/m^2 significantly exceeds the value of 3 W/m^2, which can be obtained by the present technology.

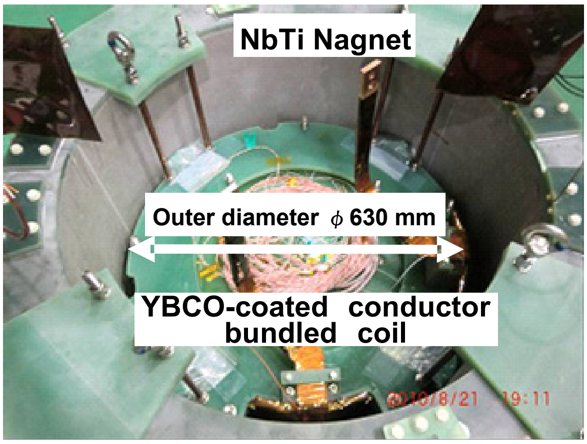

Fig.1 High-hoop-stress test (YBCO-coated conductor bundled coil inserted in NbTi backup magnet, tested at 4.2 K)

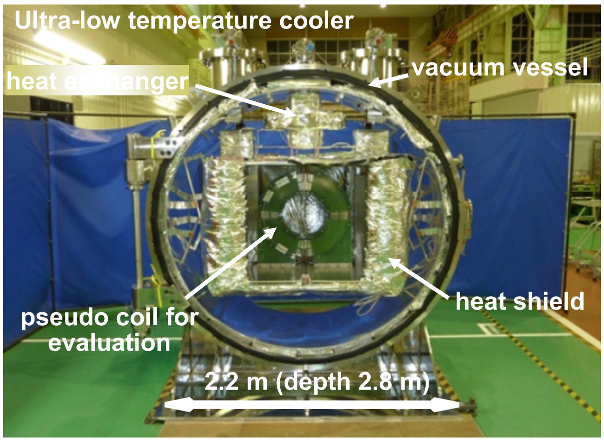

Fig. 2 Cooling system for SMES coil

(Published in a Japanese version in the November 2010 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011
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Feature Articles: Superconducting power device
- Development of Bi-based superconducting cable

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The national project "Demonstration project for the high-temperature superconducting cable" is under way with a target to implement the transmission verification test of the superconducting cables in real electric power system. The duration of the project is six years starting from FY 2007, and the project is relegated by Ministry of Economy, Trade and Industry and New Energy and Industrial Technology Development Organization (NEDO) to three companies—Sumitomo Electric Industries, Mayekawa Mfg. Co., and Tokyo Electric Power Co.

In the first two years of the project, elementary technologies for superconducting cable were developed. Specifically, favorable results have been obtained in the development of the technology to reduce the AC loss at AC2 kA to 1 W/m or less per phase, the technical development of the terminal and the joint of a large-capacity cable indispensable for practical use, and the verification of the stability of fault current and recooling characteristics. Favorable results have been obtained in the verification tests using short-length model cables.

In 2009, the preliminary verification test was implemented using a superconducting cable of 30 m prior to verification test using the actual electric power system. Fig.1 shows a schematic diagram of the test system. It consists of three-in-one superconducting cable having a 90° bend with a bending radius of 5 m. Intermediate joint is provided in a space simulating a manhole in real grid. These systems are cooled by circulating coolant, and various tests are being conducted. Until now, the performance verification tests including critical current measuring test, insulation performance test, loss measuring test as well as long term loading test of one month have been implemented. These tests proved that the superconducting cable has the design characteristics. In addition, severe tests such as heating and recooling test and the verification of characteristics under excess current have been conducted to confirm the stability of the superconducting cable. The results, so far, were assessed by Intermediate evaluation subcommittee of NEDO, and the continuation of the project was approved because of the favorable results.

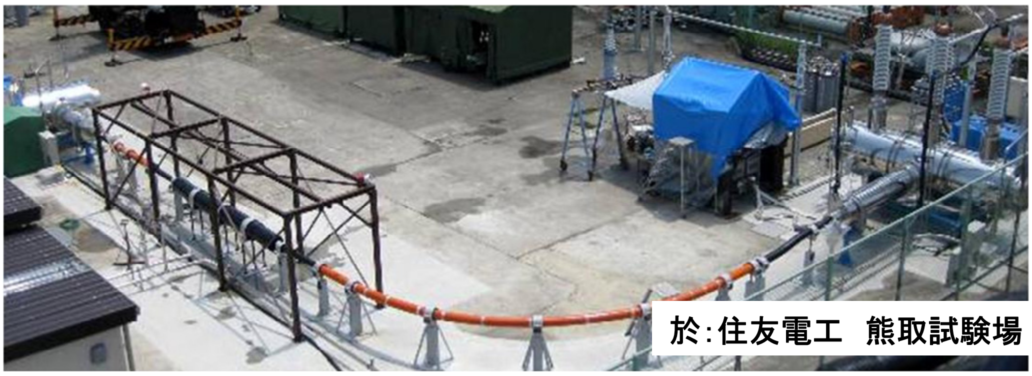

Fig.1 Appearance diagram of 30-m test system: at Kumatori test site of Sumitomo Electric Industries, Ltd.

Winter, 2011 Date of Issue: January 17, 2011
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In 2010, the confirmation of basic performance of the cooling system for Asahi Substation and the operation control of several refrigerators and pumps are being implemented. The outline of the total test is shown in Fig.2. Site preparation started in 2010; the installation of the superconducting cables and cooling system will start in 2011; and the verification test is scheduled to start in the autumn of 2011.

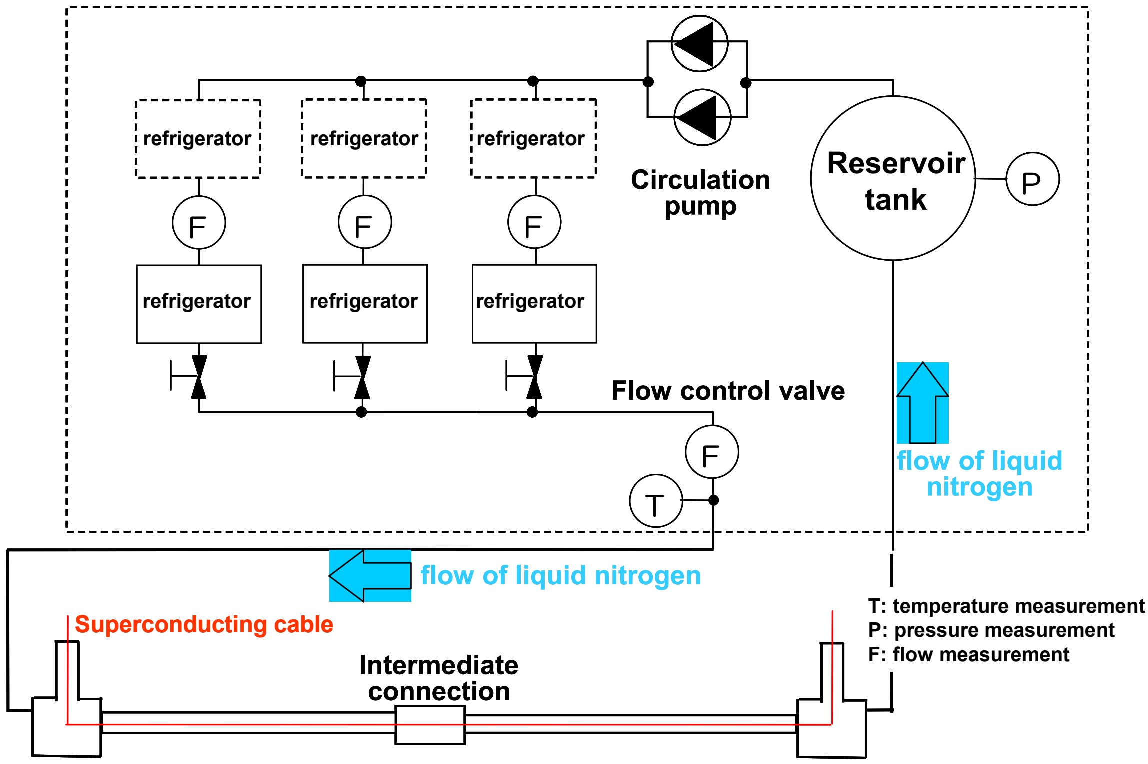

Fig.2 The outline of the entire cooling system verification test

(Published in a Japanese version in the November 2010 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011
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Feature Article: Superconducting power device
- Development of 66-kV-class REBCO superconducting power cable

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In urban areas where no land space can be spared for building pylons, underground power cables are used to transmit electricity. Quite a few underground cables are in overload condition at the peak of power demand as the power demand is concentrated in urban areas. Since it has become difficult to construct new conduits and cable tunnels because of the overcrowded underground space, the commercialization of superconducting cables that enable the large-capacity power transmission using existing conduits is expected.

With such background, in "Technological development of yttrium-based superconducting power equipment" project (2008–2012), a 66-kV/5-kA-class "3-in-One" superconducting cable (Fig.1) has been developed using REBCO wires. The superconducting film is formed by PLD (pulse laser deposition) method on a textured metal substrate. REBCO wires have a higher critical-current density compared to BSCCO wires, and the AC loss subjected to a parallel magnetic field is extremely smaller because of the thin-film structure of the superconducting layer. Therefore, the superconducting cable with large-capacity and low-loss is expected to be developed. The targets of this project are as follows:

- AC loss: less than 2 W/m/ph @ 5 kA (less than one thirds of conventional cables)
- Maximum fault current: 31.5 kA, 2 sec (standard of 66-kV-class circuit breakers)
- Compactness: to be installed in the existing conduits of 150 mm Φ.

Fig. 1 Manufactured "3-in-One" superconducting cable sample.

Until now, model cables were fabricated using narrow REBCO wires (width: 2 mm and 4 mm) and measured AC losses were compared with simulation results. These results were fed back to the wire and cable designs, and the AC loss of 1.5 W/m @ 5 kA was achieved (see Fig.2). The final target of AC loss as 2 W/m/ph @ 5 kA will be achieved in this fiscal year. Next, a 10-m-long 3-cores sample (see Fig.1) was experimentally manufactured under the same conditions as actual products. The fault current tests (Max. 31.5 kA, 2 sec) were conducted for cable samples to be verified their soundness. Furthermore, 5-kA-class current leads for cable terminations were developed, and the 5-kA loading tests were successfully finished.

The project is now in the third year of its 5-year plan. The development of the elementary technologies will be completed within 2010. A 15-m-long cable will be manufactured in 2011, and the long-term system operation at the test yard will be conducted in 2012.

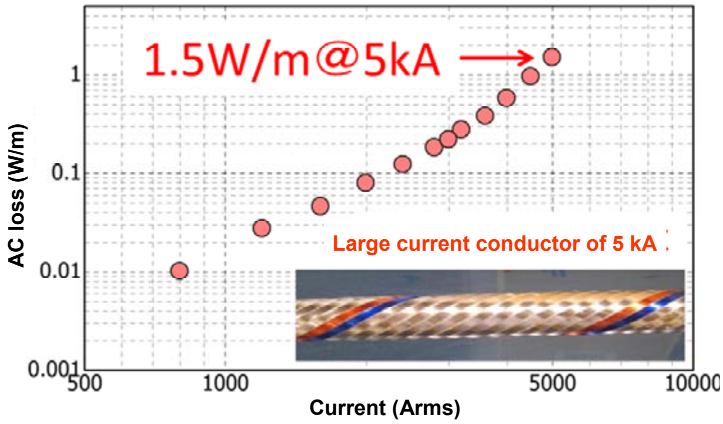

Fig. 2 Measured AC loss of a large current conductor

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Top of Superconductivity Web21

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Feature Articles: Superconducting power device
- Development of 275-kV Y-based superconducting cable

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A major target of high-temperature superconducting development in Japan has been in 66 kV/77 kV class voltage. Since the cables with a capacity comparable with that of CV cable and OF cable of 275 kV class used in 150 mm conduit line can be produced using 66 kV/77 kV superconducting cable, it is expected to be the replacement for the underground transmission cables when they get aged in the future.

275 kV Structure of the superconducting cable

In the electric power system of Japan, the voltage of the electric power generated in the power stations located in suburbs is increased to 500 kV or 275 kV and transmitted to transmission network through overhead power line installed in the power station. Then the voltage is decreased to 275 kV at the core substations in the urban neighborhood, and the power is sent to the urban areas through the 275-kV underground cables. To reduce the global greenhouse gas in the future, it is important to reduce the loss in the transmission line, and the use of superconducting cables as high-voltage transmission cables is considered to be effective for this purpose. Therefore, as a part of "Technical development of yttrium-based superconducting power device" sponsored by New Energy and Industrial Technology Development Organization (NEDO), Superconductivity Research Laboratory, Furukawa Electric, SWCC Showa Cable Systems, Fujikura, Kyoto University, Waseda University, and Nagoya University are developing a high-voltage cable of 275 kV/3 kA. In the development of a high-voltage superconducting cable, it was necessary to start with basic the investigation of electric insulation at 275 kV, which is the highest target voltage in the world. There was an expected problem that thicker electric insulation might cause trouble in conductor cooling, which required reduction in AC loss more than ever.

In an attempt to reduce the AC loss, it was tried to homogenize the critical current distribution in the wire by setting the width to 3 mm and by winding the wire finely on the former, thus eliminating the gaps because a numerical analysis indicated that the AC loss of the conductor of the superconducting cable constructed by winding YBCO tape is affected by the gaps between the wires, and the decrease in I_c at the end of wire. As a result, the low loss of 0.235 W/m @ 3 kArms was obtained in 3 kA energization, which is the lowest AC loss in the world.

As for the electric insulation, considering that the point of design in the electric insulation of the superconducting cable is the partial discharge, rational electric insulation design with low dielectric loss is being attempted based on the clarification of the mechanism of partial discharge generation, precise measurement of the electric field generated by partial discharge, and the accumulated electric field values. To accumulate the design data, an outdoor termination is prepared, to which a voltage of 300 kV level can be applied, to test the superconducting cable models provided with the insulator of 10 mm to 20 mm thick and implement impulse test. It has been confirmed that the superconducting cable modes provided with an electric insulator of 20 mm thickness stands the application of 320 kV for 10 min, and it is intended to establish a high-voltage insulation technology including reliability.

In addition to the reduction in the AC loss and high-voltage insulation, other technologies required for the realization of a 275-kV superconducting cable including short circuit current protection at 63 kA-0.6 s are being developed. Utilizing the basic technologies and elementary technologies that have been accumulated, the tests of 30 m long models are scheduled in the latter two years of the project.

(Published in a Japanese version in the November 2010 issue of *Superconductivity Web 21*)

Top of Superconductivity Web21

Winter, 2011 Date of Issue: January 17, 2011

Superconductivity Web21

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Feature Articles: Superconducting power device
- Technical development of superconducting power transformer
- consistent progress toward establishing commercialization technology

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Kyushu Electric Power Co.

In the technical development of superconducting transformers being promoted as a part of "Technical development of yttrium-based superconducting power device" (hereinafter referred to as Y-based project), elementary technologies and system technologies are being developed with Kyushu Electric Power Co. acting as the leader, in cooperation with Kyushu University, Iwate University, International Superconductivity Technology Center (ISTEC), Fujikura, SWCC Showa Cable Systems Co., Taiyo Nippon Sanso Corporation, Japan Fine Ceramics Center (JFCC). In the intermediate assessment subcommittee for the Y-based project held in September, the consistent progress of the project, the short circuit test by Y-based superconducting transformer, which was the first case in the world, and the current limiting function, which is a newly found function, were reported (see October issue of Superconductivity Web 21 for details).

In this project, the following subjects have been investigated; (1) technical development of winding, (2) technical development of the cooling system, (3) technical development of the transformer provided with current limiting function, (4) technical development of stable supply of the wires for the transformers, (5) design of the superconducting model transformer of 66 kV/6.9 kV-2 MVA and superconducting transformer of 66 kV/6.9 kV-20-MVA class for distribution. At the present stage, the steady-going results have been obtained except for the part of the stable supply of thin wire. (Fig.1, Table 1). As the favorable results have been obtained, the fabrication of thin wires of IBAD-MgO substrate (hereinafter referred to as MgO substrate wire) and the winding test were added in the tests from the viewpoint of cost reduction, which also showed good results. In the basic verification of current limiting function, sufficient function as theoretically anticipated was obtained. Based on these favorable results, the research on wire fabrication process was extended by one year in order to insure the stable supply of MgO substrate wires, and the trial production of the current limiter model was brought forward by one year instead.

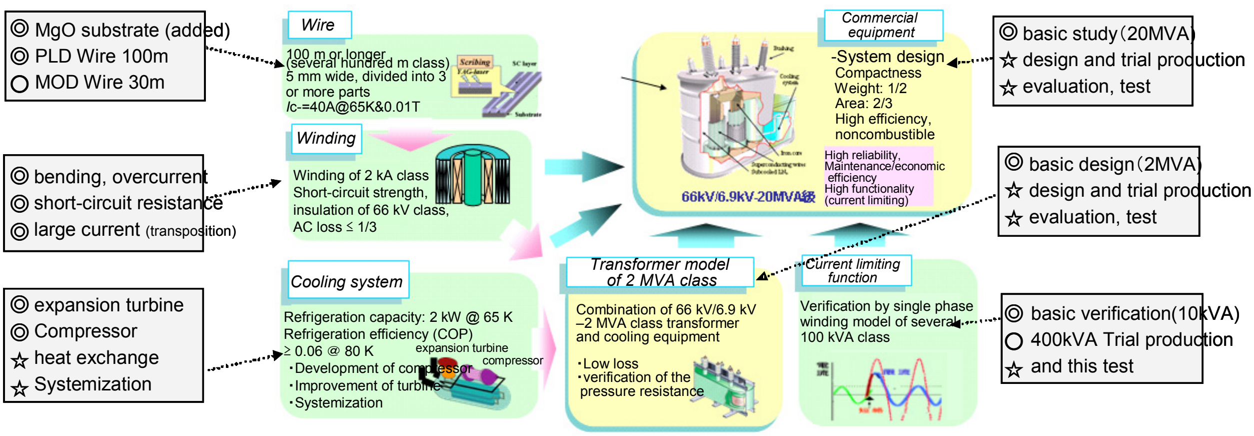

Fig.1 Status of the achievement on the technical development of superconducting transformer (◎intermediate target achieved, ○will be achieved within this fiscal year, ☆will be achieved by the end of project)

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Table1 Major results in the technical development of superconducting transformer

	Intermediate target (by end of 2010)	Result	Future plan
Technical development of winding	Verification of short-circuit strength (corresponding to 20 MVA, %Z, 15%) Establishment of optimum technology for transposition	・Soundness six times the rated short-circuit current was confirmed by a short-circuit model of 400 kA. ・It was confirmed that the deviation is 14% or less in transposition homogeneous current model.	
Technical development of the cooling system	Expansion turbine: turbine: adiabatic efficiency: ≥65% Turbocompressor: adiabatic efficiency: ≥65%	・Expansion turbine efficiency is approximately 70%. ・Turbocompressor efficiency is approximately 68%. ・Downsizing of the heat exchanger was confirmed by analysis. ・Simplification of the cold-heat-transfer structure was confirmed by analysis.	
Technical development for providing the current limiting function	Verification of the current limiting function by transformer winding model Trial production of several hundred kVA class transformer	・Current limiting function was confirmed by winding model. ・400 kVA transformer provided with a current limiting function was designed utilizing the test results. Trial production was brought forward (added).	Trial production of the transfor-mer (2010)
Technical development of stable fabrication of the wire	Stable production: tripartition to 5 mm width, 100 m or longer (Ic = 40 A @ 65 K & 0.01 T)	・The PLD wire was confirmed with 100-m length. ・The MOD wire was confirmed with 30-m length. ・Applicability of MgO substrate effective for cost reduction was confirmed (added).	Verification of MOD wire (2010)
Verification of the 2-MVA transformers	System design for 66 kV/6.9 kV-2 MVA class transformer	・2 MVA class transformer model was designed.	

1 Technical development of stable supply of wires

MgO substrate is expected to reduce the wire cost because of increased substrate fabrication speed (about 100-fold) because it is extremely thin than GZO substrate. Therefore, in the added confirmation test for the applicability to transformers, favorable data were obtained in the measurements of bending strain characteristics, overcurrent characteristics (Fig.2), and resistance between fine elementary wires (1 MΩ/m or larger).The target relating fine wire (I_c = 40 A @ 65 K & 0.01 T, tripartition or more) has been achieved for PLD wire by obtaining a 100 m long wire after splitting into 5 mm width and tripartition scribing processing (Fig.3). However, since 30 m is the maximum length for MOD wire, further technical development is required to improve the uniformity of the superconductivity characteristics in the longitudinal direction and across-the-width direction.

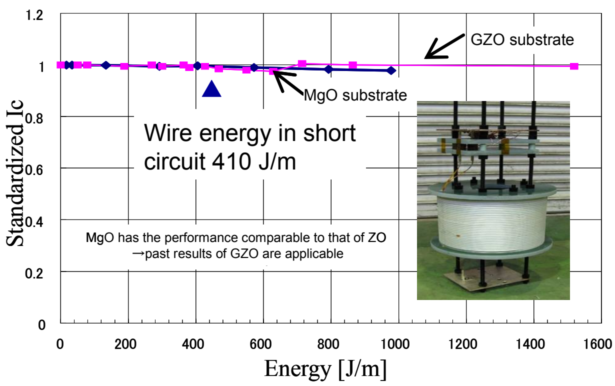

Fig.2 Results of the overcurrent test for MgO substrate wires

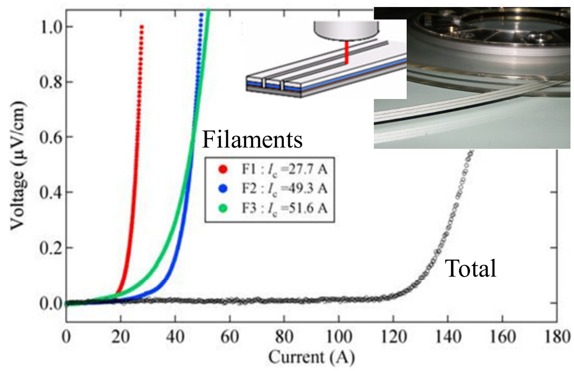

Fig.3 Results of I_c measurement (PLD wire) before and after thinning the wire

2 Technical development of winding

In the technical development of winding, short-circuit performance, large increase in current, and reduction in loss were verified. Since the results of the short-circuit performance were published in October issue of Web21, the results of the other two are described here. For a large increase in the current aiming at

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2 kA class energization in a commercial device, the bending test of the triple winding model provided with stabilized copper was implemented, and the soundness in the overcurrent test with two-fold energy of short-circuit energy (410 J/m) was confirmed. Furthermore, it was confirmed that a multi-layer, parallel conductor (12 layer, 2 parallel row) transposition homogeneous current model is applicable to transformers since the inhomogeneity in the current distribution between the elementary wires is 14 % at maximum (Fig.4). In the technology development for low loss, current distribution characteristics between the filaments of the winding model using fine wires produced by splitting 5 mm wide wire into three was confirmed (Fig.5). It is scheduled to verify the AC loss reduction using a low-loss prototype model using a tripartition wire of 100 m class.

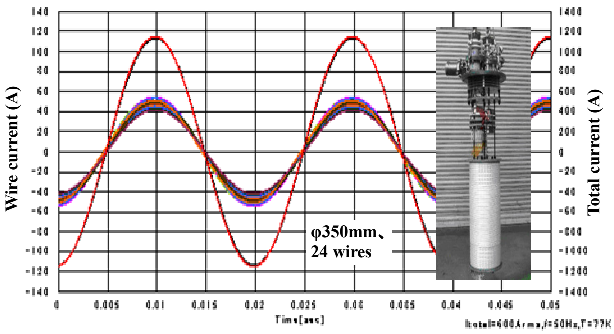

Fig.4 Current distribution characteristics between the wires of the 4-trasnsposition homogeneous current model

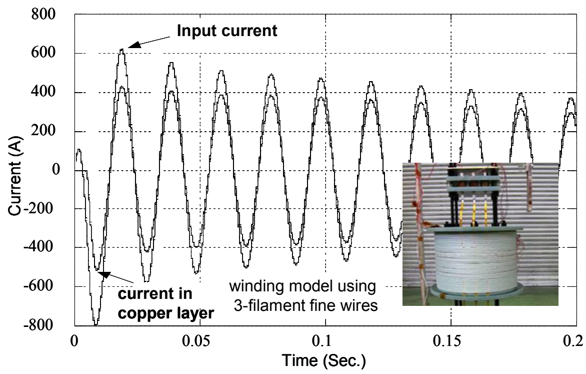

Fig.5 Current distribution characteristics of the winding using fine wires

3 Development of cryogenic system

Based on the results of the previous project, neon coolant is used (Fig.6) and a no-sliding expansion turbine with 5-axis control magnetic bearing was developed aiming at efficiency improvement, high reliability, and long life. The adiabatic efficiency was confirmed to be higher than the target value of 65 % (Fig.7). As for the no-sliding turbocompressor, a small-size turbocompressor with 5-axis control magnetic bearing was manufactured experimentally, and an adiabatic efficiency of 68 % (target: 65 % or higher) was obtained. It was also confirmed that the developed three-block neon refrigerator is sufficient although the conventional refrigerators require five blocks. A simulation of the cooling operation on the basis of the above-mentioned results proved that the final target of COP0.06 can be theoretically achieved.

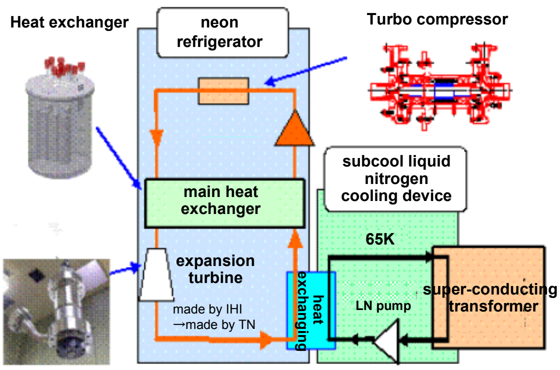

Fig.6 Constitution of cryogenic system

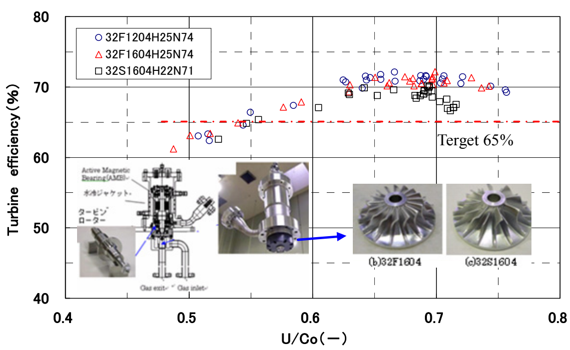

Fig.7 Characteristics of the non-sliding expansion turbine

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4 Development of transformer system

To realize a 20-MVA class superconducting transformer for distribution, taking the constitution of winding, it is necessary to implement verification for the manufacturing technology and characteristics using a transformer model with the minimum capacity of 2 MVA (Fig.8). In the design of the model, the following items were studied: (1) technologies corresponding to commercial device were applied because of the rated voltage resistance of 66 kV and the constitution of equipment; (2) in particular, multi-layer, parallel-row conductor and transposition homogeneous current model technology were applied to the winding technology; (3) results of the elementary technology development were reflected. Continuous current tests (including single transformer test, cooling test, and rated current test) were also investigated. It was theoretically confirmed that the loss can be reduced to about 1/6 and the weight to about 1/2 by schematic design of commercial transformer of 20 MVA compared to the conventional transformers.

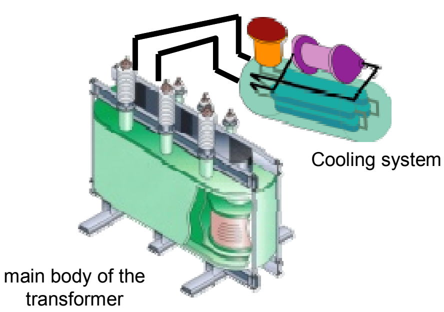

Fig.8 2-MVA transformer model

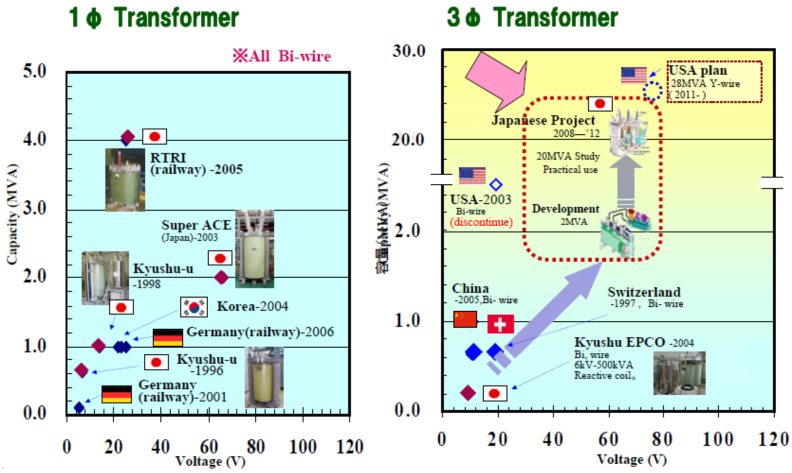

Fig.9 R&D of HTS-Transformer in the World

In the intermediate assessment subcommittee, the international comparison of superconducting transformer development (Fig.9) and applications to other fields were reported in addition to the above-mentioned results. Although developments using Bi-based conducted overseas has become inactive due to the problems of AC loss and insulation, a plan of 28 MVA class has been recently restarted in USA. Japanese projects seem to be running at the top at present, continuous vigorous push in the technological development is required. Since almost all types of power devices require a transformer, there is enough room for the expansion of applications. Applications for downsizing and higher efficiency are promising in the fields of industry and transportation because it contributes to the realization of a low-carbon society. In the field of electric power, the use of compound application with superconducting cable as a transformer provided with current limiting function is promising.

It is intended to steadily promote the projects in progress so that the early commercialization of the distribution transformer of 20-MVA class is realized through the development and verification of 2 MVA transformer model.

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Top of Superconductivity Web21

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Standardization Activities

Topics in August

- Masato Murakami, Vice-President of Shibaura Institute of Technology, received Chairperson Award of IEC-APC

Masanao Mimura, Director
Standardization Affairs Division, ISTEC

IEC-APC (IEC Activity Promotion Committee of Japan) honored the chairperson award of IEC-APC to 10 persons including Masato Murakami, Vice-President of Shibaura Institute of Technology for major contributions made to IEC international standardization in the 20th General Assembly of IEC-APC.

IEC-APC organization was established in 1991 to promote the contribution of Japan to IEC (International Electrotechnical Commission) and to reflect the opinions of the industry. The chairperson award of IEC-APC, which was established 1995, is honored every year to individuals or groups for major achievements or contributions among people engaged in standardization activity relating to IEC.

Masato Murakami (Vice-President of Shibaura Institute of Technology, Superconducting Material Laboratory, Materials Science and Engineering) was honored the award because he promoted international standardization in IEC/TC90 and remarkably contributed to the international standardization. He has been acting as the convener of WG10 (a test method for trapped magnetic flux density of the bulk material) of IEC/TC90 (Superconductivity) as a part of the responsibilities of Japan's first experience as TC secretariat of IEC, and worked for coordinating the comments from the member countries to Japan's original proposal. After 2000, he has been contributing to domestic and international standardization activities by promoting international standardization in IEC/TC90 and VAMAS (the Versailles Project on Advanced Materials and Standards) through the activities in WG10 of IEC/TC90.

Photograph of awardees (Masato Murakami is in the extreme right of the back row.)

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Top of Superconductivity Web21

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Standardization Activities

Topics in September
- The 8th panel discussion on the international standardization of superconductivity technology

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

From four o'clock in the afternoon of August 1 (Sun), the previous day of the opening of Applied Superconductivity Conference, the 8th panel discussion on the international standardization of superconductivity technology was held at Omni Shoreham Hotel in Washington DC, USA. Even though the meeting was held one day before the Conference, 18 persons participated in the meeting from five countries—Japan, USA, China, Switzerland, and Russia.

After an opening address by Matsushita (Kyushu Institute of Technology) including what had been discussed in the past seven panel discussion meetings, the Committee member Osamura (Research Institute for Applied Sciences) reported on the General Requirements for superconducting wire, which had been investigated by Ad Hoc Group 3 of IEC (International Electrotechnical Commission)-TC90 (Superconductivity Committee), and was the major issue in the previous panel discussion. After explaining the proposals including "label" that was pointed out in the last discussion in plain words so that the proposals are accepted, he asked for the approval of the General Requirements by preaching the indispensability of the international standardization for the expansion of market illustrating an example of an optical cable. Replying to this, Dr. Cooley (Fermi Laboratory) explained the attitude of USA, which has been taking a rather conservative position since the previous discussion. The exchange of opinions followed for a long time between Japan and USA, and the importance of such standardization and the necessity of individual items were generally understood. The necessity to study the specific nature was pointed out. For example, how should such terms represented by "stability," the meaning of which significantly changes according to the purpose, be treated. Furthermore, the appropriateness of the term "General Requirement" itself was discussed. It seems that the expression "requirements" sounded too strong, giving uncomfortable feeling to the USA side. After the explanation of Japan, there was an opinion that the "requirements" is nothing but the "General Characteristics." It was agreed upon to investigate the total framework including the issue of terms. The Committee member Osamura asked USA to dispatch a member to Ad Hoc Group 3, which was agreed willingly. This made a firm step toward the standardization of the "superconducting wires."

Then, International Secretary Sato (Sumitomo Electric Industries) reported on the activity status of IEC, in which he stated that 15 standards have been published including the current lead and introduced standards being promoted and being proposed. The circumstances surrounding the superconducting cable being studied by CIGRE (International Council on Large Electric Systems) were also reported.

Subsequently, Professor Shintomi (Nippon University) introduced the applications of superconductivity to electrical power industry in Japan. He introduced the progress in the individual applications of superconductivity to the electric power industry in the NEDO project, which is being promoted centering on International Superconductivity Technology Center as well as superconducting DC cable being developed by Chubu University, motor for ship propulsion, and automobile equipped with superconducting motor. After that, future schedule for the standardization of the diversified superconducting power devices were explained, which broadly showed the future direction of standardization to the participant.

Later, USA proposed to discuss further details on the superconducting cables, which gives the expectations for its future active development.

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Top of Superconductivity Web21