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Superconductivity Web21

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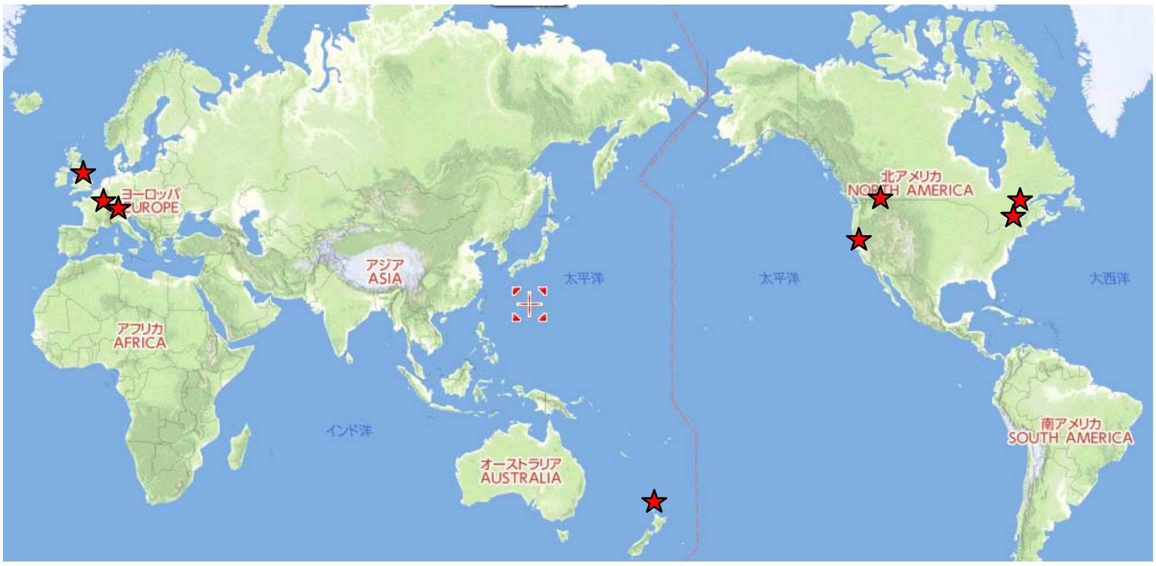
What's New in the World of Superconductivity (June, 2013)

초전도 뉴스 –세계의 동향-

超导新闻 -世界的动向-

chāo dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC



★News sources and related areas in this issue

▶ Industrial Application 의료응용 医疗应用 [yīliáo yìngyòng]

Collaboration for New Cryogen-free NMR Products

Stelar S.r.l and HTS-110 Ltd. (May 27, 2013)

Stelar S.r.l. (Italy) and HTS-110 Ltd. (New Zealand) have announced an international collaboration for the development of new nuclear magnetic resonance (NMR) products. The companies will combine their know-how and expertise in cryogen-free superconducting magnets and specialized technology developed for NMR relaxometry and Fast Field Cycling NMR to develop new integrated solutions for industrial and research applications. By integrating Stelar's NMR Fast Field Cycling technology with HTS-110's variable

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field cryogen-free superconducting magnet, the companies hope to extend the measurement of the field dependence of spin relaxations up to the field strength of the latest generation of clinical MRI scanners (3 tesla). Gianni Ferrante, CEO of Stelar commented, "The Stelar and HTS-110 combined system will allow the full profiling of [contrast] agents, creating the perfect instrument for analysis of contrast agents or for other applications requiring spin relaxation times at higher magnetic field strengths." Donald Pooke, CTO of HTS-110, added, "The compact form and capability for variable field make the HTS magnet a very attractive partner for Stelar's unique magnetic resonance know-how. The combination of the two technologies will open up new measurement possibilities which will be developed by this collaboration."

The collaboration announcement was made at the recent European Molecular Imaging Meeting (EMIM) 2013, in Turin, Italy, and was introduced by Clare Louise Wilson, the New Zealand Consul General and Trade Commissioner (Milan, Italy), who is working to facilitate trade between businesses in Italy and New Zealand. Wilson commented, "It is a pleasure to see that two small, highly specialized companies at opposite ends of the globe are able to work well together to offer an integrated, unique product with a worldwide sales potential."

Source: "Stelar and HTS-110 Formalize International Partnership in Magnetic Resonance Technology Development"
HTS-110 Ltd. press release (May 27, 2013)
URL:
http://www.scott.co.nz/news/pdf/2013_Stelar_and_HTS-110_collaborative_on_NMR_relaxometry_development.pdf
Contact: Stelar s.r.l.: Gianni Ferrante, CEO, ferrante@stelar.it, HTS-110 Ltd : Tye Husheer, CEO, t.husheer@hts-110.com

New MRI Developed to Overcome He Shortage

MR Solutions (June 20, 2013)

MR Solutions has developed a range of high-performance, 3-T MRI scanners using superconducting magnets that do not require liquid helium cooling. This achievement is particularly relevant given the extreme global shortage of helium that has led some scientists to call for a ban on helium use for all but the most essential applications. This situation has created difficulties for many research projects, as helium cooling is extensively used in medical scanners such as MRIs, medical MEG scanners, and specialist brain scanning equipment. Some medical centers have had to stop scanner bookings because of helium shortages or have had to invest in expensive helium-capture technology. The MRI scanners from MR Solutions utilize a revolutionary magnet design that incorporates new superconducting wire and a standard low-temperature fridge to cool the magnet to 4 K.

Source : "Helium shortage no longer an issue for researchers as new kind of MRI is launched"
MR Solutions press release (June, 2013)
URL: http://www.mrsolutions.co.uk/newsandevents/
Contact: MR Solutions Ltd, sales@mrsolutions.co.uk

Source: "MR Solutions new pre clinical MRI scanners overcome helium shortage"
Business Wire News (June 20, 2013)

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URL:
http://www.businesswire.com/news/home/20130620005969/en/Solutions-pre-clinical-MRI-scanners-overcome-helium
Contact: Simon Vane Percy, simon@vanepercy.com

▶ Electronics 엘렉트로닉스 电子应用 [diànzǐyè yìngyòng]

Availability of New Chip Fabrication Process for Next-generation Superconducting Circuit

HYPRES, Inc. (July 5, 2013)

HYPRES Inc. has announced the availability of a new six-layer planarized chip fabrication process that enables an increase in the integration level of superconducting ICs and an increased critical current density of Josephson junctions. These features make the process ideal for customers developing high-performance, energy-efficient solutions for high-end computing, advanced wireless communications and instrumentation. Dr. Oleg Mukhanov, Chief Technology Officer at HYPRES, commented, “Next-generation superconductor circuit development requires commercially available fabrication processes well beyond today’s four metal layers and critical current densities. We have made six planarized layers—and soon, more—and various increased critical current densities available as part of our commercial foundry services. We made our first customer delivery earlier this year and have new orders in process.” The new fabrication process involves many new processes and techniques included in a provisional patent application for a Rapid Integrated Planarized Process for Layer Extension (RIPPLE). The new process has been thoroughly evaluated and has been successfully used to produce working circuits. Earlier in 2013, Stanford University became the first commercial customer to use the new fabrication process. HYPRES is presently processing a second order from Stanford, with tailoring to meet the university’s new design parameters and specific needs.

Source: “HYPRES Announces Commercial Availability of New Chip Fabrication Process for Next-generation Superconducting Electronics Circuits”
HYPRES, Inc. press release (July 5, 2013)
URL:
http://www.hypres.com/newsroom/hypres-announces-commercial-availability-of-new-chip-fabrication-process-for-next-generation-superconducting-electronics-circuits/
Contact: General Inquiries, contacts@hypres.com, Products & Services, sales@hypres.com

▶ Accelerator 가속기 加速器 [jiāsùqì]_

Next-generation Particle Collider, International Linear Collider (ILC), Now Ready for

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Construction

CERN (June 12, 2013)

A blueprint for the International Linear Collider (ILC), a next-generation particle collider to complement and advance beyond the capabilities of the Large Hadron Collider at CERN, has been published and given to the International Committee for Future Accelerators (ICFA), an international oversight board for projects in particle physics. The Technical Design Report represents the latest, most technologically advanced and most thoroughly scrutinized design for the ILC. Sakue Yamada, Research Director for the ILC, commented, “The discovery of a Higgs boson at the LHC has made the case for the ILC even more compelling. The ILC can study its properties in detail and will thus be a great complementary machine to the already very successful LHC.” Highlights of the report include the successful construction and commissioning of superconducting radiofrequency test facilities for accelerators worldwide, great strides in improving the production processes for accelerating cavities, and plans for the mass production of the 16,000 superconducting cavities that will be required to drive the ILC’s particle beams.

Source: “Next-generation particle accelerator is ready for construction – International Linear Collider publishes its Technical Design Report”
CERN press release (June 12, 2013)
URL:
http://press.web.cern.ch/press-releases/2013/06/next-generation-particle-accelerator-ready-construction-international-linear
Contact: press office, press.office@cern.ch

▶ Basics 기초 基础[jīchǔ]

LAO/STO Interface Shows both Superconductivity and Magnetism

SLAC National Accelerator Laboratory, Stanford University (June 7, 2013)

Scientists at SLAC and Stanford University have used finely tuned X-rays at the Stanford Synchrotron Radiation Lightsource (SSRL) to identify the source of a mysterious magnetism that appears when two insulating perovskites—lanthanum aluminum oxide (LAO) and strontium titanium oxide (STO)—are sandwiched together. The resulting “heterostructure” can conduct electricity at the interface where the LAO and STO materials meet; when cooled to near-absolute zero, the heterostructure becomes a superconductor. Furthermore, magnetic qualities are seen at the juncture where the LAO and STO meet, even though neither material exhibits such qualities alone even when doped with impurities. Using sample heterostructures formed from an extremely thin layer of LAO on an STO substrate, the researchers used tuned X-rays to examine only the titanium in the STO slice or only the oxygen and found that the magnetism originated from the ground state of the titanium atoms. Intriguingly, the structure of this magnetic ground state in the titanium of STO is the same structure necessary for its transition to a superconductor, suggesting that the LAO/STO interface may exhibit another unconventional behavior: the coexistence of

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magnetism and superconductivity. While the researchers were unable to study the magnetic titanium at temperatures low enough to cause the heterostructure to transition to superconductivity, their research does support findings previously published in Nature Physics (2011) in which both superconductivity and magnetism were detected at an LAO/STO interface. The present group's work has been published in Nature Materials.

Source: "Man-made Material Shows Surprisingly Magnetic Personality"
SLAC press release (June 7, 2013)
URL: http://www6.slac.stanford.edu/news/2013-06-10-oxide-interface.aspx
Contact: only in website, http://www6.slac.stanford.edu/about/contact-slac.aspx

Create Superconductor from Solvent, CS_2

Washington State University (July 1, 2013)

Researchers at Washington State University and the Carnegie Institution of Washington have turned a non-metallic solvent into a superconductor. The group found that when carbon disulfide was subjected to high pressure and cold, it began to act like a metal, exhibiting properties such as magnetism, a high energy density, and superhardness, with its molecules reassembling into three-dimensional structures similar to those found in diamonds. Usually, non-metallic molecules are too far apart to conduct electricity. However, when the researchers compressed the carbon disulfide to 50,000 atmospheres and cooled the compound to 6.5 K, the combined effect of the pressure and temperature not only brought the carbon disulfide molecules together, but rearranged them into a lattice in which the natural vibrations of the molecules enabled the electrons to move so well that the material became a superconductor. The findings provide insight into how superconductivity works in unconventional materials, which are typically made of atoms with lower atomic weights allowing them to vibrate at higher frequencies, increasing their potential to become superconductors. The group's work has been published in the Proceedings of the National Academy of Sciences.

Source: "WSU researchers create superconductor from solvent"
Washington State University press release (July 1, 2013)
URL: http://news.wsu.edu/articles/36704/1/Researchers-create-superconductor-from-solvent
Contact: Choong-Shik Yoo, csyoo@wsu.edu

▶ Management and Finance 경영정보 经营信息[jīngyíng xìnxī]

China's Sinovel Indicted in the United States

AMSC (June 27, 2013)

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AMSC has requested that the Obama administration and Congress re-evaluate the U.S. trade relationship with China in view of the recent Department of Justice indictment of Sinovel and two of its employees for the theft of AMSC's trade secrets—specifically, AMSC's proprietary software code and the use of this intellectual property in four 1.5- MW Sinovel turbines that have been installed in Massachusetts. The indictment follows a Federal Bureau of Investigation's investigation verifying that the Sinovel-manufactured wind turbines do indeed contain AMSC's stolen intellectual property. Daniel P. McGahn, AMSC's President and CEO, commented, "The fact that Sinovel has exported stolen American intellectual property from China back into the United States — less than 40 miles from our global headquarters — shows not only a blatant disrespect for intellectual property but a disregard for international trade law. These criminal acts have led to significant financial harm to AMSC, its employees and their families as well as its shareholders. Over the past two years, more than 500 staff members worldwide have lost their jobs following Sinovel's egregious and unlawful behavior." In September 2011, AMSC filed four legal actions against Sinovel in China and requested that the Chinese police bring criminal action against Sinovel and some of Sinovel's employees, the Chinese police do not yet appear to have undertaken an investigation and China's civil courts have yet to begin substantive hearings regarding the cases. McGahn added, "Enforcement and protection of intellectual property—the DNA of new products and technologies—is essential for U.S. companies to compete successfully in a global economy. This is impossible if companies in countries such as China are brazenly stealing trade secrets through industrial and cyber espionage. China's president, Xi Jinping, recently said that China will protect legitimate rights of foreign enterprises. However, to date, the experience of companies like AMSC has proven otherwise… The inability to rely on the rule of law is creating a risk for U.S. businesses operating in China. The administration has been incredibly supportive of our issue and so I'm requesting that, together with Congress, they examine how trade secret theft is impacting American jobs and innovation and address the issue before it further impacts economic development." AMSC has received support regarding this issue from officials within various branches of the U.S. and E.U. governments.

Source: "China's Sinovel Indicted in the United States for Stealing AMSC Trade Secrets"
AMSC press release (June 27, 2013)
URL:
http://files.shareholder.com/downloads/AMSC/2165855216x0x673451/326a7bc2-fd1f-48b2-bd40-697bca108d65/AMSC_News_2013_6_27_Commercial.pdf
Contact: Kerry Farrell, kerry.farrell@amsc.com

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Feature Article: Technological Development of Yttrium-based Superconducting Power Equipment
- Research and Development of High Temperature Superconducting Magnetic Energy Storage (SMES) Systems

Shigeo Nagaya, Director
Superconductivity Group, Electric Power R&D Center
Chubu Electric Power Co., Inc.

The progression of a number of potential superconducting equipment is ongoing, however, amongst these developments, only the SMES has been currently realized for practical use and commercialized. The reason behind its success has been the SMES functionality and performance characteristics in specific practical applications that prove to have a cost advantage over other methods. Therefore, the SMES success story is not just limited to power equipment. When substitute technology and methods provide no advantageous cost benefits compared with existing equipment, the commercialization of practical applications cannot be realized even if the technology is well established.

Even though the equipment may exhibit superconductivity-like characteristics that utilize specific superconductivity attributes for its functionality, the lack of demand in having such functionality will prevent it from being realized practically. The same is true for currently available methods or systems, where it is the incumbent methods that prevail and emerge as forerunners able to address future challenges.

Cryogenic cooling is mandatory for superconducting equipment. In addition to the costs required to maintain cryogenic status, concerns associated with reliability can far outweigh cost issues alone for specific power equipment applications, dependent on their operational environment. In particular, equipment that is assembled in series with power systems is now multiplexed in case of a loss in functionality. However, this is proving to be practically less advantageous and further drawbacks when multiplexing using normal-conducting equipment is emerging.

SMES on the other hand is fundamentally assembled in parallel from a power storage functionality point of view. The power system functionality remains uninterrupted even if the SMES itself stops and loses functionality. Thus such practical cost advantages allow for potential equipment exploitation.

Technological developments in Yttrium-based superconducting power equipment have been spearheaded based upon 200m and 500m-long Yttrium-based wire technology developed earlier in an R&D project focused on fundamental technology for superconductivity applications. The first half of this project was aimed at fabricating the required volume of wires vital for building the equipment, and establishing mass-production methods to improve yields. At the project’s conclusion, demonstration trials were planned for the equipment fabricated in the latter half of the project. The entire progress of all such efforts has been aimed at realizing and commercializing practical applications.

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The advancement in wires and coils has continued in parallel with the development of a Toroidal coil system – a developmental target necessary for SMES functionality. However, the fabrication of the full Toroidal coil system planned during the latter half of the project was hampered by the lack of fabricated wires available. Hence, only partial verification of several coils was performed. Degradation in coil characteristics of a max-sized φ60cm-class Yttrium-based testing coil was measured and attributed to a delamination phenomenon associated with the Yttrium-based wire structure. Therefore, the plans for the latter half of the project were altered and instead focused on advancing the development of a durable delamination technology to improve coil reliability for all potential applications, including those necessary for the SMES.

The technological advancement of SMES superconducting power equipment involved development of the coil designs necessary for SMES storage, under the assumption it was aimed at large-capacity SMES for grid control. Whilst a large-scale coil is inevitable, coiling feasibility is determined by the hoop stress generated during current transport rather than limitations associated with superconducting wire characteristics. Therefore, the technological project prospectus for realizing large capacity SMES was aimed at developing coiling technology that maximized upon the superior tensile strength of Yttrium-based wires, as well as understanding their performance limits.

A high-strength and high-field coil having 600 MPa-class hoop stress was set as the initial target, and was achieved by employing coiling methods that took advantage of the aforementioned mechanical strength of Yttrium-based wires. However, a φ60 cm-class coil that was used for the partial verification trials of the Toroidal coil system encountered deterioration in superconductivity characteristics owing to the cooling heat cycle. The type of failure was also categorized according to differences in the wire manufacturing process.

In a typical coiling method scenario, the Yttrium-based wires are impregnated and integrated using epoxy resin. Tensile stresses occur within the coil towards the delamination plane in the wire, which result in breakages between the substrate/buffer layer, buffer layer/superconducting layer, and superconducting layer itself. This phenomenon was already predicted since the initial coiling investigations. In particular, since thermal stresses accompanying cooling depend upon the internal-external diameter ratio of the coil, this becomes fatal for a large-scale coil with many numbers of turns.

The major outcome from this SMES development is the advancement of a new coil structure described henceforth.

As mentioned earlier, degradation of coiling characteristics was due to internal stresses that occurred when the coil was formed, which led to wire delamination and deterioration in the current transport properties of the coil. Thus, the aim here was to increase the delamination resistance of the wire or reduce the internal coil stresses to less than the wire delamination resistance. However, it was determined that the origin of the delamination was due to internal wire defects, with the delamination resistance deteriorating according to the area measured.

The internal stresses generated within a coil are determined by the coil's internal-external diameter ratio and can be controlled using a split coil method. However, considering the existence of micron-sized defects

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within a wire that is typically several hundreds of meter long, means that there is a probability of defects in infinite wire lengths, and therefore areas with zero delamination cannot be industrially eliminated.

The fabrication of reliable coil therefore requires the establishment of a coiling technology without a dependency on wire characteristics.

The coiling structure developed has the following attributes:
. A non-impregnated coil structure
. Wire coated by a newly developed low-temperature-curable polyamide resin
. Outer coil comprising of sidewall and side-plate
. Filling the inside of the coil with paraffin

A YOROI coil (Y-based Oxide Superconductor and Reinforcing Outer Integrated Coil) with these four characteristics has been developed.

A non-impregnated structure is employed to suppress the wire delamination phenomenon. The electrical insulation provided by the resin mold allows an insulating polyamide resin coating to be applied over the entire wire length, which can also be cured at low temperatures and below where the characteristics of Yttrium-based superconductors does not deteriorate. The major attributes of this solution are to sustain the hoop stress generated within the coil by utilizing the side-plates of the coil.

This structure has significantly limited the generation of hoop stress within the large-scale coil and resulted in the realization of a high strength coil exceeding the strength of Yttrium-based wire. (For further details, please refer to “The development of high strength pancake coil (YOROI-coil)”, Cryogenics and Superconductivity Society of Japan Vol.48 No.5 (2013)).

The utmost superior characteristics afforded by superconductors are their ability to generate high magnetic fields. However, the large-scale coil developed thus far has not been fully able to demonstrate this ability due to restrictions associated with mechanical strength rather than limitations with superconductivity characteristics.

The development of the YOROI coil can be applied to the fabrication of other irregular-shaped coils and is not just limited to circular coils such as used in the SMES. The potential number of future applications able to utilize Yttrium-based wires has thus broadened.

The performance attributes of the YOROI coil, as employed in the SMES coil system is to be introduced in the July issue of Web21.

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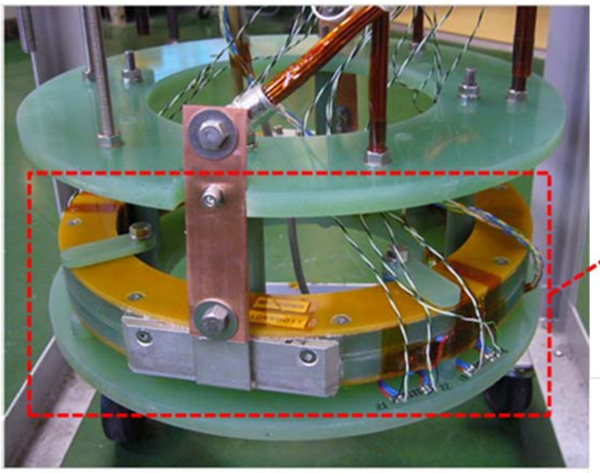
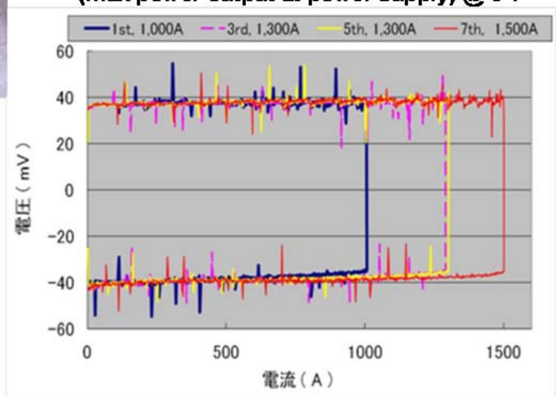
High strength structural coil (Yoroi-coil)



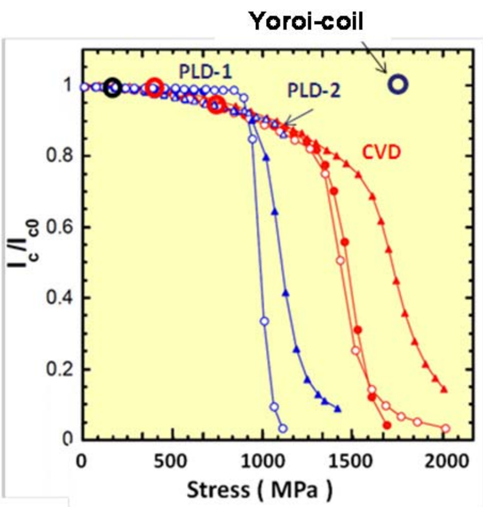
Coil current transport 1,500 A
(max power output at power supply) @ 8 T



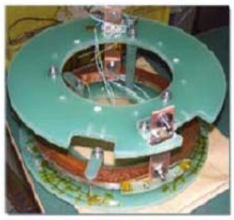
Investigations for SMES component technology(2011)

Double-pancake coil
Internal diameter : 219 mm
External diameter : 240 mm
Height : 30 mm
Maximum electromagnetic force : 1.7 GPa

Status of Y-based superconducting coil development



Investigations of SMES component technology (2010)
Single-pancake coil
Internal diameter : 200 mm
External diameter : 250 mm
Height : 12 mm
Max. electromagnetic force : 740 MPa



Y-based superconducting motor (ISTEC)
Planar racetrack type coil
Short diameter : 184 mm
Long diameter : 514 mm
Height : 86 mm
Max. electromagnetic force : 150 MPa

Concentric coil for NMR development (RIKEN)
Wound layer
Internal diameter : 50 mm
External diameter : 113 mm
Height : 88 mm
Max. electromagnetic stress : 408 MPa

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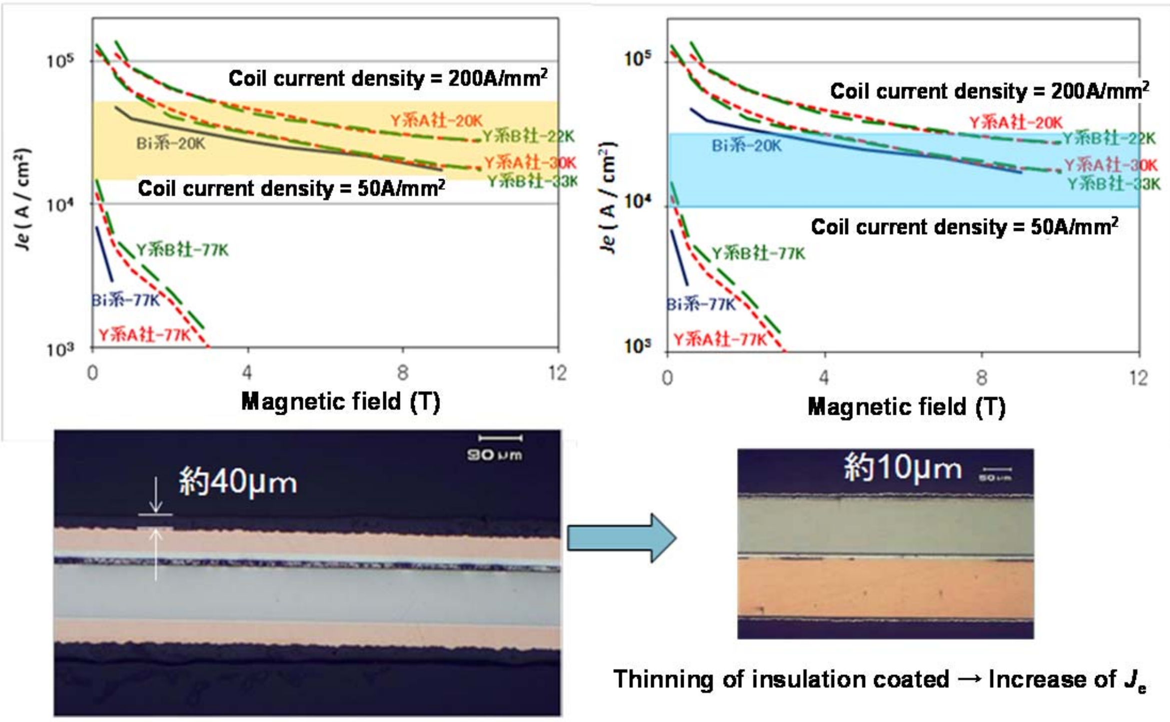
High current density coil investigations



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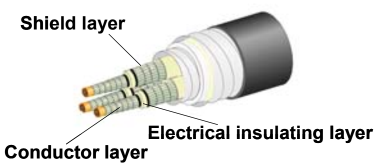
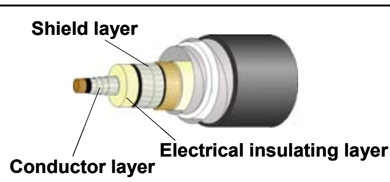
Feature Article: Technological Development of Yttrium-based Superconducting Power Equipment - Research and Development of Superconducting Power Cables

Takeshi Ohkuma, Director
Electric Power Equipment Division
SRL/ISTEC

When compared with existing power cables, the advantageous characteristics afforded by superconducting power cables include their capacity to handle large power transmissions within a compact structure and their low-loss transmissions characteristics. Thus, superconducting power cables are highly expected to play a significant role in energy savings and offer solutions to avert global warming. At the Superconductivity Research Laboratory (SRL), International Superconductivity Technology Center (ISTEC), the "Research and Development of Superconducting Power Cable" was launched in FY2008, and aimed at the fabrication of cables utilizing Yttrium-based superconducting wires exhibiting high current density and low-loss characteristics, with the research focusing on reducing losses and increasing capacities even further whilst maintaining their compact design. This R&D has been advanced as part of the "Technological Development of Yttrium-based Superconducting Power Equipment (M-PACC: Material and Power Applications of Coated Conductors)" project (FY2008-FY2012) led by New Energy and Industrial Technology Development Organization (NEDO), and sponsored by Ministry of Economy, Trade and Industry. The project concluded at the end February 2013. A summary of the R&D activities relating to superconducting power cables are introduced herewith.

1. Development of superconducting power cables

Table 1 Targets for Yttrium-based superconducting power cable development

Name	Large current cable	High voltage cable
Specifications Structure (capacity)	66 kV, 5kA Three-in-one (570 MVA)	275 kV, 3 kA Single core (1420 MVA)
Outline figure		
Diameter	150 mmϕ Can be housed in duct	150 mmϕ Less
Loss	2.1 W/m-phase@5 kA	0.8 W/m-phase@3 kA
Excess current withstand	31.5 kA, 2 sec.	63 kA, 0.6 sec.

This project involved the development of two kinds of cables, namely, a 66kV/5 kA-class large current cable and a 275 kV/3 kA-class high voltage cable. Together with this, the development of important component

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technology imperative to practical realization was undertaken in collaborations with ISTEC, Sumitomo Electric Industries, Ltd., Furukawa Electric Co., Ltd., Fujikura Ltd., Showa Cable Systems Co., Ltd., Mayekawa MFG. Co., Ltd., and JFCC. The first 3 years of this project has seen the development of important component technology required by each cable, including low AC-loss, large current conductor/high capacity connection technology and high voltage insulation/high voltage connection technology. Additionally, R&D activities focused on having a stable manufacturing/process technology of Yttrium-based superconducting wires were undertaken. From these findings, the latter 2 years of the project was dedicated to the fabrication of cable systems along with corresponding demonstration trials, allowing the reliability of the cables to be verified and thus meet the developmental targets set for each cable, as shown in Table 1.

1.1 66 kV/5 kA-class large current cable

The development of a large current cable has involved the progress of a 3-in-one superconducting cable that can transmit three-phase 66kV, 5kA currents, in addition to verification trials of a 15m-class cable with terminal connectors.

A cable was designed and fabricated having a total loss of less than 2.1 W/m-phase (AC loss 2.0 W/m-phase, dielectric loss 0.1 W/m-phase), and in an appropriate size that could be housed within an existing cable duct (diameter 150 mm). To verify the performance of the cable tolerance to system faults when installed in a power grid, excess current trials involving a short-length cable sample subjected to 31.5 kA-2 second excess currents was undertaken and proven to have no damage or detrimental loss in performance characteristics.

Since Yttrium-based superconducting wires have a thin superconducting layer with a thickness of several µm, magnetization losses in parallel magnetic fields are miniscule. However, losses in the formed cable are mainly dominated by vertical magnetic fields generated at the gaps between the wires. To address this issue, the wires were thinned and the cable was fabricated with a layer cross-section being as close as possible to a perfect circle. This produced a reduction of AC loss by reducing the vertical magnetic fields generated between the gaps of the wires. The development of a large current cable involved thinning 30 mm-width tapes to a thickness of 2-4 mm width. A hybrid cable core structure was fabricated by utilizing a 2 mm-width wire for the outer layer (fourth layer), which out of the four conductor layers was the layer predominantly subjected to magnetic fields, whilst the other conductor and shield layers had a 4mm-width. Trials to determine the AC loss characteristics realized 1.5 W/m-phase (@71 K, 5 kA). A conductor employing superconducting wires all thinned to 2 mm-width achieved 0.4 W/m-phase (@74 K, 5 kA) characteristics.

The 15 m-long large current cable system employed a hybrid cable structure consisting of 2 mm-width wires for only the outermost layer of the conductor. Figure 1 shows the 3-in-one cable structure used for the cable system. Also shown in the figure is the Cu former installed at the center of the cable, which is responsible for the mechanical strength of the cable as well as acting as a bypass for excess currents generated by power grid faults. A four-layer thinned wire is spirally wound around the former and creates the conductor layer. The outward-facing side of the conductor is coated with an electrical insulating layer, where on top two superconducting wire layers and a Cu shield layer are placed, thereby producing a single-phase cable core consisting of a 3-in-one structure, where the 3 cores are housed within the cable.

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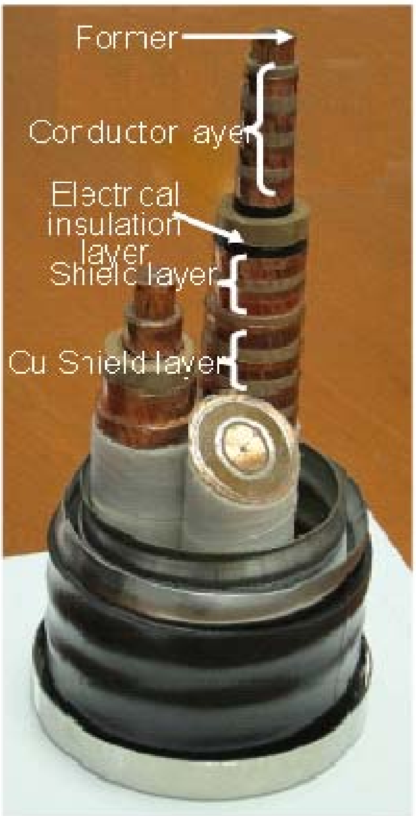

Fig.1 Large current cable (Three-in-one)

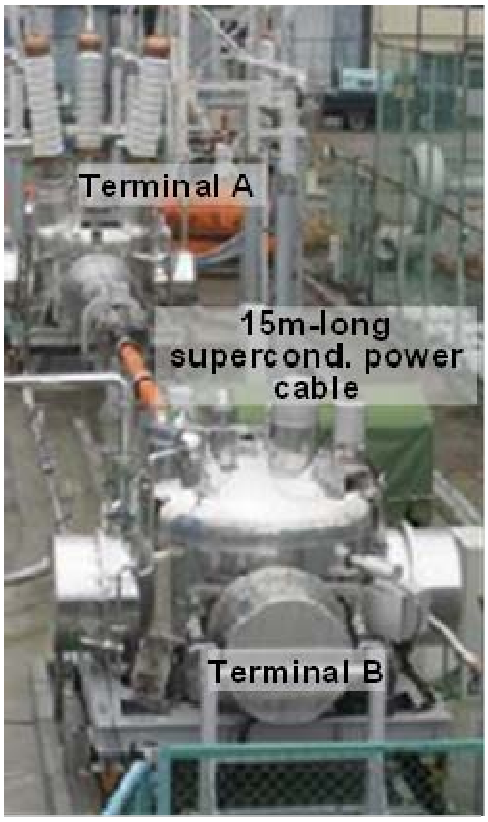

Fig.2 66 kV/5 kA-class large current cable system (Sumitomo Electric Industries, LTD., Kumatori, Japan)

Figure 2 shows the 15m-long 3-in-one cable system constructed. The large current cable system has termination connectors (terminals) at both ends where, terminal A is the input current connected via current lead bushing, where terminal B has a short circuit structure of three-phase cable within the terminal container.

Cable loss tests when applied with a rated current of 5 kA (less than 2.1 W/m-phase), voltage-withstand tests and long-term current tests were all performed for this cable system. The initial targets set for each of the tests were met and thus proved the reliability of the 66kV-class large current cable system.

The 3-in-one single-phase cable fabricated is shown in Figure 3. It utilizes high I_c=500A/cm-w(@77K)-class wires, fabricated from the research undertaken under the “Wire Technology Development for Superconducting Equipment” as part of the “Technological Development for Yttrium-based Superconducting Power Equipment” project. This led to the fabrication of a 66kV/5kA, 10m-class cable system as shown in Figure 4, and AC transport properties of high-I_c wire characteristics were verified with the results confirming reduced load factors and achieving low-losses of 0.95 W/m-phase (@67K, 5kA) and 1.37 W/m-phase (@77K, 5kA) for short-length wire samples.

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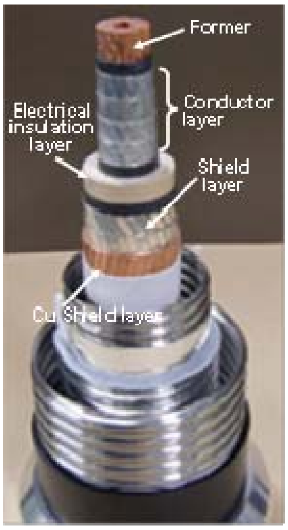

Fig. 3 Large current cable (single-phase)

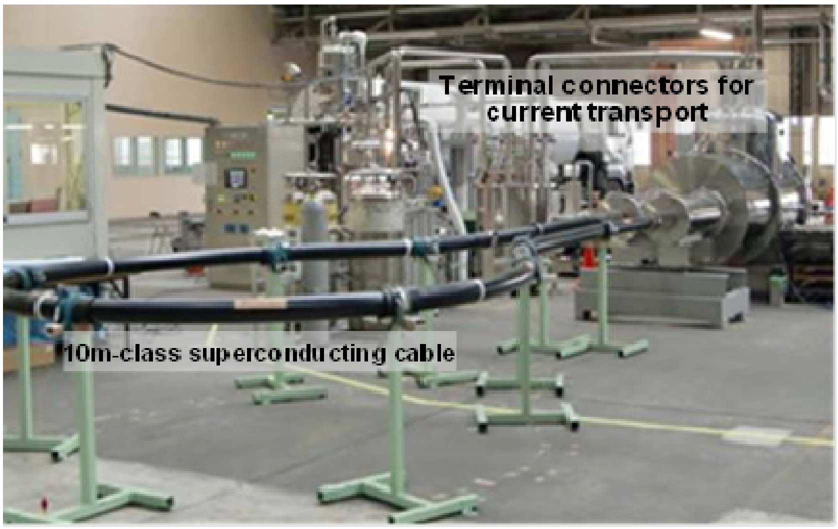

Fig. 4 66 kV/5 kA-class large current cable system
Fujikura Ltd., Sakura, Japan

1.2 275kV/3kA-class high voltage cable

The development of a high voltage cable led to advancements in single-core cables allowing the transport of single-phase 275kV, 3kV currents, together with a selection of electrical insulating materials and associated testing methods to determine their characteristics. Progress too was made on verification trials involving 30-m long cables with terminations and intermediate joint.

The cable has an external diameter of less than 150mm and a total loss set at less than 0.8 W/m-phase (AC loss 0.2 W/m-phase, dielectric loss 0.6 W/m-phase). The application of excess currents of 63kA for 0.6 seconds in short-length cables confirmed that no damage occurred or no deterioration in performance characteristics was observed in the cable and at its midpoint connector. Constructing another cable utilizing a thinned superconducting wire in a similar manner to that applied to the large current cable minimized the AC loss in the cable. Characteristics of 0.124 W/m-phase (@73.7K, 3kA) were achieved for a conductor utilizing 3mm-width thinned superconducting wires.

Figure 5 shows the single core structure of a 30m-long high voltage cable system. As shown in the figure, the conductor layer is formed using a two-layer thinned superconducting wire wound spirally around a Cu former. The outer facing conductor-layer is coated with an electrical insulating material where on top a single superconducting wire layer and a Cu shield are placed, forming the single-phase cable core (single core cable). A 30m-long cable system employing this single core cable is shown in Figure 6. The high voltage cable system is equipped with terminations at both ends of the wire, being connected to the current transport facility via current lead bushing. Furthermore, the cable structure has intermediate joint available to connect each single core cable.

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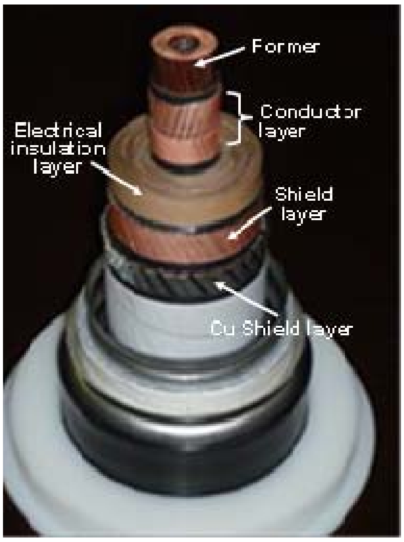

Fig. 5 High voltage cable (single core)

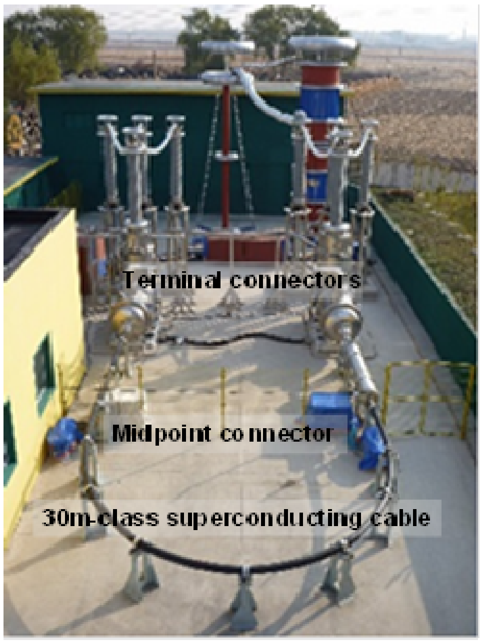

Fig. 6 275kV/3kA-class high voltage cable system (Furukawa Electric Co., Ltd., Jiangsu, China)

Cable losses (less than 0.8W/m-phase), voltage withstands tests and long-term current applications tests were all measured at 3kA rated current. All initial targets under each testing category were met, thus verifying the reliability of the 275kV high voltage cable system.

Acknowledgements
The New Energy and Industrial Technology Development Organization (NEDO) commissioned the research results introduced in this article.

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Feature Article: Technological Development of Yttrium-based Superconducting Power Equipment - Outcomes from Superconducting Transformer Technology Development

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The development of superconducting transformer technology is being progressed as part of the Yttrium-based Superconducting Power Equipment Technology Development Project (hitherto, Y-based project), and involved Kyushu Electric Power Co., Inc., who led a consortium of manufacturers, with collaborations between Kyushu University, Iwate University, International Superconductivity Technology Center (ISTEC), Fujikura, Showa Cable Systems Co., Ltd., Fuji Electric Co., Ltd., Taiyo Nippon Sanso Corporation, and JFCC. This project has investigated component and system technology developments for the periods from 2008-2012, and involved verification trials of a prototype 2MVA-class superconducting transformer in order to determine the feasibility of a 66/6kV 20MVA-class superconducting transformer system. Also, the aim has been to verify the current limiting function of a prototype transformer being several-hundred kVA-class utilizing superconducting wires.

Specifically, the project has focused on: 1) the wire development required for a superconducting transformer (100m-long, 5mm-width/three-filament), 2) the wire winding technology development (low loss ≦1/3 compared to an non-divided wire, 2kA-class high current), 3) cryocooling system technology development (2kW@65K, COP0.06@80K), 4) technology development equipped with current limiting functionality (excess current < 3x rated current), and 5) demonstration of a prototype 2MVA-class superconducting transformer (fabrication and evaluation of a prototype 2MVA-class transformer, and designing a 20MVA-class transformer for practical use). Each stage of development has achieved its final set targets and the project concluded as of February 2013 (Figure 1).

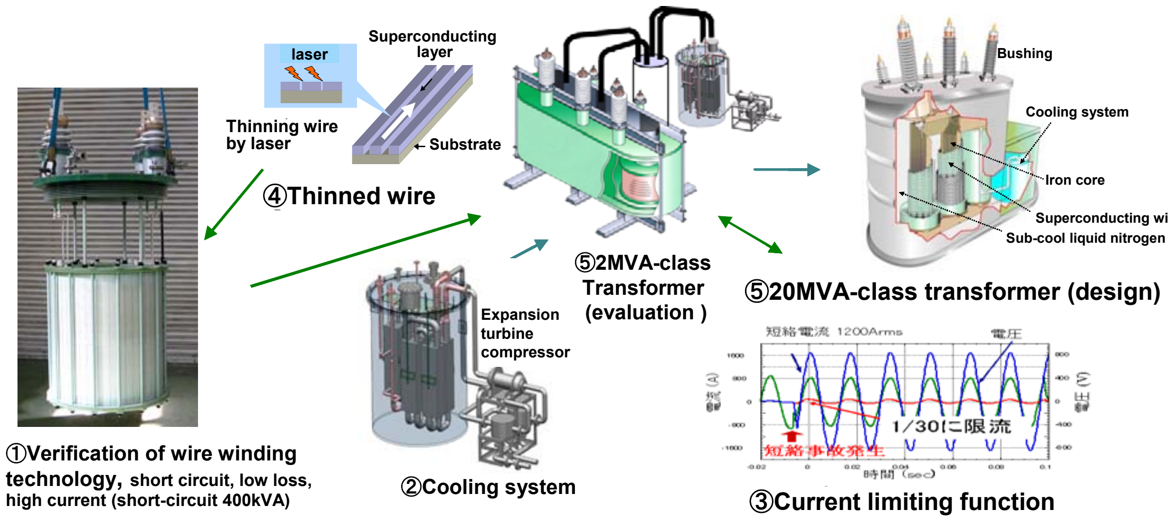

Fig.1 Summary of superconducting transformer technology development

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A progress report on items 1) & 4) and on 3) & 5) mentioned above were reported in the November 2011 and the December 2012 issue of Web 21, respectively. The high current aspects of item 2) and the outcomes from item 5), which are the conclusions of the final results and the completion of the demonstration trials, are introduced in this article.

1. Demonstration of 2kA- class large-current winding technology

The conceptual design of a 20MVA superconducting transformer aimed for practical use consisted of parallel conductors (12-layer wires, 2-parallel), comprising of 24 wire strands with a 1673A rated current in the secondary windings. In this way, reducing the number of parallel strands improves current homogeneity between strands, decreasing the probability of loss and transformer cost. On the other hand, the windings of a superconducting transformer have almost zero electrical resistance and its inductance is homogenized by homogenizing the current between the strands using a transposition methodology. A prototype air-core coil winding comprising of 24 parallel conductors has so far established a transposition technology that is able to suppress shunt currents to less than 15%. This time a prototype 2kA-class large current winding with an iron core (24 parallel conductors) was fabricated and its shunt current characteristics measured. The prototype wire winding tests are shown in Figure 2, with Figure 3 showing the results from shunt current measurements from each strand when a maximum 2057A current was applied to the secondary wire windings having an iron core, and comparing the results to that of an air-core prototype. The results show that the shunt current rate of each strand was 90.1%-109.0%, leading to more favorable characteristics than the air-core prototype.

Fig. 2 Testing of a 2 kA-class large current winding

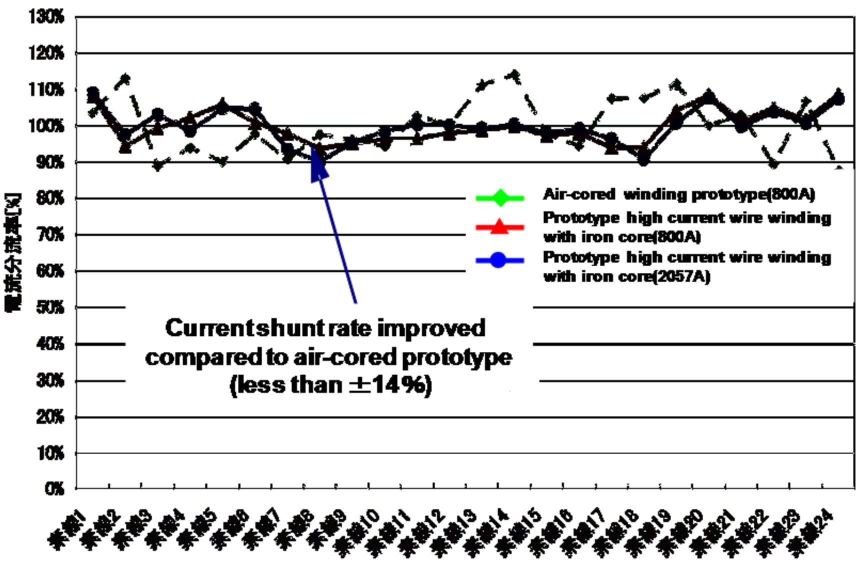

Fig. 3 Current shunt measurement results between strands of a high current winding prototype (air-cored, iron core)

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2. Demonstration of a prototype 2MVA-superconducting transformer

In order to envisage the realization of the future prospectus of a 20MVA-class superconducting transformer for practical u se, a prototy pe 2MVA-class superconducting transfo rmer was fabricated. The prototype 2MVA-class transformer has the same voltage capacity and the equ ivalent wire-winding configuration to a practical transformer. Its performance has been verified to foresee the characteristics of a superconducting transformer, the fabrication technology, and the te chnology combined with cooling system. Testing of this prototype followed that of a JEC2200 transformer and involved investigating the fundamental, insulation and thermal performance characteristics. The specifications of this prototype are shown in Table 1, and an outline picture in Figure 4.

Table 1 Specifications of a prototype 2MVA transformer

Number of phases, wires connected	3, Y-Y
Rated voltage	66 kV/6.9 kV
Rated current	17.5 A/167.4 A
% Impedance	3 % (2 MVA-base)
Number of winding layers	8-layer / 2-layer
Number of turns	918/96
V/N	41.5
Conductor structure	One conductor/8-parallel (4-layer 2 parallel)
Measurements of wire cross section	5.3 mm x 0.35 mm
Wire length	6.3 km/3.8 km
Cooling method	Sub-cool liquid nitrogen cooling
Cooling capacity	2 kW@80 K

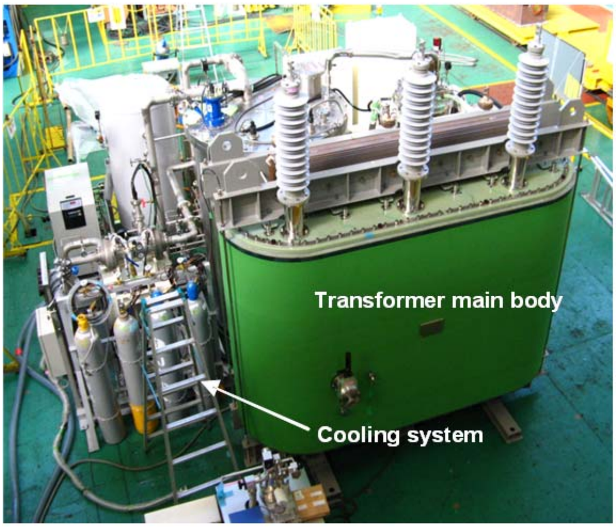

Fig. 4 Prototype 2MVA transformer

The major testing items of this prototype transformer are shown in Ta ble 2 along with the results obtained, all of which w ere favorable. Amongst the se tests, the lightening-impulse withstand voltage test shown in Figure 5 confirmed its reliability at a 352kV full-wave impulse test. The cooling system test shown in Figure

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6 involved te sts of the circulation of sub-cooled liquid nitrogen at 30L/min, and steady co oling of a superconducting coil with the transit of liquid nitrogen at temperatures of around 67-68K flowing within the transformer.

Table 2 Major testing parameters

Fundamental performance test	**Wire winding resistance, DC I-V characteristics, Transformation ratio, Short-circuit impedance as well as load loss, no-load loss and no-load current**
Insulation characteristics test	**Insulation resistance, short-time AC withstand voltage, lightening impulse withstand voltage**
Thermal characteristics test	**Thermal invasion volume, Insulating container, Initial cooling characteristics of wire winding, Characteristics with the refrigerator stopped, Initial cooling characteristics of refrigerator, Cooling capacity of cooling system, Cooling characteristics when rated current applied**

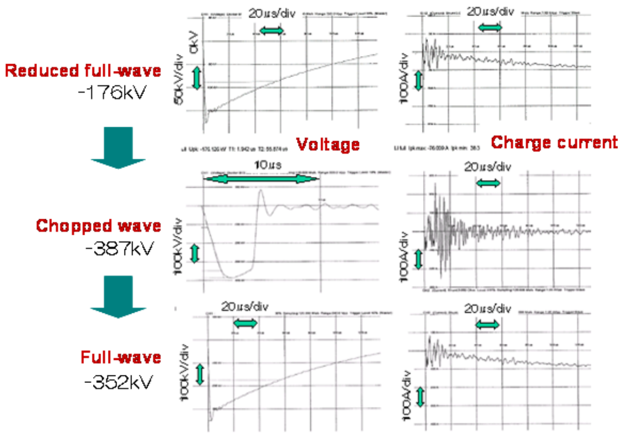

Fig. 5 Test results of lightening impulse withstand voltage

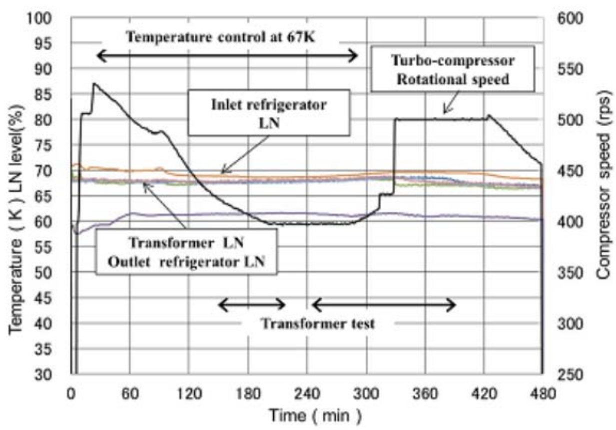

Fig. 6 Test results of cooling system

3. Design investigations for 20MVA superconducting transformer for practical use

The design of the 20 MVA-superconducting transformer for practical use was undertaken based upon the outcomes from the a forementioned component and transformer system technology. The design parameters were 1) an allo wable 10% impedance because o f the reduction of wire volume and being equipped with a protective current limiting function (an allowable 15 % impedance without current limiting function), 2) sub-cooled liquid nitrogen wire windings in order to ensure insulation, 3) locating iron core a t room temperature to avoid cooling system thermal loads, and 4) cylindrical superconducting wire windings located within the GFRP reel. The design involved an analysis of the iron-core weight, wire lengths and the coil height as determined by the voltage generated between the turns as the parameter, and an optimum

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value of 41.5 V/turns calculated. Specifications of superconducting transformer designed are shown in Table 3, the conceptual diagram in Figure 7, and a comparis on of superconducting and oil-immersed transformers in Table 4. Table 4 clearly shows that superconducting transformers offer greater efficiencies having around half the weight and footprint compared to oil-immersed transformers.

Table 3 Specifications of 20MVA transformer

Number of phases, wires connected	3, Y-Y, With current limiting function
Rated voltage	66 kV/6.9 kV
Rated current	175 A/4.674 A
% Impedance	10 % (20 MVA Benchmark)
Number of turns	918/96
V/N	41.5
Conductor structure	3-parralel (3-layer)/24-parallel (12-layer 2-parallel)
Wire cross section	5.3 mm x 0.35 mm
Wire length	18.0 km/15.1 km

Table 4 Comparisons between superconducting and oil-immersed transformers

Type	Superconductivity	Oil-immersed
Loss	46 %	100%
AC loss/Cu loss	31 % (AC loss)	91 % (Cu loss)
Iron loss	7 %	9%
Thermal invasion	8 %	-
Efficiency	99.7 %	99.4%
Weight (incl cooling system)	50 %	100%
Installation footprint (Ditto)	51 %	100%

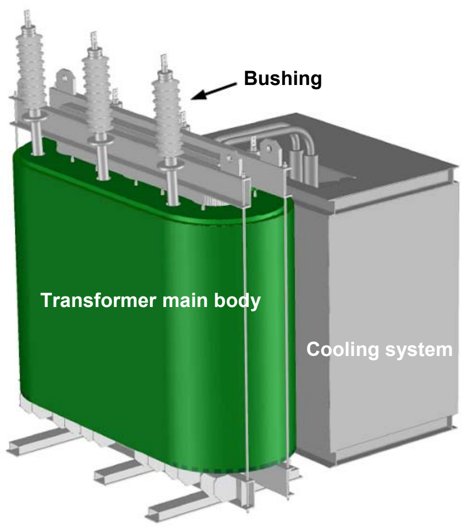

Fig. 7 Conceptual diagram of 20 MVA superconducting transformer

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4. Summary

The technological development of superconducting transformers has advanced over a 5-year period from 2008-1012, and this time, the verification of 2 kA-class winding technology and the development of a 2 MVA superconducting transformer system have been undertaken. Furthermore, designs from these outcomes has provided the future prospectus for the characteristics necessary for practical superconducting transformer systems, and highlighted the significant performance attributes compared to an existing oil-immersed transformer. The project target was thus achieved with most of these findings being a world's first.

These findings are expected to bring about further technological deployment in transformers applicable for use by industry and power grid applications, as well as progressing the realization of future practical transformers. Taiyo Nippon Sanso Corporation has successfully commercialized the cooling system developed in this project.

This technological development was undertaken as part of the Yttrium-based Superconducting Power Equipment Technology Development, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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Feature Article: Materials & Power Applications of Coated Conductors - Development of Coated Conductors for Superconducting Power Equipment

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R&D Division of Superconducting Tapes and Wires
SRL/ISTEC

The themes in this project involve the "development of coated conductors (CCs) with high specifications required for demonstration trials", expected soon after the completion of the project, in addition to the "development of CCs with greater specifications necessary for commercialization and market diffusion stage", and anticipated for around 2020. Interim and final goals for CCs specifications for SMES, superconducting transformers and transmission cables required for each aforementioned period have been agreed and set. Specifically, the goals for CCs development have been re-categorized according to the aforementioned component technology and reorganized under five themes.

Table 1 Target values of CCs development for superconducting equipment

Themes	Interim goals	Final goals
①Understanding characteristics	*Determination of conditions applicable for cable tolerance tests	■Tolerance evaluations for Transformer
② High Ic under magnetic fielsIn-field	*30A/cm-w @77k.3T-50m *300A/cm-w @65k, 0.02T-50m	■ 50A/cm-w@77K, 3T-200m ■ 400A/cm-w@65K, 0.1T-100m
③Low AC loss	*2mm-width-300A/cm-w-80m *5mm-width 5-filament, AC loss reduction of 1/5 compared to a non-divided wire	■2-4mm width-500A/cm-w-200m ■5mm-width 10-filament, AC loss reduction of 1/10 compared to the non-divided wire
④High strength & high J_e	*300A/cm-w-1 gPa-50m *Je=30kA/cm2-50m	■ 500A/cm-w-1GPa-200m ■Je=50kA/cm2-200
⑤ Low cost & high yield	*Verification of a technological cost of 3 yen/Am	■Verification of a technological cost of 2 yen/Am ■ A interim set target of establishing a stable fabrication technology

1. Understanding of CCs characteristics

Assuming CCs designed for practical use, evaluation studies to investigate their characteristics were undertaken to determine the effects of time and year, with accelerated life-cycle trials designed to mimic a variety of environments, which included storage, operation, as well as simulating accident situations.

Before the fabrication of a superconducting transmission cable, first of all, the CCs humidity tolerance characteristics were evaluated in a controlled humid environment (40°C, relative humidity 100 %). The test results revealed a rate of deterioration in I_c characteristics with changes in temperature and humidity, which

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followed an Arrhenius expression, and that it would take a total of 9 years to degrade the superconducting characteristics in the aforementioned environment. Additionally, thermal loads, stress-strain tolerance evaluations and current application/excess current load tests have been performed and with cable tolerance testing plans drawn-up the interim goals were achieved. The latter half of the project focused upon the requirements necessary for transformer applications, which have led to evaluation studies to determine the "resistance-to-environment" of scribed CCs necessary for low loss characteristics. Procedures to elucidate delamination mechanisms and techniques to improve strength have also been developed. Investigations on the delamination phenomenon involved an observation of the delamination surface, the results from which led to a better understanding of the relationship between factors triggering and affecting delamination strengths. The development of a suppression method successfully led to wires with greater delamination tolerances, and the final goals were thus achieved.

2. Development of CCs with high in-field critical currents (I_c)

With regards towards aiming for high temperatures and compact superconducting equipment, it is the operational environment of the equipment that dictates such high performance attributes. More specifically, the progression necessary includes improving critical current and mechanical strength characteristics when operating in wide-ranging magnetic fields; low magnetic fields of around 0.1T for transformer applications, to high magnetic fields of around 11T required by SMES applications. To address this, fabrication technology of CCs exhibiting high in-field I_c characteristics were developed under "high I_c thick film" and "control of artificial pinning center" projects.

To improve characteristics to accomplish the low magnetic field (0.1 T) targets, development involved employing thick film CCs without artificial pinning centers. Thick-film IBAD-PLD(GdBCO) CCs fabricated at high-speeds, which realized high J_c characteristics that successfully produced 158m-long wire (film thickness 1.6 μm), 725 A/cm-w(@65 K, 1 T). An interim heat treatment step was developed for the fabrication of IBAD-MOD CCs. Efforts to densify and homogenize a superconducting film proved successful and led to the fabrication of a 100m-long CCs (film thickness 2.0 μm), 524 A/cm-w(@65 K 1 T), thus meeting the final set objectives.

The high magnetic field goal was achieved by the discovery of $BaHfO_3$ (BHO) introduced thick films having less deterioration of in-field characteristics compared to conventionally established BZO pinning centers, prepared using IBAD-PLD methods. A 200 m-long wire (54 A/cm-w @77 K, 3 T) was successfully fabricated utilizing this material system, meeting the set objective. Additionally, an IBAD-MOD CCs integrating BZO by using the aforementioned interim heat treatment was developed. A 124 m-long wire (50 A/cm-w@77 K, 3 T)) was successfully fabricated.

3. Development of low AC loss CCs

To reduce AC losses in superconducting power cables and superconducting transformers aimed at AC applications, it is required that superconducting power cables are configured having a perfect circular cross section with a controlled deformation and gap number/distance between the CCs. In order to reduce AC losses in coiling configurations due to changes in vertical magnetic field components, filament (thinning) and winding transposition technologies are employed. The fabrication technology of CCs applicable to such equipment is required. Here, the fabrication technology of low AC loss CCs required for "superconducting

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power cable" and "superconducting transformer" developments were advanced under the "fabrication technology for homogeneous CCs characteristics" as well as the "filament process technology".

IBAD-system buffer layer deposition is a common aspect for both IBAD-PLD and IBAD-MOD CCs technology, with its effectiveness confirmed by etching process. Applications of this technology led to the fabrication of 200 m-long uniform IBAD-PLD CCs having I_c□540 A/cm-w characteristics for 2 mm-w CCs, and thus meeting the objectives set for the cable. In addition, a 100m-long CCs was fabricated in a similar fashion and by cutting the wire into 5 mm-w followed by 10-filament scribing, allowed this CCs to be applicable for transformer applications. A loss reduction of 1/10 was confirmed, thereby meeting the final target. Also, the 100 m-long IBAD-MOD wire was also processed to 5 mm-w, 10-filament wire, confirming an AC loss reduction of 1/10 and meeting the final goal.

4. Development of high strength/industrial & high critical current density (J_e) CCs

CCs applicable to SMES applications are subjected to strong hoop stresses generated under strong magnetic fields and during cooling, and it is therefore difficult to achieve contraction tolerances within the internal structure. The development of high-strength & high J_e CCs is required for high current cables where it is assumed that stress loads occur during cooling. To address these issues developments entitled, "high strength CCs on metal substrates" and "high critical current (I_c) CCs", has progressed and the fabrication technology of high strength and high J_e CCs required for "SMES" and "superconducting power cable" developments established.

The high I_c targets have been met by high strength substrates developed using a deformation-induced process. For IBAD-PLD CCs, buffer layer grain alignment and further improvements to laser power, and controlled plume formation with the control of oxygen partial pressure have all resulted in the deposition on 217 m-long, 70 μm-thickness high strength metal substrate. The measured J_e was more than 52 kA/cm^2, and met the final goal value. Furthermore, 200 m-long CCs were fabricated utilizing the high-strength metal substrate with 100 μm-thickness, achieving an I_c of more than 500 A/cm-w(@77 K, s.f.). This target was also met achieving strengths of more than 1 GPa confirmed.

5. Development aiming for low cost and improvements in yields

At the start of this project technological costs were realized to be around 8-12 yen/Am. However, further reductions in costs are necessary for the realization of practical superconducting equipment. Procedures to reduce cost have been attempted with the development of less expensive substrates based on an IBAD-MgO buffer layer and Ni compound substrate. The superconducting layer deposition technology development has advanced to high I_c, high speeds, high material yields, and high manufacturing yields based on PLD and MOD methods, leading to further cost reductions.

For substrate/buffer layer development, an Y_2O_3 seed layer allowed greater irradiation during IBAD layer deposition, which resulted in greater grain alignment of the buffer layer. PLD CCs have seen technological developments in high J_c and laser power improvements utilizing grain alignment technology in this buffer layer as well as controlled plume formation by oxygen partial pressure control, all leading to the technological development of films with improved characteristics. With achievement in characteristics of I_c=604 A/cm-w(@77K, s.f.) at 30 m/h, technological costs of 1.6 yen/Am was successfully verified. IBAD-MOD fabricated CCs have seen improvements in densification and uniformity with the development

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of an interim heating process. Additionally, an improved coating process was also developed for film thickening with suppression of cracks. The characteristics of I_c>605 A/cm-w(@77K, s.f.) were achieved at a manufacturing speed of 5m/h(calcination) & 10m/h(crystallization) for 2.3 μm-thickness superconducting layer, which further corroborated the technological cost of 1.6 yen/Am. All the steps undertaken have achieved their final goals. The development of stable CCs manufacturing technology, which has an interim-level goals required during the deployment period of practical technology, has been undertaken.

Finally, the achievements in all the themes are shown in Table 2.

Table 2 Status of the achievements in CCs development

Interim targets	R&D outcomes	Degrees of achievement
①Understanding characteristics	■ Determination of conditions applicable for power cable tolerance tests ■Elucidation of delamination mechanisms →Elimination of low, mid strength delamination factors ■Tolerance evaluation for filament CCs	Final goals achieved
② High Ic under magnetic fielsIn-field	<PLD>■54 A/cm-w@77 K,3 T- 200 m ■770 A/cm-w@77 K,0.1 T- 158 m <MOD>■50A/cm-w@77 K,3 T-124m ■524 A/cm-w@65 K,0.1 T- 100 m	Final goals achieved
③Low AC loss	<PLD> ■2 mm-w -I_c≧540 A/cm-w -200 m ■5 mm-w・10Filament, Loss1/10 - 100m <MOD> ■4 mm-w-Ic≧590 A/cm-w -80 m ■5 mm-w・10Filament, Loss1/10 - 100m <RABiTS-PLD> ■2 mm-w-Ic≧400 A/cm-w -78 m	Final goals achieved
④High strength & high Je	<PLD> ■$I_{c,min}$ > 500 A/cm-w – 1GPa - 200 m ■J_e>52 kA/cm2 - 200 m <RABiTS-PLD>■J_e>52A/cm2 – Short-wire	Final goals achieved
⑤ Low cost & high yield	<PLD>■I_c=604 A/cm-w @30 m/h -35 m 1.6JPY/Am <MOD>■I_c=605 A/cm-w @5,10m/h -30 m 1.6JPY/Am	Final goals achieved
	＜Sumitomo Electric＞Cable wire⇒(representative value) 2 mm-w wire characteristic yields：47% ＜Furukawa Electric＞Cable wire⇒(representative value) J_e characteristic yields：36% ＜Fujikura＞Transformer wire⇒(representative value) Low field characteristic yields：88% ＜Showa Cable＞Low cost wire⇒(representative value) Low cost condition yields：64%	Final goals achieved

The world ranking for those achievements are summarized in Table 3. Each target is world leading, and it clearly shows Japan's superiority in this field.

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Table 3 Comparisons with the world trend regarding Y-based superconducting wire development

Research themes	World trends	Project outcomes and world rankings
①Understanding characteristics	■ No example of systematic evaluation studies undertaken for degradation and delamination behaviors	.Undertook load test required .Elucidation of delamination mechanism and proposal solutions .World's first systematic results
② High Ic under magnetic fielsIn-field	LANL（USA） : IBAD-PLD(Short CCs) *I* c= 234 A/cm-w@75 K, 1T SuperPower(USA) : IBAD-MOCVD Short CCs *I* c=1353A/cm-w@50 K,3 T 50 m *I* c=14 A/cm-w@77 K,3 T amsc（USA） : RABiTS-TFA-MOD Short CCs *I* c=10 A/cm-w@77 K,3 T	Short CCs I_c=141A/cm-w@77 K,3 T(PLD) →Ic=1400A/cm-w@50 K,3 T 200 m Ic=54A/cm-w@77 K,3 T(PLD) Short-wireIc=56 A/cm-w@77 K,3 T(MOD) 124 m Ic=50 A/cm-w@77 K,3 T(MOD) World's highest in-field characteristics (long-wire in particular)
③Low AC loss	SuperPower(USA) : IBAD-MOCVD 12-filament for 12mm-w short CCs No reports for long CCs	100 m-5 mm-w 10Filament-Loss1/10(PLD) 100 m-5 mm-w 10Filament-Loss1/10(MOD) World-leading technology
④High strength & high Je	SuperPower(USA) : 50mm-thickness HastelloyTM metal substrate amsc（USA） : Metal substrate with grain alignment structure	70 μmHastelloyTM metal substrate *I* c,min=539A/cm-w-*J* e>52 kA/cm2 -200 m 100 mmHastelloyTM metal substrate *I* c,min>500A/cm-w-1GPa-200 m (Ag30μm assumed) World's strongest
⑤ Low cost & high yield	SuNAM（Korea) : IBAD-Co-evaporation method 1000 m-*I* c=422 A/cm-w@77 K,s.f. (IcxL＝422 kAm) SuperPower(USA) : IBAD-MOCVD 1065 m-long-*I* c=282 A/cm-w@77 K,s.f. (IcxL＝300 kAm)	Fujikura : IBAD-PLD 816 m-*I* c=572 A/cm-w@77 K,s.f. （IcxL＝467 kAm) ↓ Leading the world with long-wire characteristics USA and Korea leading the world for wire length

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Feature Article: Technological Development of Yttrium-based Superconducting Power Equipment - Standardization of Superconducting Power Equipment Applications Technology

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1. Introduction

As well as Japan's active promotion of an international standardization for superconductor technology, the aim of establishing international standards for superconducting power equipment in parallel with the "Development of Yttrium-based Superconducting Power Equipment Technology" project is important from an industrially competitiveness point of view.

Here, the activities of the "standardization of superconducting power equipment applications technology" has implemented investigations concerning the trends of technology and standardization needs, with a view to establishing universal standardization in superconducting power equipment, including superconducting wires and superconducting power cables employing those wires. Preliminary draft standards led to an initial international standard draft paper have been prepared by harmonizing an international consensus. This process is expected to promote the earlier realization of a standard for superconducting power equipment with a smooth introduction into the marketplace, and an expansion of the global market.

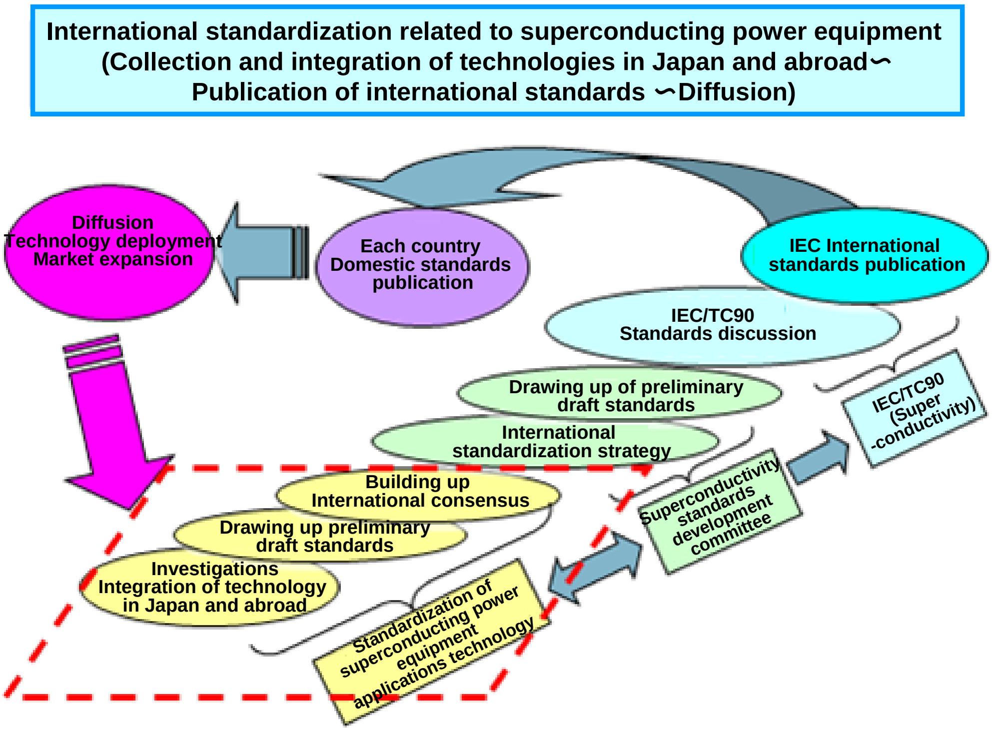

Fig. 1 International standardization related to superconducting power equipment
(Collection and integration of technologies in Japan and abroad∽Publication of international standards ∽Diffusion)

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The process of drawing up international standards will go through various stages that include the collection and integration of technologies available in both Japan and abroad, as well as the publication and diffusion of international standards, shown by the flow diagram in Figure 1. This work has involved investigations/collection and integration of technologies from Japan and abroad over a period of five years from 2008 to 2012, along with preparation of draft standards and international agreements. The superconductivity standards development committee has spearheaded an international standardization strategy and has been drawing up draft standards over three years from 2010 to 2012. Furthermore, the IEC (International Electrotechnical Commission) holds discussions into the publication of standards, and this activity is now expected to be held in parallel with the IEC/TC90 (superconductivity), where Japan has the responsibility as Secretariat.

2. Development targets and status of achievements

Agreed development targets for the "standardization of superconducting power equipment applications technology" have been set for the end of the 5 year project, which include "contributing to IEC proposals for international standards on superconducting wires and its testing methods", "contributing to IEC proposals for international standards for superconducting power cables and testing methods", and "drawing up a first draft standard for specifications and associated testing methods for superconducting equipment such as transformers and SEMS". Drawing up draft and international standard agreements as required for the IEC international standards proposals has been undertaken on superconducting wires and superconducting power cables. Also, investigations into superconducting power equipment which include transformers and SMES, have been performed for the purpose of data systematization, and is the basis required for standardization. This was followed by preliminary draft standards. Moreover, proposal papers aimed at deregulation related to safety and operability of cooling system has been undertaken. These activities have achieved all their final targets. The following account summarizes the individual target contents.

3. Standardization of superconducting wire technology

The standardization of superconducting wire technology has investigated the testing methods employed for superconducting wires and to determine the characteristics of Yttrium (Y)-based superconducting wires and superconducting wires designed for practical use. Additionally, information has been gathered through investigations and discussions among international experts in USA, Europe and Asia, in order to build up an international consensus. From this, a preliminary draft proposal related to general craracteristics for superconducting wires has been drawn up and selected as an NP (New Work Item Proposal) for discussions at IEC/TC90, leading to an establishment of a WG (Working Group) 13. Two pillars up for discussion are general characteristics pertaining to superconducting wires, which include a general category, and the characteristic testing methods employed. Based upon this, a first CD (Committee Draft) has been prepared for discussions. A preliminary draft standard on the critical current measurement of Y-based superconducting wires has been prepared for discussions. Furthermore, Japan's RRT (Round Robin Test) measuring the critical currents of short-length Y-based superconducting wires has been performed as a pre-trial for full-scale comparisons to be made between international testing laboratories, with the findings from this study made available to IEC/TC90. The results from WG3 were reported at the IEC/TC90, held in Xi'an on August 2012. The meeting concluded that a future international RRT would be undertaken using commercially available wires. Examples of the results obtained from Japan's RRT is shown in Figure 2.

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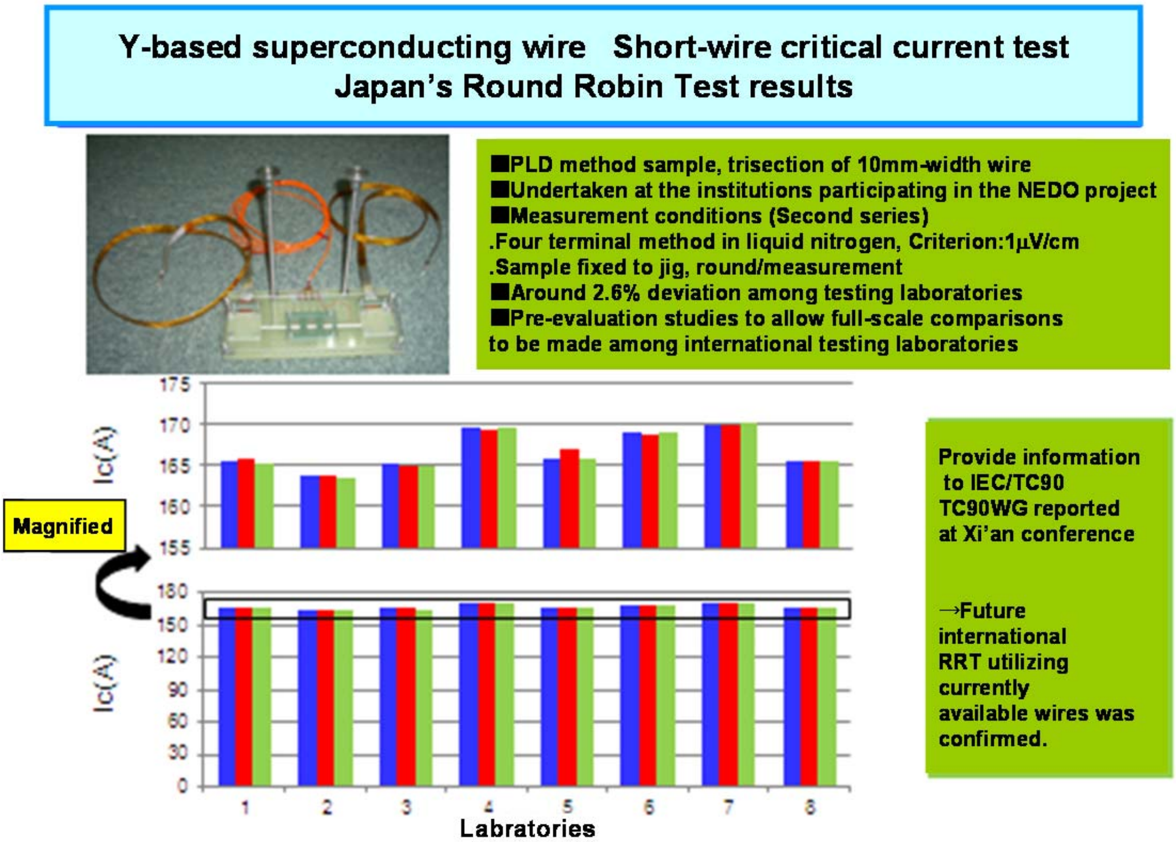

Fig. 2 Round Robin Test results of short-wire critical current test using Y-based superconducting wire in Japan

4. Standardization of superconducting power cable technology

As an initial step to establish the standardization of superconducting power cable technology, existing standards and associated technology trends has been investigated. With cooperation from CIGRE (International Council on Large Electric Systems) and IEC/TC20 (conventional power cable), information has been collated via discussions among international experts to allow an international consensus to be formed. This has allowed a preliminary draft standard to be drawn up that relates to generalrequirements and testing methods employed for superconducting power cable systems utilizing high temperature superconducting wires. A summary of the preliminary draft standard is shown in Table 1. Also, the testing methods used for superconducting power cables were investigated using the guidelines prepared at CIGRE and the findings fed back to CIGRE. CIGRE published a final report and it was confirmed that a JahTF (Joint adhoc Taskforce) would be established, which would involve TC20, TC90 and several volunteers at IEC. In the future it is planned to undertake activities aimed at setting IEC international standards proposals related to superconducting power cables in the background of international consensus.

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Table 1 A summary of preliminary draft standards pertaining to superconducting power cables and associated testing methods

General requirements of superconducting power cable systems Preliminary drafts standards
1. Application ranges
2. Reference standards
3. Technical terms and definitions
4. Operating conditions
5. System structure
6. Performance
7. Tests
8. Report
9. Supplementary item
Annex A (reference)Fundamental structural concept of superconducting AC power cables
Annex B (reference) Structural concept of superconducting power cables
Annex C (reference) Testing items for superconducting A power cable systems

Testing methods for superconducting power cable Preliminary draft standards
1. Application ranges
2. Reference standards
3. Technical terms and definitions
4. Operating conditions
4.1 General testing conditions
4.2 Superconductor-specific testing conditions
5. Tests
5.1 Types of tests
5.2 Specific items tested
5.3 Test items
5.4 Superconductor-specific testing methods
6. Performance
6.1 Declaration of fundamental specification items
6.2 Declaration of individual performance items
6.3 Examples of the performance of superconducting
AC power cables
Annex A (Standards) Individual testing methods of superconducting AC power cables
Annex B (Reference) Formal testing contents investigated at CIGRE
Annex C (Reference) Example tests of superconducting AC power cable systems

5. Standardization of superconducting power equipment-related technology

The standardization of supe rconducting power equipment-related technology has investigated equipment specifications for SMES an d superconducting transformers constructed using Y-based superconducting wires, in addition to examining th e fundamental data for t he standardization of these associated testing methods. Investigations for technological trends and standardization needs have also been un dertaken. Based upon these findings, a prelimi nary draft standard regarding equipment specifications for SMES and superconducting transformers, incl uding their asso ciated testing me thods has been prep ared. Table 2 summarizes the preliminary draft standards. Furthermore, in the course of advancing the standardization of superconducting power eq uipment such as superco nducting current limiters, the discu ssions have emphasized the necessity for cooperati on with other institutions. Th is has led to uniting liaisons between IEC/TC90 and CIGRE D1 (Study Committee of Materi als and Emerging Technology), as well a s following

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up on activities to build up an international consensus. Deregulations towards safety and operability of cooling systems have been investigated using past proposal documents on superconducting power cables. Up-to-date trends have been formulated from surveys conducted at institutions, which has led to a proposal document aimed at deregulation.

Table 2 Preliminary draft standards summary of SMES and superconducting transformers

Preliminary draft standards summary of SMES
1. Application ranges
2. Reference standards
3. Technical terms and definitions
4. Principles
5. Characteristic testing items
6. Characteristic testing methods
7. Reports
8. Supplementary items
Annex A (Reference) Power input/output and storage capacity of representative SMES system
Annex notes B (Reference) Conceptual structure of the fundamental components of superconducting magnetic energy storage system
Annex notes C (Reference) Recommended testing methods for SMES system
Annex notes D (Standards) SMES device testing methods
Annex E (Reference) Conceptual diagram and example specifications of superconducting magnetic energy storage system

Preliminary draft standards of superconducting transformers
1. Application ranges
2. Reference standards
3. Technical terms and definitions
4. Structure
5. Operating conditions
6. Rated and general requirements
7. Tap
8. Connection
9. Temperature increase
10. Insulation
11. Short-circuit strength
12. Report
13. Safety, environment and other necessary issues
14. Tolerances
15. Tests
16. Supplementary items
Annex A (Reference) Conceptual diagram of superconducting transformer
Annex notes B (Reference) Items specified for reference as well as their order necessary for a superconducting transformer
Annex C (Standards) Superconductor-specific testing methods for superconducting transformers

6. Future course of action

The standardization of superconducting wire technology, CD2 (Committee Draft Version 2) pertaining to general characteristics of superconducting wires will be published in 2013. The CDV (Committee Draft for Vote) proposal is planned for 2014 and following this activities for the IEC international standardization will be undertaken. International RRT regarding critical current measurements of Y-based wires will be undertaken and further activities towards IEC international standards are in planning. The standardization of

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superconducting power cable technology will also see the establishment of a JahTF, and activities for international standard proposals are in planning. The standardization of superconducting power equipment-related technology will involve liaisons between IEC/TC90 and CIGRE D1, cooperating on common themes related to superconducting power equipment. It is important to undertake activities in cooperation with other institutions when it comes to deregulation. The author will continuously strive towards activities aimed at an international standardization of superconducting power equipment based upon the outcomes achieved in this work.

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