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What's New in the World of Superconductivity

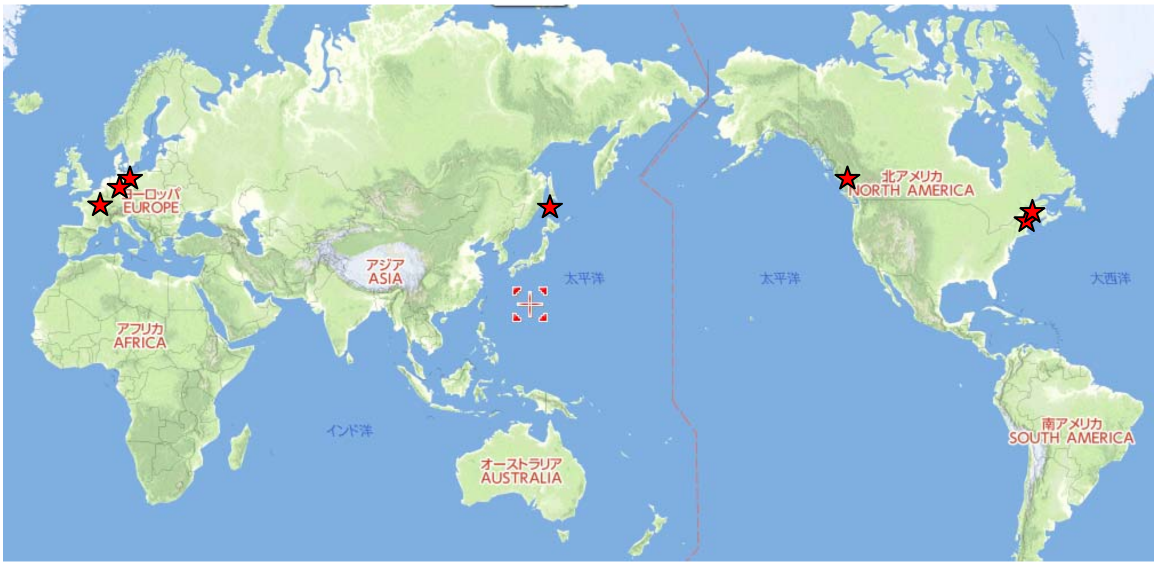
(October, 2015)

초전도 뉴스 −세계의 동향−

超电导新闻 −世界的动向-

chāo diàn dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC



★News sources and related areas in this issue

▸Basic

Superconductivity at -70 °C

Max Planck Institute for Chemistry (18 August, 2015)

Researchers at the Max Planck Institute for Chemistry, led by Mikhael Eremets and in collaboration with researchers at the Johannes Gutenberg University Mainz, observed that hydrogen sulfide becomes superconductive at -70 °C under a pressure of 1.5 million bar - corresponding to half the pressure of the earth's core. The researchers in Mainz have not only set a new record for superconductivity, their findings, published in Nature, also highlight a potential new way to transport current at room temperature with no loss.

The researchers believe that hydrogen is responsible for the loss in electrical resistance under high pressure at relatively high temperatures since hydrogen oscillates in the lattice with the greatest frequency. The team is now looking for materials with even higher transition temperatures. At high temperatures, the electron structure changes in such a way that the transition temperature slowly begins to drop again. An obvious high transition temperature candidate is pure hydrogen, which is expected it would become superconductive at room temperature under high pressure. However, pressures of three to four megabar are required, which makes any experimentation difficult.

Source: "Superconductivity: No resistance at record temperatures Hydrogen sulfide loses its electrical resistance under high pressure at minus 70 degrees Celsius" (18 Aug, 2015) Research News
http://www.mpg.de/9366213/superconductivity-hydrogen-sulfide
Contact: Mikhail Eremets, mikhael.eremets@mpic.de

▸Power Application

Success in DC Superconducting Transmission

Ishikari Superconducting DC Power Transmission System (research association) (6 August, 2015)
Ishikari Superconducting DC Power Transmission System has succeeded in superconducting power transmission over a distance of 500 m - the world's longest-distance superconducting direct-current (DC) power transmission and having 1.5 kA, 100 MVA power transmission capabilities. The superconducting cable was buried under a public road (the first such case in Japan). Also, by employing a new piping structure, the thermal loss in the power transmission path was reduced by half, the association said.

The project has been supported by METI who have promoted a DC power transmission project using high-temperature superconducting cables in Ishikari City, Hokkaido. The project comprises two phases. The first phase aims to supply solar power to the company's "Ishikari Data Center" connected using a 500 m high-temperature superconducting cable so that solar electricity can be used at the data center without being converted to AC power. In the second phase, Hokkaido Electric Power Co (HEPCO) Inc's transformer station and the data center will be connected using a 2 km-long superconducting cable by end of March 2018. HEPCO's commercial DC power can then be transmitted.

Source: " Researchers Succeed in Long-distance Superconducting DC Power Transmission" (6 Aug, 2015) Nikkei BP News
http://techon.nikkeibp.co.jp/english/NEWS_EN/20150808/431400/?ST=msbe
http://i-spot.jp/wp/wp-content/uploads/2015/07/20150806_kaisenn1.pdf
Contact: Kenji Kaneko, Nikkei BP Clean Tech Institute

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▸Fusion and Accelerator

REBCO Can Make a Small Fusion Reactor

Massachusetts Institute of Technology (10 August, 2015)

The era of practical fusion power, which could offer a nearly inexhaustible energy resource, is coming nearer. Advances in magnet technology have enabled researchers at MIT to propose a compact new design tokamak fusion reactor. Employing new commercially available REBCO superconducting tapes to produce high-magnetic field coils enables greater magnetic confinement; they can increase fusion power by about a factor of 10. Additionally, the resulting compact size makes the whole system less expensive and faster to build.

The proposed reactor is designed for basic fusion research and also as a potential prototype power plant. The reactor uses a tokamak (donut-shaped) geometry design is described in a paper in the journal *Fusion Engineering and Design*, co-authored by Dennis Whyte, a professor of Nuclear Science and Engineering and director of MIT's Plasma Science and Fusion Center. The basic reactor concept and its associated elements are based on well-tested and proven principles developed over decades of research at MIT and around the world, the team says.

The ITER fusion reactor currently under construction in France is expected to cost around $40 billion. The MIT team estimates that the new design, which is half the diameter of ITER, will produce the same power at a fraction of the cost and in a shorter construction time. The new superconducting magnets would allow the reactor to operate for longer periods of time with a steady power output, unlike today's experimental reactors that can only operate for a few seconds at a time without overheating of copper coils.

Source: "A small, modular, efficient fusion plant" (10 Aug, 2015) MIT News
http://news.mit.edu/2015/small-modular-efficient-fusion-plant-0810
Contact: Andrew Carleen, acarleen@mit.edu

MgB_2 Coil for Superconducting Shield

CERN (5 August, 2015)

A research team from CERN is working on the European Space Radiation Superconducting Shield (SR2S) project, which aims to develop a superconducting magnet to protect astronauts from high-energy cosmic rays. The idea is to produce an active magnetic field using a racetrack coil wound with an MgB_2 superconducting tape to shield from high-energy particles. The prototype coil is designed to quantify the effectiveness of the superconducting magnetic shielding technology. Additionally, MgB_2 superconductors can operate at higher temperatures (25 K) thereby allowing the design to incorporate a simplified cryogenic system.

Source: "A Superconducting shield for astronauts" (5 Aug, 2015) CERN Updates
http://home.web.cern.ch/about/updates/2015/08/superconducting-shield-astronauts
Contact: Press Office, press.office@cern.ch

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▸Electronics

Quantum Computing System

D-Wave Systems (20 August, 2015)

D-Wave Systems Inc., announced the D-Wave 2X™ quantum computing system featuring a 1000+ qubit quantum processor. The processor computes 21000 possible solutions simultaneously, a factor of up to 15x gains over highly specialized classical solvers. Measuring only the native computation time of the D-Wave 2X quantum processor shows performance advantages of up to 600x over these same solvers. The system comprises of 128,000 Josephson tunnel junctions, believed to be the most complex superconductor integrated circuits ever successfully used in production systems. It operates at temperatures below 15 mK, with increased control circuitry precision and a 50 % reduction in noise also contribute to faster performance and enhanced reliability.

Jeremy Hilton, vice president of processor development at D-Wave, said, "The D-Wave 2X system provides user incentives to develop methods to harness this revolutionary technology for their own applications." To showcase the performance of the system, a paper benchmarking a set of bioinformatics, inductive logic programming, and natural language processing and computer vision results problems native to the D-Wave 2X system will be posted to the arXiv. A summary of the results and a link to the paper are on the company's blog.

Source: "D-Wave Systems Announces the General Availability of the 1000+ Qubit D-Wave 2X Quantum Computer" (20 Aug, 2015) Press Release
http://www.dwavesys.com/press-releases/d-wave-systems-announces-general-availability-1000-qubit-d-wave-2x-quantum-computer
Contact: Beth Sanzone, dwave@launchsquad.com

World's Fastest Commercially-available Superconductor Integrated Circuits

HYPRES (5 August, 2015)

HYPRES, Inc., the Digital Superconductor Company™, offers ICs with increased critical current densities of 10 kA/cm^2 having a minimum junction size of 0.7 µm. This is all made possible by the company's recent patent-pending six-layer planarized chip fabrication process, RIPPLE (*Rapid Integrated Planarized Process for Layer Extension*).

HYPRES also offers shunted and un-shunted Josephson junctions with a dual critical current option. HYPRES will continue to make ICs that feature 4.5 kA/cm^2, 100 A/cm^2, 30 A/cm^2 and other customizable parameters and legacy processes. These enhance HYPRES' ability to meet the demanding performance needs of next generation supercomputing systems, Digital RF systems, and advanced superconductor instruments.

Oleg Mukhanov, Ph.D., Chief Technology Officer at HYPRES, stated that the company is now best placed to address the needs of its customers developing high performance applications, including exa-scale-and-beyond computing.

Source: "HYPRES increases speed of world's fastest commercially-available superconductor integrated circuits" (5 Aug, 2015) Newsroom
http://www.hypres.com/newsroom/hypres-increases-speed-of-worlds-fastest-commercially-available-superconductor-integrated-circuits/
Contact: contacts@hypres.com

▸Bulk

Bulk Levitation for Lexus

Lexus (5 August, 2015)

The Lexus Hoverboard project began 18 months ago through collaboration with a team from IFW Dresden and evico GmbH. Up to 200 meters of permanent-magnetic track was laid under the Hoverpark surface to create the dynamic test, offering Lexus the opportunity to exhibit tricks no skateboard could ever perform, like travelling across water. The technology features two cryostats that are used to cool a superconductor to -197 °C using liquid nitrogen. The magnetic field between the magnet and the superconductor is strong enough to allow the rider to stand and even jump on the board. It is now concluding its successful testing phase with pro skateboarder and Hoverboard test rider Ross McGouran, who stated "Skateboarding, but without friction it feels like I've had to learn a whole new skill."

Source: "New film for the latest Amazing in Motion campaign shows final testing in Barcelona" (5 August, 2015) News
http://www.lexus-int.com/news/lexus-hoverboard-ride-revealed.html
Contact: Manager, PR Operations, erica.haddon@tgb.toyota.co.uk

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Feature Article: SQUID / Medical Equipment
- Magnetic Particle Imaging for In-vivo Medical Diagnosis

Keiji Enpuku, Director General
Research Institute of Superconductor Science and Systems
Kyushu University

Magnetic particle imaging for in-vivo medical diagnosis has amassed attention in recent years. The method offers greater detection sensitivities, a performance characteristic not achieved by conventional systems. Breast cancer diagnosis is one example where a potentially new in-vivo medical diagnosis technique using magnetic particle imaging is envisaged. As depicted in Figure 1, the cancer cells are detected by injecting magnetic particles into the body, which bind to disease-related proteins (Her 2) produced on the cell surface. Application of an external excited field generates a signal from the magnetic particles emanating from the affected tissue region. The position of the diseased area and the degree of damage can be determined at the body surface by analyzing the measured magnetic signal. The method offers spatial detection resolutions of the order of around 10 mm for 1 μg-sized magnetic particles concentrated 30-50 mm below the body surface. Previous research studies on the detection system suggest the performance can be significantly enhanced over conventional X-ray inspection (mammography).

Figure 2 shows the prototype magnetic particle imaging system. The system comprises of three coils: excitation coil, pick-up coil, and gradient coil. The excitation coil generates a field with a root mean square value of 1.5 mT and an ac magnetic field at 3 kHz magnetizes the magnetic particles. The pick-up coil detects the field signal from the magnetic particles. The signal from the magnetic particles becomes a dipole field and attenuates rapidly because the magnitude is in inverse proportion to the distance to the third power. Thus, the measured field signal at the body surface emanating from the magnetic particles concentrated within the body produces an extremely weak signal of pT. To address this issue, the author's group has focused on cryocooling the pick-up coil at liquid nitrogen temperatures to attain greater sensor sensitivity. A method to detect third harmonic waves is being developed to avoid excitation field interference, using the non-linear magnetization curve of the magnetic particles. The sensor measurement system has realized high sensitivity with field noise characteristics of 12 fT/Hz$^{1/2}$.

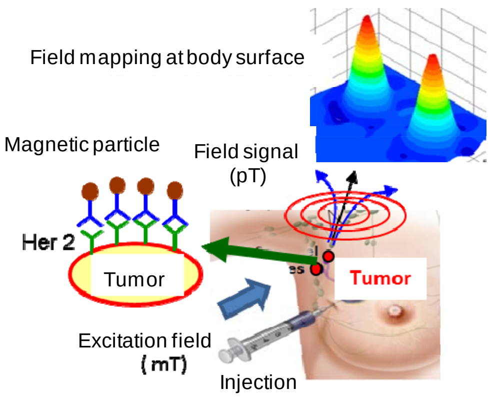

Fig. 1 In-vivo medical diagnosis utilizing magnetic particle imaging

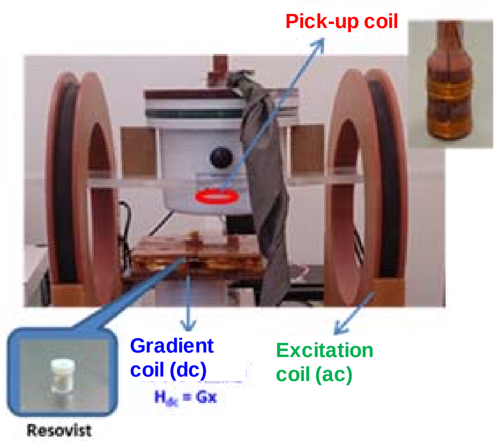

Fig. 2 Magnetic particle imaging system prototype

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Table 1 shows detection sensitivity of the magnetic particles. Here, the so-called Resovist is used as MRI contrast agents for the magnetic particles. The signals from the magnetic particles measured at distance of Z=50 mm from the pick-up coil are shown in the table. A 1 μg magnetic particle was successfully detected at SN ratio 4.

Table 1 The signal detected as function of weight of magnetic particle, spacing z=50 mm set between the testing sample and the bottom of pick-up coil

Sample weight	Signal detected (pT)	SN ratio
1 μg	0.23	4.3
5 μg	0.91	17
10 μg	2.08	39
100 μg	21.4	404

A gradient coil is used to improve the magnetic particle spatial resolution, as shown in Figure 2. The gradient coil generates a dc (gradient field), varied spatially at gradient G. A selective third harmonic signal is generated only from magnetic particles located close to the zero-point of the dc field generated (known as Field Free Point: FFP) owing to the non-linear magnetization curve of the particles. In this way, magnetic particle detection can be performed with greater spatial resolution. Whilst spatial resolution is inversely proportional to the magnetic field gradient G, a gradient field of G=0.3 T/m has been employed this time.

Figure 3 shows the experimental results. Two magnetic particle samples enclosed in 5 mm-diameter containers were employed with a spacing of Δ = 15 mm between them, and Z=50 mm apart from the pick-up coil. Figure 3(a) shows the result from field mapping. As shown in the figure, a significant signal (red) was obtained at these two sample positions indicating the success in identifying these samples. Figure 3(b) shows the results obtained from the concentration distribution of the magnetic particles by analyzing the field map, utilizing the so-called singular value decomposition (SVD) method. Two magnetic particles 5 μg in weight were clearly detected as shown in the figure.

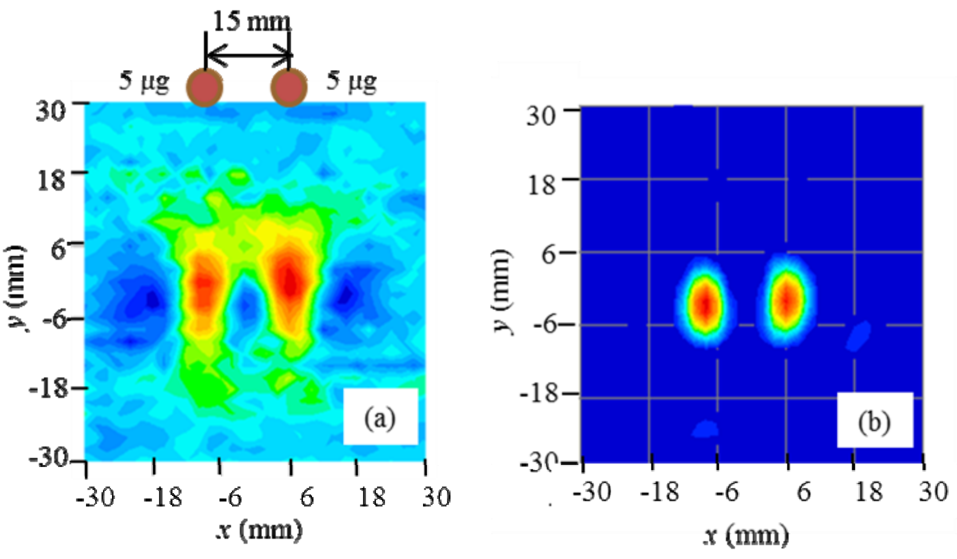

Fig. 3 (a) Field maps generated from the two samples placed in close proximity with a spacing of 15 mm, and at a depth z=50 mm, (b) Concentration distribution of magnetic particles, reconstructed by employing the SVD method

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The experimental findings from the prototype system indicate the feasibility of the system for the in-vivo medical diagnosis application for breast cancer. The group aims to develop the detection system to realize a measurement system with greater sensitivity.

Acknowledgements: The research has been undertaken under JST's R&D Program entitled S-Innovation (Strategic Promotion of Innovative Research and Development).

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Feature Article: SQUID – Medical Equipment -Measuring Magnetic Distribution to Visualize the Electrical Characteristics of Solar Cells Using HTS-SQUID

Kenji Sakai
Division of Medical Bioengineering
Graduate School of Natural Science and Technology
Okayama University

1. Introduction

Greater performance and tolerance attributes are required by solar cells, rechargeable batteries and fuel cells to address current energy issues. Typical methods to ascertain the characteristics of such batteries involve measuring the voltage and current generated at the battery terminals. Further improvements in performance can be attained by internally mapping the battery to evaluate the electrical properties. The author's group have developed a current distribution mapping system using HTS-SQUID to visualize the electrical characteristics, and reported measurements conducted on solar panels [1),2)]. Measuring the magnetic field components parallel to the panel, and using an arrow map to indicate the current flow allowed the artificial defects introduced in a solar cell to be determined.

2. A summary of the measurement system and the distribution in the electrical characteristics of solar cells

Figure 1 shows the measurement system configuration developed to determine the electrical characteristics. A pick-up coil detects and transmits the field signal generated by the current through the solar panel to a superconducting coil. The superconducting coil is magnetically coupled to an HTS-SQUID. The signal acquired at the pick-up coil can be therefore detected by the HTS-SQUID. The HTS-SQUID is a ramp-edge Josephson Junction type developed at ISTEC [3)]. To automate the measurement system, the solar cell is secured on a PC-controlled XY stage to scan each point of the surface. The x (B_x) and y (B_y) magnetic field components parallel to the solar cell surface are detected by the pick-up coils, as shown in Figure 1. Actual measurements of the solar panel involved applying an ac voltage, and using a lock-in amplifier, detecting the same frequency component of the applied voltage. The signals generated here are dB_x/dV and dB_y/dV, differentials of two independent magnetic field components B_x and B_y with applied

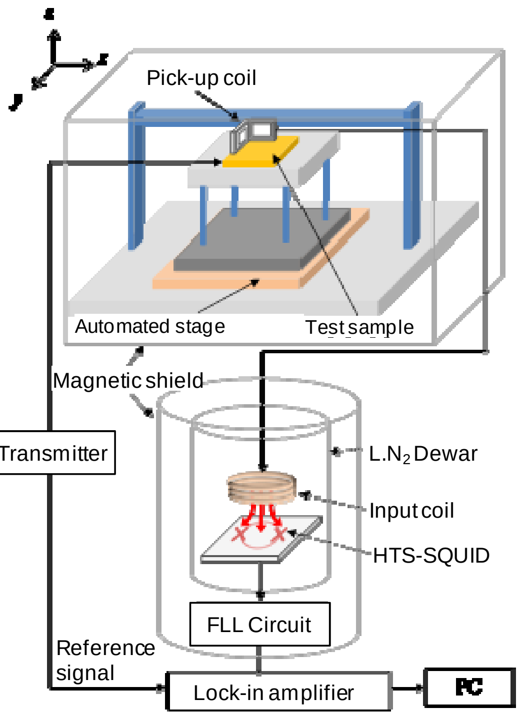

Fig. 1 Measurement system developed to visualize the electrical characteristics

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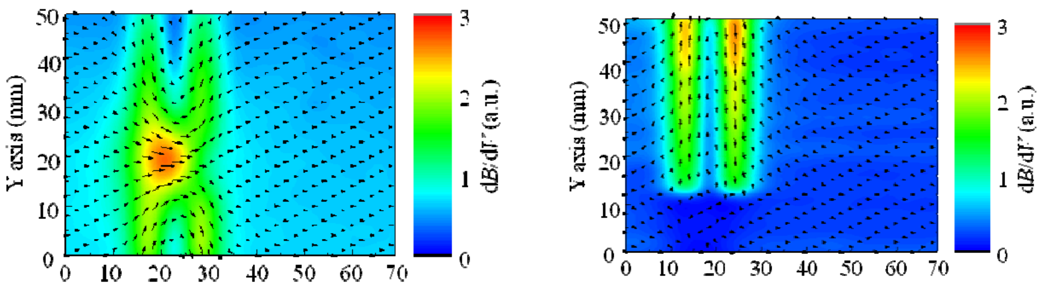
voltage V. The combined amplitude of all these signals is proportional to the current I flowing directly under the pick-up coil. Therefore, this will also be proportional to the differential conductivity dI/dV directly under the pick-up coil. The resulting map demonstrates the distribution in electrical characteristics of the solar panel.

This measurement system has visualized the electrical distribution characteristics of amorphous silicon solar panels. Two solar cell panels have been tested. One of the panels was intentionally delaminated and an artificial defect about 1 mm-square introduced on the back electrode. Measurements were made at a central area around 70 mm x 50 mm of a solar cell sized as 150 mm x 110 mm. The measurement spacing was 1 mm. An 8.8 V-offset voltage was applied together with an ac signal at a frequency of 1.7 kHz and 0.5 V_{pp}. Measurements were made on the backside of the panel under dark conditions. The electrical distribution characteristics of the panel with defects produced large differential conductance at the defect areas, as shown in Figure 2(a). The mapping vector comprising of the two magnetic field components demonstrated the current direction and also highlighted the significant current change observed around a defect. The mapping partially highlighted non-uniform current phases in a solar panel without artificial defects. Such non-uniformity implies variations in electrical characteristics for those solar cells even without defects.



(a) (b)

Fig. 2 Electrical Distribution of amorphous silicon solar cell (a) Delamination of electrode at backside and (b) without defect

3. Conclusions

A measurement system to visualize the distribution in electrical characteristics and current direction has been developed by detecting the magnetic field component parallel to a test sample utilizing two-pick up coils. The system was successful in visualizing the non-uniform distribution in electrical characteristics of a defect-induced solar cell as well as in a supposedly healthy solar panel. Future studies will include the development of a system employing a SQUID for direct detection and not via pick-up coil, as well as being able to evaluate solar cells other than the Si-type solar cells.

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2) T. Kiwa *et al*., Physica C, vol. 471, no. 21-22, pp. 1238-1241, 2011.
3) A. Tsukamoto *et al*., Supercond. Sci. Technol. vol. 26, 015013, 2013.

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Feature Article: SQUID / Medical Equipment
-Measuring the Thickness of Iron Plates Using Superconducting Coils

Teruyoshi Sasayama, Assistant Professor
Graduate School of Information Science and Electrical Engineering
Kyushu University

Bridges, tunnels, and reinforced concrete buildings constructed mainly during high economic growth periods are now ageing. Appropriate maintenance is therefore necessary to maintain their longevity. Steel materials including iron have been utilized in their construction. The requirement is to determine the erosion of the steel materials by employing a highly sensitive method to detect the thickness of iron plates.

Non-destructive methods comprise ultrasound, X-ray, and electromagnets. Amongst these, electromagnetic methods offer non-contact inspection at high speeds, and also there is another advantage of no risk of radiation exposure. In this research, a feasibility study to realize a practical electromagnetic system to detect the thickness of iron plates has been undertaken [1)].

Steel materials such as iron exhibit high permeabilities, producing extremely shallow skin-depths compared to copper-based materials. A low frequency detection method is therefore required to detect the thickness of steel materials. Here, changes in coil inductance L and coil resistance R, were measured for steel materials placed under a HTS coil as shown in Figure 1. The HTS coil can precisely measure small changes in L and R of the steel material, as the coil resistance is minute compared to a copper wire coil. The HTS coil was fabricated using a 3 mm-wide and 0.3 mm-thick Bi-based HTS tape.

A steel material was placed with 20 mm lift-off under the HTS coil and the impedance change of the coil, being a function of plate thickness, was measured. Commonly used steel (SM490A) was employed as the testing sample.

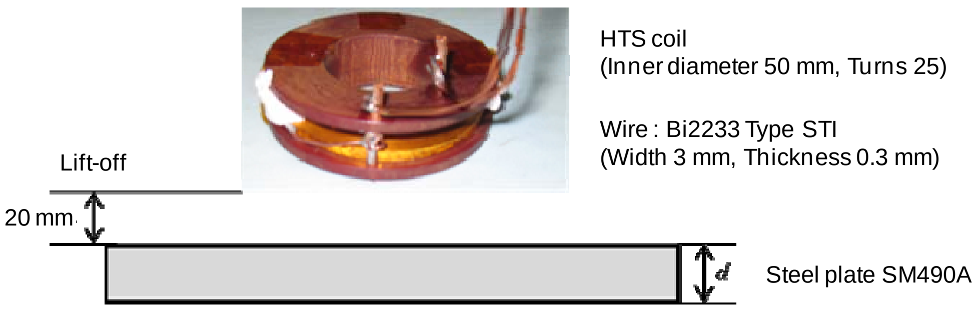

Fig. 1 Measurement of steel plate thickness utilizing HTS coil

Figure 2(a) shows changes in L (ΔL), and Figure 2(b) shows changes in R (ΔR). As shown in Figure 2(a), a slight increase in ΔL is observed with increasing steel thickness. However, saturation occurs when the plate thickness increases above a certain value. On the other hand, Figure 2(b) shows a monotonic increase in

ΔR with thickness d, showing monotonic increase in ΔR, even at thickness of 20 mm and particularly at 4 Hz. This therefore concludes that the thickness of steel plate can be predicted by measuring the changes of resistance R.

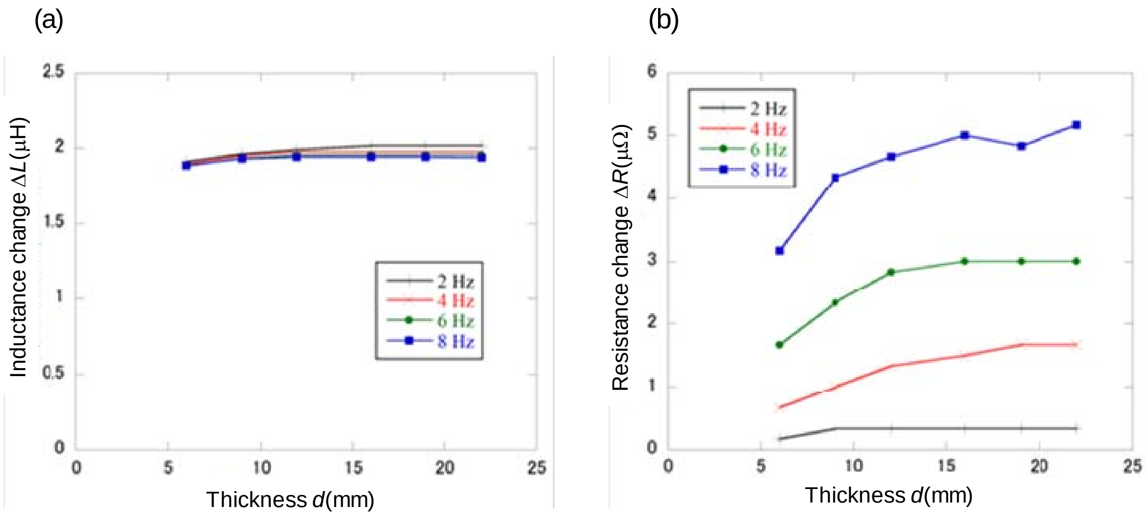

Fig. 2 Inductance change (a) and resistance change (b) as a function of plate thickness

This research was partially supported by JST's Cross-ministerial Strategic Innovation Promotion Program (SIP).

References :

1) T. Ishida, T. Sasayama, M. Matsuo, and K. Enpuku, "Measurement of Iron-plate Thickness Using HTS Coil," Proc. 15th International Superconductive Electronics Conference (ISEC) 2015.

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Feature Article: SQUID – Medical Equipment
-Ultra-low Magnetic Field MRI (Biomedical Application)

Masanori Higuchi, Professor
Applied Electronics Laboratory
Kanazawa Institute of Technology

SQUID-based MRI systems are operated in less than several-hundred μT static magnetic fields and are classed as ultra-low field MRIs. Although image resolution is inferior to high-field MRIs, they offer distinct advantages when integrated with a magneto-encephalography (MEG) system. A MEG measures the magnetic fields generated by cranial neural activity. Here, brain imaging is required to ascertain the source of the magnetic field. A typical MEG captures brain images using conventional MRI, installed separately from the MEG. If the same functionality can be exploited by an integrated system, enhancements in user convenience and precision adjustable focus can be expected. An example can be found in Europe, where a research group has been working towards realizing this aim but has not yet produced a practical system. On the other hand, it is reported that MRIs themselves demonstrate such effectiveness without the combination of a MEG. For example, the developmental aims of MRIs have been to discriminate between tumor tissues, utilizing the advantages of the T1 relaxation time image contrast at ultra-low fields.

An actual ultra-low field MRI developed is introduced herewith. Figure 1 shows the low field MRI system developed at the author's laboratory, as well as examples of captured images. The system was developed aiming for the above-mentioned MEG/MRI system for small animals. Ultra-low fields produce weak spin magnetization and thus the magnetic resonance signal remains small. Ultra-low field MRI systems therefore require a nuclear magnetization coil in addition to a static field coil to strengthen spin magnetization. However, technical knowhow for constructing such configurations and control system functionality are required because of the high currents involved. Other issues to be addressed include the necessary protection measures because of the induced noise due to the various coils positioned around the SQUID.

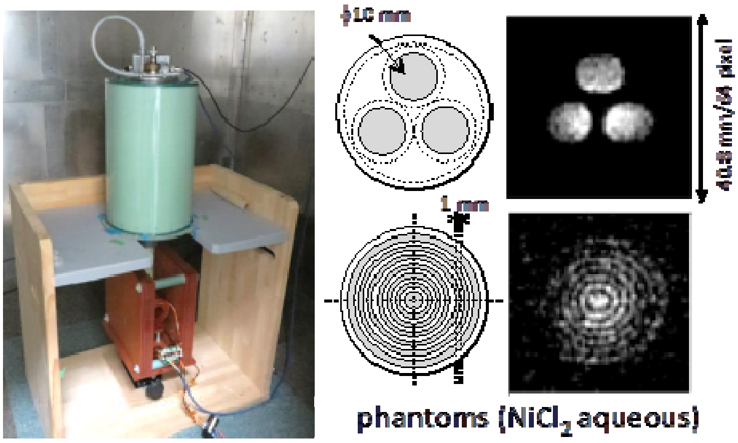

Fig. 1 Ultra-low field MRI system prototype utilizing SQUID

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A challenging application for ultra-low field MRI is having a functional MRI able to image neural activity. The principle of operation relies upon there being a weak magnetic field due to the neural activity, which influences the nuclear magnetic resonance phenomenon at ultra-low fields (Figure 2). Whilst there are many issues remaining towards the realization of such MRIs, an epoch is the potential possibility to obtain a brain functional image, which has not been possible by conventional high-field fMRI and MEG.

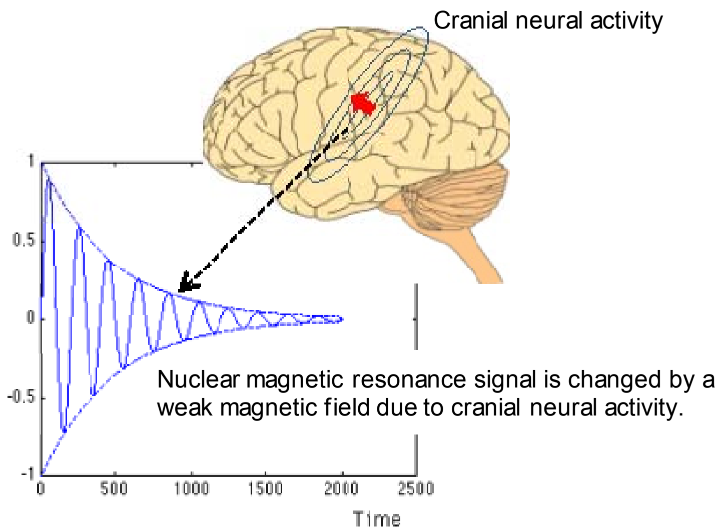

Fig. 2 Principle of functional MRI at ultra-low fields

Refer to the following references for further research details. Related references are also noted.

Daisuke Oyama, Masanori Higuchi "Ultra-low-field MRI Using Superconductive Magnetic Sensors", The Institute of Electronics, Information and Communication Engineers, Vol.98, No.1, pp40-47, 2015

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