Electric and Magnetic Property Control Technologies for Manipulating Machinery Products with High Precision and Efficiency, Contributing to Energy Savings

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Abstract

The KOBELCO Group's electric control technology and magnetic property control technology have been nurtured alongside the development of cutting-edge electronics and magnetic materials, such as semiconductors, magnetic materials, and superconductors. These technologies have been instrumental in enhancing competitiveness and promoting the development of new machinery products utilizing these materials. With the backdrop of carbon neutrality, electrification, mainly in the transportation sector, is rapidly accelerating. In response to changing demand, electric and magnetic property control technology has become even more crucial. This paper provides an overview of the KOBELCO Group's electric control technology and magnetic property control technology, along with introducing various technical topics associated with each area.

Introduction

Environmentally compatible, fuel-efficient technologies started attracting attention in the 2000s, particularly in the automotive sector. The KOBELCO Group has been pursuing various electrification initiatives to contribute to a green society, such as by developing hybrid hydraulic excavators. Further development within the company is related to mechatronics control technologies for industrial machinery such as factory automation robots and excavators. Developments in these areas and in semiconductors and telecommunications - focal points of the company leading into the 1990s - cultivated electronic circuit technology that has led to developments in power electronics, including control and circuit technologies for motor drives. The KOBELCO Group has also developed design and evaluation technologies for motors and other electrical components that take advantage of the pure iron-based soft magnetic materials we produce and provide.

The objective of carbon neutrality has accelerated the shift toward the electrification of vehicles and other transportation equipment. The KOBELCO Group is using advanced control technology to respond to increased demand in the applicable sectors. Specifically, the company is expanding the market of magnetic materials and fortifying the competitiveness of its machinery products. Beyond simply extending our product portfolio, we at Kobe Steel ensure that our electrification solutions resolve customers' challenges through technologies related to magnetic materials and electric motors. Thus, electric and magnetic property control technologies belong to our set of essential core technologies. This paper introduces the ways in which Kobe Steel's electric and magnetic property control technologies are used in machinery products, process technologies, and materials solutions.

1. Electric control technology

The KOBELCO Group's electric control technologies include digital control technology and power electronics technology, which together ensure the exceptional speeds and efficiencies our machinery products are known for.

Kobe Steel has an extensive track record in process control innovation for steelmaking processes and large plants. The appearance of high-performance controllers with built-in microprocessors in the 1980s spurred the use of digital control in steel mill operations to improve electrical control system responsiveness and accuracy. Moreover, our machinery division has advanced digital control through developments in rotating machinery such as compressors, in factory automation robots, and in industrial machinery such as construction machinery.

We released multiple technologies that were integral to the semiconductor business in the 1990s, including technologies related to application-specific integrated circuits (ASICs) and signal processing technology that uses digital signal processors (DSPs). Our high-level contributions to the information and telecommunications sector include the SolidAudio Player, a semiconductor-based audio device with excellent sound quality powered by the world's smallest battery at the time of the device's release. Our technologies were used to develop new controllers for construction machinery in the 2000s[1] and to reduce cost, safeguard quality, and optimize electronic circuits in mass-produced products. In the 2010s, our technologies led to the development of inverters for hybrid excavators and power source platforms for welding process control. Kobe Steel thereby cultivated advanced current and voltage control technologies in the power electronics field and established these as core technologies in power electronics circuitry and controls in our products.

Recent progress in electrification for carbon neutrality and in electric control technology has become indispensable for providing customers with unprecedented levels of functionality, features, value, and ease of use in Kobe Steel machinery products. At Kobe Steel, which has both materials and machinery divisions, electric control technology is used to control both machinery (e.g., power electronics) and equipment used in the manufacturing process (e.g., welding power sources). Following are some examples of the KOBELCO Group's machinery products that make use of electric control technology.

1.1 Electrical control in hydraulic excavators

Kobelco Construction Machinery Co., Ltd., a member of the KOBELCO Group, developed an excavator that complies with Tier 3 emissions regulations in the early 2000s. A powerful computer processor was used to develop control technology for high-efficiency engine and hydraulic pump operation. Further control technology developed uses solenoid valves to reduce losses in the hydraulic circuit. Together, these innovations resulted in the launch of a hydraulic excavator with 20% better energy efficiency than previous models.[2]

Other manufacturers also began developing energy-efficient construction machinery following this launch. Kobelco Construction Machinery Co., Ltd. was the first in the world to develop hybrid construction machinery with the release of hybrid excavators SK80H in 2009 and SK200H-9 in 2012.[3] In 2016, the company developed the SK200H-10 (**Fig. 1**), the first machine to use a high-output, large-capacity lithium-ion battery.[4] We produced the generator motor, swing motor, and lithium-ion battery of the SK200H-10 in house to meet the target energy efficiency and maximize operational capacity. All components are water cooled to achieve compactness and high output. The generator motor, located between the engine and hydraulic pump, is a three-phase AC (alternating current) synchronous permanent magnet motor that has a flat geometry with an axial dimension of about 140 mm. The high-output, compact electric swing motor can be installed in the same location as the hydraulic swing motor. We also developed a compact inverter unit that serves as a joint inverter for the swing motor and generator motor, ensuring ease of installation in the machine frame. The SK200H-10 consumes 17% less fuel than conventional hydraulic excavators and 12% less fuel than the SK200H-9.

1.2 Development of welding power source platform

Kobe Steel's Welding Business capitalizes on having both welding consumables and robotics solutions operations to propose welding solutions that provide value to customers throughout the welding process. A complete solution requires a welding power source to bridge the gap between consumables and systems. To meet this need, Kobe Steel developed a welding power source development platform that uses power electronics circuit design technology to provide an experimental development environment (**Fig. 2**). Digital control is made possible by this power source platform via DSP-based signal processing technology and high-speed processing devices such as FPGAs (field-programmable gate arrays). This platform has become the foundation for developing new welding processes by bringing developers' welding process control concepts to reality. These efforts enabled us to release the SENSARC™ RA500 welding power source, which achieves precise output even at currents over 400 A. Our development work also made possible the world's first wire feed control process, AXELARC™, which synchronizes the oscillation of the welding wire with the output of the power source and uses inertia for droplet transfer (see p.125 of this issue, "Development and Practical Applications of Welding Core Technologies"). Additionally, we are exploiting recent advances in power semiconductors and increased processing power of control CPUs to develop power sources that use these technologies, yielding a more compact and responsive design.[5]

Fig. 1 Overview of SK200H-10

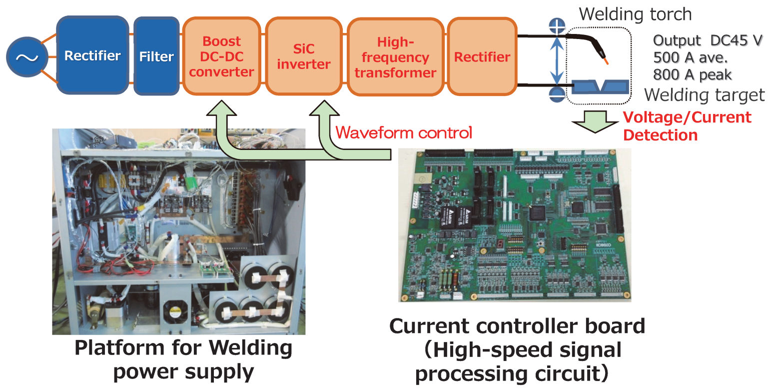

Fig. 2 Platform for welding power source

2. Magnetic property control technology

Magnetic property control technology at the KOBELCO Group combines advanced electromagnetics design technology with materials development and analysis technology. This enables us to develop unique electrical components and solutions that make the most of our magnetic materials.

The KOBELCO Group manufactures and distributes magnetic materials across a broad spectrum of industries. Our products range from superconductive materials to pure iron-based soft magnetic materials such as steel powder and steel wire rod and bar. Since about 1985, we have supported the steel wire rod and bar sector by refining ELCH2 (extra-low-carbon cold heading wire), our pure iron-based soft magnetic wire with excellent magnetic properties and cold forgeability. Its high magnetic flux density and workability have led to its widespread use in DC drive components such as solenoid valves and electromagnetic clutches.[6), 7)] We have been supporting the steel powder sector since the 1990s by developing dust cores made by compressing steel powder with an insulative coating. Magnetic steel powder exhibits magnetic isotropy, enabling three-dimensional design flexibility. It is used in reactors, and expansion of its application to motors is forthcoming.[8)] The trends toward vehicle electrification and energy-efficient electrical equipment are driving us to develop technologies with high magnetic flux density and high strength. Specifically, we are optimizing the composition and microstructural control of soft magnetic materials. We are also developing ultra-heat-resistant coatings to reduce core loss and thereby open up more possibilities in AC component applications. Additionally, we use advanced magnetic field analysis technology to design and analyze electromagnetic components such as motors and solenoids that use these soft magnetic materials. This technology yields data that enables the proposal of structures and manufacturing processes that meet customers' needs optimally. Kobe Steel also develops motors that take advantage of the properties of magnetic materials. As a result, we will strengthen the competitiveness of our machinery products and expand our portfolio.

To support innovation in the field of superconductor development, we began researching superconducting wire in 1964. In 2002, we established Japan Superconductor Technology Inc. (hereinafter, JASTEC)[Note 1)], a group company that manufactures and distributes superconducting wire and magnets. We are currently expanding our business of superconducting magnets and wire for NMR (nuclear magnetic resonance), MRI (magnetic resonance imaging), and research applications. Kobe Steel applied its microstructure control and AC component core loss reduction technologies to the development of high-performance Nb_3Sn superconducting wire for the International Thermonuclear Experimental Reactor (ITER) project currently underway in France. We have supplied approximately 20% of the wire for the entire project. In the field of superconducting magnets, we are optimizing magnet arrangements to achieve a high magnetic field, establish high-uniformity design technology, and support the development of NMR and MRI elements. A further endeavor comprises the development of compact ultra-high-magnetic field magnets that use high-temperature superconducting wire. This section introduces the KOBELCO Group's solution technologies for magnetic materials and technologies that use these materials.

Note 1) Kobe Steel, Ltd. transferred all shares of JASTEC to JEOL Ltd. on January 6, 2025, and JASTEC became a wholly-owned subsidiary of JEOL Ltd.

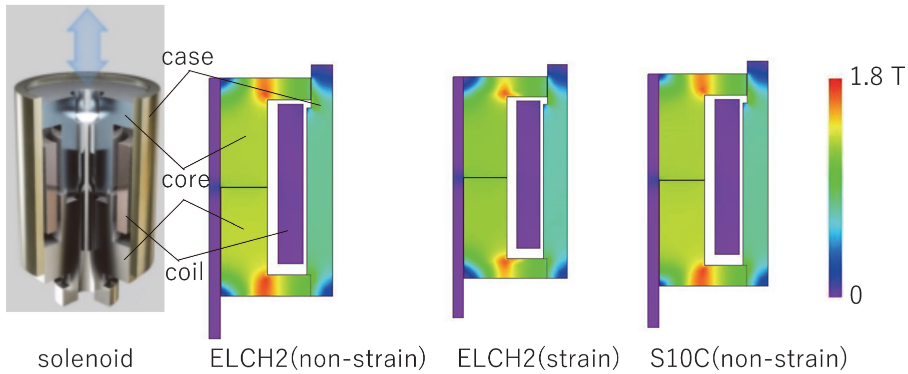

Fig. 3 Contour plot of magnetic flux density

2.1 Solution technologies for pure iron-based soft magnetic materials

Stress and strain from machining change the magnetic properties of magnetic materials. Hence, we are studying solutions to predict component performance and optimize machining processes in a way that accounts for the effects of machining.

In support of carbon neutrality, energy consumption must be reduced by avenues such as omitting or curtailing heat treatment processes. This need led us to examine the feasibility of using ELCH2 immediately following cold forging, without magnetic annealing, in a solenoid core. We used FORGE (forging analysis software) to map cold forging strain and entered the resulting strain distribution data into JMAG (electromagnetic analysis software) for magnetic field analysis (**Fig. 3**). In this way, we analyzed the effects of cold forging strain on component properties.

Results revealed that the performance of materials that do not undergo magnetic annealing is comparable to that of conventional products.[9)]

Expansion is anticipated in the market of electric motors. These components must become smaller and lighter, and there is a shift away from radial-gap motors (hereinafter, RGM) in favor of axial-gap motors (hereinafter, AGM). We are optimizing motor design using JMAG and are researching the use of magnetic steel powder in AGMs to capitalize on this material's many strengths, such as three-dimensional design flexibility (**Fig. 4**). Our research includes evaluating the effects of powder core processing on the performance of mass-produced motors.[10)] While ELCH2 has excellent magnetic properties, its low electrical resistance increases core loss in the magnetic materials of AC components such as motors. As such, we developed thin ELCH2 designed to reduce core loss while maintaining magnetic properties. This wire enables the design of new AGMs that are smaller and lighter than conventional RGMs.[11)]

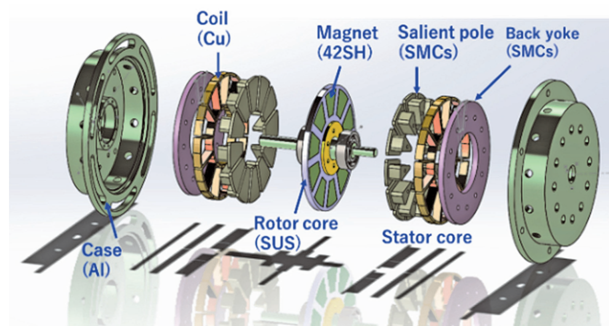

Fig. 4 Axial-gap motor configuration (SMC: soft magnetic composite)

We will promote carbon neutrality by improving the performance of the materials covered in this section and incorporating them into motors.

2.2 Development of a motor with a 3D magnetic pole structure

Compared with hydraulic motors, electric motors are easier to control and exhibit lower losses. The entire system of an electric motor, including power source and auxiliary equipment, is also more compact. And although electric motors have lower horsepower than hydraulic motors, their excellent performance at high speeds has driven their widespread use. However, much of Kobe Steel's machinery products, construction machinery, and compressors require low-speed, high-torque drivetrains. This is fulfilled by combining motors that have excellent high-speed performance with mechanical elements such as hydraulics and gears with high reduction ratios. However, such combinations entail nonlinearities such as hysteresis, rattles, and friction, which adversely affect controllability, accuracy, and efficiency. This led us to develop a low-speed, high-torque structure that can eliminate these nonlinear mechanical factors as much as possible.

Kobe Steel devised a magnetic pole structure[12)] that has increased responsiveness to electric current because it allows magnetic flux to pass in three dimensions (**Fig. 5**). This design eliminates the constraints of high-speed electric motors by taking advantage of the isotropic magnetic properties of our magnetic steel powder and pure iron. Electric motors using this technology exhibit large losses at high speeds. However, because they use fewer permanent magnets compared with conventional motors to generate larger changes in magnetic flux, they achieve greater electromagnetic force with less power consumption at low speeds, and in a compact and lightweight frame.

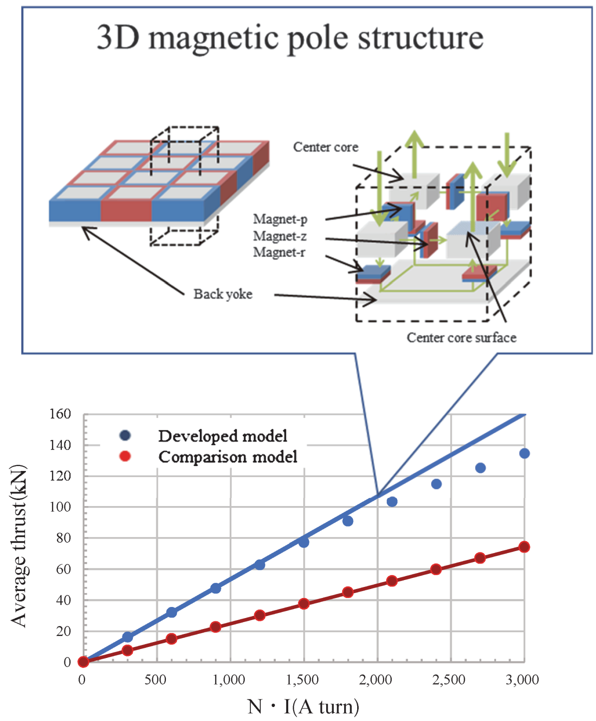

Fig. 5 3D magnetic pole structure and linear synchronous motor drives

Kobe Steel is developing a direct drive linear motor that can generate an electromagnetic driving force of 100 kN without gearing, with the objective of using this in our industrial machinery.

This technology is a unique and distinctive foundational technology for the electric motor market, which is expected to expand against the backdrops of electrification, automation, and reduced workforce numbers. To support immediate action, we will center our technological development and new business opportunities around applications requiring direct drives.

2.3 Development of ultra-compact 1 GHz NMR magnet

In 2015, Kobe Steel collaborated with the National Institute for Materials Science (NIMS), RIKEN, and JEOL Ltd. to develop the world's first ultra-high field 1 GHz (1.02 GHz) NMR magnet. We achieved this by using bismuth-based high-temperature superconductors in the innermost layer, where the magnet generates its highest magnetic flux density. In 2022, Kobe Steel's group company JASTEC collaborated with RIKEN, JEOL Ltd., the Tokyo Institute of Technology, and others to refine the aforementioned technology and thereby develop the world's lightest and most compact ultra-high field 1 GHz NMR element. It is approximately one-tenth the weight of conventional NMR elements (**Fig. 6**).[13)] We increased the current density of the

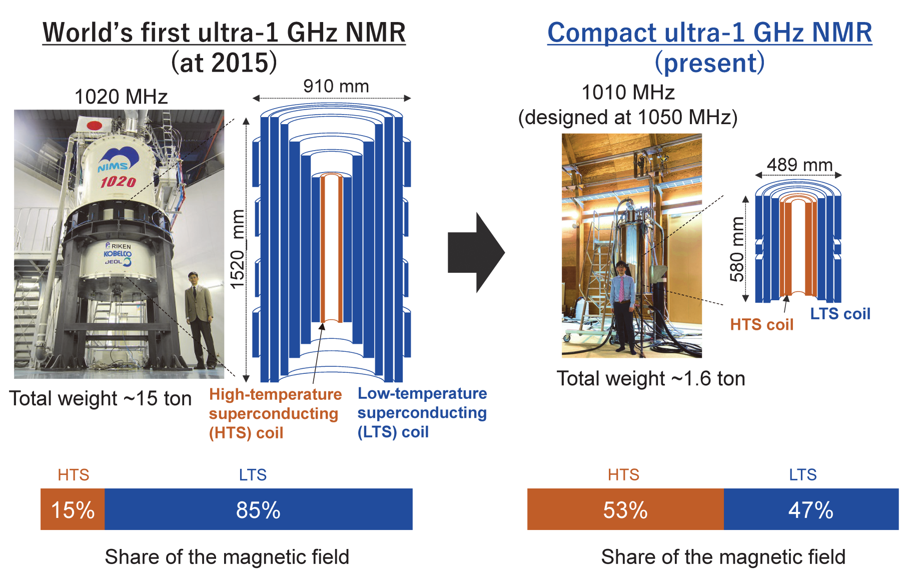

Fig. 6 Overview and cross-section of ultra-high field 1 GHz NMR

bismuth-based high-temperature superconducting coil in the innermost layer to 1.5 times greater than in conventional models. As a result, the high-temperature superconducting coil contributes more than 50% of the entire magnetic field, making the entire magnet more compact. However, in the center of the high-temperature superconducting coil of this structure is an electromagnetic force of over 100 tons. Hence, we developed a technique to tightly wind high-temperature superconducting wire reinforced with high-strength metal to preserve the integrity of the coils and achieve a high current density and a significant reduction in size.

We will continue improving the properties of both superconducting wire and magnets to support cutting-edge technological development in the field of superconductivity.

Conclusions

This paper introduced the KOBELCO Group's electric control technology and magnetic property control technology, which are under the umbrella of the company's 21 core technologies. We will refine these technologies to strengthen the competitiveness of the KOBELCO Group's products, develop cutting-edge technologies, and solve societal challenges such as realizing carbon neutrality.

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