The Maglev Systems Technology Division is committed to advancing fundamental research on superconducting magnetically levitated transport systems (hereinafter referred to as "superconducting Maglev systems"). Our mission extends beyond basic research; we are leveraging the findings and insights gained from a comprehensive series of research and development (R&D) efforts to enhance conventional railway systems. Our exploration of high-temperature superconductivity spans a considerable period, during which we have effectively integrated basic and applied R&D efforts. This integration has enabled us to refine core technologies and develop practical applications across various facets of conventional railway systems. Here, we present a selection of recent research projects undertaken by the Maglev Systems Technology Division.

Maglev Systems Technology Division

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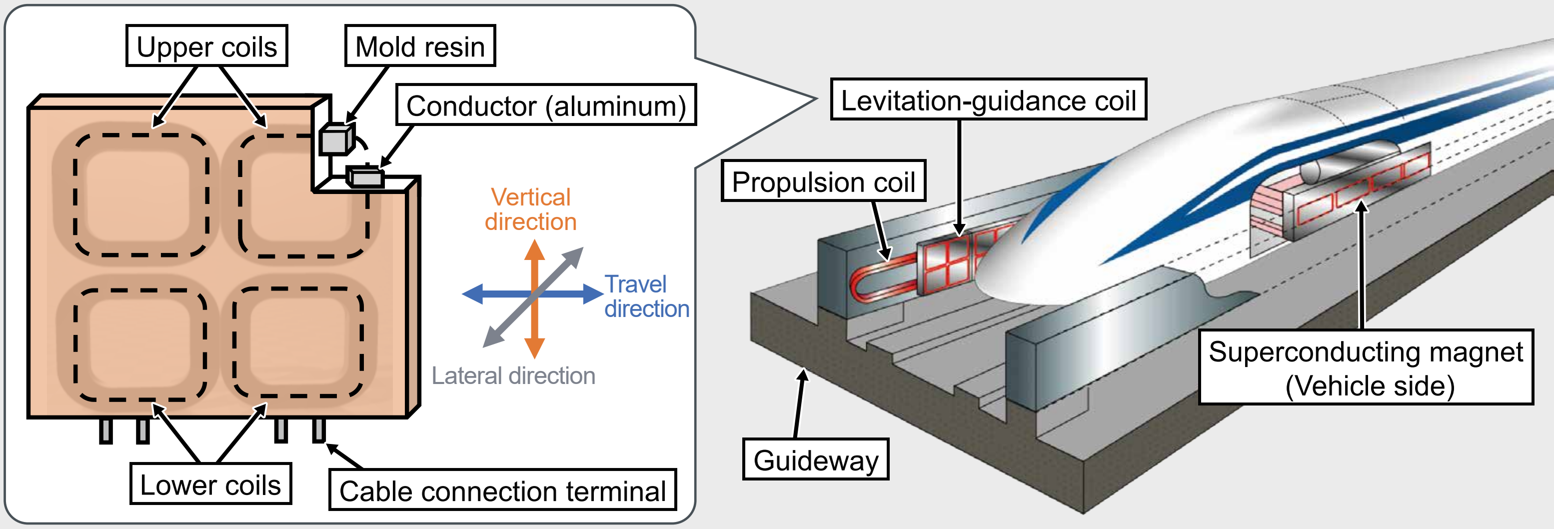
Introduction

The Maglev Systems Technology Division evaluates both the ground coils for superconducting Maglev systems and the magnetic fields associated with conventional railway systems. Our division has also dedicated significant resources to a diverse array of R&D projects focused on superconducting technology. Our foundational research focuses on the fabrication of high-temperature superconducting materials and assessing their performance. In applied research, we focus on enhancing winding and coiling technologies for superconducting materials. Additionally, we are advancing the development of integrated approaches combining superconducting technology with essential railway technologies such as power transmission, energy storage, and power converters. The Maglev Systems Technology Division has consistently devoted substantial resources to R&D aimed at the practical implementation of superconducting Maglev technology in real-world railway operations.

Maglev Railway System and Technology

Evaluation of Remaining Life of Ground Coils

Basic Configuration of Superconducting Maglev System and Structure of its Ground Coils shows the basic configuration of the superconducting Maglev system and



Basic Configuration of Superconducting Maglev System and Structure of its Ground Coils

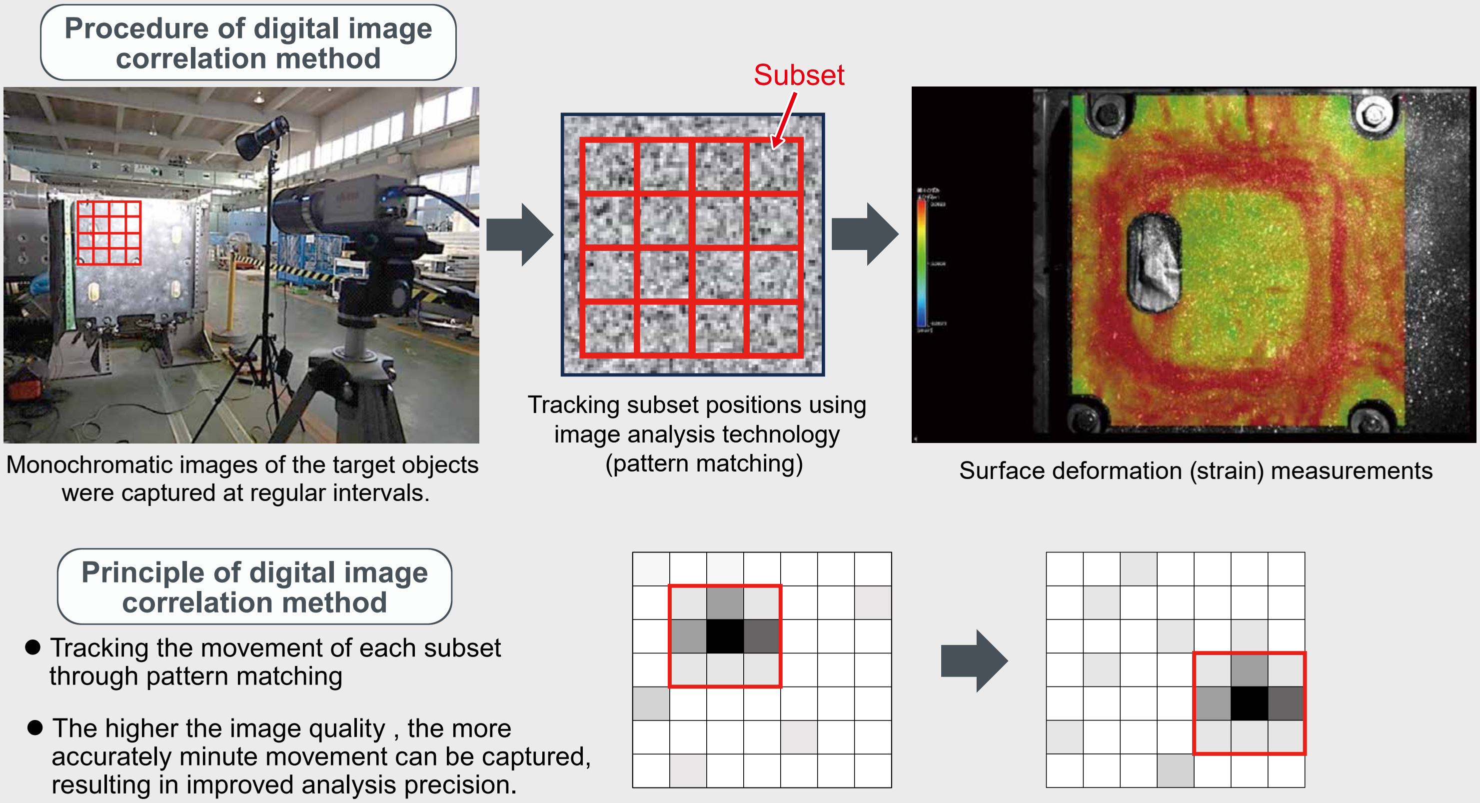
the basic structure of its ground coils. In superconducting Maglev systems, a large number of ground coils installed along the sidewalls of the guideway makes durability a critical factor. Consequently, we engaged in R&D aimed at evaluating the service life of ground coils. Ground coils are electromagnets responsible for generating propulsion, levitation, and guidance forces for vehicles and can be categorized into two types: propulsion coils and levitation-guidance coils. The levitation-guidance coils generate levitation and guidance forces through their interactions with superconducting magnets. During the operation of Maglev vehicles, these ground coils vibrate due to the reaction between the levitation and guidance forces. Therefore, the ground coils must have mechanical strength and dynamic durability against vibrations. To address this, we conducted electromagnetic excitation tests in a stationary setup using superconducting magnets and levitation-guidance coils. The results from our numerical analysis and the obtained vibration data confirmed that an electromagnetic force equivalent to that experienced at 500 km/h could be applied to the levitation-guidance coil. Looking ahead, we plan to conduct long-term electromagnetic excitation tests to assess the remaining service life against vibrations.

Image Processing Technology

To evaluate the mechanical strength of ground coils, it is essential to understand the strain induced by electromagnetic forces during vehicle passage and deformation from temperature rise in windings. Conventionally, strain gauges have been employed to measure strain; however, assessing strain distribution across the entire ground coil necessitates numerous sensors, complicating actual measurements. To overcome this problem, we examined the application of the digital image correlation (DIC) method, which analyzes deformation in images captured by cameras to measure strain. By pre-applying a random pattern to the ground coil surface and energizing the windings, we were able to by a observe the deformation caused temperature increase through image processing. This approach enabled us to measure the strain near the coil windings (*Strain Evaluation of Ground Coils Using Digital Image Correlation Method*). We plan to use this technique to further strength evaluations.

Evaluation of Low-Frequency Magnetic Fields in the Railway Environment

The evaluation of magnetic fields generated by superconducting magnets installed on the Maglev railway system began during running tests at the Miyazaki Test Center, a facility of the Railway Technical Research Institute (RTRI). Leveraging the expertise from these early experiments, the



Strain Evaluation of Ground Coils Using Digital Image Correlation Method

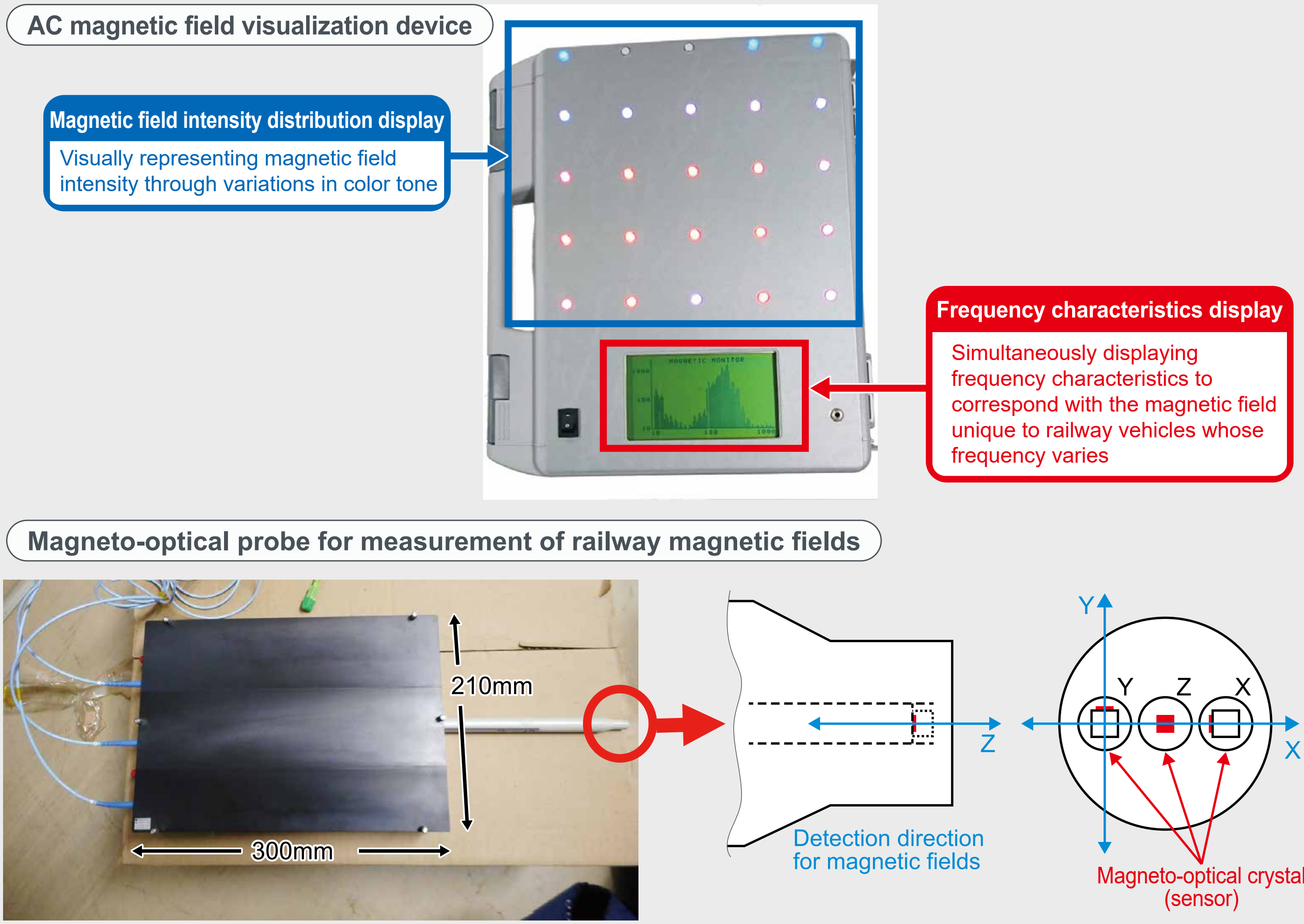
Maglev Systems Technology Division currently conducts measurements and evaluations of magnetic fields in conventional railway vehicles, including the Shinkansen. During this process, we developed a Magnetic field visualization device to simplify the understanding of magnetic field distribution. Additionally, for detailed evaluations at specific locations, we developed a new tri-axial magneto-optical probe that utilizes light as a magnetic field sensor (*AC Magnetic Field Visualization Device (Top) and Magneto-Optical Probe for Railway Magnetic Field Measurement (Bottom)*). This measurement probe detects magnetic fields using a phenomenon known as the Faraday effect. It can be applied for measurements over a wide frequency range.

Superconductivity

Fundamentals of Superconductivity

High-temperature superconducting materials are generally classified into two primary forms: cylindrical bulk materials used for magnetic field applications and longitudinal tape-like materials for power transmission. Despite differences in shape, both types utilize similar materials and fabrication processes, including the mixing, forming, and sintering of raw material powder. Our laboratory focuses on the fabrication and evaluation of these high-temperature superconducting materials, with all basic research activities conducted entirely within the institute.

Bulk materials are produced by packing mixed powder into a mold, pressing it into a disk shape, and sintering it in an electric furnace. To achieve uniform crystal orientation during sintering, crystals are grown via the melt-solidification method using a single-crystal seed. This technique promotes crystal growth from the center outward. Precise control of temperature and

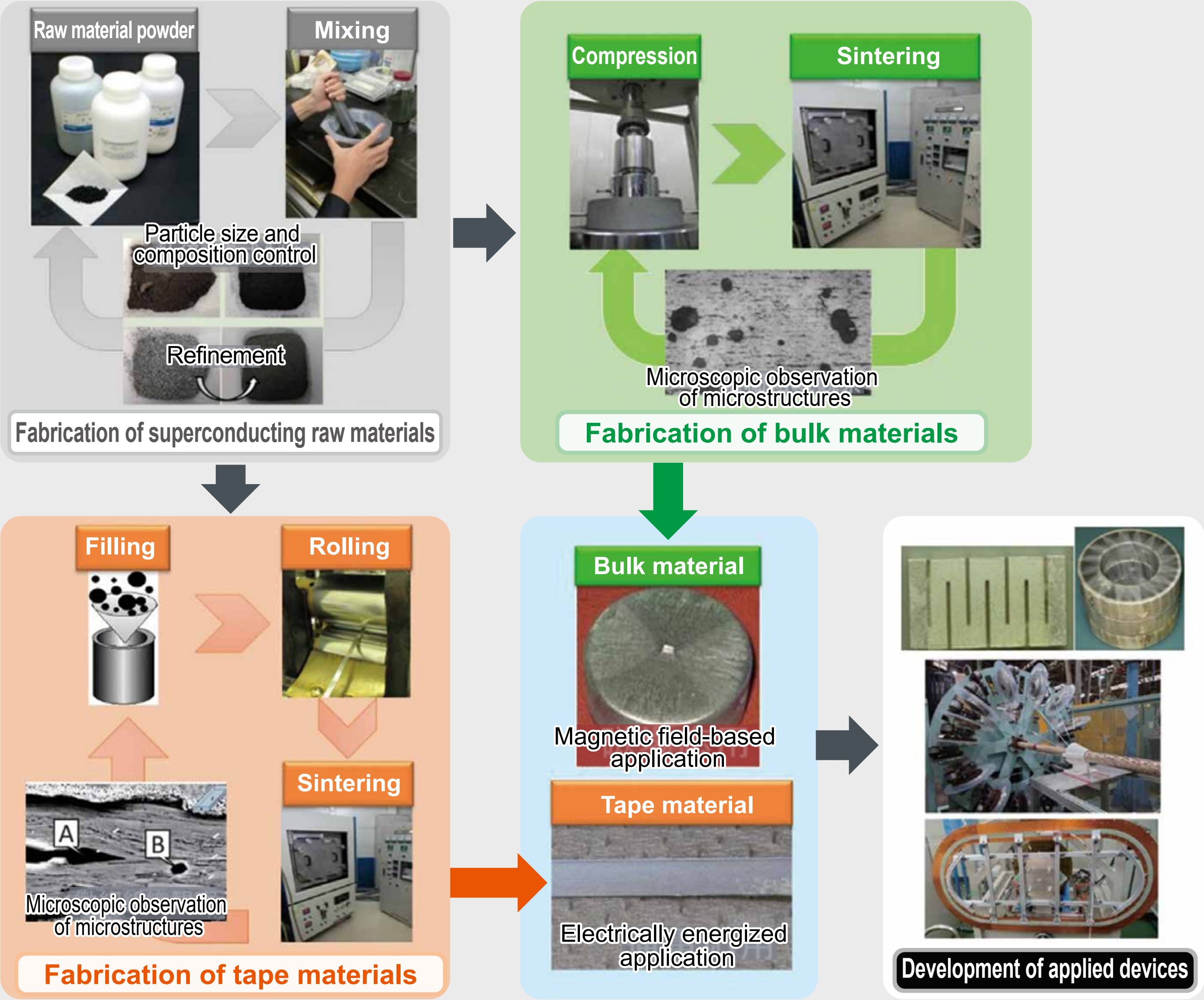


AC Magnetic Field Visualization Device (Top) and Magneto-Optical Probe for Railway Magnetic Field Measurement (Bottom)

composition is critical for uniform crystal orientation. Our research focused on the following aspects: minimizing factors such as particle size, controlling the composition of the powders to be synthesized, and temperature conditions during sintering in an electric furnace (*Development of Superconducting Technologies*).

For tape materials, powder is filled into metal tubes and drawn into tapes using rolling machines, which helps align the crystal orientation. Microscopic examination revealed impurity phases within the tape, which disrupted the continuity of the crystal plane of the superconductor. We reduced these impurity phases and controlled crystal orientation by adjusting the sintering temperature and applied pressure. Additionally, a method for aligning crystals on a metal substrate exists.

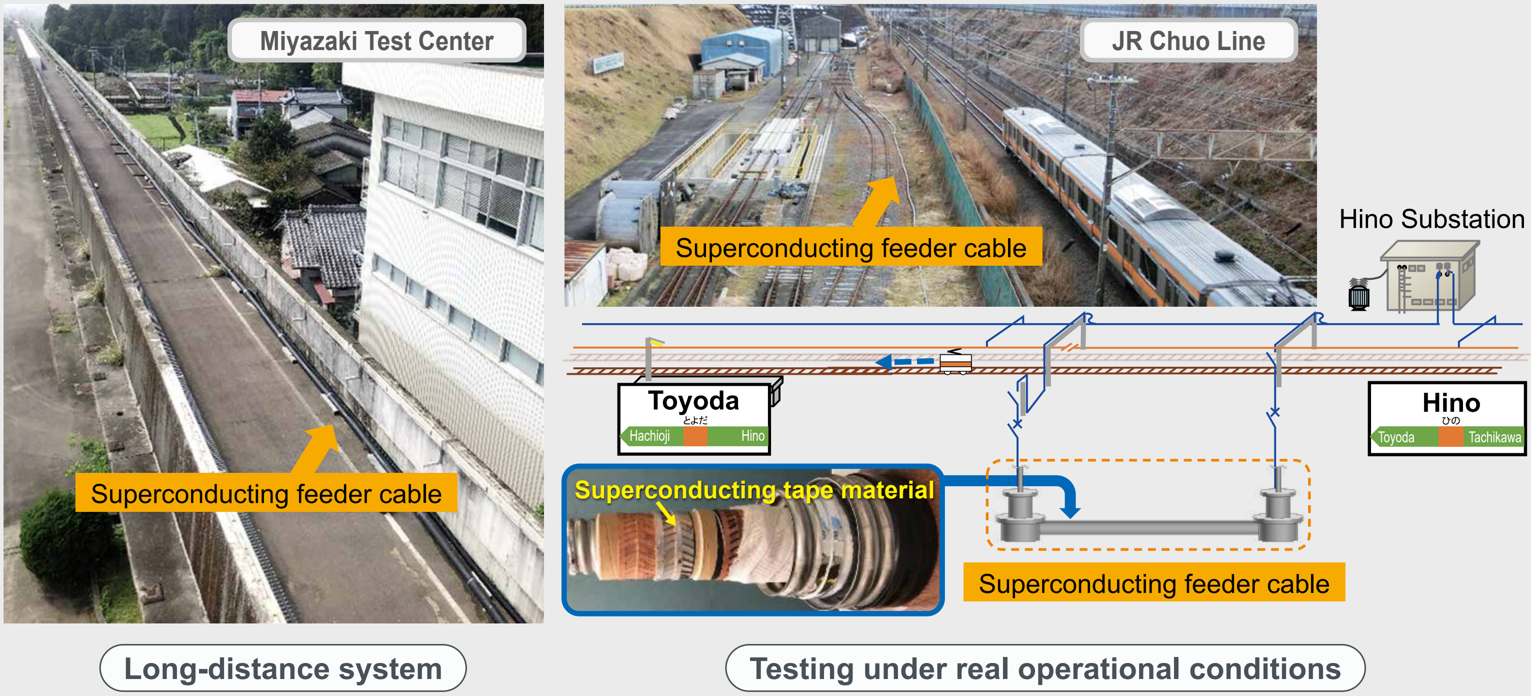
Based on these research outcomes, we are advancing evaluation techniques and technologies for winding and coiling. Through prototype testing of cables and coils, we aim to develop superconducting devices for railway applications, including power transmission and energy storage.



Development of Superconducting Technologies

Superconducting Feeding Systems

In electric railways, power transmission losses and voltage drops occur due to electrical resistance of the transmission lines delivering electricity from substations to vehicles. Substations are strategically located to ensure a reliable power supply for railway operation, particularly on urban lines. To mitigate issues related to increased electrical resistance from multiple substations, we are developing superconducting feeding systems. By utilizing superconductors with zero electrical resistance, we expect energy-saving benefits, including reduced transmission losses, improved regenerative efficiency, and consolidation of substations[1]. Our R&D began with studies on high-temperature superconducting materials, followed by optimization of cable structures and system experiments. This process culminated in demonstration testing on a test track within our facilities. Subsequently, we connected a 408-m superconducting feeder cable to a section between the Hino and Toyoda stations on the JR Chuo Line. By running a 10-car E233 series train, we confirmed that the voltage



Superconducting Feeding Systems

drop was suppressed on an actual railway line[2]. At the Miyazaki Test Center, we are currently advancing the construction of a long-distance (km-scale) superconducting feeding systems designed for intersubstation connections. These R&D efforts aim to realize practical superconducting feeding systems that will revolutionize the energy efficiency and reliability of railway operations (*Superconducting Feeding Systems*). These advancements will lead to a more sustainable future for electric railways.

Conclusions

Over a century has elapsed since the development of superconducting, magnetically levitated transport systems. During this time, numerous innovations emerged alongside the Maglev railway system. For instance, superconducting feeding systems transmitting power using high-temperature superconductors officially approved by the Ministry of Land, Infrastructure, Transport, and Tourism as railway equipment. The world's first demonstration of superconducting power transmission in commercial operation is being conducted[3]. This technology offers a fundamental solution to issues caused by electrical resistance in conventional railway systems. We will continue to refine superconductivity and other innovative technologies to address the challenges faced by the Maglev, Shinkansen, and conventional railway systems. Our aim is for these technologies to significantly contribute to the future of railway systems.

References

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2) Railway Technical Research Institute, "Superconducting Feeder Cable Systems–Running Test Conducted on 1500 V DC Chuo Line–," News Release, August 6, 2019, https://www.rtri.or.jp/eng/press/2019/nr201904_detail.html.
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