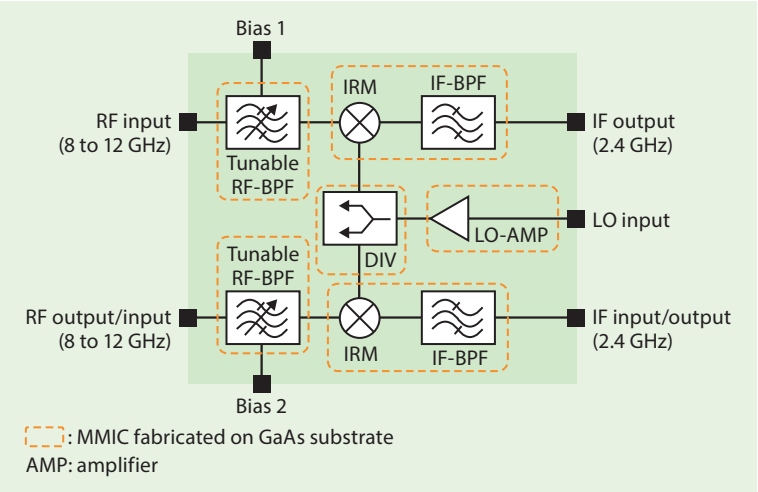
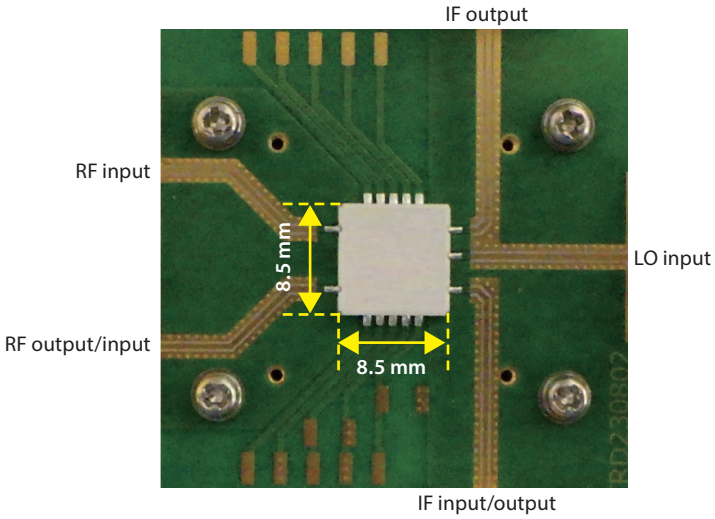
3. Infrastructure Systems

3.1 Compact Frequency Converter Module Using MMIC Technology



Frequency converter module block diagram



Compact prototype frequency converter module

Toshiba Corporation has developed a compact frequency converter module for X-band radar applications. A typical frequency converter module consists of an image rejection mixer (IRM), a bandpass filter (BPF), and a divider (DIV). The IRM suppresses the unwanted image frequency. The BPF passes signals within a specific range and frequencies and removes signals outside that range. The BPF is connected to a radio-frequency (RF) or intermediate-frequency (IF) output terminal of the IRM. The DIV is designed to divide a local oscillator (LO) input into two signals of the same frequency, allowing them to be converted into IF or RF signals using two IRMs. The conventional frequency converter module houses these components in separate packages, requiring a large footprint.

To solve this issue, we have applied a monolithic microwave integrated circuit (MMIC) and ceramic packaging technologies:

(1) MMIC technology

Commercially available IRMs provide limited flexibility in terms of layout because of fixed pad positions and input/output terminal size. They also require an external 90-degree coupler for the IF terminal, increasing the size. We therefore manufactured the IRM on our own and built a 90-degree coupler on the same MMIC using a gallium arsenide (GaAs) substrate. In addition, we integrated an IRM and an IF-BPF on the same MMIC to further reduce the size of the frequency converter module. We also developed other constituent components internally to enhance layout flexibility.

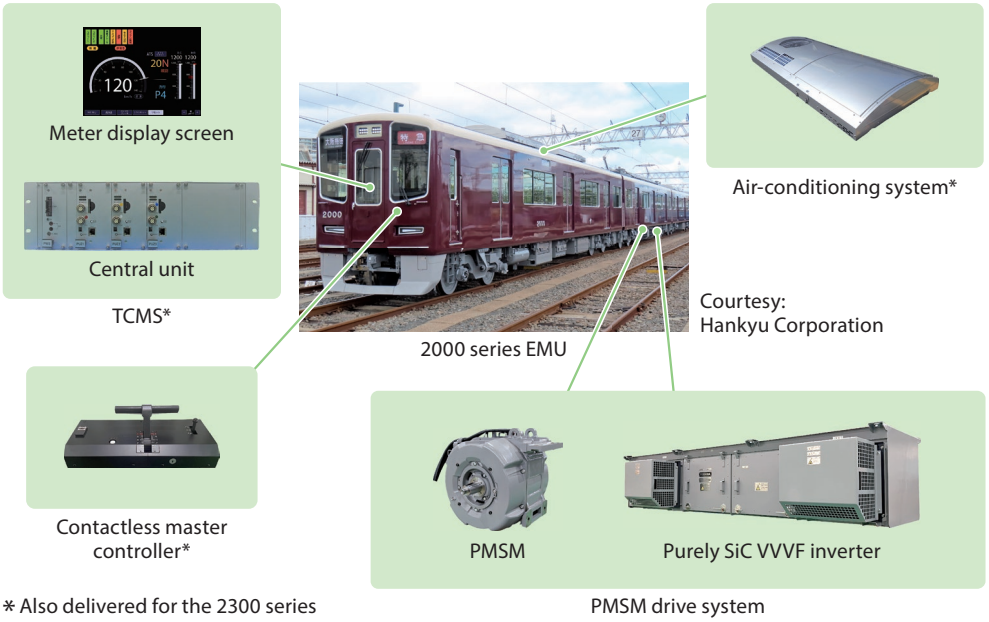
(2) Ceramic packaging technology

Even with MMICs, the module size increases when a conventional leaded package is used. To solve this issue, we adopted a ceramic package with a castellated structure and reduced the overall module size.

The new frequency converter module provides a conversion loss of 18 dB, equivalent to that of the conventional model, and measures only 8.5×8.5 mm. The overall size is less than half of the conventional module.

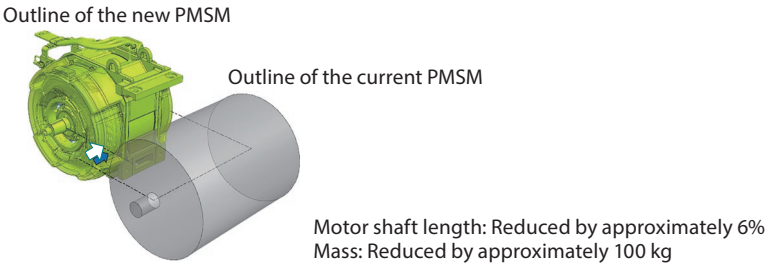
We will use the new compact frequency converter module for X-band radar applications.

3.2 Delivery of Electrical Equipment for 2000 and 2300 Series EMUs of Hankyu Corporation



Hankyu Corporation 2000 series EMU

SiC device



Comparison of existing and new PMSM exteriors

Toshiba Corporation has received orders for electrical equipment from Hankyu Corporation for its electric multiple units (EMUs), including permanent magnet synchronous motor (PMSM) drive systems for new 2000 series commuter trains as well as master controllers, train control and management systems (TCMS), and air-conditioning systems for 2000 series commuter trains and new 2300 series limited express trains. We delivered these orders as they were made ready.

The 2300 series commenced operation in July 2024, following the completion of on-site testing of the delivered electrical equipment in June. The 2000 series began operation in February 2025, following the completion of on-site testing of the delivered electrical equipment in December 2024.

The features of the above electrical equipment are as follows:

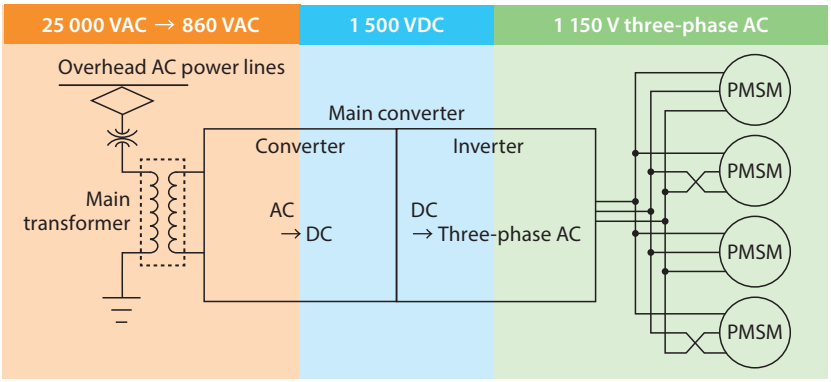
(1) PMSM drive system: This incorporates a purely silicon carbide (SiC) variable-voltage, variable-frequency (VVVF) inverter, which is capable of operating at higher temperatures and has lower conduction and switching losses than silicon insulated-gate bipolar transistor (IGBT) inverters. This has resulted in an approximately 10% smaller power unit than that of the previous PMSM drive system delivered for the 1000 series in 2013. Leveraging the improved main motor current characteristics of the purely SiC VVVF inverter, we have optimized the design of the PMSM to improve its efficiency. Furthermore, we have adopted a frameless, fully enclosed external fan cooling structure to increase the output and reduce the weight of the PMSM. Simulation results indicate that this is expected to provide an approximately 10% reduction in energy consumption compared to the previous model.

(2) Master controller: A contactless operating mechanism has made the master controller smaller, lighter, and easier to maintain than the one with a conventional contact-type operation mechanism. Additionally, the master controller provided improved reliability through self-diagnosis functions and a dual redundancy configuration.

(3) TCMS: This consists of a system to control and monitor traction, braking, and other devices as well as an information network to control service-oriented devices such as information displays and security cameras. The control and monitoring system provides enhanced reliability because of the redundancy of the main and branch lines. In the future, we will develop a system to upload information from onboard equipment to a cloud server to improve operational and maintenance efficiencies.

(4) Air-conditioning system: An inverter control system provides finely controlled air conditioning, contributing to energy saving. Additionally, a comfort control function learns control, temperature, train running, and other information to regulate air conditioning according to the season, time of day, and stop frequency.

3.3 PMSM System for Korea Railroad Corporation AC/DC Trains



Overview of PMSM system for overhead AC power lines

PMSM for new KORAIL trains

Toshiba Corporation has developed an AC PMSM system for AC/DC trains operated by Korea Railroad Corporation (KORAIL). It is our first PMSM system to receive electricity from overhead AC power lines. The system is composed of a main blowerless transformer, a main power converter equipped with a three-level converter, and a PMSM.

The PMSM is highly efficient because it has no secondary copper loss. Also, the three-level converter in the new AC PMSM system further reduces the power loss of the main transformer as it generates less harmonics. Simulations have confirmed that the new AC PMSM system consumes 21% less power than the system installed on the existing train, eliminating the need for a blower.

Thanks to the main blowerless transformer and the fully enclosed PMSM, the new AC PMSM system does not require much time or effort for maintenance.

Growing environmental concerns are driving energy conservation awareness while the declining workforce is driving the need for low-maintenance systems. We are therefore aiming to expand the sales of the AC PMSM system to solve the above issues in South Korea although our DC PMSM system is already being used in the country.

3.4 Application of Next-Generation MCR30 Multi-relay to Switchgear

Next-generation MCR30 Multi-relay for switchgear

Indicators easily visible even from distance

The Multi-relay is a protective relay installed on the front of switchgear, integrating multiple functions such as measurement, protection, and control into one device. It monitors substation current, voltage, and power to detect and isolate electrical faults instantaneously, thereby protecting the electrical equipment at factories and buildings. The Multi-relay plays an important role in society in ensuring a stable power supply. Preventing human errors and malfunctions is crucial to the operation and management of substations. Therefore, important factors for the Multi-relay include not only functionality but also visibility and operability.

With this in mind, Toshiba Corporation has applied the next-generation MCR30 Multi-relay featuring enhanced visibility and operability to its switchgear. The main features of the MCR30 are as follows:

(1) Cylindrical indicator lights are designed to provide improved visibility, considering the working environments at maintenance and inspection sites. The cylindrical light-emitting diode (LED) indicators, which show switchgear status, are easily recognizable even from an oblique angle and when multiple MCR30 units are arranged side by side.

(2) The operation buttons are arranged in a simple manner to be intuitive and prevent errors, and only frequently used buttons are exposed. These buttons are designed to enhance usability together with an LCD panel that provides clear and concise instructions on button usage.

(3) A large, high-definition color LCD panel provides improved visibility and makes it easy to view a long list of information. The color LCD panel and color scheme with a black background enhance visibility even in dim environments. Bar graphs and other visual representations also clearly display switchgear conditions.

In the future, we will expand the Multi-relay functions and provide switchgear equipped with the highly reliable, user-friendly Multi-relay which is suitable for diverse electrical equipment, thereby contributing to achieving a sustainable society.

3.5 LF62xxB Electromagnetic Flowmeter Converter with Improved Operability

LF622xB remote type electromagnetic flowmeter converter

LF620xB integral type converter (integrated with LF410 detector)

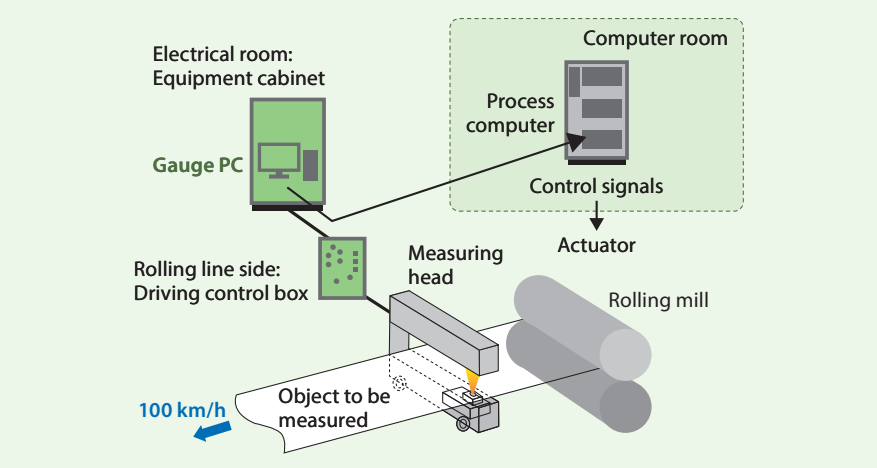
An electromagnetic flowmeter is an instrument that measures the volumetric flow rate of a conductive fluid using Faraday's law of induction. A flowmeter converter provides functions to process a flow rate signal from a detector's electrodes using software to display the measured flow rate, convert the flow rate signal to analog format for external use, and communicate with a host device.

Toshiba Corporation has developed the LF62xxB electromagnetic flowmeter converter as a successor to the LF62xxA(*). While maintaining advantages such as the accuracy, noise resistance, and robustness of our existing electromagnetic flowmeters, we have improved LF62xxB operability based on customer feedback on the previous model. The LF62xxB also provides a new alarm function convenient for on-site use, and an early fault detection function. Because the LF62xxB is housed in the same aluminum die-cast casing as the LF62xxA, the LF62xxB serves as an easy replacement for the LF62xxA.

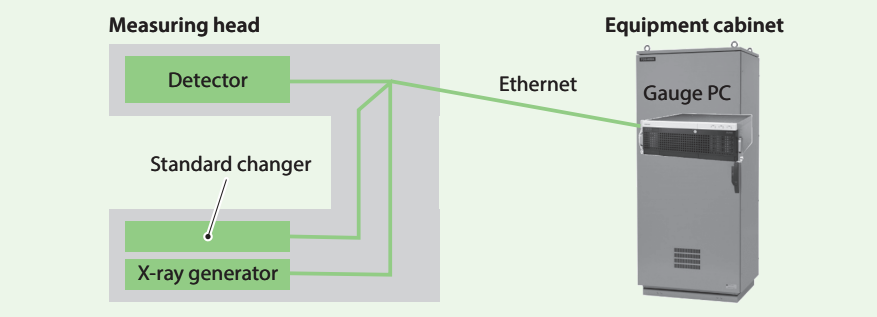
In the future, we will expand functions to communicate with host devices to contribute to digital transformation (DX).

(*) x is a model-specific number.

3.6 TOSGAGE-8000RS Series X-Ray Thickness Gauges Enabling High-Speed Sensing



X-ray thickness gauge configuration

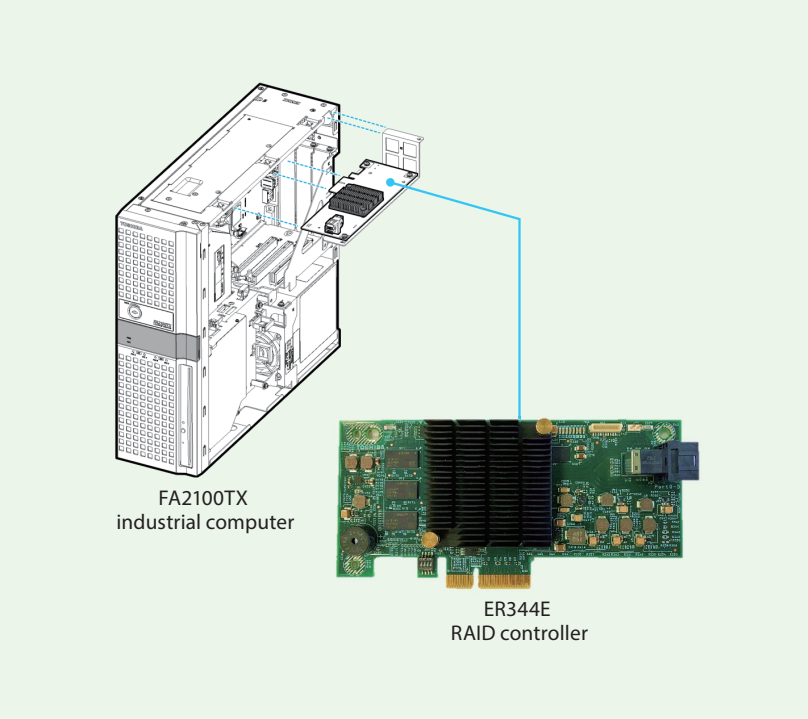


X-ray thickness gauge measuring head

X-ray thickness gauges are widely used for online measurement of plate-shaped object thickness in rolling lines at steel plants and other facilities. The thickness measurement data is used to control the rolling mill that determines the steel plate thickness, so precision and reliability are required. Also, in recent years, the introduction of rolling equipment with high-speed responsiveness has resulted in a growing need for high-speed X-ray thickness gauge sensing.

With this in mind, Toshiba Corporation has developed the new TOSGAGE-8000RS series X-ray thickness gauge capable of high-speed sensing with a sampling period of 1 ms. The TOSGAGE-8000RS series incorporates a hardware logic circuit based on a field-programmable gate array (FPGA) to process all communications between the X-ray generator, X-ray detector, standard changer, and Gauge PC, thereby achieving a processing time of 1 ms or less. The TOSGAGE-8000RS series is also equipped with a field sensor to collect data on the measuring head environment in real time. The collected environmental data are expected to make it possible to analyze the cause of abnormalities in greater detail and improve the environment.

3.7 ER344E RAID Controller with Original FPGA Logic



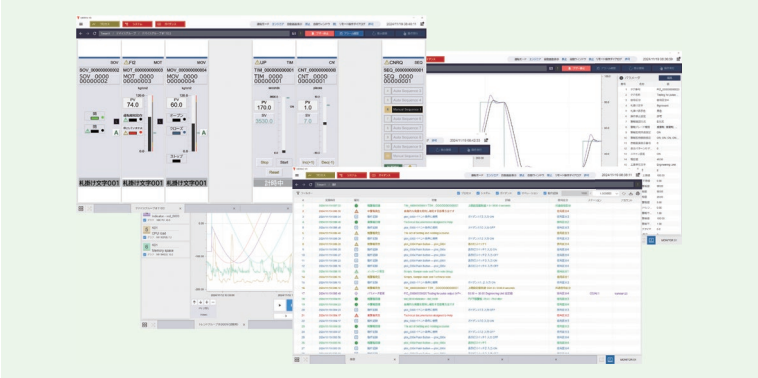
RAID controller in industrial computer

Industrial computers from Toshiba Corporation incorporate a redundant array of independent disks (RAID) function to reduce the risk of data loss and system downtime due to storage drive failure. This RAID function is achieved by an internally developed RAID controller, which incorporates our extensive expertise in storage drive monitoring and diagnostics, enhancing reliability and availability.

However, the dedicated integrated circuit (IC) with a RAID function used in conventional RAID controllers has been discontinued and is no longer available. Because there is no alternative IC, we have developed a new RAID controller using an FPGA with an embedded processor as a substitute. We have achieved general-purpose interfaces in the FPGA by using existing standard intellectual property (IP) cores while relying on original custom-designed logic to provide unique functions such as command queueing for storage access. Additionally, we have ported firmware to the embedded processor to the maximum extent possible to maintain high reliability and availability equivalent to those of the previous models. Leveraging the new RAID controller, we will continue to offer industrial computers over the long term.

3.8 TOSDIC VS Integrated Control System Promoting DX Initiatives for Process Control

Unified Controller Vm series typeL



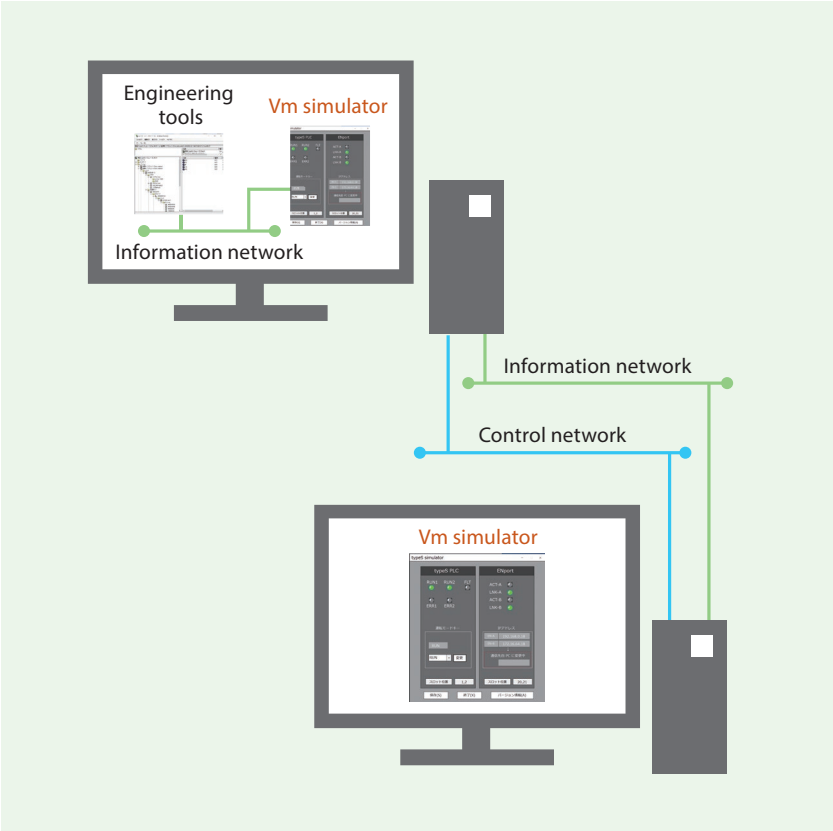
OI-VS10 and OI-VS20 screen display examples

To promote process control DX, Toshiba Corporation has released the Unified Controller Vm series typeL industrial controller and the next-generation OI-VS10 and OI-VS20 human-machine interfaces (HMIs). The typeL and the OI-VS10/OI-VS20 are components of our TOSDIC VS integrated control system for the next-generation distributed control system (DCS).

Integrating control and computing functions, the typeL solves transmission load and communication delay issues, enabling real-time data collection and analysis. The OI-VS10 and OI-VS20 provide web-based monitoring screens to allow system monitoring anywhere. Also, using an open-source general-purpose database makes it possible to accumulate large volumes of data. We are also planning to expand the utilization of the accumulated data through a standard application programming interface (API).

Our next step is to further streamline and optimize industrial monitoring and control systems by utilizing cloud platforms for combining operational technology (OT) and information technology (IT).

3.9 Vm Simulator to Support Efficient Engineering Using Unified Controller Vm Series typeS



Vm simulator for Unified Controller Vm series typeS

Efficient engineering is required to respond promptly to the needs of manufacturing sites. To meet these needs, Toshiba Corporation has developed the Vm simulator to support efficient engineering using the Unified Controller Vm Series typeS, a high-speed sequence controller with a programmable logic controller (PLC) released in 2020.

The Vm simulator can emulate typeS operations on Windows. It allows for verification of an application's behavior and checking the front LED of the typeS without the need for actual hardware, making it easier to set up a development environment and reduce development costs. Additionally, because there is no need to prepare actual hardware or to wire input/output (I/O) modules, it is easy to verify the behavior of an application under various conditions and quickly debug it.

Furthermore, the Vm simulator can also emulate the operations of the typeL, a DCS controller in the Vm series, enabling a wide range of engineering tasks.

3.10 SCiB™ Module with Aluminum Baseplate and Enhanced Heat Dissipation Performance

SCiB™ module with aluminum baseplate

Parameter		Specification
Product name		SCiB™ module with aluminum baseplate (Type4-23 (FM01202CCB04))
Dimensions	(mm)	203.8×395.0×132.4
Weight	(kg)	Approx. 16.5
Rated capacity	(Ah)	45
Nominal voltage	(V)	27.6
Maximum current	(A)	160 *1 (continuous) 350 *1 (30 seconds)

Parameter		Specification
Ambient operating temperature	(°C)	-30 to 50
Built-in function		CMU integration
Number of connections		Up to 30 units can be connected in series.
Rated isolation voltage	(V)	1 000 (DC)
Voltage range	(V)	18.0 to 32.4 (DC)
Cell configuration		23 Ah cell 2 in parallel × 12 in series

CMU: cell monitoring unit

∗1: Performance is based on natural air cooling and may vary when combined with a cooling system.

∗2: Specifications listed above are not guaranteed values and are subject to change without notice. Additionally, performance may vary depending on usage conditions.

Specifications of SCiB™ module with aluminum baseplate

SCiB™, a highly durable lithium-ion battery from Toshiba Corporation, is frequently used in high-temperature environments with high input and output, necessitating efficient cooling. To address this, we have developed a new SCiB™ module with an aluminum baseplate delivering enhanced cooling performance.

This SCiB™ module provides approximately 1.8 times higher thermal conductivity between the baseplate and battery cells than the existing SCiB™ modules without compromising a 1 000 V withstand voltage between the main circuit and the casing. As a result of simulations under natural air-cooling conditions with continuous charge and discharge at 125 A for 300 seconds, the new SCiB™ module exhibited only a 47°C rise in battery temperature from 25°C, a 12°C lower rise than the SCiB™ module housed in the conventional resin casing. The battery cell temperature rise during rapid charging and high-power discharging can be mitigated considerably by combining the new SCiB™ module with a customer's cooling solution, such as a liquid-cooling device.

This feature makes the new SCiB™ module suitable not only for mobile vehicle applications such as electric buses, electric ships, construction machines, and railways, but also for uninterruptible power systems (UPS) and power sources for primary frequency regulation requiring high-power discharging.

3.11 SCiB™ Pack Suitable as Replacement for 24 V Lead-Acid Batteries

Parameter		Specification
Nominal voltage	(V)	25.3
Rated capacity	(Ah)	19
Cell configuration		11 SCiB™ 20Ah-HP cell connected in series
Dimensions	(mm)	230 (W) × 170 (D) × 202 (H)
Weight	(kg)	Approx. 8.3
Shape		D23 size for starter lead-acid batteries compliant with JIS D 5301
Voltage range	(V)	16.5 to 29.7 VDC
Cold cranking ampere	(A)	400 (at -18°C)
Ambient temperature	(°C)	-30 to 55
Environmental conditions		IP*1 X9K, IP X7
Communication function		CAN
Protection functions		Overcharging, overcurrent, overheating

∗1: The waterproof International Protection (IP) code as defined by the International Organization for Standardization (ISO) 20653 standard
∗2: The above specifications should be considered only as a guide and are subject to change without prior notice. The actual product appearance may differ from the above image.

Main specifications of 24 V SCiB™ pack suitable for lead-acid battery replacement

Toshiba Corporation has developed a 24 V SCiB™ pack that consists of a string of 11 SCiB™ cells in a D23 size enclosure designated for starter lead-acid batteries compliant with Japanese Industrial Standard (JIS) D 5301. The new SCiB™ battery pack serves as an easy replacement for existing 24 V lead-acid batteries of the same size and can be used on its own or connected in series and parallel configurations. It is suitable for various applications, including commercial vehicles such as buses and trucks, construction machinery, agricultural equipment, and marine vessels. Mass production of the new SCiB™ pack is scheduled to begin in fiscal 2025.

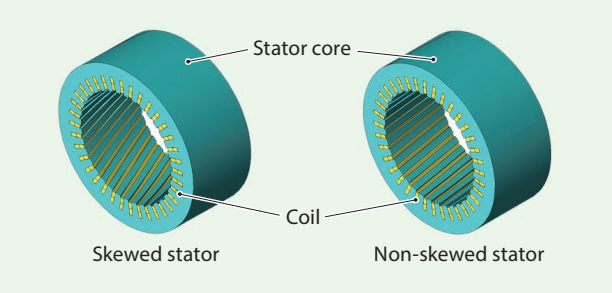
Its main features are as follows:

(1) Up to six SCiB™ packs can be connected in parallel to provide a 2.88 kWh capacity at 24 V. Connecting 12 SCiB™ packs in a 2-series, 6-parallel configuration provides a 5.76 kWh capacity at 48 V.

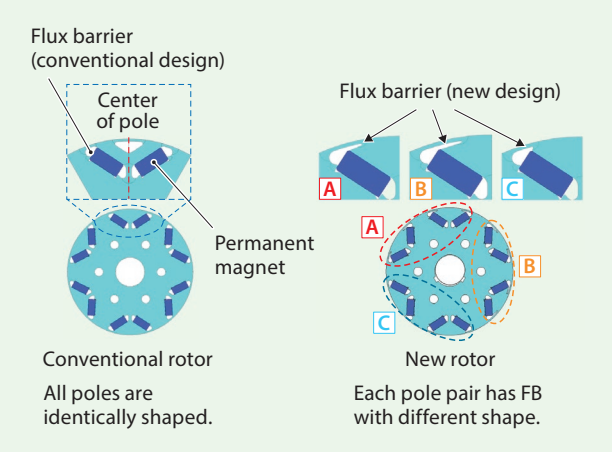
(2) The SCiB™ incorporates a control board to prevent overcharging, overcurrent, and overheating and provides a Controller Area Network (CAN) interface. The CAN interface allows a host device to control a system while monitoring the state of charge (SOC) and other battery states. Even when multiple SCiB™ packs are connected in parallel, they can communicate with one another via dedicated communication lines. Therefore, a customer's system can obtain information about multiple SCiB™ packs by communicating with a single SCiB™ pack only.

CAN is a registered trademark of ROBERT BOSCH GmbH.

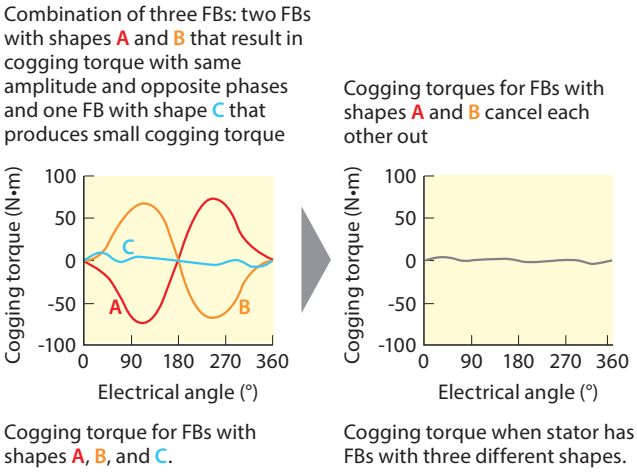
3.12 Optimization of Rotor Magnetic Circuit to Reduce Pulsating Torque in PMSMs



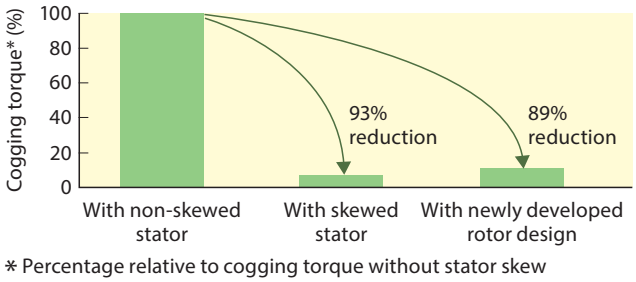
Stator structural differences with and without skew



Flux barrier shapes of conventional and new rotor design



Principle of cogging torque reduction



Cogging torque reduction effect

PMSM drive systems are becoming increasingly popular for rolling stock applications because of their energy efficiency and environmental friendliness. PMSMs produce pulsating torque (cogging torque), which generates mechanical vibration and acoustic noise. This occurs as the magnetic attractive force between the stator and the rotor changes with no current applied. Stator skewing is employed to reduce cogging torque, but it results in a reduction in output power and requires a complicated manufacturing process.

With this in mind, Toshiba Corporation has developed a rotor magnetic circuit with different shapes of flux barriers (FBs)(*1) for each pole pair(*2) to reduce cogging torque while maintaining motor performance without skewing stator windings. In the new rotor magnetic circuit, the shapes of FBs on the outer circumference of the rotor are changed to convex. Each pole is axially symmetric around the pole center, and the paired north and south poles have the same FB shape. Cogging torque can be reduced by combining FBs with appropriate convex shapes.

We explored the convex shapes of the FBs to minimize the cogging torque of a six-pole motor using a randomized algorithm. Cogging torque was reduced by 89% without stator skew by combining three FBs: two FB shapes that result in cogging torque with almost the same

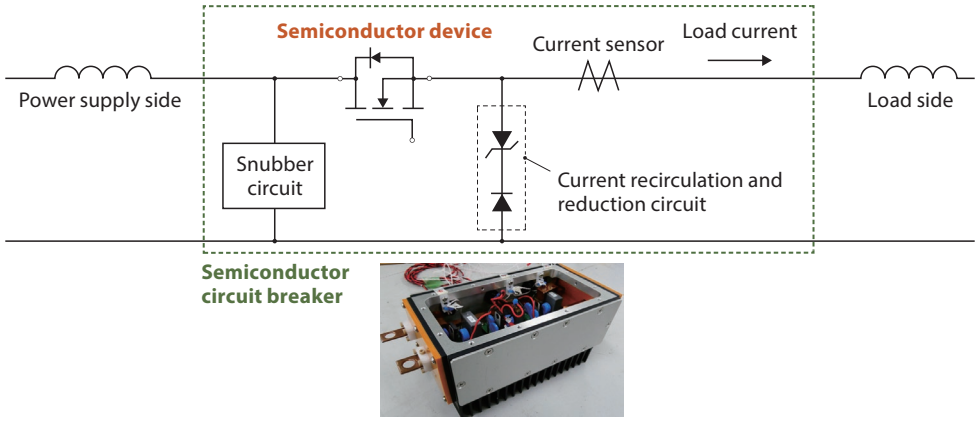
amplitude and opposite phases and one FB shape that produces small cogging torque. The cogging torque was reduced by 93% when the stator was skewed. We confirmed that the rotor magnetic circuit reduces cogging torque almost as much as stator skewing.

We will proceed with field demonstrations of motors using the rotor magnetic circuit and expand its applications to industrial and automotive motors.

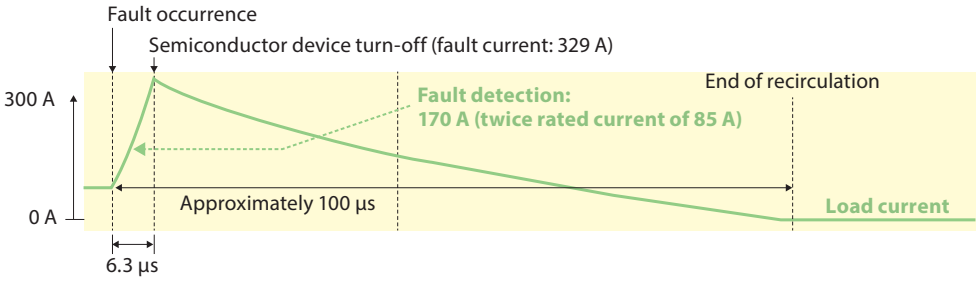
(∗1) Air gaps placed around a magnet in the rotor core

(∗2) A pair of north and south poles

3.13 Semiconductor Circuit Breaker for Low-Voltage DC Distribution Systems Using Current Recirculation and Reduction Circuit



Circuit configuration and prototype of proposed semiconductor circuit breaker for low-voltage DC distribution systems using current recirculation and reduction circuits

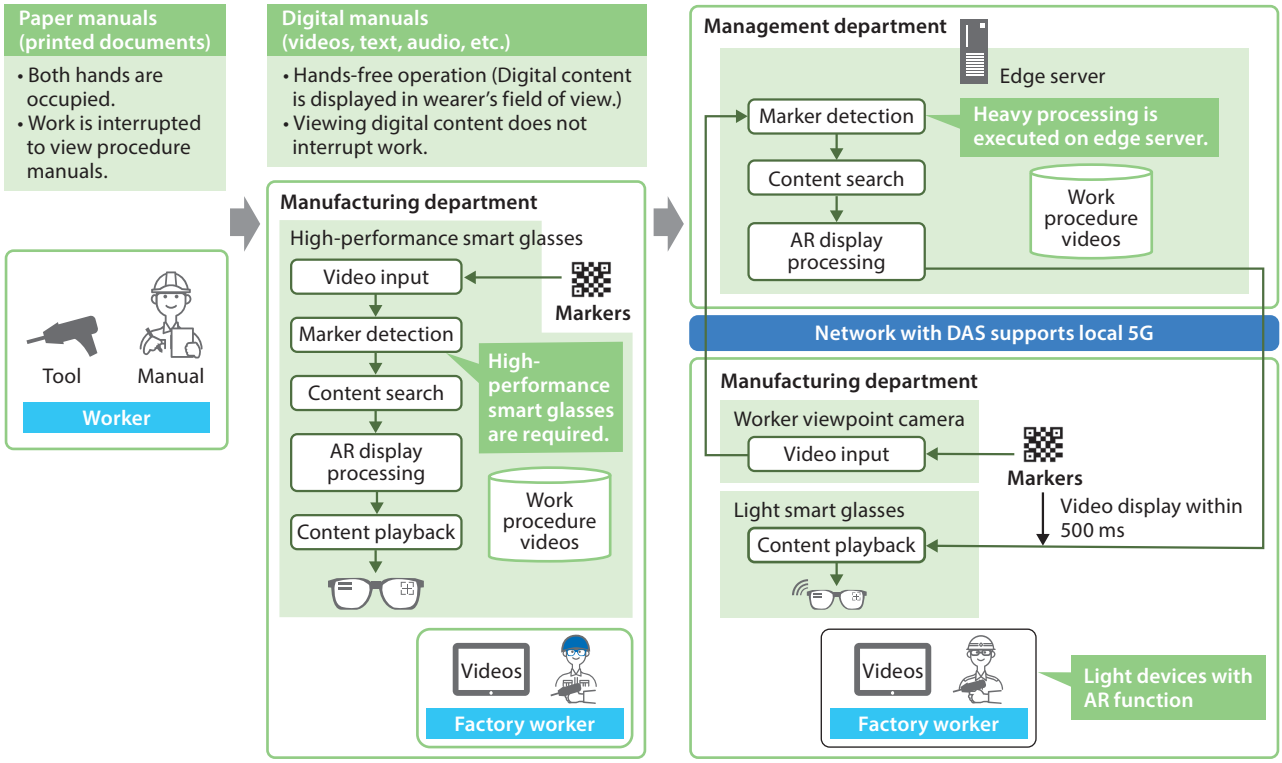


Experimental results of fault current interruption of proposed semiconductor circuit breaker

Low-voltage DC distribution systems with a rated voltage of less than 750 V are attracting much attention as a means of connecting renewable energy sources, battery storage systems, and load equipment via DC links. DC distribution systems require fewer power conversions and can transmit electric power more efficiently than AC distribution systems. However, because DC current does not have a natural zero-current point, interrupting it is more difficult than interrupting AC current. Mechanical circuit breakers take several milliseconds to interrupt a DC fault current, necessitating DC distribution systems with high current interruption and withstand capabilities.

To solve this issue, Toshiba Corporation is developing DC interruption technology using semiconductor devices because semiconductor switches provide instantaneous DC current interruption without producing arcs. We have developed a prototype semiconductor circuit breaker which passes a DC fault current to a unique current recirculation and reduction circuit and thus helps mitigate the withstand voltage requirement for semiconductor devices. We evaluated the prototype, demonstrating its current interruption capability on the order of microseconds.

3.14 Work Support Solution for Factory Shop Floors Using AR and Local 5G



DAS: distributed antenna system

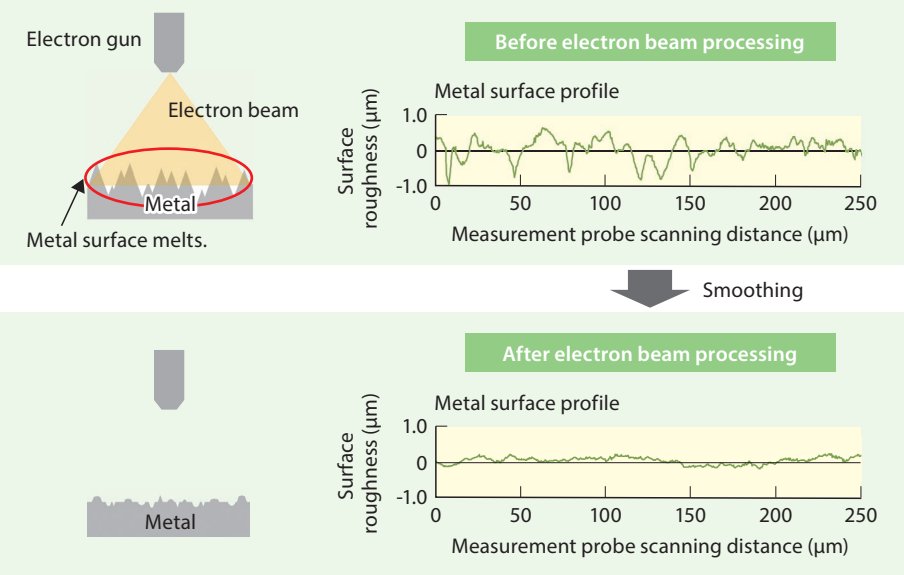
Work support solution on factory shop floors

The purpose of DX in factories is to improve productivity through digitalization of manufacturing processes. Toshiba Corporation is developing a work support solution for factory shop floors using a high-capacity, low-latency local fifth-generation (5G) mobile network. Converting paper-based work instructions into videos for smart augmented reality (AR)(*) glasses is helpful in difficult assembly operations as AR makes it possible to compare dynamic three-dimensional (3D) digital representations with real-world objects. However, AR requires costly computing power for such tasks as marker detection, content search, and display processing.

To solve this issue, we have developed a solution that enables marker detection with a worker viewpoint camera and offloads content search and AR display processing to an edge server on a local 5G network. The new solution helps mitigate performance requirements for smart glasses, reduce their size, and cut hardware costs by 70%. We performed operational verification in a local 5G environment at our factory and confirmed that the new solution can display Full HD (high-definition) videos on smart glasses within 500 ms. We will utilize this work support solution to replace paper manuals.

(*) A technology to overlay 3D digital content onto real-world environments

3.15 Partial Discharge Suppression Technique Using Electron Beam to Process Surfaces of Metal Components on Vacuum Interrupters



Electron beam metal surface smoothing technology

Designed to interrupt fault currents, vacuum interrupters play a crucial role in switchgear in protecting electrical circuits and equipment and preventing the spread of electrical accidents. Nowadays, there is growing demand for reducing the size of vacuum interrupters. Doing so requires partial discharge (PD) suppression technologies as reducing the size of their components increases the probability of PD occurrence.

The machining process of metal components creates electrical weak points such as microprotrusions and surface contamination, which tend to produce PD. Although Toshiba Corporation has already developed polishing and discharge conditioning processes, they were insufficient for removing electrical weak points. Therefore, we have developed a new technique using an electron beam to melt and smooth metal surfaces. Experiments have confirmed that the new electron beam technique is remarkably effective for PD suppression.

We plan to employ the new technique to reduce the size of vacuum interrupter components.