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Instrumentation, Control, and Information Systems Contributing to Automation and Energy Saving

Fuji Electric

Innovating Energy Technology

FUJI ELECTRIC
REVIEW

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Instrumentation, Control, and Information Systems Contributing to Automation and Energy Saving

The landscape surrounding industry and daily life has changed significantly due to the rise in demand for environmental measures related to decarbonization and in labor shortages. As digitalization and IoT solutions evolve, our customers increasingly require advancements in automation and energy saving, which contribute to their digital transformation (DX).

Fuji Electric provides system solutions that combine engineering and services with field devices such as measuring instruments and controllers.

This special feature introduces instrumentation, control, and information systems that contribute to automation and energy saving, as well as the components (equipment), technologies, and the associated engineering work and services that support these systems.

Cover Photo:

(1) "MICREX-VieW FOCUS Evolution" monitoring and control system
(2) "SPH5000EC" controller compatible with EtherCAT
(3) Monitoring post
(4) "FCX-A Ⅳ Series" Differential and Gauge Pressure Transmitters

The archives from the first issue, including articles in this issue, are available from the URLs below.

FUJI ELECTRIC REVIEW (English)
https://www.fujielectric.com/company/tech/contents3.html

FUJI ELECTRIC JOURNAL (Japanese)
https://www.fujielectric.co.jp/about/company/contents_02_03.html
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Development of Real-Time Monitoring Using Soft Sensors

FUNATSU, Kimito*

The processes of chemical plants and various other production systems must be continuously monitored and controlled in order to assure their proper functioning. This operation requires accurate, low-cost measurement of process variables, such as temperature, pressure, and flow rate. Although measurements like temperature, pressure and flow rate can be obtained at low cost and in real time, data on the physical properties and concentrations of chemical products can only be obtained after a costly and time consuming chemical analysis. Real time monitoring of such physical properties and concentrations is usually required to control the processes rapidly, which, however, is difficult to be achieved with the conventional approaches. Against this background, soft sensors have been developed to estimate physical properties and concentrations, which are difficult to measure in real time, using process variables that are easy to measure in real time, such as temperature, pressure, and flow rate. Currently, soft sensors are used not only in chemical plants but also for quality control in various product manufacturing processes. A soft sensor, also explained in detail in this special issue, consists of a statistical model $y = f(x)$, which formulates the relationship between the process variables (x) that are easy to measure in real time and the process variable (y) that is difficult to measure in real time. With its application, soft sensors are expected to have both economic and environmental effects: reducing the number of chemical analyses; speeding up control; and, consequentially, reducing waste through the improved quality control of products.

To lead this coming era of soft sensors, the 143rd Committee of the Japan Society for the Promotion of Science and Process Systems Engineering established the workshop No. 32 “Soft Sensor Implementation” (chaired by Kimito Funatsu) in October 2016. In March 2020, the Committee oversaw the successful completion of tools to develop more accurate soft sensors for targeted processes easily and quickly and to deploy and use the soft sensors on-site. After that, to spread the use of this soft sensor tool and lay the foundation for its continuous maintenance, Fuji Electric, a member of the workshop, has started a service for supporting utilization of the tools and is preparing to offer them as products.

Soft sensors now serve as indispensable tools for real time monitoring and control of manufacturing processes, including semiconductor processes, small and large scale chemical processes, and continuous pharmaceutical processes. They have been also being introduced to monitor the internal state of combustion equipment and heat exchangers. As input process variables for soft sensors, in addition to the process variables measured by conventional hard sensors (e.g. temperature, pressure, and flow rate), near-infrared (NIR) spectroscopy and other spectral data have begun to be actively utilized as input variables to directly measure target chemical properties in the processes mentioned above, and its use is becoming widespread. Soft sensors using spectral data will also soon be used routinely for real-time monitoring and process control of raw materials and main- and by-products in flow reactors. It is important to note that using expensive spectral instruments for the inputs will hinder the widespread use of soft sensors. Fortunately, inexpensive and compact spectral instruments are now beginning to appear in the market.

Various efforts have been launched under the keyword of process informatics, whose fundamental roles are to know the present and to predict the future of the target processes. In this sense, soft sensor is a keyword inherently connected with process informatics. Innovative soft sensors beyond conventional concepts are expected to be developed to meet the distinctive features of individual target processes that need to be monitored and controlled. Soft sensors are mostly used for monitoring current process in real time, but they are also being increasingly used to predict process conditions in the near future. They are an important tool not only for the monitoring and controlling chemical plants, but also for the automatic optimization of high-yields, by-product-free reaction conditions through Bayesian optimization, and for design, development, and automatic operation of flow reactors, which stably produce target products. The time is just around the corner when soft sensors are commonly implemented in small to large scale manufacturing equipment as a new technology for continuous manufacturing of various products.

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Instrumentation, Control, and Information Systems Contributing to Automation and Energy Saving: Current Status and Future Outlook

TETSUTANI, Hiroshi* MATSUMOTO, Yasushi*

1. Introduction

In recent years, the environment around industry and daily life has changed significantly due to the increasing demand for environmental measures related to decarbonization and labor shortages. For this reason, further capital investment in decarbonization, automation and digital transformation (DX) are sought on a global scale. In the fields of factory automation equipment and systems, demand for components has remained uncertain due to the impact of the spread of COVID-19 and difficulties in the procurement of semiconductors and other parts around the world. However, market conditions in Southeast Asia and India are expected to continue to recover from the COVID-19 pandemic. In the plant control systems field, the steel and chemical sectors are expected to see demand for upgrades to improve productivity, as well as strategic investments for higher functionality, electrification and

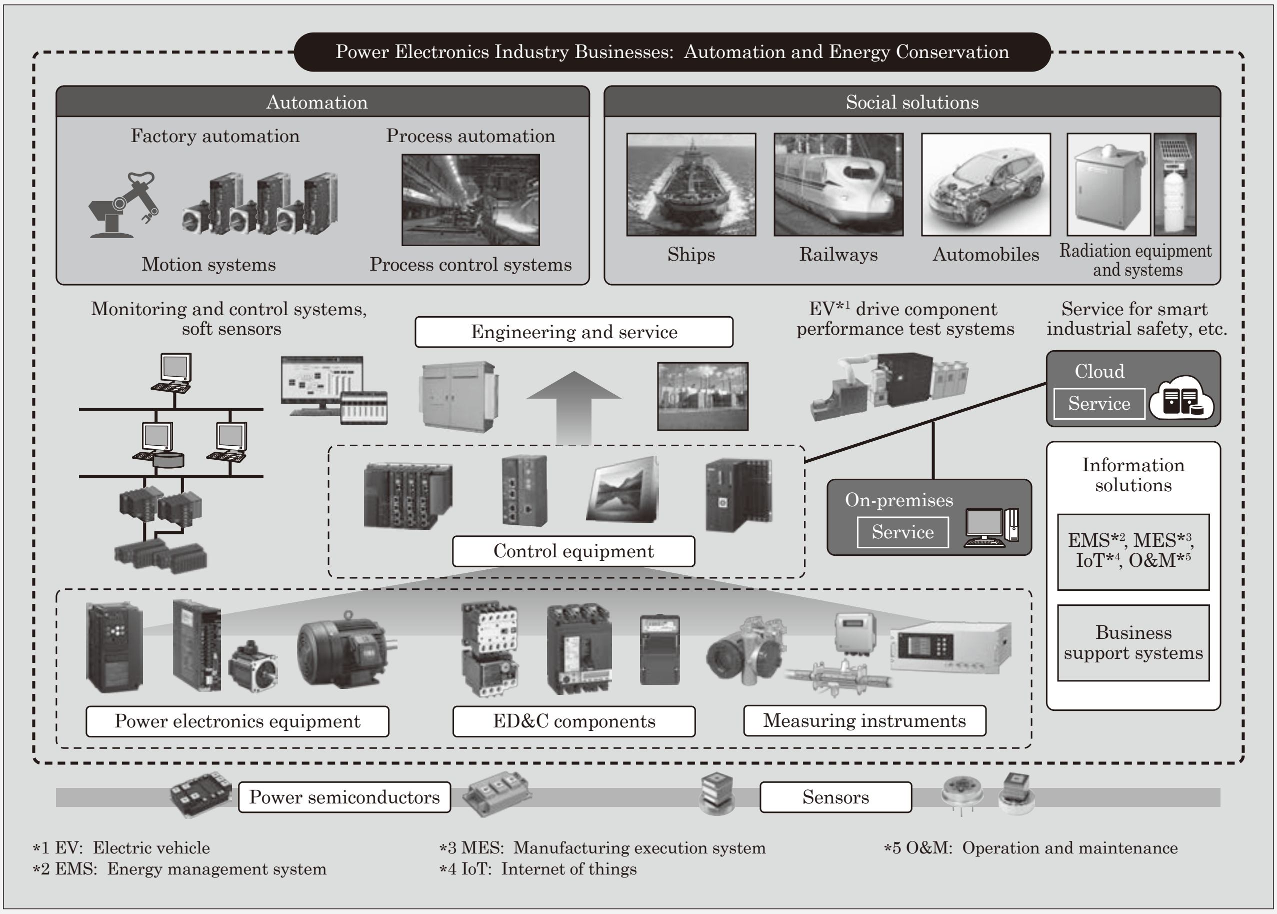


Fig.1 Overview of power electronics equipment and instrumentation, control and information systems of Fuji Electric, and their applications

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

carbon neutrality.

Through innovation in energy and environment technology, Fuji Electric has created competitive components that contribute to the achievement of a responsible and sustainable society as it continues to further enhance systems and expand its systems business. Figure 1 shows an overview of the power electronics equipment and instrumentation, control and information systems of Fuji Electric, as well as their applications.

This paper describes Fuji Electric's new approaches and outlook for measuring instruments, control equipment, and systems that contribute to its efforts in automation and energy saving, as well as the engineering and services thereof.

2. Plant Monitoring and Control Systems

2.1 Market trend of plant monitoring and control systems

Plant monitoring and control systems have contributed to the visualization, automation and stable operations of production equipment and processes, thereby streamlining production and operations at production sites.

The market for these systems is growing mainly in regions where populations are growing, such as China and India. On the other hand, business in Japan has been centered on system updates and the extension of service life, and the market has been saturated. However, investment in plant monitoring and control systems has begun to increase as a new need for equipment modifications for DX and carbon neutrality rises.

Plant monitoring and control systems that were previously closed both in Japan and overseas are now generally connected to external networks. Accordingly, security measures and wide-area data linkage have become critical functions alongside monitoring and control functions.

2.2 Fuji Electric's approaches

(1) Monitoring and control systems

Fuji Electric supplies optimal monitoring and control systems and solutions according to the process automation field and the scale of the plant. Figure 2 shows the lineup of monitoring and control systems.

Covering all plant equipment, these monitoring and control systems constantly collect on-site information such as pressure, flow rate and temperature using measuring instruments in order to perform monitoring and control and ensure an optimal automatic operation according to the situation. Fuji Electric offers the "MICREX-VieW XX (double X)" as a core plant monitoring and control system (see right center in Fig. 1). This system is a monitoring and control system excellent in high reliability and maintainability that enables continuous operation of a plant and is suitable mainly for monitoring and control of iron and steel, cement, and waste treatment plants.

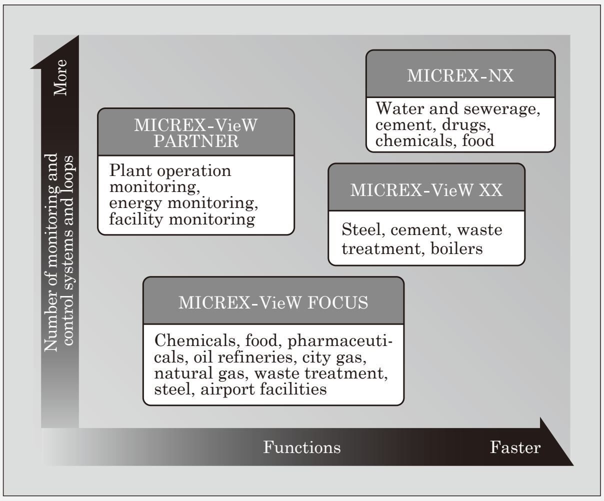
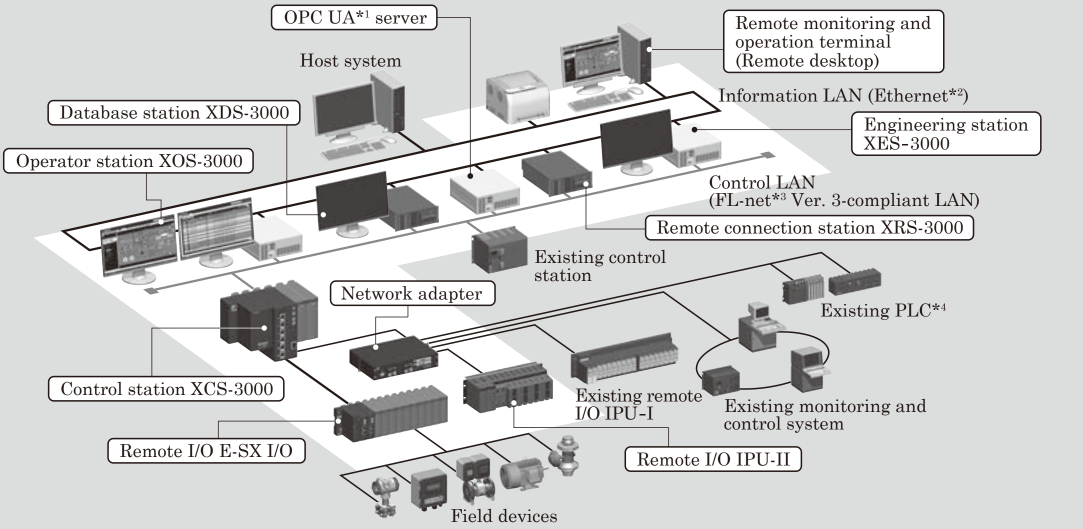


Fig.2 Lineup of monitoring and control systems

The "MICREX-NX" has high affinity with information-system and is suitable for application to large-scale plants with large number of monitoring points, such as water-treatment plants with large treatment volumes.

The "MICREX-VieW PARTNER" makes it possible to visualize the site without choosing equipment or scale, and it is suitable for application to energy-monitoring and equipment monitoring. The "MICREX-VieW FOCUS" is an open supervisory and control system with its human machine interface (HMI) introducing supervisory control and data acquisition (SCADA) for general purpose rather than system specific and is suitable for applications in chemical, food and pharmaceutical, and gas fields. This time, the product category has been expanded with the addition of the user-friendly "MICREX-VieW FOCUS Evolution" to the lineup. This monitoring and control system is easy to learn how to use, enabling customers to perform engineering work and engineers outside of Japan to complete the construction of their system at their worksites. This system integrates various programming tools and is equipped with an engineering environment in which application software can be easily and efficiently created by drag-and-drop operations on PC screen. It also has a function to easily customize the operation screen according to the customer's requirements. In the future, we will continue to increase its value and expand its applications to other industries and the outside of Japan. (Refer to "Engineering Support Tool That Reduces Lead Time and Improves Quality, Accelerating DX" on page 21.)

Figure 3 shows an example of a system configuration for the MICREX-VieW XX, which is an



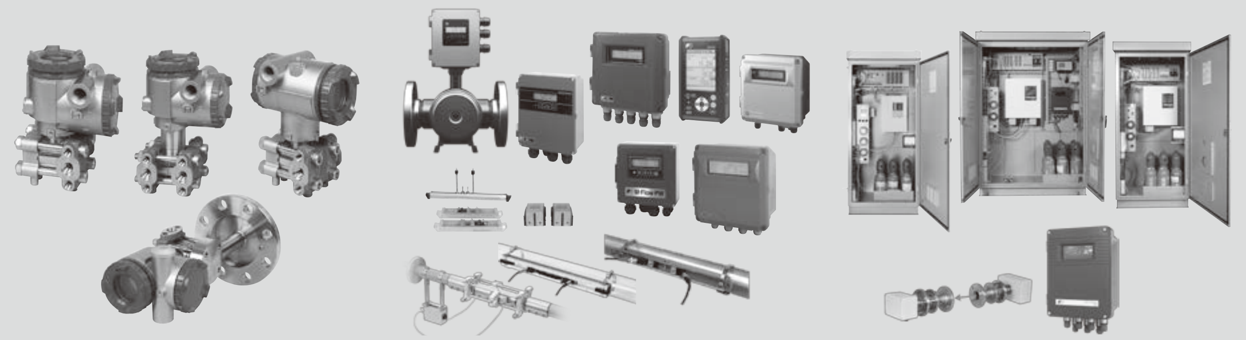
*1 OPC UA is a trademark or registered trademark of the OPC Foundation.
*2 Ethernet is a trademark or registered trademark of FUJIFILM Business Innovation Corp.
*3 FL-net is a trademark or registered trademark of the Japan Electrical Manufacturers' Association.
*4 PLC: Programmable logic controller

Fig.3 Example system configuration for the "MICREX-VieW XX"

example of a basic monitoring and control system. The engineering station is a tool environment for engineering of the operator station, which is responsible for the controllers and HMI. At the operator station, monitoring operations are performed by plant operators, and automatic control is performed by collecting and outputting the data necessary for plant operation via the control station, as well as the remote I/O and field devices. This monitoring and control system enables the combination of a variety of solution content, which can be shared with other monitoring and control systems.

For overseas product deployment, the focus is on expanding the overseas systems business by offering and standardizing primarily small-scale systems such as environmental monitors, water treatment systems and small boilers in South East Asia and India.

In the field of plant control systems, monitoring and control systems act as a platform for plant monitoring, and the issue of how data collected in such operations is handled is becoming increasingly important. In fact, sophisticated prediction technology that utilizes numerical models is being applied at worksites by combining collected data and artificial intelligence (AI) technology. As one such approach, Fuji Electric is working on the on-site application of soft sensors that calculate and estimate current values of important quality data, such as component concentrations of products regularly sampled on site, by using quality values that have already been collected. We are also expanding functions to support plant operations, such as a function to import large amounts of plant monitoring data in a fixed cycle to reproduce past plant conditions on the screen. (Refer to "Soft Sensor-Systems for Optimizing Plant Operation" on page 16.) Going forward, Fuji Electric will continue to advance efforts



(a) Differential and gauge pressure transmitters
(b) Flowmeters
(c) Analyzers

Fig.4 Fuji Electric's differential and gauge pressure transmitters, flowmeters and analyzers in the collection and utilization of data.

(2) Supporting systems with measuring instruments

Fuji Electric contributes to environmental protection and energy saving with a lineup that includes various gas analyzers that support environmental measurement work, including air pollution measurement; flowmeters that support energy saving by measuring fluids such as saturated steam, liquid and air; and the "FCX Series" of differential and gauge pressure transmitters used in various fields around the world. Figure 4 shows various differential pressure and pressure transmitters, flowmeters and analyzers made by Fuji Electric.

Since its launch in 1989, over one million units of FCX Series product category have been sold worldwide. To further improve performance and respond to requests for new functions including measures for functional safety, Fuji Electric has developed the "FCX-AIV Series." (Refer to "Differential and Gauge Pressure Transmitters That Sophisticate Plant Monitoring and Control Systems" on page 36.)

3. Factory Automation Systems

3.1 Market trend of factory automation systems

In the market for factory automation systems, there is also a growing need for solutions that contribute to DX to enable customers to create new value by implementing the internet of things (IoT) primarily for digitization purposes. While each manufacturer engages in solutions in the specialty domain of systems, customers are seeking solutions that integrate multiple areas. Fuji Electric aims at upgrading of manufacturing, quality, inventory, maintenance, and energy control of customers by digital solutions that are hierarchical in manufacturing execution and production management (L3), monitoring control and monitoring (L2), and equipment and control (L1), based on hierarchical system model advocated by the International Society of Automation (ISA) in its standard ISA-95. Figure 5 shows an overview of DX for factory systems. Section 3.2 describes the manufacturing execution system in L3, as well as the motion control system and electric vehicle (EV) drive component performance test system in L1.

3.2 Fuji Electric's approaches

(1) Manufacturing execution system

Manufacturing execution systems (MES) are generally systems that seamlessly link core business systems such as enterprise resource planning (ERP) systems with on-site control systems to issue process-specific manufacturing instructions based on a manufacturing plan and collect manufacturing results data.

In addition to providing the basic functions above, Fuji Electric's MES is based on a concept that ensures quality traceability and supports improvement feedback through sophisticated analyses of manufacturing results.

As its latest approach, Fuji Electric has created a new MES concept to begin the development

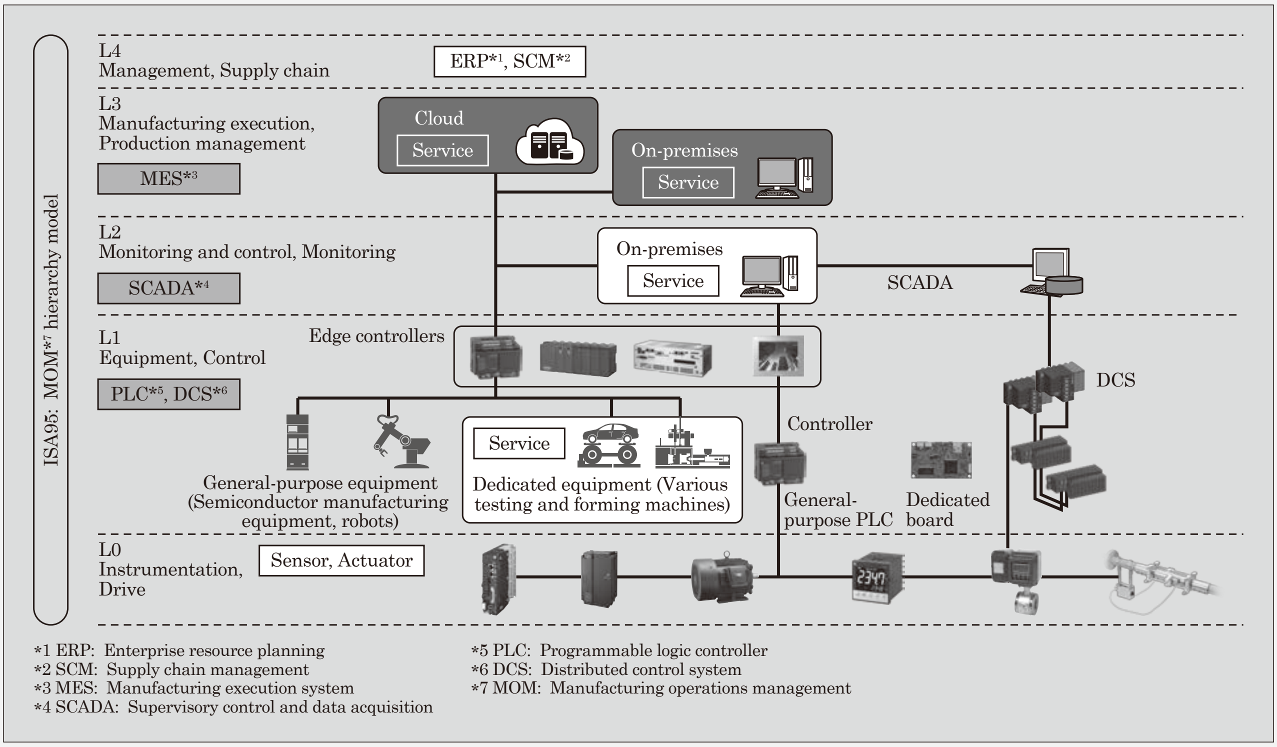


Fig.5 Overview of DX for factory systems

of an MES package with a new architecture. With a structure that is compliant with the OPC UA*1 standard data model, we aim to achieve an environment that responds to various changes in the future in a sustainable manner and analyzes various data (events, trends, text, images, voice, etc.) with the same usability.

Moreover, Fuji Electric is promoting the proposal of its "Global Smart Factory" concept for customer needs such as upgrading of plant environment, realization of digital twin environment, standardization from global viewpoint, and realization of carbon neutral. This proposal integrates packaged products, such as manufacturing, maintenance, facilities, and energy-information integrated databases at manufacturing bases, and MES, energy management systems (EMS), maintenance systems and facility monitoring systems using AI and analysis technologies as core technologies. Figure 6 shows the packages of the global smart factory.

On the other hand, as for the engineering function of MES, it has conventionally been defined specially for the function implemented, and it is efficient but difficult to change the function or use it in other applications. The new system adopts the information model that is the conception of OPC UA and can systematically manage required information, making it easier to change functions and utilize it in many applications by constructing digital twin as an information model that abstracts the manufacturing site. (Refer to "Manufacturing Execution Systems Encouraging DX on the Manufacturing Floor" on page 26.)

(2) Motion control system

A motion control system is a system that performs motion control such as precise positioning, speed control, and torque control for industrial machines and devices such as industrial robots. Motion control systems generally consist of an actuator such as servo motors, motion controllers, programmable operator interfaces, control software and so forth.

In these purposes, there are demands for coping with complicated operations and machining, shortening of process time, and higher precision, and performance that can be synchronously controlled at a higher speed control period is required with more control axes. Furthermore, in response to the increasing proliferation of EtherCAT*2 as an open network that allows users to select the optimal components from multiple manufacturers, Fuji Electric developed the "SPH5000EC," an EtherCAT-compatible controller. Figure 7 shows an EtherCAT system configuration.

This controller uses a "multi-core platform" that uses a processor with two cores, allowing it to simultaneously execute application software for two conventional programmable logic controllers (PLCs).

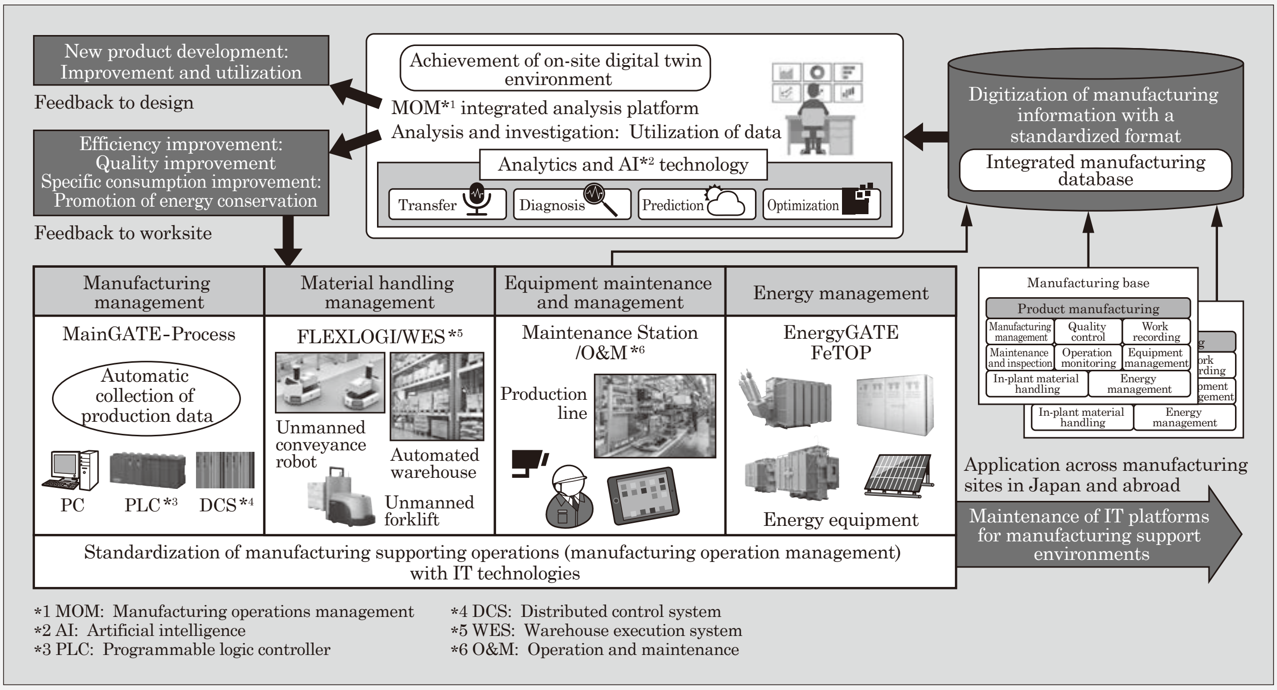


Fig.6 Global smart factory packages

***1 OPC UA**

OPC UA is a trademark or registered trademark of the OPC Foundation.

***2 EtherCAT**

EtherCAT is a trademark or registered trademark of Beckhoff Automation GmbH & Co. KG.

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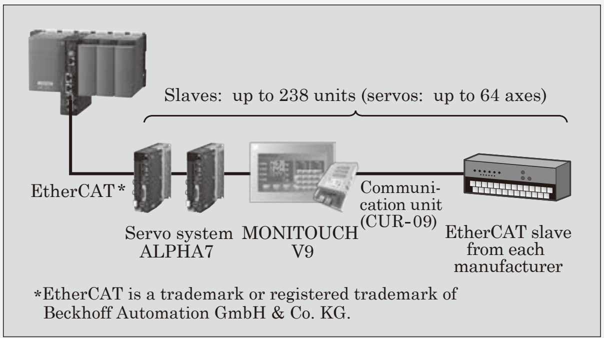

Fig.7 EtherCAT system configuration

Additionally, by simultaneously executing sequence control and motion control in parallel, it can achieve four times the motion control performance of previous models. It can also support large-scale systems through the synchronous control of multiple EtherCAT systems. (Refer to "Motion Controller Contributing to Automation of Factory Equipment" on page 31.)

(3) EV drive component performance test system

Since the control of EVs is more complicated than that of gasoline vehicles, the labor hours required for development and testing by completed vehicle manufacturers tend to be higher than those required for conventional gasoline vehicles. For this reason, there is demand for test systems that contribute to the improvement of test efficiency. Fuji Electric's EV drive component performance test system consists of an EV drive component performance testing equipment, a thermostatic chamber and a temperature control equipment. Figure 8 shows the EV drive component performance test system. The system can evaluate the performance of high-speed motor-based drive components across the entire temperature range, from low to high temperatures, while maintaining environmental factors with high accuracy.

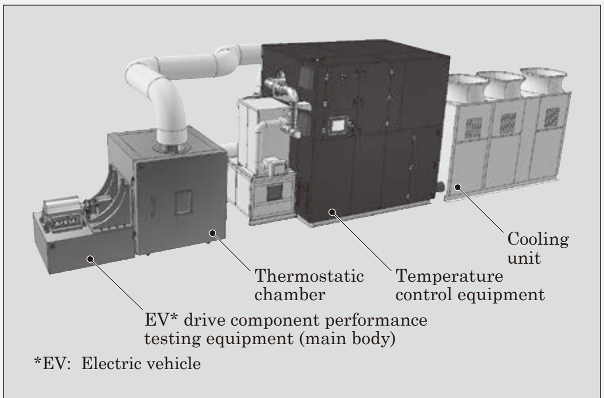

Fig.8 EV drive component performance test system

There are worries about the trouble with the testing equipment for high-speed rotation motors caused by the vibrations accompanied with its high-speed rotation, and it is required to reduce the complication of the maintenance for the trouble prevention as well as the troubleshooting. The newly developed EV drive component performance testing equipment is designed to be highly reliable as testing equipment by simulating with the finite element method and by optimizing the dynamic balance of the rotating shaft and is structured to simplify the maintenance.

Further, in order to improve the precision of the test environment conditions, it is necessary to keep the thermostatic chamber at a constant temperature by absorbing the heat generated from the parts to be tested. This time, by designing a refrigerant circuit and a control method to improve the cooling unit's response to heat generation, and by eliminating the defrosting function of the evaporator used in typical temperature control equipment, Fuji Electric developed a temperature control equipment capable of ±1°C temperature tracking in response to thermal load fluctuations. (Refer to "Performance Test System Reproduces the Usage Environment of EV Drive Components" on page 40.)

4. Other Systems, Solutions and Services

Fuji Electric offers systems, solutions and services that utilize the measurement and control technology we have cultivated in various industrial fields.

4.1 Ship IoT system

Exhaust gas cleaning systems (EGCS)*3 are increasingly being adopted in the maritime industry in response to the strengthened sulfur oxide (SOx) emissions regulations specified by the International Maritime Organization (IMO). Fuji Electric offers EGCSs that minimize operation costs by achieving optimal control using the world's smallest [10-MW class (as of 2020, according to Fuji Electric research)] SO_X scrubber and the laser gas analyzer. However, EGCSs burden ship owners, management companies and seafarers with monitoring and maintenance tasks. We developed the "Ship IoT System," which contributes to a safe and efficient ship operation through automatic collection of EGCS operation data and predictive diagnosis of faults. (Refer to "Ship IoT System for Efficient

***3 EGCS**

EGCS stands for exhaust gas cleaning system. These systems consist of SO_X scrubbers that remove sulfur from exhaust gas by cleaning the gas with sea water, measuring instruments that analyze the components of exhaust gas and discharged water, and other components.

Operation Management of Exhaust Gas Cleaning Systems" on page 45.)

4.2 Radiation control solutions

There is growing momentum around the world to depart from the use of fossil fuels and utilize nuclear power. To promote the utilization of nuclear power, thorough safety measures are essential, and to ensure safety and security in the local area, radiation management is indispensable. Fuji Electric has been contributing to the safe and secure use of nuclear energy by offering measuring instruments such as personal dosimeters, gas and dust monitors, as well as radiation monitoring systems. To further improve measurement reliability and promote automated management, we have developed monitoring posts with higher environmental resistance, dosimeters, environmental radiation monitoring telemeter systems and other equipment. (Refer to "Radiation Management Solutions Contributing to Safety and Security" on page 49.)

4.3 Service for Smart Industrial Safety

In the petroleum, chemical, power and gas industries and other energy-related infrastructure industries, the workload required for maintenance has been increasing as a result of the aging of equipment, as well as the aging and long-term shortage of security workers. Under such circumstances, there is an urgent need for the stable operation of equipment and the streamlining and sophistication of the maintenance work. Fuji Electric offers the "Comprehensive Service for Smart Industrial Safety," which addresses issues arising from existing analog maintenance operations and supports the management of highly efficient operations by utilizing IoT and AI technologies. In this way, the service optimizes equipment maintenance, encompassing everything from the development of maintenance plans to the proposal of equipment monitoring and maintenance management measures. (Refer to "Comprehensive Service for Smart Industrial Safety, Which Improves Maintenance and Inspection Efficiency and Delivers Predictive Maintenance" on page 54.)

5. Postscript

In this paper, we described the current status and future outlook of instrumentation, control and information systems that contribute to Fuji Electric's efforts in automation and energy saving. Going forward, we will continue to contribute to society by promoting automation and energy saving.

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Global Monitoring and Control System That Improves Plant System Engineering Efficiency

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ABSTRACT

In recent years, the engineering function of plant monitoring and control systems have been required to support the entire plant lifecycle. To meet the requirement, Fuji Electric has developed the "MICREX-VieW FOCUS Evolution" global monitoring and control system to improve the efficiency of plant system engineering. The MICREX-VieW FOCUS Evolution enables users to build flexible monitoring and control systems tailored to the scale and application they require by offering both easy customization and high versatility, as well as supporting OPC UA, which is used as a standard multi-vendor communication protocol.

1. Introduction

In 2014, Fuji Electric released the "MICREX-VieW XX (double X)" monitoring and control system for small- and medium-scale industrial plants. Since then, we have been contributing to the stable operation of industrial plants in fields such as steel, chemicals, food, waste treatment.[1] In recent years, plant monitoring and control systems have also been increasingly introduced outside of Japan. However, since the turnover rate for engineers is high overseas, there is demand for computer software-based engineering tools that are easier to learn. Monitoring and maintenance from remote locations and compliance with international standards are essential when delivering plant systems to markets outside of Japan.

To meet these requirements, Fuji Electric developed an integrated engineering system for local engineers both in Japan and abroad. This paper describes the "MICREX-VieW FOCUS Evolution" global monitoring and control system.

2. Challenges in Monitoring and Control Systems

2.1 Overview

Figure 1 shows an example of a MICREX-VieW XX system configuration. At the engineering station, engineering work is performed on the operator stations that serve as the human machine interface (HMI) and the controls stations[2]. At the operator station, personnel use the control station, remote I/O and field devices to monitor and operate the plant to collect the data necessary for plant operation and perform control. Through these operations, the system provides highly reliable and optimal solutions, thereby contributing to energy saving and the stable and safe operation of the plant.

2.2 Challenges

(1) Enhancement of user support functions

With the advancement of digital technology, the engineering work for recent plant monitoring and control systems has evolved and are now starting to support the entire lifecycle of the operator station and the control station, from engineering to service. Outside of Japan, there is a need to consolidate the engineering environments of entire plant systems to improve engineering efficiency. As such, companies require engineering environments that allow for the effective use of developed application assets regardless of the scale of the plant system.

Since the engineer turnover rate is high outside of Japan, engineering tools that are easy to learn are required. In addition, to meet the need for support for remote work and collaborative work among engineers in different locations, it is necessary to provide environments in which engineering operations can be easily performed by anyone from anywhere.

(2) Enhancement of the HMI function

When carrying out development work in Japan in response to changes in specifications for plant monitoring and control systems abroad, the process of translating specification changes into Japanese and the time losses due to time difference during verification of specifications. To allow engineers outside of Japan to quickly carry out tasks from application development to testing on site, it is necessary to provide a simple and efficient engineering environment. The HMI environment needs accommodating rules that are specific to local engineers, as well as customization and pack-

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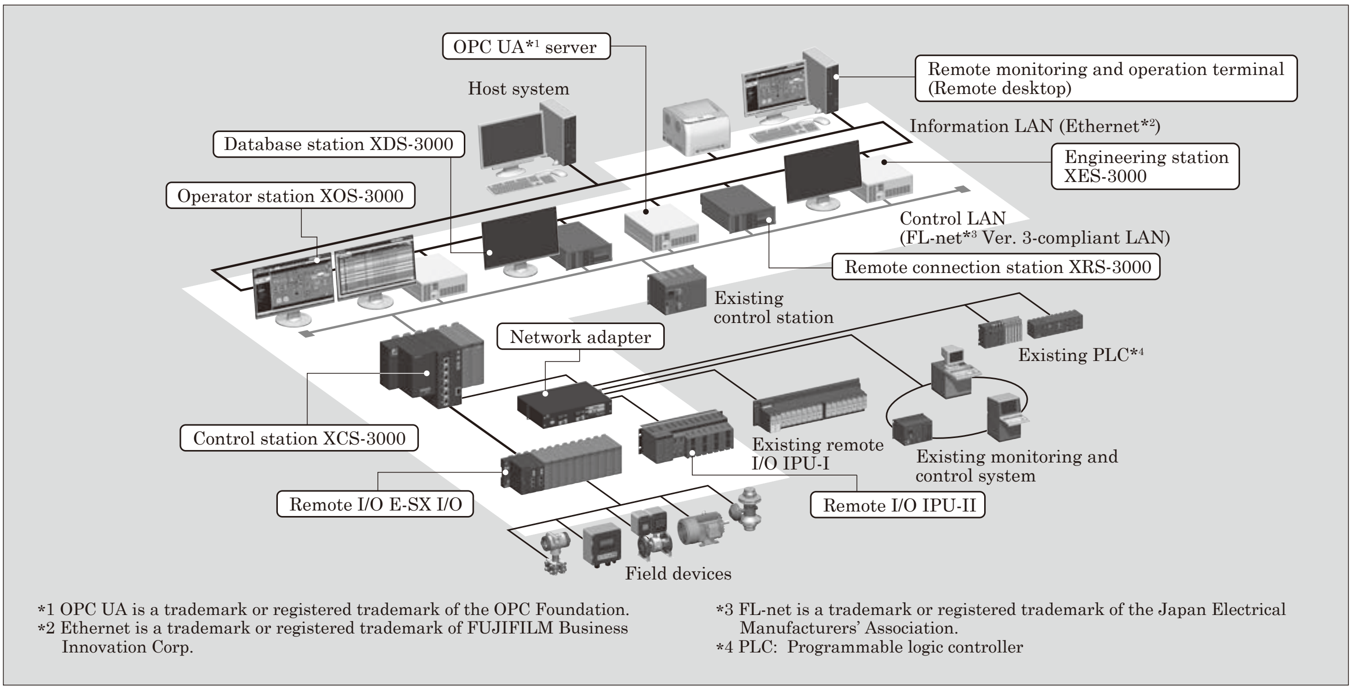

Fig.1 Example of a "MICREX-VieW XX" system configuration

aging based on user requirements.

(3) Improving versatility

Systems that employed the MICREX-VieW XX required dedicated equipment. For example, when equipment failed in plants abroad, recovery took time because replacements needed to be sent from Japan. To achieve systems that facilitate procurement, implementation, and engineering even abroad, such constraints need to be eliminated.

(4) Enhancement of monitoring and maintenance functions

For Japanese plant manufacturers operating outside of Japan, prerequisites for adopting a plant system include the ability to perform maintenance in a timely manner and in short lead times similar to operations in Japan. Accordingly, we need to provide an environment that allows remote monitoring and maintenance without the need to visit the worksite.

3. Characteristics of the "MICREX-VieW FOCUS Evolution" Global Monitoring and Control System

3.1 Outline

Figure 2 shows an example of a system configuration for the MICREX-VieW FOCUS Evolution. Designed to be applied in plants abroad, the MICREX-VieW FOCUS Evolution enables users to develop applications with the integrated engineering tool, and build flexible systems tailored to the scale and application. It also supports the remote operation of multiple sites using smart devices. This is a monitoring and control system that ensures both customization and versatility at a high level.

3.2 Integrated engineering tool and application package

(1) Automatic synchronization of tool integration and TAG information

For this system, we offer an integrated engineering tool that achieves higher usability by combining multiple engineering tools that were previously separate. Figure 3 shows the configuration of the integrated engineering tool. The following tools can be combined and used flexibly under the integrated environment. Fuji Electric offers packages that can be used with the various applications that run on these tools [see (3) for details].

- ○ Network configuration engineering tool
- ○ Controller engineering tool
- ○ HMI screen engineering tool
- ○ Simulation
- ○ Standard template and standard library

The integrated engineering tool centrally manages not only the various tools and applications described above, but also the TAG information used to identify the devices and equipment that are subject to monitoring and control. Since the tool automatically synchronizes all applications, every time a user edits an application or operates the control station, the information of related tools and applications is also automatically updated. Therefore, users are relieved from the hassle of managing applications for each tool as was required in the past. In addition, users do not need to reconnect TAG information, which was previously retained separately for the controller and the HMI screen, every time the information is updated. These functions significantly lighten engineering workload and improve efficiency.

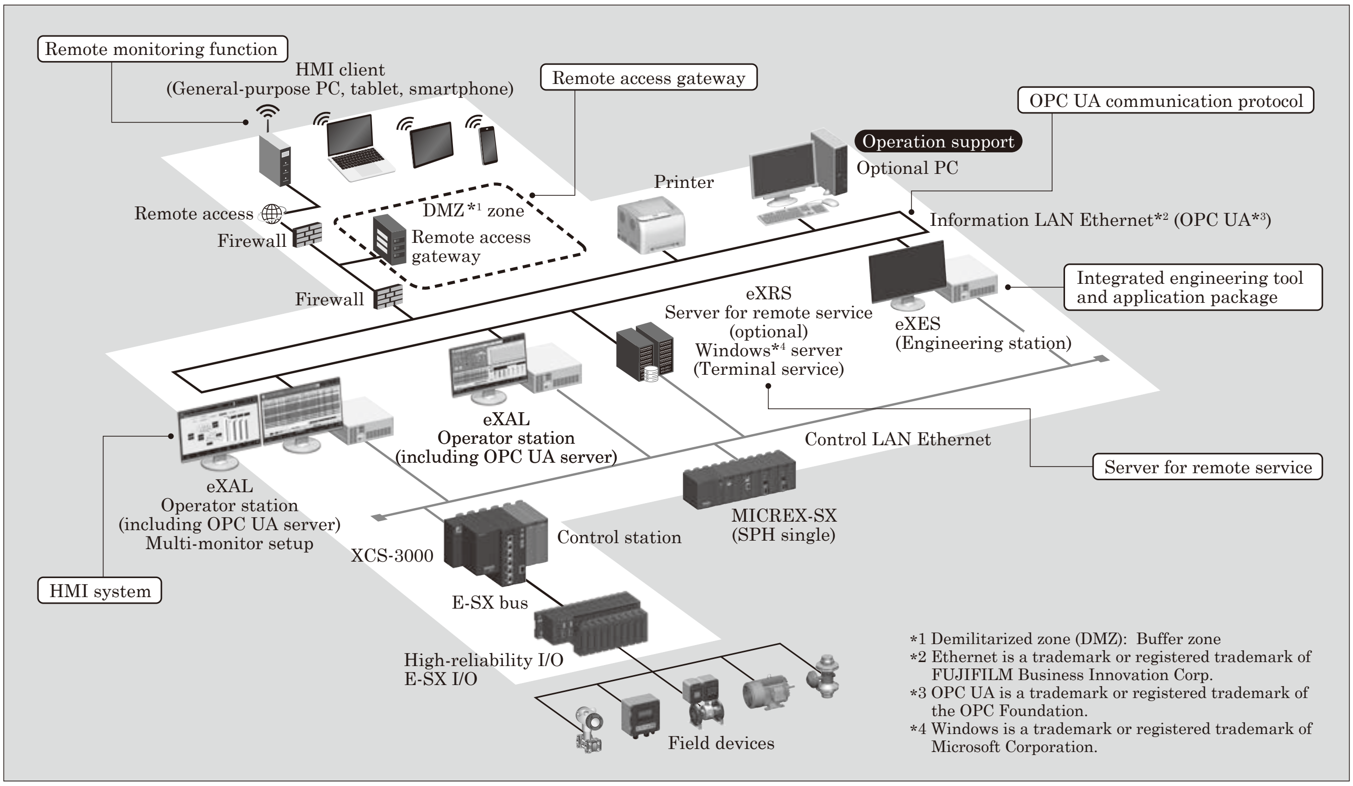

Fig.2 Example of a “MICREX-VieW FOCUS Evolution” system configuration

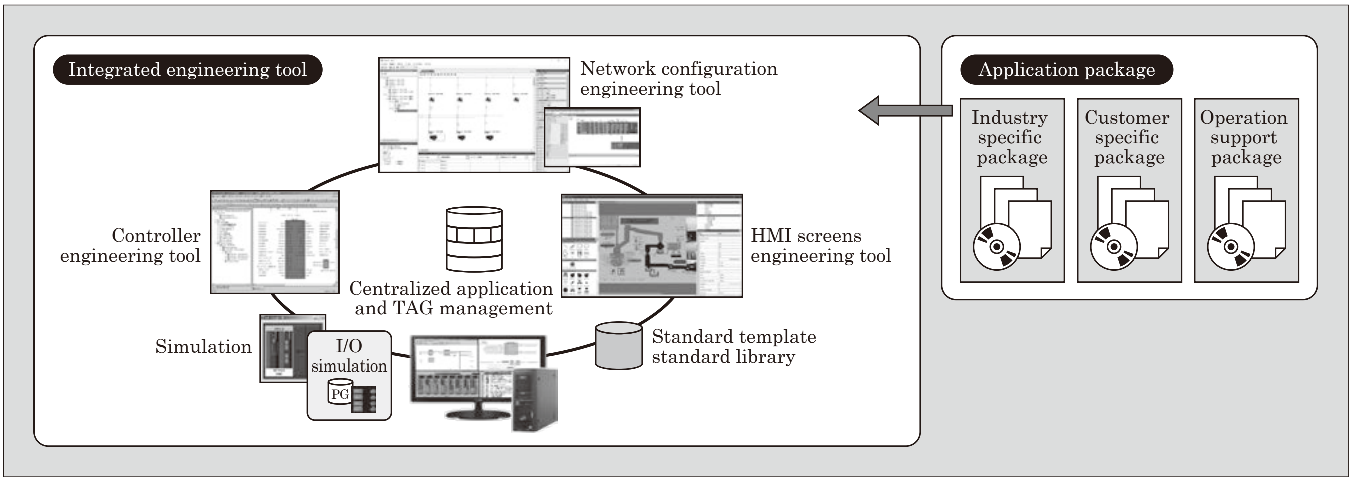

Fig.3 Configuration of the integrated engineering tool

(2) Multi-user function

Engineers in Japan and abroad are increasingly collaborating in the development of plant monitoring and control systems for countries outside of Japan. In such cases, there are concerns that development efficiency may decline due to mistakes in the management of the application development process, and that labor hours may increase due to complex management. To prevent these issues, we developed the multi-user function. Since application files under development are centrally and exclusively managed on the dedicated server, multiple engineers cannot modify the same application at the same time.

Furthermore, users can reuse developed applications at new worksites. Reusing proven and reliable applications is effective for improving development efficiency.

(3) Sophisticated utilization of application packages

Fuji Electric offers application packages to help users develop applications. A wide range of packages are available for various industries and for operational support, allowing engineers to select a suitable package for the plant control system to be developed. To improve the efficiency of application development, users have not only used these packages, but have also created templates of programs and screen data that have a proven track record and managed them for the purpose of reuse with their own management rules. However, since local engineers could not modify the individual specifications of these application packages and templates for reuse, they needed to ask the developers of the template or package to develop the modified version.

To solve this issue, we developed the object sharing system illustrated in Fig. 4. The system works as follows: When a user registers developed program parts and screen parts in the package library for the purpose of reuse, the user defines information known as structured TAG data to link the definition information of the program variables and screen parts to be reused to the elements of the structured TAG data. This system allows local engineers to modify the individual specifications of applications, which could previously only be done by the developers. By simply arranging program parts during program development, the corresponding screen parts can be automatically created.

Utilizing these functions will drastically improve development efficiency at worksites outside of Japan and allow development to be completed locally.

3.3 HMI system

(1) Screen customization by the user

The HMI screen is an important user interface on which plant operators constantly perform monitoring and operation. Thus, its usability affects customer satisfaction significantly. Screens must meet the specific requirements for various fields and end users. In particular, the ability to perform flexible customization is important for local engineers to satisfy such requirements.

We developed a new function to customize screens with a general-purpose scripting capability that enables the execution of simple programming languages. Figure 5 shows the internal structure of the HMI system of the MICREX-VieW FOCUS Evolution. Since the HMI platform used to be equipped with screens and parts in advance, users could only modify the combination of parts. By separating them from the HMI platform, we have made it possible to perform customization and packaging of screens and screen parts on the HMI system of the MICREX-VieW FOCUS Evolution. By using the general-purpose ECMAScript*1 for customization, users can add plant-specific motions to the HMI screen. ECMAScript supports 258 script functions for 21 categories to enable flexible customization.

(2) Multi-window function

Figure 6 shows an example of the multi-window display (tile display). The HMI system of the MICREX-VieW FOCUS Evolution has a multi-window display function that displays a maximum of eight

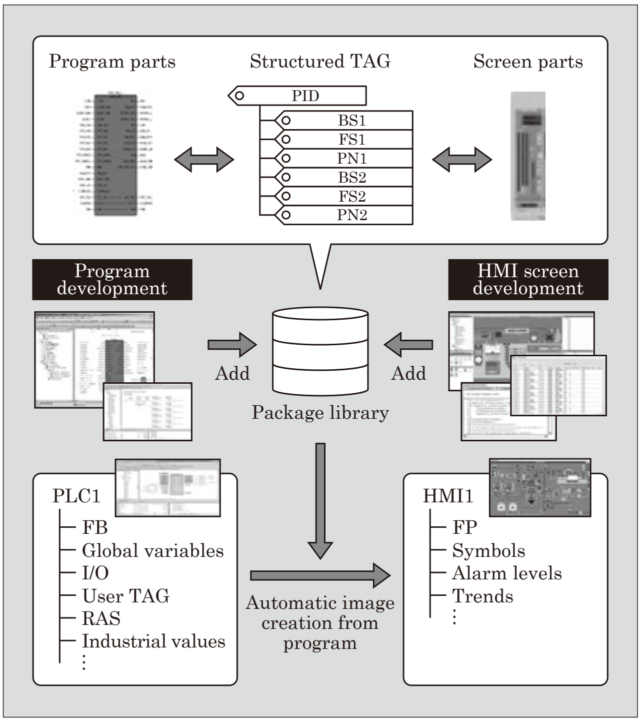

Fig.4 Object sharing system

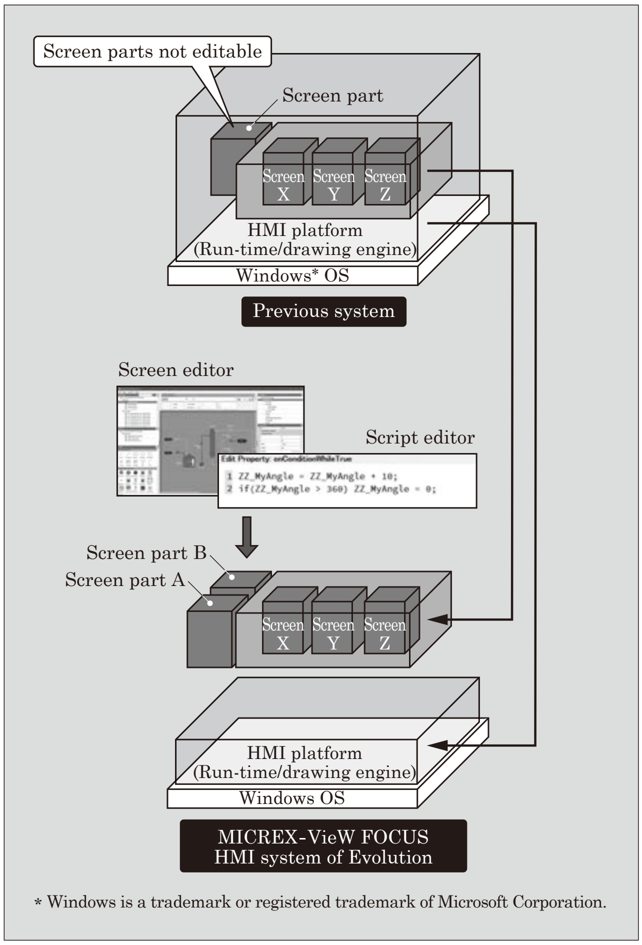

Fig.5 Internal structure of the HMI system of the "MICREX-VieW FOCUS Evolution"

*1 ECMAScript is a trademark or registered trademark of Ecma International.

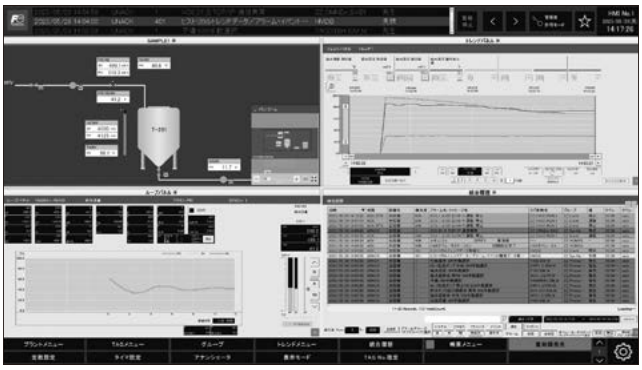

Fig.6 Example of the multi-window display (tile display)

monitoring screens at the same time. Users can select from the following three display types.

○ Tab display
○ Floating display
○ Tile display

(3) Increase in PC choices

We adopted our own proprietary database to eliminate the use of Microsoft SQL Server*2, which was necessary in the previous system. This measure relaxed the requirements to use the system on computers, enabling general-purpose PCs to be used.

3.4 Remote monitoring system

(1) Remote monitoring function

The MICREX-VieW FOCUS Evolution can be used to remotely monitor local plants by means of HMI clients such as general-purpose PCs, tablets, and smartphones.

This function was implemented using a remote service server (HMI server) on the control LAN as shown in Fig. 2. The information LAN has a demilitarized zone (DMZ: buffer zone) with firewalls to accommodate the remote access gateway. As a result of this feature, users can connect HMI clients to the remote service server via the Internet to monitor and operate the plant from the browser. This system allows users to remotely monitor even plants located outside of Japan with ease without constructing a virtual private network (VPN) on the client devices.

(2) Adoption of OPC UA*3 communication protocol

For the monitoring and control systems of industrial plants, it is important to have multi-vendor communication technologies, which enable connections to the systems, devices and even cloud systems of other vendors. Currently, many technologies are available for multi-vendor communication, and they can be selected according to the purpose. Among those, OPC UA is gaining attention as a promising option.

OPC UA is growing as a communication technology for control systems. It has become an international standard as a protocol recommended in IEC 62541, which is a communication-layer (communication function) standard of the Reference Architecture Model Industrie 4.0 (RAMI4.0), which in turn is a reference architecture model of Industrie 4.0, promoted mainly by Germany. China and Singapore have adopted OPC UA as national standards, and it is expected to spread to other regions outside of Europe.

For the MICREX-VieW FOCUS Evolution, we provided the operator station with an OPC UA server function to smoothly synchronize the system to various systems both in Japan and abroad. The OPC UA synchronization data automatically synchronizes with the TAG information defined using the integrated engineering tool.

As a result, for the various processes that make up the engineering process, from the software design process to testing, the number of labor hours can be reduced to half of that of the previous system, as shown in Fig. 7. This will also allow customization to be performed locally when plants are to be expanded in scale.

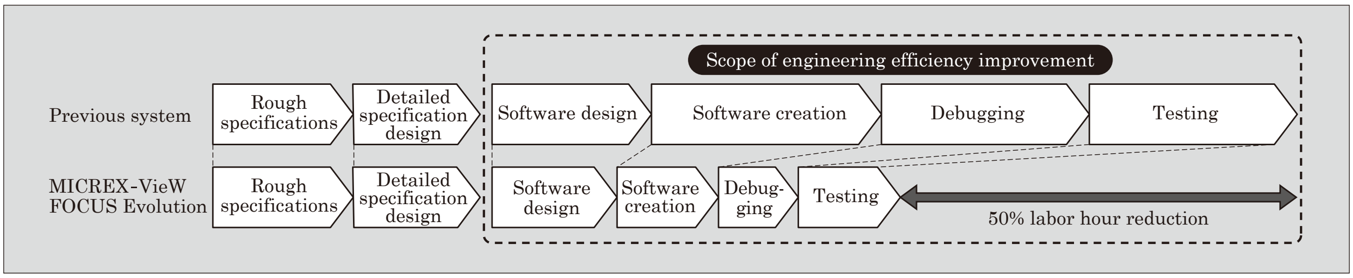

Fig.7 Reduction of engineering labor-hours

*2 SQL Server is a trademark or registered trademark of Microsoft Corporation.
*3 OPC UA is a trademark or registered trademark of the OPC Foundation.

4. Postscript

In this paper, we have described a global monitoring and control system that improves the efficiency of plant system engineering. This system allows users to build flexible systems tailored to the scale and application and can be operated globally. It also supports the stable operation of plants through remote monitoring using smart devices. This monitoring and control system ensures both easy customization and high versatility and is constantly evolving.

Fuji Electric will continue to expand the functions of the monitoring and control system to improve the engineering environments of our customers.

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Soft Sensor-Systems for Optimizing Plant Operation

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ABSTRACT

In recent years, an increasing number of companies have been promoting DX initiatives in industrial processes in order to improve productivity. Fuji Electric has been developing technology for soft sensors that can estimate quality in real time using temperature, pressure, and other process data. Our newly implemented soft sensor design tool enables efficient building and deployment of highly accurate mathematical models that were challenging in the past. The performance of the soft sensors was verified with a process simulator. The new soft sensor designed with our tool is able to estimate quality values that have been difficult to measure in real-time and improve plant control, resulting in reduced specific consumption and lower costs.

1. Introduction

In recent years, industry has been increasingly promoting digital transformation (DX) for automation and increased efficiency in manufacturing processes. As society and markets change, an increasing number of companies in steel, chemicals, and other process industries have also been advancing efforts toward digitalization to improve safety, reduce environmental impact, stabilize quality, and reduce costs and workload.

As on-site plant operation is crucial in process industries, operators must have an accurate understanding of the status of plants to appropriately implement intervention and control. Soft sensors, helping understand the status of plants, can further innovate plant operation and promote DX in the process industries.

2. Soft Sensors

2.1 What are soft sensors?

Soft sensors are attracting attention as sensors designed for the safe and stable operation of manufacturing plants, as well as for the maintenance and control of quality.

In the process industries, key quality values such as the concentration of components in a product are still measured via sampling-based laboratory analysis. The problem with this method is that it takes a long time to obtain results and is costly. On the other hand, since in-process temperature and pressure measurements can be taken in real time and at a low cost, if those measurements are correlated to quality values, quality can be estimated in real time. A soft sensor is a mathematical model that enables the estimation of quality values, which are response variables, from explanatory variables such as temperature and pressure, which are easy to measure. They are called soft sensors because their functions are implemented as software.

2.2 Roles and effects of soft sensors

A soft sensor will yield the following benefits:

(a) As in Fig. 1, operators used to operate plants without knowing the current quality and could not perform operations with confidence. If a soft sensor shows the estimated current quality in real time, operators can appropriately perform plant operation and intervention.

(b) Real-time estimated quality reduces the margins that were previously established under the assumption that quality was uncertain, thereby reducing waste, improving quality and saving energy.

(c) When a target quality value can be measured by equipment, soft sensors can detect equipment errors.

2.3 Challenges for soft sensors

Achieving the effects described in Section 2.2 requires the efficient design and implementation of accurate soft sensors.

To accurately estimate process quality values with a soft sensor, it is necessary to apply appropriate mathematical models and parameters using suitable combinations of explanatory variables. Users need to select optimal combinations from many candidates, which requires enormous efforts because it can only be enabled by manually searching the combinations by trial and error. A major challenge to achieve the practical implementation of soft sensors is to drastically

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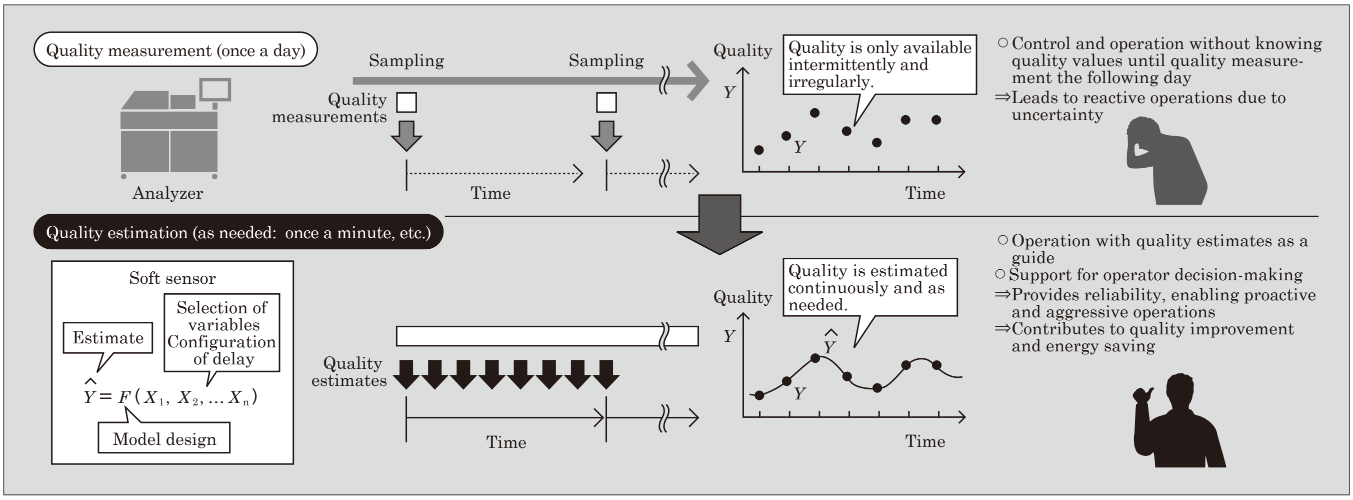

Fig.1 Effects of a soft sensor

improve the efficiency of the processes required for this soft sensor design.

In addition, in order to operate designed soft sensors in actual plants, users need to implement systems to input explanatory variables such as temperature and pressure measurements and perform calculations using mathematical models to output quality estimates (response variables). A mechanism is also necessary for updating the parameters of the estimation models of the soft sensor in response to changes in actual plants.

3. Soft Sensor Design Tool

3.1 Outline of the soft sensor design tool

We developed a tool to efficiently design highly accurate soft sensors without the manual trial and error process that was previously necessary. This soft sensor design tool was jointly developed by universities, quality control and production management departments of chemical companies, engineering companies and Fuji Electric at the Workshop No. 32 “Soft Sensor Implementation” (chaired by Kimito Funatsu) at the 143rd Committee on Process Systems Engineering organized by the Japan Society for the Promotion of Science. In this workshop, the series of procedures have been standardized and automated to determine combinations of explanatory variables, estimation model types and parameters, which had been a major challenge in soft sensor design in the past. Section 3.2 describes the series of processes that were automated.

3.2 Steps from soft sensor design to operation

The steps from soft sensor design to operation are shown in Fig. 2.

(1) Data collection

In this step, the data required for soft sensor design is collected. It is necessary to obtain both the response variables to be estimated, such as product quality, and explanatory variables that may affect the response variables, such as process data.

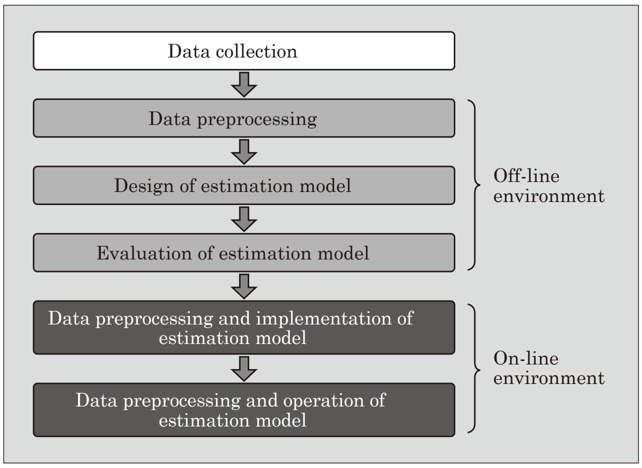

Fig.2 Steps from soft sensor design to operation

(2) Data preprocessing

Collected explanatory variables may contain outliers, irregular data or noise. Since these will interfere with the proper design of the soft sensor, data preprocessing is performed, such as removing outliers and irregular data and eliminating noise by moving average, in this step.

(3) Building and evaluation of the soft sensor

There are several candidate methodologies to estimate response variables from explanatory variables. Notable candidates are regression models such as partial least squares (PLS) and support vector regression (SVR), as well as just-in-time (JIT)-PLS, which sequentially and automatically update estimation models in response to changes in processes. Many candidate soft sensors are built with the combinations of these estimation models and explanatory variables to compare the accuracy of their estimates for evaluation.

(4) Implementation of the soft sensor

According to the evaluation results, users select a soft sensor that will achieve the target accuracy and implement it on the inferential PC provided in the on-line environment.

(5) Operation of the soft sensor

The process data to be used as explanatory variables is measured in real time and stored in the data server of the process control system. The inferential PC feeds the explanatory variables obtained from the data server of the control system into the soft sensor and writes the estimated outputs into the data server and pass it on to the control system.

(6) Redesign of the soft sensor

If the characteristics of the plant equipment changes over time due to the accumulation of scale (deposit) inside piping or other factors, it may cause a difference from the estimation model, and the estimation performance of the soft sensor may deteriorate. Redesign of the soft sensor is required before the deterioration of estimation performance exceeds the permissible level. Users can redesign the soft sensor by repeating the data collection, data preprocessing, and soft sensor design and evaluation processes.

3.3 Configuration of the soft sensor design tool

Figure 3 shows an example of a system configuration of the soft sensor design tool. This design tool is provided with a mechanism that standardizes and automates the series of designing steps described in Section 3.2. This tool consists of two software components, the off-line tool and on-line tool.

(1) Off-line tool

The off-line tool allows users to design a soft sensor.

The tool generates several condition-specific candidate estimation models using training data according to the conditions specified by users such as the data range (period) to be studied, the selection of candidate explanatory variables, the range of delay time, and the types and settings of candidate estimation models. By applying each candidate estimation model to the test data, the tool estimates response variables and calculates the root mean squared error (RMSE) and the determination coefficient R^2. The tool automatically performs these processes to compare values and select a estimation model (a soft sensor) that achieves the best performance. Text format files are generated to deploy to the on-line tool with response and explanatory variables, as well as for the selected model information.

Table 1 lists the functions of this off-line tool.

(2) On-line tool

The on-line tool allows users to operate a soft sensor in actual processes.

This tool estimates product quality values (response variables) from the explanatory variables sequentially loaded from the database of the plant's control system, using a estimation model based on the model information generated in the off-line tool. Thus, the tool can immediately operate the model selected by the off-line tool in an actual plant. The estimated

Table 1 List of functions of the off-line tool

No.	Description of function	Remarks
1	Loading of past data (explanatory variables, response variables)	–
2	Selection of samples (for training and testing)	–
3	Settings of fixed/selected variables, configuration of maximum delay	–
4	Variable selection, model building, and performance evaluation based on training data	–
5	Evaluation of estimation performance based on test data	RMSE*1, R^{2}*2
6	Calculation and enumeration of all selected variables and models as candidates for search	–
7	Output of model file	–

*1 RMSE: Root mean squared error
*2 R^2: Coefficient of determination

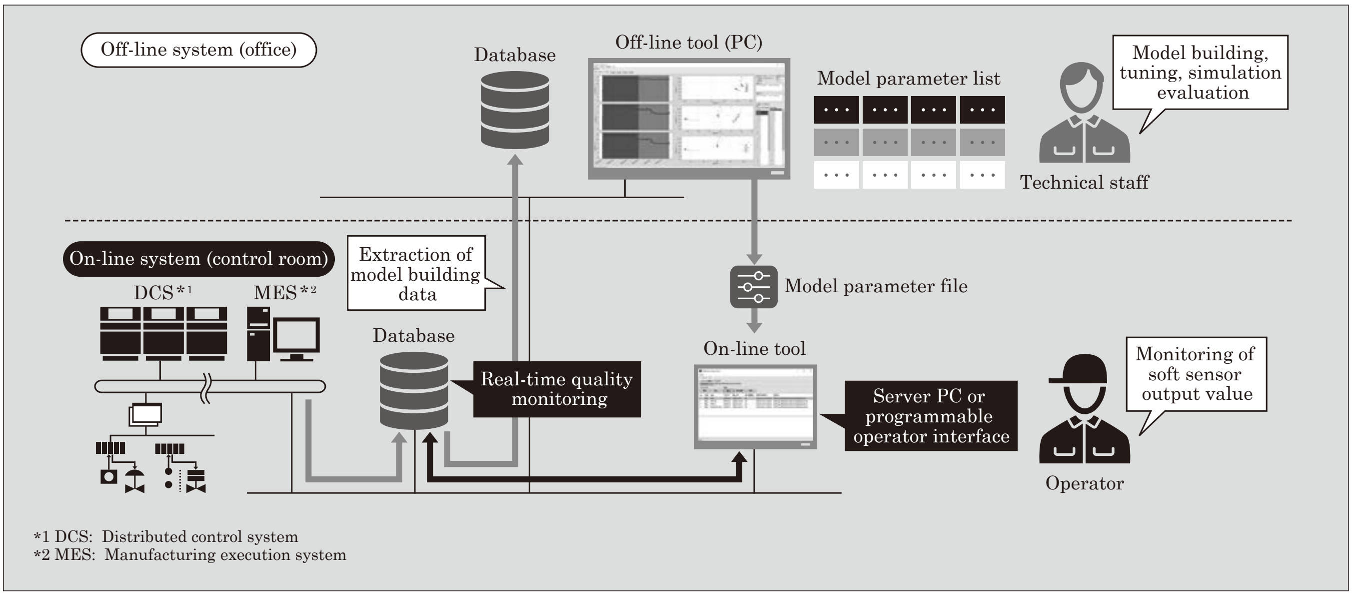

Fig.3 Example of a system configuration for the soft sensor design tool

Table 2 List of functions of the on-line tool

No.	Description of function	Remarks
1	Loading of model files	–
2	Starting and stopping estimation (by model)	Several models acceptable
3	Entry of historian data (instantaneous values)	Each cycle
4	Calculation and output of estimates according to historian data and model inference	Each cycle
5	Indication and storage of results	Each cycle

quality values are stored in the database of the plant's control system, allowing operators to check the values any time.

Table 2 lists the functions of the on-line tool.

Using these tools allows users to standardize a soft sensor development procedure without trial and error. Users can simply and quickly implement the steps from soft sensor development to operation, saving a significant number of engineering labor hours compared to manual implementation.

4. Application Example of the Soft Sensor Design Tool

4.1 Target process

To verify the effect of the soft sensor designed with the developed tool, we used the data generated with a vinyl acetate monomer (VAM) manufacturing process simulator[(1),(2)] developed at the Workshop No. 27 "Process Control Technology" at the 143rd Committee on Process Systems Engineering organized by the Japan Society for the Promotion of Science. Since this simulator has been developed to enable simulations in environments similar to those in actual plants, we can use it as a benchmark model for purposes such as quality estimation, as in this case, as well as control.

The VAM manufacturing process shown in Fig. 4 produces VAM as a product by subjecting ethylene (C_2H_4), acetic acid (CH_3COOH) and oxygen (O_2) that have been input as materials to processes such as reaction, gas-liquid separation and absorption, and then separating and refining them in a distillation column. Then, we estimate the response variable (in this case, the water concentration at the bottom of the distillation column) is estimated according to 49 explanatory variables for temperature, pressure and flow rate. If the water is returned to the reactor, stability will degrade. Since it is difficult to measure water concentration in real time, sampling measurement by means of manual analysis was common in the past.

4.2 Verification result

We carried out the steps from data preprocessing to evaluation of the estimation model using the data obtained from the VAM manufacturing process simulator described in Section 4.1. While explanatory variables are measured per minute in this data, response variables are measured once a day. As such, the data acquisition timing is differs. The newly developed tool can automatically identify and select explanatory variables that are acquired at the same time as response variables. To design an estimation model, we provided the estimation models of PLS, SVR and JIT-PLS with adjusted coefficients to obtain dozens of combinations of candidate estimation models. Figure 5 highlights how the soft sensor design tool reduces labor hours. By using this tool, we have reduced the time it takes to complete the processes up to evaluation of the estimation model to approximately a third of that of the manual trial-and-error method.

In this verification, the JIT-PLS was selected as best estimation model for the soft sensor. We compared its performance with that of the PLS-based soft sensor, which was the main model previously used based

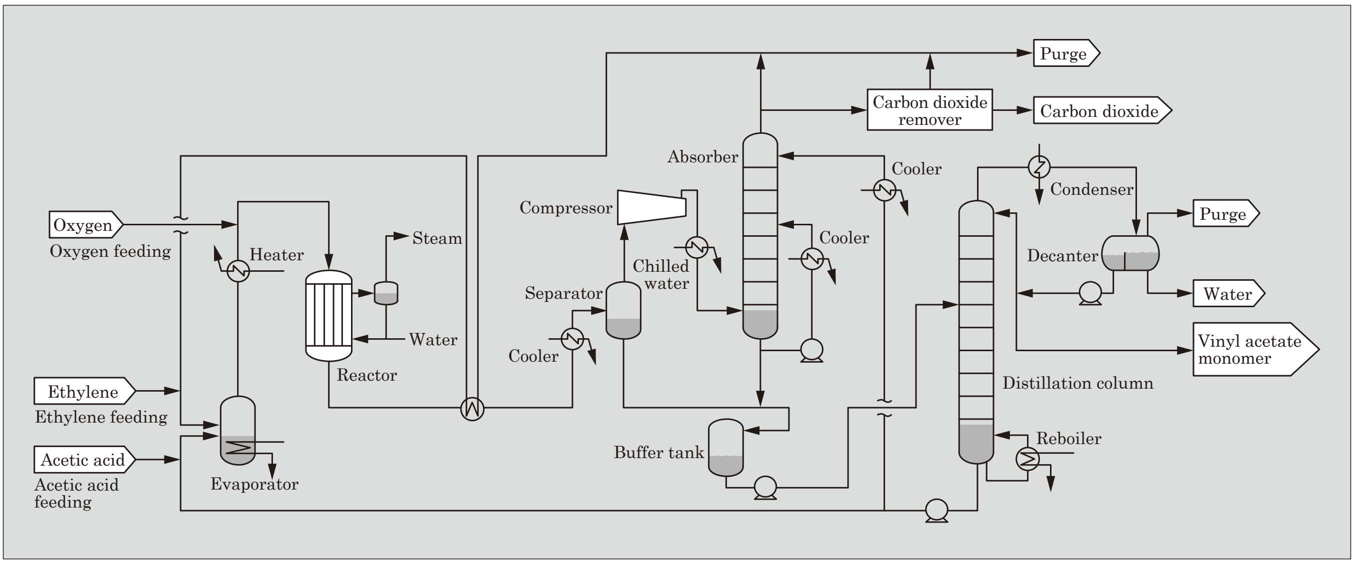

Fig.4 Vinyl acetate monomer (VAM) manufacturing process[(1)] (Translated by Fuji Electric)

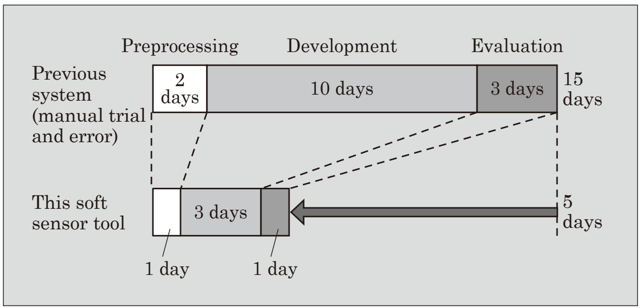

Fig.5 Breakdown of labor-hour reductions achieved by the soft sensor design tool

on manual construction. Figure 6 compares the optimization results from the use of the soft sensor design tool. The RMSE (estimated error) of the conventional method (PLS) was 0.46%, while that of the best result (JIT-PLS) was 0.26%; showing a higher accuracy for the soft sensor designed with this tool.

4.3 Cost reduction effect of the soft sensor

Using the VAM simulator described in Section 4.1, we estimated the improvement of the plant operation that would result when applying this soft sensor to the VAM manufacturing process. In the past, it was not possible to measure the water concentration at the bottom of the distillation column in real time. For this reason, the water concentration could not be controlled directly, and it took long time to stabilize the plant. Now, however, since the soft sensor enables its real time estimation, the water concentration in the reboiler at the bottom of the column can be directly controlled with the estimated value to achieve quick stabilization. As a result, the water concentration at the relevant area can be reduced in a stable manner, and in tandem, the amount of steam to be fed to the evaporator and reactor can also be reduced, along with the consumption rate of raw materials. With these improvements, a cost reduction equivalent to 8 million yen a year can be expected. In addition, there were no errors in the soft sensor estimates that would negatively affect the control of the abovementioned reboiler.

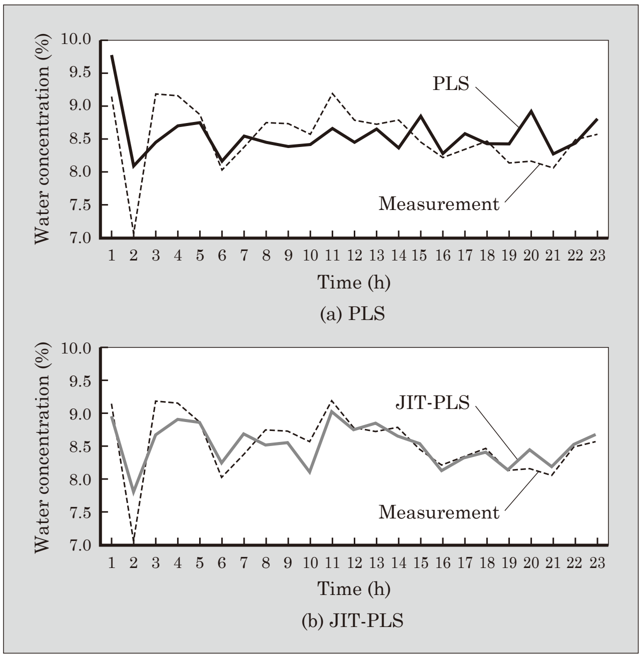

Fig.6 Example of optimization by the soft sensor design tool

5. Postscript

In this paper, we have described soft sensors that contribute to the optimization of plant operation. This technology allows us to easily introduce soft sensors into existing control systems. The technology will contribute to increased productivity in plants by optimizing control using the estimated output by the soft sensor to achieve stabilization of product quality, improved energy saving and safety, reduction of operator workload and environmental impact, and more. By synchronizing this technology with the plant information management system (PIMS) implemented in the Fuji Electric monitoring and control system “MICREX-VieW FOCUS Evolution,” seamless integration with the existing software of plant operation support can be achieved. Fuji Electric will contribute to the innovation of the plant operations of customers by expanding functions that support plant operation.

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Engineering Support Tool That Reduces Lead Time and Improves Quality, Accelerating DX

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ABSTRACT

Conventionally, engineering work involved in new construction, expansion, and renewal of plants and facilities required a considerable amount of manual work. This resulted in significant variations in lead time and quality. The engineering support tool "HEART" accelerates DX by supporting the innovation in engineering operations, work flows, and business processes through automation and the use of data and digital technologies. It contributes to reducing lead time and improving quality by efficiently creating function specifications and project completion documents and automating the generation of control programs, the visualization of changes in various specifications and drawings, and the recording of test results in the control function specifications.

1. Introduction

Work patterns are rapidly changing as a result of the acceleration of globalization and the recent rise in worker diversity, work style reform, improvements to working environments, remote work, and other changes. Under these circumstances, there is an increasing need for digital transformation (DX) to provide new value to customers and improve corporate profits.

The engineering lead time and quality of monitoring and control systems in the construction, expansion, and renewal of plants and facilities are highly dependent on the skills and experience of engineers.

Accelerated globalization has led to an increase in the diversity of engineers, and the retirement of experienced workers in Japan has led to an increase in the proportion of engineers without extensive experience or advanced skills, reducing the efficiency and quality of engineering operations. In the past, it was necessary to spend a lot of work hours on various types of manual work, such as creating customer requirements specifications into control function specifications, turning function specifications into software, comparing and clarifying changes, and reflecting internal and on-site test results in the specifications, which caused large fluctuations in lead time and quality.

To solve these problems, engineering operations must be transformed. Provided by Fuji Electric, the engineering support tool "HEART" uses digital technology to transform a series of engineering operations, including specification compilation, design, manufacturing, internal testing, on-site testing, and technical drawing follow-ups, as well as operation flows and operation processes.

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2. Problems in Previous Engineering Operations

From the confirmation of requirements to follow-ups on on-site test results, many people were involved in conventional engineering operations, resulting in the following problems:

(1) During creation of control function specifications

Engineers create control function specifications based on the requirements specifications created by the customers. This procedure required them to create new symbols used in figures, tables, and control function specifications and convert them into PDF or image files and paste them.

In many requirements specifications, control logic is omitted to the extent that the outlined functions can still be understood, or the same processes are expressed in table format. On the other hand, control function specifications contained detailed logic diagrams that accurately represent functions and actions. For this reason, even though the logic was correct, the control contents were difficult to understand when viewed by anyone other than the author.

(2) During the design of control programs

After creating control function specifications and having them verified by the customer, the control program design phase begins. For the creation of control programs, dedicated loaders that were different for each controller model were used. To design a control program from the contents of the control function specifications, it was necessary to have advanced skills and experience, such as knowledge of controller programming and dedicated loaders. Furthermore, the large amount of work involving human intervention gave rise to discrepancies in how specifications were interpreted, as well as oversights.

(3) When changes are occured

Previously, when changes are occured in the addresses of the input and output signals of various devices used for control or monitoring, or in the tags treated as identifiers, it was necessary to manually locate the control function specifications and the places where the tags and addresses are used in the control program, and to manually change both. In addition, it is necessary to clearly indicate the changed portions of the control function specifications and the control program so that they can be noticed by those other than the author. In the past, modified pages were printed, and changes were indicated by hand using revision clouds or other markings so that they could be noticed. As such, it took time to extract the changed portions and write symbols indicating changes, and in addition, there were at times oversights in the indication of changes.

(4) During testing

To write test results in control function specifications and test reports, it was necessary to copy them by hand while looking at the test data, and mistakes in writing sometimes occurred.

(5) During reflecting results to project completion documents

Changes in specifications and in the circuits of control programs often occur when on-site tests and adjustments are conducted at customer plants and facilities. Upon completion of on-site testing and adjustments, the test results need to be reflected in the control function specifications. However, the field engineers often only modified the control programs and neglected to revise the control function specifications. For this reason, the control function specifications needed to be reverse-engineered from the control programs. The discrepancy between the control function specifications and the control programs was a factor that led to a deterioration of quality in the revisions and updates that followed.

3. Transforming Engineering Process with the Engineering Support Tool "HEART"

3.1 Streamlined creation of control function specifications

(1) Creation of control function specification from requirements specifications

The requirements specifications that compile the needs of end users are usually prepared with general OA software[1], such as Microsoft Office*1, Excel*2 and Visio*3. Engineers need to take detailed and concrete control specifications that meet the needs indicated in the requirements and create them into control function specification documents. Here, based on the electronic files of the requirements specifications provided by the customer, the engineer can efficiently create control function specifications by adding control circuits using the many symbols provided by HEART. Because it utilizes familiar OA software, it is very easy for engineers to adopt.

(2) Clarification of control function specifications

HEART provides functions to express complex processes in control function specifications in a simplified manner using symbols, as well as to express the same processes compiled in the form of a table. Figure 1 shows the clarification of control function specifications. These functions make it possible to create simple, no wasted, and to-the-point control function specifications and to make the documents easier to understand.

3.2 Automatic generation of control programs

HEART provides a function to automatically generate control programs[1], which eliminates the need to manually create control programs from control function specifications. It enhances the reliability of control programs by eliminating omissions and errors in creation, which are inevitable in manual work, as well as through the constant logical alignment of control function specifications with the control programs. In addition, it supports many types of controllers, eliminating the need to program using a dedicated loader according to the type of controller, enabling engineering with familiar OA software.

Figure 2 shows a comparison of ways of engineering to create control function specifications into control programs.

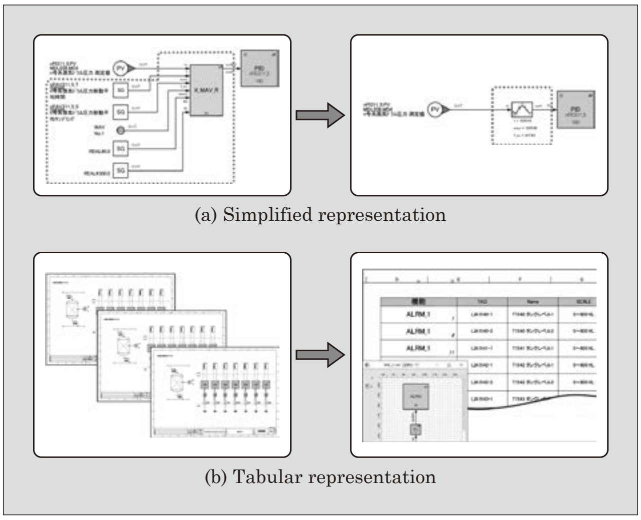

Fig.1 Clarification of control function specifications

*1 Office is a trademark or registered trademark of Microsoft Corporation

*2 Excel is a trademark or registered trademark of Microsoft Corporation

*3 Visio is a trademark or registered trademark of Microsoft Corporation

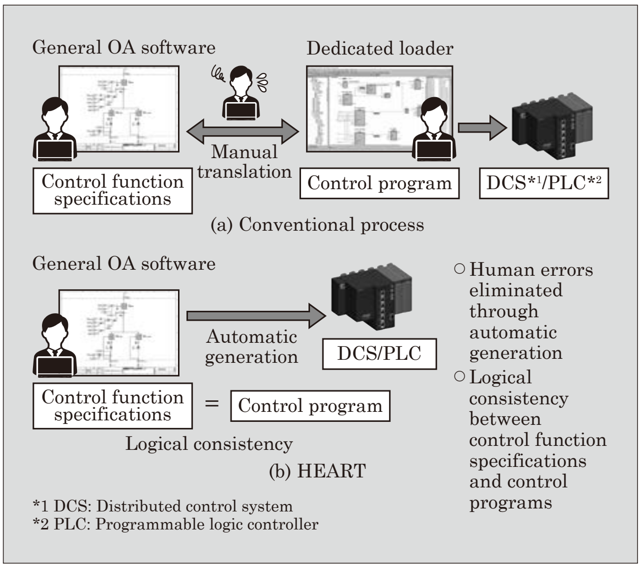

Fig.2 Comparison of ways of engineering to create control function specifications into control programs

3.3 Detection and automatic application to affected areas during design and modification

When changes to tags are made in control function specifications, HEART is able to automatically detect the affected areas and list the points that need to be modified. By double-clicking a point on the list detected by HEART, you can jump to the corresponding page of the control function specifications and apply the tag change with a single action. The list will continue to be displayed until the user decides whether to implement or reject the changes, allowing them to avoid omitting changes or entering the wrong tags. It also automatically detects discrepancies in placement, such as overlapping tags or missing control instructions to the output signal, and displays them in the list. Figure 3 illustrates the ease with which specification changes can be made with HEART.

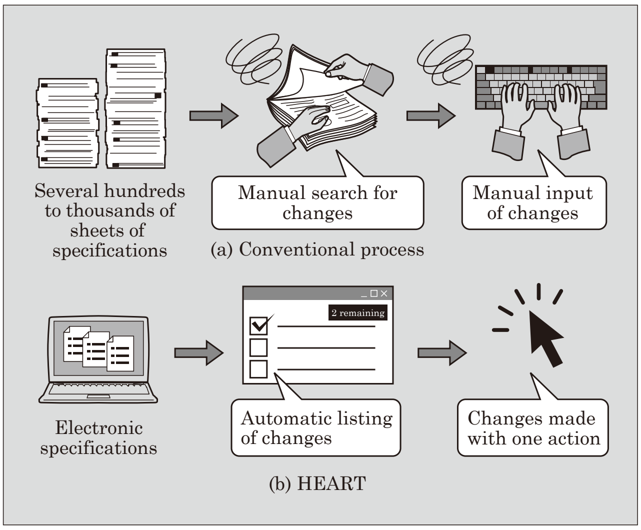

Fig.3 Ease of making changes to specifications using "HEART"

3.4 Automatic visualization of changed portions in various specifications and drawings

There are hundreds to thousands of specification documents per project. Revisions are made as needed through specification meetings and design reviews, then shared with customers and those in charge of the next process. Engineers need to determine the extent of direct and indirect impacts on the plant from changes made as a result of the revisions. As such, an accurate representation of the changed portions is required.

HEART provides a function to digitize handwritten changed portion marks to visualize the affected areas[2]. Figure 4 shows an overview of the automatic changed portions visualization process.

The main features are as follows:

(1) Extraction of page layout-independent changes

Figure 5 illustrates how changes are extracted independently of the layout within the page. When revising specification documents, specifications are added or deleted. These changes often cause the positions of subsequent specifications to change. If an

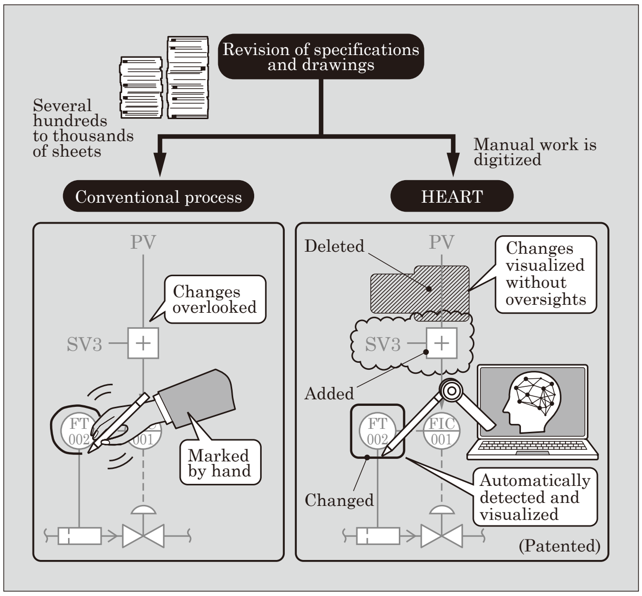

Fig.4 Overview of automatic visualization of changed portions

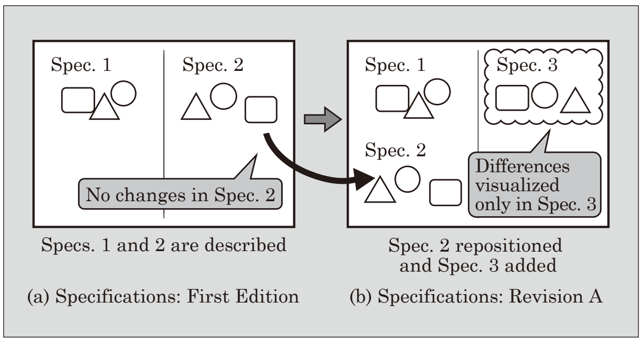

Fig.5 Extraction of page layout-independent changes

image recognition technique is used according to the layout within the page when extracting changes, unchanged specifications are also extracted. To solve this problem, this tool turns the characters, graphic elements, and software elements that comprise the specifications into a database and applies an original algorithm that is independent of the layout within the page to accurately identify changes such as additions, modifications and deletions. For example, even if "Spec. 3" is added to Fig. 5(a) by repositioning "Spec. 2" as shown in Fig. 5 (b), only "Spec 3" will be displayed as a change.

(2) Easy-to-see marking of changes

Figure 6 shows the easy-to-see marking of changes. As shown in Fig. 6(a), when changes are displayed in a detailed manner on the specifications, they may not be easy to see, causing a reduction in readability. To solve this problem, an algorithm for classifying changes and determining visual overlap is applied, resulting in easy-to-see views. As shown in Fig. 6 (b), when multiple changes of the same classification overlap, the markings can be automatically combined. This function eliminates the need for manual entry of revision clouds, ensures that there are no oversights, and enables accurate communication of changes to other people. Greater accuracy in the visualization of changes provides useful information to ensure that design verification in engineering work and testing of subsequent processes are carried out reliably.

3.5 Automatic recording of test results in control function specifications

By adding input and output results of test data and evaluation fields, control function specifications prepared using HEART can also be used as test procedures and reports. Figure 7 shows the use of test procedures and reports for monitoring. During testing, values processed by the controller and setting values can be monitored on the specifications[1], and results can also be automatically evaluated. Through automatic recording, it is possible to prevent testing oversights and falsification of results, thereby ensuring reliability as evidence. In addition, this tool supports the automatic conversion of specification modifications and additions that occur during testing into control programs by modifying the control function specifications, allowing the user to efficiently retest and record results simply by monitoring the modified specifications again.

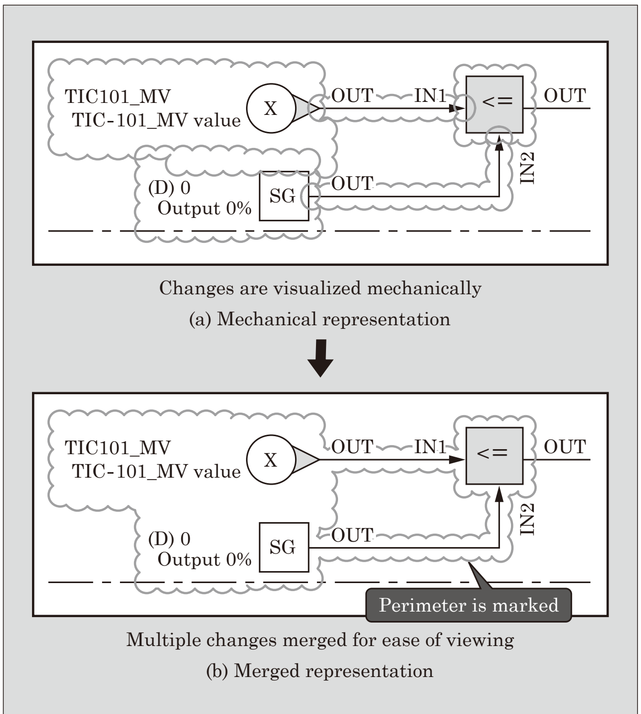

Fig.6 Easy-to-see marking of changes

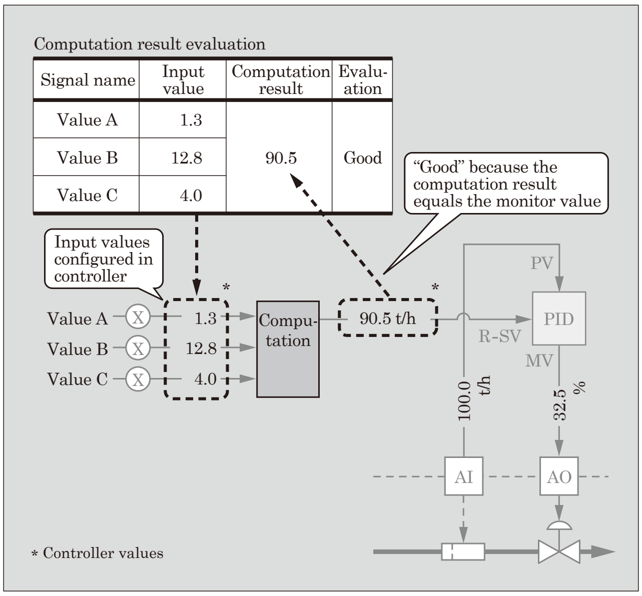

Fig.7 Test procedure and reports using monitor function

3.6 Labor saving in reflecting results to project completion documents

Figure 8 shows the reverse engineering process

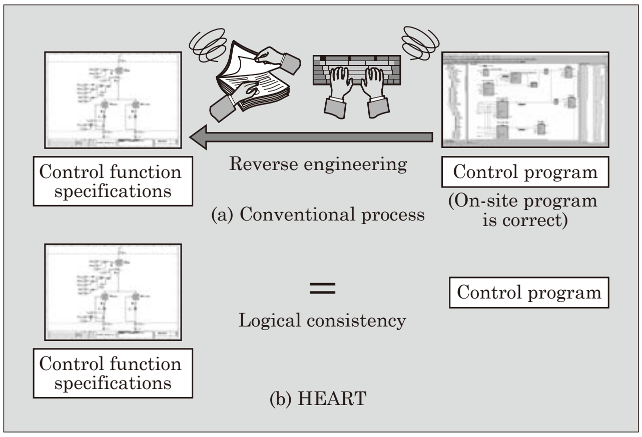

Fig.8 Reverse engineering for reflecting results to project completion documents

in reflecting results to project completion documents. HEART automatically generates control programs from control function specifications, eliminating the need for reverse engineering and reducing the amount of labor required for the preparation of project completion documents. When performing engineering work on HEART, changes made due to mechanical or external factors that could not be assumed before shipment are always reflected in the control function specifications. For example, even if the system is to be revised in a few years, problems such as inconsistency between the control function specifications and the control programs will not occur.

4. Postscript

This paper has described a support tool that reduces engineering lead time and improves quality, accelerating DX.

To further promote DX in engineering going forward, we intend to provide optimal value to our customers while responding quickly to the changing times and user requirements, such as by adding cloud and multi-engineering capabilities to engineering support tools.

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Manufacturing Execution Systems Encouraging DX on the Manufacturing Floor

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ABSTRACT

In recent years, the manufacturing industry has been accelerating the introduction of manufacturing execution systems (MES) to improve the efficiency of manufacturing processes and enhance productivity and quality through DX. MES can be interfaced with various systems to help improve product traceability and to quickly detect and solve problems in production processes. Fuji Electric has developed a MES that can be used for various applications such as food manufacturing by digitally twinning manufacturing floors as information models and systematically managing them. The MES can share information models among model users, use information identifiers, and link manufacturing information models with quality management information, allowing it to contribute to high productivity and quality.

1. Introduction

Digital Transformation (DX) refers to initiatives to drive the improvement of business processes and innovation by making advancements in information technology. In the manufacturing industry, DX is expected to make manufacturing processes more efficient and improve productivity and quality.

Among such initiatives, the adoption of manufacturing execution systems (MES) plays an essential role in DX. MESs are systems that collect and analyze data, as well as control and monitor production lines on the manufacturing floor. They are useful for increasing productivity and carrying out quality control and inventory management. For example, they can optimize the availability of production lines to increase production volume. In addition, an MES works with the core enterprise resource planning (ERP) system to enable visualization of not only the manufacturing floor but also entire supply chain, as well as data sharing and analysis. This improves the traceability of products and allows problems in the production process to be detected and solved at an early stage.

This paper describes manufacturing execution systems that contribute to DX on the manufacturing floor.

2. Overview of Manufacturing Execution Systems

2.1 What are manufacturing execution systems?

Manufacturing execution systems are information systems used to understand and control the manufacturing process, as well as to instruct and support workers. They are used in conjunction with each manufacturing process on the factory production line. The main functions include the 11 types[(1)] defined in the MESA-11 (Manufacturing Enterprise Solutions Association) model, such as work instruction management, shipment management, quality management, and maintenance management. This allows manufacturers to implement the necessary functions according to the line of business and purpose to which they are applying the system.

The applicable manufacturing industries can be

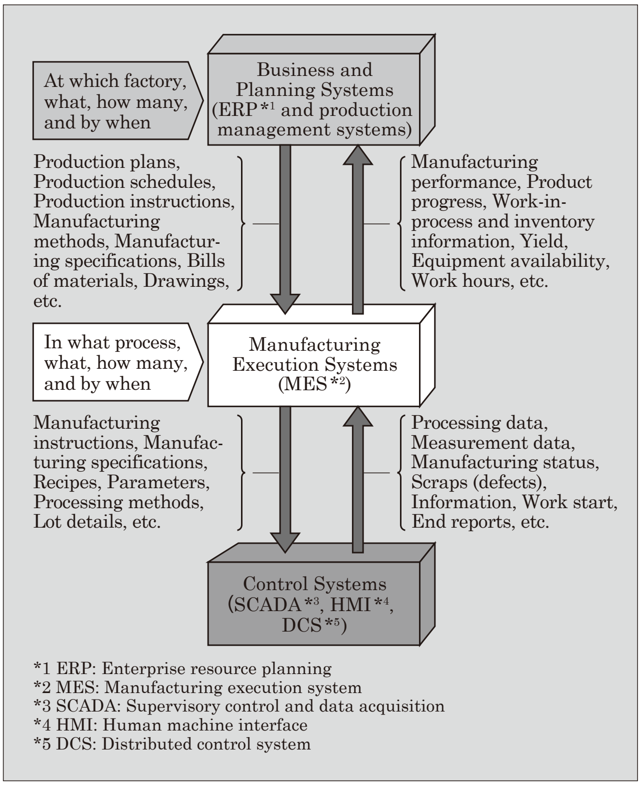

Fig.1 Roles and positioning of the MES

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

roughly divided into two categories according to how the products are made: discrete manufacturing, in which raw materials and parts are processed and assembled into products, and process manufacturing, in which raw materials are sequentially input into manufacturing plants and other facilities. For example, the manufacture of automobiles, machines, and their parts falls under the discrete manufacturing category, while the manufacture of materials, food, and pharmaceuticals falls in the process manufacturing category. Fuji Electric offers two types of MES package solutions tailored to the characteristics of each category.

Figure 1 shows the roles and positioning of the MES. At the top are the ERP and production management systems, and at the bottom are control systems such as distributed control systems (DCSs) and programmable logic controllers (PLCs), which are used to manage manufacturing equipment. MES interconnects the data of the top systems and the bottom systems.

At Fuji Electric, we believe that the starting point of the manufacturing industry lies in the manufacturing activities performed at the worksite. As such, the MES is positioned to function as a bridge between the worksite and management.

2.2 Fuji Electric's manufacturing execution system

Fuji Electric has provided the "MainGATE Series" MES packages shown in Fig. 2 to a variety of customers in the food, chemical, and pharmaceutical industries, thereby contributing to the improvement of customer productivity and quality. Fuji Electric has also provided vertically integrated solutions by achieving seamless synchronization with its DCSs and PLCs.

The following products are available according to the function.

- ○MainGATE/PO: Production order deployment, production orders
- ○MainGATE/EM: Manufacturing event management, manufacturing progress monitoring
- ○MainGATE/IM: Master management
- ○MainGATE/PPA: Manufacturing performance management, traceability
- ○MainGATE/MSPC: Quality trend management

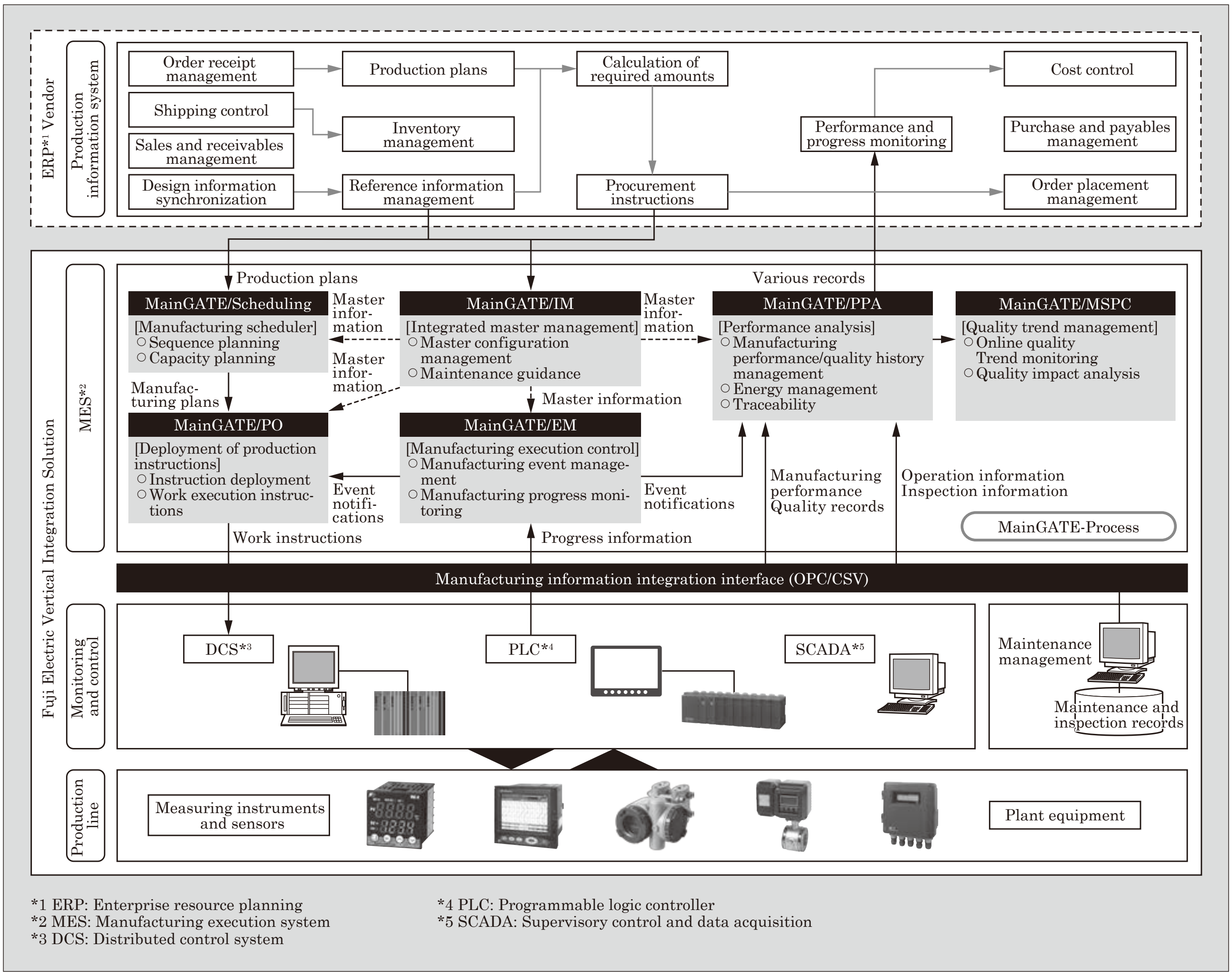

Fig.2 "MainGATE Series"

They include the following features.

(a) Provision of modules for each MES function
(b) Ability to systematically expand functions, including by partially introducing or switching functions, while maintaining data consistency
(c) Provision of high-efficiency engineering tools
(d) Easy follow-up for additional manufacturing items, changes in work procedures, addition of equipment, etc.
(e) Free extraction of data according to purpose of use

The most important feature is the availability of engineering tools. We built a flexible and versatile architecture for the engineering tools as the nature of manufacturing has been transitioning from low-mix, high-volume production to high-mix, low-volume production. Using the tools can make the change to the system in response to changes in procedures and the addition of control items in manufacturing equipment.

However, it has come to light that the current packages need to be improved in the following areas.

The database structure of the current packages use the lot number and the batch number as keys. It does not support data that is not linked to these keys, such as inventory.

In addition, raw material management and other work support functions that are positioned a level below on the management hierarchy were provided separately as add-on functions when requested individually by customers.

To utilize the accumulated data for various needs, such as operation, quality, and maintenance, employing highly flexible data structure is eligible, increasing the demand for the adoption of open architectures that facilitate data linkage. The current packages do not specifically support data management with a focus on equipment. Instead, each of them separately handles data management from multiple perspectives, including equipment.

3. New Manufacturing Execution System

A new MES package is under development to meet new needs while retaining the features of the current packages. The engineering functions of the present systems are efficient because they are specific to the implemented functions. However, it is difficult to change the functions or use them for other purposes. This new system uses a digital twin of the manufacturing floor as an OPC UA information model*1. In this way, the necessary information can be systematically managed for various applications.

3.1 Information models and information objects

The new system expresses information in terms of “information models” and the “information objects” that they represent (see Fig. 3).

An information model refers to a basic model that

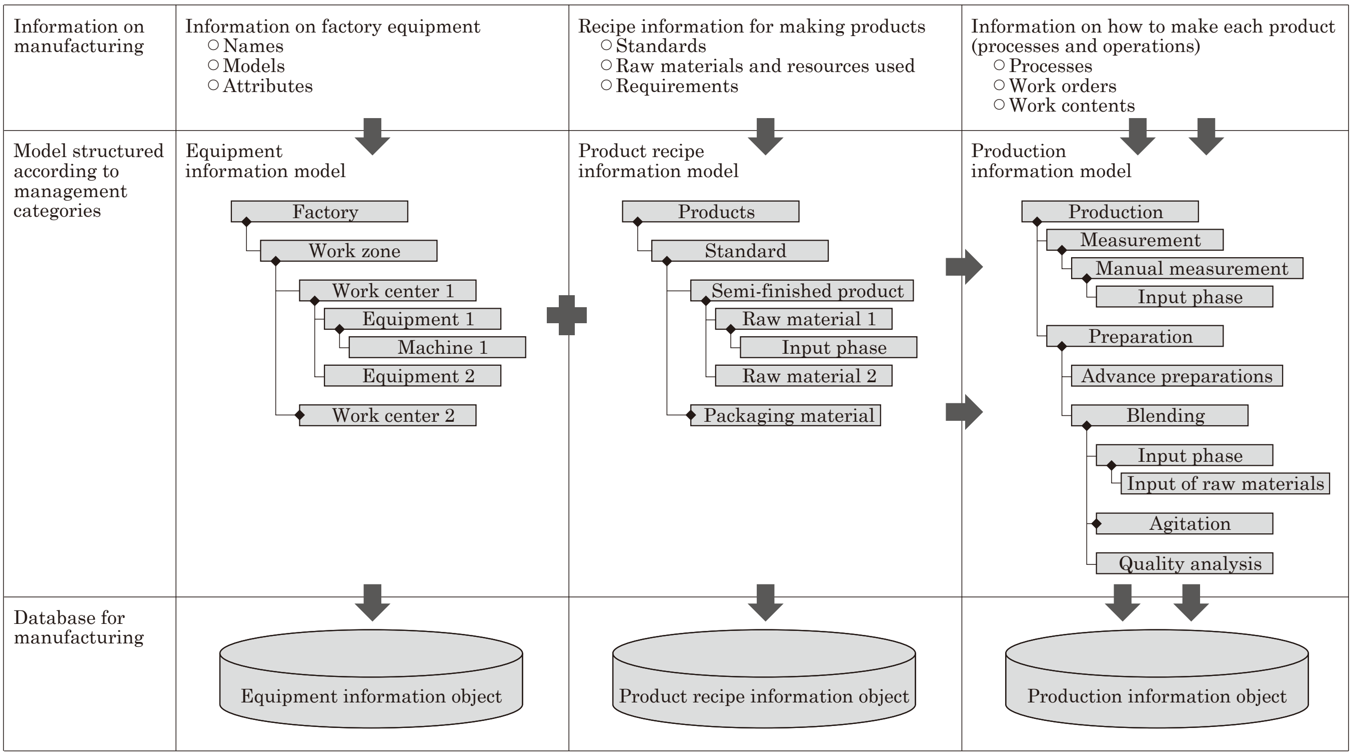

Fig.3 Overview of information models and information objects

*1 OPC UA is a trademark or registered trademark of OPC Foundation.

standardizes information. Information objects are tangible information related to equipment, products, and materials on the manufacturing floor that are represented by the information model.

By defining an information model, manufacturing standards for individual units such as companies and factories can also be defined, and manufacturing can be standardized that have been defined as individual work procedures for individual units such as factories and work zones. Standardization in manufacturing will facilitate management and improve production efficiency and quality.

Worksite information related to manufacturing execution can be classified into the following three types.

(1) Equipment information models and information objects

These are models that express the composition of production equipment segments on the manufacturing floor. They correspond to the "process segments" specified in ISA-95*[2]. To represent the physical configuration of the worksite, the structure is represented hierarchically. Generally, the hierarchy consists of the following seven hierarchical levels.

(a) Factories
Factories for producing products

(b) Work zones
Factory units divided according to function

(c) Work centers
Production control units into which work zones are further subdivided, used for issuing work orders

(d) Equipment types
Groups of equipment divided according to purpose of use

(e) Equipment
Equipment physically separated according to purpose of use

(f) Machinery
Units responsible for single control functions such as preparation, agitation or temperature control

(g) Instrumentation
Control of pumps, valves, flowmeters, and other instruments.

(2) Product recipe information models and information objects

These are models that represent the composition and attribute information of products, semi-finished products, and intermediate products, as well as a recipes (raw materials, packaging materials, and requirements) for production and quality control inspection items. These correspond to the "operation segments" specified in ISA-95. The structure for products is represented in the following hierarchy.

(a) Products
Mainly used in industry; refers to finished products resulting from the processing of raw materials

(b) Semi-finished products
Intermediate products that have not undergone all the steps necessary for completion. Semi-finished products are those that can be sold or at least stored outside of the process after undergoing certain processing.

(c) Intermediate products
Refers to products in intermediate manufacturing processes. Products at this stage are subject to sampling inspection to be checked for problems, and if no problems are found, the subsequent process is started. These are sometimes called intermediate manufacturing products. Intermediate products are half-finished products that will become completed products after undergoing the subsequent manufacturing processes.

(d) By-products
Products (recovered goods) necessarily obtained as a result of the processes used to produce something.

(e) Packing materials
Materials used in packaging. These materials include paper, plastic film, wooden boxes, and cardboard boxes.

(f) Raw materials
The basic materials used to manufacture and process products.

(3) Production information models and information objects

Production information models are generally structured according to the ISA-88*[3] procedure control model. Each piece of production procedure information in a production information model contains managed data related to manufacturing, such as instruction values, results values, and measurement values.

Since quality inspection is also one of the production procedures, quality inspection results are also managed in conjunction with the production information model.

3.2 Effects of information model application

(1) Advancing quality control efficiency

For products made in factories, quality control is indispensable. Many factories have quality checklists that are prepared and used manually. This new system uses production information models to manage not only production performance and measurement values but also quality inspection results together with production procedures. In this manner, it enables the required checklists to be easily prepared by simply ar-

*2 ISA-95 is a collection of standards for information systems related to the manufacture of goods specified by the ISA (International Society of Automation for automated equipment).

*3 ISA-88 is the international standard for batch processing, which suggests models for batch processing (including processes, equipment, control, and management).

ranging data for quality control.

(2) Utilization of accumulated data

(a) Utilization of information objects

The new system accumulates information about production processes in a form that is linked to each information object. As such, information can be obtained by accessing information at the necessary hierarchical level. When equipment is the focus, the information can be accessed through equipment information objects. Likewise, when raw materials are the focus, information can be accessed through product recipe information objects, and when production is the focus, information can be accessed through production information objects. As a result, necessary information can easily be synchronized between users who share information models, and the data can be utilized for operations such as analysis and evaluation of information.

(b) Use of information identifiers

Information models manage the state of the worksite in a hierarchical structure so that the necessary information can be accessed by tracing the hierarchy. However, when acquiring the production results of equipment used for the production of multiple products, the information models alone are not efficient because it is necessary to trace the production information model of each product one by one. To handle such applications, all information items should be assigned information identifiers. In doing so, the necessary information can be directly accessed by using the acquired information identifier as a key.

4. Postscript

This paper has described a manufacturing execution system that contributes to DX on the manufacturing floor.

Going forward, we will use information models to design systems that link together not only Fuji Electric products but also machinery and equipment made by other manufacturers in order to provide customers with solutions that implement our concept of connected factories, which we have adopted in our own operations. In doing so, we will continue to contribute to the improvement of the productivity and quality of the manufacturing operations of our customers.

References

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Motion Controller Contributing to Automation of Factory Equipment

KUBOSUMI, Hajime*

ABSTRACT

Motion controllers are being increasingly required to increase the speed and precision of industrial machinery and equipment and improve the efficiency of equipment design, debugging, and start-up. To meet these customer needs, we have developed the "MICREX-SX Series" CPU module. By executing sequence control and motion control in parallel, this module can improve application execution performance by a factor of four compared with conventional products. It also supports EtherCAT, which is becoming increasingly popular as an open network, to enable faster and more accurate machines. In addition, it can utilize motion control FBs and logging functions to dramatically improve program development, debugging efficiency, and system reliability.

1. Introduction

Motion controllers are used to control the motion of industrial robots and other industrial machinery and equipment, thereby contributing to the automation of factory equipment. The handling of complex operations and machining, reduced process time, and improved precision are sought in industrial machinery and equipment. As such, motion controllers are required to have a level of performance that allows them to control a greater number of control axes at higher speeds. In addition, there is increasing demand from customers for the ability to select control system components with the best performance and price from among multiple manufacturers, resulting in the rapid popularization of EtherCAT*1 as an open network capable of realizing such system configurations. Furthermore, there is demand for a logging function for obtaining and visualizing control information to improve the efficiency of equipment design, debugging, and start of production; to determine the cause of failures; and to shorten response times.

In response to these market demands, Fuji Electric has developed new CPU modules for the "MICREX-SX Series" of integrated controllers for control, operation and monitoring. One of these is the "SPH5000M," which is compatible with the "E-SX bus," which realizes fast and highly accurate control performance. The other is the "SPH5000EC," which is compatible with EtherCAT and logging functions. This paper describes the SPH5000EC.

*1 EtherCAT is a trademark or registered trademark of Beckhoff Automation GmbH

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

2. Features of the "SPH5000EC"

When the EtherCAT-compatible SPH5000EC is used as a motion controller, motion control programs can be executed four times faster than when using the conventional product, the "SPH3000D."

Figure 1 shows an example of a motion control system configuration that uses the SPH5000EC, Fig. 2 shows an example of coordinated high-speed control via an enhanced processor bus, and Table 1 shows the main features of the SPH5000EC. In addition, Fig. 3

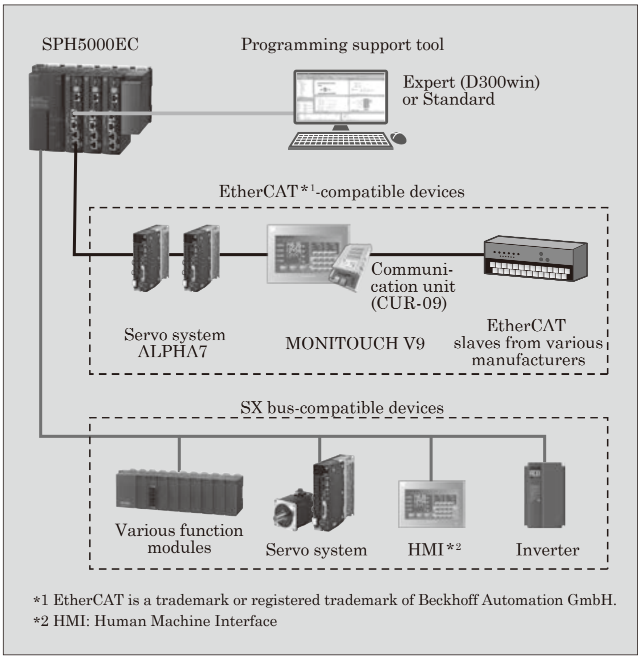

Fig.1 Example of a motion control system configuration that uses the "SPH5000EC"

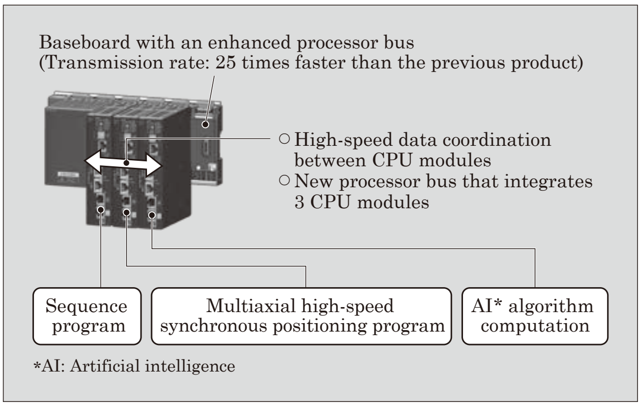

Fig.2 Example of coordinated high-speed control via an enhanced processor bus

Table 1 Main features of the “SPH5000EC”

Feature	Details
Application execution performance	Multi-core microcomputer achieving 4 times the speed of the previous model, the SPH3000D
Large capacity memory	Program memory: 512 Ksteps Data memory: 5,120 Kwords
Data backup	Maintenance-free battery with battery-less data backup method
Information network	Gigabit Ethernet*1 high-speed communications
Motion network	Support for EtherCAT*2
Data transmission between multiple CPUs	Enhanced processor bus achieving 25 times the transmission rate of the previous product Parallel execution of 3 SPH5000EC units for high-speed control
Logging function	Data collected inside the controller without affecting control, stored on an SD card, and displayed and replicated on a PC (Supported formats: NP1PA1C-256E, NP1PA1C-512E)

*1 Ethernet is a trademark or registered trademark of FUJIFILM Business Innovation Corporation
*2 EtherCAT is a trademark or registered trademark of Beckhoff Automation GmbH

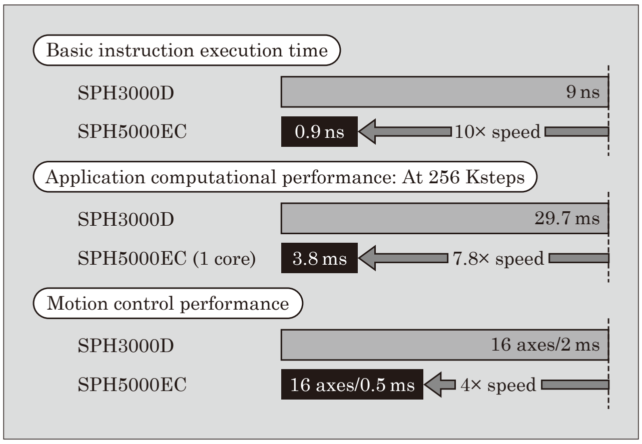

Fig. 3 Application execution performance comparison

compares its application execution performance with that of the SPH3000D.

3. Technology to Support Increased Speed and Reduction of System Construction Cost

3.1 EtherCAT communication technology

With the SPH5000EC, an open network can be configured by installing an EtherCAT communication port with high-speed and real-time performance on the front of the module.

Figure 4 shows the configuration of an EtherCAT system. As an EtherCAT master, the SPH5000EC can connect to various EtherCAT slaves, allowing a flexible system to be constructed by combining up to 238 slave devices to meet customer requirements. Such devices include Fuji Electric’s “ALPHA7” servo system and “MONITOUCH V9” programmable display, as well as equipment made by other manufacturers.

In addition, when combined with a baseboard equipped with an enhanced processor bus, up to three SPH5000EC units can operate in synchronization with the control cycle.

For example, multi-axis motion control is possible for a maximum of 48 axes when the control cycle is set to a minimum of 0.5 ms (using three SPH5000EC units with 16 axes per EtherCAT line) and for a maximum of 192 axes (using three SPH5000ECs with 64 axes per EtherCAT line) when the control cycle is set to 2 ms.

In addition, as shown in Fig. 5, the SPH5000EC supports the EtherCAT Hot Connect function and is capable of connecting and disconnecting slaves while operating as the EtherCAT master. Since the configuration can include unconnected slaves at the end or in the middle of the network, the system configuration can be a mixture of required slaves and optionally added slaves.

Accordingly, we have developed an EtherCAT configurator that can be used to efficiently configure a flexible system.

As shown in Fig. 6, the EtherCAT network can be configured by launching the EtherCAT configurator from the “Expert (D300win)” programming support tool. Batch management of EtherCAT master and slave configurations can be performed in tree view by

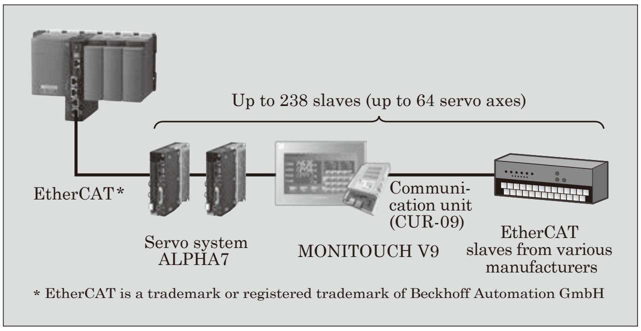

Fig.4 EtherCAT system configuration

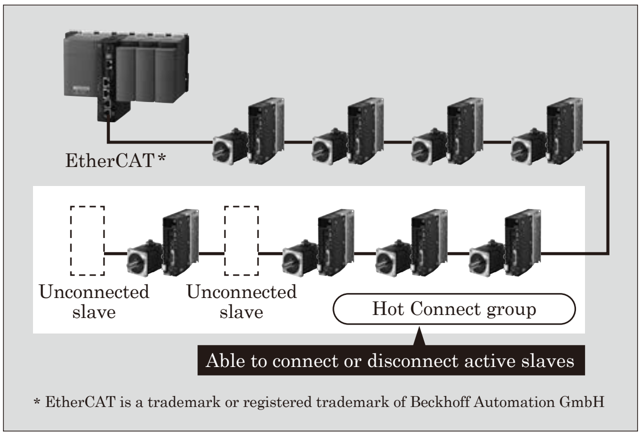

Fig.5 Hot Connect function

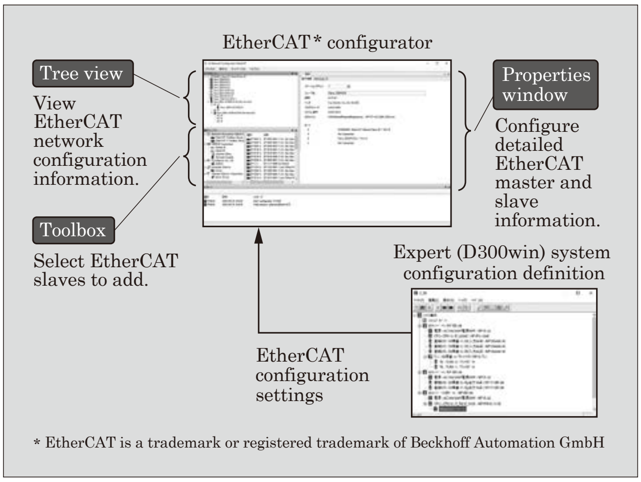

Fig.6 EtherCAT configurator

using simple operations, and the combined use of the Expert (D300win) and the EtherCAT configurator enables the configuration of flexible systems that include original Fuji Electric networks, such as SX bus, E-SX bus and T-Link.

3.2 Various motion control libraries

In addition to Fuji Electric's original motion control function blocks (FBs), we developed motion control FBs that conform to PLCopen[*2] specifications as functional software that reduces the system construction cost borne by the user.

With Fuji Electric's original motion control FBs, various motion controls such as point to point (PTP) positioning, linear interpolation, arc interpolation, interrupt positioning, and synchronous operation can be easily realized. Furthermore, the motion control FBs

*2 PLCopen is a third-party organization that promotes the international IEC 61131-3 standard for PLC programming and formulates the specifications of and certifies standardized function blocks independent of vendors. It is also a trademark or registered trademark of the PLCopen association.

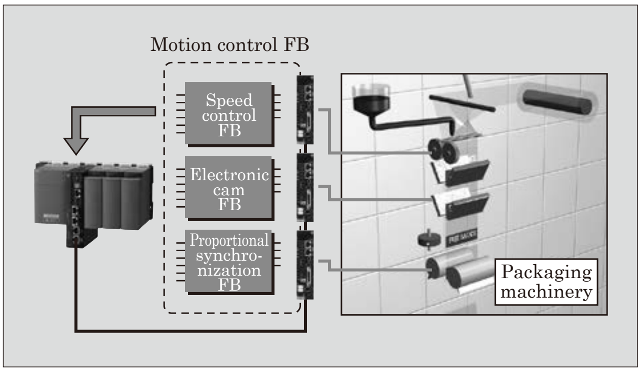

Fig.7 Example application of motion control FBs

that conform to PLCopen specifications enable the reduction of hardware dependency and improve the reusability of user programs. They can also reduce training and support costs.

By combining these various FBs, users can construct motion programs for large-scale systems in a short amount of time and freely configure functions required by the machine for each axis. Figure 7 shows an example of the application of motion control FBs. The reuse of FBs can dramatically improve program development efficiency, debugging efficiency and system reliability.

3.3 User data logging technology

We have equipped the CPU module of the SPH5000EC with a newly developed logging function. By using the logging function, it is possible to store any user data in the CPU module at any time without affecting the scan time of the application.

By using the simultaneously developed user program and waveform display tools, it becomes possible to visualize saved chronological user data on the waveform or program monitor, and use it for user program debugging and analysis of failure causes.

Figure 8 illustrates the collection modes of the user data logging function. SPH5000EC has a trigger mode and a trace mode for logging user data.

In trigger mode, user data before and after a trigger condition specified by the user can be collected for a specified number of samples and stored on the SD card. This mode is useful for understanding the behavior of the application before and after an error terminal of an FB or another component is turned on, or to store the quality information before and after each manufacturing cycle.

On the other hand, in trace mode, user data can be continuously collected at any time specified by the user and stored on the SD card for each fixed size specified by the user. This mode enables the user to learn about the quality characteristics and other characteristics from changes in data that is continuously collected at fixed times.

Figure 9 shows the SX monitor and waveform monitor integration function. All of the application data

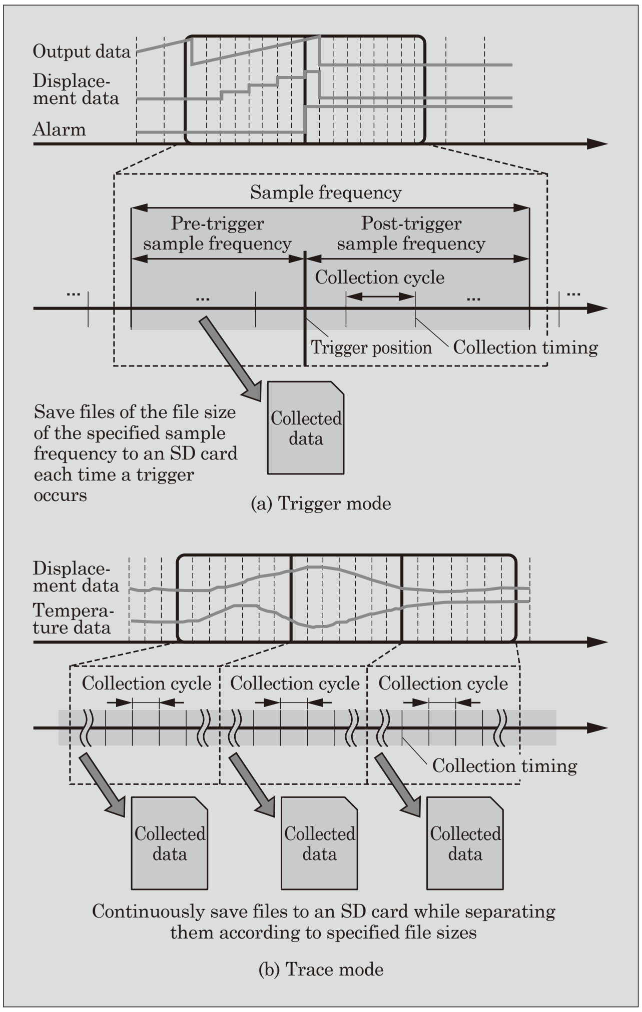

Fig.8 Collection modes of the user data logging function

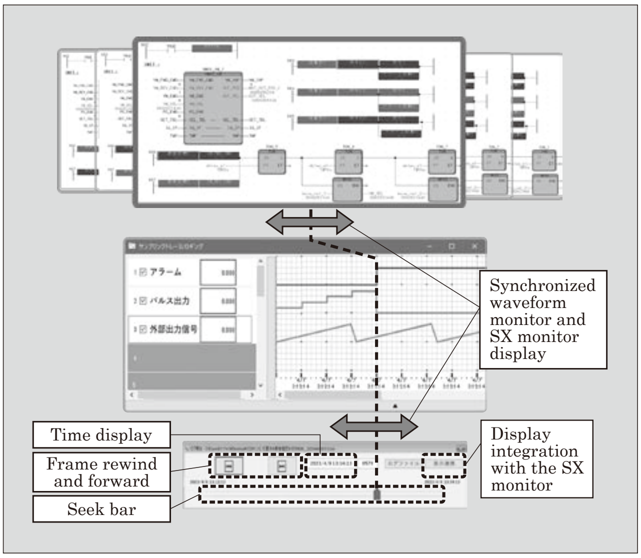

Fig.9 SX monitor and waveform monitor integration function

can be saved at each scan, and the SX and waveform monitors can be used in combination to replicate the behavior of the application from the user's desk. By integrating the display of the SX monitor with that of

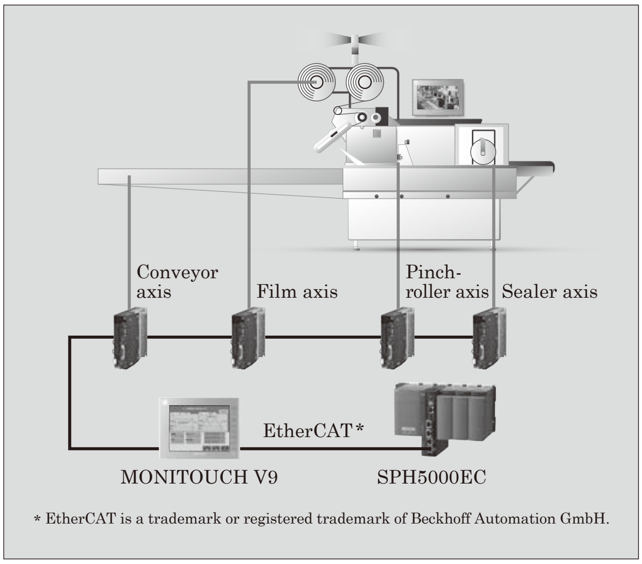

Fig.10 Example of a packaging machinery system that uses the "SPH5000EC"

the waveform monitor, and by making it possible to advance and reverse the frame, the behavior of the application can be debugged at every scan.

In addition, data can be continuously acquired at regular times such as daily, hourly, every minute, or every second, or at regular intervals that are integral multiples of the tact period, and it can be used to collect information on the operating status of the equipment and the production status.

4. Application Example

This chapter covers a case study of the application of the SPH5000EC to a packaging machinery system.

The packaging machinery system uses multiple sensors and actuators to perform sequence control and motion control. In particular, high-speed and high-precision motion control is required to improve productivity and quality.

In the previous packaging machinery system that used the SPH3000D, sequence control and motion control needed to be performed by one single-core microcomputer, making it difficult to achieve higher speeds.

The SPH5000EC has a system configuration that utilizes a multi-core computation execution engine. Figure 10 shows an example application of a packaging machinery system that uses the SPH5000EC.

This system performs sequence control with one computation execution engine and motion control with the other, thereby achieving integration of the sequence control and motion control functions of the previous configuration.

5. Postscript

This paper has described a motion controller that contributes to the automation of factory equipment.

The use of the “MICREX-SX SPH5000EC” for motion control applications improves the performance of sequence control and multi-axis high-speed synchronous control and further increases the speed and accuracy of machines, thereby improving production efficiency. Furthermore, by incorporating artificial intelligence (AI) algorithms such as multivariate statistical process control (MSPC), this controller can also be used for the diagnosis of defects in FA systems.

Going forward, we intend to expand the application of controllers to solve problems at manufacturing sites.

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Differential and Gauge Pressure Transmitters That Sophisticate Plant Monitoring and Control Systems

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ABSTRACT

Since its release in 1989, Fuji Electric's "FCX Series" of pressure transmitters have been used to monitor and control plants in various industries. The "FCX-A IV Series," the latest model developed to meet new needs, utilizes a capacitive pressure sensor to achieve high measurement accuracy and long-term stability, as well as fast response, high visibility, and better operability. Its unique structure allows this series to be used for hydrogen permeation resistance applications, and its use of optimal materials enables it to be utilized for corrosion resistance applications. Furthermore, the series uses piezo pressure sensors for applications that require ultra-high pressure resistance beyond the application range of capacitive pressure sensors.

1. Introduction

Since its release in 1989, Fuji Electric's "FCX Series" of pressure transmitters has been used to monitor and control plants in various industries, including chemicals, steel, waste treatment, oil and gas, while continuing to evolve in function and performance[1]. This paper describes the latest "FCX-A IV Series" of pressure transmitter models, which have been designed for greater reliability and ease of use to meet the new needs of customers.

2. Overview of the "FCX-AIV Series"

For the heart of the pressure detection unit, the FCX-A IV Series uses capacitive pressure sensors with an extensive track record, thereby achieving high measurement accuracy, while the optimized structure provides long term stability. In addition, the signal processing component has been enhanced to shorten the measurement cycle. A wealth of variations are available to support a wide range of applications. As an example, for fields requiring functional safety, the products have acquired Safety Integrity Level (SIL) 2 certification for the IEC 61508 international standard. In addition to a model with hydrogen permeation resistance, which is required for hydrogen production equipment, and a model with corrosion resistance that can be applied to various acid and alkali handling equipment, our lineup includes a model that can be used under high temperatures and high vacuum. Furthermore, we also offer a model with piezo pressure sensors in the detecting unit for applications that require ultra-high pressure resistance, such as offshore oil fields. Figure 1 shows the appearance of the FCX-A IV Series of differential and gauge pressure transmitters.

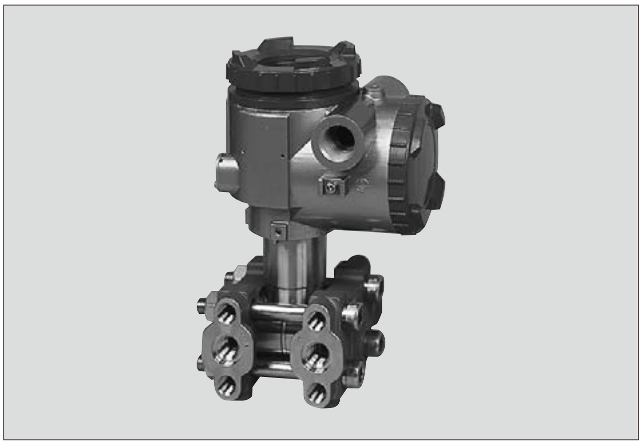

Fig.1 "FCX-A IV Series" of pressure transmitters

3. Features of the "FCX-A IV Series"

3.1 High accuracy and long-term stability

The capacitive pressure sensor used in the pressure detectig unit has higher sensitivity than other measuring systems, and it is made of a single-crystal silicon material, which has small hysteresis, resulting in excellent stability and reproducibility. In addition, the optimized structure has realized output with long-term stability. Furthermore, the advanced floating cell structure, in which the sensor floats in an incompressible fluid, protects the sensor from various harsh environments and excels in ensuring the stability of the sensor. With these features, the following performance characteristics have been achieved.

(a) High accuracy measurement: ±0.065% (standard)

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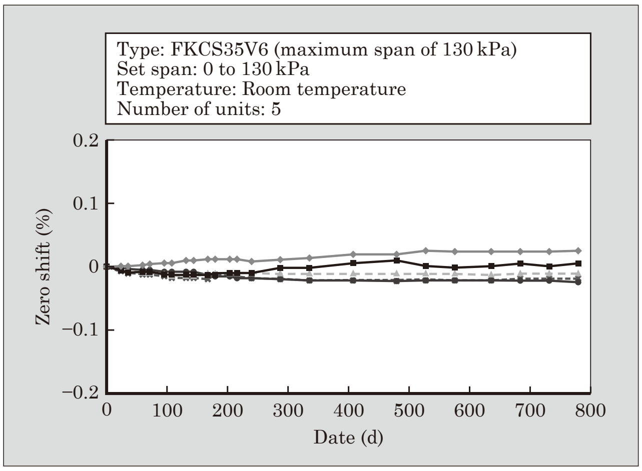

Fig.2 Zero shift data of the “FCX-A IV Series”

(b) Long-term stability: ±0.1%/5 years

Figure 2 shows the zero shift data of the FCX-A IV Series.

3.2 High-speed response

Distributed control systems (DCS), responsible for controlling plant operations, have become faster and more reliable as digital transformation (DX) has progressed, and accordingly, higher accuracy and higher speed are required also for field equipment such as transmitters. The performance of the FCX-A IV Series has been improved compared to the previous series due to the adoption of a high-speed CPU and the optimization of software processing, resulting in the highest level of responsiveness (update cycle of 40 ms, dead time of 60 ms) available in pressure transmitters. It is suitable for processes such as steam flow rate measurement for gas turbines that require high-speed response. Figure 3 shows the output response characteristics of the FCX-A IV Series.

3.3 Excellent visualization and usability

The equipped digital indicator shows digital measurements and units simultaneously, helping users gain an accurate understanding of the data. When an abnormality occurs, an error code is also displayed, making it possible to quickly understand the situation and respond to the abnormality. The FCX-A IV Series also provides an additional bar graph display, allowing users to understand the situation intuitively. All parameters built into the digital indicator can be configured and adjusted without opening the indicator cover by using non-contact switches from the outside. Figure 4 shows the appearance of an FCX-A IV Series digital indicator.

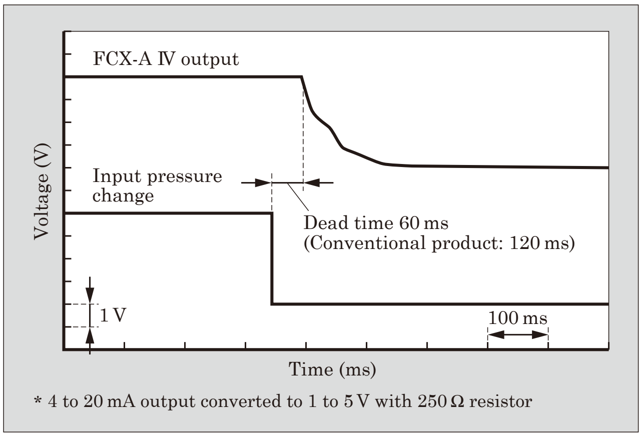

Fig.3 Output response characteristics of the “FCX-A IV Series”

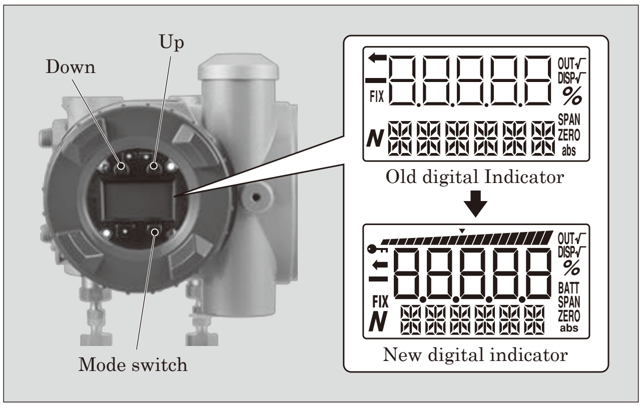

Fig.4 Appearance of the “FCX-A IV Series” digital indicator

3.4 Acquisition of SIL2 certification

This series is compliant with the IEC 61508 safety standard and has obtained SIL2 certification. It can be used in fields requiring functional safety. Further, implementing redundancy (combination) with two transmitters can achieve the level equivalent to SIL3 certification.

3.5 HART* communication support

The series is equipped with HART protocol output as standard and supports HART communication (the latest version, Revision 7), which can be easily coordinated across international worksites. Synchronization with a higher level controller enables engineering, monitoring, and equipment management for the HART system.

3.6 Responses to various applications

(a) Hydrogen permeation resistant applications

If a measured object contains hydrogen, a slight electromotive force is generated in the pressure-receiving diaphragm part of the transmitter, which is composed of dissimilar metals, and the hydrogen ions align there and permeate into the diaphragm. This is called the hydrogen permeation phenomenon, which will hinder accurate measurement. As a countermeasure, hydrogen permeation can be suppressed over long periods of time by applying gold plating to the seal diaphragm base material and

* HART is a trademark or registered trademark of FieldComm Group.

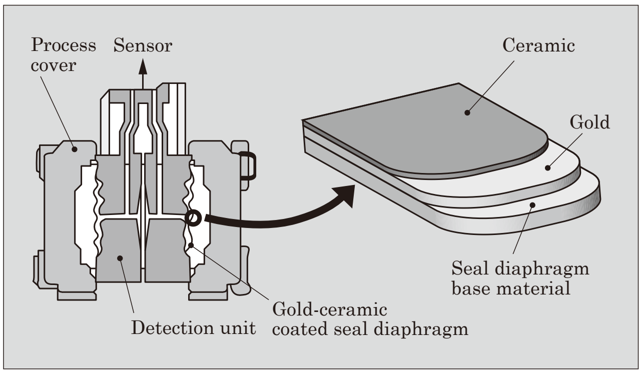

Fig.5 Structure of a gold-ceramic coated seal diaphragm

forming a gold-ceramic coating seal diaphragm with a ceramic film as an insulator. This structure is an original Fuji Electric technology that contributes to accurate hydrogen measurement at hydrogen purification plants and other facilities. Figure 5 shows the structure of a gold-ceramic coated seal diaphragm.

(b) Corrosion-resistant applications

In addition to hastelloy-C, monel, and tantalum, we offer titanium and zirconium as seal diaphragm materials. Selecting the optimal materials from a wide range of corrosion-resistant options can reduce the frequency of maintenance operations to deal with corrosion.

4. For Ultra-High Pressure Applications

4.1 Limitations of capacitance pressure sensors

In many offshore oil fields where pressure transmitters are used, the pressure is approximately 100 MPa. However, in recent years, as the depth of oil fields has increased, the pressure has exceeded 130 MPa in some fields. Under such ultra-high pressure, it becomes difficult to apply capasitive pressure sensors. The detected capacitance is determined by the electrode area, the distance between electrodes, and the permittivity of the sealed oil that fills the space between electrodes. However, the permittivity of the sealed oil changes according to the pressure, and the difference in the permittivity between the high pressure side and the low pressure side of the sensor increases in the high pressure range, resulting in errors. In addition, in the low pressure region, the capacitance is formed by a uniform gap formed by electrodes positioned opposite to each other in parallel, but in the high pressure region, the diaphragm becomes deformed, causing the gap to become uneven, which also results in errors. In addition, fluids measured in offshore oil fields, such as crude oil, groundwater and water vapor, contain hydrogen sulfide and salt, which are highly corrosive. For this reason, high corrosion resistance is essential for wetted parts such as seal diaphragms.

4.2 Ultra-high pressure capacity with piezo pressure sensors

We have developed a model that uses piezo pressure sensors for ultra-high pressure applications. Figure 6 shows the appearance of a pressure transmitter for ultra-high pressure applications.

The piezo pressure sensor detects the stress generated in the diaphragm by the pressure as a change in the piezo resistance value. The piezo pressure sensor is manufactured by forming a resistor and a wiring pattern on the surface of a silicon substrate, as well as a diaphragm on the back using dry etching, then using surface activated bonding to bond it together with a glass substrate before cutting them into the shape of a chip. As shown in Fig. 7, the structure of the chip is very simple. In addition, since substrates are bonded directly to each other at normal temperatures when using surface activated bonding, the high temperatures and high voltages applied in the commonly used anodic bonding technique are avoided, which means that deterioration of the substrates and residual stress do not occur. Compared to capasitive pressure sensors, there are fewer parts that deform and become error factors. For this reason, pressure can be detected

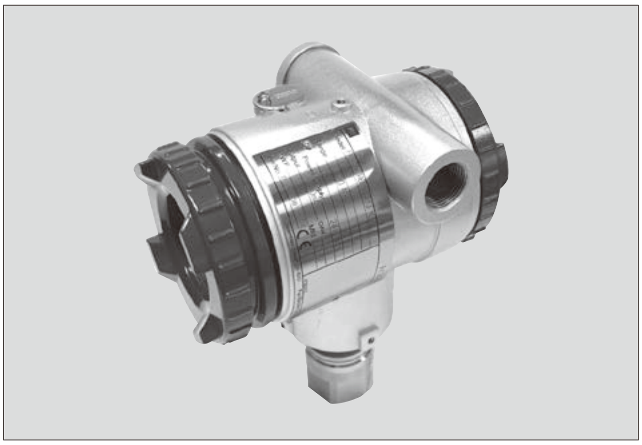

Fig.6 Pressure transmitter for ultra-high pressure applications (with a built-in piezo pressure sensor)

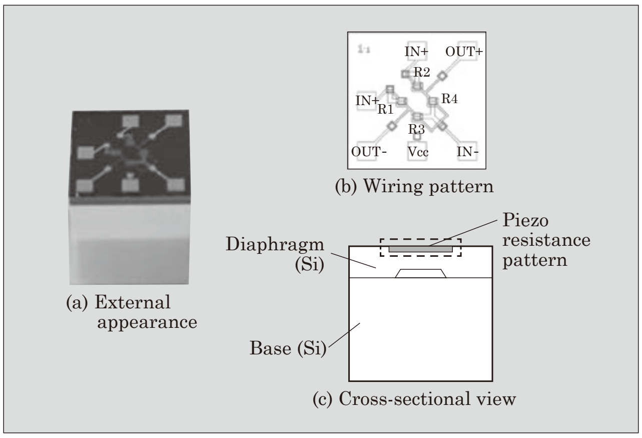

Fig.7 Piezo pressure sensor structure

Table 1 "FCX-AIV Series" lineup

Type	FKC	FKG	FKA	FKE	FKB	FKD	FKP	FKH	FKR
	 Differential pressure (flow rate)	 Gauge pressure	 Absolute pressure	 Level	 Remote seal type Pressure	 Remote seal type differential pressure (flow rate)	 Pressure (Direct mount)	 Absolute pressure (Direct mount)	 Ultra-high pressure (piezo direct mount)
Maximum span (kPa) [URL]	1 6 32 130 500 3,000	130 500 3,000 10,000 50,000	16 130 500 3,000	32 130 500	130 500 3,000 10,000 50,000	32 130 500	130 500 3,000 10,000	130 500 3,000	70,000 150,000
Mass (kg) (No indicator)	3.1	2.9	2.9	Approx. 9 to 19	Approx. 4 to 18	Approx. 9 to 19	1.8	1.8	1.5
Accuracy rating	±0.065%		±0.2%	±0.2%	±0.2%	±0.2%	±0.1%	±0.2%	±0.065%
Diaphragm material	316L SS Hastelloy-c Monel Tantalum 316L SS gold plating Gold & ceramic coating		316L SS Hastelloy-c Monel Tantalum	316L SS Hastelloy-c Monel Tantalum Titanium Zirconium 316L SS gold plating			316L SS		Inconel 625 Inconel 625 + Gold plating
Process connection dimensions	Rc 1/4			Flange standards			NPT 1/2, Rc 1/4, Rc 1/2, NPT 1/4		Autoclave F250C
Shared specifications	Span setting range: 1 to 1/100 URL Measurement period: 40 msec Temperature range (wetted parts): −40°C to +120°C (High temperature type available)*1 Ambient temperature: −40°C to +85°C Power supply voltage: 10.5 to 45 V DC Output signal: 4 to 20 mA DC				Supported communication protocol: HART Other additional specifications: Digital indicator, Degreasing, Cleaning for oxygen service*2, Chlorine measurement, Stainless steel tag plate, Local configuration function*3				

*1 FKR: −40°C to +100°C
*2 FKR: Cleaning for oxygen service not selectable
*3 FKR: Chlorine measurement not selectable

without a decline in measurement accuracy even under ultra-high pressure.

In addition, to enhance the corrosion resistance of the seal diaphragm that comes in contact with corrosive, high-pressure measuring fluids, we used inconel, a material with high mechanical stress sustainability and good corrosion resistance.

Table 1 shows the lineup of the FCX-A IV Series with the features described above.

5. Postscript

This paper described the "FCX-A IV Series" of differential and gauge pressure transmitters, which contributes to the enhancement of plant monitoring and control systems. We will continue to make efforts to expand our product lines to meet the diverse needs of our customers, thereby contributing to the advancement of more sophisticated energy saving control and automation.

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(1) Kishiro, M. et al. FCX-AIII Series of New Type Differential Pressure/Gauge Pressure Transmitters. FUJI ELECTRIC REVIEW. 2008, vol.54, no.3, p.99-103.

Performance Test System Reproduces the Usage Environment of EV Drive Components

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ABSTRACT

The electrification of automobiles has been progressing rapidly today in the face of global emissions regulations and decarbonization. As electric vehicles (EVs) especially use complex control, the labor-hours for testing can significantly increase to develop them and demand has been increasing for EV test equipment. In response to this demand, Fuji Electric has developed an EV drive component performance test system. The system can simulate the load during actual road driving and actual environmental testing factors of temperature and humidity to improve test efficiency and reliability.

1. Introduction

In the automotive industry, electrification has been progressing rapidly in the face of global emissions regulations and decarbonization, and it is estimated that approximately 55% of the vehicles sold in Japan in fiscal 2030 will be electric vehicles (EVs)(1). Unlike gasoline-powered or diesel-powered vehicles, EVs use complex control. For this reason, the labor hours required to test them may be significantly higher, and demand has been increasing for EV test equipment to improve reliability and test efficiency.

In response to this demand, Fuji Electric has developed an EV drive component performance test system.

This paper describes a performance test system that reproduces the usage environment of EV drive components.

2. Overview of the EV Drive Component Performance Test System

The EV drive component performance test system consists of an EV drive component performance tester, a thermostatic chamber, and a temperature controller. This system can reproducing realistic driving environments to test EV drive components, such as motors, inverters, and decelerators.

Figure 1 shows the EV drive component performance test system.

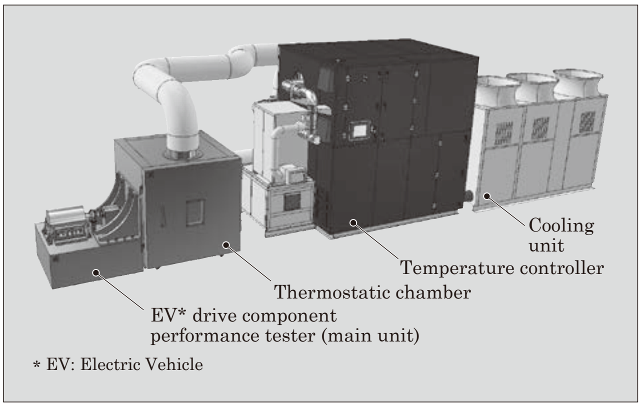

Fig.1 EV drive component performance test system

In order to reduce their size and weight, progress is being made in the rotation speed of EV motors, with the maximum speed reaching 20,000 r/min. In addition, the thermal environment of in-vehicle parts has become extreme due to the high-speed rotation and dense concentration of EV motors, inverters, and electronic parts. Therefore, it is necessary to evaluate whether any problems in performance and reliability arise under extreme temperature environments.

2.1 EV drive component performance tester

The EV drive component performance tester is designed to evaluate a single specimen, simulating the load in actual road driving conditions. This tester is composed of a dynamometer for generating a load on the specimen and reproducing load states such as driving conditions, a torque meter for measuring the rotational force applied to the shaft between the dynamometer and the drive components, an intermediate bearing for supporting and reducing the load applied to the dynamometer and the drive components, an angle plate for attaching an EV motor, and a rack for assembling these parts. Figure 2 shows the EV drive component performance tester (main unit).

For EV motors, high-speed rotation is indispensable for achieving both size and weight reduction, as

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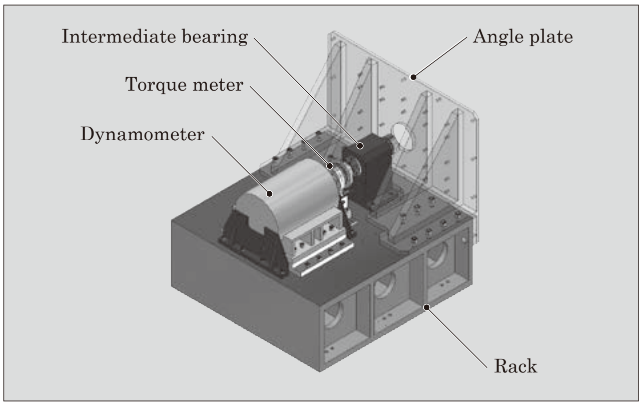

Fig.2 EV drive component performance tester (main unit)

well as high power. It is necessary to deal with specific problems caused by high-speed rotation in the test equipment. A high-speed rotating system requires the characteristic vibrations of the system to be detuned according to the rotation speed of the specimen to suppress the generation of resonance, as well as a cooling system and auxiliary equipment for lubrication due to the rise in temperature in the system caused by high-speed operation. For these reasons, the mechanical configuration becomes complex, resulting in more mechanical challenges than electrical challenges.

2.2 Thermostatic chamber and temperature controller

The thermostatic chamber and temperature controller are for reproducing the usage environment, including temperature and humidity in the thermostatic chamber. This system comprises a temperature controller for controlling temperature and humidity in the thermostatic chamber, a cooling unit for supplying refrigerant to a cooler in the temperature controller, a humidifier for supplying moisture, and other components. Figure 3 shows a diagram of the thermostatic chamber and temperature controller configuration.

In electric vehicles, the amount of heat generated by electronic parts has increased due to the reduced size and increase in capacity of motors, inverters, batteries, and other components, as well as the integration of these components in limited spaces. The increase in the amount of heat generated by electronic parts may decrease their performance or shorten their life. Automakers and auto parts suppliers are increasingly required to evaluate the reliability of electronic parts from the viewpoint of safety and security and must verify quality through rigorous testing in various realistic simulated driving environments. However, small-capacity products for evaluating small parts are common for environmental test equipment, while large-capacity equipment for evaluating medium- and large-sized auto parts in the driven state is rare. In addition, equipment that simulates the temperature environment while absorbing the exothermic load fluctuation of the unit is expensive because they are one-off products, rather than general-purpose product. For this reason, many of this type have not been introduced in the market. Therefore, evaluation tests are often conducted in a natural progression according to a cold or hot start.

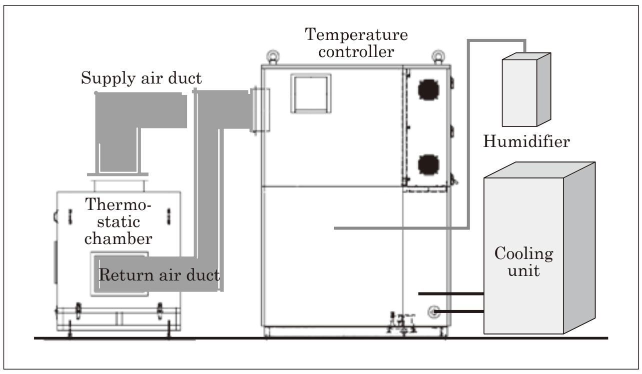

Fig.3 Thermostatic chamber and temperature controller configuration diagram

3. EV Drive Component Performance Tester Features

3.1 Challenges

In the high-speed rotation tests, the resonance may cause sudden wear and tear of the bearing and increase the swing of the rotating shaft system, leading to failure. To avoid machine breakage, it is necessary to separate the characteristic vibrations from the rotational frequency of the test equipment. As a countermeasure, it is effective to increase the rigidity and reduce the weight of the EV drive component performance tester. In addition, to reduce centrifugal force, the design must take into account the dynamic balance adjustment of the rotating shaft.

As the increase in energy in high-speed rotation tests results in a large amount of generated heat, flaking failure may occur due to bearing seizure caused by poor lubrication. Therefore, oil is commonly used to lubricate and cool the bearing simultaneously. However, when oil lubrication is used, the machine configuration must include an oil pump and a heat exchanger, leading to increased complexity. Furthermore, the surrounding area becomes contaminated by oil mist, and as a result, the scope of equipment maintenance expands. For this reason, many users have asked to avoid the use of oil lubrication if possible.

3.2 Countermeasures and effects

When developing highly-reliable, high-speed rotating test equipment, it is necessary to predict the characteristic vibrations of the equipment at the design stage to ensure suitable rigidity of the structure. We set the vibration frequency to 333 Hz (20,000 r/min) at the driving rotational speed and the detuning rate* to

* Detuning rate: Separation rate with respect to the rated speed of the resonant speed

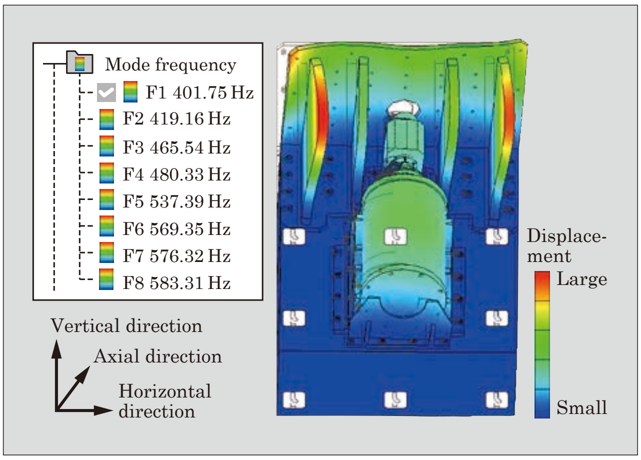

Fig.4 Vibration modes of the EV drive component performance tester and primary characteristic vibration analysis results

approximately 20% as the design value. In the design of the test equipment, we conducted vibration analysis using the finite element method and obtained characteristic vibrations. Based on the analysis results, we adjusted the beam and thickness to optimize the structure by balancing the high rigidity and light weight of the equipment.

Figure 4 shows the vibration modes of the EV drive component performance tester and the primary characteristic vibration analysis results.

As a result of structural optimization, the characteristic vibrations of the primary vibration mode was 401.75 Hz, and a detuning rate of 20.4% was ensured against the rotational frequency vibrations (333 Hz).

In addition, we measured the vibrations by actually operating the equipment to confirm the validity for the resonance examination. In the measurement, we evaluated the intermediate bearing, which is most likely to generate vibrations because it supports the weight of the rotating body, and the rack, which is affected by vibrations from the whole rotating system. With regard to the evaluation criterion for vibration measurement, the limit value for vibration speed was set to 2.8 mm/s or less in accordance with JIS B 0906 to determine whether the measured vibration value was a normal value or an abnormal value.

Table 1 shows the measurement results of the vibration level of the EV drive component performance tester. The vibration speed of 2.8 mm/s or less was cleared at all measurement points, and the desired vibration level was achieved under high-speed rotation.

The intermediate bearing uses grease lubrication instead of oil lubrication. The advantage of grease lubrication is that it does not require disassembly work for the equipment piping or other components, nor does it require internal oil treatment work. Instead, only the simple task of greasing is required for maintenance. Although grease lubrication means good maintainability, the cooling efficiency is lower than that of oil lubrication, so care must be taken to prevent seizures caused by temperature rise.

Table 1 Measurement results of the vibration level of the EV drive component performance tester

Subject	Intermediate bearing					
Measuring point	Specimen side			Dynamometer side		
Vibration direction	Axial	Horizontal	Vertical	Axial	Horizontal	Vertical
Vibration speed (mm/s)	1.87	1.82	0.01	0.01	2.52	1.99
Subject	Rack					
Measuring point	Specimen side			Dynamometer side		
Vibration direction	Axial	Horizontal	Vertical	Axial	Horizontal	Vertical
Vibration speed (mm/s)	0.30	0.43	0.26	0.27	0.48	0.25

Table 2 Intermediate bearing temperature measurement results

	Dynamometer rotational speed (r/min)
	20,000
Specimen side temperature (°C)	60
Dynamometer side temperature (°C)	57

In this design, we set the upper limit temperature of the bearing to 120°C or less and examined the following three points as key considerations for suppressing temperature rise in the intermediate bearing by reducing the vibration of the bearing, improving the rotation accuracy, and properly lubricating the bearing.

(1) Examination of the suppression of centrifugal force

We determined the balance grade to reduce to a target value the spherical surface pressure of the bearing due to centrifugal force.

(2) Selecting pressurization that takes into account rotation accuracy and lubrication

Axial-direction constant surface pressure is designed to be applied to the bearing in spite of against temperature changes.

(3) Selecting a lubricant agent

We selected urea grease for its heat resistance.

To confirm the validity of this design, we measured the temperature of the intermediate bearing.

Table 2 shows the intermediate bearing temperature measurement results. The results of the temperature measurements were within the upper limit of use.

4. Temperature Controller Features

4.1 Challenges

Automotive tests include soaking operation and mode tests. As soaking operations stop until the specimen reaches the test temperature, no heating load is involved, and the cooling unit stops due to the light load. The stopped cooling unit cannot provide constant cooling performance or maintain stable temperatures because it restarts after a restart prevention delay time has elapsed. On the other hand, in the mode test, the heating load fluctuates greatly between 0% and 100%, and the equipment must be optimally controlled to track the temperature according to the fluctuations.

We consider these problems to be challenges to tackle in the process of achieving the following targets in equipment development.

(a) Temperature tracking performance within ±1°C with respect to thermal load fluctuation
(b) Construction of an environment that enables continuous operation even in low temperature environments
(c) Minimization of installation area, ancillary work, and adjustment time

The conventional method of constructing an automobile test environment is to combine heat source equipment that produce normal temperatures, low temperatures, and high temperatures at the test site. In this development project, we have integrated and optimized heat source equipment of all temperature ranges as a means of addressing these challenges.

4.2 Countermeasures and effects

To achieve a temperature tracking performance within ±1°C with respect to heat load fluctuations, it is necessary to prevent stoppage and hunting of the cooling unit to ensure stable operation regardless of the state of heat load fluctuations. Figure 5 shows the configuration of a temperature controller configuration.

(a) As a countermeasure against light load stoppage of the cooling unit during soaking operations, heat is output from electric heater (a) installed on the primary side of evaporator (a), and the heat load is applied to evaporator (a) to continue operation of the cooling unit, as shown in Fig. 5. On the other hand, in the mode test, the refrigerant flow rate is controlled by expansion valve (a), and the evaporation pressure is controlled by evaporation pressure regulating valve (a) according to the exothermic load fluctuations of the specimen. In addition, we found the optimum value of the variable PID control of the electric heater before and after evaporator (a), while simultaneously ensuring the continued operation of the cooling unit.
(b) Using the return refrigerant piping at the outlet of the dehumidifier system that was integrated with the cooling unit system, a suction injection circuit is formed. As a result, the intake piping gas temperature of the compressor is kept within the specified value, and continuous operation of the cooling unit is ensured even under light load with an elevated temperature setting. Figure 6 shows the cooling circuits.
(c) Deviating from the practice of using different cooling units selected from the viewpoint of efficiency for evaporators of different temperature zones and using low-temperature cooling units to achieve –40°C, we adopted a cooling unit that can respond to large load fluctuations. While the refrigerant of conventional equipment is R404A (boiling point of –46.1°C), the refrigerant in the newly developed equipment is R410A (boiling point of –51.4°C). Figure 7 shows the capacity control of the cooling unit for the conventional equipment as compared to the newly developed cooling unit. The conventional equipment consists of a medium-temperature inverter and a cryogenic constant-speed machine, but the newly developed equipment uses an inverter that can cover the entire temperature range, enabling stable capacity control against load fluctuations.

Figure 8 shows the load tracking performance during the mode test. As shown in Fig. 8, as a result of the measures in (a) and (b), a highly accurate load tracker with an air supply temperature in the range of –40±1°C has been achieved, even when the load fluc-

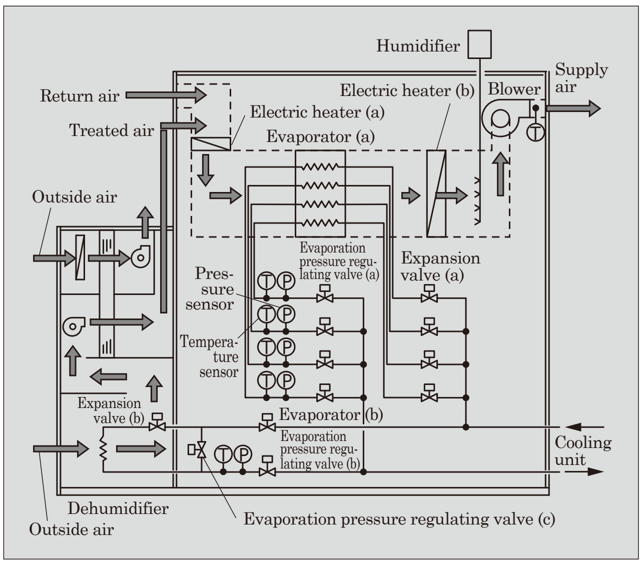

Fig.5 Temperature controller configuration diagram

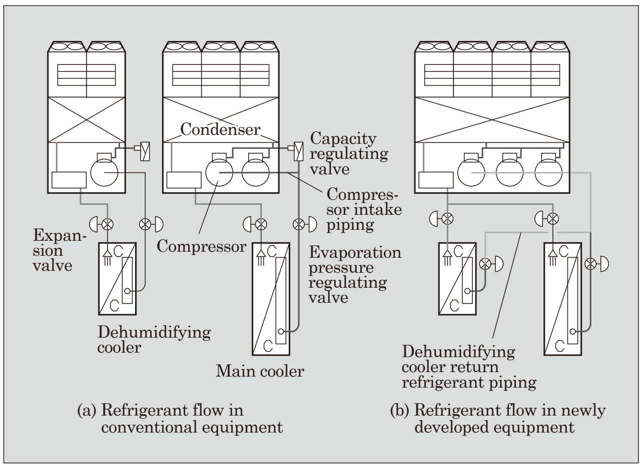

Fig.6 Cooling circuits

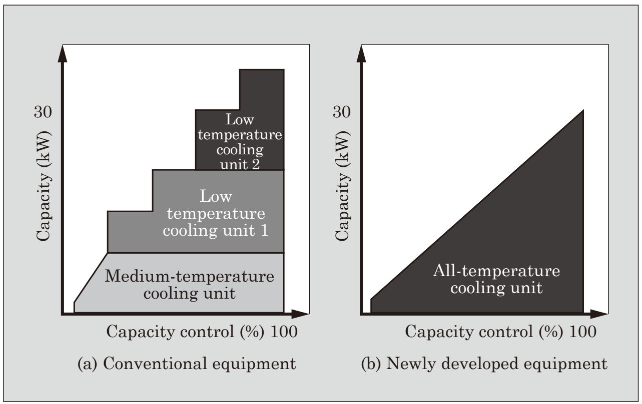

Fig.7 Capacity control of conventional equipment and the newly developed equipment cooling unit

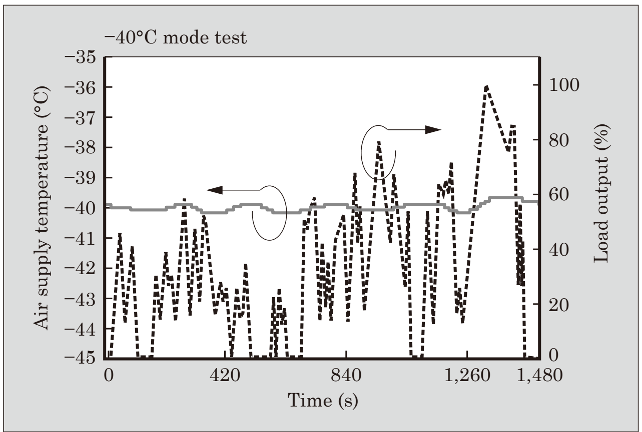

Fig.8 Load tracking performance during mode testing

tuates by 0% to 100% in the low temperature region, which is the most severe condition.

In addition, as a result of the comprehensive optimization and review of components conducted in the process of implementing the measures described (a) to (c), we have completed a small, packaged product. As a key example, the pitch of the heat transfer fin has been narrowed from 8 mm to 6 mm because the introduction of the dehumidifier has prevented frost from forming. Moreover, the frosting coefficient used to take into account the decrease in heat exchange efficiency caused by frost, which had been a consideration in the design of conventional coolers, can be set to 1 (usually, 0.6 to 0.7), resulting in a significant reduction (by approximately 45%) in the volume of the cooler, which affects

Table 3 Results of comparison with conventional equipment

Conventional equipment		
Cooler		Cooling unit
Medium temperature cooler 1	14 columns × 20 rows × 830 L	10 HP inverter
Low temperature cooler 2	16 columns × 10 rows × 830 L	20 HP constant-speed machine
Low temperature cooler 3	16 columns × 10 rows × 830 L	20 HP constant-speed machine
Dehumidifying pre-cooler	16 columns × 6 rows × 250 L	5 HP inverter
Total	522 m (1.3 m^3)*1	55 HP (4.3 m^2)*2

Product prototype		
Cooler		Cooling unit
All-temperature cooler	22 columns × 20 rows × 650 L (quadruple split)	40 HP inverter
Dehumidifying pre-cooler	16 columns × 6 rows × 250 L	
Total	310 m (0.7 m^3)*1	40 HP (2.4 m^2)*2

*1 Volume occupied by the effective part of the cooler
*2 Cooling unit installation area

the device size. In addition, as described above, the cooling unit system has been integrated to reduce the installation area (by approximately 45%).

Table 3 compares the newly developed equipment with conventional equipment.

4. Postscript

This paper has described a performance test system that reproduces the actual environmental conditions in which EV drive components are used. Future EV systems are expected to have higher rotational speeds and higher voltages. As such, new technological challenges need to be tackled. Fuji Electric will continue to provide products that contribute to the improvement of test efficiency and reliability in powertrains.

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Ship IoT System for Efficient Operation Management of Exhaust Gas Cleaning Systems

YASUNOBU, Tomohiro *

ABSTRACT

Recent stricter international environmental regulations in the maritime industry have been encouraging the installation of exhaust gas cleaning systems (EGCS) to purify the exhaust gas emitted from ships. As part of this effort, Fuji Electric has developed a ship IoT system that utilizes increasingly popular ship-to-shore broadband communications. This IoT system is able to monitor EGCS measurement log data and alarms by utilizing a cloud server. It also provides a diagnostic function to predict abnormalities and facilitates timely maintenance before equipment malfunctions in order to shorten equipment downtime and reduce the work costs required for troubleshooting.

1. Introduction

In recent years, stricter international environmental regulations in the ship industry have increased the need to switch from conventionally used fuels to fuels that conform to environmental regulations and install exhaust gas cleaning systems (EGCS). However, systems that comply with environmental regulations are more sophisticated than conventional ship equipment and are difficult to handle, making it difficult for crew members alone to deal with equipment failures. In addition, ships often sail at sea throughout the year, which results in the unique problem that manufacturers are not able to attend ships immediately. On the other hand, the spread of land-to-ship broadband communications using satellite communications is rapidly advancing, and ships sailing at sea can enjoy fixed-price, high-speed communication services.

To resolve the ship-specific problems described above, Fuji Electric has developed an Internet of Things (IoT) system for ships to be applied to EGCSs(1). This equipment is used to monitor measurement log data and alarms using a cloud server. When a fault occurs in the equipment, remote support can be provided, such as by determining the point of failure from the measurement log data and providing repair instructions without anyone having to attend the ship. The ship IoT system provides a diagnostic function to predict abnormalities utilizing Fuji Electric's artificial intelligence (AI) technology(2), enabling condition-based maintenance (CBM), in which faults in equipment are predicted, and maintenance is performed at optimal times. The function helps reduce downtime caused by equipment failure and suggests the optimal timing for replacement and the purchase of spares.

2. Ship IoT Systems and Current New Needs

Figure 1 shows a configuration diagram of the ship IoT system. In this system, the edge device "FiTSA Σ" embedded in the IoT relay panel installed on the ship transmits measurement log data stored in the EGCS monitoring control panel and the alarm history of each device to the Fuji Electric cloud server at fixed periods using satellite communications. The ship management company can monitor ship data by accessing the cloud server. Taking into consideration the characteristics of satellite communications, the communication protocol adopted for cloud servers is Message Queue Telemetry Transport* (MQTT), which uses retransmission and other means to ensure the reachability of information even when the network environment is unstable. The connection between the IoT relay panel and the line used by the ship management company can be completed by setting a fixed IP address and a default gateway, just like a typical Internet connection. In addition, regarding the security of cloud servers, risk reduction and protection of important information are implemented in accordance with ISO/IEC 27017:2015 (cloud security standard) and Fuji Electric's security policy.

Fuji Electric began offering the ship IoT system in April 2021(1). Figure 2 shows the workflow of response to failures before and after the introduction of the ship IoT system. Prior to the introduction of the system, if a fault occurred in a ship's system or equipment, the situation would be reported by email from the ship to

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

* MQTT is short for Message Queue Telemetry Transport, which is a lightweight messaging protocol that communicates using the TCP/IP protocol.

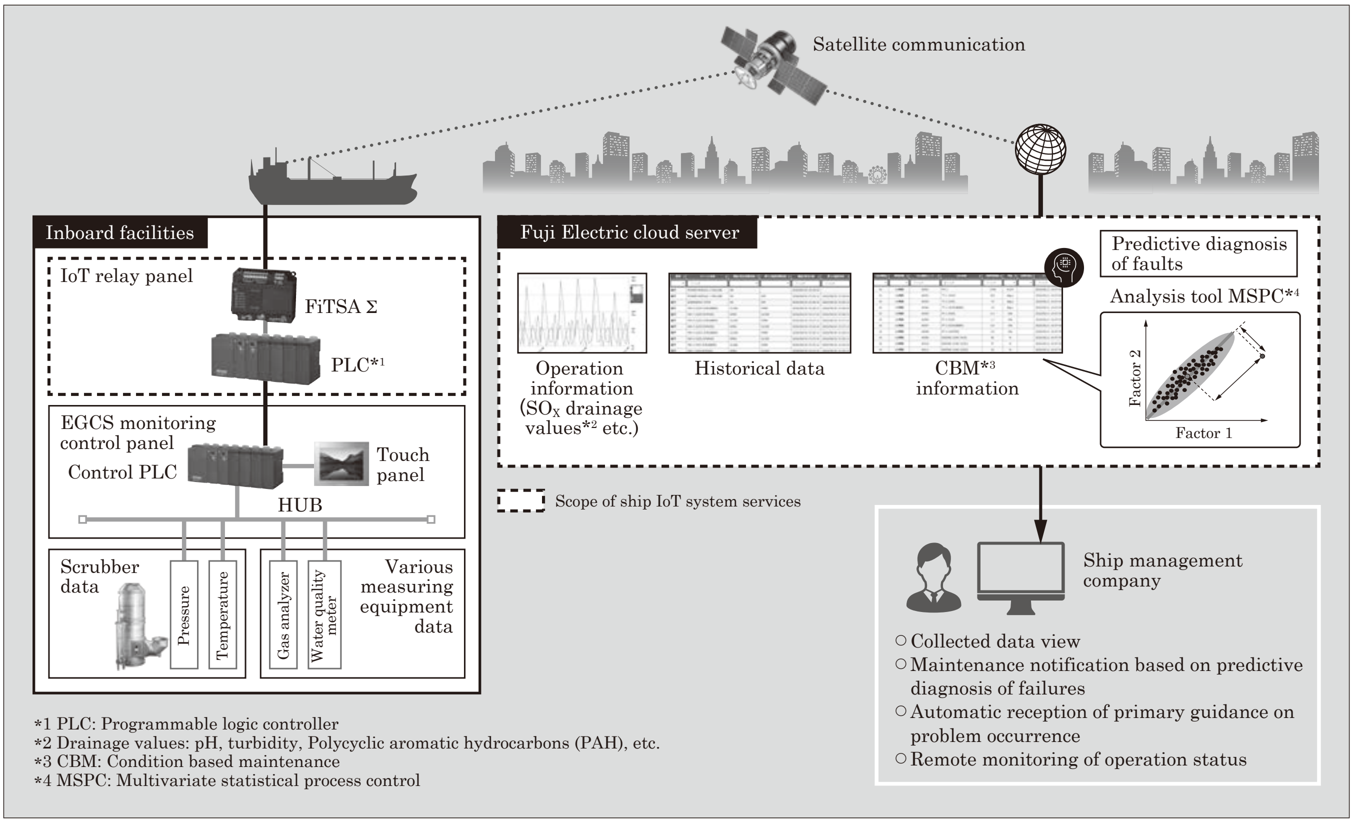


Fig.1 Ship IoT system configuration diagram

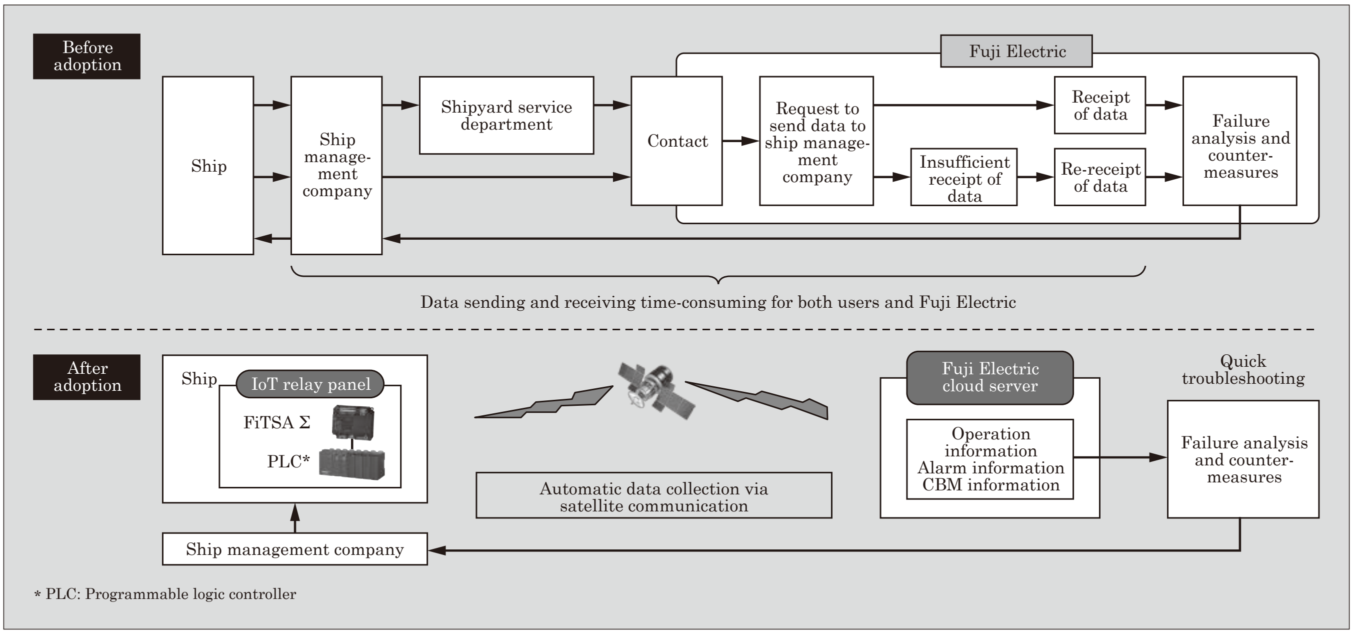


Fig.2 Workflow of responses to failures before and after the introduction of the ship IoT system

the ship management company, who would request a fix from Fuji Electric, the supplier of the system or equipment that seems to be the cause of the problem. Upon receiving the request, Fuji Electric would contact the ship management company about the cause of the fault and solutions, and the ship management company would relay information to the ship. If the problem could not be resolved by the provided solutions, the situation would be reported to Fuji Electric again. The same interaction would be repeated until the fault is resolved, and therefore, resolving problems generally took a lot of time.

The introduction of the ship IoT system allows Fuji Electric to understand the condition of the facilities and the issued alarms by checking the measurement log data and historical data stored in the cloud server without waiting for a call from the ship management company, enabling quick responses to failures. In addition, the ship IoT system automatically delivers an email containing the details of the alarm and what action to take when an alarm is issued, enabling the ship's crew to respond quickly without waiting for the manufacturer to contact them.

In recent years, however, ship management companies and crew members who use EGCSs have increasingly been calling for the ability to find how to respond to problems via the cloud server and the ability to use collected data to prevent problems.

3. New Services to Streamline Operations Management

To meet the needs described in Chapter 2, we have developed a diagnostic function to predict abnormalities utilizing Fuji Electric's analytics and AI technology[(2)].

For the ship IoT system, we built our diagnostic services to predict faults by adopting multivariate statistical process control (MSPC), which falls under the diagnostic technology category of analytics and AI technologies. Figure 3 is an overview of our MSPC. MSPC uses multivariate analysis to quantify out of the ordinary values from the correlation of multiple data. Ships operate around the world, and their equipment runs under various seasons, temperatures, weather, and other conditions. Therefore, even given the same equipment, the data characteristics differ from ship to ship. In addition, satellite communications are used to send and receive data, but data may be lost due to weather or sea conditions. To deal with usage environments that are specific to each ship, this service preprocesses data using data cleansing and characteristic acquisition technology to automatically generate a sound model. The condition of the facility can be understood from the deviation (Q value) between the sound model and the present value. Furthermore, the contribution of the Q value is shown for each diagnosis, which makes it possible to know which measurement values deviate significantly, allowing the cause of the deviation to also be identified. Conventional services

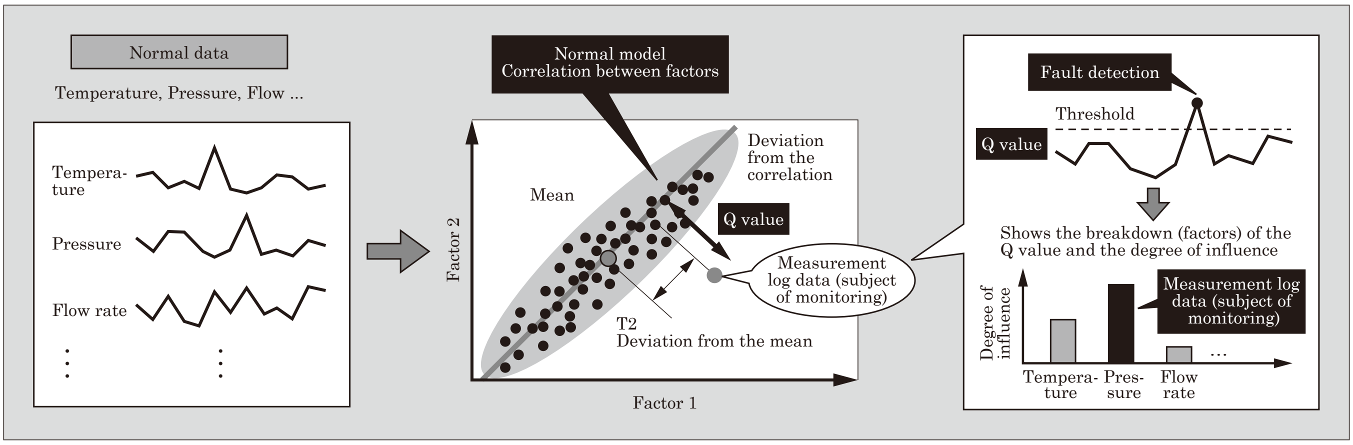
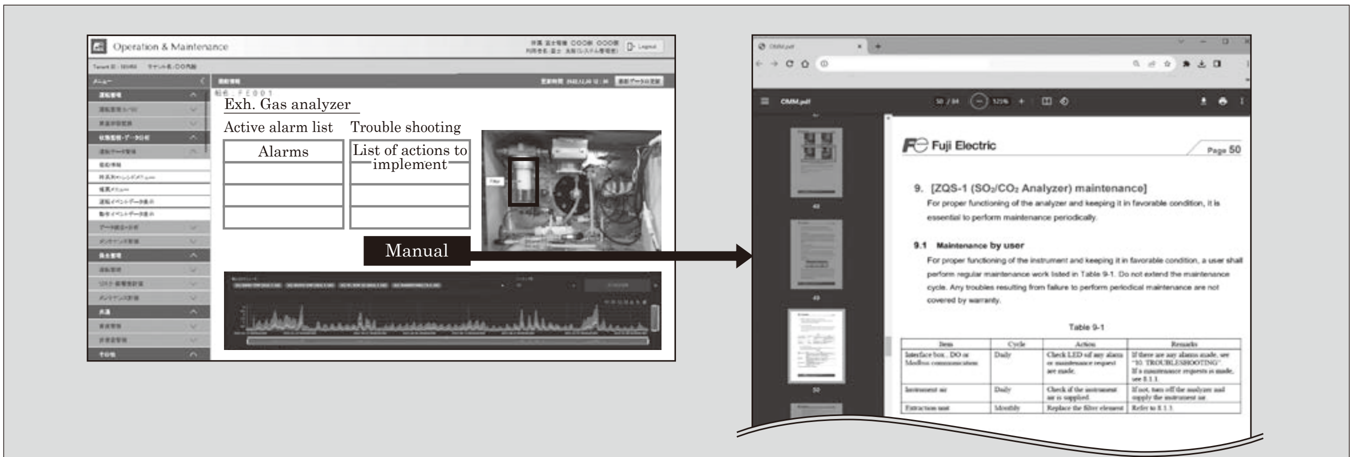


Fig.3 Overview of MSPC



(a) Screen for the predictive diagnosis of faults

(b) Maintenance manual (excerpt)

Fig.4 Predictive diagnosis of faults screen (as of March 2023) often perform upper and lower limit monitoring for each measurement value, but MSPC can detect signs of faults that would be missed by the this method.

Figure 4 shows the screen for predictive diagnosis of faults for the Fuji Electric gas analyzer used in our EGCS. The alarm shown here does not indicate an equipment failure, but rather the detection of a tendency of the equipment to deviate from the normal state, and this tendency is determined based on the results of the predictive diagnosis of faults. The generated alarm and troubleshooting for the alarm are linked together, and the maintenance manual can be displayed by clicking the View Manual button. This allows the crew of the ship to take appropriate and prompt action. In the past, when equipment failed, troubleshooting was time-consuming because it was necessary to find the maintenance items in the instruction manual according to the problem. However, by utilizing this diagnostic function to predict faults, the equipment downtime and labor required to respond to problems can be reduced.

4. Postscript

This paper has described a ship IoT system that achieves the efficient operation management of exhaust gas purification systems. Going forward, we will expand the scope of predictive diagnosis of faults and propose the optimal maintenance and replacement timing for spare parts to reduce the burden of ship maintenance. We will also respond to needs for solutions for ship equipment other than EGCSs.

Although the adoption of fuels that comply with environmental regulations and the development of equipment compatible with these fuels have progressed remarkably, the safe and efficient use of new fuel oil is also essential, and the need for remote monitoring by combining sensors and IoT devices is increasing. In addition, development in the automatic operation of ships is progressing, and with the aim of keeping marine operations safe, the need for remote monitoring and other diagnostic methods for the prediction of faults is expected to increase further. In light of this social environment, Fuji Electric will continue to provide services that utilize its strengths in analytics and AI technology.

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Radiation Management Solutions Contributing to Safety and Security

MAEKAWA, Osamu* ABE, Yohei*

ABSTRACT

Fuji Electric provides facilities and local governments that handle radioactive materials with radiation management solutions to contribute to safety and security. In environmental radiation monitors, which were proved useful to support the recovery from the Great East Japan Earthquake, we have developed monitoring posts that use diversified communication functions to improve continuous monitoring capability during disaster and real-time dosimeters with improved detection accuracy and stability. For environmental radiation monitoring telemetering systems, which collect measurement data, including radiation doses, and display them on the screen, we have developed a platform that can be expanded to meet customer needs. In addition, we have developed the detector for alpha-ray aerosol monitors that improves alpha-ray measurement performance by reducing noise and improving resolution.

1. Introduction

Climate change caused by global warming is a crucial issue and a major threat to create a sustainable society. Various measures are implemented around the world to overcome this problem. In recent years, rapid changes in world situation have exposed major risks to the stable energy supply. In particular, Japan is not rich in energy resources, and rising fuel costs and other factors are beginning to have a significant impact on people's lives and business activities. Under the circumstance, the government of Japan has announced that it will promote decarbonization, shifting social and industrial infrastructure away from reliance on fossil fuels to focus on clean energy. The government is going to change policy to decarbonized society with stable energy supply.

Japan has announced that their decarbonization initiative includes not only breaking away from excessive dependence on fossil fuels, but also the use of nuclear energy as a highly decarbonized power source, promoting the shift to a resilient energy supply-and-demand structure.

For use of nuclear energy, the government has indicated a policy to maximize utilization of existing facilities, focusing on reactivation of nuclear power plants following safety evaluations. Based on lessons learned from the accident at the Fukushima Daiichi Nuclear Power Station, plan is safety first by cooperating closely with local residents.

As a manufacturer of comprehensive radiation measuring instruments, Fuji Electric has developed and delivered various instruments and systems for radiation control, and contributes to safe operation of nuclear facilities.

Since the Great East Japan Earthquake, Fuji Electric has delivered real-time ambient dose equivalent meter to support the reconstruction of the Fukushima area, developed disaster-resistant radiation monitors, and redundant communication lines. This paper describes proposal for radiation control, which contribute to safety and security.

2. Overview of Radiation Control Solutions

Instruments used for radiation control are classified as monitor of personal radiation exposure control, surface contamination monitors, environmental radiation monitors, or facility radiation monitors. These monitors work in corporation with radiation monitoring panels and computer systems to manage measurements. Figure 1 shows a image that illustrates a radiation control system.

The features of each monitor and of typical detec-

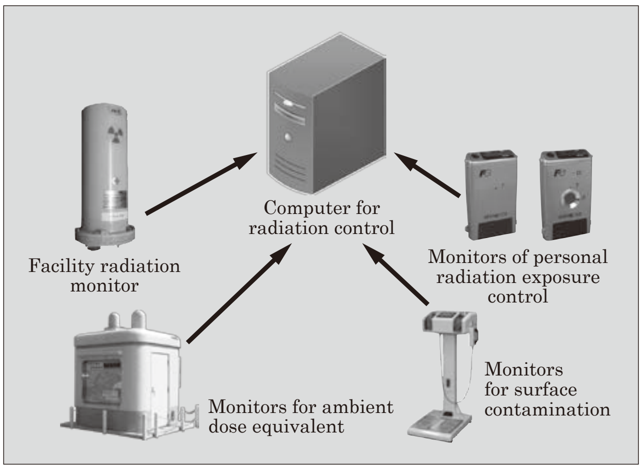

Fig.1 Radiation control system image

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

tors are as follows:

(1) Monitors for personal radiation exposure control

Monitors for personal radiation exposure control measure the external and internal exposure of workers engaged in work at nuclear facilities and related facilities. External exposure means exposure to radiation from outside the body, and internal exposure means exposure to radiation from radioactive materials that enter the body. Typical monitors include monitors of personal radiation exposure control and whole body counters.

(2) Monitors for surface contamination

Monitors for surface contamination measure whether radioactive contamination exists or not in workers and objects. Nuclear facilities have areas called radiation controlled areas where radiation exposure is properly controlled, and presence of monitors of clothes surface for beta rays is measured when workers exit or bring out objects from these areas. Typical monitors include radioactive surface monitors for the human body, as well as survey meters.

(3) Monitors for ambient dose equivalent

Monitors for ambient dose equivalent are mainly used to measure ambient doses around nuclear facilities. Typical monitors include real-time ambient dose equivalent meter and monitoring posts.

(4) Monitors for radiation in nuclear facilities

Monitors for radiation in nuclear facilities measure ambient radiation doses in nuclear facilities and concentration of radioactive materials emitted from facilities. Typical monitors include area monitors, gas monitors, and aerosol monitors.

In recent years, needs increase that radiation monitoring at boundary and around nuclear facilities. After Chapter 3, it and subsequent chapters describe the latest monitors for ambient dose equivalent and software platforms of environmental radiation monitoring telemeter systems. These chapters describe facility radiation monitors that are being upgraded in preparation for reactivation of nuclear power plants.

3. Monitors for Ambient Dose Equivalent

3.1 Monitoring posts

(1) Overview

Monitoring post is monitor that measures ambient doses. Figure 2 shows the appearance of a monitoring post. The monitoring post consists of detector, measurement unit, and external housing. Although monitoring posts are installed in various environments, Fuji Electric's monitoring posts can adapt to customer requirements, as there are two types: one with an all-in-one radiation measurement unit and calculation unit, and the other in which these two units are separate. These monitoring posts are equipped with a sodium iodide (NaI) scintillation detector. The NaI scintillation detector consists of a NaI scintillator and a photomultiplier tube. Electrons inside the scintillator are excited

(a) All-in-one type

(b) Separated type
Detection Assembly with control unit:
type A: non-display
type B: with display

Fig.2 Monitoring post

by incident radiation and then return to base to emit light. This monitor measures radiation by amplifying this light through a photomultiplier tube and detecting it as an electrical signal. The measurements processed by the measurement unit are transmitted to nuclear facilities and radiation control systems managed by central agencies and municipalities for remote monitoring. Table 1 shows the specifications of the monitoring post.

(2) Features

(a) Energy compensation and temperature compensation functions

The measurement results of the NaI scintillation detector depend on the energy of gamma rays and the ambient temperature, and this equipment corrected them using the G(E) function weighting operation method. For temperature dependence, a thermometer is installed inside the detector to compensate for output changes by temperature changes. This compensation enables the variation of response within ±10% (100 keV to 3 MeV, ^{137}Cs) and the temperature characteristics within ±5% (–10°C to +45°C).

Table 1 Monitoring post specifications

Category	Specifications
Radiation detected	Ambient gamma rays
Detector	Temperature compensation type 2” ϕ × 2” NaI (Tl) scintillation detector
Measurement range	Background level to 100 μGy/h
Energy range	50 keV to 3 MeV
Limit of variation/ Reference source	±10% (^{137}Cs)
Variation of response	Within ±20% at 50 to 100 keV ±10% at 100 keV to 3 MeV (^{137}Cs)
Energy resolution	10% or less (for the high output wave of ^{137}Cs photopeak)
Detector temperature range	Within ±5% at –10ºC to +45ºC
Power supply	100 V AC ±10%, 50/60 Hz

Fig.3 A NaI scintillation detector

(b) Automatic correction function for gain change

When the NaI scintillation detector is used for long time, long-term drift of components may cause changes in gain and errors in measurement results. To handle this problem, Fuji Electric's detectors can correct automatically the gain using the 40 K peak channel in nature as the reference channel.

(c) Integration of the detector and the measurement unit

In conventional monitoring posts, the detector and the measurement unit are separate, but in this monitoring post, the measuring unit function is built into the detector to minimize size. Figure 3 shows a NaI scintillation detector. To meet the energy analysis requirements for gamma rays, this monitoring post is equipped with the multi-channel wave height analysis function used in conventional measurement units. The product also complies with the relevant standards [Equipment for continuously monitoring gamma radiation in the environment: JIS Z 4325 (2019)] and No. 17 of the Radioactivity Measurement Method Series.

(d) Diversification of communication functions

It is important for monitoring posts to be responsive to the diversification of communication functions, as their role becomes more crucial in disaster. The demand for the diversification of communication functions is increasing since the Great East Japan Earthquake, and Fuji Electric has continued to respond accordingly. In addition to the wired and cellular phone networks, the monitoring posts can support satellite communication networks and enable continuous monitoring even in congestion or cutoff of general lines.

3.2 Real-time ambient dose equivalent meter

(1) Overview

While monitoring posts are installed around nuclear facilities for main purpose of measuring changes in environmental radiation doses caused by the facilities, real-time ambient dose equivalent meters are installed mainly in schools, parks, and government offices, and are responsible for ensuring safety and security for residents. Figure 4 shows a real-time ambient dose equivalent meter.

The device consists of a radiation detector, a measurement unit, a communication unit, a solar panel, a battery, and a dose indicator, and has environmental radiation measurement, communications, and dose rate indication functions. In addition to commercial power supply, the power can be supplied by solar panels and internal batteries. This enables continuous measurements even during blackouts. Table 2 shows the specifications of the real-time ambient dose equivalent meter.

(2) Features

(a) Improved detection performance and enhanced stability of semiconductor detectors

The real-time ambient dose equivalent meter is equipped with a newly developed semiconductor detector. This semiconductor detector has a larger detection surface than the previous product[(1)], and its arrangement has been optimized, improving accuracy. Redundant electromagnetic shield and improved noise immunity have reduces the influence of various electromagnetic waves, contributing to measurement stability.

(b) Improved environmental resistance

The radiation detector, measurement unit, and communication unit are housed in reinforced plas-

Fig.4 Real-time ambient dose equivalent meter

Table 2 Real-time ambient dose equivalent meter specifications

Category	Specifications
Radiation detected	Ambient gamma rays
Detector	Semiconductor detector
Measurement range	Background level to 99.99 μSv/h
Energy range	50 keV to 3 MeV
Relative error	±20% (based on 60 keV to 1.25 MeV, ^{137}Cs reference)
Variation of response	±25% (based on 60 keV to 1.25 MeV, ^{137}Cs reference)
Operating environment	Non-weather protected, fanless
Power supply	100 V AC ±10%, 50/60 Hz

tic enclosure, but there are concerns about negative effects of infiltration of rainwater and moisture on electronic devices in stormy weather. The electrical parts and devices built in enclosure in small boxes by function with moisture-proof and waterproof finish. They make lower failure rate, and longer service lifetime by protecting from moisture.

4. New software platform for environmental radiation monitoring telemeter systems

(1) Overview

Radiation monitors such as monitoring posts measure radiation and radioactive materials emitted from nuclear power facilities 24 hours per day, 365 days per year. Measured data are collected by environmental radiation monitoring systems controlled by nuclear power facilities, central ministries, and municipalities, and used for monitoring operations. For residents near nuclear facilities, the data are displayed in real time on large-screen at government offices. The data are informed on internet. Fuji Electric has contributed well to providing systems, as well as development and manufacturing of radiation monitors. To meet recent diversification of customer requirements, we have developed a new software platform compatible with cloud systems and standard interfaces.

(2) Features

(a) Cloud migration

Conventional systems were on-premises mainly, in which customers own and manage infrastructure equipment such as servers. In recent years, plans to implement cloud systems have increased by business continuity plans (BCP) and system scale extensibility. The new software platform uses open source databases and middleware to ensure compatibility with next mainstream hosting clouds, reducing initial implementation and maintenance costs.

(b) Providing of various monitoring methods

The system screen is for management radiation doses in area to monitor the measurement data. The conventional system used Internet Explorer*1 as the standard browser with single window screen, causing inconvenience. HTML Living Standard based new development supports current mainstream browsers such as Microsoft Edge*2 and Google Chrome*3, and can also be displayed on smartphones and tablets. The operation screen offers multi-window mode to improve efficiency of monitoring operations. Figure 5 shows the displayed content of new platform using JavaScript*4. For front-end browser screen development, conventional platforms used JSP and Java*5 applets. New software platform uses JavaScript to implement a browser based on the HTML Living Standard, which enables the display of various contents such as videos and graphics.

(c) High scalability system

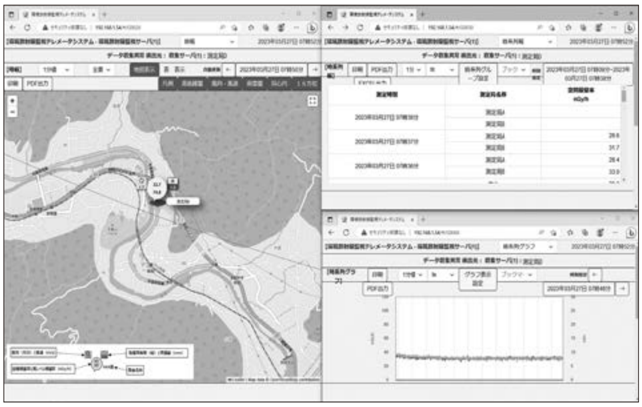

Fig.5 Display on new platform with JavaScript

Environmental radiation monitoring telemeter system renewal sometimes require security enhancement, operability improvements, function enhancement, and modification. Resources are often required to use the existing system for continuity of operations, and problem is that systems are hard to expand. The new software platform uses JavaScript Object Notation (JSON) as an interface to unify communications in several processes, making it easier to extend to meet customer requirements. There are JSON libraries adapt other programming languages enable to use existing resources.

5. Alpha-Ray Aerosol Monitor

(1) Overview

Nuclear power plants generate electricity by energy from fission of uranium, and plutonium as artificial radionuclide is produced on the process. The spent nuclear fuel contains uranium and plutonium that can be reused as fuel. Reprocessing extracts the uranium and plutonium and mix together to form the fuel called mixed oxide (MOX).

Japan is not rich in energy resources and is working for realization of a plutonium-thermal system with this MOX fuel in conventional nuclear power plants. To use plutonium safely and effectively, it is important to

*1 Internet Explorer is a trademark or registered trademark of Microsoft Corporation.

*2 Microsoft Edge is a trademark or registered trademark of Microsoft Corporation in the United States and other countries.

*3 Google Chrome is a trademark or registered trademark of Google LLC.

*4 JavaScript is a trademark or registered trademark of Oracle Corporation and its subsidiaries and affiliates in the United States and other countries.

*5 Java is a trademark or registered trademark of Oracle Corporation and its subsidiaries and affiliates in the United States and other countries.

improve the measurement of alpha rays emitted from plutonium, and Fuji Electric has developed an alpha-ray aerosol monitor that measures plutonium more accurately. Figure 6 shows a aerosol monitor image and an alpha-ray aerosol monitor. The alpha-ray aerosol monitor absorbs particle in a sampled air using the filter paper on precipitator to measure alpha rays.

(2) Features

(a) Noise reduction

Conventional aerosol monitors send measured pulse signals from radiation detector to separate measurement unit. But this way would mix noise in pulse. The alpha-ray aerosol monitor features an all-in-one detector and measurement unit to reduce noise contamination in communication line. Measurement and subsequent units use a digital communication system to reduce noise.

(b) High resolution

Detector is placed on filter paper on precipitator to measure alpha rays. Alpha rays are emitted at various angles from filter paper, and detector incident distances are various. As a result, there are fluctuations in the measured energy. This means that the resolution becomes lower, making it difficult to distinguish artificial radionuclides from radon and thoron, which are natural radionuclides. Alpha ray incident component of new detector has a honeycomb structure. Diagonally incident Alpha rays are blocked, and vertical incidents can be detected only (see Fig. 6). As a result, the range distance of alpha rays incident on detector is almost same, and this has reduced variation of measurement energy and achieved high resolution. Figure 7 shows measurement results of americium 241 (^{241}Am), an alpha-ray emitting radionuclide, and radon (Rn) and thoron (^{220}Rn), natural radionuclides. These results show that americium 241 has been measured separately from radon and thoron, which are natural radionuclides.

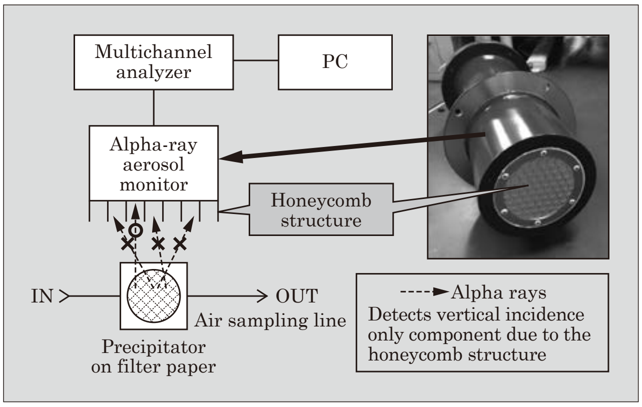

Fig.6 Aerosol monitor configuration and an alpha-ray aerosol monitor

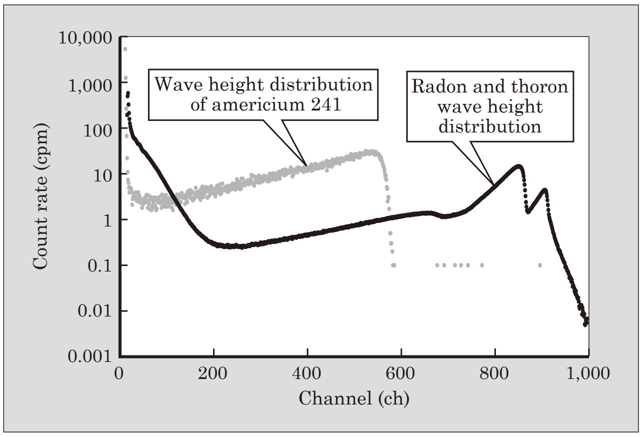

Fig.7 Measurements of americium 241, radon, and thoron

6. Postscript

This paper proposed radiation control, which contribute to safety and security. The achievement of decarbonized society and stable energy supply require to utilize nuclear energy. Fuji Electric, a manufacturer of comprehensive radiation measuring equipment providing from radiation detectors to systems, has innovated technologies to contribute to safe operation of nuclear power facilities.

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Comprehensive Service for Smart Industrial Safety, Which Improves Maintenance and Inspection Efficiency and Delivers Predictive Maintenance

SUNAGA, Yugo* FUKUSHIMA, Soji*

ABSTRACT

Utilities of industry and energy infrastructures such as power distribution equipment are faced with urgent challenges to overcome issues of aged deterioration of equipment, long-term shortages and aging of workers for repair and maintenance, and capability degradation to pass down technologies and skills. Demand is thus increasing for smart maintenance, improved inspection efficiency, and predictive maintenance. Fuji Electric offers "Comprehensive Service for Smart Industrial Safety," in which we collect and analyze a variety of information from the equipment to plan maintenance planning, monitor equipment, and suggest maintenance management measures, optimizing equipment maintenance. We are expanding the application of these services by adding new services, such as equipment operating condition and trend monitoring and rotating machine vibration monitoring.

1. Introduction

The fields of industrial and energy infrastructure are facing a number of issues, including the deterioration of equipment due to age, long-term labor shortages and the aging of the repair and maintenance workforce, and a rapid decline in the ability to pass down technologies and skills. In addition, in order to maintain a healthy infrastructure, it is necessary to respond to various changes, such as the increasing severity of disasters, the risk of terrorism, and the advancement of a digital society defined by new technologies.

To address these challenges, the Public-Private Council on Smart Industrial Safety was established by the Ministry of Economy, Trade and Industry on June 26, 2020, and the Smart Industrial Safety Action Plan has been proposed for the field of electrical security. In accordance with this action plan, electrical equipment suppliers, including Fuji Electric, and customers who operate equipment are asked to maintain and enhance their maintenance capability and improve productivity to advance smart maintenance for electric equipment. They accordingly aim to promote the proliferation and expansion of smart industrial safety technologies and to introduce various new technologies to industrial safety service sites, such as the Internet of Things (IoT), artificial intelligence (AI), wearable devices, and drones. This paper describes Fuji Electric's "Comprehensive Service for Smart Industrial Safety," which contributes to improving the efficiency of maintenance and inspection and implementing predictive maintenance.

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

2. Services Provided by Fuji Electric[(1)]

Figure 1 shows an overview of Fuji Electric's smart integrated service solutions that use digital transformation (DX).

The Ministry of Economy, Trade and Industry defines DX as "efforts by companies to establish competitive advantages, respond to significant changes in business environments, utilize data and digital technology, and reform products, services and business models, as well as organizations, processes and company culture, based on the needs of customers and society."

The Comprehensive Service for Smart Industrial Safety, described in detail in Chapter 4, aims to improve efficiency by innovating maintenance operations, such as routine patrol inspection, conducted by human resources with digital technologies. At the same time, most of these maintenance work requires human senses and intuition, which cannot be replaced by digital technologies or tools. Therefore, it is also necessary to continue training workers and improving efficiency using digital technology.

Fuji Electric will integrate service solutions that apply digital technology in both aspects to offer smart integrated services, with the maintenance work made more smart, efficient and optimal.

3. Equipment Maintenance Related Challenges[(2)]

Industrial infrastructure such as power distribution equipment and factories containing production equipment are typically faced with challenges of operating equipment stably and reducing maintenance costs. Until now, equipment has been managed so that stable operation can be maintained through time based maintenance (TBM), which is carried out in the form of regular manual inspections and maintenance

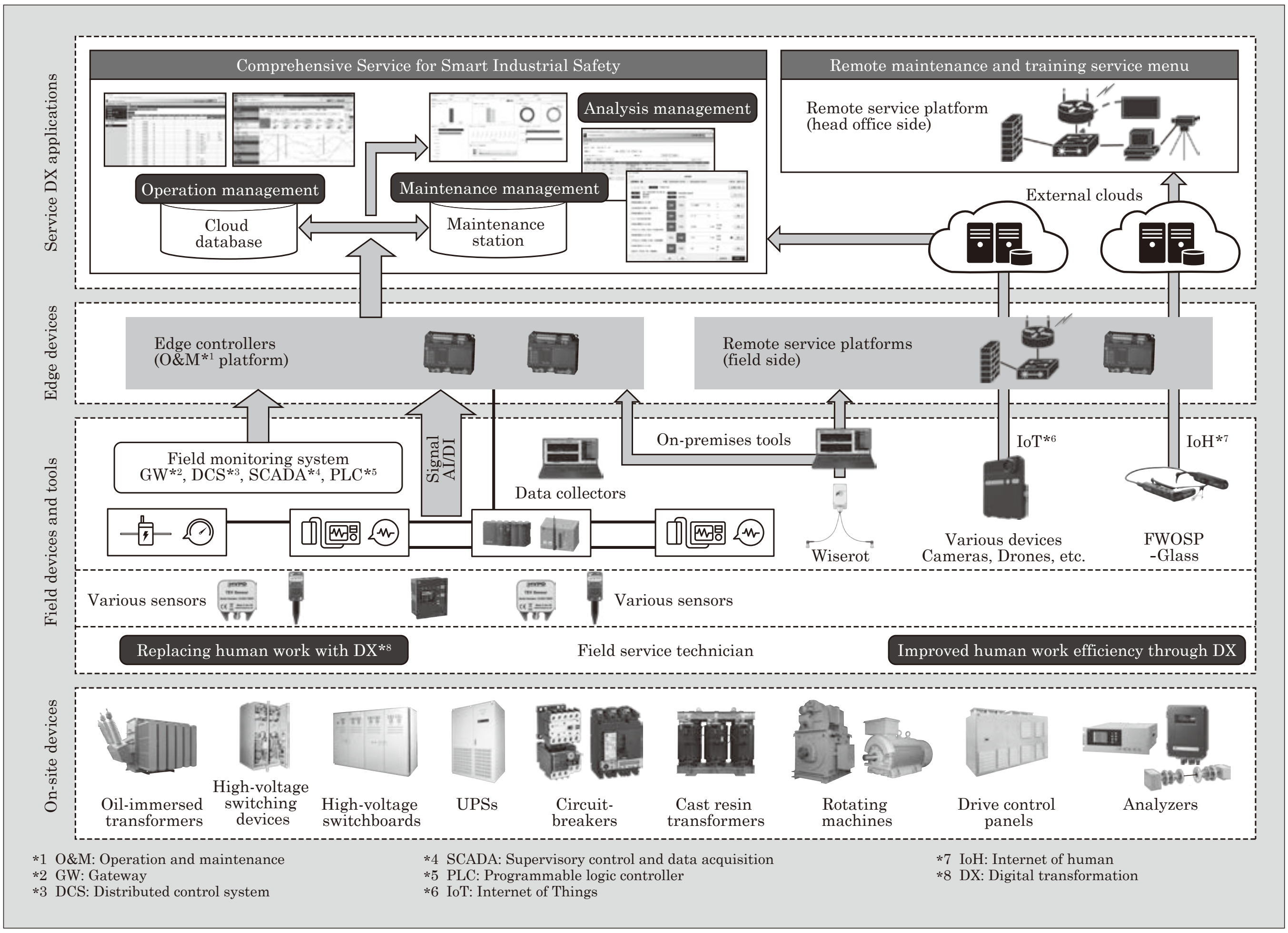

Fig.1 Overview of smart integrated service solutions

operations. On the other hand, condition based maintenance (CBM) involves the collection of various information pertaining to equipment and the identification and analysis of equipment conditions to perform maintenance work depending on the conditions. CBM is expected to optimize inspections, improve efficiency, counter the shortage of personnel required for maintenance, and enable predictive maintenance through the analysis of condition information. To achieve this, we need to promote "smart industrial safety" by applying IoT and digital technologies to maintenance work that was manually conducted; automating the collection, recording, and management of information; and applying software to analyze the collected data in an integrated manner.

4. Fuji Electric's "Comprehensive Service for Smart Industrial Safety"

In fiscal 2022, Fuji Electric began offering its Comprehensive Service for Smart Industrial Safety, which uses IoT and AI to optimize equipment maintenance, from maintenance planning to equipment monitoring and the proposal of maintenance management measures for power distribution equipment.

4.1 Overview of the "Comprehensive Service for Smart Industrial Safety"[3]

Figure 2 shows an overview of the Comprehensive Service for Smart Industrial Safety. The Comprehensive Service for Smart Industrial Safety consists of operation and maintenance (O&M) service applications that conform to ISO 18435 (O&M integrated model). By sharing equipment information between customer worksites, administrators, and Fuji Electric, mainly through an Azure*1 based cloud system, we will build a smart industrial safety system.

As shown in Fig. 2, by using a cloud system, worksite personnel, administrators, and Fuji Electric can share and utilize maintenance related information even from locations far from the worksite, and by using service applications on the cloud, cumbersome tasks such as software update and management become unnecessary.

The collected data ranges from operating information from on-site devices, measurement data from sensors and meters, maintenance records, inspection

*1 Azure is a trademark or registered trademark of Microsoft Corporation.

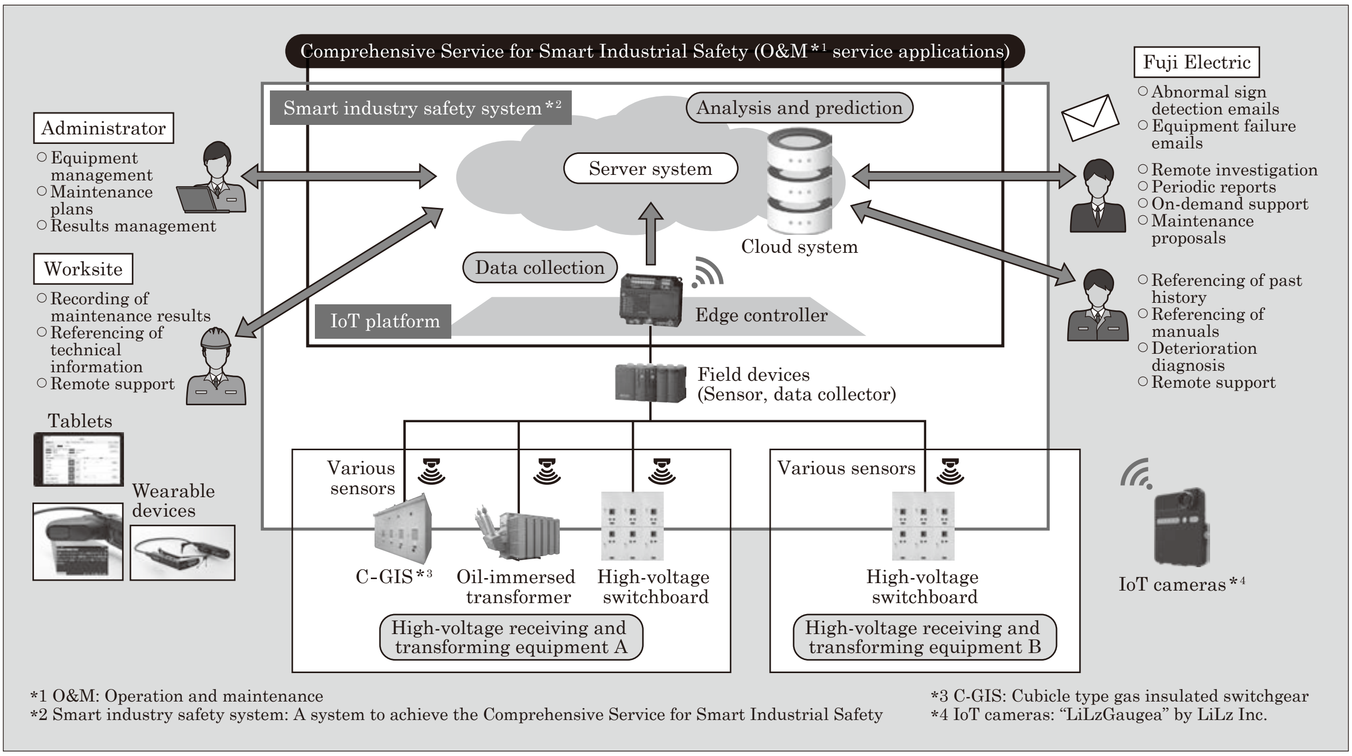

Fig.2 Overview of the "Comprehensive Service for Smart Industrial Safety"

records, and to daily and monthly reports. It is expensive and difficult to build, install, and maintain data servers that accumulate data over periods of ten years or more at the worksite. Furthermore, the worksite is required to bear all of the data security risks. Cloud systems allow customers to maintain and manage data for a long time by always using the latest security technology.

4.2 Functions of the "Comprehensive Service for Smart Industrial Safety"

Figure 3 shows the functional configuration of the Comprehensive Service for Smart Industrial Safety. The Comprehensive Service for Smart Industrial Safety consists of the following three functions.

(1) Operation management functions

The management of online information collected from the desired equipment

(2) Maintenance management functions

The management of offline information such as work plans, work instructions, work results, and maintenance results mainly pertaining to maintenance work performed by people

(3) Analysis management functions

The integration of various kinds of data and the implementation of "individual analysis" and "advanced BI analysis." Business intelligence (BI) analysis refers to the analysis and visualization of various company data for management and business purposes.

These functions systematically collect online equipment information, such as operation state, failure, and deterioration data, as well as offline information pertaining to maintenance work, such as work contents and inspection records, and store them in a database to perform multidirectional analysis. This function enables users to monitor operating information and

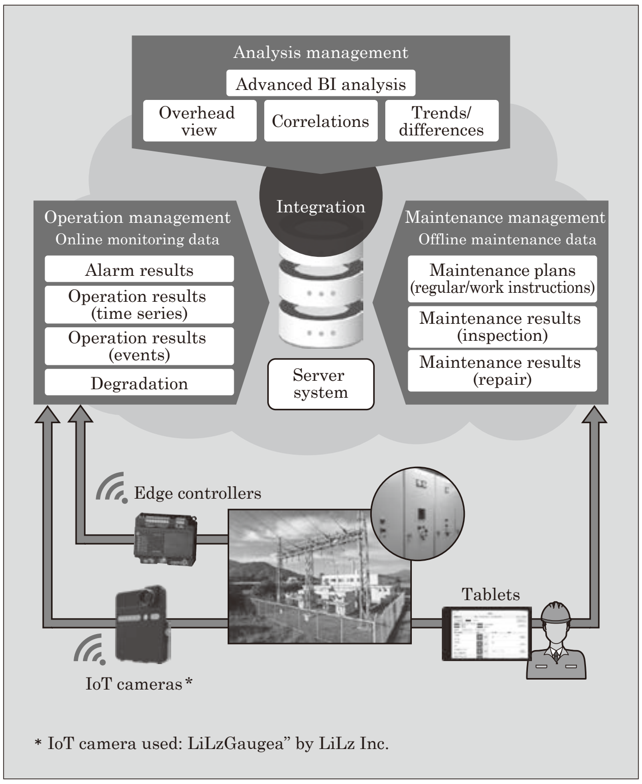

Fig.3 Functional configuration of the "Comprehensive Service for Smart Industrial Safety"

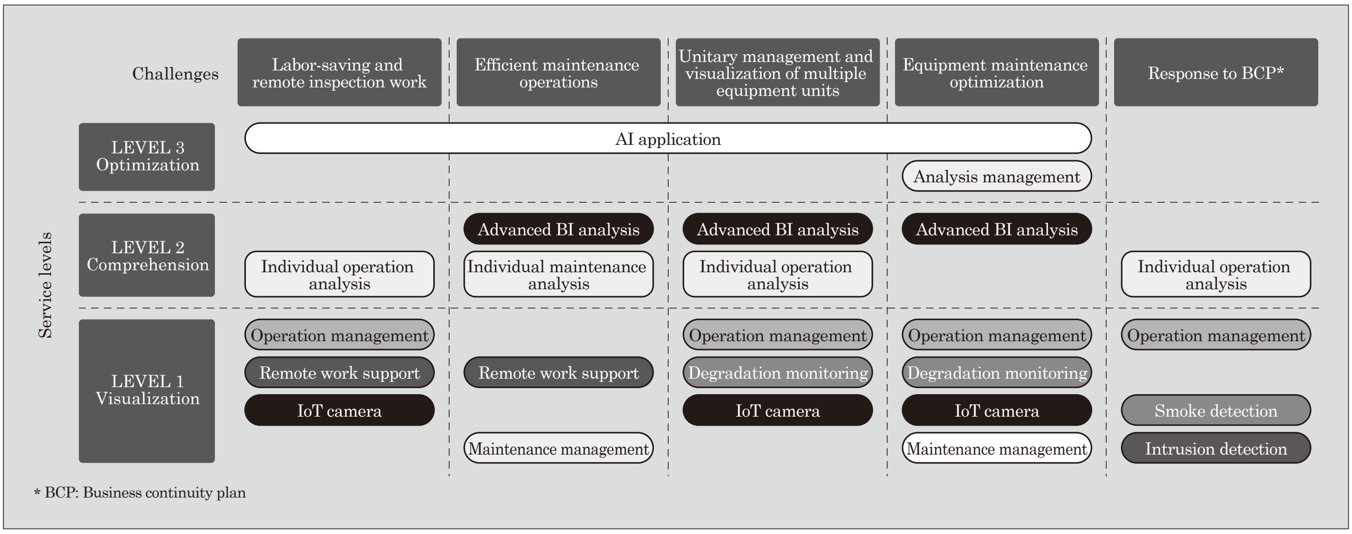

Fig.4 Smart levels in maintenance operations

deterioration diagnosis information by viewing them in the form of trends, improve maintenance efficiency by utilizing digital tools, and check equipment conditions before and after inspections by comparing them with inspection results. Furthermore, changing the cycle of periodic inspections based on the details of analyzed information can reduce maintenance costs and catching failure signs through data analysis and performing proper maintenance can stabilize equipment operations.

4.3 Smart maintenance work that the "Comprehensive Service for Smart Industrial Safety" aimed for

Figure 4 shows the smart levels of maintenance work. As shown in the figure, the Comprehensive Service for Smart Industrial Safety categorizes challenges and smart levels at worksites, allowing users to gradually increase the level of provided services according to customer's maintenance situations.

(1) Level 1 (Visualization)

Visualization will promote the digitization of maintenance site information by introducing IoT devices, digitizing work records, and supporting remote work. These activities include visualizing work results and the maintenance conditions of equipment by acquiring digital images of equipment states through remote monitoring and IoT cameras, as well as by digitizing device deterioration monitoring information and inspection records. They also include disaster prevention and security such as fire prediction and intrusion detection.

(2) Level 2 (Comprehension)

Comprehension refers to individually analyzing the trends and differences in various types of operation and maintenance information and identifying challenges and improvements through BI tools that perform multifaceted advanced analysis such as overviews and correlations of various types of data. These analyses and diagnostic results lead subsequent inspections, maintenance, and updates.

(3) Level 3 (Optimization)

The optimization phase is aiming at achieving optimization through automated evaluation, diagnostic accuracy improvement, and sign detection by adopting AI engines suitable for individual tasks to provide integrated improvement services such as analysis and consultation regarding equipment conditions and maintenance needs from multiple perspectives. This phase has remained room where further technological advancements are still required. To reach this goal, we must strive to achieve visualization and comprehension together with customers. The Comprehensive Service for Smart Industrial Safety is a collaborative DX solutions for maintenance and safety services, in which Fuji Electric works closely with its customers to make the services more smart.

5. Application Examples

This chapter describes Fuji Electric's efforts at the Yamanashi Factory as an example of the application of the Comprehensive Service for Smart Industrial Safety. The Yamanashi Factory manufactures semiconductors and has promoted the smartness of the receiving and transforming equipment and other particularly important auxiliary equipment.

5.1 Visualization of the operating conditions of high-voltage receiving and transforming equipment

Figure 5 shows examples of the monitoring of operating conditions and trends for high-voltage receiving and transforming equipment. The operating conditions of equipment and their soundness can be understood visually by converting the operating conditions of the equipment into data and monitoring trends over long periods of time.

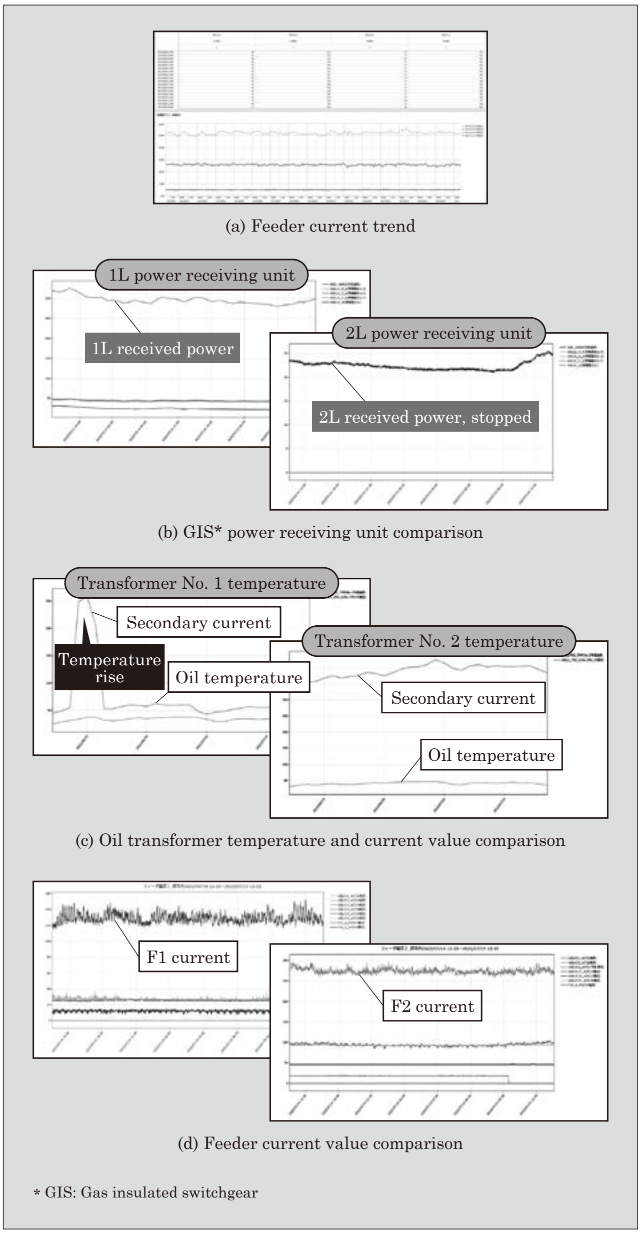

Fig.5 Examples of operating condition and trend monitoring of high-voltage receiving and transforming equipment

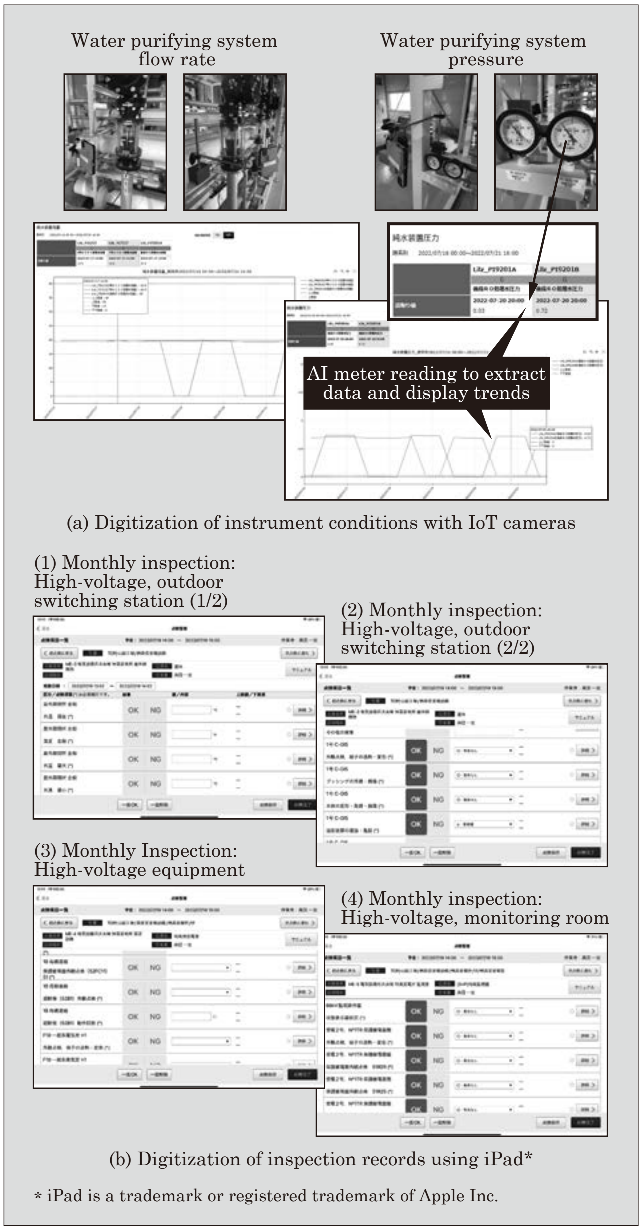

Fig.6 Examples of visualization of maintenance operations

5.2 Examples of visualization of maintenance operations

Figure 6 shows some examples of the visualization of maintenance operations. In conventional maintenance operations, the values of various instruments and meters were checked visually by personnel during routine patrol inspections and recorded on paper. These can now be automatically read and recognized using AI-applied IoT cameras and recorded as digital data. Similarly, inspection records that were conventionally recorded on paper are being digitized and made more efficient by using tablet devices such as iPads*2.

*2 iPad is a trademark or registered trademark of Apple Inc.

5.3 Integration of operation monitoring and maintenance management data, and advanced BI analysis

Figure 7 shows an example of the application of BI tools. This is an example of a trial for efficiency analysis of inspection operations through the integration of maintenance management data, such as inspection plans and inspection performance records, with operation monitoring data. In addition to differences in inspection time and comparisons between plans and results, the tool can be used to check the operating conditions of equipment before and after each inspection to provide feedback on the proficiency of inspection workers and the optimization of inspection sequence. BI tools can analyze correlations and trends of various types of information in multiple ways, but the information and analysis results are often specific to the target

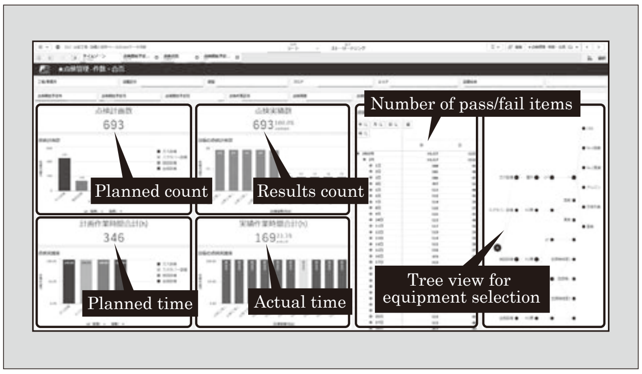

Fig.7 BI tool application example

equipment and maintenance personnel. Fuji Electric will cooperate with customers who operate and manage equipment by introducing the Comprehensive Service for Smart Industrial Safety and share information with them to add value and improve maintenance and efficiency.

5.4 Rotating machine vibration monitoring

Figure 8 shows an example of vibration monitoring for a rotating machine. Rotating machines are commonly used for production equipment such as generators, pumps and compressors, and when they stop operating due to failures, production plans are greatly affected. The Comprehensive Service for Smart Industrial Safety provides predictive maintenance through vibration monitoring by utilizing the rotating machine failure sign monitoring system "Wiserot." It analyzes information from wireless vibration sensors by using an original algorithm, detects bearing failures, and suggests maintenance accordingly.

5.5 Electrical room fire sign monitoring

Figure 9 shows an example of fire sign monitoring.

The Comprehensive Service for Smart Industrial Safety provides a function for monitoring warning signs of fire accidents, which are often seen in electrical rooms and switchboards. By linking a fire sign detection system from NOHMI BOSAI LTD., which can

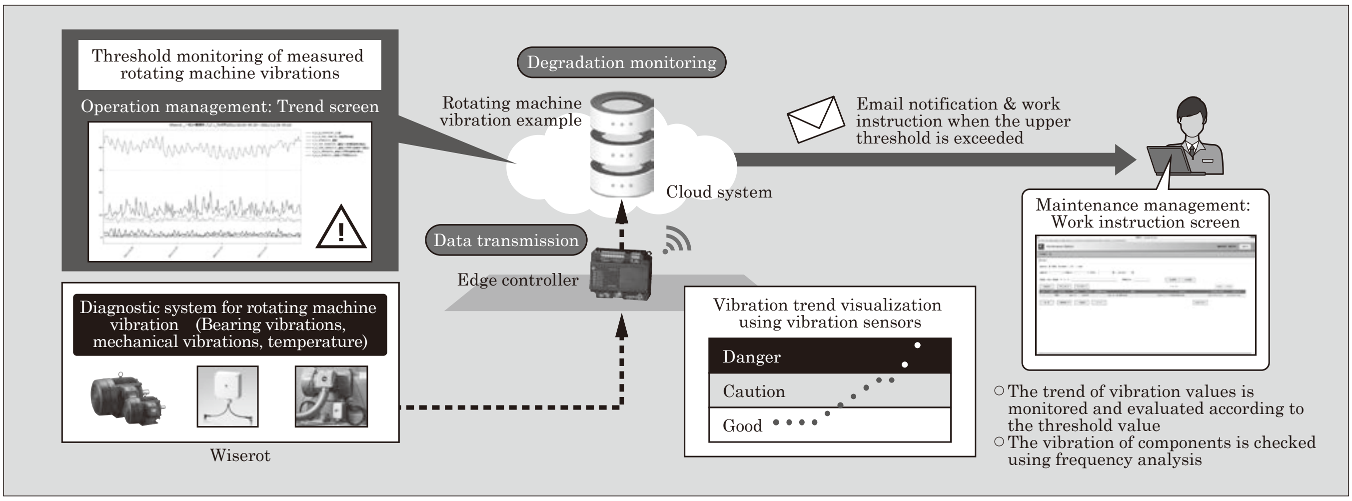

Fig.8 Rotating machine vibration monitoring example

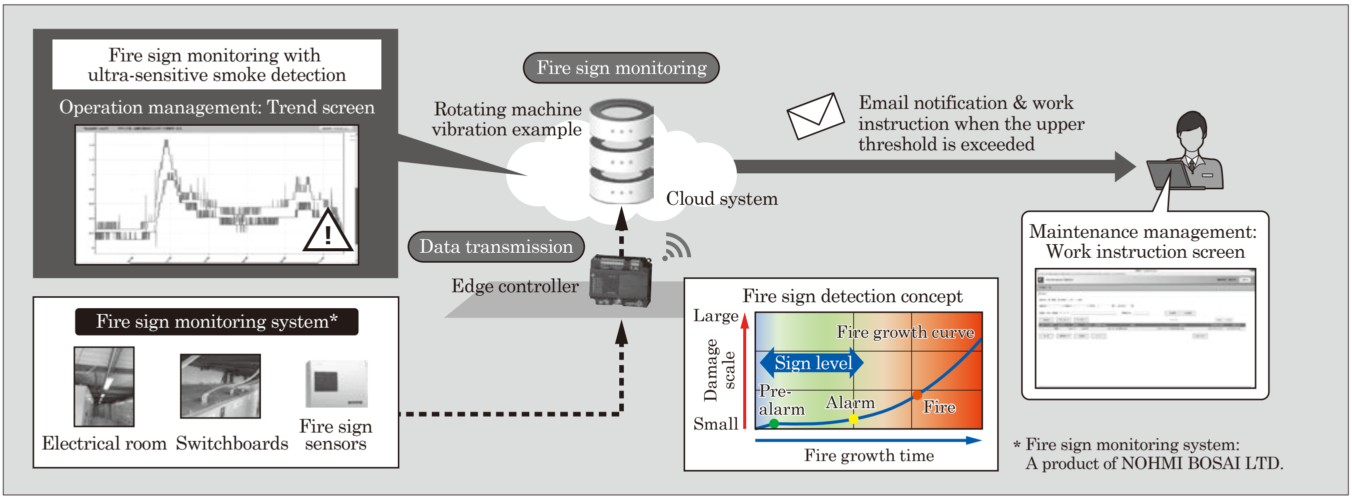

Fig.9 Example of sign monitoring for fires

detect the outbreak of smoke as a warning sign from the earliest stage of a fire, the cloud monitoring function of the Comprehensive Service for Smart Industrial Safety can detect the initial signs of fire and respond promptly and thoroughly by issuing not only on-site alarms, but also email notifications.

6. Postscript

This paper has described smart industrial safety services that contribute to improving the efficiency of maintenance and inspection and achieving predictive maintenance. Fuji Electric will continue to improve its "Comprehensive Service for Smart Industrial Safety" by enhancing the deterioration diagnosis function, proactively incorporating various IoT devices and digital technologies to expand the scope of security operations and improving the interface to make it easier to understand the conditions. We also intend to strengthen our knowledge of advanced analytical technology obtained through accumulated data, build up our track record of verification and identification of effects through the use of demonstration equipment at our own factories, and work together with our customers to add even more value.

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4-in-1 Modules with Ratings of 1,700 V / 75-200 A

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Power conversion devices, especially insulated gate bipolar transistor (IGBT) modules, are widely used as core devices in power conversion system that convert electrical energy between AC and DC or vice versa. IGBT modules are required to have not only high performance and high reliability, but also features contributing to simplified equipment design work and equipment downsizing. In addition, they must also have characteristics that are suitable for circuit systems of various applications.

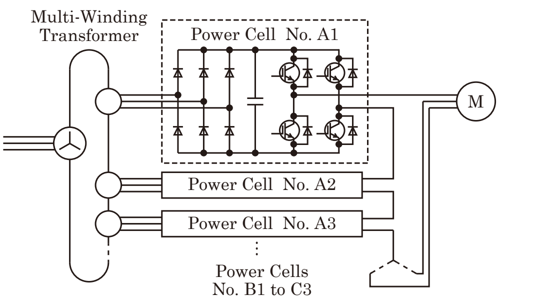
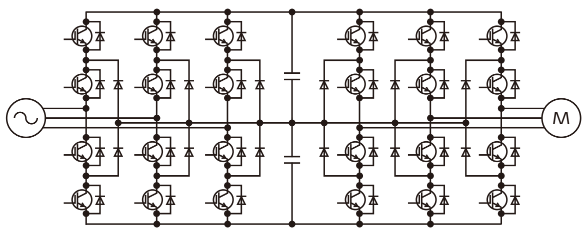
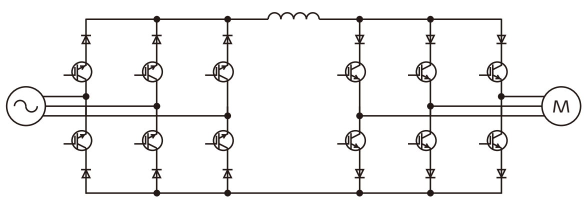
This paper describes a newly developed 1,700-V/75- to 200-A 4-in-1 module optimized for the circuit configuration of medium-voltage inverters.

1. Features

Medium-voltage inverters are power converters that control output voltage and frequency, designed for high input voltages of 690 V or higher. They are used in a variety of fields, including metal processing, chemical plants, and natural gas and fossil fuel mining. Table 1 shows circuit systems of medium-voltage inverters. Among these circuit systems, the series-connected multi-stage unit type occupies nearly 60% of the global market share, primarily in China, due to its simple configuration and easy maintenance features. In the future, it is expected to continue to be a mainstream medium-voltage inverter.

Conventional series-connected multi-stage unit type medium voltage inverters combine two 2-in-1

Table 1 Medium-voltage inverter circuit systems

	Circuit example	Features	Applicable module	Market share percentage and primary regions of use
Series-connected multi-stage unit type		○ Simple topology ○ Easy maintenance ○ Output adjustable according to the number of series ○ Input transformer required (High cost)	1,700 V/75–1,200 A 2-in-1 module	60% Worldwide (China, etc.)
3-level type		○ With no transformer ○ Complex topology	3.3 kV/800–1,500 A 4.5 kV/400–1,500 A HPM	30% Europe and the U.S.
Current source type		○ Reverse blocking diode required (High loss)	6.5 kV/400–1,500 A Press Pack (GCT)	10% Europe and the U.S.

* Semiconductors Business Group, Fuji Electric Co., Ltd.
⁑ Fuji Electric (Shenzhen) Co., Ltd.

modules and one converter diode module. In contrast, the newly developed 1,700-V 4-in-1 module, as shown in Figs. 1 and 2, optimizes the input rectifier circuit and output inverter circuit, and incorporates a three-phase rectifier circuit, H-bridge circuit, and thermistor in one package. Since an inverter unit can be configured with only one of these modules and passive components, the unit can be easily multi-leveled. By providing the product as a single package, the footprint of the module has been reduced by 54%.

The newly developed 1,700-V 4-in-1 modules are lined up in the same packaging up to 75 A to 200 A, as shown in Table 2.

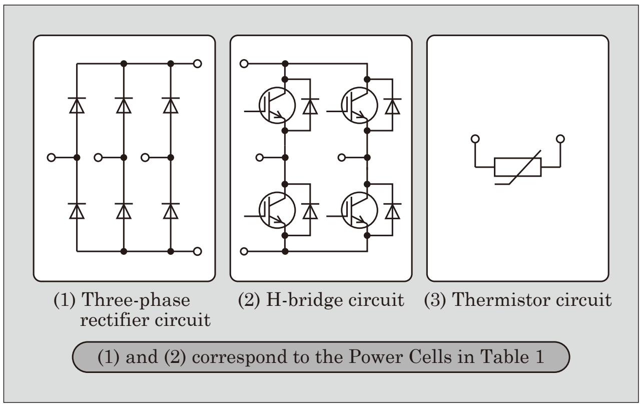


Fig.1 Equivalent circuit diagram

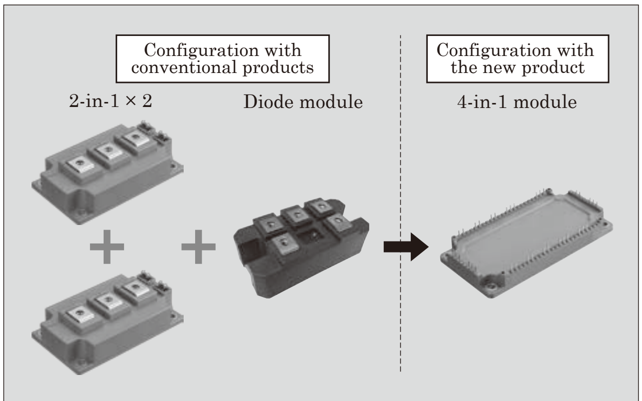
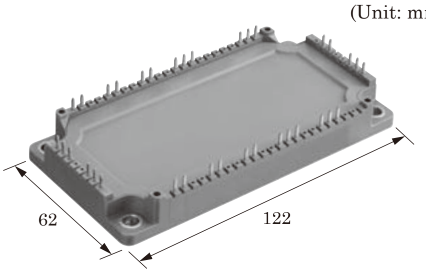


Fig.2 Comparison of medium-voltage inverter module configurations

Table 2 Lineup of the 1,700-V 4-in-1 module

Rated voltage (V)	Rated current (A)			
	75	100	150	200
1,700	⟶	⟶	⟶	⟶
Appearance EconoPIM™ *	(Unit: mm) 			

* EconoPIM™ is a trademark or registered trademark of Infineon Technologies AG

2. Applied Technologies

2.1 Heat concentration reduction through layout optimization

Since the footprint has been reduced by 54% as described in Chapter 1, the module's thermal density has increased. Therefore, one of the technical challenges in the development of this product was to suppress the rise in chip temperature caused by thermal interference between adjacent chips.

The new product uses the 7th-generation free-wheeling diodes (FWDs) to reduce power loss during inverter operation, thereby suppressing the rise in temperature of the module and making it possible to mount a 4-in-1 circuit in a single package, instead of the conventional configuration of two 2-in-1 packages.

To suppress the temperature rise, this module has an optimal chip arrangement to minimize the effect of thermal interference between chips. Figure 3 shows the result of temperature analysis using the finite element method. This result has demonstrated that when all built-in chips are producing heat at the same time, under the most severe conditions, the maximum temperature of the IGBT chip is 142.6°C. The maximum temperature of this module is less than 5% higher than 136°C, the average of all chips. The results confirm that the temperature of one chip does not rise excessively even when the heat generation density increases.

2.2 Higher reliability through the use of 2,200-V converter diodes

Considering the use of medium-voltage inverters in areas with an unstable power supply, it is necessary to improve the overvoltage withstand capacity to external surge voltages, and the input surge current withstand capability to surge currents generated during recovery from instantaneous voltage drops. Therefore, we have developed a converter diode with a withstand voltage of 2,200 V, exceeding the module's withstand voltage of 1,700 V, as well as surge current withstand. Figure 4 shows a comparison of the surge current withstand

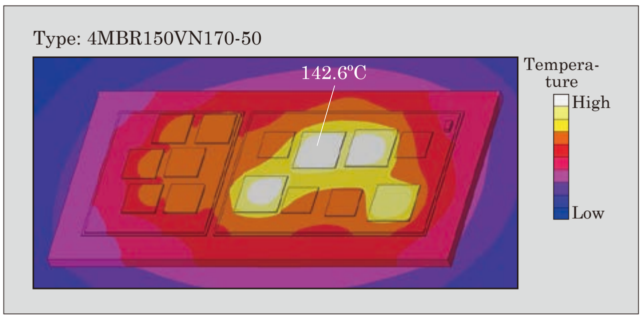


Fig.3 Result of temperature analysis using the finite element method (total phase heat generation)

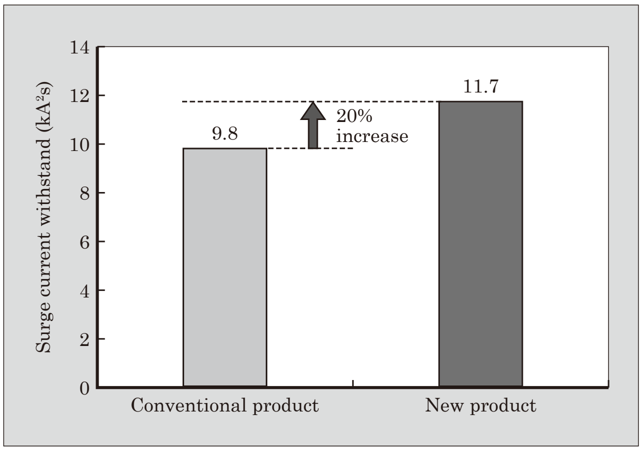


Fig.4 Results of a comparison of surge current withstand (T_{vj} = 150°C)

capacity of the conventional module and the new product module. Compared with the conventional module, the withstand capacity has been increased by 20% and achieved higher reliability.

3. Application Examples

Figure 5 shows the comparison data of the dissipation loss on a medium-voltage inverter that uses the newly developed 4-in-1 module with the conventional 2-in-1 module. The newly developed 4-in-1 module (4MBR150VN170-50) demonstrated a 3% reduction in generated loss compared to the conventional 2-in-1 module (2MBI150VH-170-50). As a result, it is possible to install a 4-in-1 module with a footprint 54% smaller than conventional models without changing

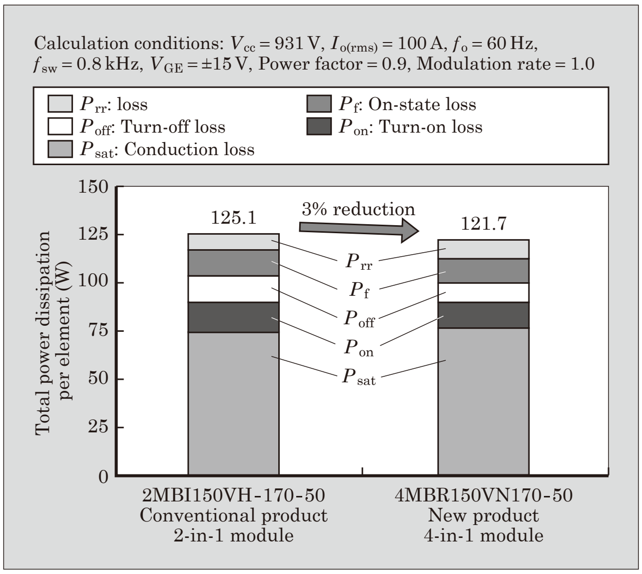


Fig.5 Results of a comparison of generated loss

the inverter's peripheral components, contributing to the miniaturization of the entire system.

Launch Date

April 2021

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External Operating Handles and Terminal Covers for Molded-Case Circuit Breakers and Earth Leakage Circuit Breakers

ISHIDO, Hideki*

Molded-case circuit breakers and earth leakage circuit breakers (hereinafter "circuit breakers") mounted on the control panels of electrical and mechanical equipment widely use optional accessories such as external operating handles used for turning ON and OFF the devices from outside the panel, as well as terminal covers that cover the live part of terminals to prevent electric shock. In recent years, the diversification of usage environments has been progressing. As such, control panels are required to deliver better waterproof performance, improved safety for in-panel equipment maintenance, ease of installation, and maintainability.

In response to these needs, we simultaneously developed N-shaped external operating handles (directly attached to the circuit breaker) and terminal covers for the "G-TWIN Series" of 32 to 100 ampere frames (AF). Launched in December 2021, these accessories provide latest protection structure for electrical safety (see Fig. 1).

1. External Operating Handles

1.1 Features of the N-shaped external operating handles for the 32 to 100AF

The features of the newly developed external operating handles are as follows.

(1) The waterproof structure has been improved to IP54 compared to the conventional model (IP50 equivalent).

(2) The product conforms to regional standards of IEC, JIS, GB, and UL/CSA. They have also obtained the EN/CE mark through a third-party assessment.

(3) The lineup includes a flat handle provided with a flat decorative plate to prevent the handle operation parts from protruding from the panel surface. It reduces the risk of damage during panel transportation and erroneous operation after installation.

(4) Alignment marks are added to both the handle itself and the decorative plate to reduce the time required for fitting and adjustment.

(5) The door can be opened while the handle is in the locked state (locked with a padlock in the off position) (optional). This saves the trouble of removing the padlock when opening the door and enables safe maintenance and inspection work.

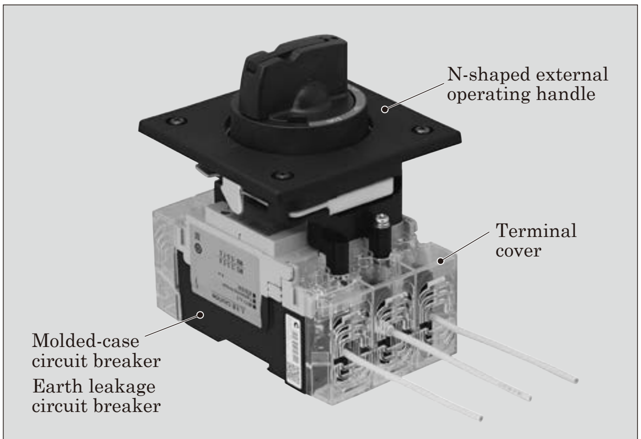

Fig.1 N-shaped external operating handle and terminal cover

1.2 Applied technologies

(1) Waterproof rating

Although the conventional N-shaped external operating handles comply with the U.S. NFPA 79 (U.S. Electrical Standard for Industrial Machinery) standard, additional waterproof performance is required at some installation sites. For this reason, we have completely revised the structure of the operation parts of the N-shaped external operating handles. To prevent water from entering from the outside, we have innovated the engagement of the electromechanical parts and installed packing at the surface contacts between the decorative plate and the door panel and between the latch and the cover (see Fig. 2). In addition, we

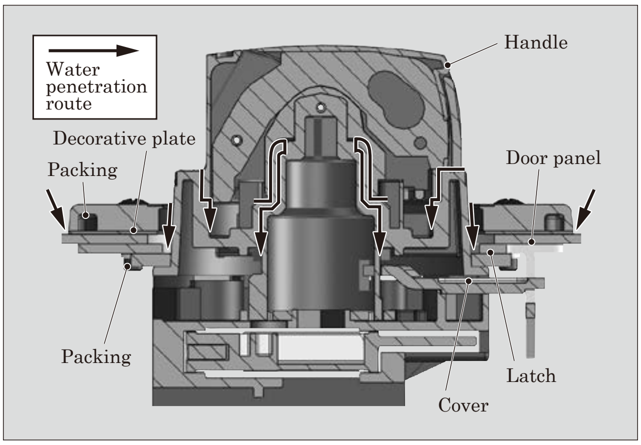

Fig.2 Internal structure of the N-shaped external operating handle

* Fuji Electric FA Components & Systems Co., Ltd

have revised the design to comply with IP54 and provide dust protection, thereby obtaining third-party performance certification.

(2) Door panel opening function

The external operating handle has a locking mechanism that prevents the door panel from opening even when the circuit breaker is OFF (no current flows through the circuit). This is a standard safety feature to prevent the door panel from being opened carelessly. On the other hand, there is a need for some users to prioritize maintainability so that they can open the door to perform maintenance on internal equipment when the circuit breaker is OFF. We therefore offer a special product with a redesigned handle operation locking mechanism. Only when the panel is not energized and the handle is locked by a padlock so that ON operation cannot be done, the release mechanism allows the door panel to be open with a tool such as a screwdriver (see Fig. 3).

(3) Non-protruding door panel surface

As shown in Fig. 4, conventional external operating handles commonly protrude from the door panel surface. However, protrusion from the door panel surface sometimes leads to unintentional erroneous operation or damage during transportation or installation. Therefore, to prevent erroneous operation and damage, we have added a new special product with a decorative plate attached to the door panel. This prevents the entire handle from protruding from the door panel surface, as shown in Fig. 5.

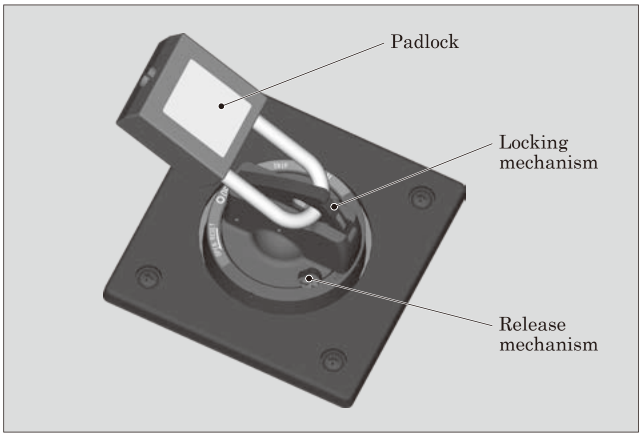

Fig.3 Panel door-opening structure in the OFF state of the circuit breaker

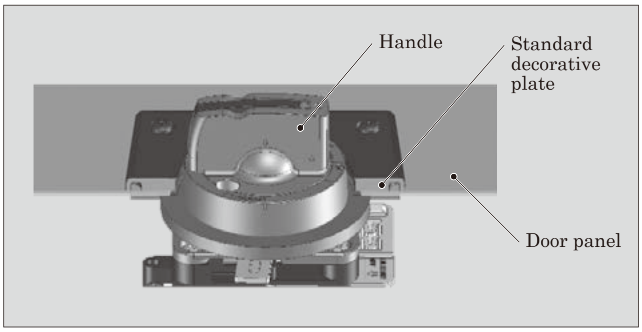

Fig.4 External operating handle (standard decorative plate) structure

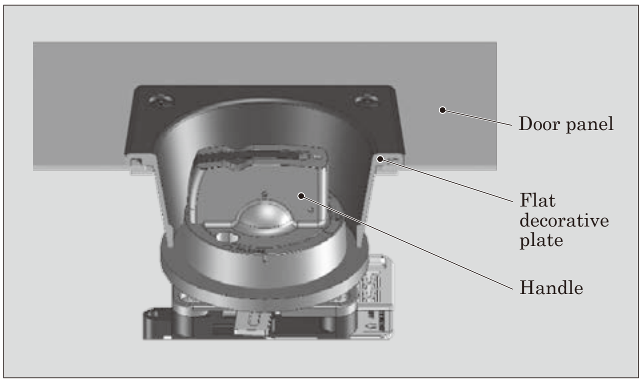

Fig.5 External operating handle (flat decorative plate) structure

2. Terminal Covers

2.1 Features of the terminal covers for the 32 to 100AF

The features of the newly developed terminal covers are as follows:

(1) A short type and a long type can be selectable according to the protective structure of the exposed live part of connected round crimp terminals.

(2) The products comply with the IP20 protection requirement for the power supply side of the power disconnector in the control panel standard. It also complies with IP20 on all sides, providing electric shock protection even when accessed from the back side for maintenance and inspection. By cutting the terminal cover opening in accordance with the wire size, an IP20 degree of protection can be maintained for the live part.

(3) The products conform to regional standards of IEC, JIS, and UL/CSA. Furthermore, they have also obtained the EN/CE mark through a third-party assessment.

(4) A protective hole structure has been adopted, allowing the terminal screws to be tightened and the power to be tested without removing the terminal cover.

(5) The terminal cover can be attached and detached even when the main unit is mounted in a dense, side-by-side configuration, making attachment and detachment easy even when used for a branch circuit.

(6) Fire-resistant materials have been adopted as standard (UL 94 flame retardant level: V-2).

2.2 Applied technologies

(1) Degree of protection

The conventional terminal cover has a structure that prevents fingertips from touching the live part of the terminal from the front, but with the recent increase in the demand for safety, it has become necessary to protect the live part from all sides, including the back. Therefore, to prevent fingers and tools from entering from the front, back, sides, and wire opening, we have restructured the terminal cover into two parts, a lower terminal cover and an upper terminal cover. In this manner, IP20 compliance is achieved in all directions (see Fig. 6).

(2) Improved maintainability

A new guide hole has been added to allow tools to be inserted when tightening terminals and conducting power inspections. This makes it possible to perform maintenance work without removing the terminal cover (see Fig. 6).

(3) Improved applicability

As shown in Fig. 7, the wire openings on the terminal covers have a structure that enables cutting with a nipper according to the size of the wires, thereby achieving IP20 compliance for wires of 2 to 60 mm^2 used for currents of 3 to 100 A. Furthermore, it is possible to modify the upper and lower terminal covers to widen the wire openings, thereby enabling the parallel connection of two wires (see Fig. 7).

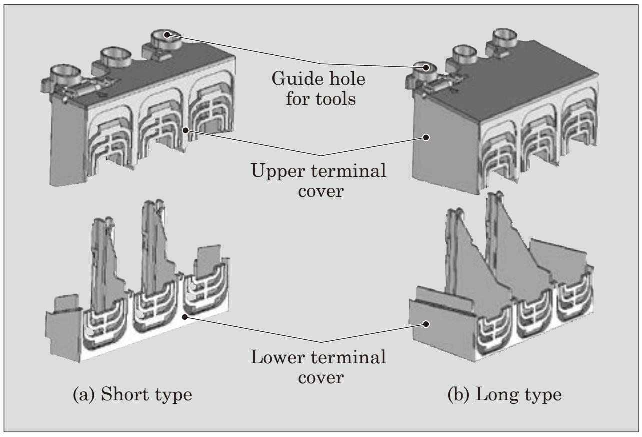

Fig.6 Terminal cover (3-pole product) structure

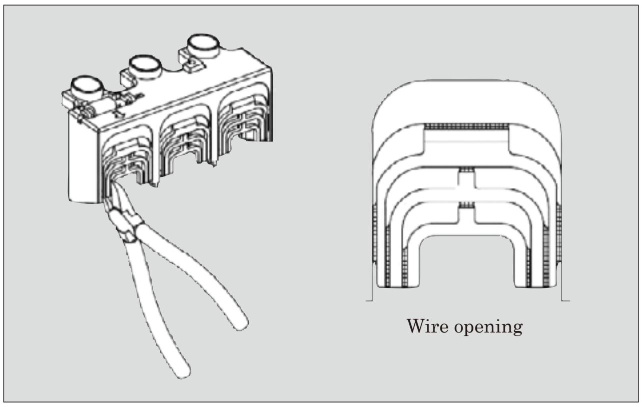

Fig.7 Wire opening structure of the terminal cover

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* Non-consolidated subsidiaries

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Sales of semiconductor devices, electrical distribution and control equipment, and drive control equipment
URL http://www.fujielectric.com.tw/

Fuji Electric Korea Co., Ltd.
Sales of power distribution and control equipment, drive control equipment, rotators, high-voltage inverters, electronic control panels, medium- and large-sized UPS, and measurement equipment
URL http://www.fujielectric.co.kr/

Fuji Electric Co.,Ltd. (Middle East Branch Office)
Promotion of electrical products for the electrical utilities and the industrial plants
Tel +973-17 564 569

Fuji Electric Co., Ltd. (Myanmar Branch Office)
Providing research, feasibility studies, Liaison services
Tel +95-1-8382714

Representative office of Fujielectric Co., Ltd. (Cambodia)
Providing research, feasibility studies, Liaison services
Tel +855-(0)23-964-070

■Equity-method Affiliates

Fuji Furukawa E&C (Thailand) Co., Ltd. *
Design and installation contracting for electric facilities construction
Tel +66-2-308-2703

Europe

Fuji Electric Europe GmbH
Sales of electrical/electronic machinery and components
URL https://www.fujielectric-europe.com/

Fuji Electric France S.A.S
Manufacture and sales of measurement and control devices
URL https://www.fujielectric.fr/en

Fuji N2telligence GmbH *
Sales and engineering of fuel cells and peripheral equipment
Tel +49 (0) 3841 758 4500

China

Fuji Electric (China) Co., Ltd.
Sales of locally manufactured or imported products in China, and export of locally manufactured products
URL http://www.fujielectric.com.cn/

Shanghai Electric Fuji Electric Power Technology (Wuxi) Co., Ltd.
Research and development for, design and manufacture of , and provision of consulting and services for electric drive products, equipment for industrial automation control systems, control facilities for wind power generation and photovoltaic power generation, uninterruptible power systems, and power electronics products
Tel +86-510-8815-9229

Wuxi Fuji Electric FA Co., Ltd.
Manufacture and sales of low/high-voltage inverters, temperature controllers, gas analyzers, and UPS
Tel +86-510-8815-2088

Fuji Electric (Changshu) Co., Ltd.
Manufacture and sales of electromagnetic contactors and thermal relays
URL http://www.csfe.com.cn/

Fuji Electric (Zhuhai) Co., Ltd.
Manufacture and sales of industrial electric heating devices
URL http://www.fujielectric.com.cn/fez/

Fuji Electric (Shenzhen) Co., Ltd.
Manufacture and sales of photoconductors, semiconductor devices and currency handling equipment
URL http://www.szfujielectric.com.cn/

Fuji Electric Dalian Co., Ltd.
Manufacture of low-voltage circuit breakers
Tel +86-411-8762-2000

Fuji Electric Motor (Dalian) Co., Ltd.
Manufacture of industrial motors
Tel +86-411-8763-6555

Dalian Fuji Bingshan Vending Machine Co., Ltd.
Development, manufacture, sales, servicing, overhauling, and installation of vending machines, and related consulting
Tel +86-411-8754-5798

Dalian Fuji Bingshan Control Systems Co., Ltd.
Energy management systems, distribution systems, and related system engineering
Tel +86-411-8653-6010

Fuji Electric (Hangzhou) Software Co., Ltd.
Development of vending machine-related control software and development of management software
URL http://www.fujielectric.com.cn/fhs/

Fuji Electric FA (Asia) Co., Ltd.
Sales of electrical distribution and control equipment
Tel +852-2311-8282

Fuji Electric Hong Kong Co., Ltd.
Sales of semiconductor devices and photoconductors
URL http://www.hk.fujielectric.com/en/

Hoei Hong Kong Co., Ltd.
Sales of electrical/electronic components
URL http://www.hoei.com.hk/