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Mitsubishi Electric

ADVANCE

The Latest FA Technologies and Systems

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Changes for the Better

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The Latest FA Technologies and Systems

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Technical Reports

Precis

The manufacturing industry has been working to improve productivity and quality using the Internet of Things (IoT). In order to satisfy customers and expand the FA business, Mitsubishi Electric Corporation has been enhancing the development and design of FA integrated solution e-F@ctory, which enables next-generation manufacturing using IoT.

This issue introduces the latest FA technologies and systems.

Overview

Author: *Thomas Usländer**

Agile Service Engineering in IIoT Ecosystems

The trend towards the Industrial Internet of Things (IIoT) is very strong and irreversible. Is it driven by customer demand or rather by the idea that the new technological possibilities such as smart sensors and the handling of big data offer new business opportunities? Considering the industrial production domain, optimization in industrial production has thus far mainly targeted material, energy and cost. However, the potential of data, information and knowledge in industrial production is still widely unexploited. IIoT technologies, ranging from smart sensors and actuators, edge and cloud-based data storage and analytics up to informed decision support, promise to exploit this potential.

Throughout the world, various initiatives are aimed at following this approach. Germany has started this competitive race with its Industrie 4.0 initiative that claims to have disruptive effects at the business level. It may finally lead to the fourth industrial revolution. In Japan, similar ideas are pursued by the Robot Revolution Initiative and the Industrial Value Chain Initiative. There is one common need at the technological level: an open architecture for networked cyber-physical systems with agreed standards for communication (such as OPC UA) and information modeling (such as AutomationML or OPC UA companion specifications). Furthermore, these technological achievements enable the development of product-service systems. This means that in the future, automation products such as machine tools, robots, sensors or conveyors cannot be sold without being accompanied by software-based services. These services encompass or support capabilities for condition monitoring, preventive maintenance, machine learning or artificial intelligence, either close to the asset (edge processing) or in data centers (cloud processing). However, as the end user wants to use these capabilities for an entire production plant across individual, possibly heterogeneous plant components, the associated services have to fit together perfectly. Furthermore, cooperation is performed in order to achieve integrated services for entire production plants, maybe even integrating supply chains.

This has severe consequences for the whole engineering process for product-service systems:

1) The analysis and design for product-service systems must encompass the service engineering, too.
2) Service engineering has to consider the IIoT platform for which the services will be offered. In particular, this relates to the architecture and generic capabilities of the selected IIoT platform.
3) In order not to be "locked-in" to one IIoT platform vendor, it is preferable to support open standards for the communication and information modeling aspects of the services.
4) The service engineering must encompass the whole lifetime of the product including the usage and maintenance phase. As the IIoT platforms undergo revisions, too, an agile service engineering approach that is well synchronized with the version management of the associated product is indispensable.
5) Continuous and automated testing of the products including their services must be organized and carried out in order to master the complexity.

Likewise, the IIoT platforms have to be prepared for such highly flexible and open service ecosystems. There are no fixed use cases that can be clearly analyzed by surveying the future demands of customers. The customer base is not fully known and the known customers are not able to express their requirements as they learn from the capabilities of the rapidly emerging IIoT platforms. Hence, a product and development manager needs a service engineering methodology and tool to break down hypothetical use cases to IIoT platform requirements and map them to existing and emerging technologies and IIoT platform products.

Exploitation of the economic potential and promises of the IIoT will only be possible if the strategic importance of systematic engineering is understood, including the specifics of the emerging IIoT ecosystem landscape

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Application package "iQ Monozukuri ANDON"

Authors: *Kazuhiro Hayashi** and *Yukihiro Hanaki**

Manufacturing sites mainly in Japan have introduced ANDON systems, which show the current production quantities against the targets. Now that the Internet of Things (IoT) has recently been applied to factories (manufacturing sites), there is an increasing need for ANDON systems linked to IT systems. In addition, the automation of equipment has further reduced the man-hours required, but the means for quickly detecting equipment errors is an emerging issue.

To satisfy the increasing need for system linkage and to address the emerging issue of error detection, Mitsubishi Electric Corporation has developed the application package "iQ Monozukuri ANDON" to assist management of the manufacturing process at production sites and share information between workers, thus contributing to improved productivity.

The main strengths are listed below.

(1) Makes it easy to introduce ANDON systems
iQ Monozukuri ANDON provides systems in which graphic operation terminals (GOTs) obtain production data from the sequencer or contact input and display the production status on ANDON monitors and other displays.

(2) Reduces the man-hours for designing screens thanks to the template screens for ANDON
Provides template screens for checking the production status (progress), detecting equipment errors, notifying the staff of tooling changes, and other tasks.

(3) Easy to use thanks to the schedule software for ANDON
Provides software that makes it easy to select the screens to be displayed on ANDON and set the time periods.

(4) Visualization at manufacturing sites and remote offices
Provides support to detect and handle problems quickly, contributing to improved productivity.

1. Introduction

The Graphic Operation Terminal GOT2000 Series products were developed to differentiate Mitsubishi Electric Corporation from other companies under the concept of "Easy & Flexible," and are rated highly by customers in Japan and around the world.(1) In addition, in response to diversifying customer needs and the demand for higher quality, Mitsubishi Electric Corporation offers the FA application package "iQ Monozukuri" to help solve issues at manufacturing sites.

Mitsubishi Electric Corporation released the application package "iQ Monozukuri ANDON" in July 2017 to make it easy to establish ANDON systems using GOT2000 terminals.

2. Why the solution was improved

2.1 ANDON

The ANDON system visualizes the production status at manufacturing sites and the equipment operation status to provide information to the maintenance staff and operation supervisors. The use of ANDON to quickly understand problems at the manufacturing site, share information, and consider countermeasures can improve the site's productivity.

Japanese manufacturers in particular have been introducing ANDON systems. In response to the recent production of diverse product types in various quantities, there is an increasing need for ANDON systems that are linked with IT systems to visualize the production data and equipment status more quickly and specifically. In addition, the need for ANDON systems for new installation may intensify overseas to further visualize manufacturing sites.

2.2 Aim of iQ Monozukuri ANDON

We have been promoting iQ Monozukuri to realize our "e-F@ctory" concept through the linkage of FA and IT. The concept aims at improving the overall efficiency of business operations in the manufacturing industry and reducing the total cost of ownership (TCO).(2) iQ Monozukuri optimally combines expertise to assist customers in solving various manufacturing problems, thus making it possible to efficiently introduce, extend, operate, and maintain systems.

The iQ Monozukuri ANDON package displays data obtained from production equipment on the ANDON monitors via GOT2000 terminals, making it possible to share information on the manufacturing site and improve productivity. In addition, iQ Monozukuri ANDON makes it easier to introduce and use the ANDON systems, reducing overall system costs.

**Nagoya Works*

3. Characteristics of iQ Monozukuri ANDON

iQ Monozukuri ANDON consists of GOT2000 terminal(s), template screens for ANDON that are used in system design, and schedule software for ANDON to be used during operation after system introduction (Fig. 1). Customers design the screens and items to be displayed based on the specifications of the lines into which the ANDON systems are to be installed, and using iQ Monozukuri ANDON can reduce the man-hours required to design the ANDON screens. Unifying the ANDON monitor and the signage screen can reduce the space and cost and also improve other factors.

The main characteristics of iQ Monozukuri ANDON are described below.

3.1 Easy installation of ANDON systems using the GOT2000

System designers can easily establish systems that connect not only to Mitsubishi's FA equipment but also to other companies' controllers and open networks by selecting from the many communication drivers of the GOT2000. Therefore, by installing the GOT2000 into existing lines and equipment having various types of controllers, various types of data on production equipment can be gathered, making it easier to establish ANDON systems (Fig. 2).

3.2 Reduction of man-hours for designing screens thanks to template screens for ANDON

The multiple template screens provided for ANDON are appropriate for understanding the production status and operation conditions of the manufacturing lines and equipment (Fig. 3).

The use of the GOT screen design software "GT Designer3" allows the template screens to be customized, making it easy to renew the ANDON screens. Therefore, the man-hours required to design screens can be reduced and operators at manufacturing sites can quickly incorporate improvements (Fig. 4).

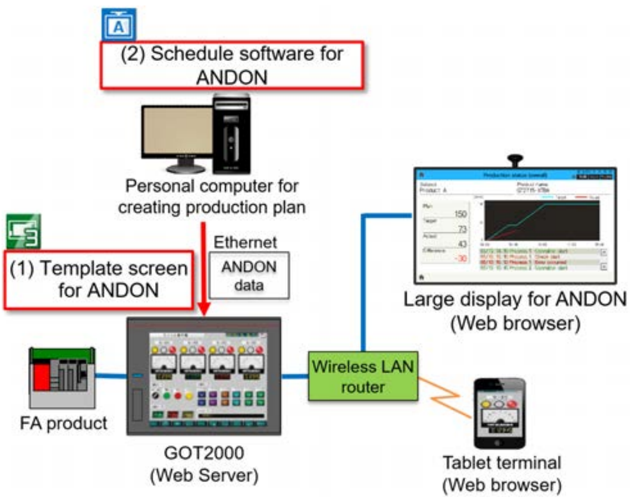

Fig. 1 iQ Monozukuri ANDON system

In addition to visualizing the production and operation status, various functions are provided to improve the efficiency of operations at manufacturing sites, for example, the leader call screen (Fig. 5) and the remote control screen to switch ANDON screens from tablet terminals (Fig. 6). Such functions can improve the productivity and equipment operation rate.

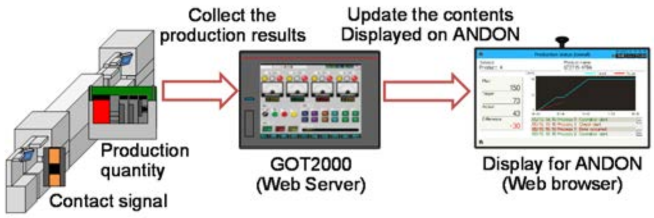

Fig. 2 Easy installation of ANDON system

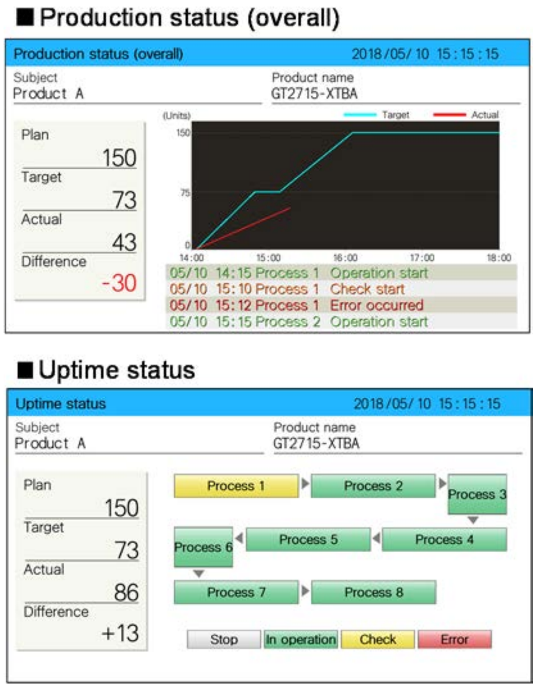

Fig. 3 Template screen examples for ANDON

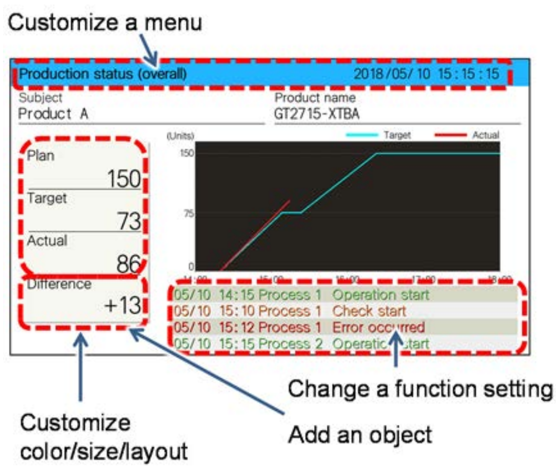

Fig. 4 Customization of ANDON screens

3.3 Easy operation with the schedule software for ANDON

Using the schedule software for ANDON, production plans can be added, deleted, and revised similar to using commercially available schedule software (Fig. 7). In addition to production plans, the software can also set signage, and thus be used to issue notifications at manufacturing sites and view training materials, resulting in more efficient management of manufacturing sites (Fig. 8).

In addition, the schedule software for ANDON can control up to five GOT2000 terminals, enabling comprehensive ANDON management for medium- to large-scale lines and equipment involving multiple GOT2000 terminals (Fig. 9).

3.4 Visualization at manufacturing sites and remote offices

iQ Monozukuri ANDON can manage the contents to be displayed on up to five ANDON systems using the "GOT Mobile" function regardless of the display size of the ANDON.

Therefore, the contents to be displayed on ANDON can be set specifically for the relevant persons and location. This makes it possible to check the operation status in detail and handle problems quickly, thus further improving the equipment operation rate (Fig. 10).

4. Technologies to realize the characteristics

The production plan and signage data (e.g., notice board) to be displayed on ANDON are updated daily based on the production status and schedule. To minimize the impact from such high updating frequency on the processing by GOT2000 terminals and controllers, the screens to be displayed on the ANDON monitors, the production plans for products, and the signage data are separate from each other to allow them to be individually managed.

As shown in Fig. 11, data on the template screens for ANDON is stored in the GOT2000's internal memory as is done with the data on the screens displayed on other GOT2000 terminals. However, the schedule data to be displayed on the ANDON monitors, such as the production plan and signage, is stored on an SD card. The processing section for ANDON compiles this data to configure the screens to be displayed on the ANDON monitors.

This mechanism allows system designers to freely design and customize ANDON screens using GT Designer3 (GOT screen design software). Meanwhile, operators at manufacturing sites and ANDON system users do not require experience in screen design on GOT2000; they can use ANDON systems by setting the production plans and signage data with the schedule

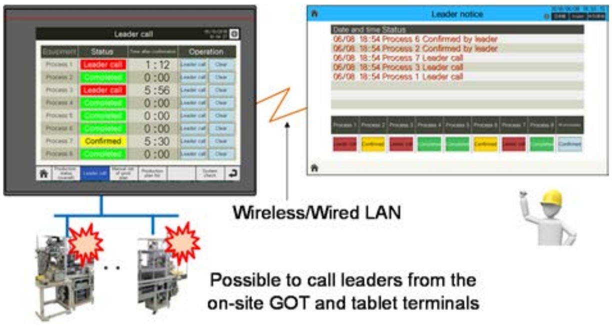

Fig. 5 Leader call screen

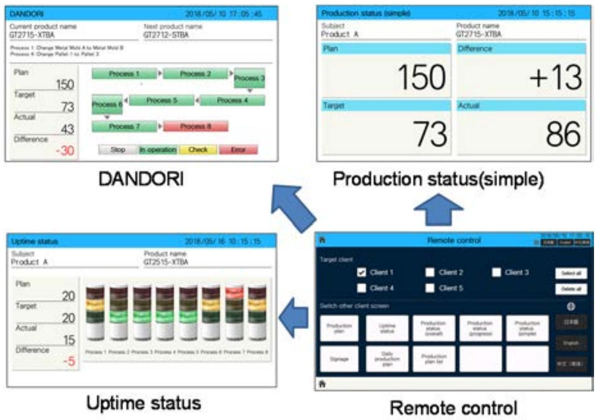

Fig. 6 Switching ANDON screens with remote control screen

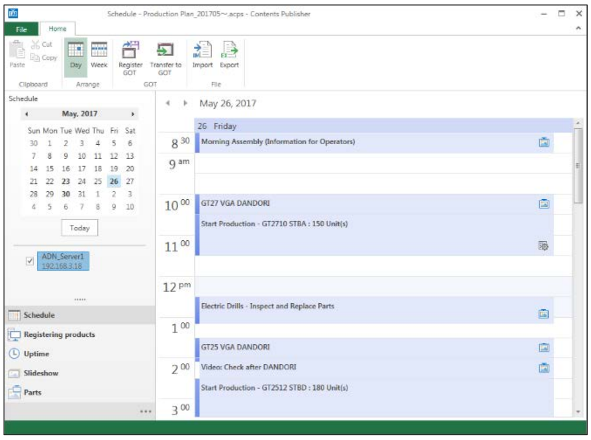

Fig. 7 Schedule software for ANDON

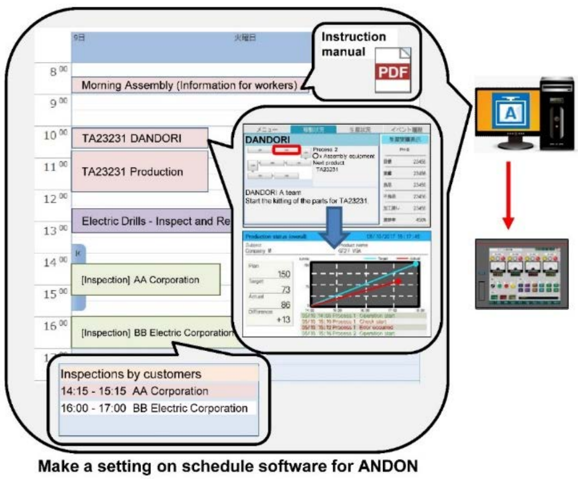

Fig. 8 Easy operation at production site

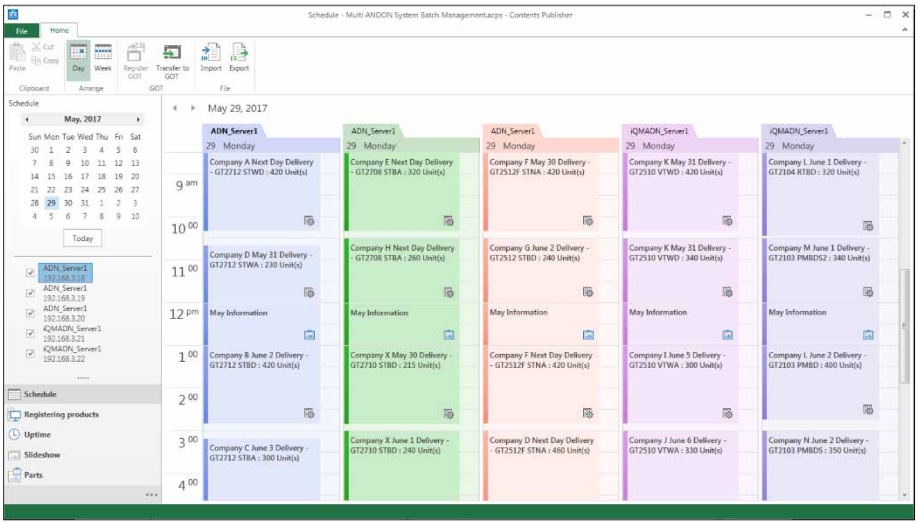

Fig. 9 Multiple schedule management settings

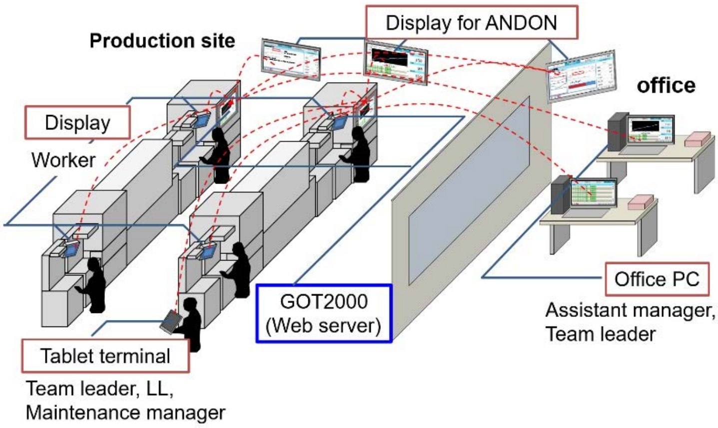

Fig. 10 Visualization of production site from remote location

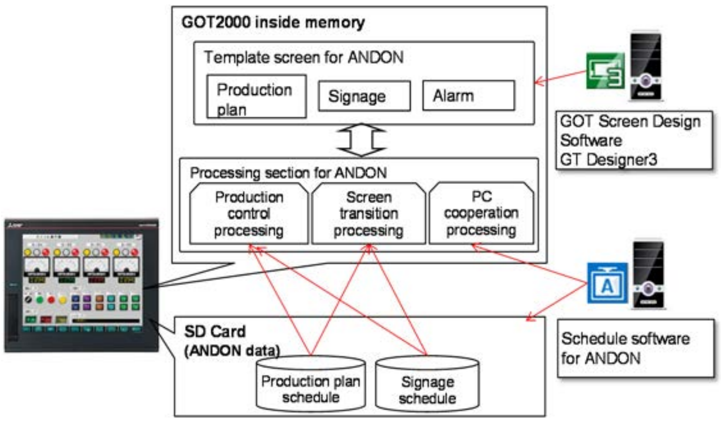

Fig. 11 Relationship between ANDON data and ANDON process

software for ANDON. These techniques make the system user-friendly with minimum effect on GOT2000.

5. Conclusion

This paper described the application package iQ Monozukuri ANDON that makes it easy to establish ANDON systems through the linkage of FA and IT. We will continue to expand the application package and develop solutions to problems at manufacturing sites, offering added value to our customers.

6. References

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Development of FA Integrated Engineering Software for PLM

Authors: *Ryo Kuya** and *Hiroaki Yamakawa**

Mitsubishi Electric Corporation has developed "MELSOFT iQ Works," factory automation (FA) integrated engineering software for programmable logic controllers (PLCs), motion controllers, human-machine interfaces, robots, and inverters. MELSOFT iQ Works, with "MELSOFT Navigator" system management software as its core, is an integrated suite of engineering software programs. The product is already on the market and has helped improve the efficiency of equipment design in product lifecycle management (PLM) through data linkage between our engineering software programs.

Recent years have seen the increasing use of mechanical and electrical CAD software in equipment design, accompanied by rising demand for linking CAD software with engineering software. In addition, to shorten the period for on-site equipment adjustments after completion of the control design, customers are calling for more efficient program debugging without using actual equipment.

To meet these needs, Mitsubishi Electric Corporation has developed MELSOFT iQ Works functions for enhanced interconnection in the PLM engineering chain to provide design and debugging environments in addition to the control design phase: We have achieved (1) linkage simulation of a PLC, motion controller, network, human-machine interface, and 3D CAD and (2) data linkage between electrical CAD and MELSOFT iQ Works.

1. Introduction

The FA sector mainly in Japan, Europe, and the U.S. is faced with increasing labor costs for engineering work, such as system design, programming, operation, and maintenance, due to the introduction of larger FA systems with more functions. In emerging countries such as China and Southeast Asia, the labor cost for engineers has also been increasing, which is becoming a worldwide issue. Accordingly, there is a demand mainly in the manufacturing industry to reduce the total cost of ownership (TCO) by making engineering work more efficient.

In response, we developed "MELSOFT iQ Works" FA integrated engineering software and released it in 2009. MELSOFT iQ Works can be used for implementing system design and programming, creating human-machine interface screens, and starting, operating, and maintaining equipment through an integrated approach.

This paper describes two new functions that MELSOFT iQ Works offers along with its mechanisms and characteristics.

2. Configuration of MELSOFT iQ Works and its New Functions

MELSOFT iQ Works consists of the following six software programs.

(1) System management software "MELSOFT Navigator"

Provides a system management function that serves as a core for linking the individual engineering software programs (2) to (6).

(2) PLC engineering software "GX Works3"

Supports the programming, configuration, and maintenance of PLCs that control FA equipment.

(3) Interface engineering software "GT Works3"

Supports the preparation of human-machine interface screens.

(4) Motion controller engineering software "MT Works2"

Supports the programming, configuration, and maintenance of motion controllers that drive servo motors and other equipment.

(5) Robot engineering software "RT ToolBox2"

Supports the programming, configuration, and maintenance of robots.

(6) Inverter setup software "FR Configurator2"

Supports the configuration, adjustment, and maintenance of inverters.

In line with the increasing use of mechanical and electrical CAD software in equipment design there is increasing demand for linking CAD software with engineering software. In addition, to shorten the period for on-site equipment adjustments after completion of the control design, customers are calling for more efficient program debugging without using actual equipment. To meet these demands, Mitsubishi Electric Corporation has developed MELSOFT iQ Works functions for enhanced interconnection in the PLM engineering chain to provide design and debugging environments in addition to the control design phase.

Figure 1 illustrates the functions that contribute to enhanced interconnection in the PLM engineering chain with MELSOFT iQ Works as the core. MELSOFT iQ Works offers the following two new functions.

(1) Linkage simulation function for PLCs, motion

*Nagoya Works

controllers, networks, human-machine interfaces, and 3D CAD
(2) Function for data linkage between electrical CAD and MELSOFT iQ Works

3. Linkage Simulation

The simulation function of MELSOFT iQ Works offers a PLC simulator, motion simulator, and human-machine interface simulator. Each simulator makes it possible for system designers to check the program functions before the equipment and machines are assembled, thus reducing man-hours for programming.

Customers also want to shorten the period for on-site equipment adjustments. To meet this need, Mitsubishi Electric Corporation provides a linkage simulation function for PLCs, motion controllers, networks, human-machine interfaces, and 3D CAD, making it possible to check the operation of all equipment by simulation alone (Fig. 2). This function significantly reduces system designers' man-hours for programming and improves the quality level before on-site adjustments, thus reducing TCO.

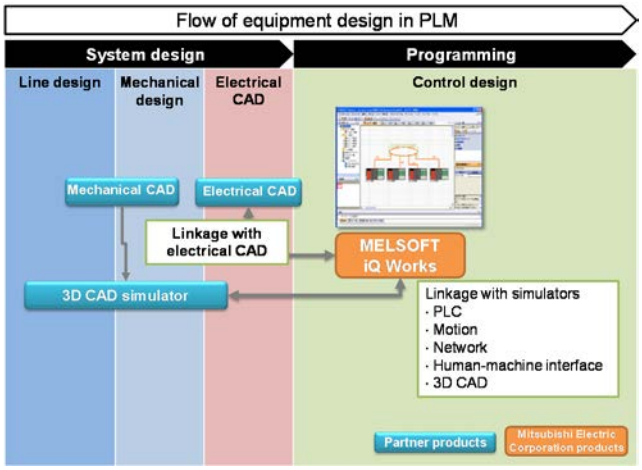


Fig. 1 Outline of the functions contributing to enhanced PLM engineering chain linkage with MELSOFT iQ Works as its core

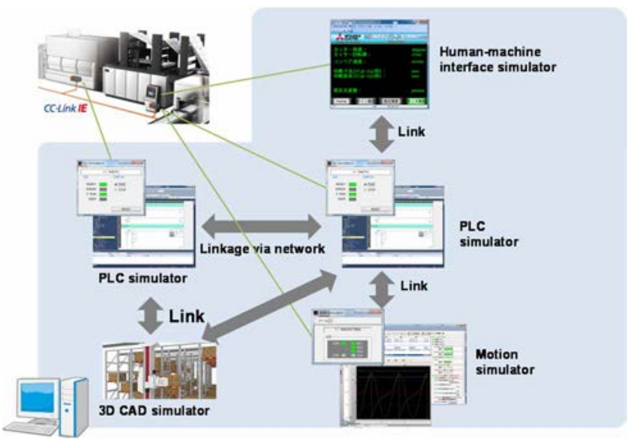


Fig. 2 Outline of linkage of a PLC simulator, motion simulator, human-machine interface simulator, and 3D CAD simulator

This section describes PLC-motion linkage simulation, network linkage simulation, and 3D CAD simulation linkage.

3.1 PLC-motion linkage simulation

3.1.1 Motion systems

For equipment requiring motion control, a multi-CPU system having a PLC CPU and motion CPU is often used. The motion CPU handles complex motion control tasks and the PLC CPU handles other sequence control tasks. As a result, the processing load can be distributed, which makes it possible to increase the number of equipment units and achieve high-speed processing.

The GX Works3 simulation function imitating a PLC CPU makes it possible to verify the sequence control without using the actual equipment, while the MT Works2 simulation function imitating a motion CPU makes it possible to verify the motion control without using the actual equipment. However, these simulation functions can only debug each CPU; therefore, each program must be downloaded to the actual equipment to verify the commands, response timing, and data exchange between the CPUs.

3.1.2 Realization of a PLC-motion linkage simulation function

To eliminate the inconvenience of downloading each program described in section 3.1.1, Mitsubishi Electric Corporation has developed a new PLC-motion linkage simulation (hereafter, "system simulation") function that allows the PLC CPU to work with the motion CPU. This function enables the debugging tasks listed below without using actual equipment.
(1) Operation check of an interrupt program through inter-module synchronization of the PLC CPU with the motion CPU
(2) Operation check of startup linkage of motion-specific sequence commands
(3) Operation check of buffer memory data exchange between CPU modules by multi-CPU setting

In addition, the system simulation function saves the run status of the GX Works3 and MT Works2 system simulation. This means that if the processing is interrupted in the middle of a simulation, debugging can be restarted from the stopped point.

3.1.3 System simulation function

For the PLC CPU to work with the motion CPU through the system simulation function, a new system bus imitation function was developed, which has realized the following functions (Fig. 3).
(1) Inter-module synchronization function

A motion CPU processes motion control at fixed-

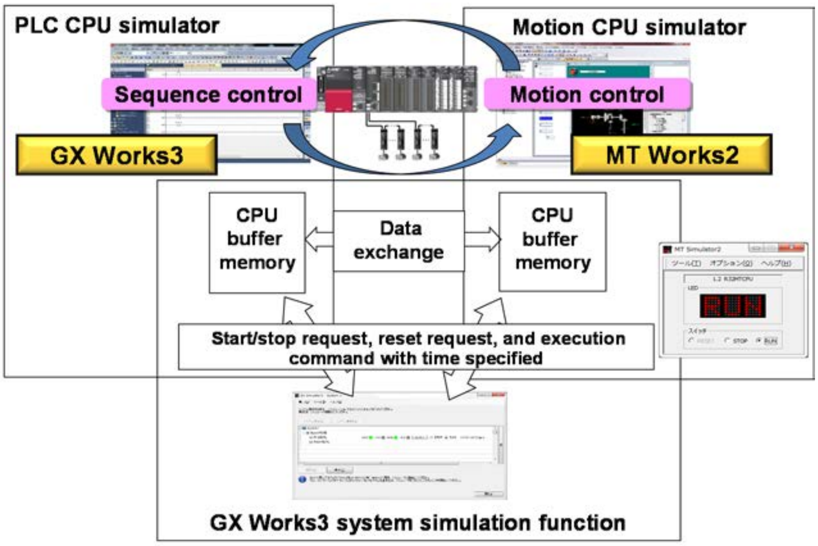


Fig. 3 Schematic diagram of the system simulation function

cycle intervals (222 μs in the shortest case) as the module specification. Inter-module synchronization of the GX Works3 PLC CPU simulator with the MT Works2 motion CPU simulator has been realized by allowing the system simulation function to imitate the fixed-cycle inter-module synchronization at intervals of 222 μs.

(2) Inter-module communication function

Imitation of the inter-module communication function enables automatic incorporation by reading and writing to each CPU memory for communications and notification of interruption between the CPUs.

3.2 Network linkage simulation

3.2.1 Network systems

Systems with multiple PLCs connected via networks are used in the semiconductor, liquid crystal, and automobile sectors where large-scale manufacturing equipment is required.

The conventional GX Works3 simulation function could only debug a single PLC CPU. Consequently, each program needed to be downloaded to the actual equipment to verify the data exchange via a network.

To solve this problem, the system simulation function described in section 3.1.2 was expanded to the network level, which enables verification of entire systems including PLCs, motion controllers, and networks. This function allows debugging of cyclic data exchange between network modules without using the actual equipment.

3.2.2 Realization of a network linkage simulation function

To realize a network linkage simulation function, two new functions were added to the system simulation function.

(1) Inter-network synchronization function

Data is periodically exchanged between network modules by link scanning. A simulator carries out inter-process communications at link scan intervals to synchronize the processing timing by queuing (time synchronization).

(2) Network module imitation function

By imitating a network module included in a network, it is possible to handle network parameters set to the control station (CC-Link IE Control) or master station (CC-Link IE Field). This function enables verification of data exchange set to the network parameters without using the actual equipment.

3.3 3D CAD simulation linkage

The 3D CAD simulator software is used for checking the operation of a mechanism in mechanical design. Previously, a 3D CAD simulator was used to check the mechanical design and a PLC simulator was used to check the control design. However, even after a thorough check, problems occurred when the equipment and control were combined, and it was necessary to return to the design phase.

To solve this issue, Mitsubishi Electric Corporation has realized a function for linking the 3D CAD simulator, the system simulation function described in section 3.1, and the “GT simulator,” which is a human-machine interface simulator. This enables verification of the operations listed below without using actual equipment.

(1) Mechanism operation when the equipment and control are combined
(2) Sequence control operation when the equipment and control are combined
(3) Combined operation of the human-machine interface and sequence control

To realize these linkage functions, an “EZSocket” interface has been implemented in PLC CPU simulators.

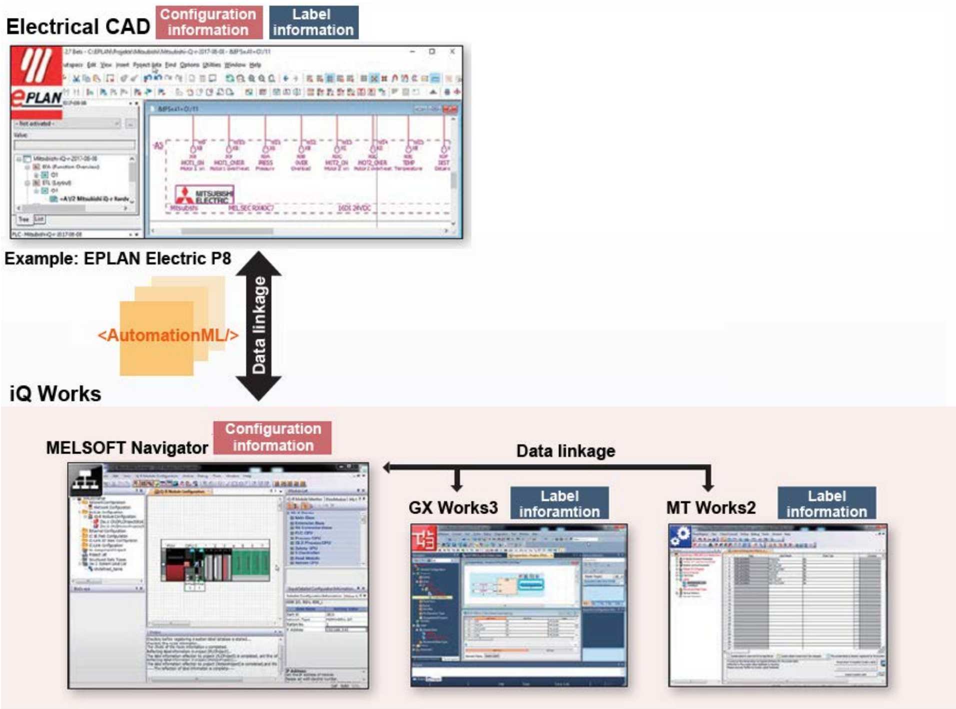


Fig. 4 Example of data linkage between electrical CAD and MELSOFT iQ Works

EZSocket refers to the interfaces used on actual CPUs. This implementation allows access to actual CPUs and CPU simulators in the same procedure.

The GT simulator and 3D CAD simulator having a function for accessing the EZSocket can work together.

4. Electrical CAD Data Linkage in MELSOFT iQ Works

Regarding the electrical design and control design, although the information set to the PLC module configuration is the same as that set to the labels, the software used for electrical CAD is different from that for MELSOFT iQ Works, which poses the following issues.

(1) The number of man-hours required for setting is doubled.

(2) An operation mistake results in deviation of the settings between the two software programs.

These issues have been solved by means of data linkage between the electrical CAD and MELSOFT iQ Works. Users set the module configuration information and label information on either the electrical CAD or MELSOFT iQ Works: The data linkage function allows the information to be incorporated in other software. The data linkage function can eliminate repeated work by users, improving the efficiency of operations. In addition, since human work is not required, the results are free from human errors, setting errors, and omissions.

MELSOFT iQ Works enables data linkage of module configuration information and label information with electrical CAD thanks to MELSOFT Navigator. MELSOFT Navigator can link label information with GX Works3 and MT Works2, making it easier to incorporate label information in the programming software. Figure 4 shows an example of data linkage.

Open standard AutomationML is used for data linkage. AutomationML is a data format in Extensible Markup Language (XML) developed to seamlessly connect engineering tools. Existing XML data format standards, such as Computer Aided Engineering Exchange (CAEX), PLCOpenXML, and Collaborative Design Activity (COLLADA), have been combined to achieve the specifications. The use of the open standard eliminates work for individual electrical CAD tools and enables cooperation with all electrical CAD vendors that use AutomationML. Currently, electrical CAD tools that support data linkage with AutomationML are EPLAN Electric P8 (EPLAN Software & Service) and the E3.series (Zuken Inc.). The number of such tools may increase further in the future, resulting in an increase in the number of linkable electrical CAD tools as well.

5. Conclusion

This paper described two new functions added to MELSOFT iQ Works FA integrated engineering software for enhanced interconnection in the PLM engineering chain. In addition to these functions, we will continue to improve MELSOFT iQ Works as engineering software that con tributes to reducing customers' TCO.

New Technologies of CNC "M800/M80 Series"

Authors: *Toshihiro Azuma** and *Takao Katsuta**

Mitsubishi Electric's computerized numerical controller (CNC) M800/M80 series released in 2014 offers high machining performance and ease of use through the application of CNC-dedicated CPUs. Meanwhile, manufacturing sites are facing a decreasing number of skilled workers and frequent worker turnover. Under these circumstances, there is a high demand for functions that make it easier for inexperienced workers to perform high-productivity machining. To meet this demand, Mitsubishi Electric has expanded the usability and productivity of the functions listed below.

(1) Program edit function

Two functions have been developed to make it easier to design the processing programs: (1) interactive cycle insertion function and (2) finish shape view programming function.

(2) Simulation function

To reduce the number of test runs prior to actual production, a 3D solid program check function has been developed so that users can check the programs in the preparation process.

(3) Five-axis control function

The spline interpolation function has been improved to enhance the speed and precision of the machining processes.

(4) Network function

In response to the need for factory automation and higher production efficiency through active use of the Internet of Things (IoT), the following four functions have been developed: (1) Manufacturing execution system (MES) interface, (2) Seamless Message Protocol (SLMP) server, (3) remote desktop, and (4) field network.

1. Introduction

Economic growth in Asian countries, increased demand for machine tools for the aeronautics industry, and active investment in factories and equipment by electronics manufacturing services (EMS) companies have steadily boosted the demand for machine tools. Against this background, CNCs for machine tools must deliver higher machining performance and also be safe and reliable. Meanwhile, given the decreasing number of skilled workers and frequent worker turnover, machining operations need to be more user friendly while still maintaining high productivity. Achieving this requires ease of use for inexperienced workers, establishment of factory automation systems, and enhanced compatibility with production management systems.

Mitsubishi Electric released the latest CNC model, the M800/M80 series, in 2014[1] and users have highly evaluated its machining performance and ease of use. Still, we have been expanding the functions to meet the growing need for higher productivity.

This paper describes the new technologies in the M800/M80 series developed for the program edit, simulation, five-axis control, and network functions that greatly contribute to productivity among the various functions.

2. Strong Points of the M800/M80 Series

2. 1 CNC-dedicated CPUs for revolutionary high-speed processing performance

The M800/M80 series incorporates our CNC-dedicated CPUs for high-speed processing performance and high productivity. These CPUs have also realized programmable logic controller (PLC) performance that can process large-scale ladder programs at high speed.

2. 2 Wide product lineup supporting diverse needs

Figure 1 shows the M800/M80 series lineup. The new M80W series was added to the standard model lineup in 2016. The human-machine interfaces are separated from the controllers in the configuration, which enables flexible installation. The number of expansion card slots was increased to more than that of the M80 to enhance its expandability as the standard model.

3. Expansion of Support Functions

Recent years have seen increasing demand for ease of use. Therefore, the M800/M80 series' functions for supporting tasks in each manufacturing process have been expanded (Fig. 2). In the design process, the interactive cycle insertion function and finish shape view programming function were added to make it easier to create processing programs. For the preparation process, the 3D solid program check function was developed to allow users to check programs in the preparation process, thus reducing the number of test runs prior to actual production. For the machining process, the five-axis control function was expanded and enhanced to achieve high-speed and high-precision five-

*Nagoya Works

axis machining. In addition, we are working to expand the network function in response to the need for factory automation and higher productivity using IoT, which has been attracting attention in recent years.

3. 1 Expansion of the program edit function

As the M800/M80 series' program edit function, two functions have been added: (1) Interactive cycle insertion function that allows users to insert cycles that support machining and preparation in processing programs being edited in dialogue form and (2) finish shape view programming function that immediately displays the 3D cutting results from the processing programs. These functions allow users to intuitively create processing programs and they immediately display user input errors in 3D, which can reduce the time required to create programs.

When issuing instructions for machine tool movement to the CNC, users need to enter the tool paths in 3D space and the tool movement patterns into the processing programs. The interactive cycle insertion function creates processing programs automatically once the users specify the type of shape and its dimensions, so users can create programs intuitively (Fig. 3). In addition, the function can create processing programs for any shape specified by the users or based on drawing data. Particularly in Europe, where multiple models are manufactured in smaller lots, users like the function for creating processing programs interactively on the CNC.

In addition, the finish shape view programming function displays the 3D cutting results from the processing program being created whenever the program is revised. This allows users to immediately see any input errors (Fig. 4).

Usually, in a processing program, the material is gradually shaved to obtain the final shape. However, if all these processes are simulated, the geometric calculation for displaying the shape may take time and the screen display response may become slow. Therefore, the finish shape view programming function extracts only the movement related to the final shape from the processing program created with the interactive cycle insertion function and displays the shape. This allows users to see the input results immediately.

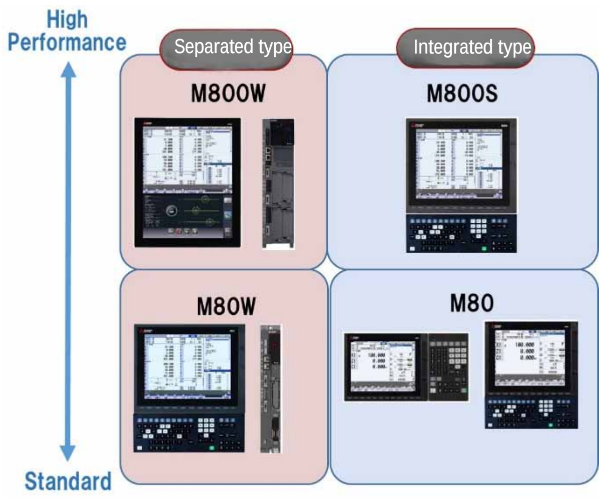


Fig. 1 Lineup of M800/M80 Series

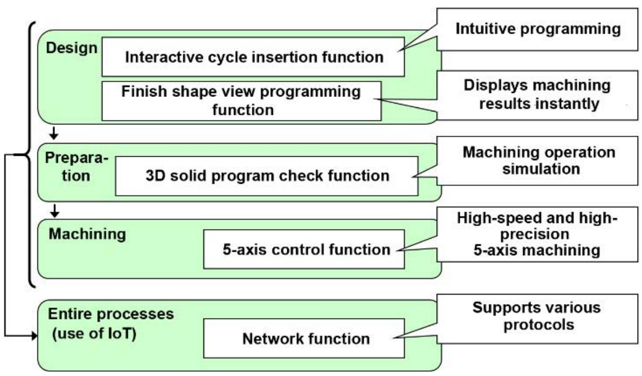


Fig. 2 Functions for assisting with tasks in manufacturing processes

3. 2 Expansion of simulation functions

The M800/M80 series now has the new 3D solid program check function and other simulation functions to eliminate mistakes in creating processing programs and making preparations.

The 3D solid program check function allows users to see the behavior of processing programs in 3D graphic images without activating actual machine tools

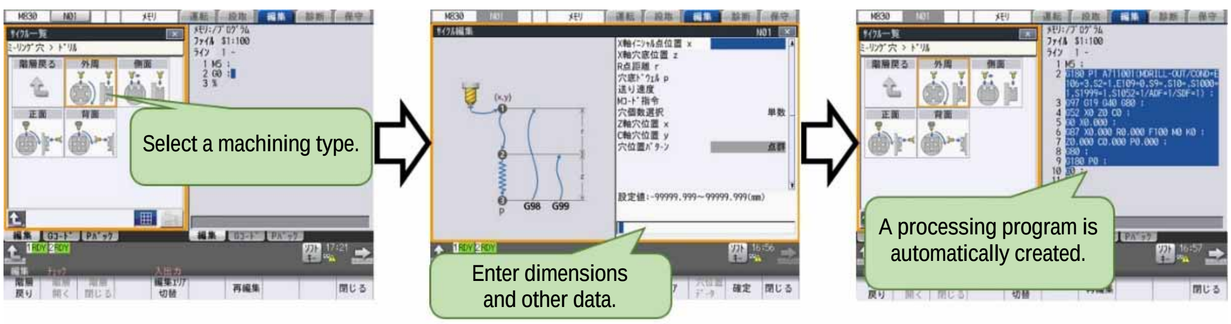


Fig. 3 Interactive cycle insertion

(Fig. 5). This function can reduce the number of test runs prior to actual production.

For equipment requiring immediate response, a pre-assigned memory area is often used for calculation, but this memory may not be sufficient for simulating complex shapes. Therefore, the 3D solid program check function shares a memory area with other functions: The memory area is not assigned in advance but is dynamically assigned. This newly developed technology has enabled the simulation of complex shapes without adding more memory.

3. 3 Expansion of the five-axis control function

The M800/M80 series' spline interpolation function has been improved to remove noise, for example, unnecessary level differences, included in fine segment programs created with computer aided manufacturing (CAM) to achieve smooth machining.

The improved function smoothly moves the tool on a curved line that passes within the specified tolerance. Therefore, even when a fine segment program contains unnecessary level differences and other noise, the quality of the obtained machined surfaces is high, without flaws. This function also supports simultaneous five-axis control, so it can smoothly move both the tool center point and tool orientation within the tolerance during the tool center point control. Therefore, in simultaneous five-axis machining in which complicated changes occur in the tool position and orientation, flawless and smooth machined surfaces can be obtained without the user having to correct the processing program, thanks to the spline interpolation function (Fig. 6).

When a curved line is simply created such that it remains within the tolerance, the outward path is different from the return path, which may cause a flaw. To solve this problem, a new algorithm was developed for this function. The algorithm creates a curved line such that the return path will be the same as the outward path, while evaluating the characteristics of the shape (e.g., corners), achieving flawless and smooth machined surfaces.

3. 4 Expansion of network functions

IoT is attracting increasing attention. At manufacturing sites involving machine tools, the need for network functionality is also increasing. To meet this need, network functions for the M800/M80 series have been developed and are being gradually expanded.

This section describes four of these functions.

3. 4. 1 MES interface

The newly developed manufacturing execution system (MES) interface function sends machines' operation status data from the CNC to databases automatically when an event occurs, for example, when the machining is completed or an alarm is issued. This function makes it easy to visualize the machines' operation conditions and makes it possible to quickly

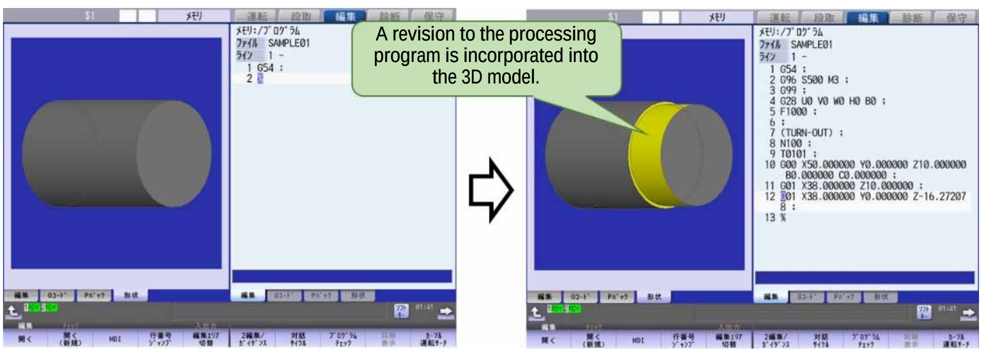


Fig. 4 Finish shape view programming function

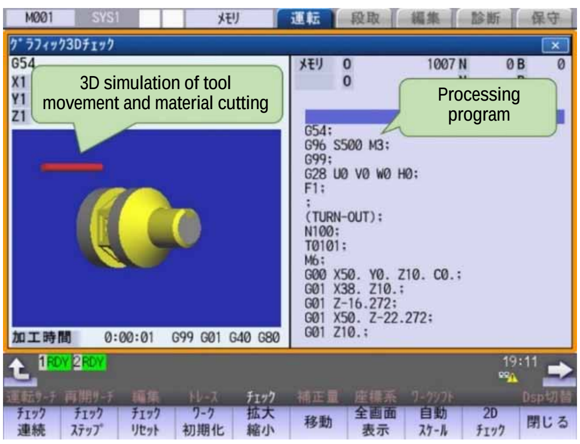


Fig. 5 3D solid program check

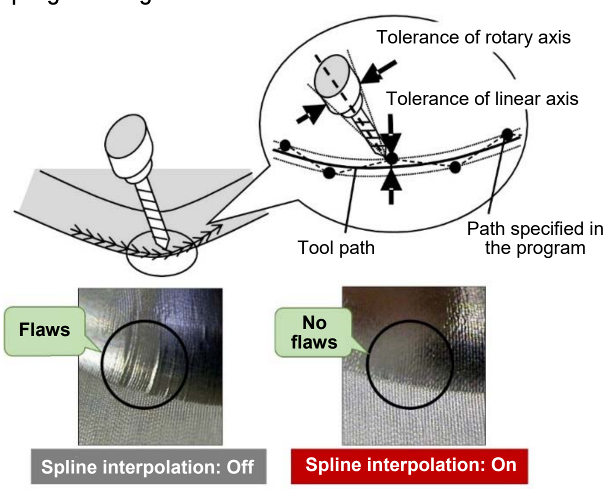


Fig. 6 Five-axis spline interpolation

recover from machine problems, prevent problems, and thoroughly manage the quality in each manufacturing process, thus improving productivity (Fig. 7).

3. 4. 2 SLMP server

The newly developed Seamless Message Protocol (SLMP) server function can transmit data from peripheral equipment to the CNC via Ethernet.*[1] This function makes it easy to connect machine tools and peripheral equipment supporting the SLMP to networks with only LAN cables. In addition, the SLMP can be used with the Transmission Control Protocol/Internet Protocol (TCP/IP). Therefore, the CNC, peripheral equipment, and higher-level systems can be connected using a single type interface and data can be seamlessly linked between the higher-level systems and peripheral equipment.

For example, when a barcode reader supporting the SLMP is connected to a CNC and a higher-level system with LAN cables, the ID of the workpieces being machined can be sent not only to the CNC but also to the production management system. This makes it possible to visualize information on workpieces on the production management system, thus boosting productivity at the factory (Fig. 7).

3. 4. 3 Remote desktop

The new remote desktop function makes it possible to display and operate CNC screens remotely on another computer via a network. A PC or tablet installed in an office or factory can be used to view and operate the screens of a machine tool installed at a manufacturing site, thus reducing the labor-hours for testing machine tools (Fig. 8).

3. 4. 4 Field network expansion cards

In recent years, the need to connect machine tools to peripheral equipment, such as robots and sensors, has been increasing as a part of factory automation. The field network required for connection varies depending on the use environment of peripheral equipment, so we have been gradually increasing the number of supported field network types for the M800/M80 series. This time, a new type of expansion card was developed to support field networks with an RS-485 serial interface (PROFIBUS-DP*[2] and CC-Link).

In addition, recently developed field networks that can transmit signals at high speed using Ethernet (CC-Link IE Field and EtherNet/IP) have been spreading, so conventional serial interfaces may be replaced with Ethernet interfaces. Therefore, we are planning to support various Ethernet field networks in turn in the future (Fig. 9).

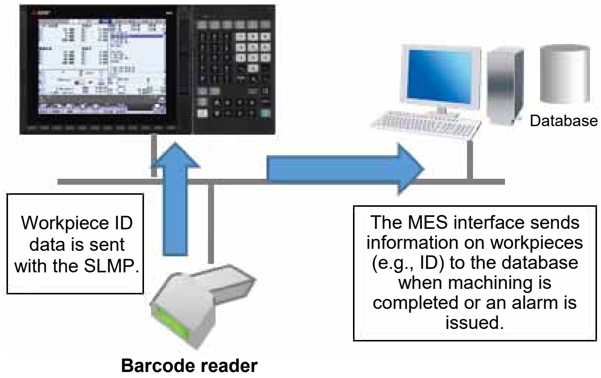


Fig. 7 Usage example of MES Interface and SLMP

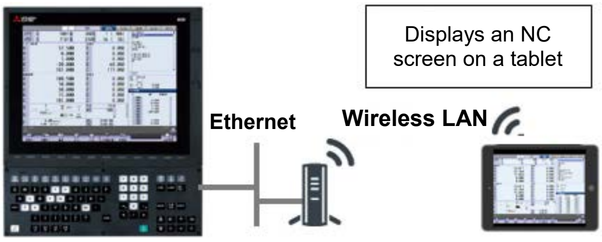


Fig. 8 Usage example of remote desktop

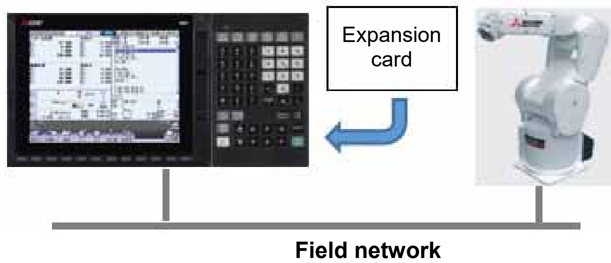


Fig. 9 Connectivity to field networks through expansion cards

4. Conclusion

This paper described the latest CNC model, the M800/M80 series. This series will contribute to upgrading machine tools that support the fundamentals of manufacturing. We will continue working to develop products that meet the changing market needs.

5. Reference

(1) Nakamura N., et al.: Brand-new Model of CNC “M800/M80 Series”, Mitsubishi Denki Giho, 89, No. 4, 247–250 (2015)

[1] Ethernet is a registered trademark of Fuji Xerox Co., Ltd.

[2] PROFIBUS is a registered trademark of PROFIBUS User Organization.

Industrial Robot FR Series "MELFA Smart Plus"

Author: *Kenji Murata**

Diversifying customer needs and globalization have brought the manufacturing industry to a period of major reform. Industrial robots must deliver higher performance and flexibility in order to perform more complex operations in addition to conventional simple tasks.

In response to this market environment, Mitsubishi Electric has added the MELFA Smart Plus option to the industrial robot MELFA FR series lineup.

The MELFA Smart Plus option provides functions to facilitate the introduction and support the automation of high-level operations.

The main functions of MELFA Smart Plus are described below.

(1) Robot mechanism temperature compensation function

This function corrects positional errors caused by thermal expansion in the robot arm to stabilize precision operations.

(2) Calibration assistance function

This function automates the calibration between the robot and the vision sensor, between the robot and the workpiece, and between robots.

(3) Coordinated control for additional axes

This function improves productivity and increases the types of processible workpieces through coordinated control of additional axes and robots.

1. Introduction

Industrial robots are increasingly being used at manufacturing sites for next-generation production systems to keep up with the global competition. The background to this environment includes the following four factors: (1) Promotion of automation to secure stable factory workforce; (2) transition to cell production systems suitable for multi-type variable-quantity production due to diversifying customer preferences; (3) demand for designable production systems that can be implemented quickly and at a low cost; and (4) need for automation of high-level operations such as precision assembly, transfer of soft goods, and high-speed handling.

To meet such needs, Mitsubishi Electric has developed the industrial robot MELFA FR series with improved intelligent functions.[(1) (2)] This series now offers the new MELFA Smart Plus option that makes it possible to automate high-level operations, in addition to intelligent technologies that use conventional force sensors and 3D vision sensors. The new functions have enhanced the ability to solve various issues that hinder automation.

This paper describes the main functions of MELFA Smart Plus and examples of application.

2. MELFA Smart Plus Functions

The MELFA Smart Plus option provides advanced functions for all operating phases, from design and startup to operation and maintenance. Examples of such functions are linkage with various types of sensors and autonomous adjustment of startup. The various functions of MELFA Smart Plus are enabled by inserting the MELFA Smart Plus card into the robot controller CR800, as shown in Fig. 1.

The following section describes the robot mechanism temperature compensation function, calibration assistance function, and function for coordinated control for additional axes among the functions of MELFA Smart Plus.

2. 1 Robot mechanism temperature compensation function

The robot mechanism temperature compensation function estimates the temperature of the robot arm in real time and automatically corrects positional errors due to thermal expansion in the arm.

When robots are performing high-level operations such as precision assembly and processing, positional errors due to thermal expansion of the arm may hinder stable operation. Previously, to reduce the influence of thermal expansion, pre-production warmup was recommended. However, the MELFA Smart Plus temperature compensation function can reduce positional errors due to thermal expansion to

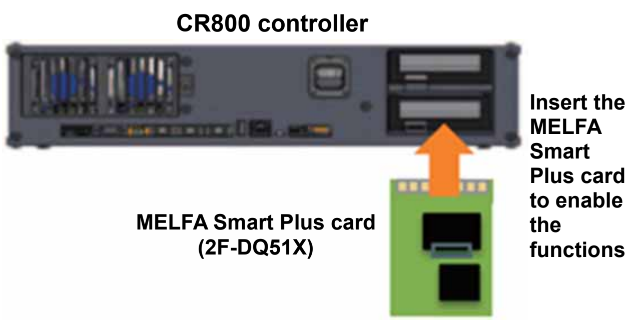


Fig. 1 Enabling the MELFA Smart Plus functions

*Nagoya Works

approximately one-fifth compared to the previous level (Fig. 2). Therefore, this function enables precision operations without the need for warmup or correction of taught positions.

The displacement of an arm due to thermal expansion is approximated by a polynomial expression using data from the temperature sensor installed at the motor (encoder) on each axis. The magnitude of displacement of the arm end position is calculated using this expression whenever necessary and a compensation command that offsets such influence is added to the position command for the motor of each axis.

This method can automatically eliminate the influence of thermal expansion of the arm without the need to revise the positioning data.

2. 2 Calibration assistance function

The calibration assistance function consists of automatic calibration, workpiece coordinate calibration, and inter-robot relational calibration.

2. 2. 1 Automatic calibration

The automatic calibration handles troublesome and time-consuming calibration (positioning) of the coordinates of the vision sensor image and the robot (Fig. 3).

Previously, such calibration operations were manually performed, which required time to start and reposition the systems. In addition, it was difficult to maintain the accuracy of calibration due to the variation of operations.

With the automatic calibration function, users only need to enter the items specified on the calibration screen of the engineering tool RT ToolBox3 (Fig. 4). In addition, calibration operations can be saved as a robot program for repeated use with the same degree of accuracy.

When multiple systems with the same model are started up and recalibration is required due to a problem, reusing programs makes it easy to perform calibration with high reproducibility.

2. 2. 2 Workpiece coordinate calibration function

The workpiece coordinate calibration function adjusts the position of the robot according to the location of the target workpiece (aligns the robot coordinates and workpiece coordinates) based on the information from the 2D vision sensor installed at the end of the robot hand. Installing this function can establish a system that autonomously corrects positional errors between the robot and the target workpiece.

To perform workpiece coordinate calibration, a calibration sheet as shown in Fig. 5 is installed in the operation area. The positional relationship between the reference marks on the calibration sheet and the origin of the workpiece coordinate system is known. Once a special program is executed, three-dimensional inclination of the calibration sheet and the position of the origin of the workpiece coordinate system are automatically measured based on multi-viewpoint imaging data and robot position

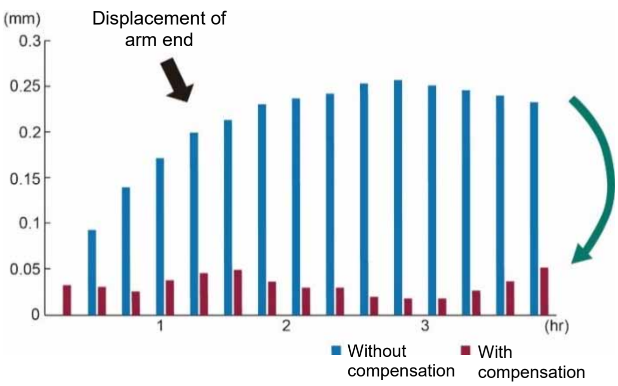


Fig. 2 Displacement of arm end locations by operation time

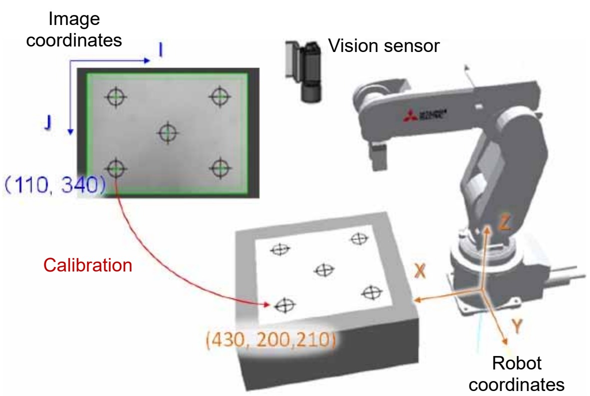


Fig. 3 Calibration of vision sensor and robot

Fig. 4 Screen for automatic calibration

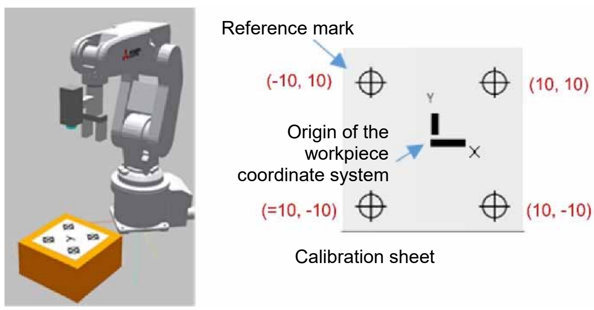


Fig. 5 Workpiece coordinate calibration

data and the workpiece coordinates viewed from the robot coordinates are calculated.

2. 2. 3 Inter-robot relational calibration function

The inter-robot relational calibration function corrects installation errors between robots in a system where multiple robots work in cooperation with each other.

As shown in Fig. 6, the calibration of robot 1 and the workpiece coordinates and the calibration of robot 2 and the workpiece coordinates are performed to calculate the relative positional relationship between the two robots.

2. 3 Function for coordinated control for additional axes

The function for coordinated control for additional axes allows synchronous operation of the robot and direct-acting axis. Included are a control function for base coordinate systems and an additional axis tracking function.

2. 3. 1 Base coordinate cooperative control function

This function expands the motion range where continuous processing is possible by using travel axes (direct-acting axes).

For operations that previously required a large-scale robot due to the limited motion range of a small robot, installing this function enables such operations by a small robot by combining it with a travel axis, thus reducing the work space and system cost.

As shown in Fig. 7, when a robot processes the circumference of a large workpiece, continuous operation is made possible by changing the base coordinates of the robot (position of the robot coordinates viewed from the world coordinates) while the coordinates are linked with the behavior of the direct-acting axis in real time.

2. 3. 2 Additional axis tracking function

The additional axis tracking function enables assembly, processing, and other operations using an additional axis while following a moving workpiece.

As shown in Fig. 8, the robot keeps up with the moving workpiece by using the additional axis (direct-acting axis) and is able to perform an operation on the moving workpiece similar to that with a static workpiece, thanks to the real-time control that ensures a relative speed of zero between the workpiece and the robot tool end.

Previously, a workpiece needed to be stopped before assembly, processing, and other operations. However, the additional axis tracking function eliminates this requirement and enables simultaneous processing and transfer operations, thus significantly reducing the takt time.

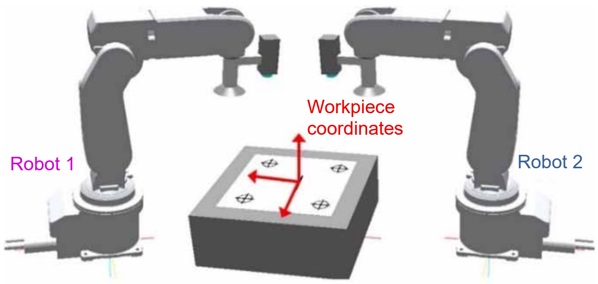


Fig. 6 Inter-robot relational calibration

3. Applications

Example applications using the MELFA Smart Plus functions are described below.

3. 1 Application to copying cells[*1]

When copying a cell identical to the master cell for which the startup adjustment has been completed as shown in Fig. 9, calibration and teaching operations were

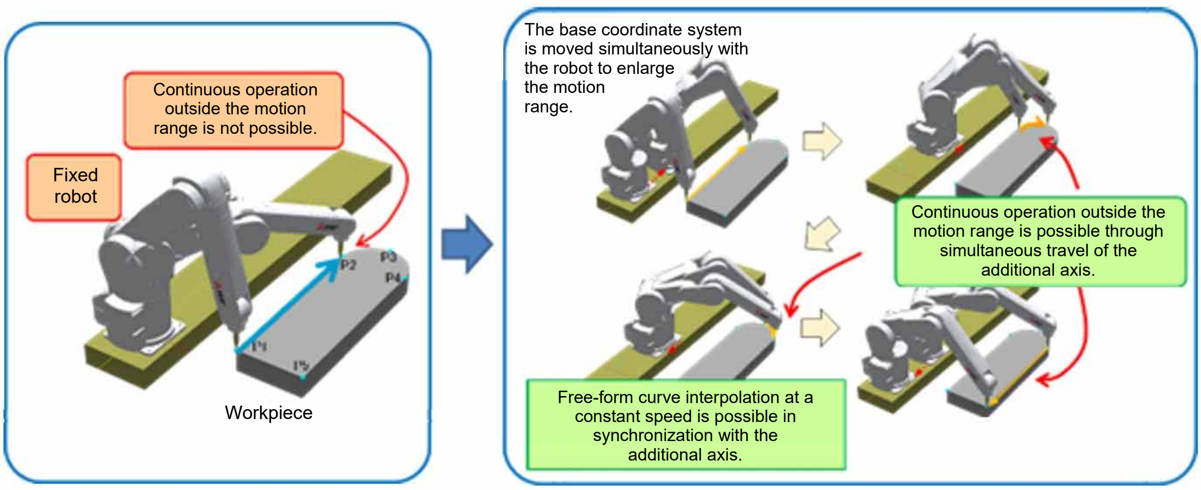


Fig. 7 Base coordinate cooperative control

[1] Refers to copying a cell in the same manufacturing process in cell production.

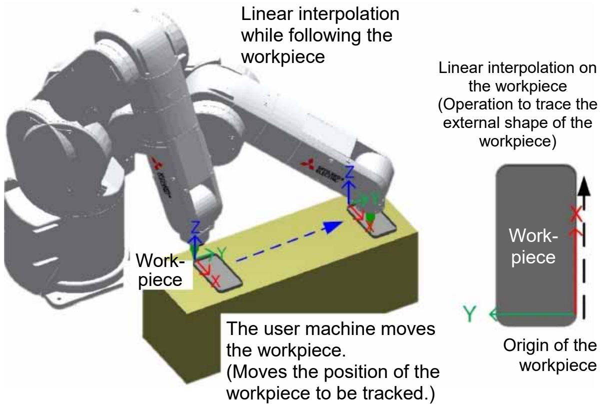


Fig. 8 Additional axis tracking

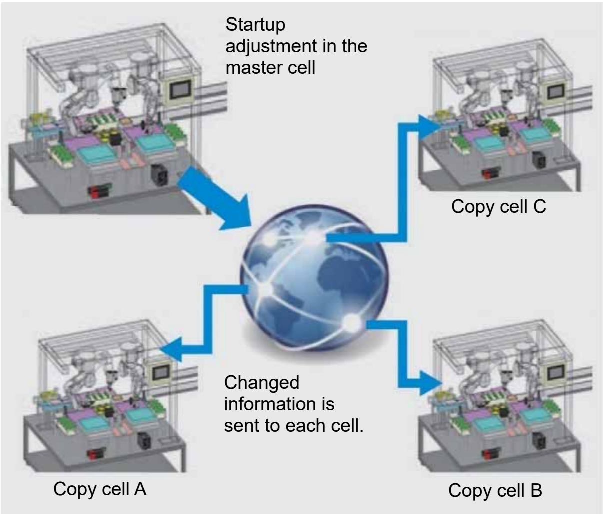


Fig. 9 Application example of copying cells

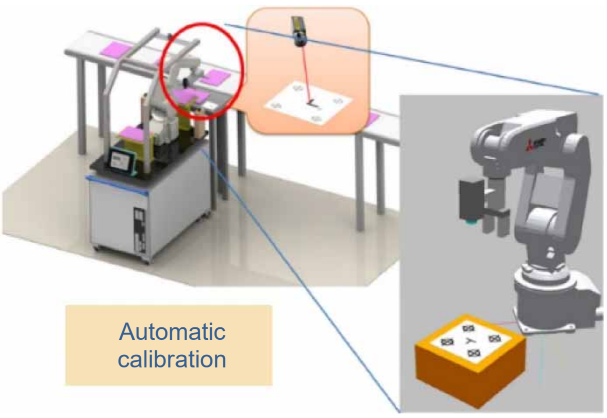


Fig. 10 Application example for a robot on a mobile cart

previously required for each cell. The robot mechanism temperature compensation and automatic calibration functions provided by MELFA Smart Plus can automatically correct machine differences between cells. With these functions, changes to information of the master cell can be similarly applied to separate cells, enabling linked operation between the master cell and other cells.

3. 2 Application to mobile robots

For systems in which robots are installed on automated guided vehicles (AGVs) and mobile carts to transfer them between machines, the operation accuracy deteriorates due to errors in the stopped positions of the AGVs or carts at the destination. The calibration assistance function of MELFA Smart Plus effectively solves this problem.

The workpiece coordinate calibration function can automatically correct the three-dimensional displacement between a robot and the surrounding equipment, making it possible to operate the robot without changing the robot program and taught position for each AGV (Fig. 10).

4. Conclusion

This paper described the main functions and example applications of the new MELFA Smart Plus option for the MELFA FR series. These functions include automatic correction of positional errors due to thermal expansion, automatic calibration, and automatic coordinated control of additional axes.

We plan to incorporate sensing and AI technologies in MELFA Smart Plus in the future to provide functions that overcome problems with automation in all phases from design and startup to operation and maintenance.

5. References

(1) Miyamoto M.: Industrial Robots “MELFA FR Series”, Mitsubishi Denki Giho, 90, No. 4, 243–246 (2016)
(2) Miyamoto M.: Industrial Robots “MELFA FR Series”, Mitsubishi Denki Giho, 91, No. 4, 217–220 (2017)

Expanded Lineup and Improved Performance of MDU Breaker "W&WS Series"

Author: *Hiroaki Oohashi**

Mitsubishi Electric's contributions to energy conservation for reducing greenhouse gas emissions include the development of MDU breakers as energy-saving devices. The MDU breaker has a current transformer (CT) and a voltage transformer (VT) in the circuit breaker main body for measuring the load current, line voltage, electric power, electric energy, and other electric variables. The main features are listed below.

(1) Space-saving and easy to install
(2) High performance and multifunction

Recent years have seen an increased demand for more advanced energy management activities, such as the leveling of electric power load. Mitsubishi Electric has developed new models of the W&WS series that deliver higher performance. For enhanced usability, these models were designed with an emphasis on the following two aspects:

(1) Improvement of visibility
(2) Expansion of display functions

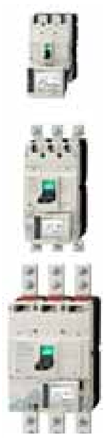
This paper describes the main features of the new models of the W&WS series along with several technical issues and their countermeasures.

1. Product models and features of the latest series

1.1 Product models

Table 1 shows the lineup. The newly added models (enclosed with the black lines in Table 1) can display their specification data in the panel openings (breaker

Table 1 Product lineup

	6-digit 7-segment LED display type			LCD type		
250A frame molded case circuit breaker				NF250-SEV/HEV with MDU		
400A frame molded case circuit breaker	NF400-SEP/HEP with MDU		Newly developed models	NF400-SEW/HEW with MDU		
630A frame molded case circuit breaker	NF630-SEP/HEP with MDU			NF800-SEW/HEW with MDU (300–630A)		
800A frame molded case circuit breaker	NF800-SEP/HEP with MDU			NF800-SEW/HEW with MDU (400–800A)	**External mounting**	**Breaker mounting**
Tolerance of main body measurement	· Load current and line voltage: ±2.5% (relative to the measurement rating) · Electric power: ±2.5% (relative to the measurement rating) · Harmonic current, leakage current, and leakage current containing harmonics: ±2.5% (relative to the measurement rating) · Electric energy: ±2.5% (rating: 5–100%, pf = 1) · Power factor: ±5.0% (relative to the electrical angle of 90°)			· Load current and line voltage: ±1.0% (relative to the measurement rating) · Electric power: ±1.5% (relative to the measurement rating) · Reactive power, harmonic current, leakage current, frequency, and leakage current containing harmonics: ±2.5% (relative to the measurement rating) · Electric energy: ±2.0% (rating: 5–100%, pf = 1) · Reactive energy: ±3.0% (rating: 10–100%, pf = 0) · Power factor: ±5.0% (relative to the electrical angle of 90°)		

*Fukuyama Works

mounting), in addition to the 250A frame LCD type. The external mounting type is made selectable when required, as with the 6-digit 7-segment LED display type.

1.2 Features of the latest MDU series

For enhanced usability, the visibility of the latest MDU breaker series was improved and the display functions were expanded.

1.2.1 Improvement of visibility

The latest models have LCDs with high-luminance white backlighting. Normal display (Fig. 1(a)) or color inversion (Fig. 1(b)) is selectable depending on the use environment.

1.2.2 Expansion of display functions

The display functions listed below were installed using the LCD function.

(1) Setting item list display function (only for external mounting)

This display function shows the setting items for the overcurrent tripping characteristics (to be set using the breaker main body) and others on the display (Fig. 2).

(2) Free item display function (only for external mounting)

The free item display function enables the registration of all necessary measurement items to be displayed (Fig. 3).

(3) Three-phase (four-phase) display function

A display function for each phase of the measurement items (current and voltage) is provided (Fig. 4). In addition, the screen orientation can be changed as a specification when a breaker is installed in the horizontal direction.

(4) Function for displaying red backlight when an alarm is issued

The backlight color when an alarm is issued has been changed to red to make it easier to notice an error from a distance (Fig. 5). In addition, the display format for the red backlight (lighting up or blinking) can be selected as a specification.

(a) Normal display (three-phase display)
(b) Color inversion (three-phase display)

Fig. 1 LCD display screen

Fig. 2 LTD setting value screen of setting item list display function

2. Technical issues and their countermeasures

2.1 Improvement of the design efficiency of LCD backlight

To improve the visibility of the LCDs, a backlight with light guide plates was adopted. Two types of backlight – white and red – are used. Simulation was carried out to reduce the trial and error process, which made it possible to efficiently design a backlight with high and even luminance. Specifically, the incident end face and surface shape of the light guide plate, the mounted location and required number of backlight LEDs, the shape of the reflection and diffusion sheets, and other conditions were changed to identify those that produced a high and even luminance over the entire LCD.

Figure 6 shows the simulation results. Figure 7 shows a circuit board with backlight LEDs mounted and a light guide plate.

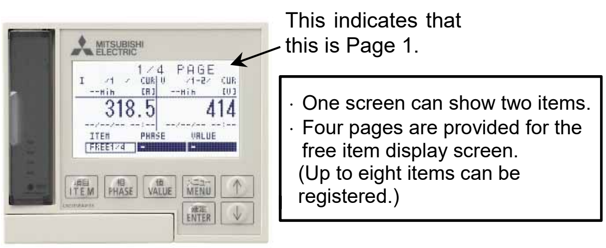


Fig. 3 Free item display screen

Fig. 4 Three-phase display screen

Fig. 5 Red backlight indication at alarm occurrence

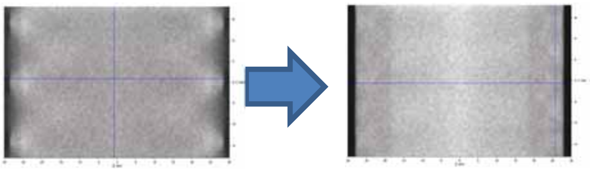


Fig. 6 Simulation results of backlight design for LCD

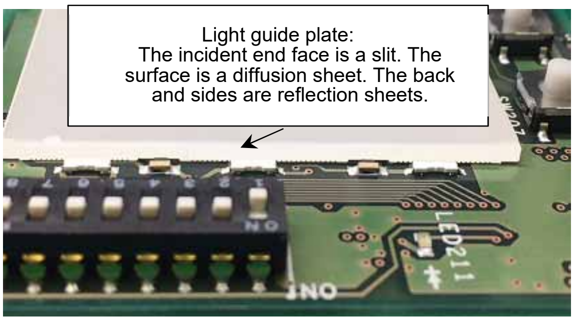


Fig. 7 LED mounting board for backlight and light guide plate

2.2 Front loading for countermeasures against EMI

Electrical noise emitted from electrical equipment propagates through space or wireways and may affect the operation of other electrical equipment and radio equipment, so the emission levels need to be equal to or lower than the standard values. For products with many restrictions on the mounting area, in particular, a revision (e.g., addition or change of parts and change of circuit board patterns) in the evaluation phase, which is a later stage of development, requires redesigning under many restrictions along with reevaluation due to the revision, greatly affecting the development schedule. This section describes front loading performed in the circuit design and circuit board design phases (early stages of the development) for countermeasures against conducted and radiated noise.

2.2.1 Front loading for countermeasures against conducted noise

(1) Consideration of circuit analysis models

The noise level must be reduced to that equal to or lower than the standard value by a noise filter circuit (CR passive filter) in the power circuit input stage installed as a countermeasure against conducted noise. Since there are many restrictions on mounting, a revision to the circuit due to the addition of a filter stage and other reasons requires heavy reworking, which may delay the delivery date. Therefore, we focused on the fact that the switching transformer of the power circuit is the propagation path of normal noise and common noise that are the cause of conducted noise: a simulation was performed using a circuit analysis model with a high-accuracy equivalent circuit of the switching transformer to evaluate the circuit. Figure 8 illustrates the equivalent circuit of the switching transformer.

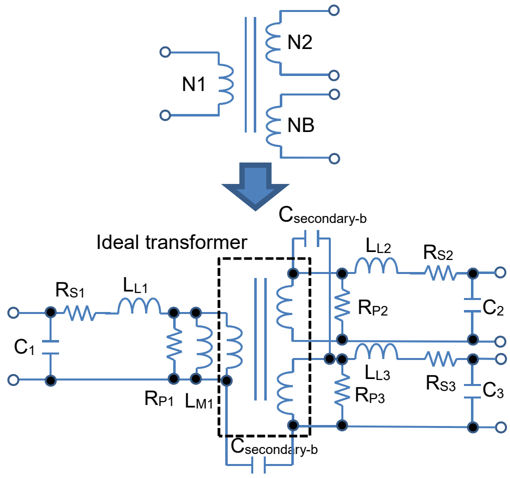
For the equivalent circuit constants of the switching transformer (e.g., leakage inductance and winding stray capacitance), the values were calculated by measuring the impedance of the parts adopted.

(2) Simulation results and measured data

The high-accuracy equivalent circuit analysis model was used for simulation in the early design stage to determine the number of filter stages and the constants of the parts such that the noise level would be reduced to the standard value or lower, where the carrier frequency (fc) of the switched mode power supply was 75 kHz (design value). Next, prototypes were fabricated based on these circuit conditions and they were used to measure the noise level. The evaluation results were excellent. In other words, front loading in which high-accuracy simulation is performed in the early design stage to check the necessary filter configuration, reduced the development period. Figure 9(a) shows the simulation results of the conducted noise. Figure 9(b) shows the measurement results using an actual product.

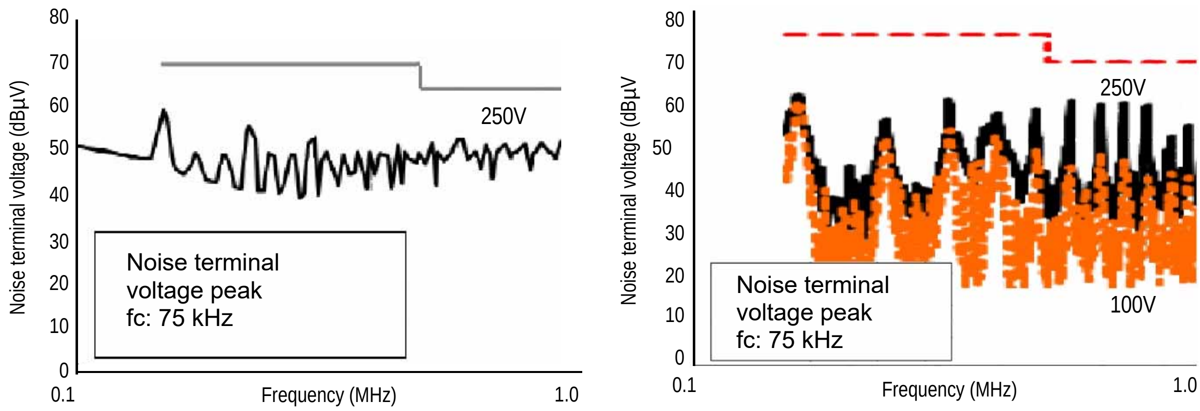
2.2.2 Front loading for countermeasures against radiated noise

As countermeasures against radiated noise,



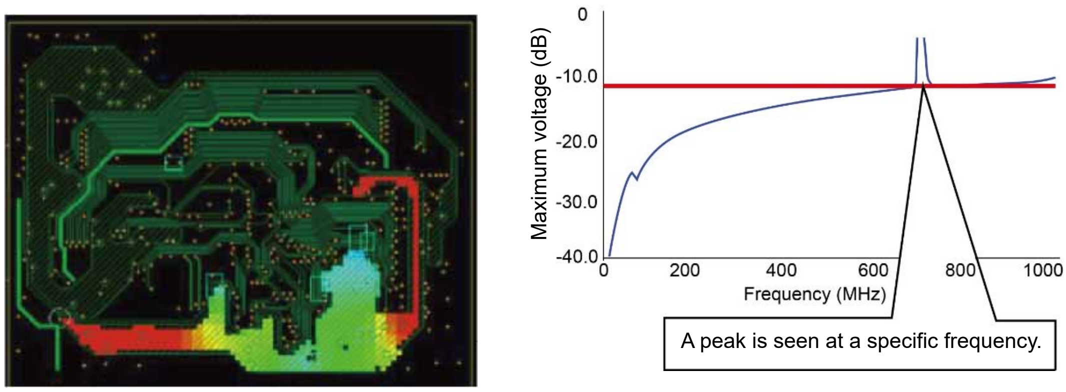
L_{M1}	Primary magnetizing inductance
L_{L1}	Primary leakage inductance
L_{L2}	Secondary leakage inductance
L_{L3}	Bias winding leakage inductance
R_{S1}	Primary winding copper loss component
R_{S2}	Secondary winding copper loss component
R_{S3}	Bias winding copper loss component
C_1	Capacity between primary winding lines
C_2	Capacity between secondary winding lines
C_3	Capacity between bias winding lines
R_{P1}	Primary magnetic loss component
R_{P2}	Secondary magnetic loss component
R_{P3}	Bias winding magnetic loss component
$C_{primary\text{-}b}$	Primary-bias winding stray capacitance
$C_{secondary\text{-}b}$	Secondary-bias winding stray capacitance

Fig. 8 Equivalent circuit of switching transformer

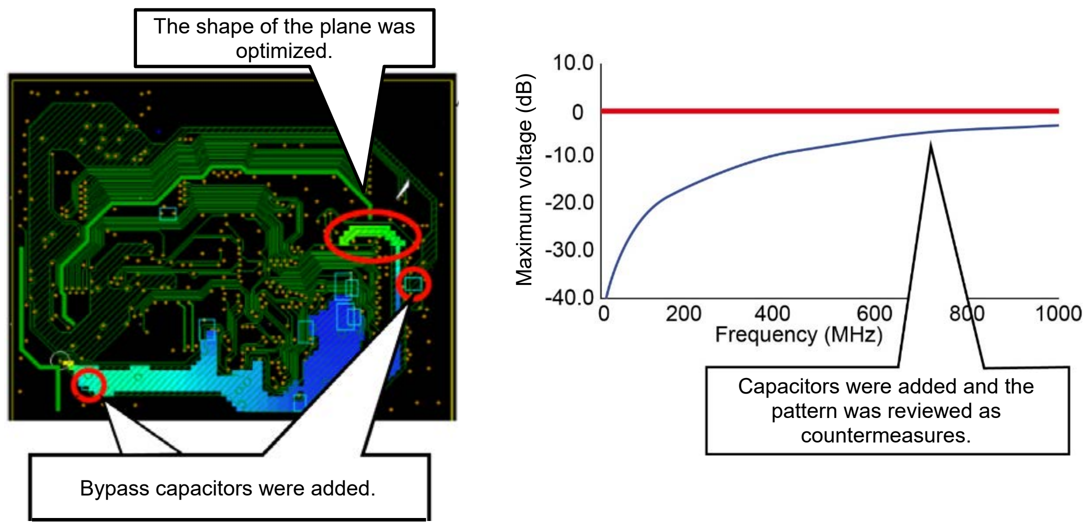


(a) Simulation results (b) Measurement results using an actual product

Fig. 9 Evaluation of conducted noise



(a) Before countermeasures



(b) After countermeasures

Fig. 10 Results of substrate resonance analysis of radiated noise

resonance between a power supply and ground plane that could generate radiated noise was analyzed in the circuit board design phase to optimize the shape from the power supply to the ground plane. In addition, it was determined to add bypass capacitors. This achieved the design to suppress the peak at a specific frequency and reduce the noise voltage level to the standard value or lower. Figure 10 shows the analysis results of the resonance of circuit boards before and after the countermeasures against radiated noise.

3. Conclusion

This paper described the features of the latest MDU breaker models along with several technical issues and their countermeasures. We will continue developing high-quality products that meet user needs.

MITSUBISHI ELECTRIC CORPORATION