ISSN 1345-3041

Jun.2018 / Vol.162

Mitsubishi Electric

ADVANCE

FA Technologies Latest Trend in e-F@ctory System

MITSUBISHI ELECTRIC
Changes for the Better

Jun. 2018 / Vol. 162

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FA Technologies Latest Trend in e-F@ctory System

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Mitsubishi Electric Advance is published on line quarterly (in March, June, September, and December) by Mitsubishi Electric Corporation.

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Technical Reports

Precis

Recently, the application of the Internet of Things (IoT) is accelerating in the field of manufacturing in pursuit of productivity and quality improvements. Against this backdrop, we actively enhance the development and design for e-F@ctory, our FA integrated solution service to create next-generation manufacturing systems using IoT. In doing so, we strive for highly satisfactory service for customers, and in turn for an increase in the FA business.

This issue introduces the latest FA technology on which e-F@ctory is based.

Overview

Author: *Toshiya Kaihara**

A New Production Paradigm in a “Society 5.0” Era

The fifth Science and Technology Basic Plan suggests the concept of a “super-smart society (Society 5.0)” and positions a “new manufacturing system” as one of the preliminary 11 systems supporting the concept. In contrast, looking at overseas trends, there is a rapid movement toward new manufacturing systems using IoT such as Industry 4.0 in Germany and the Industrial Internet Consortium (IIC) in the United States.

As domestic and overseas trends indicate, it is essential for manufacturing in the future to analyze and use the enormous quantities of data obtained from the IoT environment and to have secure domestic and overseas linkages of plant systems. The role of FA technology, which is the focus of this issue, will become greater than ever. In addition, in order to provide highly value-added products and services, it will be important not only to seek high function, high quality and low price as before, but also to shift the paradigm to service-led values for manufacturing that are required by users.

In the Cross-ministerial Strategic Innovation Promotion Program (SIP), we are researching and developing a new manufacturing system whereby creators and users of products and services jointly create value by working closely together, as well as by integrating plant equipment and products under the IoT environment. The proposed concept of value co-creation spiral will play a key role in the new smart manufacturing system which supports the super-smart society of the future.

* *Professor, Graduate School of System Informatics, Kobe University*

CC-Link IE Field Network Basic Supporting e-F@ctory

Authors: *Tomoyoshi Ueno** and *Takashi Ichimura**

CC-Link IE networks using Ethernet technology are spreading in the manufacturing fields of automobiles, liquid crystal displays/semiconductors, etc. requiring high-speed/large-capacity communication. On the other hand, in the global market including Asia, there is an increasing demand for products for small-scale systems, with an emphasis on cost effectiveness. In a small-scale system, it is necessary to reduce not only the product cost, but also the setting/start-up and maintenance costs, and to improve ease of use. While attention is paid to the IoT (Internet of Things), there is increasing demand for network compatibility among equipment and systems, which has been difficult to achieve due to the time and cost of development required. To meet these demands, we have developed an open network for small-scale systems: the "CC-Link IE Field Network Basic," which operates on standard Ethernet (Fig. 1).

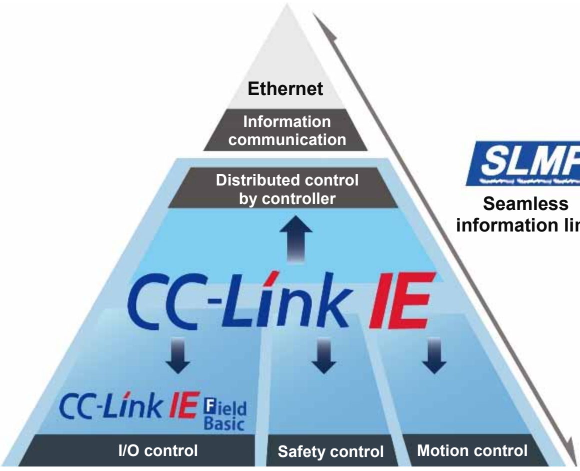

Fig. 1 Positioning of CC-Link IE Field Network Basic

1. Specifications of CC-Link IE Field Network Basic

Table 1 shows the specifications of CC-Link IE Field Network Basic, which is a protocol that can be established by software alone using standard Ethernet communication. The topology complies with that of the Ethernet, and is basically a star type. A line type topology can be supported by using a slave station with a built-in switch function (function with two Ethernet ports that allows packet relay using the switch function IC). In communication, the master station transmits the request via broadcast, and the slave station returns the response via unicast, achieving cyclic communication (Fig. 2). Cyclic communication is a function that regularly updates the distributed shared memory, which is shared between the master station (controller) and each slave station (target control station). In this CPU module (MELSEC iQ-R series) connected to 16 slave stations, the link scan time (time required for all stations to transmit control data to the master station) is 10 ms or less.

Table 1 Specifications of CC-Link IE Field Network Basic

Item	Specification
Communication speed	100 Mbps
Installation type	Software
Topology	Star, line
Cable	Ethernet category 5 or higher
Number of maximum stations connected	64
Number of occupied slave stations	1 to 16
Cyclic communication	Control signal (bit data) 8192 bits maximum RX (slave → master) 4096 points RY (master → slave) 4096 points Control data (word data) 4096 words maximum RWr (slave → master) 2048 points RWw (master → slave) 2048 points
Combination with Ethernet standard protocol	Allowed

2. Features of CC-Link IE Field Network Basic

2.1 Seamless information link

CC-Link IE Field Network Basic is the protocol of the application layer. Below the application layer, the protocol is equivalent to the standard Ethernet protocol (Fig. 3). Accordingly, combination with other protocols (HTTP/FTP/SLMP, etc.) operated on standard Ethernet is possible. Also, on an Ethernet-based wireless system, packet priority control, etc. can be used. This can put the IT system in the level above the machine at the production site into One Network; this feature can easily achieve the e-F@ctory solution.

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2.2 Establishment of highly cost-effective system

2.2.1 Wire-saving by combination with TCP/IP communication

Since the combination with TCP/IP communication is allowed, a special line for control is not required. This enables the existing network to be used and the network types to be unified. The resultant wire saving reduces the cost (Fig. 4).

2.2.2 CPU module supporting master station

Since the CPU module (MELSEC iQ-R series/iQ-F series/Q series/L series) has the built-in master station function of CC-Link IE Field Network Basic, a special network module is not required and the network can be established with the minimum configuration.

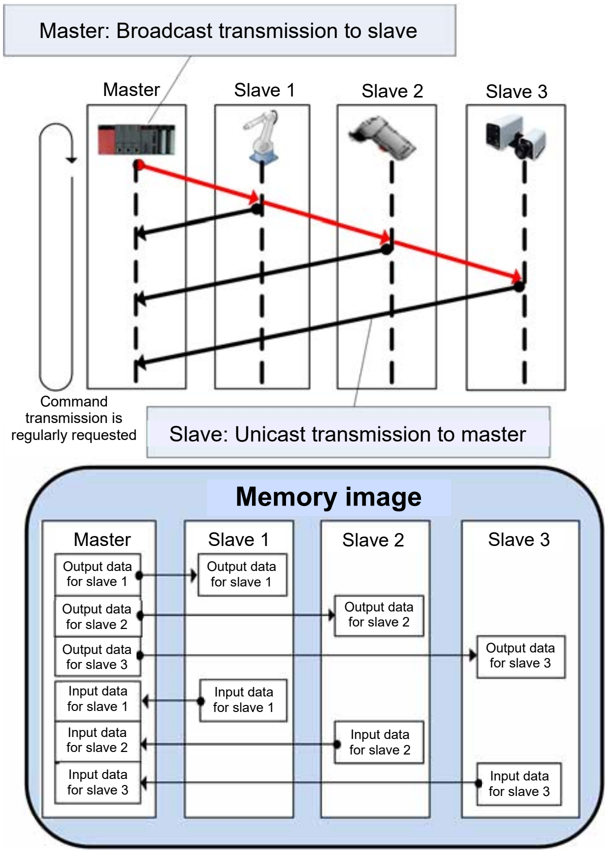


Fig. 2 Communication system of CC-Link IE Field Network Basic

2.2.3 Using general-purpose Ethernet products at 100 Mbps

In CC-Link IE Field Network Basic, existing general-purpose Ethernet equipment can be used, eliminating the need for a special hub or cables. Thus, it is not necessary to purchase a new unit and the system can be built at low cost.

2.3 Reduction of system establishment time

2.3.1 Achieving cyclic communication without programming

For communication via Ethernet, it has conventionally been necessary to define the request/response messages and prepare the program. In CC-Link IE Field Network Basic, cyclic communication can be performed through parameters settings by defining the IP address and subnet mask of the master station, the IP address and subnet mask of the slave station, and the device to be refreshed. In this way, it is not necessary to set the request/response messages or the program considering the protocol (Fig. 5).

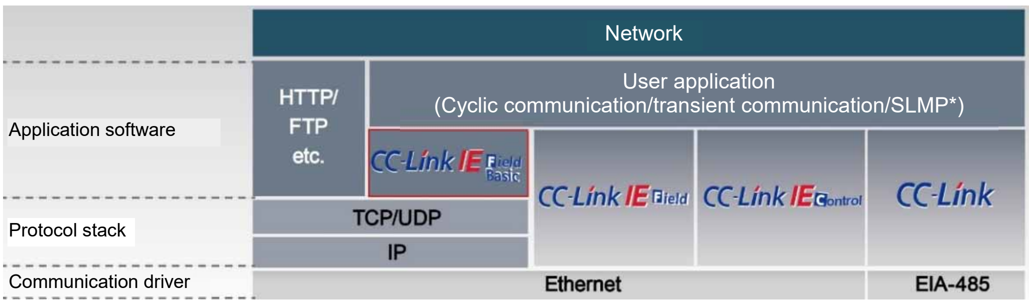
This feature can reduce the time taken to establish the system and ensure that the slave unit is controlled only by a user to manage the data link status. The maintenance cost can also be reduced.

2.3.2 Simple setting of slave unit

When the parameters are set, a compatible unit on the Ethernet line is detected using the engineering tool, and the IP address, etc. necessary for connection can be changed through the online network. Using CSP+ (unit profile compatible with common protocol connecting FA units), which describes the parameter information, etc. for the slave units, specific parameters for each slave unit can be changed by using the engineering tool through the online network. This provides a simple way to not only set the parameters for the master station, but also those for the slave stations.

2.4 Reducing down time of the system with diagnostic function

In CC-Link IE Field Network Basic, the communication status or operation status of the slave



*SLMP: Seamless Message Protocol

Fig. 3 Protocol layer of CC-Link IE Field Network Basic station is obtained from the cyclic data and is integrally controlled in the master station. This information can be checked by monitoring the diagnostics screen using the engineering tool. The location of a problem can be seen at a glance (Fig. 6). If a problem occurs, troubleshooting can be performed even by someone without expertise, by displaying the cause and corrective action on the diagnostics screen. This feature reduces the system down time if a problem occurs.

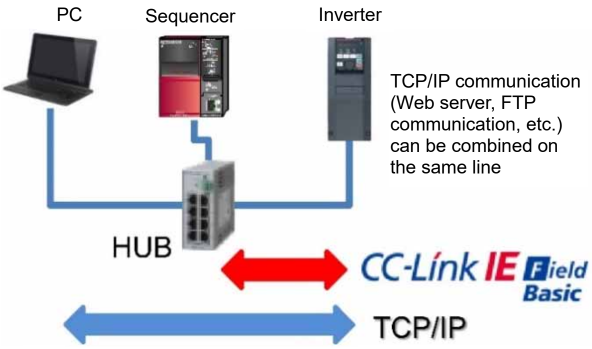


Fig. 4 Combination with TCP/IP communication

2.5 Developing compatible products simply by installation of software

CC-Link IE Field Network Basic is the protocol of the application layer. It can be additionally installed on the hardware for standard Ethernet. Since installation by software is allowed, the development period is reduced, and since special hardware is not required, the unit price is lower.

3. Conclusion

This paper describes the development background, features and applied technology of CC-Link IE Field Network Basic. We will continue to respond to the ever-changing market status and the needs of users to reinforce the link with our FA units and promote attractive product manufacturing.

Reference

(1) Hisafumi Komoto: CC-Link IE Field Network, Mitsubishi Denki Giho 88, No. 3, 179–182 (2010).

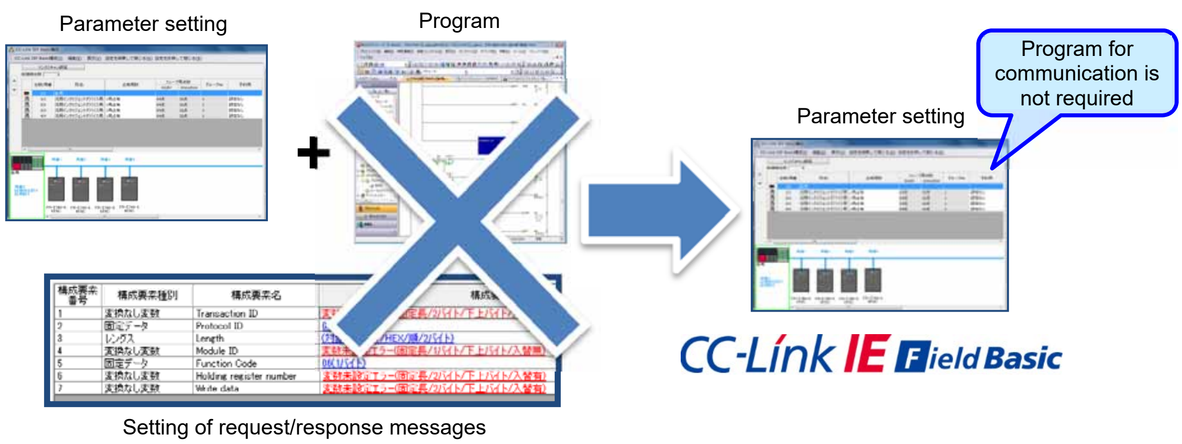


Fig. 5 Simple setting

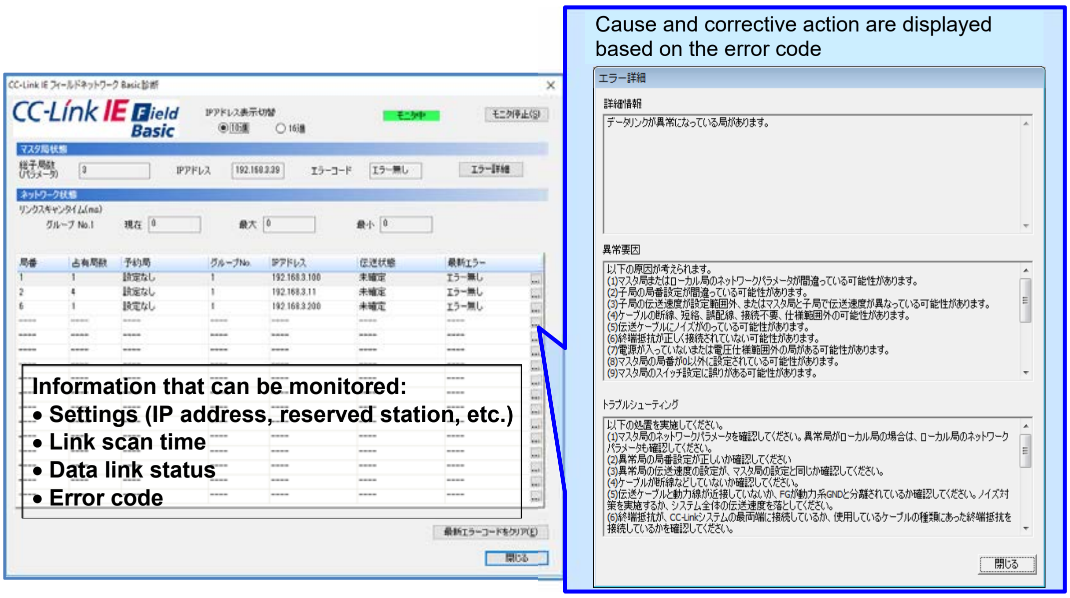


Fig. 6 Troubleshooting

MELSEC iQ-R Engineering Environment and Integrated Monitoring System for Process Control

Authors: *Akira Tsubone** and *Masahira Ikeda**

To meet the evolving requirements of the process automation market, we have developed the MELSEC iQ-R process CPU, which facilitates the advanced process control function and greatly improves its performance together with the features for process control of the programmable logic controller engineering environment GX Works3 and SCADA (supervisory control and data acquisition) software MC Works64. This report introduces the features for process control of GX Works3 and MC Works64.

1. Features for Process Control of GX Works3

In the conventional programmable controller engineering environment, it was necessary to perform programming by using two separate tools (Process control: PX Developer, Electrical control: GX Works2) suitable for each control type. Therefore, in defining and managing the labels (tags), compiling programs and downloading programs to the programmable controller, the use of two tools complicated the process and created a problem. To solve this problem, GX Works3 integrated the process control and the electric control into one tool, which eliminated the complex operation and reduced the programming hours (Fig. 1).

In the process control, it is necessary to describe the logic that continuously processes the analog value including the PID loop control. A suitable programming language for describing such logic is the FBD language of the IEC61131-3 standard. However, the FBD language is not suitable for describing logic that combines complicated AND/OR logic operation in ON/OFF status such as for an interlock circuit. Thus, GX Works3 allows a mixed description of ladder language components such as contacts or coils in the FBD language compliant with IEC61131-3 (Fig. 2).

In GX Works3, the process control tag FB was added as a library to easily achieve advanced control in the process control system like a PID loop equipped with cascade control or feedforward control (Fig. 3). Operation of these process control tag FBs can be changed by setting the detailed properties. Therefore, usage of the process control tag FB has made programming of advanced process control logic easily available.

The process control tag FB can also provide a popup display of the faceplate. This allows a visual check for operation of the program. In addition, GX Works3 contains not only the faceplate, but also the process control tag tuning tool with the standard screens such as a tuning panel, trend graph, etc. generally used in tuning the process control tag. After preparing the program, process control tag tuning can immediately be performed using this tool. Thus, the hours required for engineering can be reduced.

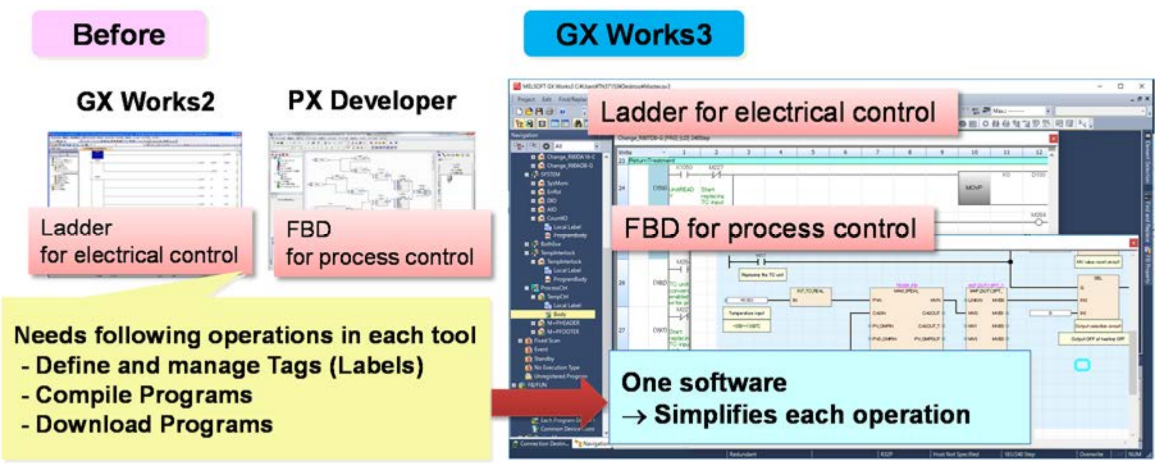


Fig. 1 Integrated engineering tool

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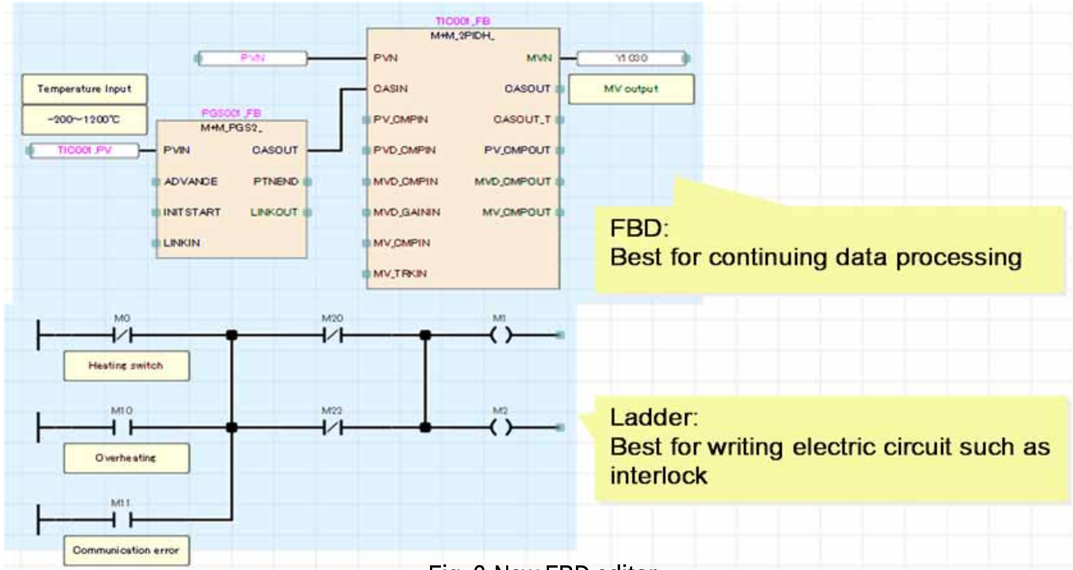

Fig. 2 New FBD editor

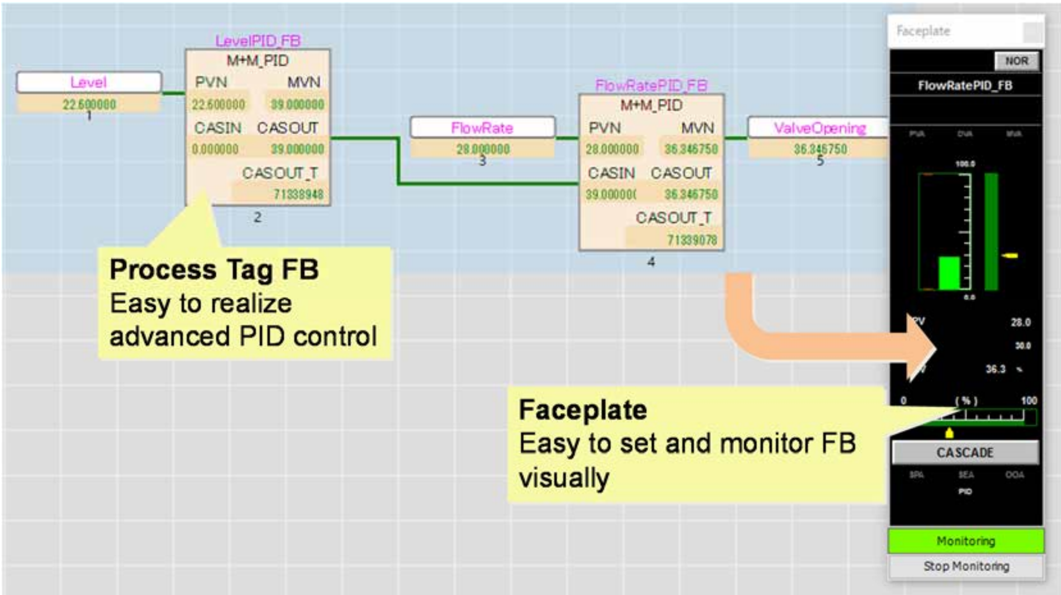

Fig. 3 Process Tag FB and Faceplate

2. MC Works64

MC Works64 is SCADA software that establishes the integrated monitoring system and has been used in a wide range of fields, especially the manufacturing industry. MC Works64 has excellent functions such as high-definition graphics display, mobile display, and cloud support. However, the process control monitoring encountered several problems including the availability of a standard screen suitable for monitoring and managing the process control tags, instantaneous notification of important data changes including alarms, and ease of communication settings. The functions developed to solve these problems are described below.

MC Works64 has the auto generating function of monitoring screens as a standard unit that facilitates establishment of the integrated monitoring system. With this function, monitoring screens can automatically be generated according to the device for monitoring by using the registered template screen.

A faceplate and tuning panel for monitoring and managing the process control tags and for parameter tuning were newly added as the template screen (Fig. 4).

This allows saving of screen creation for monitoring and managing the process control tags.

MC Works64 communicates with our PLC (programmable logic controller) with the OPC server function. Conventionally, this function has supported only polling type communication, which requests data from the programmable logic controller at constant intervals. However, in polling type communication, if there is a particularly large number of monitoring points, then important event notifications such as alarms or mode changes on the process control system may be delayed.

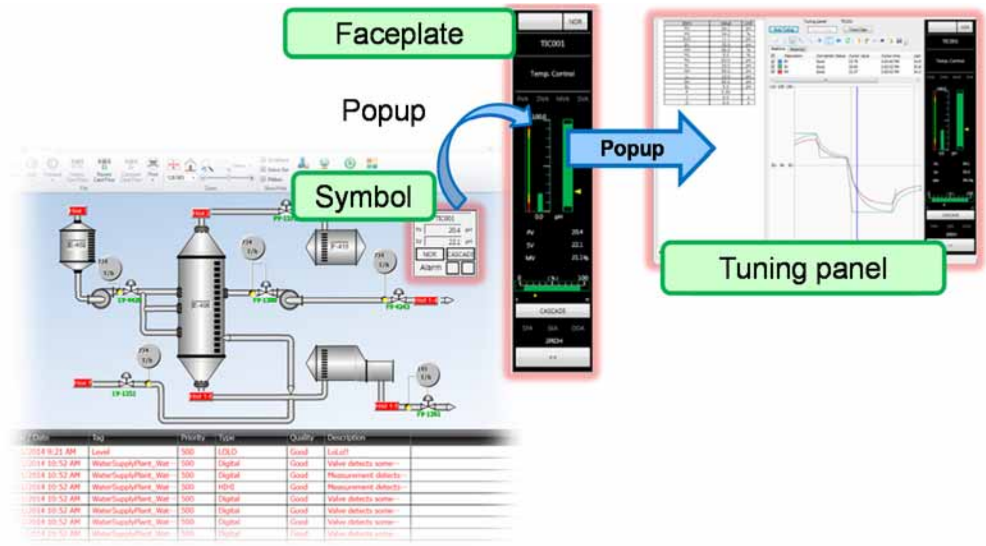

Fig. 4 Screen image of Faceplate for Process Tag

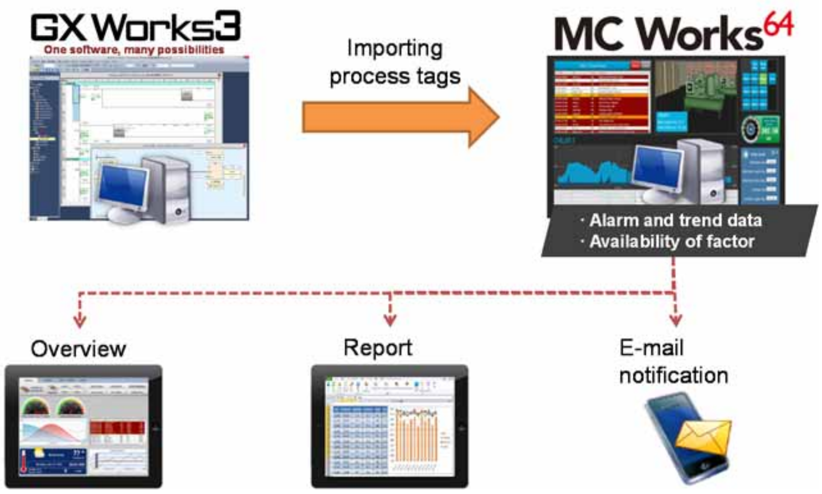

Fig. 5 Importing process tags and remote monitoring with mobile devices

Therefore, our process control tag FB has an event notification function that transmits the applicable tag information from the iQ-R process CPU to the server upon the occurrence of an event. By adding the event receiving function to this OPC server function, MC Works64 is able to instantaneously detect an important event.

To monitor the process control tags with MC Works64, tag communication setting, alarm setting and data logging setting are required. If the number of process control tags increases, the workload of these settings becomes larger. Therefore, a function was developed that takes the process control tag definition data from the project created with GX Works3 and incorporates it in each setting in MC Works64. This reduces the workload of the setting on MC Works64.

MC Works64 also has a function that analyzes device operation based on data collected from the programmable controller, and a function that provides alarm/trend information using a mobile device, displays the analysis results in a graph/list, outputs the report and sends notification by e-mail. The combination of these functions with the incorporation of the process control tag definition data previously described allows operation analysis using the incorporated measurement data, and remote monitoring of the analysis results and the process control related data (alarms, trends, etc.) easily using a mobile device (Fig. 5) in the process control monitoring system.

3. Conclusion

This report introduced GX Works3 and MC Works64 compatible with the MELSEC iQ-R process CPU. We will listen to many opinions of customers and will continue to develop and provide a product which realizes attractive quality.

Reference

(1) Tsubone A., et al.: Instrumentation Engineering Environment and Integrated Supervisory System for "MELSEC iQ-R Series," Mitsubishi Denki Giho 91, No. 4, 221–224 (2017).

MITSUBISHI CNC C80 Series

Author: *Kenji Kato**

We have developed the C80 Series with CNC-dedicated CPU units compatible with the MELSEC iQ-R Series. The new C80 Series optimizes overall plant operations through the coordination of various FA device groups. It improves the added value of the manufacturing line system and contributes to the reduction of TCO (total cost of ownership) in all aspects of development, manufacturing and maintenance.

1. Introduction

Various production lines, typically in automobile manufacturing, require an easily integrated automation system that leads to high productivity and stable production quality. To date, Mitsubishi Electric has suggested the "e-F@ctory" integrated FA solution, which optimizes plant operations and supports the future of manufacturing using advanced technology and information based on the main concept of TCO reduction regarding all aspects of development, production and maintenance. The integrated FA platform that forms this base is the "iQ-Platform." The C70 Series, which supports this solution, has been introduced into many production lines and is highly acclaimed.

Meanwhile, the demand for IoT-related functions is increasing. Requests from the global market including for optimization/visualization of the overall plant operations and for information linkage between the production site and the upper-level information system have advanced and diversified. To meet these requests, the computerized numerical controller (CNC) "C80 Series" supporting the MELSEC iQ-R Series was added to the product line. This paper describes the main features of the C80 Series.

2. System Configuration of C80 Series

The system configuration of the C80 Series is shown in Fig. 1. The C80 Series CNC is installed on the base unit of the MELSEC iQ-R Series. A maximum of three sets of CNC CPUs can be installed on one base unit. In total, a complicated machine with up to 21 part systems and 48 axes can be controlled. Our graphic operation terminal (GOT) is used for the display and an intuitive operation feel has been achieved for the touch panel. In addition, operation is standardized for the Mitsubishi CNC by displaying on the GOT a screen equivalent to the standard screen of the M800 Series.

3. Features of C80 Series

3.1 Productivity

The C80 Series has a uniquely developed CPU specifically for the CNC as is the case with the M800 Series and the basic performance has been greatly improved. M-code processing capability (representing the miscellaneous function command processing time of CNC machining programs and the index value of the

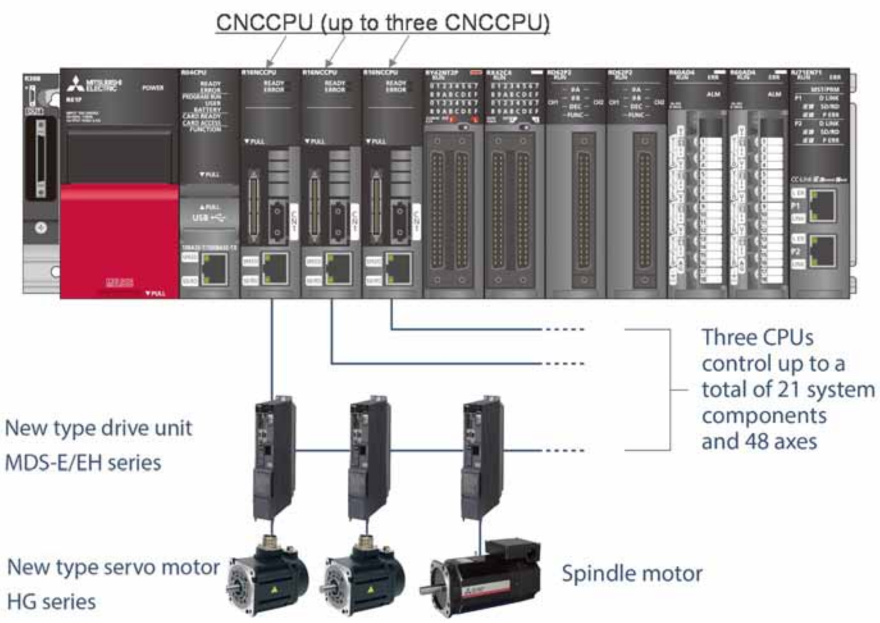

Fig. 1 C80 Series system configuration

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Fig. 2 CNC Monitor2

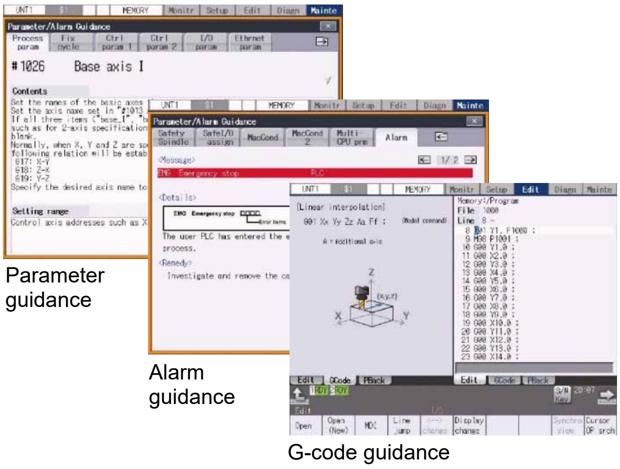

Fig. 3 Screen for guidance functions

cycle time reduction) is about 1.5 times greater compared to the C70 Series.

3.2 Expandability

In the C80 Series, a diverse group of MELSEC units can be used. Devices can be selected according to the production scale and the application of the production line, thus creating a flexible system.

3.3 Usability

The C80 Series uses GOT as the display, like the C70 Series, and intuitive operation has been achieved for the touch panel. For the CNC operation screen, the newly developed CNC Monitor 2 displays a screen image equivalent to the M800 Series standard screen (Fig. 2). This CNC Monitor 2 allows touch selection of screen items, which was not possible with the C70 Series, and more intuitive operation of the screen. In addition, parameter guidance, alarm guidance and G-code guidance are installed as standard functions, significantly improving convenience for users (Fig. 3).

3.4 Maintainability

In the production line, reduction of equipment downtime is required. Thus, the C80 has the following features to improve maintainability for users.

(1) Main unit battery of CNC CPU

By using a nonvolatile SRAM for the built-in memory of the CNC CPU, it is not necessary to have a battery to hold data such as parameters and machining programs stored in the CNC CPU. This eliminates the risk of data loss due to battery replacement error or omission.

(2) Backup restore function

Data stored in the CNC CPU can be backed up to the memory card of the GOT. In the event of a problem such as CNC CPU failure, the system can be easily restored by using the backup data after replacing the CNC CPU, thus reducing downtime.

3.5 Reinforcement of function safety support

The safety monitoring function of the C80 Series conforms to “EN ISO13849-1:2015 (Cat.3, PL d)” and “EN 62061:2005/A2:2015 (SIL CL2),” which are the latest safety standards. Table 1 shows the safety monitoring function supported by the C80 Series.

Table 1 Safety observation function list

SLS (Safely limited speed)	Safety-related I/O observation
SOS (Safe operating stop)	Emergency stop observation
SBC (Safe brake control)	STO (Safe torque off)
SLP (Safely limited position)	SS1 (Safe stop 1)
SSM (Safe speed monitor)	SS2 (Safe stop 2)
SCA (Safe cam)	

In this project, a new safety signal unit was developed with a function for monitoring safety-related signals (Fig. 4). This function can ensure safety by using the duplicate control circuit of a safety-related signal such as a door signal or emergency stop in the CNC CPU with operation of the other circuit if one circuit fails.

Fig. 4 Safety signal unit

4. Conclusion

We introduced the CNC C80 Series supporting the MELSEC iQ-R Series. We will further develop this product to meet various market requirements in the future.

Wire EDM MV Series with M800 Controller

Authors: *Ken Inukai** and *Kiyohito Kamiya**

As a new product line in the MV series of wire electrical discharge machines, we have developed the MV D-CUBES series, which has a new control system using IoT technology and supports a wide range of applications including high-precision die machining and component machining. We have also introduced IQ Care Remote4U, a remote service option that supports productivity improvement.

1. Introduction

Since its release in 2012, the MV wire electrical discharge machine series has accounted for about 90% of the total global sales of wire electrical discharge machines. The cumulative number of MV units sold worldwide has exceeded 5,000. The series has been popular not only in Japan but also in overseas markets. However, customers' needs have changed over time. Higher performance of electronic devices, automobile components, and mobile devices requires that dies and components manufactured and machined for these products be of higher precision, low cost, delivered more quickly, and provide other improvements to make the products more competitive in the global market.

To meet these needs, we have developed the new D-CUBES control system by optimizing our M800W computerized numerical controller for use in electrical discharge machining, to be integrated with the MV series (Fig. 1). D-CUBES delivers excellent operability and functionality that improves productivity thanks to a navigation function, real-time detection function for remaining wire electrodes, etc.

Another of our initiatives was to apply e-F@ctory, our solutions program since 2003 for optimizing production operations, to the field of electrical discharge machining using IoT. In order to launch the e-F@ctory service for electrical discharge machining, we introduced the iQ Care Remote4U service with two features: the Dashboard function to monitor the status of machine operation and maintenance in real time from a PC or smartphone; and the Remote Diagnosis function to remotely operate the machine and check its status on the screen, thereby reducing machine downtime.

This article describes the features of the new D-CUBES control system and the iQ Care Remote4U remote service.

2. Features of New Control System

2.1 Productivity improvement by enhancing the operability

The new control system was developed to help customers improve their productivity by manufacturing

Model name		MV1200S/MV1200R	MV2400S/MV2400R
Movement amount along axes (X×Y×Z)	[mm]	400×300×200	600×400×310
Movement amount along axes (U×V)	[mm]	±60 × ±60	±75 × ±75
Maximum dimensions of workpiece	[mm]	810×700×215	1050×820×305
Applicable wire electrode diameter	[mm]	φ0.1–0.3	φ0.1–0.3
Applicable machining fluid		Water	Water
Installation dimensions (width × depth)	[mm]	2025×2760	2687×3030

Fig. 1 MV Series

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quality products more quickly and at lower cost. The key development targets were simplified operation, human error reduction, and connectivity.

Regarding the connection target, data communication with the Dashboard and the Remote Diagnosis of iQ Care Remote4U have been achieved as described later. In addition, the Dashboard can be directly viewed on the new control system.

2.2 Simplified operation and human error reduction

The new control system has a screen that is 15 to 19 inches wider than the screens of existing models, with a touch panel that allows users to operate the system in the same manner as a smartphone or tablet. The increased screen size makes it possible to add the HOME screen on which users can view the machining progress, machining stability, and status of consumables at a glance. Also, a newly developed function allows the user to call up other functions from the HOME screen with one touch (Fig. 2).

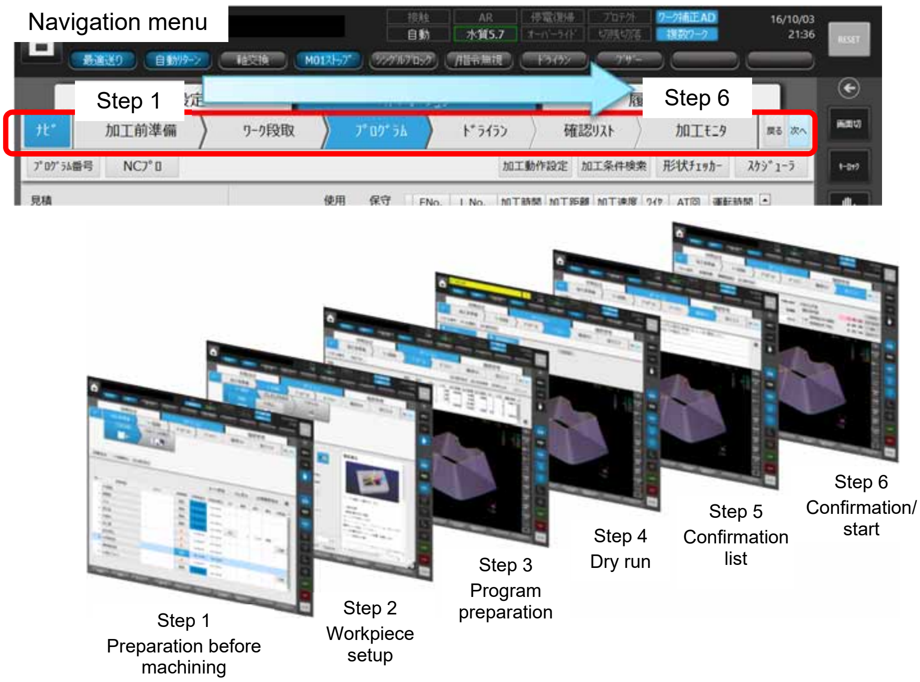
Electrical discharge machines involve many manual operations including those that require sophisticated skills. It takes time to train the operators and human errors are likely to occur, resulting in poor machining quality. To solve these problems, a new operation navigation function has been developed to clarify the operation procedures and prevent the omission of a procedure. Along with this, the screen switchover, determination of inputs, etc. of previous models were modified for each procedure. The number of screen operations was reduced by approx. 40% from that of the previous models, raising work efficiency (Fig. 3).

In addition, an operation procedure function using a procedure checklist has been provided to reduce human errors such as poor machining quality caused by operators who omit a procedure. (Conventionally, each customer creates and uses their own procedure checklist.) In the case of a procedure that is unchecked on the list, the safety interlock will be activated to stop the machining before the next procedure to prevent the omission of a procedure.

The Manual Operation Box frequently used in the setup work has been renewed as well. A liquid crystal display is used, and a function has been added to override the Z-axis soft limit for preventing interference

The screen can be opened from each panel with one touch.

Fig. 2 HOME screen



Following the menu items in sequence from the left guides the operator through the machining process.

Fig. 3 Navigation function

with the workpiece or a jig and to override the axis moving speed during a dry run. This has improved the work efficiency.

3. Features of the iQ Care Remote4U Remote Service

3.1 Dashboard function

The Dashboard function allows customers to check machine operation information, estimated machining time, power consumption, replacement time for consumables, etc. at any time from a PC, smartphone or tablet. Operators can reduce the time it takes to stop a machine by being notified of the completion of work, alarm information, remaining wire electrode information, etc. by e-mail. Managers can collect information on the operation rate and cost for each machine on the IoT platform and retain the data under integrated control for analysis. Analysis results of the data can be used for improving the production process and reducing the running costs (Fig. 4).

In addition to obtaining operation information on the electrical discharge machines, the ability to visualize the operating status allows customers to identify time-consuming tasks in the setup work including setting the flatness and parallelism and determining the reference positions for workpieces. This in turn allows the customers to eliminate time-consuming factors in skills improvement training for operators and in manufacturing the setup jigs, thus improving the operation ratio (Fig. 5). If multiple machines are controlled by an operator, there may be one or more machines left idle. When a machine in a lengthy idle state is detected on the Dashboard, the standby power of the machine can be minimized using the power saving mode, thereby reducing the power cost.

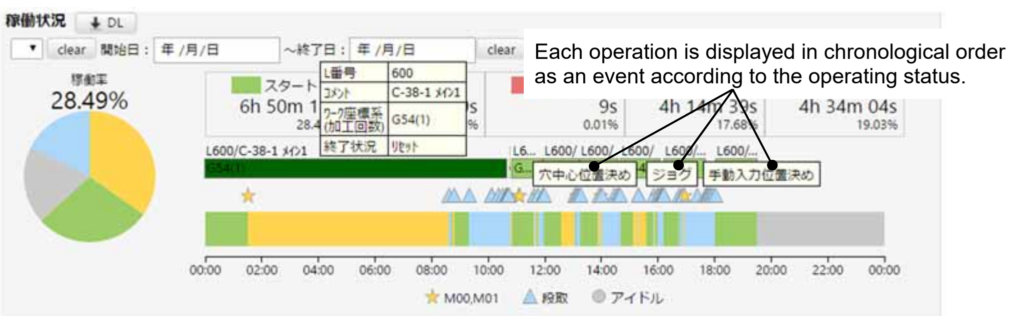
Fig. 4 Dashboard

3.2 Remote Diagnosis function

The Remote Diagnosis function directly connects a terminal installed at our service center to an electrical discharge machine at the customer's site through a virtual private network (VPN), and remotely checks the machine status. Checking alarm details and machining conditions from the service center and sharing information on the electrical discharge machine on the screen with the production site allows a quick diagnosis to minimize the machine downtime, and makes it possible to give the customer advice on ways to improve operation based on the obtained machining data, as well as improve their operation ratio and productivity. For information security, in addition to safety by encryption, there is a Remote Diagnosis switch on the machine side to prevent connection to the machine without permission from the customer.

Conclusion

This article described the features of the new D-CUBES control system and the recently launched iQ Care Remote4U remote service. We will continue helping customers to improve productivity by developing products that meet their needs.



Visualization of operating status
Automatic mode to perform automatic operation and manual mode to perform setup work.
Information provided by the input of axis movement commands from the manual operation box and by screen operation including positioning menu, etc. are used by the control system to automatically determine the operating status of the operator, and to output the operating status.

Fig. 5 Visualization of operating status

Innovation of Manufacturing Engineering Based on IoT Technologies at Production Sites

Authors: *Kazuhiro Kambara** and *Junichiro Abe***

To meet the diversified consumer needs of recent years, it is important for the manufacturing industry to make greater use of IT and IoT technologies. Nationwide initiatives involving the use of IT and IoT in the field of manufacturing are growing in the U.S. and in European and Asian countries. Accordingly, this paper describes our future image of manufacturing, together with some e-F@ctory case examples as specific approaches to achieve this vision.

1. Manufacturing Environment and e-F@ctory Initiatives

1.1 Future image of manufacturing

In the future, the use of IT and IoT and the digital space will progress in all aspects of manufacturing (Fig. 1). The demand is forecasted based on market information analysis; preventive maintenance is controlled using big data collected from production equipment; machines and workers are allocated to optimal positions using a production line simulator; and prototypes are manufactured with 3D printers. This will dramatically boost efficiency and reduce the time required for individual processes.

Along with the technology advancement that enables the sophisticated operation methods described above, the importance of data will increase; it is essential to optimize the operations and processes involved in manufacturing. In recent years, automation and optimization of manufacturing processes using artificial intelligence (AI) have shown remarkable growth. Nevertheless, the simulation results do not always match the actual results due to all the changes and differences in environments. Human knowledge is indispensable for evaluating whether results are acceptable and for making adjustments. We must bear this in mind when pursuing the ideal vision.

In order to perform the plan-do-check-act (PDCA) cycle in the operating processes as efficiently and fast as possible to optimize the manufacturing process flow by effectively using the latest technology and data, it is necessary to create the systems, basic technologies and required standards.

We have been working on innovative manufacturing by providing e-F@ctory solutions which integrate state-of-the-art FA and IT technologies since 2003, aiming to achieve the future image of manufacturing.

1.2 Integrated FA solution: e-F@ctory

With IT/IoT technologies quickly advancing, production sites need to optimize operations using data collected from equipment. e-F@ctory has provided a series of products that link production sites to IT systems (host information systems including manufacturing execution systems and enterprise resource planning systems) and networks that enable seamless connection between devices, such as sensors, and IT systems, thereby visualizing and improving production sites based on feedback obtained through real-time analysis of the collected data. This has improved the productivity, product quality, environment, and safety of production sites, and helped reduce customers' total cost of ownership (Fig. 2). In addition, we are building a total solution to support advanced

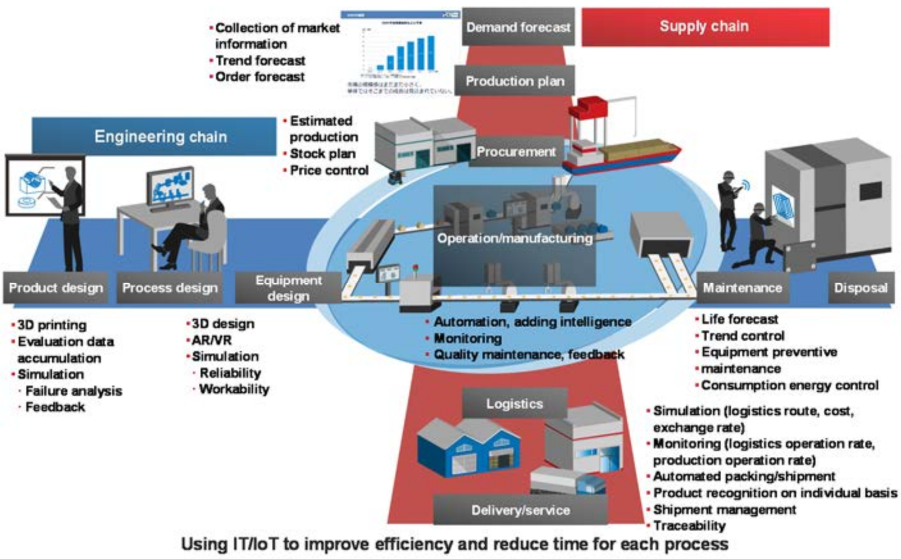


Fig. 1 Intelligent manufacturing achieved by using IT and IoT

*Nagoya Works   **Solution Business Strategy Division manufacturing through higher-speed control by making different machine models work together, information linkage between IT systems and production sites, and coordination with partners (e-F@ctory Alliance).

The intermediate layer between FA and IT plays a role in optimizing the entire system, in addition to enabling seamless linkage. We call the intermediate layer "Edge-computing," and consider that it is a remarkable feature of e-F@ctory.

e-F@ctory solutions connect FA and IT and effectively use data in such an architecture, thereby advancing manufacturing and improving corporate value.

2. Application Examples of e-F@ctory

Even when developing diverse products to meet both domestic and overseas market demand, or when producing multiple products in different quantities to cope with demand fluctuations, manufacturers must keep both product quality and productivity high. To do this, the production line must respond quickly to variation factors (changes in produced models/amount). Manufacturers need to take measures to optimize the entire production line, not just parts of the line as conventionally performed.

e-F@ctory involves collecting various types of real-time data including data on operators and equipment, thereby performing the PDCA cycle at the production site efficiently and quickly. This allows users to balance high product quality and productivity, and to immediately analyze and use the data for improvement.

Here, the initiatives at one of Mitsubishi Electric Corporation's FA equipment production sites are described as an example of flexible production that allows multiple products to be produced in variable quantities.

2.1 Factory monitoring

The production of programmable controllers, a component of FA equipment, consists of three main phases: (1) surface mounting, (2) board assembly, and (3) product assembly/testing. ((1) and (2) constitute the board mounting process.) About 3,000 models are produced while moving between multiple equipments and testers for each phase.

To maintain high product quality and productivity, it is necessary to comply with the specified production method, and to satisfy the specified quality standard. It is best to repeat the same work at a constant interval. However, in daily production work, fluctuations arising from emergency orders, equipment problems, work delays, etc., often occur and require immediate action. The programmable controller factory has a structure that allows the factory-wide production progress to be monitored in real time (Fig. 3), and also allows equipment operation information, percentage of defect-free tested products, and other fluctuating factors to be integrally visualized, analyzed and evaluated. The production information is used for planning and adjusting the production schedule of each phase and facility. By combining the restrictions on production resources, including material stock information and personnel arrangements, with the production progress and equipment operation information, highly accurate production schedules are created. As a result, when a production delay or quality problem occurs, the production resources can be quickly changed. Line downtime is minimized to maintain high productivity and quality.

2.2 Factory-wide optimization of surface-mounting line

A surface-mounting line is an automated production line for mounting electronic components on the surface of each printed circuit board at high speed, yielding high productivity. When producing multiple products in variable quantities, it is necessary to perform production efficiently and flexibly in response to changes in the model or amount to be produced. To do this, a surface-mounting operation management system is used for the line at the site to minimize losses due to equipment downtime and maintain the optimum operation cycle time by collecting equipment data for visualization and analysis (Fig. 4).

The mounter, which is the main machine in the line, collects real-time information through FA equipment including the equipment

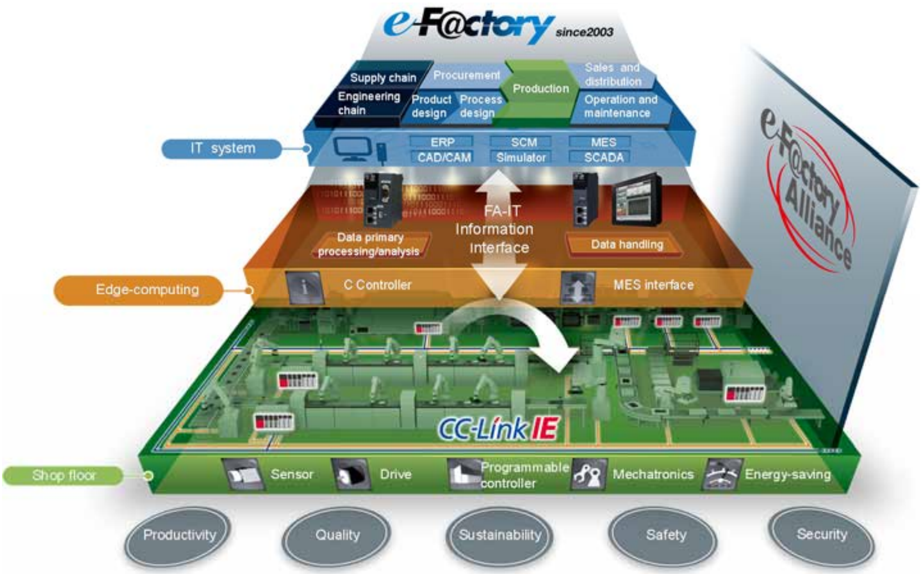


Fig. 2 FA integrated solution "e-F@ctory"

operating status and mounting status for each component to allow centralized monitoring. The four major features of this functionality are described below.

2.2.1 Improvement of the operation ratio

Causes of equipment downtime are made visible in real time. A problem existing at a point during the setup time and mounting time (equipment downtime loss) can be viewed. To reduce the setup time, the timing for a model change is determined for the production plan by managing the component locations in the factory and visualizing the setup progress for each line, and then a priority order for the setup of multiple surface-mounting lines is determined. Based on the priority instructions, operators can change models with minimal downtime of the line by setting the components on a setup cart in advance. The progress of the setup work is visualized in real time, and any delay in work can be addressed immediately by instructing other operators to assist, allowing the work to be completed as planned.

2.2.2 Reduction of equipment downtime loss

To prevent equipment downtime during the operation, real-time information on the production plan and the number of components remaining in the mounting machine is collected to prepare replenishing components in advance. At equipment sections where regular maintenance (for jigs/tools and equipment parameters) is required, systematic preventive maintenance can be conducted based on trend management using the collected real-time equipment information.

2.2.3 Quality improvement

The information on product defects found in various sections of the equipment is used to manage trends, thereby identifying the causes of defects to improve the product quality. For capturing true defects at an early stage, the appearance checker analyzes the results of actual defect collected through visual inspections to revise the inspection judgment formula, thereby improving the overdetection rate of defects. For improving the product quality, the soldering inspector analyzes defect detection results to provide feedback regarding production conditions for each section of the equipment. In addition, the product serial number printed on the board for ensuring production traceability, production lots of components/boards, and inspection/test results are associated with each other, thereby enabling the production history and variation points to be managed.

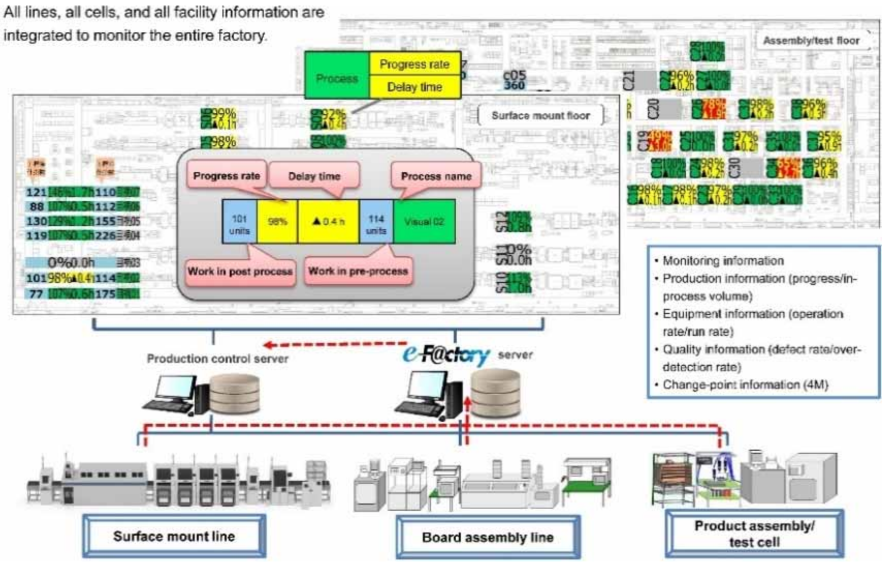


Fig. 3 Factory-wide visual control

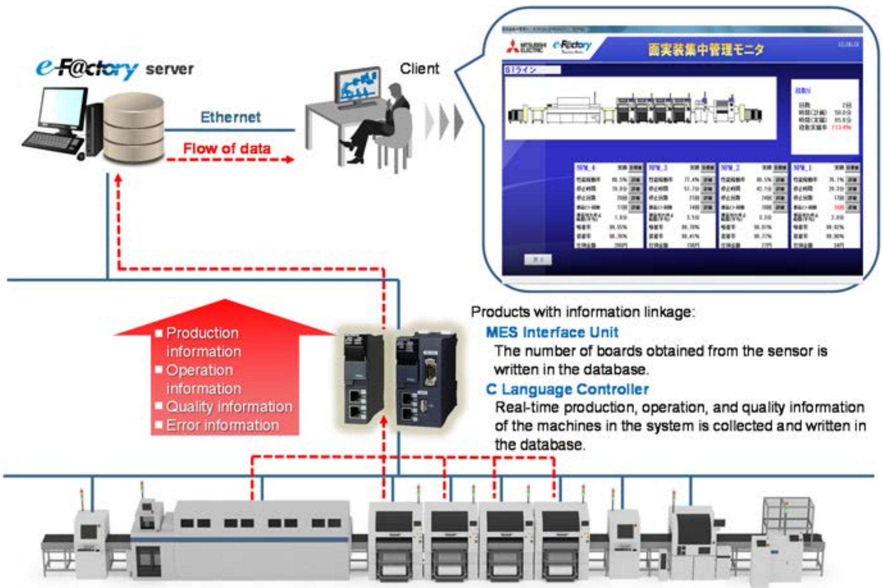


Fig. 4 Surface-mounting operation management system

2.3 Work assistance system for product assembly cells

At the production site where programmable controllers are assembled, many models are produced within a short delivery time. Accordingly, a production system is used in which human assemblers work in groups in cells (human cells), allowing small-lot multiple-cycle production. The system of human cells often causes the productivity and product quality to depend on the skills of the workers, and so work errors must be prevented and training on improving efficiency must be given.

The screw-tightening instruction system uses a programmable controller for system control that displays the procedure for each work phase on the screen. Human workers assemble components and tighten screws referring to the display. When tightening screws, information on the position for screw tightening, screw type, electric screwdriver that should be used, etc., is displayed on the screen, and the workers can complete the tasks as instructed. The operation status of the electric screwdriver is constantly monitored with the programmable controller. Whether the necessary number of screws have been tightened using the specified screwdriver, whether the correct screws have been used, etc. is automatically checked, preventing errors during the work (Fig. 5).

Furthermore, to respond to the demand for multi-model production, the time for creating work manuals needs to be reduced. This is done by using the design data already prepared for product design and by using a dedicated procedure creation tool.

Information on the operation of electric screwdrivers is automatically collected in the database as part of the operation record. The operation record is visualized using a general-purpose analysis tool to analyze simply the operation procedure for each phase of an assembly cell and the hours taken by each worker. When a change in the working time is detected, the system checks whether the change is caused by using an incorrect component, thus preventing quality defects. By analyzing the time taken by each worker, the skill level of a worker and the type of work where the worker is less skilled can be determined. This shows supervisors the areas where workers need advice, so e-F@ctory can reduce the training time for workers by about 50%.

3. Conclusion

Regarding production innovation using IT at production sites, we have described our future vision of manufacturing and an example of the initiatives to achieve the vision at surface-mounting lines and product assembly cells using e-F@ctory. These initiatives take production technology innovation one step further, using an enormous amount of data collected from the entire production site for information association and analysis, thereby finding new correlations.

In future, it is important to identify latent problems at a production site in advance through data analysis technology. We will actively promote manufacturing innovations that involve prevention and control by taking preventive measures and recurrence preventive measures. We will do this by organically associating various data remaining independent with other data, and by performing the PDCA cycle for efficient, rapid improvement by combining the knowledge accumulated based on the three conventional factors of production sites, products/materials, and current situation, together with state-of-the-art IT technologies. In doing so, we will strive to create a highly reliable production site that operates without any downtime or product defects.

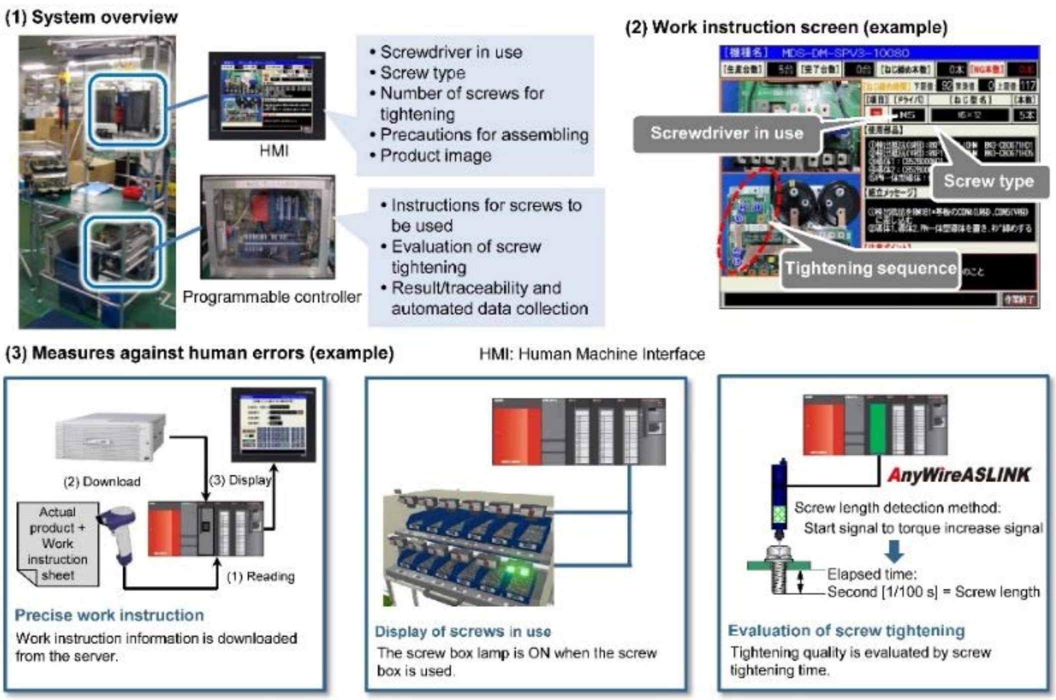


Fig. 5 Screw-tightening instruction system

EcoMonitorPlus Extension Model for Analog/Pulse Input

Author: *Yuki Nobe**

Production sites increasingly need to reinforce energy-saving measures and introduce predictive maintenance. We have developed an Analog Input Unit and Pulse Input Unit as extension units of the EcoMonitorPlus energy measurement unit. The Analog Input Unit is capable of receiving analog signals from various sensors (temperature, vibration, etc.). The Pulse Input Unit measures pulse signals that convey the production quantity, flow rate of water and air, etc.

1. Overview of the Analog/Pulse Input Units

1.1 Product specification

Table 1 shows the main specifications of the Analog Input Unit and the Pulse Input Unit. Both have been added to the product line as extension units for the following purposes: the Analog Input Unit is for customers who want predictive maintenance based on measuring temperature and vibration of equipment; and the Pulse Input Unit is for customers who need to measure production quantity and flow rate of water and air, etc. Measurements can be made with the optimum configuration for the object being measured through the combination with EcoMonitorPlus (Table 2), which is already placed in the market. The entire system can be extended according to changes in measurement needs by the adding units (Fig. 1).

1.2 Product concept

(1) Implementing energy management and predictive maintenance with one unit

In the conventional EcoMonitorPlus systems,

Table 1 Specifications of the Analog Input Unit and Pulse Input Unit

Item			Specifications	
Model			EMU4-AX4 (Analog Input Unit)	EMU4-PX4 (Pulse Input Unit)
Input specifications	No. of inputs		4	
	Input signal format		Differential input (0 V to +5 V; 0 mA to 20 mA)	Non-voltage a-contact
	Insulation type		Photocoupler insulation	
	Rated voltage/current		Voltage: 0 V to +5 V (Input resistance: 1 MΩ) Current: 0 mA to 20 mA (Input resistance: 250 Ω) Note: The input range (voltage/current) can be changed. (To be changed for each CH in some settings.)	6.5 V DC, 10 mA (supplied from the main unit)
	Input pulse conditions		–	Pulse ON time: 30 ms or more OFF time: 30 ms or more
	Measuring object[1]		AD conversion value, scaling value, number of times the limit is exceeded	Pulse input: Pulse count, pulse conversion Contact input: operation time, contact status * External input (pulse input/contact input) can be changed. (To be changed for each CH in some settings.)
	Range of measurement values[1]		AD conversion value: 0 to 4095 Scaling value: -32767 to +32767	Pulse count: 0 to 999,999 Pulse conversion: 0.001 to 999,999,000
	Accuracy		AD conversion value: ±1.0% (23°C ± 10°C) of input rating	–
	Data update cycle		1 ms x No. of channels; 50 ms x No. of channels	–
Output specifications	Output signal format		Non-voltage a contact 1 output	
	Function	Warning item	Scaling value upper/lower limit; Scaling value upper limit; Scaling value lower limit	Pulse conversion upper limit
	Rated switching voltage/current		35 V DC; 75 mA, or 24 V AC; 75 mA (power factor 1)	
	Insulation type		Semiconductor relay insulation	
External dimensions (unit: mm)			37.5(W) x 90(H) x 92.9(D) (excluding protrusions) (Maximum dimensions including protrusions: 41.5(W) x 99(H) x 92.9(D))	
Compliant with			CE marking (EMC: EN61326-1: 2013, Safety: EN-61010-1: 2010), UL: UL61010-1	

1 Measurement details of each object
- AD conversion value: Value obtained by converting an input analog value into a digital value from 0 to 4095. (Example: "0°C to 100°C" is converted to "0 to 4095.")
- Scaling value: Value obtained by converting an AD conversion value into a value on a different scale. (Example: "0 to 4095" is converted to "0°C to 100°C".)
- Number of times level exceeded: Value obtained by counting the number of times exceeding a set threshold value. (See 3(2) in the article.)
- Pulse count: Value obtained by counting the number of input pulses.
- Pulse conversion: Value obtained by converting the number of input pulses into a value on a different scale. (Example: Converted to the quantity of water used.)
- Operating time: Value obtained by integrating the time when a contact is turned ON (input). (Example: The equipment operating time is measured by contact input of equipment operation statuses.)
- Contact state: State of a contact if it is input or not (ON/OFF).

*Fukuyama Works

Table 2 List of EcoMonitorPlus Products

Category	Product name	Model number
Base unit	Energy Measuring Standard Model	EMU4-BM1-MB
	Energy Measuring High Performance Model	EMU4-HM1-MB
	Insulation Monitoring Model	EMU4-LG1-MB
Extension unit	Extension Model for Same Voltage System	EMU4-A2
	Extension Model for Different Voltage System	EMU4-VA2
	Analog Input Unit	EMU4-AX4
	Pulse Input Unit	EMU4-PX4
Option unit	Logging Unit	EMU4-LM
	CC-Link Communication Unit	EMU4-CM-C

predictive maintenance against load current and leak current is available by measuring quantity of electricity in addition to energy management by efficiently using information on the amount of electric power, etc. However, in some failure modes, it is difficult to identify a predictor of failure only by measuring the electricity quantity, and information on vibration, temperature, etc. may be required. Therefore, the new Analog Input Unit for receiving analog signals from various sensors was added to the EcoMonitorPlus extension unit line. With the Analog Input Unit, the EcoMonitorPlus predictive maintenance can now use information on vibration, temperature, etc., not only the measured electricity quantity.

(2) Measuring the electricity quantity, flow rate, and production quantity by using one unit

EcoMonitorPlus systems have only a pulse signal input to the base unit (high functionality unit) and cannot receive multiple pulse signals such as signals on the production quantity and flow rates (water and air). Therefore, the new Pulse Input Unit for receiving pulse signals was added to the EcoMonitorPlus extension unit line, enabling EcoMonitorPlus systems to measure the electricity quantity, flow rates (water and air), production quantity, and other equipment information.

2. Features of the Products and Technology Used for the Products

2.1 Sampling period and communication time for analog signals

(1) Issues in collecting analog values

The sampling periods of the Analog Input Unit have been set to 1 ms in order to detect any abnormality by vibration sensor (displacement and speed).

However, missing data may occur due to insufficient time for communication; as the conventional EcoMonitorPlus responds with the current value to a request, the host system needs to collect data for each sampling period within the communication time of 76 ms required for data collection in 1 ms (Fig. 2).

(2) Measures by changing the data collection method

Data for 1 ms cannot be collected by the conventional method that collects one data item per message due to restrictions on communication time. To solve this, by transmitting and receiving multiple MODBUS RTU data at one time, we have designed the Analog Input Unit to process batch transmission and reception of data for 100 ms saved in the Analog Input Unit. This allows 100 ms of data to be collected in 71 ms and analog values to be collected without any lack (Fig. 3).

2.2 Analog signal threshold monitoring method

Since analog signals measured by various sensors vary greatly within a short cycle, the upper/lower limits with simple thresholds lead to repeated warning and recovery messages, and cannot correctly determine an abnormal equipment state. Accordingly, in addition to the upper/lower limits originally used, we have designed the Analog Input Unit to count the number of occurrences exceeding the threshold and also the number of times exceeding the predetermined number of occurrences (number of times exceeding the limits). This function has four-stage upper/lower limits (levels) from A to D. For each limit, the

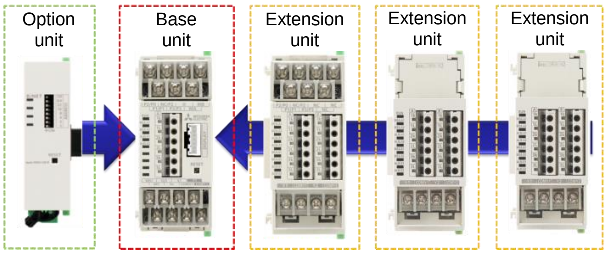


Fig. 1 How to extend an EcoMonitorPlus system

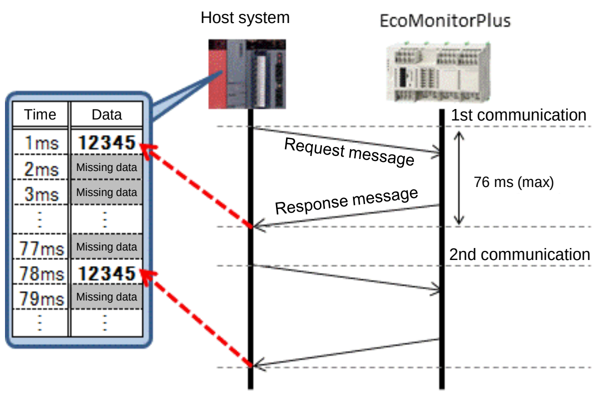


Fig. 2 Communication in 1 ms periods (conventional)

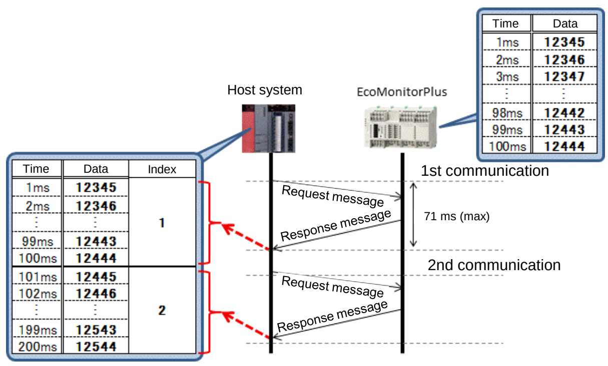


Fig. 3 Communication in 1 ms periods (Analog Input Unit)

number of exceeding times is counted. By detecting occurrences when the limit has been exceeded the specified number of times, the equipment conditions can be managed in the four stages (for example, A: Caution; B: Alert; C: Maintenance; and D: Equipment renewal), facilitating systematic equipment maintenance (Fig. 4).

3. Example of e-F@ctory Collaboration

3.1 Working with programmable controllers

Using EcoMonitorPlus and a programmable controller, energy saving and productivity can be improved by specific energy consumption management, and predictive maintenance for the equipment can also be performed. For the communication of various programmable controllers using the MODBUS RTU communication function that comes standard with the Analog Input Unit, function blocks are provided so that users can create ladder programs more quickly. (The function blocks can be downloaded free of charge from the Mitsubishi Electric FA site.)

(1) Specific energy consumption management

Based on the energy information (quantity of electricity/flow rate) measured using EcoMonitorPlus and the production information (production quantity, equipment operation status, etc.) in the programmable controller, waste can be found by the specific energy consumption management. For example, if a significant amount of energy is consumed in a time zone that involves no production operation, waste can be reduced by revising the production phases or turning the equipment power off when there is no production operation to perform (Fig. 5).

(2) Predictive maintenance

In predictive maintenance using current and temperature information, as the measurement values vary depending on the production items and the operating conditions of the equipment, determining an abnormal value is difficult with only measurement values. Instead, monitoring is performed in combination with production information (production items, equipment operation status, etc.) obtained from the programmable controller. This allows the measurement values to be compared with those when the same production items are produced, and also under the same conditions at different times (for example, at the time of launching the equipment). Thus, predictive maintenance of the equipment can be implemented (Fig. 6).

3.2 Working with Graphic Operator Terminals

By communicating with a Graphic Operator Terminal (GOT) using the MODBUS RTU communication function that comes standard with the Analog Input Unit, energy can be visualized and saved, and various types of analog signals can be visualized for predictive maintenance. We provide samples of the visualization screens. (Samples

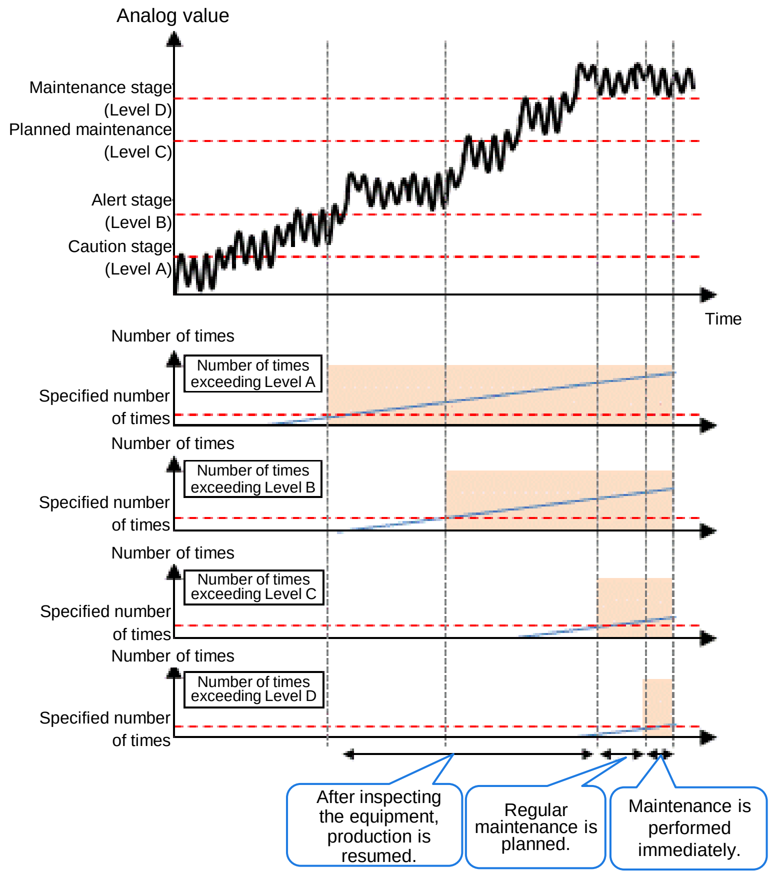


Fig. 4 Example of the number of times exceeding the limits

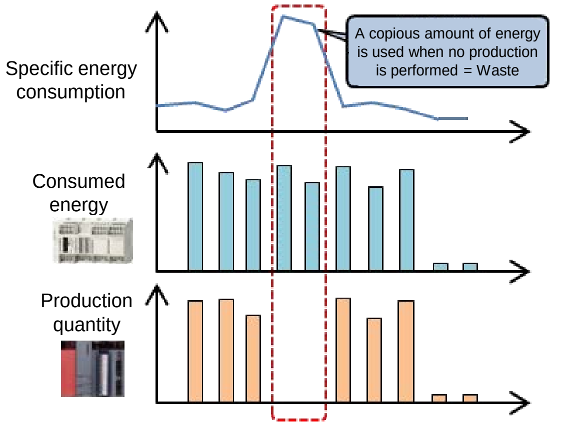


Fig. 5 Improvement based on energy information and production information

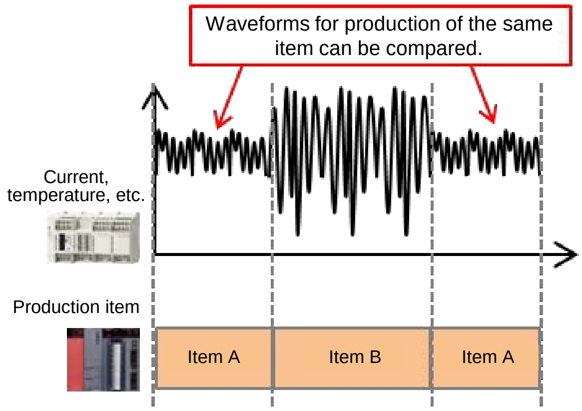


Fig. 6 Predictive maintenance based on analog signals and production information

can be downloaded free of charge from the Mitsubishi Electric FA site.)

4. Conclusion

This article has described the Analog Input Unit and the Pulse Input Unit developed as extension units of EcoMonitorPlus, an energy measuring unit that can be extended by adding units. While improving the functionality of these products and reinforcing the product line, we will continue developing energy measuring units that help customers save energy and perform predictive maintenance.

References

(1) Yasunori Matsuoka: Energy measuring unit "EcoMonitorLight," Mitsubishi Denki Giho, Vol. 88, No. 4, 269–272 (2014).
(2) Tetsushi Narui: Energy measuring unit "EcoMonitorPlus," Mitsubishi Denki Giho, Vol. 90, No. 4, 247–250 (2016).

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