

FUJI ELECTRIC REVIEW

Automation Systems

3

2008 VOL.54



Fuji Electric Group

Fuji's Measurement instruments



FCX-AIII Series
Transmitter



Cross stack
Laser gas analyzer (ZSS)



PUM Series
Multi-loop module type
Temperature controller



Ultrasonic Flowmeter
Flow Transmitter (FSV)
Detector (FLD/S/W)



Infrared gas analyzer (ZRE)



PX series
digital temperature
controller



Portable type
ultrasonic flowmeter
Flow Transmitter (FSC)
Detector (FLD, FSD)



Infrared gas analyzer
for stack gas (ZSU)



Paperless recorder
(PHU, PHL, PHF)

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Cover photo:

Capital investment in industrial systems is increasing as a result of vigorous efforts to improve and innovate production sites. By providing "vertical and horizontal integrated solutions" that seamlessly link, from the field level to manufacturing management level, various components and solutions necessary for a production site, Fuji Electric's automation systems enable the configuration of total optimization systems.

In response to increasing requests for lower risk from serious accidents and disasters and assured high safety levels for human life, the environment and equipment, Fuji Electric aims to provide integrated safety solutions that combine machinery safety, control safety and functional safety with the MICREX-NX and others, a new information and control system that conforms to international safety-related standards.

FUJI ELECTRIC REVIEW vol.54 no.3 2008

date of issue: August 20, 2008

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Automation System Trends and Overview of Fuji Electric's Solutions

Ken Kakizakai
Shigemi Wakasugi
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1. Introduction

The increase of capital investment since 2006 in the field of industrial systems has invigorated for improvement and innovation at production plants. In the field of automation systems, various initiatives are underway, including efforts to provide field intelligence according to the replacement interval, to construct seamless production information management systems by merging such core business systems as MES (manufacturing execution system), ERP (enterprise resource planning) and SCM (supply chain management), and to construct wireless LAN-based IT networks.

Product quality in the manufacturing industry implies not only the quality of the product, but also the organizational and technical capability to realize such quality, and encompasses the entirety of a company's performance (quality of management). "Quality" reflects the essence of a company and is an important factor that directly influences management.

Meanwhile, the approach to manufacturing quality has recently changed from a "product inspection centered approach" to one that emphasizes "quality assurance at the manufacturing process level," and is progressing toward a higher level of quality control. As a representative example of "visualization," efforts are underway to share (vertically integrate) manufacturing information about onsite and managerial staff and operations, and to provide an environment that supports traceability.

On the other hand, in order to reduce the risk from major accidents and disasters, and to ensure a high level of safety for human life, environment and equipment, plant safety is also being closely watched, and alarm management systems based on process hazard analyses are being introduced. Moreover, when a JIS (Japanese Industrial Standard) was created based on the international safety standards IEC 61508 and IEC 61511, compatibility with international standards was requested. As a result of this request, the application range of safety instrumentation systems, which has been limited to specific fields such as overseas petrochemical plants, is expected to expand in the future.

Furthermore, large-scale plants are operating with

fewer personnel as a result of requests for lower running costs and advances in automation technology, and the skilled operators, who have been involved in running a plant since it was built, are retiring in large numbers. On the other hand, the realized high reliability and stable operation of devices are linked to a significant decrease in the BM (breakdown maintenance) index*¹ and fewer incidences of trouble. The passing down of know-how from skilled operators to plant operators and maintenance personnel has become a critical issue. This so-called year 2007 problem is predicted to become increasingly severe in the future, and requests are growing for a more sophisticated operation support system that can provide a mechanism enabling the passing-down of operational know-how relating to the stable operation of equipment and response to equipment failure.

Environmental problems and the increase in raw materials prices as typified by the recent sudden rise in crude oil prices are spurring requests for energy savings, and the optimization of individual plant operation and trials of optimization through energy sharing among factories and regions are accelerating. Moreover, as represented by multivariable model predictive control, process improvements based on control technology are being applied, and innovation at control sites is steadily progressing.

This paper describes Fuji Electric's efforts in providing "vertically and horizontally integrated solutions" based on the requests of automation systems which have undergone the abovementioned transformations in recent years.

2. Market Trends and Challenges of Automation Systems

2.1 DCS market trends and challenges

In the 1990s, DCS (distributed control systems) evolved from dedicated system for each DCS manufacturer, to open systems based on general-purpose OSes such as UNIX*² and Windows*³. Also, with the development of Windows as the de facto standard,

*1: BM index is BM incidence/number of instruments.

the SCADA (supervisory control and data acquisition) monitoring and control package that runs on Windows has emerged, and a personal computer DCS that uses SCADA for middleware has been introduced. Additionally, with advances in Internet technology, OPC^{*4}, the de facto interface for Windows, has also penetrated the DCS world, field buses that conform to international standards are being used, and the trend towards open standards for DCS has further accelerated.

In the early 2000s, PLC (programmable logic controller) instrumentation systems began to be sold, and the automation domains of DCS manufacturers, PLC manufacturers and SCADA manufacturers became increasingly complex to separate.

Meanwhile, DCS came to be reconsidered as an effective means for lowering the user's TCO (total cost of ownership) over the total lifecycle, from DCS installation to renewal. Also, with the recent development of IT-related technology, the positioning of DCS as a means for realizing monitoring and control, to achieve automation and labor savings in manufacturing equipment, has shifted to focus on how to increase management effectiveness and company value by directly linking management to the onsite operation of a manufacturing system.

From this perspective, DCS does not exist by itself and must operate effectively with ERP, SCM and MES core business systems, and seamless integration and the filling out of a solution product line commencing with MES is a challenge for the vendor.

In terms of service, long-term DCS maintenance is needed due to the longer service life of equipment and a resolution to the conflicting proposals for greater general-use through the adoption of open standards and for longer service life is a significant challenge. Moreover, demand for DCS in the Japanese domestic market comes not only from new plants, but the majority demand is for equipment renewal in order to maintain existing plants. Because of this reason, the provision of migration technology for transitioning to new innovative systems while inheriting user assets is an important challenge for DCS manufacturers.

2.2 Market trends and challenges of industrial measurement devices

Industrial measurement devices are global products, and in recent years this market has been recovering as a result of increased capital investment by the Asian markets centered on China, and in particular, as a result of capital investment by the materials industry which is the largest customer of measurement

devices. Moreover, as concern heightens for protecting the global environment to prevent global warming and so on, demand mainly from China corresponding to strengthened emissions regulations is increased.

Industrial measurement devices are roughly categorized as field devices for transmitters and flowmeters, receivers for recorders and controllers, and analyzers. Support of field networking, wireless transmission and safety instrumentation are example of recent product trends of measurement devices. At Japan's largest exhibit of measurement and control technology (sponsored by the Japan Electric Measuring Instruments Manufacturers' Association (JEMIMA)) in November 2007, many of these devices were displayed. Moreover, the increase in number of foreign exhibitors and the size of their exhibits hints at the expectations for the Asian measurement device market.

The majority of industrial measurement devices are built-into automation systems, and as a result of progress toward a de facto standard, the demand structure for these industrial measurement devices is treated as a group of measurement devices for which global competition is intensifying. In support of the above, it is becoming increasingly important to reliably assess market requests, bring timely products to market, provide the capability for a wide range of measurements with a single device, reduce the number of models and incorporate added value.

3. Fuji Electric's Approach to Automation Systems

3.1 DCS approach

From the 1970s, when DCS first emerged, until the present day, the sophistication and performance levels of automation systems have continued to increase. As shown in Fig. 1, Fuji Electric realized total automation in a 2nd generation automation system by merging PA (process automation) and FA (factory automation), and realized EIC integration of electricity (E), instrumentation (I) and computer (C) functions in a 3rd generation. As a 4th generation automation system, Fuji Electric announced the MICREX-AX which is based on the concepts of open standards, evolution and inheritance.

The MICREX-MX information and control system released in 2004 corresponds to a 5th generation DCS. As part of collaboration on process automation between Fuji Electric and Siemens of Germany, the MICREX-NX was jointly developed based on Siemens' PCS7 DCS, and is a next-generation information and control system that features vertical and horizontal integrated solutions and integration engineering. The MICREX-NX/V7.0 released in June 2008 further expands the MICREX-NX functionality.

For medium and small systems, the FOCUS and SIRIUS systems, which can be constructed from a SCADA system and a general-purpose PLC, are available, and can support a wide variety of needs.

*2: UNIX is a registered trademark licensed by X/Open Co., Ltd. in the US and other countries.

*3: Windows is a registered trademark of Microsoft Corporation in the United States and other countries.

*4: OPC is a standard interface specification of Microsoft Corporation.

Fig.1 Development of Fuji Electric's automation systems

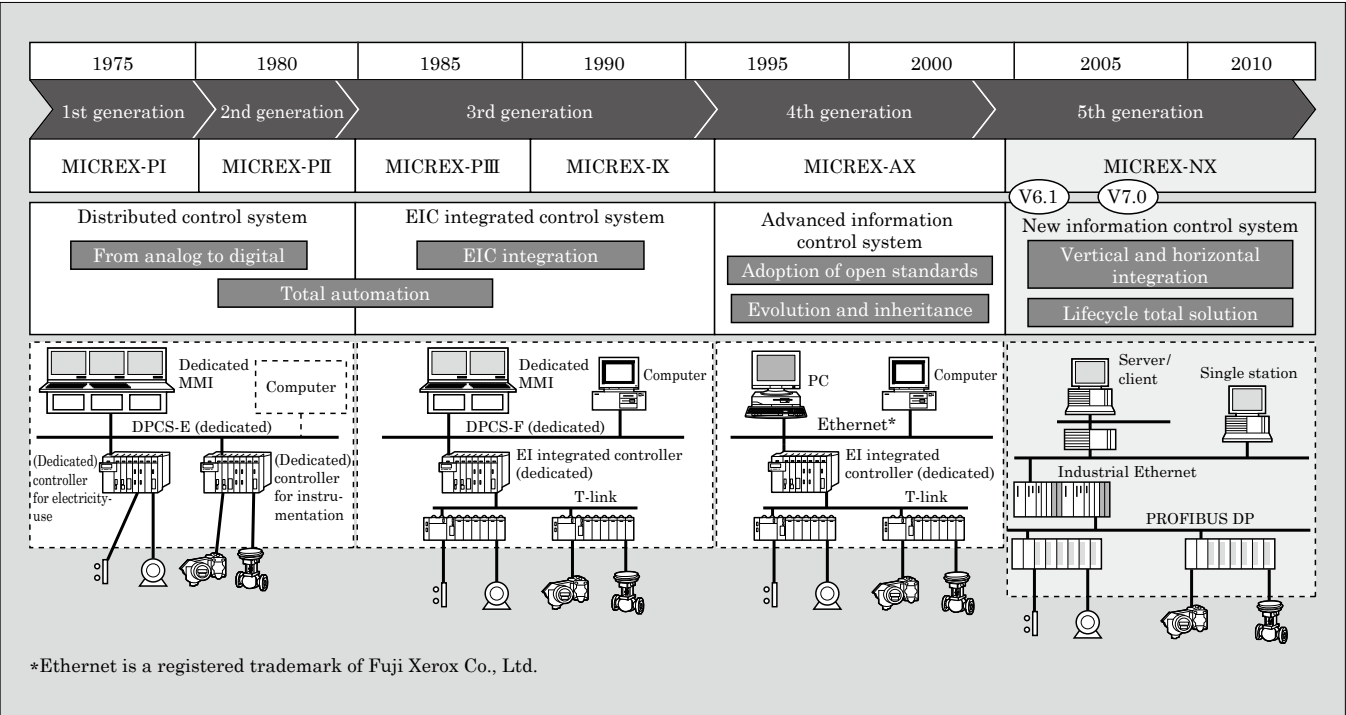


Fig.2 MICREX-NX system configuration

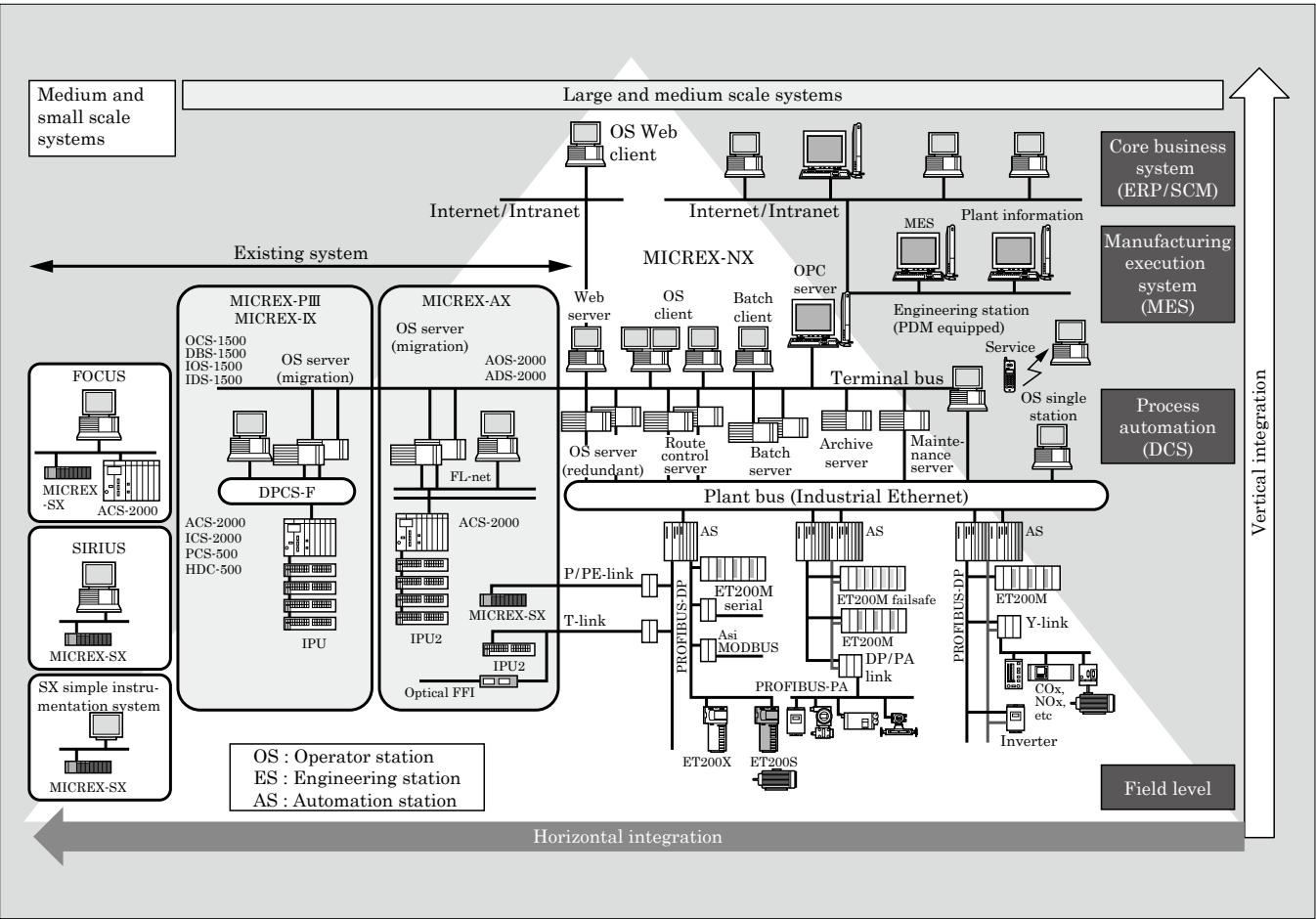


Figure 2 shows the system configuration of Fuji Electric's MICREX-NX system.

(1) Lifecycle total solution

Fuji Electric has proposed the concept of a "life-cycle total solution" for these control systems. The MICREX-NX provides various solutions to reduce the TCO and run the plant optimally in all phases of the lifecycle, from plant system construction to management (operation and maintenance) and renewal. Features of the MICREX-NX are listed below.

- (a) Scalable and open core system
- (b) Extendable and innovative system configuration featuring a core system integrated with safety instrumentation, safety PLC, etc.
- (c) Improved quality and high efficiency realized with integrated engineering environment
- (d) Efficient factory testing and onsite testing realized through use of simulator
- (e) Operation functions having hierarchical design and high degree of transparency
- (f) Improved availability with high redundancy against multiple failures and easy maintenance
- (g) Highly proactive plant maintenance with equipment management package
- (h) Migration that supports maximum use of existing assets

(2) Vertically and horizontally integrated system

(a) Vertically integrated system

MES is positioned between an instrumentation control system and a core business system, such as ERP or SCM, at a manufacturing site and serves to optimize manufacturing assets such as personnel, work, products, equipment, and so on. MES functions include schedule management, product inventory, progress management, production results management, production equipment management, quality management, etc. Fuji Electric provides the MainGATE-Process plant production management system as an MES for the manufacturing industry. In response to user requests, optimal MES systems are being provided as solutions, and by seamlessly integrating the MES with a MICREX system, a system that is vertically integrated from the field level to the manufacturing control level can be realized.

(b) Horizontally integrated system

The MICREX-NX system is suitable for applications from process control to discrete control, and can centrally manage information needed for decision making by integrating field level systems over a wide range, from production equipment at a factory to distribution and utility equipment. Furthermore, these systems are suitable for various types of work and enable plant consolidation and integration.

(3) Safety instrumentation system

The MICREX-NX's safety instrumentation system has been certified for both hardware and software by the German technical safety organization TÜV, comply with safety standards IEC 61508 and IEC 61511, and

conform to safety integrity level (SIL) 3 which is required for a qualitative risk assessment of safety.

(a) Integration of control system and safety instrumentation system

In order to support the high-level and specific requests of safety instrumentation systems, safety instrumentation systems are often commercialized separately from control systems. On the other hand, however, progress is being made in the sharing of the controller, operation environment and engineering environment between the MICREX-NX's safety instrumentation system and other control systems, so that the safety instrumentation system may exist in combination with the control system. Figure 3 shows the features of the safety instrumentation system in the MICREX-NX.

(b) Safety matrix

The safety matrix is a tool that facilitates engineering of a safety instrumentation system. By using the safety matrix and a CFC (continuous function chart), software for a safety instrumentation system can be generated easily. When safety conditions have been input with the safety matrix, a CFC deployed with the required safety function blocks is generated automatically. The safety matrix also provides several other functions in addition to engineering.

- ① Upon activation of the safety instrumentation system, the operating conditions can be displayed graphically on a HMI (human machine interface).
- ② The safety matrix also has an auto report function for verification, maintenance-use and system improvement.

By using the safety matrix, a safety instrumentation system can be designed relatively easily, and at the same time, the required condition display and analysis data can be provided to the HMI.

(4) Functional extension with MICREX-NX/V7.0

In June 2008, the MICREX-NX V7.0 was released,

Fig.3 MICREX-NX's safety instrumentation system

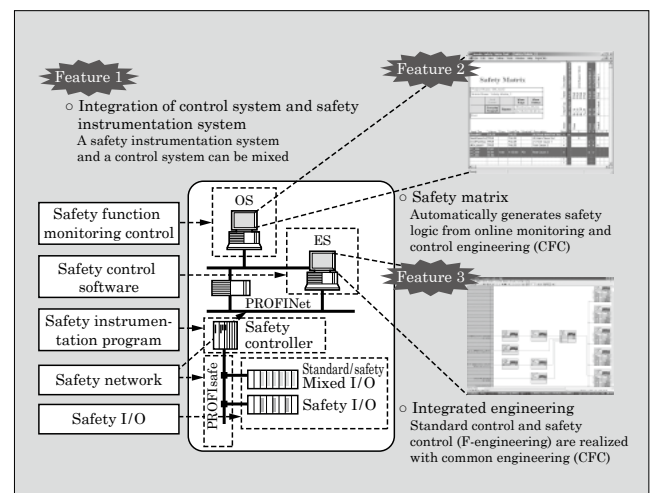


Table 1 Main functional improvements of MICREX-NX/V7.0

Category	Functional improvement	
Hardware	Industrial PC 547B (dual core processor, gigabit Ethernet)	
	Controller-use CPU (memory : 30Mbyte, instruction execution speed : 18ns)	
Operation	Alarm management	Alarm filtering for each process status
		Operator-based message limiting
	Expanded trend functions (online/archive trend mixed display, storage of trend data)	
Engineering	Version control	
	Multi-user engineering (via a network)	
	Batch control and route control system linkage	
Package/library	Advanced control	Model predictive control (MPC)
		Control performance monitor (CPM)
	Operation support system	
	Asset management (stroke counter, operation time)	
	Web display of trend alarm long-term storage data	
Safety instrumentation	Safety matrix	
	Linkage with safety integrity level (SIL) computation and evaluation tool	
Security	Security communication module SCALANCE S (VPN compatible)	
	Windows user management and integrated logon service	
Migration	FL-net gateway	
	IPU-II connection	
Miscellaneous (external interface, etc.)	External system connection station SPOSA (single point of system access, OPC/OLE DB IF)	
	PROFIBUS DP/FF link	
	PROFIBUS PA duplex	

replacing the previous V6.1. As shown in Table 1, the improved functionality of V7.0 includes increased performance of the control unit, stronger alarm management, including alarm filtering, enhanced multi-user engineering, and additions of model predictive control and the like to the package library. These improvements are described in detail in related articles of this special edition.

(5) Solution package

The MICREX-NX provides packages for each field in the various manufacturing industries and also provides many information management packages.

- (a) Equipment management package
- (b) Batch system package
- (c) Root control package
- (d) Operation support package

(6) Measurement system package for medium and small control systems

In addition to FOCUS which has been sold as a medium and small control system, and SIRIUS which is capable of supporting medium size control systems, in 2007 Fuji Electric released an SX instrumentation package for use with the "SX Simple Instrumentation System." All systems are configured with MICREX-SX, which is SCADA and a general-purpose PLC, but by applying Fuji Electric's expertise in measurement control to SCADA, an engineering environment and operation environment unchanged from those of the conventional DCS are provided.

3.2 Approach to industrial measurement instruments

Industrial measurement instruments form the basis for process equipment, and provide a critical function for productivity and quality improvements, preventive maintenance, and so on. Industrial measurement instruments are often separated from measurement and control systems in a business situation, and their features and differences are an important point for expanding sales. Fuji Electric's approach for various measurement instruments is described below and is listed in Table 2.

(1) Field devices

Representative field devices include gauge and differential pressure transmitters, flowmeters and temperature transmitters.

Transmitters have adopted de facto standards for their specifications and performance, and are fiercely competing in the global market. Additionally, there is progress being made in complying with requests for improved long-term stability, field network support functions, wireless transmission and SIL. This special edition introduces the "FCX-AIII Series of New Type Differential Pressure/Gauge Pressure Transmitters" that achieve improved long-term stability and small size.

Types of flowmeters include the differential pressure, electromagnetic and ultrasonic types and so on, and demand for the ultrasonic flowmeter is expected to increase due to its advantages of non-contact measurement and convenient installation. Fuji Electric is fo-

Table 2 Approach for main measurement devices

Function	Key technology	Approach	Main application fields					
			Oil, petrochemical	Electric, electronic	Steel	Food, medical	Environment	Water treatment
Absolute and differential pressure transmitter	Micro-silicon sensor; low power consumption; network	Support general-use (global standard) transmitter; safe; wireless	○		○	○		○
Ultrasonic flowmeter	Anti-bubble; pulse Doppler/transit time difference model	High accuracy, expanded diameter	○	○	○	○		○
Controller	High-speed control; high resolution; multi-zone optimal control	High level functionality; high accuracy; modular type		○		○		
Recorder	High-speed sampling; network	Expanded data accumulating function; multi-channel		○		○		
Gas analyzer	Infrared sensor; cross stack laser/solid electrolyte	Stack direct measurement; Multi-component simultaneous measurement	○		○		○	

cusing on ultrasonic flowmeters for measuring liquids, and has brought to market a high-precision hybrid ultrasonic flowmeter (combined method using transit time difference and Doppler effect) for certified measurements and an installed type that realizes a 0.2 s high-speed response and has a reduced size and that targets the semiconductor field (water purifying apparatus), the PA field and the management of the supply and discharge of water from factories and offices.

(2) Recorders and controllers

Recorders are transitioning from paper-based recording to paperless recording. A diversity of communications, logging and data accumulation functions, multi-channel and high-speed switching performance and functionality are requested and development is progressing to support those requests.

Demand for the single loop controllers used in the first stage process instruments was driven mainly by replacement demand. In medium and large-scale systems, controllers are being replaced by DCSes and PLCs, and in small-scale systems, are being replaced by functionally upgraded temperature controllers and other general-purpose controllers. Temperature controllers to be incorporated into machinery equipment are transitioning from a box type (panel embedding type) to board and modular types (without a display control panel), which are becoming the most common types of temperature controllers. Temperature controllers to be incorporated into machinery equipment are requested to provide improved control accuracy, expanded communication functions, and to incorporate multi-channel control, PLC functionality and the like, and development is progressing to support those requests. This special edition introduces Fuji Electric's PUM multi-loop modular controller.

(3) Gas analyzers

Gas analyzers are classified according to their use, whether for environmental monitoring, such as for monitoring air pollution, or for use in processes that measure the atmosphere in an industrial furnace or

the like. The infrared absorption type, zirconia type, and paramagnetic type analyzers are based on traditional measurement principles, but are also equipped with multi-component measurement functions, and expanded calculation functions such as auto calibration. A cross stack type (that directly attaches a sensor to the stack) using a laser has recently been introduced.

The market for environmental monitoring is growing rapidly with the increasing protection of the global environment and strengthening of regulations in China and elsewhere, and in May 2007 Fuji Electric released the ZRE single beam infrared gas analyzer for monitoring emission gases from a stationary source. This analyzer has a simple construction and is capable of measuring five components (NO_x, SO₂, CO, CO₂ and O₂) simultaneously. The ZSS cross stack laser gas analyzer introduced in this special edition has also been released on the market.

3.3 Approach to infrastructure development for measurement and control technology

Measurement and control technology is fundamental technology in all manufacturing industries, and is a core technology that consolidates the technologies of such diverse fields as steel, petrochemical and water treatment.

Fuji Electric has positioned measurement and control technology as a core competence and, to improve that technology, is basing its approaching to the infrastructure development on the following types of keywords.

- Safety instrumentation technology
- Control technology
- Systemization technology
- Embedded software technology
- Network and wireless technology
- Sensing technology

With these technologies, solutions can be provided for all industries and society, not only for process automation.

4. Postscript

Automation systems are becoming increasingly important in order to comply with requests for improved safety and security of manufacturing systems, higher operating efficiency and improved quality, to support a decreasing birthrate and aging population in the future, and to implement generational changes.

This special edition introduces Fuji Electric's approach to the safety and security of an automation system, provides examples of solutions, and discusses the control technology and measurement devices forming that foundation. Fuji Electric intends to continue to focus on the latest technology, extend it to system development, and to release distinguished systems in a timely manner.



Fuji Electric's Approach to Machinery Safety and Functional Safety — Total Safety —

Akihiko Kohanawa
Masami Hasegawa

1. Introduction

Serious accidents involving machinery and industrial plants have occurred one after another recently, and society's concern for improving safety and security has heightened. To establish safety and security requires a wide range of applied technology, such as the prediction of sources of harm, preventative maintenance for equipment, plant security, electronic recording of system data and so on. Meanwhile, new techniques for ensuring safety at the equipment design and system design stage have been standardized systematically in the form of machinery safety and functional safety.

This paper presents an overview of new techniques for establishing safety that are presently being incorporated into equipment and systems at manufacturing

plants, and also introduces Fuji Electric's approach to safety.

2. Domestic and Foreign Trends for Safety Standards

2.1 Status of safety standards

In Europe, safety standards are widely utilized to regulate basic safety-related concepts and design principles. Under these circumstances, the ISO/IEC Guide 51 has been distributed⁽¹⁾, the international standard ISO 12100 (Safety of machinery – Basic concepts, general principles for design) has been issued, and as the culmination of this standard, the safety standard pyramid shown in Fig. 1 has been established. Further enhancement of the safety standards for individual machines and systems is expected in the future.

Fig.1 ISO/IEC safety standard pyramid

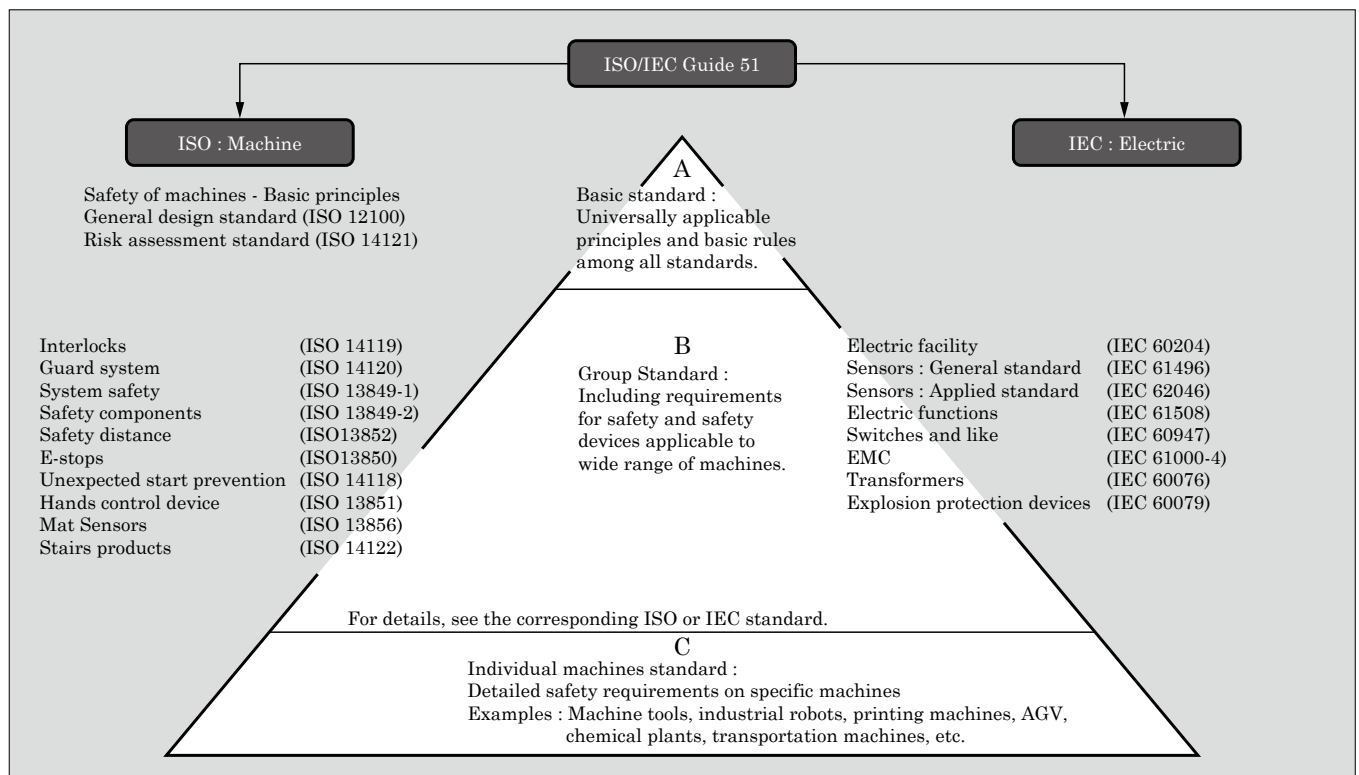
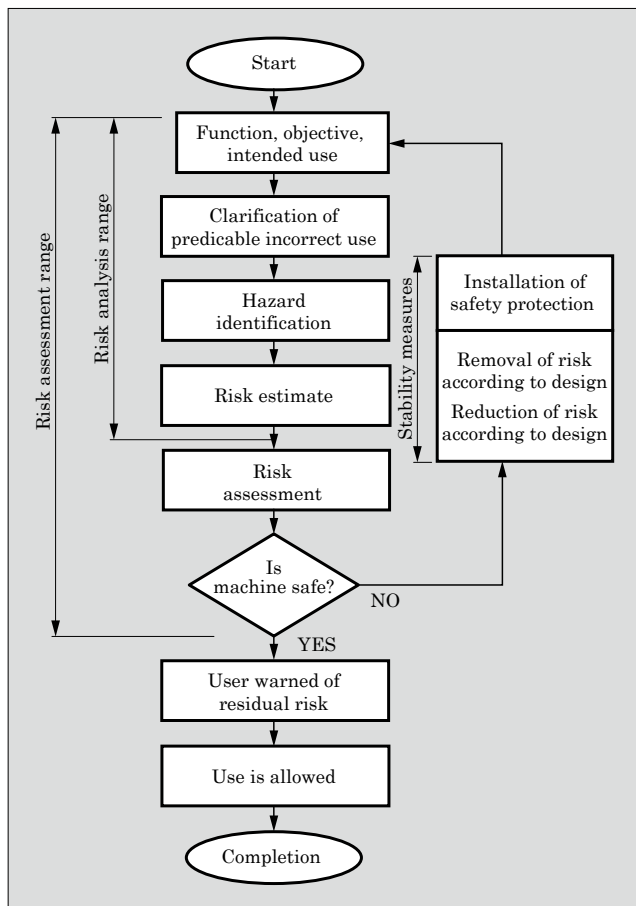


Fig.2 Amended labor safety and sanitation law

11 points of the amended labor safety and sanitation law	
1	Implementation of long-term doctor interview and guidance to worker
2	Notice to worker of results of special medical examination
3	Implementation of survey of risk and harmful effect, and required measures
4	Exemption from plan notification for authorized business
5	Prospective eligibility requirements for safety managers
6	Strengthening of safety and sanitation system
7	Implementation of coordination among work by general contractors in the manufacturing industry
8	Issuance of written order for work such as cleaning a chemical facility
9	Improved display and document issuance system for chemical substances and the like
10	Establishment of report for expose to hazardous substances
11	Prospects for licensing and skill training

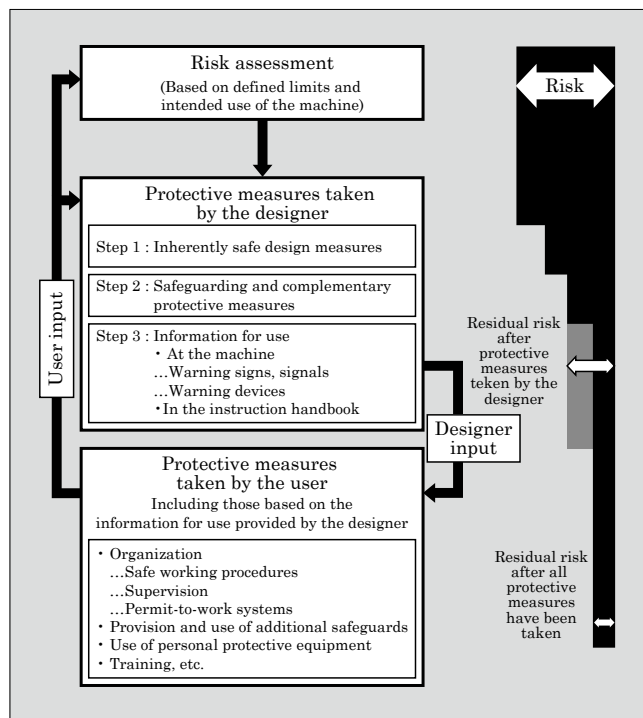
For all business offices where a safety manager is obligatory

Fig.3 Risk assessment and safety measures



In Japan, pursuant to the WTO/TBT agreement, the international standard system of Fig. 1 is accepted, and with nearly the same scheme, JIS were also established. Concurrent with these events, in April 2006 the Japanese “Labor safety and sanitation law” was

Fig.4 ISO 12100 basic concept



amended and the “Assessment of risk and hazards and implementation of required measures” was signed into law. As a result, a risk assessment must be performed when newly installing or modifying machinery or equipment, or when changing a work method or procedure (see Fig. 2).

In Japan, management responsibility has been strengthened and has come to be symbolized by the belief in “safety through onsite management.” The new risk assessment concept (ISO 14121) uses the procedure shown in Fig. 3 to investigate thoroughly processes in which hazards develop into accidents, and was established as a means for breaking the relationship between hazards and accidents. In other words, the new international safety standard trend can be called “safety through hazard management.”

2.2 Risk reduction process from the designer's perspective

ISO 12100/JIS B9700 prescribes, as general design principles for safety equipment and systems, a cycle for mutually feeding back “protective measures taken by the designer” and “protective measures taken by the user.” As shown in Fig. 4, the method of reducing residual risk by focusing mainly on inherently safe design according to the risk assessment is understood to “build safety into equipment.” In other words, the basic assumption is that “machines breakdown, and people make mistakes.” This process requires a high level of technical capability in order to identify hazards, apply appropriate countermeasures and so on, and at Fuji Electric, assessors having such technical capability are being trained.

3. Concept of Total Safety

At present-day manufacturing sites, the mechanical equipment, driving mechanisms for such equipment, overall controllers and instrumentation including reaction processes, and the like are laid out in complex arrangements. Moreover, safety systems are formed as portions of usual standard systems. Accordingly, when constructing a safety system for an entire manufacturing site, the safety system must be applied with an understanding of diverse safety standards, and this is not a trivial task. Moreover, in the past, the Labor Safety and Sanitation Department oversaw this type of safety system for manufacturing sites, and with the application of new safety standards was seen as a future challenge. As shown in Fig. 5, Fuji Electric aims to provide safety solutions by integrating all types of machinery safety, safety-related control and functional safety, and consulting with the customer. This is the concept of total safety.

4. Approach to Machinery Safety

When constructing a safety system in the FA (factory automation) field, in systems where hazardous situations arise with the operation of mechanical equipment, the basic principle is “preventive safety.” Specifically, the focus is on methods for directly guarding against the intrusion of hazards from mechanical equipment and on application of the electrical equipment of machines (IEC 60204/JIS B9960-1) safety standard. Figure 6 shows target items of the electrical equipment of machines safety standard.

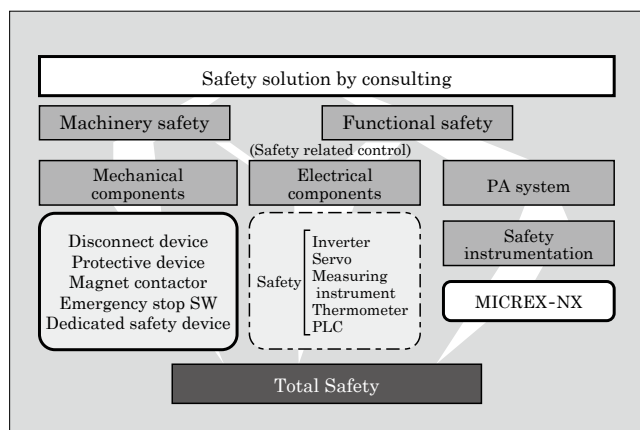
4.1 Standards relating to the safety of mechanical equipment systems

There are three high level standards relating to the safety of mechanical equipment systems: ISO 13849-1, IEC 60204-1 and IEC 61508.

(1) ISO 13849-1

General design principles of portions relating to

Fig.5 Total safety concept



the safety of mechanical equipment systems are classified according to the severity of the harm and the safety category. In the 2006 version, stochastic factors such as the mean time to dangerous failure were added to qualitative categories, and the PL (performance levels) method was adopted. There are five PL, ranging from “a” (low) to “e” (high).

(2) IEC 60204-1

This is a standard for machine control panels, and indicates the interrelationship between requirements of individual parts and the types of parts shown in Fig. 6. Mechanical system safety, with the exception of standards for intrinsic machines, must conform to this standard.

(3) IEC 61508

In order to maintain mechanical equipment is a safe condition, this standard regulates product safety for E/E/PE (electrical/electronic/programmable electronic systems) devices equipped with “functions” and is applicable to inverters, electronic control equipment and PLCs. Based on this standard, individual standards are being enacted for the abovementioned devices.

4.2 Safety of electrical equipment for machines

Figure 7 shows an example of a safety system for a machine control panel. The parts configuring the control panel shown in this figure must satisfy the safety requirements listed in Table 1. Particular attention must be paid to electrical parts of the main circuit and electrical parts related to emergency shutdown, for which compliance with standards was previously exempt, but is now required.

Fig.6 Targeted items of safety standards for electrical equipment of machines

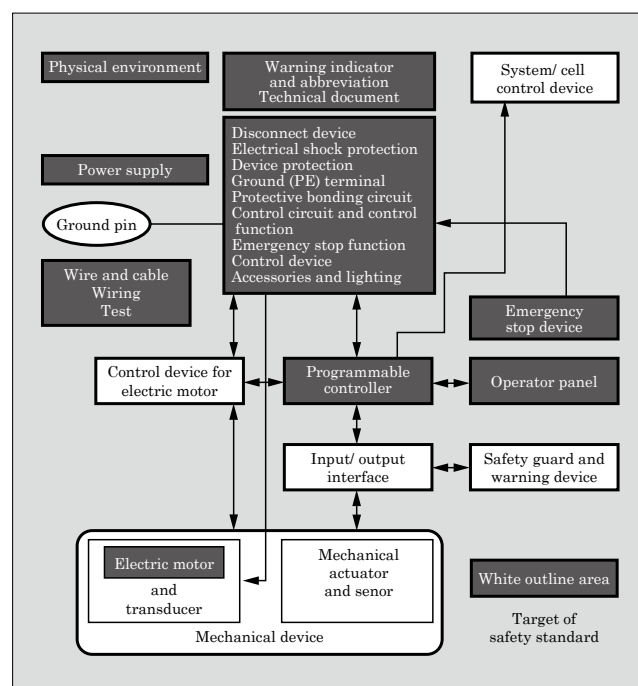
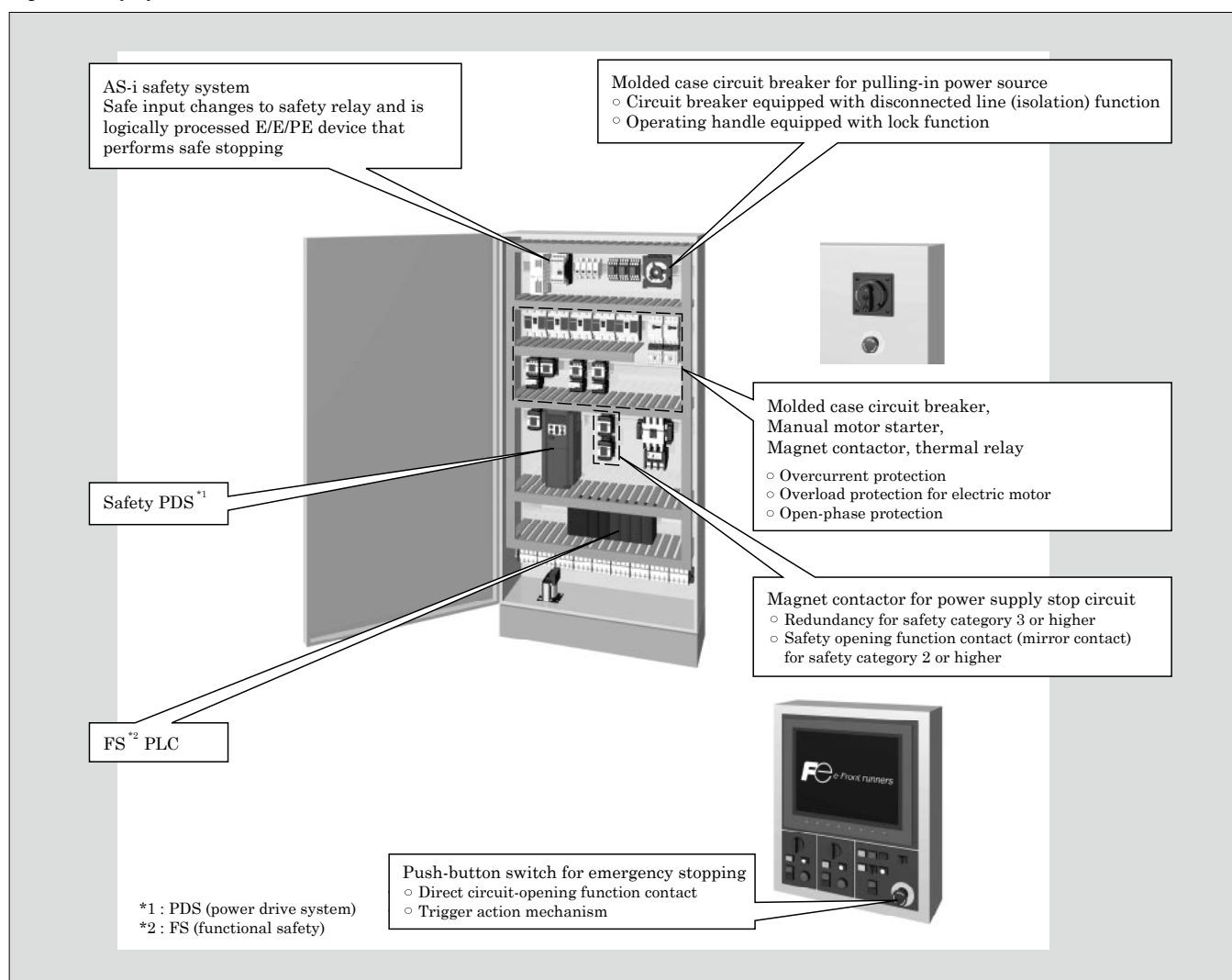


Fig.7 Safety system for control board



In order to comply with these requirements, Fuji Electric is preparing a lineup of products that incorporate safety functions in standard products.

5. Approach to Functional Safety

When constructing a safety instrumented loop in PA (process automation), the use of many measuring devices (pressure transmitters), safety controllers, and safety I/O modules are needed. These devices shall be developed in accordance with a functional safety standard (IEC 61508), and shall be certified for safety by a third-party certifying authority. Fuji Electric incorporates “functional safety” and sells the FCX-AII/CII series of pressure transmitters, and the MICREX-NX as safety controllers and safety I/O modules.

An example of a safety instrumented system realized with the MICREX-NX is introduced below.

5.1 Standards relating to safety instrumented systems

Two standards relate to safety instrumented systems, IEC 61508 and IEC 61511. The difference be-

tween these two standards is that IEC 61508 pertains to the manufacturers and suppliers of devices, while IEC 61511 pertains to the designers, integrators and users of the system. Conformance to IEC 61511 is required when installing a safety instrumented system.

Additionally, the entire safety lifecycle (specification, design and implementation, installation and commissioning, operation and maintenance, and changes after commissions) of the system is also prescribed in detail as shown in Fig. 8. In Japan, a standard corresponding to IEC 61508 has already been established with JIS, and a standard corresponding to IEC 61511 was established with JIS in February 2008.

5.2 Safety instrumented system

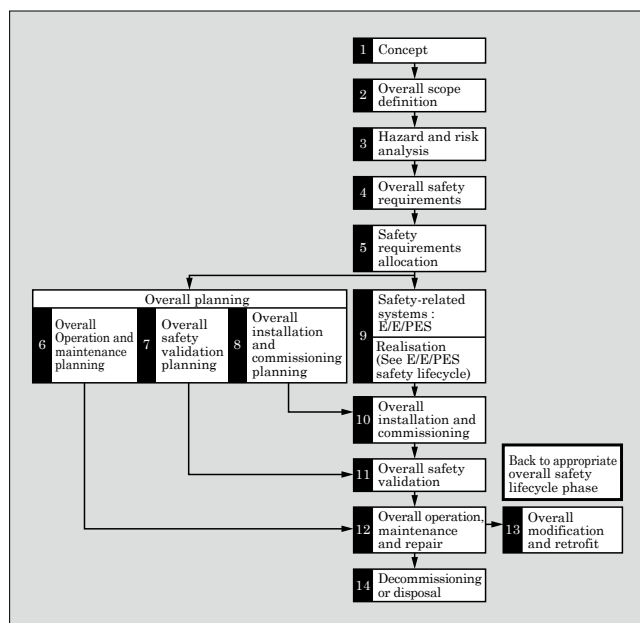
An SIS (safety instrumented system) is a critical system that reduces risk during a plant failure to within an allowable range, and ensures a high level of safety for human life, the environment and equipment. Previously in Japan, the use of a relay circuit as a SIS was typical, but in Europe, an SIS that uses a controller and conforms to new safety standards came into

Table 1 Requested safety items for electrical equipment of machines, and support

IEC 60204-1, JIS B 9960-1 requests	Products that comply with safety standards	Comments
Section 4.2, Equipment selection	Fuji global standard certified products Molded case circuit breaker, magnet contactor, push-button switch, etc.	—
Section 5.3, Power supply disconnect function	G-Twin breaker, ELB External operating panel	Isolation compliance IEC 60947-2 compliance
Section 6.2, Direct circuit break function	Finger protection structure (installed in various devices)	Protection level IP20
Section 7.2, Overcurrent protection	G-Twin breaker, ELB Manual motor starter	Cooperation among overcurrent protection devices
Section 7.3, Overload protection for electric motor	Manual motor starter Magnet contactor, thermal relay	Cooperation among over load/ protection devices
Section 9.2, Control function	If category 0 stop is used in emergency stop function, must be configured from hardwired electromechanical components only	Due to IEC revision (Oct. 2005, JIS under being revised), hardware clause was eliminated and use of electrical, electronic, programmable electronic devices became possible.
Section 9.4, Control function for time of failure	Magnet contactor	Safety opening function contact (mirror contact) IEC 60947-5-1 Appendix F
Section 10.7, Device for emergency stopping	Command switch for emergency stopping	Direct circuit-opening function contact IEC 60947-5-1 Appendix K compliant IEC 60947-5-5 compliant Safety trigger action function ISO 13850 compliant
Section 12.3, Enclosure protection rank	Command switch: IP65 External operating handle: IP54 (Molded case circuit breaker)	Requested protection level for general-purpose industrial enclosure IP32, IP43, IP54

Note) Category 0: stopping by shutting-down mechanical actuator directly

Fig.8 Overall safety lifecycle



widespread use.

(1) Hardware and software

(a) Safety controller

An SIS realized with the MICREX-NX is described below. The MICREX-NX is a controller that conforms to IEC 61508, and has acquired SIL (safety integrity level) 3 certification (see Fig. 9) from TÜV (Technischer Überwachungs-Verein). Three types of CPUs (AS412, AS414 and AS417) having differ-

Fig.9 TÜV certificate



ent processing capabilities are available for use with the MICREX-NX, enabling systems to be configured in many variations, from single setup to completely redundant setup configurations. As a result, the MICREX-NX has flexibility and scalability for selecting a system according to the size and use of a customer system (see Table 2). The realization of SIL 3 with a single CPU (single setup) is an important feature and is made possible by an architecture that implements two program logic blocks in a single CPU, enabling the soundness of the CPU to be checked from computational results (see Fig. 10). The first program is generated by a designer, and the second program is a reverse-operation program generated automatically by the system when the first program is compiled and converted into an executable form. Built into the CPU is a diagnos-

Table 2 Flexible system configuration

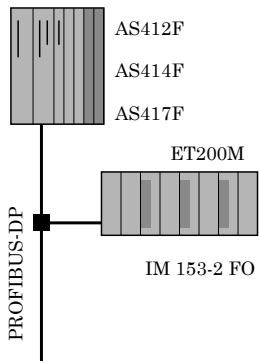
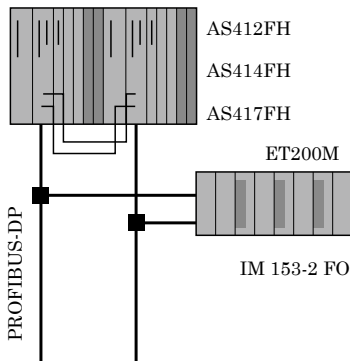
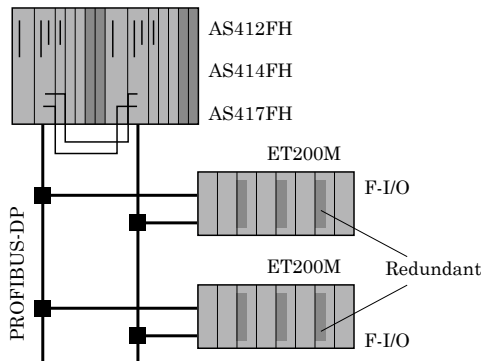
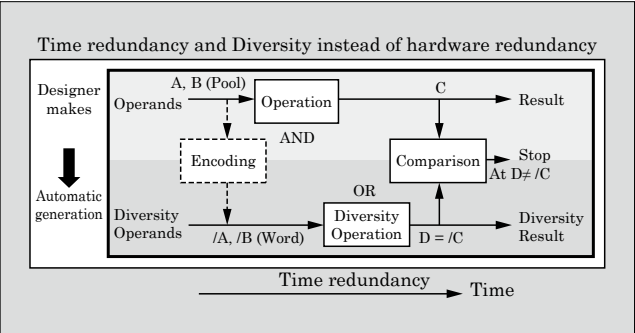
Single set-up	Redundant set-up with syngle I/O modules	Completely redundant set-up
		
A single set-up achieves SIL3	Redundant CPU and redundant bus Components can be exchanged without system stopping.	Redundant CPU and redundant bus and redundant fail safe I/O Components can be exchanged without system stopping.

Fig.10 Checking the soundness of the CPU



tic function that issues instructions for the system to operate in a stable direction when a failure is detected at the time of turning on power or during system operation. The detection of failures, broken wires and the like in the connected I/O module is also possible.

(b) Safety I/O

Table 3 lists the types of safety I/O modules. Each I/O module has acquired SIL 3 certification. Redundant circuitry within each I/O module validates the input and output signals of dual sensors, and a diagnostics circuit performs cross-checking to increase the level of safety.

(c) Safety communications

Safety communications between the safety controller and a safety I/O module is realized by using the PROFIsafe profile based on the PROFIBUS-DP⁽²⁾. PROFIsafe is the first communications system that conforms to IEC 61508, conforms to the SIL 3 safety level, and is applicable to a wide range of FA and PA fields. Using the PROFIsafe profile, a PROFIsafe telegram, as shown in Fig. 11, appends control data, counter data and CRC (cyclic redundancy check) data after safety I/O signal data to prevent the dropout of safety communications data.

(d) Engineering

The engineering of a safety control program is implemented using dedicated failsafe function blocks (FBs) (50 types). These FBs have received TÜV certification.

Required FBs are placed on the engineering screen, connected by mouse operations, and then are compiled and converted into a failsafe user program. During the engineering work, a password is requested whenever the screen is opened or data is loaded, and only appointed designers are able to design and modify the software. Thus, security considerations are taken into account so that a safety program is not modified unintentionally.

(2) Safety Matrix

The MICREX-NX is provided with a software program called “Safety Matrix.” This Safety Matrix basically has three functions (see Fig. 12). The first is an automatic programming function for the safety circuit. On the Safety Matrix, signals for abnormal conditions are defined on the horizontal axis, and output signals to devices for which safe operation is desired are defined on the vertical axis. A safety program can be generated easily by defining associations at points of intersection. The second is a function for directly displaying on an operating panel the Safety Matrix information generated by engineering. This enables accurate and timely responses to failure events (what type of failure occurred and what stopped?). The third is a function that enables data linkage with “exSILentia” by exida.com LLC⁽³⁾. exSILentia is a software program used to compute the PFD (probability of failure on demand) for each SIS operation request, and to perform SIL analysis and other assessments. Data generated by exSILentia can be imported into the Safety Matrix to increase the engineering efficiency further. Also, the Safety Matrix can partially support the safety life-cycle management prescribed by IEC 61511, and is ap-

Table 3 Safety I/O

Components	Number of input/output and safety level	Voltages and currents	Installation environment
Digital input (DI 24)	24 input : SIL2 AK4 12 input : SIL3 AK6	24 V DC	Temperature Horizontal installation : from 0 to 40 °C Vertical installation : from 0 to 60 °C Contaminant concentration SO ₂ : < 0.5 ppm H ₂ S : < 0.1 ppm
Digital input (DI 8 NAMUR)	8 input : SIL2 AK4 4 input : SIL3 AK6	24 V DC	
Digital output (DO 10)	10 input : SIL2 AK5 or SIL3 AK6	24 V DC 2A	
Analog input (AI 6)	6 input : SIL2 AK4 6 input : SIL3 AK6	4 to 20 mA	

Fig.11 PROFIsafe communication telegram

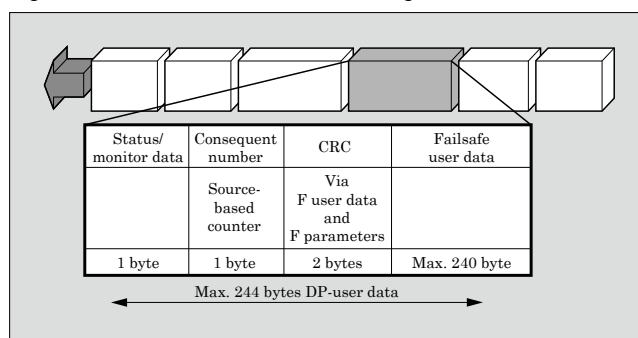
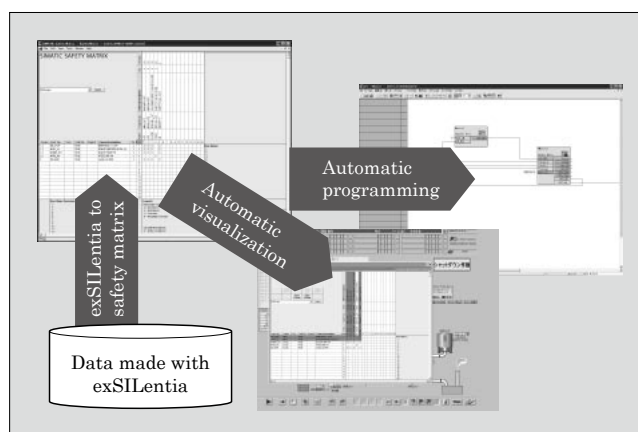


Fig.12 Function of Safety Matrix (for engineering)



plicable to a wide range of processes, from engineering to management (see Fig. 13).

(3) SIS and DCS integration

As shown in Fig. 14, monitoring of the SIS measuring state and software engineering are implemented using the same equipment as with DCS (distributed control system).

(a) Operating and monitoring

Monitoring of the SIS measuring state is implemented with DCS operator station clients. The use of the same clients as DCS has the following advantages.

- Even during an emergency, monitoring and operation can be performed reliably.
- The SIS operating state and the state of the control system can be verified on the same screen, and the plant status can be assessed

Fig.13 Function of Safety Matrix (for lifecycle management)

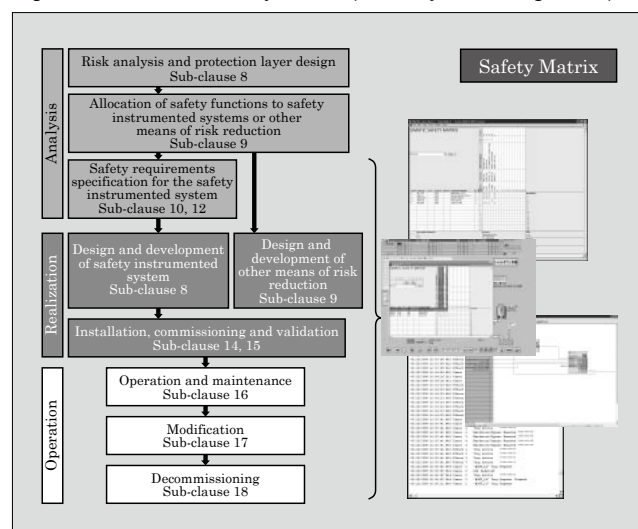
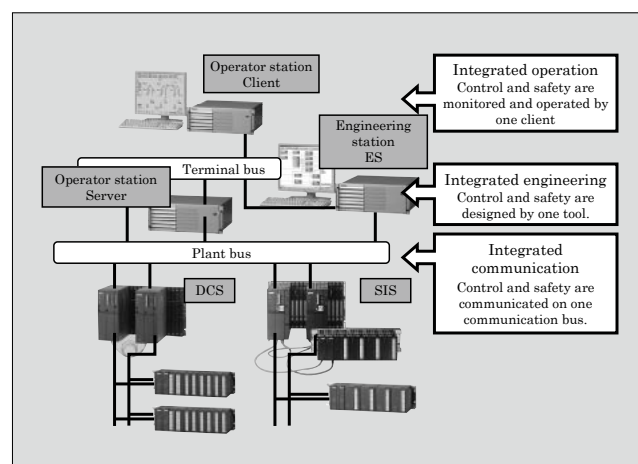


Fig.14 Integrated safety and control



accurately.

(b) Engineering

SIS engineering work is performed using the same ES (engineering station) as with DCS. The engineering work can be performed using the CFC (continuous function chart) normally used with DCS, and in the same environment and with the same procedure. In other words, since there is no need to choose between two different types of engineering for use, the engineering work can be carried

out more efficiently. Also, even in the case where signals are exchanged with the DCS side, the use of a dedicated interface FB makes it possible to construct an SIS without having to be aware of system differences.

6. Postscript

Fuji Electric's approaches to machinery safety and function safety, which aim for total safety, have been described. Safety consists not only of machinery safety and function safety, and safety that comprehensively incorporates both into a plant or equipment must be

considered. In the future, as "Total Safety" solutions, Fuji Electric intends to continue to provide safety that is stable and conforms to international standards.

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Optimal Operation System for Energy Plants

Tetsuya Koide
Kouji Matsumoto
Shinji Kitagawa

1. Introduction

Against a backdrop of healthy domestic and foreign demand, the steel industry is continuing its fundamental trend of increasing production for the manufacturing industry. Meanwhile, since the steel industry accounts for approximately 11% of final energy consumption in Japan, efforts to improve the efficiency of energy usage have been pursued actively for a long time. Since the first oil crisis, an energy savings of approximately 20% has been realized, and efforts to conserve energy have intensified with the recent recognition of the importance of preventing climate change on a global scale. Reducing the consumption of energy in manufacturing processes is a part of these efforts, and it is a goal to reduce energy consumption in fiscal 2010 to a level that is 10% lower than the energy consumption in fiscal 1990.

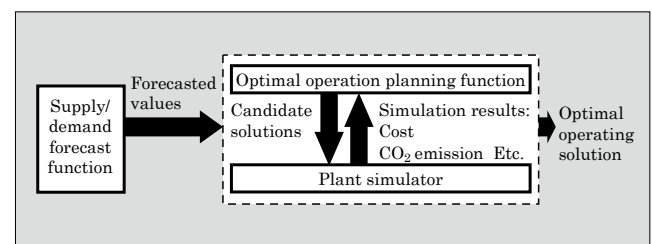
Fuji Electric was early to recognize the usefulness of energy management in steelworks, and continues to deliver “energy centers” which have become synonymous with energy management systems. The energy supply and demand configurations for steelworks are various, and have mutually complex relationships. A process computer-based real-time energy supply and demand forecast function and an optimal distribution function are essential parts of an energy center in order to supply energy stably and respond rapidly to the moment-by-moment changes in the energy supply and demand balance.

Based on these circumstances, this paper describes the application of Fuji Electric’s FeTOP optimal energy operation system package to an energy plan in a steelworks (in cooperation with the JFE Steel Corporation) and the results of optimal operation that have been verified through simulations.

2. Optimal Operation of an Energy Plant

An energy plant supplies various forms of energy, such as electricity, heat and steam, to facilities in factories, business offices, hospitals, large buildings and the like. To supply the energy, various types of equipment are used, including electric generators, boilers and en-

Fig.1 Functions for realizing optimal operation of an energy plant



ergy source facilities. To meet the demand for energy required at a facility, the energy – including electric power, gas and the like purchased externally – must be distributed and supplied to each piece of equipment.

In particular, an energy plant in a steelworks can be utilized efficiently to realize energy savings by converting gas and heat by-products generated from production facilities into a form suitable for energy use. The conversion of energy must be implemented while carefully monitoring the balance between supply and demand, and with the appropriate combination and distribution, i.e., such that optimal operation enables a reduction in the externally purchasing cost and a lower burden on the environment. However, with a boiler and other such equipment, in addition to fuel that is externally purchased, multiple by-product gases are also used simultaneously as fuel, and various constraints exist for the allocated proportions of these gas by-products. An energy plant in a steelworks must operate in consideration of constraints that are more numerous and more complex than in energy plants of other industries.

Moreover, energy supply and demand are constantly changing, and for equipment such as a holder that stores by-product gases, the optimal operation in response to supply and demand fluctuations within a fixed interval must be determined. Accordingly, as shown in Fig. 1, the optimal operation of an energy plant is realized through the use of a supply/demand forecast function, an optimal operation planning function and a plant simulator. In other words, the supply/demand forecast function predicts the fluctuations in the supply and demand of various types of energy,

including the quantity of generated by-product gases. Next, the optimal operation planning function uses the plant simulator to determine optimal operation that satisfies the forecasted energy supply and demand requirements in consideration of many various constraints.

3. FeTOP Optimal Energy Operation System Package

An overview of the main functions and a description of the elemental technology of FeTOP is presented below.

3.1 Forecasting function

The demand for energy, i.e., electricity and heat, and the amount of generated by-product gases have various characteristics which differ when affected by diverse conditions, i.e., factory operation and the weather, but also sometimes periodically exhibit the same trends. The following models are used mostly to simulate these characteristics.

- (a) Physical model that uses physical characteristic equations for the energy consumption of equipment
- (b) Statistical model that uses historical performance data
- (c) Hybrid model that combines the physical model and statistical model

These models may be described in some cases with linear equations, but must be described with non-linear equations in other cases, and various forecasting methods should be considered in order to make forecasts with good accuracy.

FeTOP allows the use of multiple forecasting methods, such as a pattern forecasting method, a multiple regression method and a neural network method.

- (a) The pattern forecasting method produces a forecast value by searching historical performance data for the closest fit to the present condition.
- (b) The multiple regression method uses a linear equation to approximate the relationship between explanatory variables for heat, humidity and so on, and objective variables such as for the power demand to be forecast.
- (c) The neural network method structures a non-linear forecasting model based on learned historical data to produce results most suitable to the present condition.

Of these methods, the analyzable structure neural network (ASNN) developed independently by Fuji Electric enables the forecasting reasons to be explained, which had been difficult to do with prior neural networks having a “black box” interior. As shown in Fig. 2, the network interior is structured for each input unit so that the forecasting reason can be explained, and the structure can be optimized since units and connecting weights that are not needed in the learning process

may be eliminated.

3.2 Plant simulator

The plant simulator supports modeling of the plant characteristics using multiple methods, such as modeling with linear or non-linear characteristic equations based on physical models of the equipment and modeling using response surface methodology and neural networks. Moreover, plant characteristics may be modeled using various expressions such as logical equations for local control, such as quantity control, and plant-specific operating rules. Additionally, the plant simulator also supports modeling of the various constraints and objective functions needed when searching for optimal operation.

The plant model may be generated graphically on a monitor screen. Standard models for many types of equipment, such as boilers and turbines, have already been developed and are available for use as templates. A model for an entire plant can be generated by positioning and connecting these templates on a monitor screen. Parameters for the model characteristics and constraints can also be designed on-screen. Additionally, an objective function can be modeled and optimized on-screen by connecting the terminals of variables in the model. Figure 3 shows an example of the creation of a plant model.

Moreover, in addition to the case where used with an online optimal operation system, this simulator may also be used in offline simulations such as for engineering an optimal operation system or for reviewing an aspect of the plant design, such as equipment selection. As a result, the user is free to set which plant variables are input as independent variables, which variables are dependent variables (variables computed by computing the modeling equations), and which variables are the state variables to be determined according to the optimization. These settings, once configured, may be changed by simple onscreen operations. Based upon category setting information for these variables and upon equipment model connection information, a model computation algorithm is configured automatically inside the simulator.

Fig.2 Overview of structured neural network

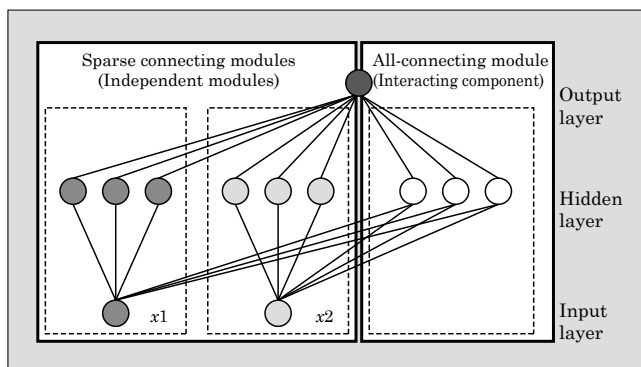
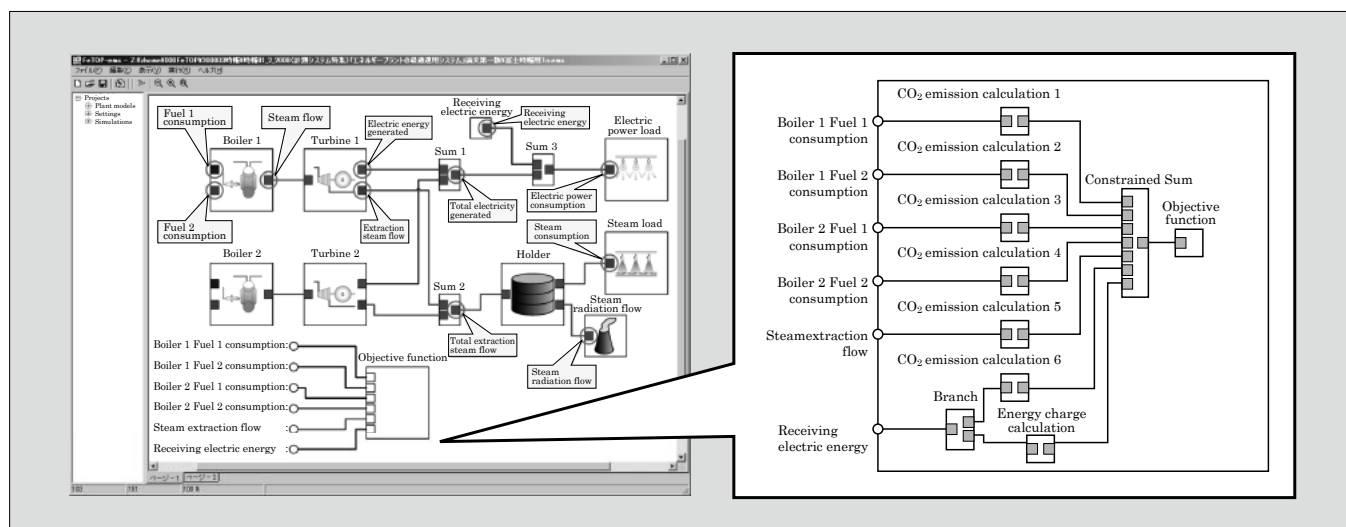


Fig.3 Example of creation of plant model with plant simulator



3.3 Offline simulation function

The FeTOP optimal operation planning function is realized using the above-described plant simulator. Accordingly, constraints and objective functions can be configured easily on the plant simulator screen, and the designation of which plant variables are to be set as state variables can also be implemented easily. As a result, in addition to performing online optimization simulations, offline optimization simulations can also be implemented using user-configured operating settings without having to perform various optimization calculations and optimization for various scenarios.

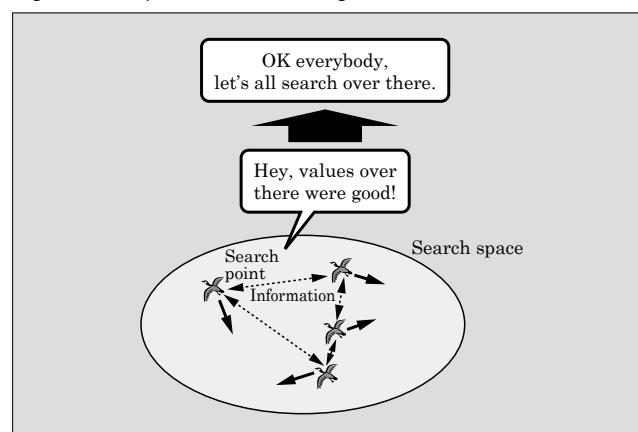
For example, simulations can be implemented for various study purposes, such as to compare optimal operation plans in order to minimize cost or minimize CO₂ emissions and to estimate the amount of by-product gas generation required for a certain operating state.

Furthermore, since the input conditions for multiple cases and the calculated results thereof can be saved collectively and reused, this function enables plans for improvement to be reviewed through the pre-assessment of operation plans and the verification of historical operation results, energy plant optimal operation plans to be drafted and the effects thereof to be verified, and plant design, including equipment selection, to be reviewed.

3.4 Optimal operation planning function

In order to realize optimal energy plant operation, the start-up and shutdown status (discrete values) and the power output (continuous values) of equipment such as generators must be determined simultaneously. Mixed-integer linear problems (MILP) that approximate device characteristics and operation conditions with a linear function have been formulated and solved previously. But, when applied to an actual plant, in addition to the non-linear characteristics of devices, logic equations for quantity control and other control

Fig.4 Concept of PSO searching



logic and operational rules must also be considered. These considerations, in order to be handled directly, must be formulated as a non-linear mixed-integer problem and solved. An effective method for solving mixed-integer non-linear problems did not exist previously, but the use of a recent method known as meta-heuristics enables such problems to be solved. FeTOP implements an optimization function that uses PSO (particle swarm optimization), one such meta-heuristic technique⁽¹⁾.

PSO is a multi-point solution search technique that models the movement of a group of animals or other swarms to solve optimization problems. As shown in Fig. 4, an optimal solution is obtained by allocating multiple search points to a search space, sharing information of favorably evaluated search points, and based on that information, by repeating the migration of the search points. In recent years, various techniques for improvement have been proposed, and FeTOP allows the use of multiple improvement techniques.

Fuji Electric has delivered an optimal operation system using PSO to the energy plant for a mechanical part manufacturing factory, and this system has

successfully contributed to achieving energy savings and reducing CO₂ emissions. However, generally in an energy plant in a steelworks, the amount used of each by-product gas is set as a state variable, the mutual interference among state variables is strong and the proportional allocation relationships thereof have many constraints, thus increasing the difficulty of finding a solution as an optimization problem. On the other hand, with FeTOP, the PSO search algorithm is simple, and with the characteristic feature of allowing the easy addition of proprietary improvements during searching, the configuration allows improvements unique to the target plant to be added.

In the optimal operation of an energy plant in a steelworks, for example, an enormous number of constraints must be considered, and these constraints are usually considered using the penalty function method. In other words, by adding, as a penalty term, the weighted sum of constraint violation values to an object function, a solution that satisfies the constraints can be obtained. In some cases, however, the addition of a penalty term causes a phenomenon whereby the search efficiency drops significantly. Therefore, this function is configured such that among the proprietary

processes added during a search, and improvement process can be added for solution that eliminates specific constraint violations. For example, by implementing an improvement process so as to correct a conflicting operation solution, such as when gas is being purchased despite the holder capacity being at its maximum capacity and diffusing gas, the efficiency of solution searching can be improved. Additionally,

Fig.5 Modeled energy plant in a steelworks

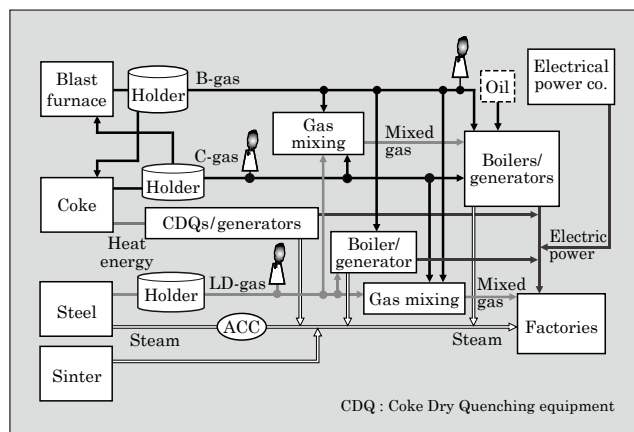


Fig.6 Example of effect of decreased energy consumption due to optimal operation

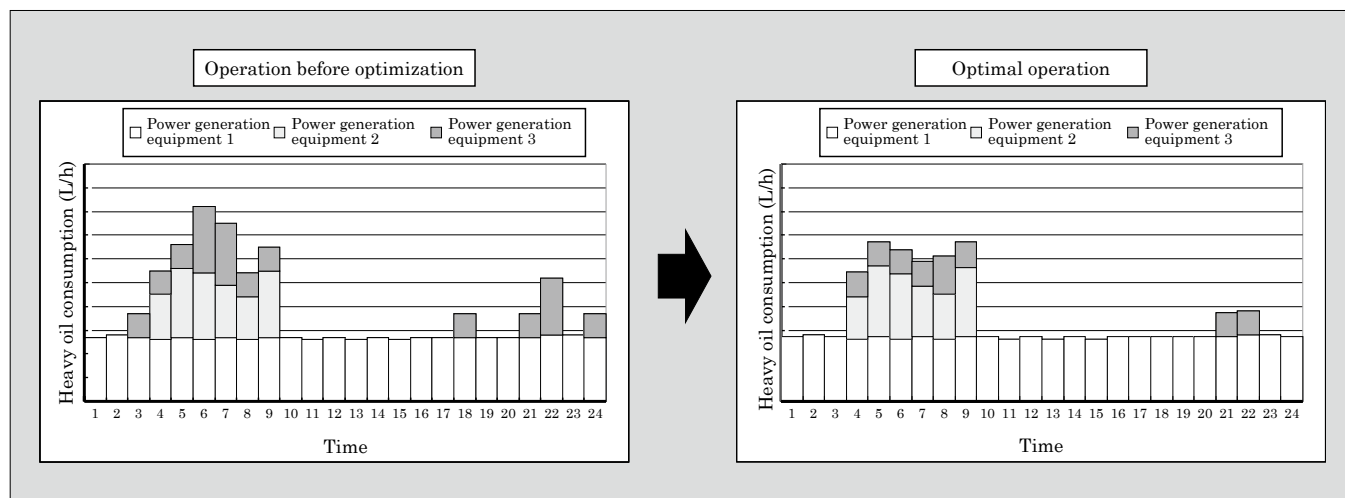
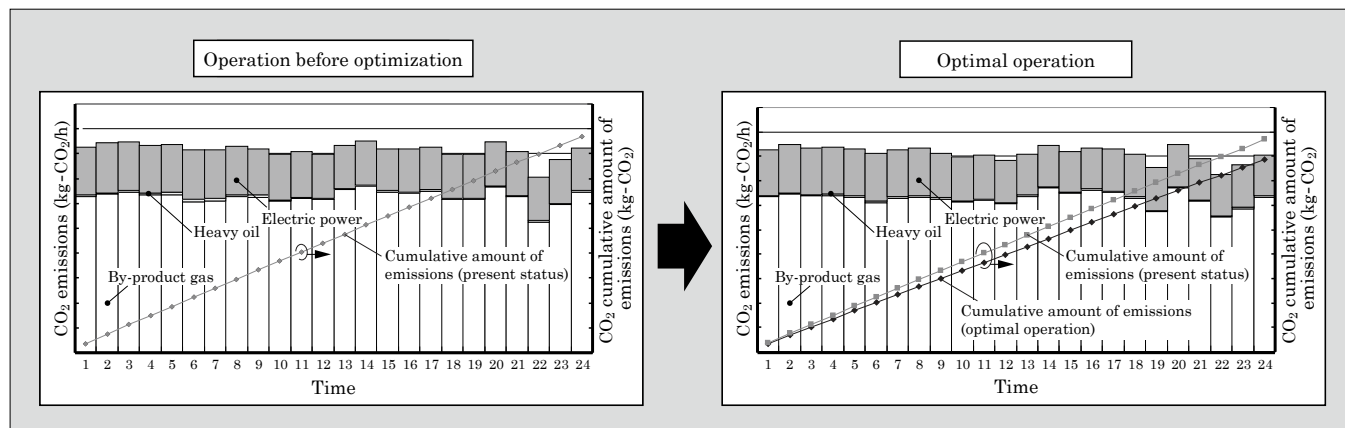


Fig.7 Example of effect of reduced CO₂ emissions due to optimal operation



when adding a penalty term, the weighting factor usually must be adjusted, but a function has also been added for automatically changing the weighing factor value according to the objective function value or the like while searching. As a result of these improvements, better searching efficiency is obtained.

4. Implemented Example

An example is presented below of an offline simulation modeling an energy plant in a steelworks.

We evaluated the optimization of the supply of energy sources such as gas and heat from an iron and steel making plant and the distribution of energy according to the demand for energy (electricity, gas, heat) required in manufacturing processes and downstream processes in order to minimize operating costs such the purchasing cost of heavy oil and to minimize CO₂ emissions. For the model plant shown in Fig. 5, the evaluation was implemented by comparing evaluation values, for the case where optimization was performed by simulating plant operation using performance data for energy demand and supply during unusual operating conditions, with evaluation values computed based on the actual operating state. From the simulation results of a number of cases that modeled several unusual operating conditions, we verified that optimization

has the effect of reducing operating costs by of approximately 1 to 3% on average and reducing CO₂ emissions by approximately 72,000 t-CO₂ annually. Figure 6 shows the effect of reducing heavy oil consumption as an example of the result of minimizing operational cost, and Fig. 7 shows the effect of reducing CO₂ emissions as the result of minimizing CO₂ emissions.

5. Postscript

We have presented the verified results of optimal operation systems for energy plants, as represented by the iron and steel industry.

Leveraging these results, Fuji Electric intends to develop these systems further in order to satisfy user needs, and will continue to work to realize efficient and optimal energy operation and to help prevent climate change on a global scale.

Lastly, the authors wish to extend their deep gratitude to the JFE Steel Corporation for their tremendous cooperation and advice in verifying the efficiency of optimal operation of an energy plant in a steelworks.

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Application of New Framework in Computer Systems for Steel Industry

Hajime Yoshikawa

1. Introduction

Computer systems (process computers) have been used in the steel industry for several decades and were originally installed at only the most important facilities, but with advances in technology, have come to be installed at nearly all facilities, and contribute to achieving safer operation and improved quality.

With the recent rapid expansion of networks and the trend toward open systems, the framework with which computers are configured has undergone significant changes. Computer systems consist of hardware, an operating system (OS), middleware and applications, and the hardware and OS have changed from manufacturer-proprietary to general-purpose formats.

Recently, new frameworks that incorporate general-purpose middleware are being configured instead of the unique middleware of each manufacturer.

Furthermore, due to quality and traceability considerations, MES (manufacturing execution system) related packages which have previously been applied to the food, chemical, and assembly and processing fields, are also progressing toward application to the steel industry.

This paper describes the application of a new framework and package to computer systems in the steel industry.

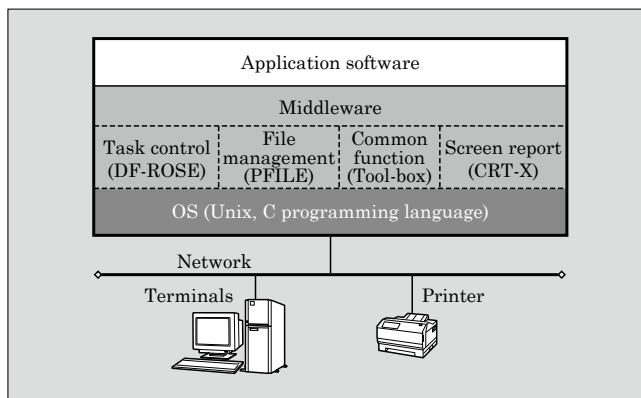
2. Challenges for Computer Systems in the Steel Industry

For computer systems in the steel industry, the C programming language has conventionally been used for application development, with each application being configured so that a facility can be optimally managed and controlled.

In order to configure these applications efficiently and to maintain good quality, middleware, such as shown in Fig. 1, is used as the framework. Systems using this framework differ for each manufacturer and have not sufficiently adopted open standards, and consequently face the following types of challenges.

(1) Since equipment models change when a system is replaced, the display screen and the like must be

Fig.1 Configuration of a conventional framework



reconfigured, requiring extra labor. Furthermore, if basic components of the system are different, the compatibility between the old and new applications will be poor, and additional labor will be required.

(2) When making modifications, since the applications are highly interdependent, components that remain unchanged must also be checked as to whether they will be affected by the modification.

To overcome these challenges, a new framework, package and interface such as described below have been introduced, and optimal combinations according to the system characteristics are being proposed and constructed.

- (a) Application of a framework for web-based system use
- (b) Application of an equipment framework
- (c) Application of a package for MES use
- (d) Application of a standard interface

3. Framework for Web-based System Use

3.1 Overview

In the information processing field, due to the rapid expansion of networks, system formats are migrating to web-based systems. So that these sorts of web-based systems can be developed efficiently, Fuji Electric has developed and is supplying the "Web@Attach" framework product.

3.2 Features

- (1) Utilization of integrated development environment (IDE)

Utilizing the IDE based on JSF (Java server faces), onscreen development for application screens is possible by dragging and dropping components.

- (2) Provision of multifunction screen components

An abundance of components are provided for web design, thereby increasing the efficiency of software development.

- (3) Provision of lightweight DI (dependency injection) container

Web@Attach provides DI container functionality. By defining application specifications with XML (extensible markup language) files, development can be performed while removing the dependency among applications.

- (4) Provision of O/R (object/RDB) mapping tool

To improve the efficiency of creating the database access area, an O/R mapping tool is utilized to enable data access without the use of SQL (structured query language).

Specifically, a function is provided that automatically generates a data access object (DAO) and mapping class from the database definition.

- (5) Support of multiple platforms

As the application server, multiple platforms such as Windows*¹, Solaris*², Linux*³ and the like are supported.

3.3 Effect of the framework application

- (1) Improved quality and development efficiency

In order to improve quality assurance during system development, software for which quality has been verified is used as much as possible, and the amount of application software created is minimized. In looking at examples of web-based system development, 70% of the cases are for standard screen development such as menu, list, simple database reference, and data input. Web@Attach focuses on this area, and through source code generation, auto creation and component utilization, helps reduce the amount of the manually generated source code and achieve higher quality and developmental efficiency than in the past.

- (2) Improved maintainability

During operation, system maintenance, particularly the modification and amending of applications, is an extremely important issue for system maintenance personnel. In particular, modification and amending are extremely difficult when complex interrelationships

*1: Windows is a registered trademark of Microsoft Corporation in the United States and other countries.

*2: Solaris is a registered trademark of Sun Microsystems, Inc. in the United States and other countries.

*3: Linux is the registered trademark of Linus Torvalds in the United States and other countries.

exist between applications. With Web@Attach, as a result of DI containers based on an interface definition in XML, the dependency among applications is eliminated and programs are easy to maintain.

4. Equipment Framework

For monitoring and controlling equipment in the steel industry, systems that incorporate object-oriented design as the method for application design are being constructed in order to improve system reusability and the ease of modification work. The challenges for applying object-oriented design and an equipment framework for the development support environment are described below.

4.1 Object-oriented design

Object-oriented design has the following advantages compared to the conventional system design method using the C programming language.

- (1) By converting work content into objects, a 1:1 correspondence between the work and software is established, enabling improvements, additions and modifications to be implemented easily.
- (2) Creating hierarchical layers for each function according to its role and standardizing the structures, as below, in order to increase the independence of each function and to improve visibility enables system improvements, additions and modifications to be implemented easily (see Fig. 2).

- (a) Scenario layer

Describes the flow of each transaction, and improves the visibility of all functions

- (b) Business logic layer

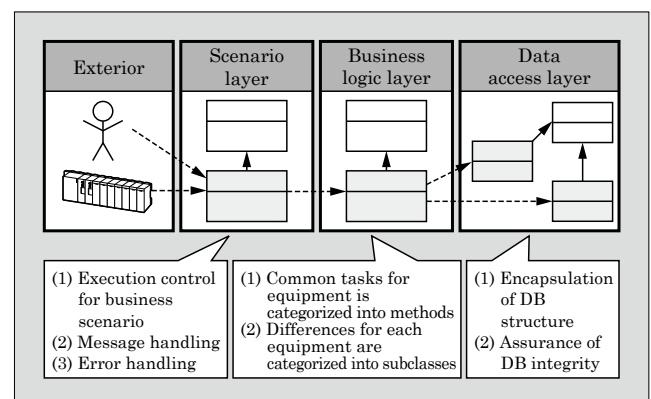
Achieves processing independency by describing the logic portion of each transaction

- (c) Data access layer

Describes the access area of the database, so that database corrections during additions and modifications are implemented easily

- (3) Dividing work content into common and unique components for equipment and converting them into objects increases their reusability with other

Fig.2 Example of hierarchy due to object-oriented design



equipment, enabling improved reliability and lower total cost.

4.2 Challenges in system construction with object-oriented design

Systems developed by object-oriented design have the above-described advantages throughout the entire system lifecycle. However, these systems have only just begun to be used in the steel industry and face the following challenges since existing assets are fewer than in a conventional system.

- (1) With object-oriented design, application functions are designed by categorizing functions into hierarchical layers according to their role, and standardizing the structures, but in actuality, since a management function for creating this configuration was built into each system there were problems in terms of development efficiency and quality.
- (2) Computer systems in the steel industry communicate with the host and other process computers, and with lower level electrical instrumentation systems, but support for this function is provided for each system, and there were problems in terms of development efficiency and quality.
- (3) The message and log management and development tools for supporting application program development were insufficient.

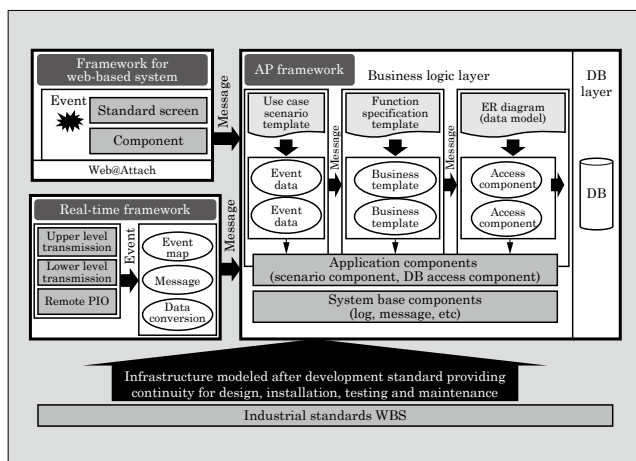
To overcome these challenges, in addition to Web@Attach, the framework mainly used for developing the above-mentioned screens, Fuji developed and is supplying an equipment framework for efficiently developing internal processing that is separate from the screen development.

4.3 Configuration of the equipment framework

Figure 3 shows the overall structure of the equipment framework that enables the efficient development of an object-oriented system. This framework has the following support functions for facilitating the construction of a system.

- (1) Application (AP) framework

Fig. 3 Configuration of equipment framework



The AP framework is equipped with a management function for providing applications with a hierarchical structure as shown in Fig. 2. When creating an application, a mechanism for system construction is established by setting up the necessary logic descriptions for functions and a table describing the associations among functions.

Moreover, the AP framework also has a message management function that centrally manages error information and message information generated by the system, and notifies the operator of the operating status, the occurrence of failures and so on.

Also provided is a log management function that performs application operation traces and outputs the state when a failure occurs, and is used for application debugging during development and for quickly resolving problems.

- (2) Real-time framework

A network communications-use prototype TCP/IP socket communication driver has been prepared to enable communications with other systems and electrical instrumentation systems. Moreover, functions for converting the coding of messages to be transmitted and for distributing to an application can be implemented with table definitions. A communications trace function for transmission data and a simulated message receiving function are also provided.

- (3) Framework for web-based system

The Web@Attach framework is utilized to develop efficiently the above-described web screens.

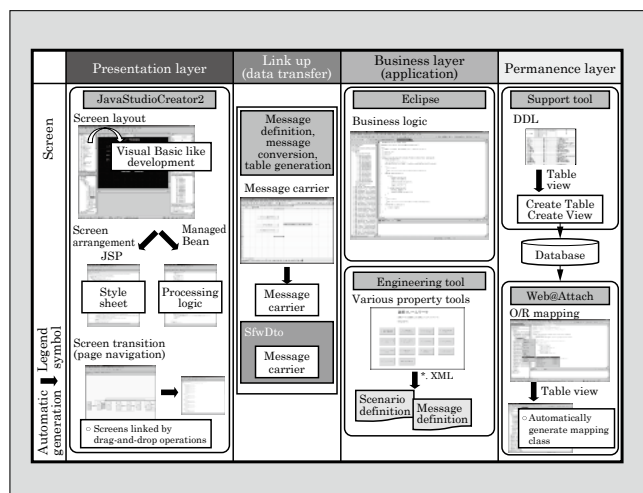
- (4) Development support tools

To make system development more efficient, various required tools are provided as listed below.

- (a) Message definition, conversion table creation tool

This tool links messages, which are to be transmitted to and received from other systems, and applications. The required processes can be generated automatically by inputting, in tabular format, the definition of each message and the data conversion

Fig. 4 Development support tools for equipment framework



format.

(b) Various property tools

These tools define the relationship of each process when hierarchical layers are set for an application. Relational definitions can be set by sampling defining a table.

Figure 4 shows the overall configuration of development support tools.

4.4 Applying effect

Use of the equipment framework enables a high-quality environment for constructing applications to be prepared in advance. As a result, system designers can concentrate on the object-orientated design of the application, allowing a system having better maintainability and reusability to be constructed.

Moreover, since the system is constructed using the Java programming language, even if the hardware and the OS environment are changed at the time of the next system replacing, the applications can be made compatible with minimal modifications, and the replacing cost can be minimized.

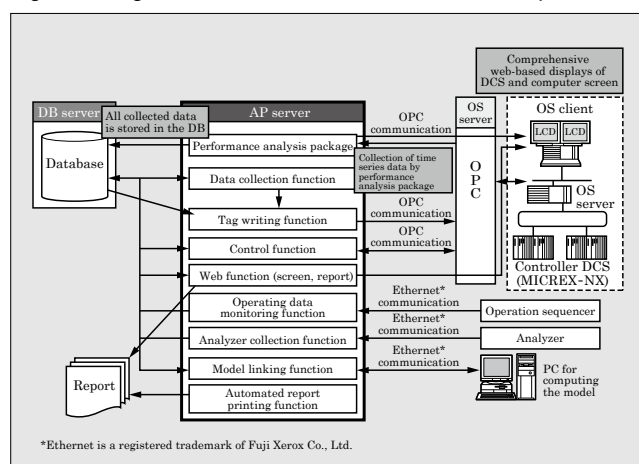
As a result, the lifecycle cost of the total system can be reduced.

5. Application of a Package for MES Use and Vertical Integration with DCS

In the steel industry, even higher quality is being requested, and the implementation of MES functions on a computer system is also requested. Thus, data is collected using Fuji's MainGATE-PPA (process performance analysis) package for MES, and the collected data is combined with a control application to construct a system that emphasizes monitoring and control.

With this combined system, all tasks such as defining the data collection, creating a screen display and generating reports of the collected data, and so on can be implemented by modifying a table with the performance analysis package engineering tool, thereby enabling significant labor savings.

Fig. 5 Configuration of the overall functions of a computer



Furthermore, a system that is vertically integrated with a DCS can also be constructed. Figure 5 shows an example configuration of a total system combined with Fuji Electric's MICREX-NX, a new information control system that is a DCS. This system, in which the DCS can be integrated with the computer screen (single window) and the communication interface can be standardized (using OPC*), has the following features.

(1) Common screen for MICREX-NX and computer

By using a web-based display for the computer screen, the screen for the DCS and computer can be combined for a single OS client, enabling seamless monitoring operation. Moreover, since the display is configured on the web, the plant screen can also be displayed on a business-use PC within the facility.

(2) Common alarm management for MICREX-NX and computer

A failure detected by the computer is sent as an alarm tag to the MICREX-NX and an alarm message is displayed to the OS client, thereby realizing common management.

(3) Data linkage between MICREX-NX and computer

Data linkage with the MICREX-NX is realized via an OPC interface, enabling tag data to be added or modified easily even during plant operation.

(4) Operational data analysis function based on performance analysis package

Process data that has been collected with the MICREX-NX is stored and accumulated so that trend graphs, reports and the like can generated by anyone using the performance analysis package.

Of the various MES packages, an example of ap-

*4: OPC is a standard interface specification of Microsoft Corporation.

Table 1 Evaluation of MES package applied to steel industry

Representative steel equipment	Computer system requirements			Evaluation of application of MES package (MainGATE)	
	Amount of data	Data collection speed	Amount of logic	Collection system, analysis system (Main GATE-PPA)	Indicator system, event system (Main GATE-PO/EM)
Energy center	Large	Low	Small	◎	◎
Coke	Small	Low	Small	◎	◎
Blast furnace	Large	Medium	Large	◎	◎
Converter	Large	Medium	Medium	◎	○
Continuous casting	Large	Medium	Medium	◎	○
Rolling	Large	High	Medium	◎	△
Process line	Large	High	Small	◎	△

◎ : Fully applicable

○ : Must be reviewed based on project specifications

△ : Applicable but there are limitations

plication of the MainGATE-PPA performance analysis package (collection and analysis systems) to the steel industry has been presented, but the applicability of the MainGATE-PO/EM package (indication and event systems) was also evaluated. Details of the evaluations are listed in Table 1, but these packages are considered to be fully applicable to upper-level processes for steelworks, and we plan to move forward with the application of these packages in the future.

6. Standard Interface

The interface between a computer and electrical instrumentation equipment is typically implemented as a network communication interface, and TCP/IP socket communication is often used. Among such interface implementations, the OPC interface espoused by Microsoft in recent years has begun to be used as the standard interface, and OPC also is used with the MICREX-NX for transferring screen system data of the client terminal. However, OPC is based on a DCOM (distributed component object model), which is Windows technology, and therefore direct communication is not possible with most process computers for the steel industry which use a UNIX OS. For this reason, in previous communication implementations using

OPC, the insertion of an intermediate gateway and protocol conversion were required. This field also is experiencing a trend toward open standards, and OPC-UA (unified architecture) is recently being proposed. OPC-UA provides the features of: (a) data structure standardization, and (b) interface standardization. If interface standardization can be realized, then free access can be achieved using the C language or Java with electrical instrumentation systems from any manufacturer, without restriction to the OS used.

Accordingly, access from either a UNIX machine or from a Windows machine can be realized with the same interface, and therefore, without modifying the interface, migration can be carried out during a system replacing, enabling an improvement in quality and labor savings.

7. Postscript

System development technology is rapidly developing as open source technology becomes more widespread. We intend to advance the applications of computer packages and frameworks that incorporate these latest technologies and are committed to further reducing lifecycle costs and to improving quality.



FCX-AIII Series of New Type Differential Pressure/Gauge Pressure Transmitters

Masami Kishiro
Norihiko Tadata

1. Introduction

Since the market launch in 1989 of the FCX series of differential pressure and gauge pressure transmitters which are equipped with a unique micro-machined capacitance silicon sensor, Fuji Electric has continued to develop this series and has subsequently released the FCX-A/C series and the FCX-AII series in 1995 and 2000, respectively. During this time, one-million of these FCX series pressure transmitters have been put into operation at plants throughout the world, and have been well received. Recently, Fuji Electric has developed the FCX-AIII series of pressure transmitters which feature further performance improvements and an even smaller size. The external appearance of the FCX-AIII series of pressure transmitters is shown in Fig. 1.

2. Features

The FCX-AIII series of differential pressure and gauge pressure transmitters have the following features.

(1) Long-term stability

An improved S/N ratio of the sensor signal realizes long-term stability of $\pm 0.1\%$ over 10 years.

(2) Smaller size and lighter weight

Establishment of a technique for directly welding together the sensor housing and the main unit, and development of a small diameter seal diaphragm enable the realization of a differential pressure transmitter having a mass of 3.1 kg, which is 70% of the prior model.

(3) High-speed response

Reducing the power supply voltage for the electronics unit enables high-speed calculations to be performed without an increase in power consumption. As a result, a measurement value update cycle of 60 ms, which is 50% of prior model, was realized.

(4) Enhanced onsite adjustment function (3 push-buttons)

To realize an onsite adjustment function without a handheld communicator (HHC), a field configurator unit with LCD display has been developed so that onsite settings and adjustments can be implemented using three buttons mounted on the configurator unit. Configurator unit is available as an option.

3. Structure

Figure 2 shows the internal structure of the FCX-AIII series of differential pressure transmitters. The internal structure is configured from a micro-capacitive silicon sensor, a new advanced floating cell and an

Fig.1 External appearance of FCX-AIII series of differential pressure transmitters

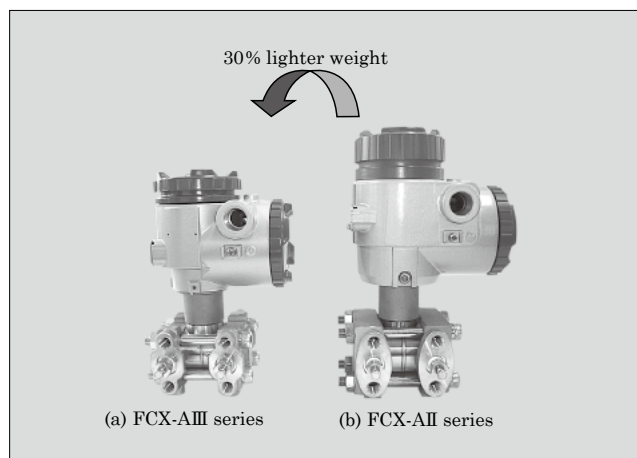
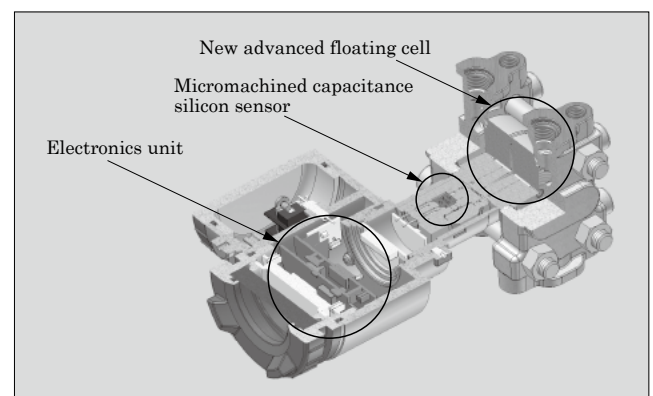


Fig.2 Internal structure of FCX-AIII series of differential pressure transmitters



electronics unit.

3.1 Micromachined capacitance silicon sensor

Figure 3 shows the sensor structure of the FCX-AIII series of differential pressure transmitters. The sensor is structured such that a pair of electrostatic capacitance measurement electrodes (fixed electrodes) face both sides of a silicon diaphragm (moveable electrode) positioned at the center of the sensor. Pressure applied to the sensor causes the diaphragm made of monocrystalline silicon to deform. The amount of displacement is proportional to the differential pressure and can be sensed with high accuracy based on the differential electrostatic capacitances C_1 and C_2 . Thus, the sensor signal F , which is proportional to the differential pressure, can be computed according to the following formula by measuring the electrostatic capacitances C_1 and C_2 .

$$F = (C_1 - C_2) / (C_1 + C_2 - 2C_s) \quad \text{..... (1)}$$

Owing to the excellent properties of monocrystalline silicon, this sensor exhibits low elastic hysteresis. Moreover, when displaced, since the silicon diaphragm having a center disk maintains its parallel orientation with respect to fixed electrodes that form electrostatic capacitance, the sensor exhibits good linearity and there is no need to perform complicated linearity computations.

For the FCX-AIII series, the S/N ratio of the sensor was improved in order to enhance long-term stability. In the electrostatic capacitance pressure sensor, as described above, the static electric capacitance formed by the silicon diaphragm and the fixed electrodes changes in accordance with pressure changes. In an ideal sen-

sor, the sensor signal is only affected by electrostatic capacitance formed between the diaphragm and the fixed electrodes, but in an actual sensor, however, other capacitance is included, i.e., electrostatic capacitance (stray capacitance) formed by the wiring pattern or the like. Through a reconsideration of the sensor structure, this stray capacitance has been minimized, and the difference in stray capacitances on the high-pressure side and the low-pressure side has been reduced. As a result, long-term stability of $\pm 0.1\%$ over 10 years has been realized.

3.2 Sensor unit

In order to make the sensor unit smaller and lighter weight, a directly coupled structure for the sensor housing and pressure receiver, and a smaller diameter of seal diaphragm were realized.

The FCX series has continued to use the same basic structure for the sensor unit, and the advanced floating cell structure which has an extensive record of success has also continued to be used. In the previous advanced floating cell structure, however, the sensor housing and the pressure receiver were welded together with a pipe disposed in-between, and the length of this pipe was an obstacle to miniaturization. Therefore, in the newly developed FCX-AIII series, this pipe was eliminated, a structure that directly couples the sensor housing and the pressure receiver was devised, and the technique for welding this directly coupled structure was established. Figure 4 shows the new advanced floating cell structure that was developed for the FCX-AIII series.

Also, the shape of the seal diaphragm was designed using a numerical analysis method based on the finite element method, and despite the miniaturization of the sensor unit, an optimal waveform diaphragm that does not degrade pressure transmission characteristics was realized.

The directly coupled structure of the sensor housing and the smaller diameter of the seal diaphragm enabled the realization of a 30% reduction in size and

Fig.3 Sensor structure of the FCX-AIII series of differential pressure transmitters

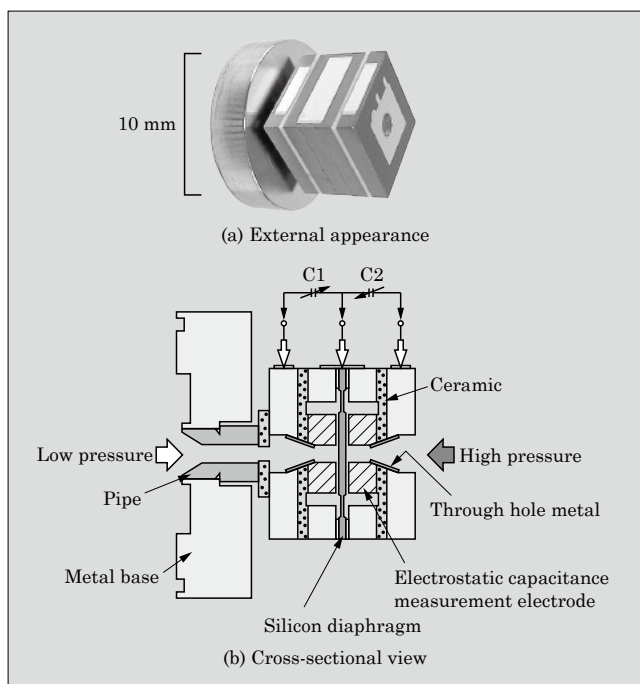
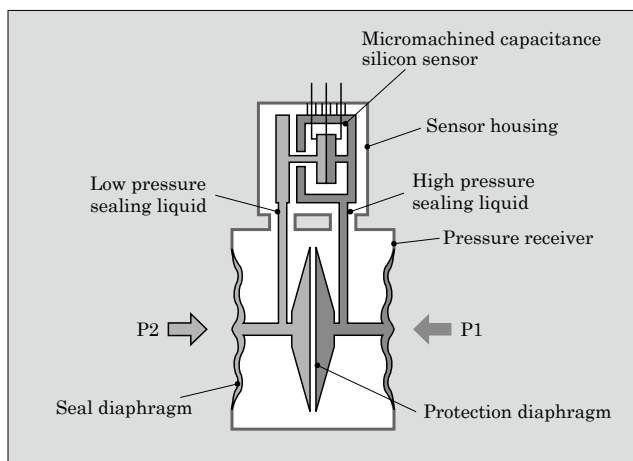


Fig.4 New advanced floating cell structure



weight compared to prior models.

3.3 Electronics unit

Figure 5 shows a schematic diagram of the electronic circuit contained the electronics unit. Pressure is detected as electrostatic capacitance by the sensor, and the sensor capacitance is converted into pulses by ASIC and the pulses are counted by a gate array to form a digital value that the CPU uses to compute the pressure. In recent years, due to requests for higher speed response, the power supply voltage has been reduced so that high-speed computations can be realized with low power consumption. Specifically, the power supply voltage for the CPU and gate array has been reduced, and the CPU's internal operating clock has been increased to twice the prior rate in order to realize higher speed computations. Moreover, in order to limit power consumption without increasing the clock frequency during the pulse counting in the gate array, a circuit that detects rising and falling clock edges was devised. Accordingly, with the same clock frequency as used previously, the same resolution can be obtained in half the counting time as before. As a result, high-speed response can be realized with a measurement value update cycle of 60 ms and dead time of 120 ms, which are double high speed response compared with the previous response speed. Figure 6 shows the step response of the FCX-AIII series.

Fig.5 Schematic diagram of electronic circuit

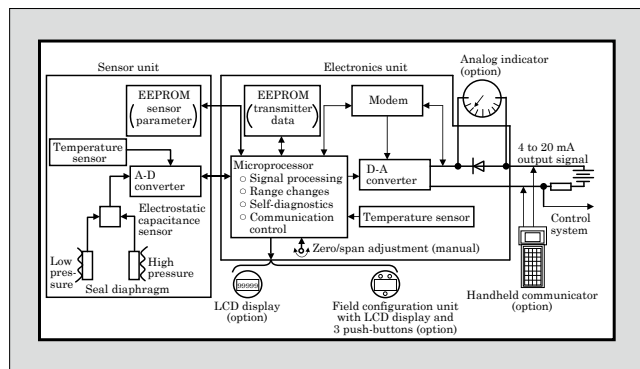
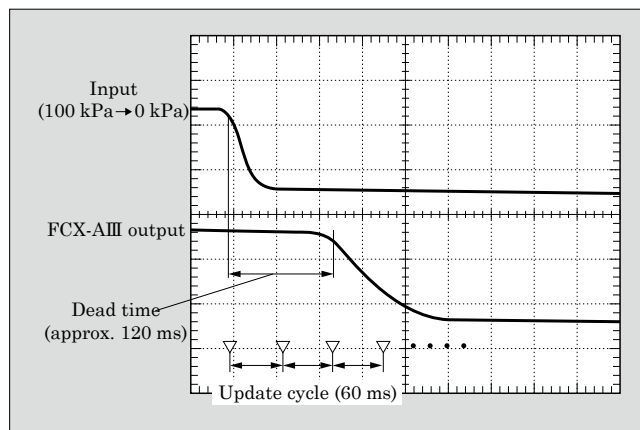


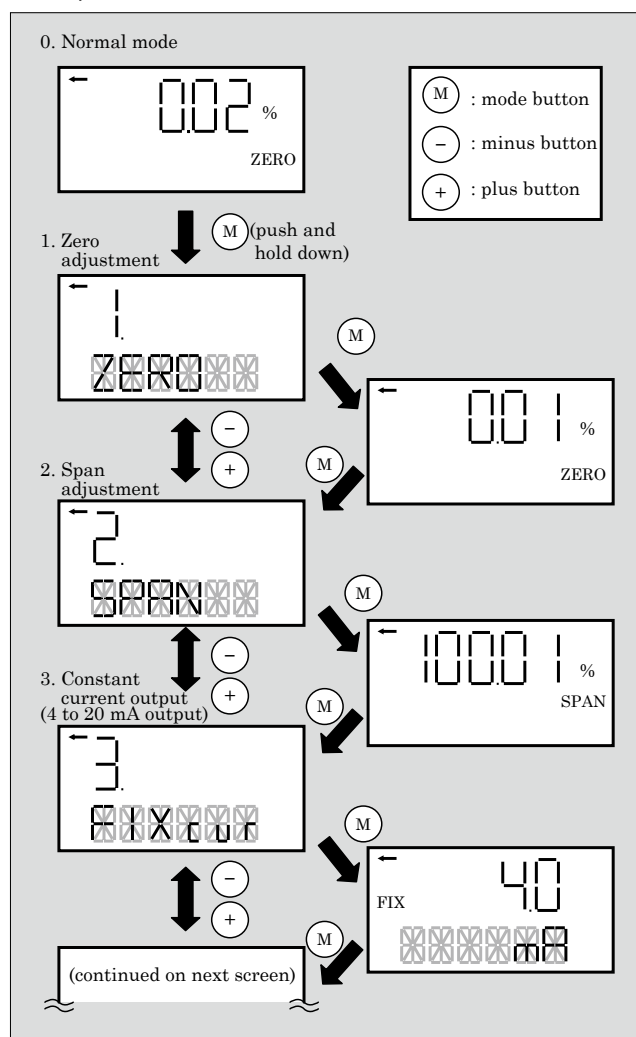
Fig.6 Step response characteristics of the FCX-AIII series



As communication functions, the Fuji protocol communication and the HART protocol communication are equipped as standard, and models that support the Foundation Fieldbus (FF) and the Profibus are also being incorporated into the product lineup. The FF extends the function blocks (FB), and provides a full lineup of AI $\times$ 2 points (pressure, temperature), PID control, IT (integrator), AR (arithmetic block), IS (input selector) and SC (signal characterizer) functions for field devices. A Link Master, which can be operated as a replacement when a master such as DCS is down, is also provided and enhances system safety specifications.

On the other hand, a field configurator unit with LCD display and 3 push-buttons is available as an option so that the main functions can be set easily and quickly without using digital communications such as described above. As an optional specification in previous models, a local adjustment unit with LCD display was limited to only implementing the setting and adjusting of basic functions, such as damping settings, zero adjustment, span adjustment, current output

Fig.7 Example of screen transitions for the display unit with 3 push-buttons



correction, and output switching between pressure and flow rate. With the three new push-buttons, owing to menu-assisted operation, the same function setting and adjustment as HHC using a digital communication are available with the transmitter unit only, thereby the onsite adjustment functions with the transmitter unit have been further improved. Figure 7 shows an example of screen transitions for the display unit with 3 push-buttons.

4. Main Specifications

Table 1 lists the main specifications of the FCX-AIII series of differential pressure and gauge pressure transmitters.

In addition to the L-shaped amp case that was standard with the previous models, a T-shaped amp case is also available. The T-shaped case was requested by overseas users, and for horizontal piping work, has the advantage of allowing the indicator to be viewed from the side.

For the gauge pressure transmitter and the absolute pressure transmitter, a direct mount screw-on type is also available.

5. Characteristics

Representative characteristics of the FCX-AIII series of differential pressure transmitters are shown in

Figs. 8 and 9. Figure 8 shows the 0 to 130 kPa measuring range of a differential pressure transmitter having a maximum span of 130 kPa, and accuracy (input and output characteristics) in the case of a 0 to 13 kPa measuring range of 1/10 the span. The micromachined capacitance sensor is capable of maintaining good lin-

Fig.8 Accuracy of FCX-AIII series of differential pressure transmitters

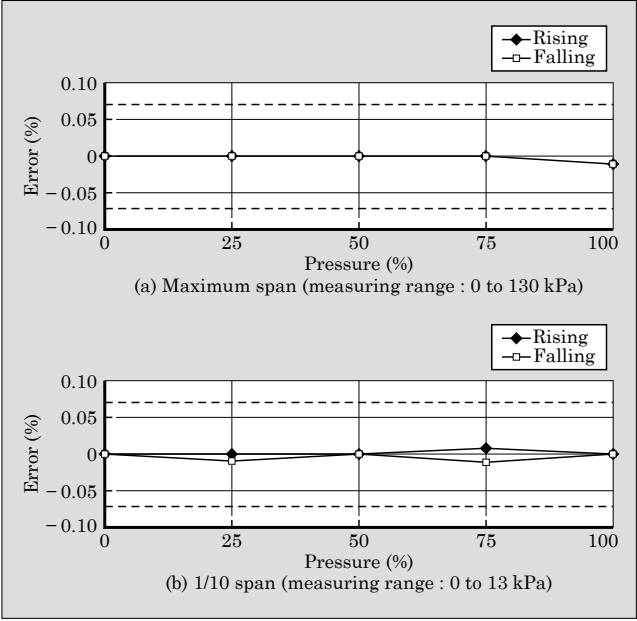
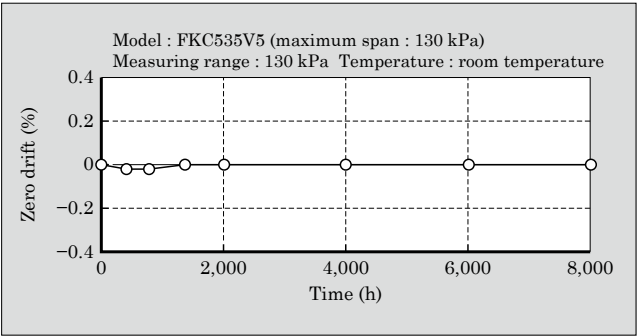


Table 1 Main specifications of the FCX-AIII series of differential pressure and gauge pressure transmitters

Model	Differential pressure transmitter	Gauge pressure transmitter	Absolute pressure transmitter	Level transmitter	Remote seal type differential pressure transmitter	Remote seal type pressure transmitter	Direct mount type pressure transmitter	Direct mount type absolute pressure transmitter
Type	FKC	FKG	FKA	FKE, FKY	FKD, FKX	FKB, FKW	FKP	FKH
Max. span (kPa)	1 6 32 130 500 3,000	130 500 3,000 10,000 50,000	16 130 500 3,000	32 130 500	32 130 500	130 500 3,000 10,000 50,000	130 500 3,000 10,000	130 500 3,000
Mass (kg)	3.1	2.9	2.9	Approx. 9 to 19	Approx. 9 to 19	Approx. 4 to 18	2.2	2.2
Accuracy rating (%)	±0.065 (inside □□□) ±0.1 (other)		±0.2	FKE : ±0.2 FKY : ±0.25	FKD : ±0.2 FKX : ±0.25	FKB : ±0.2 FKW : ±0.25	±0.1	±0.2
Output signal	DC 4 to 20 mA or electrical fieldbus signal							
Communications function	Fuji protocol and HART protocol							
Diaphragm material	316L SS Hastelloy C Monel Tantalum 316L SS + gold plating Gold & ceramic Coating		316L SS Hastelloy C Monel Tantalum	316L SS Hastelloy C Monel Tantalum Titanium Zirconium 316L SS + gold plating			316L SS	
Process connection	Rc 1/4 or NPT 1/4			Various flange standards			Rc1/4, Rc1/2, NPT1/4, NPT1/2	

Fig.9 Long-term stability of FCX-AIII series of differential pressure transmitters



earity even if turned down (measuring range reduced).
Figure 9 shows the long-term stability of zero point

output. Due to the effect of an improved S/N ratio of the sensor, the zero point output is extremely stable over time.

6. Postscript

An overview of the newly developed FCX-AIII series of differential pressure and gauge pressure transmitters has been presented.

As the FCX-AIII series of transmitters penetrates global markets, new requirements are expected to emerge. Fuji Electric intends to continue to expand the model lineup and functions of this series and to move forward with improvements while responding to these requirements.



PUM Multi-loop Modular Temperature Controller

Hideyuki Konishi
Jun Ando
Fukiko Kawai

1. Introduction

The miniaturization of semiconductors and advances in flat panel display (FPD) technology are examples of factors that have enabled the dramatic development of digital devices in recent years. It is imperative that the temperature control used in manufacturing processes for these state-of-the-art devices is highly accurate, upwardly scalable (supports multiple zones) and enables shorter tact times in order to improve the manufacturing efficiency. Moreover, accurate multiple zone-based temperature control is also required for other equipment, such as reflow soldering machines and plastic molding machines, also used in the manufacturing processes for electronic devices in order to realize higher quality and to save energy.

On the other hand, as a result of the trend toward the miniaturization of equipment, the controllers incorporated into such machines are being made smaller year after year. Consequently, the wiring work has become more difficult and there is an ongoing tendency to omit accessories (such as an indicator lamp) not directly related to functionality.

Under these circumstances, Fuji Electric has developed the PUM multi-loop modular temperature controller with the following three objectives.

- To support requests for smaller size controllers in equipment while improving the ease of use of those controllers
- To realize improved control performance in a control system where interference exists between loops, which is difficult to resolve with a single temperature controller
- To satisfy our customers in the multi-loop temperature control market

2. Overview of the PUM Multi-loop Modular Temperature Controller

Figure 1 shows the external appearance of the PUM. Six modules are connected in this figure. The modules are directly connected together by connectors mounted on the left and right sides of each module, and this structure does not require any sort of base-

Fig.1 External appearance of PUM multi-loop modular temperature controller



board. The connectors connect an internal bus and also the power supply and an external RS-485 channel, thereby eliminating the need for individual wiring to each module. Moreover, because an internal bus links data among the modules, computations and coordinated operations can be performed amongst the control loops. On the other hand, there are no common components such as a CPU module or power supply model inside the system, and each module can also operate individually.

3. Specifications of the PUM Multi-loop Modular Temperature Controller

The types of modules and their specifications are listed in Table 1, and an example system configuration is shown in Fig. 2.

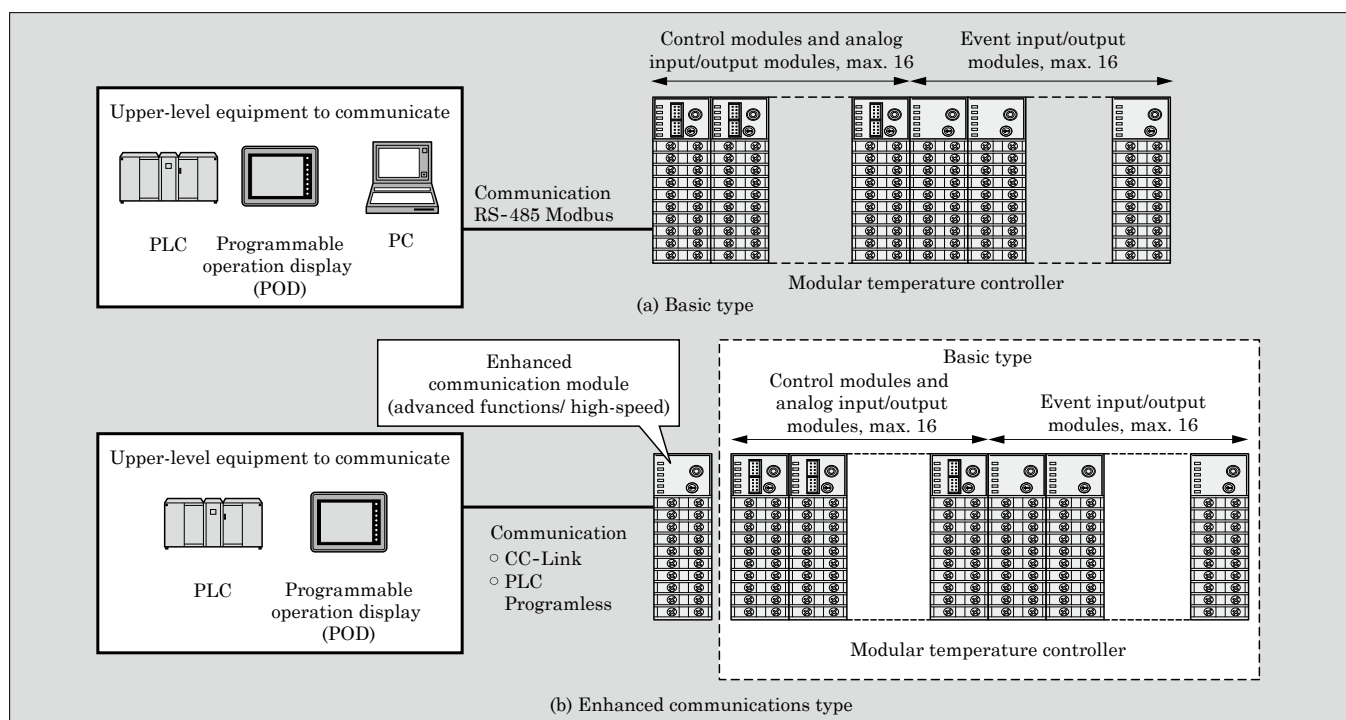
The modules can be broadly classified into the three categories of analog series modules, digital series modules and enhanced communication modules. The analog series modules include a 4-channel control module, 2-channel control module, analog input/output module, analog input module, and an analog output module. The digital series modules include an event input/output module.

A single connected system can contain a maximum of 16 analog series modules, 16 digital series modules, and one enhanced communication module. Accordingly, a maximum of 64 loops, with 128 points of digital

Table 1 Module types and specifications

Module	Specification item	Specification	Max. number per system
Common specifications of each module	External dimensions Communication function Parameter loader communication port Input accuracy Input sampling cycle Power supply	30 (W) × 85 (D) × 100 (H) (mm) RS-485, Modbus RTU, 115.2 kbits/s max. RS-232C ±0.3% 200 ms 24 VDC ±10 %	—
Control module Model : PUMA/B	No. of control channels Input type Control function Output type Heater break detector (CT) input	4-channel (PUMA), 2-channel (PUMB) Thermocouple/ resistance-temperature detector, voltage/ current PID control, PID heat/cool control Relay contact output, SSR driver output, current output 4 to 20 mADC 8 points	16 modules in total
Analog input/output module Model : PUMV	Input points/ output points Input type Output type	4 points/ 4 points Thermocouple/ resistance-temperature detector, voltage/ current Current output 4 to 20 mA DC	
Analog input module Model: PUMN	Input points Input type	4 points Thermocouple/ resistance-temperature detector, voltage/ current	
Analog output module Model : PUMT	Output points Output type	4 points Current output 4 to 20 mA DC	
Event input/output module Model : PUME	Input points/ output points Input type Output type	8 points (4 points/ common × 2 blocks)/ 8 points (4 points/ common × 2 blocks) Voltage contact input, common for sink/source (bi-directional) Relay output, transistor open collector (sink output)	16 modules
Enhanced communication module Model : PUMC	Communication standard Communication speed Communication function	RS-422/RS-232C/CC-LINK RS-422, RS-232C: 230.4 kbits/s max. CC-LINK: 10 Mbits/s max. CC-Link, PLC programless communication	1 module

Fig.2 System configuration example



input and output, can be controlled. The analog series modules and the digital series modules are equipped with high-speed communications functions (RS-485,

Modbus*¹ RTU protocol, maximum communication

*1: Modbus is a registered trademark of Gould Modicon, Inc.

speed of 115.2 kbits/s) as standard, and do not require the addition of a separate communications module. Moreover, communication using CC-Link, PLC programless communication or additional protocol other than Modbus RTU can be supported with the enhanced communication module.

4. Technical Challenges and Details of Efforts

4.1 Simultaneous realization of smaller size and improved ease of use

- (1) The realized module size of 30 (W) × 85 (D) × 100 (H) (mm), which is the industry's smallest class, and 3-block detachable structure consisting of a terminal block, main unit block and base block as shown in Fig. 3 make it possible to wire only the terminal block when installing new wiring offsite, or if replacing a module after onsite delivery, to swap out the main unit block without having to change the wiring and the installed state. Moreover, indicator lamps for all input and output signals are installed, so that the operating condition may be confirmed from the main unit block itself.
- (2) A parameter loader communication port is located on the front of each module, and parameter loader software can be used to set, control and monitor

Fig.3 3-block detachable construction

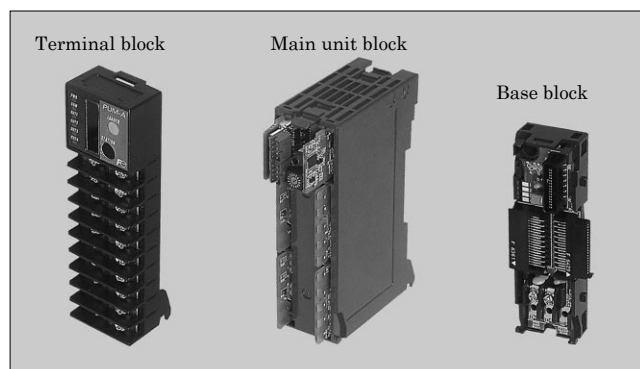
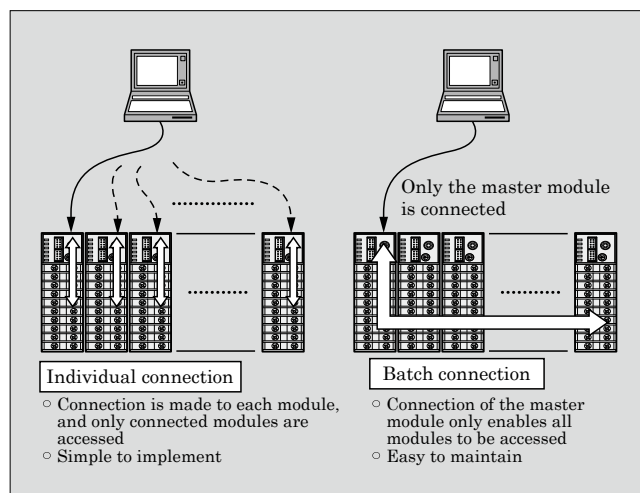


Fig.4 Parameter loader port connection method



the main unit. In addition to the method of connecting each module individually, a master module connection function is also provided and enables the entire system to be connected with only a single connection to the module set as the master in the system (see Fig. 4). This function realizes both simplicity and excellent maintainability.

Moreover, the parameter loader software is equipped with a “favorites” registration function that allows the user to register commonly used parameters (see Fig. 5) and contributes to the improved ease of use.

4.2 Improved control between control loops

Multi-zone optimal control technology using model predictive control reduces thermal interference from adjacent zones, and thus enables more precise control. An application example is described below in Section 5.

4.3 Increased customer satisfaction in the multi-loop temperature control market

(1) Improved communication performance

In the past, when a system became large in size, the speed of data updates via a communication path decreased, and consequently, the operational feel when updating data from an operation display or the like was mostly lost.

This slowdown is due to the following two factors.

- (a) Communications speed is insufficient for the quantity of data
- (b) Due to the increasing number of transmissions, the transmission frame header, response time, and the like, are appended to each transmission, and the time required to transmit other parameters besides communications data can no longer be neglected

The PUM has adopted measures to counteract each of these factors.

As a measure to improve the communications speed, the speed has been increased to 115.2 kbits/s, by a factor of 6, from the previous speed of 19.2 kbits/s for previous products.

The reason for the increased number of transmissions is because the parameters (addresses of communications data) to be accessed from the host are

Fig.5 Parameter loader software “favorites” registration function

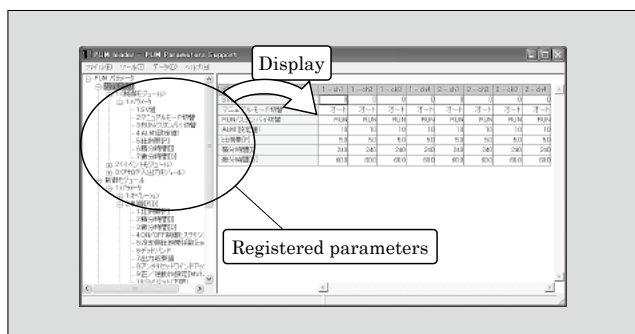
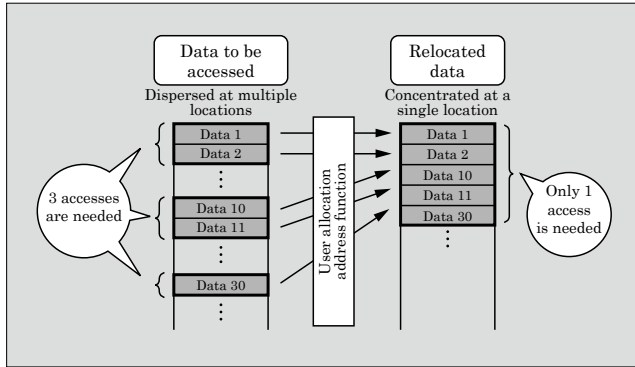


Fig.6 User allocation address function



non-sequential. Therefore, the PUM is provided with a “user allocation address” registration function that relocates data stored at non-sequential addresses to a continuous series of addresses, so transmissions to the same station can be collectively performed in a single access (see Fig. 6). Moreover, by using the enhanced communication module, all connected modules can be treated as a single station. The collection of data previously required the same number of transmissions as there were modules, but with the PUM, the number of transmissions can be reduced to one.

(2) Removal of restriction on number of control points when adding functions

A 4-channel control module is provided with heater break detector CT (current transformer) inputs at 8 points. Accordingly, 3-phase power break detection is possible for each channel without reducing the number of control loops. In Fuji Electric’s previous products, the CT input was limited to a single-phase CT input, and a 3-phase detector had to be installed separately when 3-phase detection was required. As a result, regardless of whether a 3-phase heater break detection function is provided, the same minimal system configuration (number of control modules, input and output wiring) can be used as needed, helping to reduce construction cost for a customer system.

5. Example Application of Multi-zone Optimal Control

In a multi-zone temperature control system, one cause of decreased temperature stability is thermal interference from an adjacent zone, and by decreasing this thermal interference, improves the temperature stability. With the conventional method of PID control, the decrease in thermal interference was limited because of the single loop control. Therefore, multi-zone optimal control using model predictive control, for which the results of many successful applications to oil and chemical plants have been reported⁽¹⁾⁽²⁾, was developed and applied to injection molding machines to verify its effectiveness.

In model predictive control, the algorithm has a model (internal model) of the object to be controlled,

Fig.7 Conceptual diagram of model predictive control

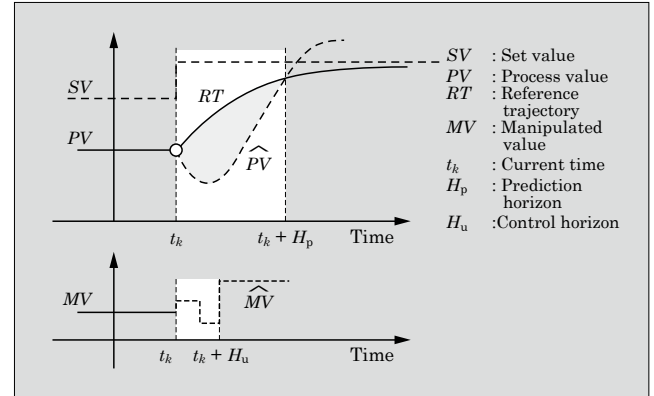
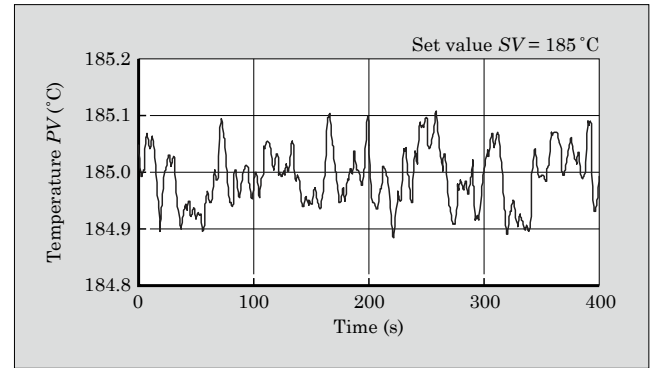


Fig.8 Temperature stability of nozzle with conventional control method (PID control) only

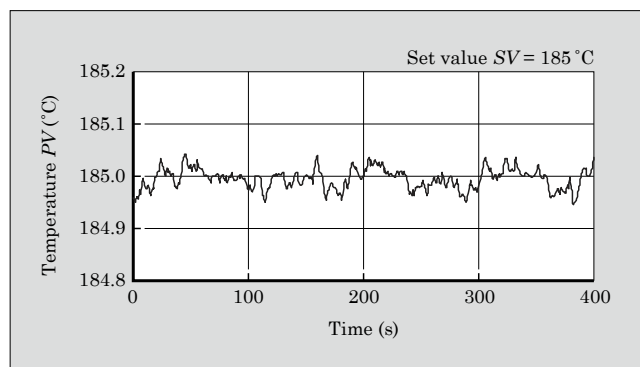


and a value for the amount of manipulation is determined such that the behavior of the object to be controlled is optimal from the present time until a certain future time. Figure 7 shows a conceptual diagram of model predictive control.

Consider the case in which a set value SV is changed at the current time t_k . A future manipulated value MV is calculated such that the difference between a preset reference trajectory RT and a future process value PV calculated from the internal model is a minimum during the interval known as the prediction horizon H_p . At this time, the manipulated value MV is assumed to operate only during an interval known as the control horizon H_u . Of the subsequently calculated manipulated values MV , the manipulated value $MV(t_{k+1})$ at the time t_{k+1} is the actual manipulated value. Repeating this operation sequentially enables optimal control to be implemented constantly while predicting the future. The above-described advantage is easily extended to cases where there is a multivariable system (interference system) or limitations on the object to be controlled.

We applied multi-zone optimal control to an actual injection molding machine (80 ton, 4 zones). Figure 8 shows the temperature stability of the nozzle (width: 0.2°C , $\pm 0.1^\circ\text{C}$) when using a conventional control method (PID control) only, and Fig. 9 shows the nozzle temperature stability results (width: 0.1°C , $\pm 0.05^\circ\text{C}$)

Fig.9 Temperature stability of nozzle with multi-zone optimal control



when using multi-zone optimal control. From these results, we verified that the temperature stability was improved due to the multi-zone optimal control.

6. Postscript

With the higher level of quality requested of manufacturing technology, manufacturing equipment is

trending toward more dense and sophisticated designs, and Fuji Electric has developed the optimal controller for incorporation into such manufacturing equipment. Multi-zone optimal control technology has realized stable temperature control in adjacent injection molding machines.

In the future, to widen the range of applications, we plan to apply multi-zone optimal control to the FPD industry for temperature control in semiconductor manufacturing equipment. Moreover, by improving the present specifications for the input sampling cycle (200 ms) and input accuracy ($\pm 0.3\%$ FS), and by supporting various types of communication functions, Fuji Electric intends to develop modular controllers applicable to various diverse industries.

References

- (1) S. J. Qin, et. al. "A Survey of Industrial Model Predictive Control Technology," Control Engineering Practice, vol. 11, 2003, p. 733-764.
- (2) IEEE Control Systems Magazine, Snapshots of Process Control Part II Glassmaking, vol. 26, no. 6, 2006-12.

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# ZSS Cross Stack Laser Gas Analyzer

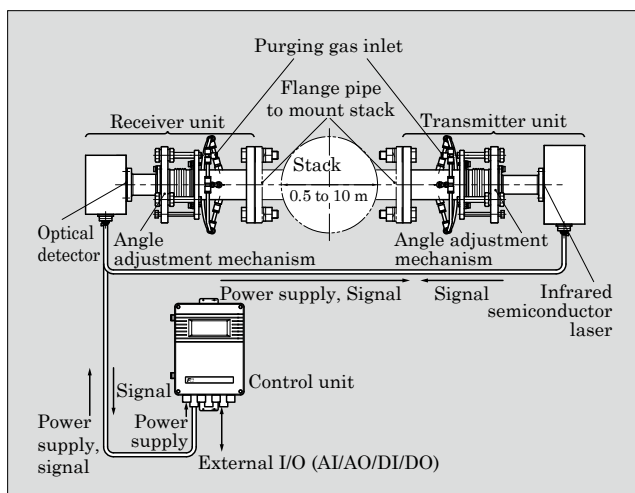
Hideo Kanai  
Yusuke Nakamura  
Kazuhiro Koizumi

## 1. Introduction

To protect society from air pollution and to preserve living conditions and the environment, Japan enacted an Air Pollution Control Law in 1968. The Air Pollution Control Law prescribes emissions standards for each type of emission matter according to the type and size of a facility, and also regulates the total pollutant load control criteria by region.

At incinerators and industrial waste incineration facilities, the emission of hydrogen chloride, a harmful chemical substance, must be controlled. For this purpose, a continuous analyzer for hydrogen chloride is often used to measure sampling gas, which is automatically and continuously extracted from the vicinity of a smokestack outlet at a facility, by passing the sampling gas through an absorption tank and then using the ion selective electrode method to take measurements. Also, at large boilers used for power generation and the like, denitrification equipment that uses ammonia is often installed and ammonia analyzers are provided to monitor the residual ammonia and to monitor the denitrification. As in the measurement of hydrogen chloride, ammonia is measured by continuously extracting a gas sample and measuring it with infrared analysis, chemiluminescence or the like.

Fig.1 Configuration of the cross stack laser gas analyzer



Fuji Electric's ZSS, which uses a laser and does not require sampling, is the first cross stack laser gas analyzer to be released in Japan, and the structure, operating principles, features and uses of the ZSS cross stack laser gas analyzer are described herein.

## 2. Device Configuration

Figure 1 shows the configuration and Fig. 2 shows the external appearance of the ZSS cross stack laser gas analyzer. The device is configured from three units: a transmitter unit, a receiver unit and a control unit.

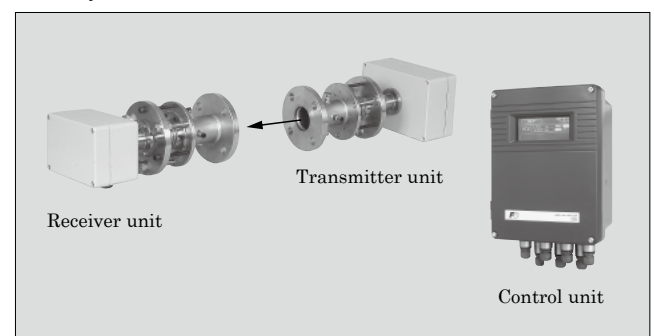
### (1) Transmitter unit

The transmitter unit is configured from an infrared semiconductor laser, a laser temperature control circuit, a Peltier and the like, and emits light having a stable wavelength suitable for the absorption spectrum of the component to be measured.

### (2) Receiver unit

The receiver unit is configured from a photodiode, an amplification circuit, a concentration detector circuit and the like, and converts light that has passed through the stack into electrical signals to detect the concentration. The transmitter unit and the receiver unit are also provided with angle adjustment mechanisms, attached so as to sandwich the stack and enabling the optical axis displacement to be adjusted according a shift in the flange attachment location or warping of the stack. Additionally, a purging mecha-

Fig.2 External appearance of the cross stack laser gas analyzer



nism is also provided to prevent dust from causing clogging or dirty windows.

### (3) Control unit

The control unit supplies electric power to the transmitter unit and the receiver unit, corrects the concentrations in consideration of gas temperature, gas pressure and the like, displays the concentration levels and alarms, and controls the inputting and outputting of signals.

## 3. Measuring Principles<sup>(1)</sup>

Gas molecules of hydrogen chloride, ammonia and the like each have their own unique infrared absorption spectrum. Figure 3 shows the absorption wavelength ranges of various gases and the absorption spectrum for hydrogen chloride. Infrared absorption exists as a line spectrum.

Laser light emitted from the transmission unit is absorbed according to the concentration of measuring gas in the stack, in accordance with the Lambert-Beer law, and then reaches the receiver unit. The intensity of the received light is sensed to measure the concentration of gas inside the stack.

$$I(L) = I_0 \exp(-knL) \dots\dots\dots (1)$$

$I(L)$  : Received light intensity

$I_0$  : Emitted light intensity

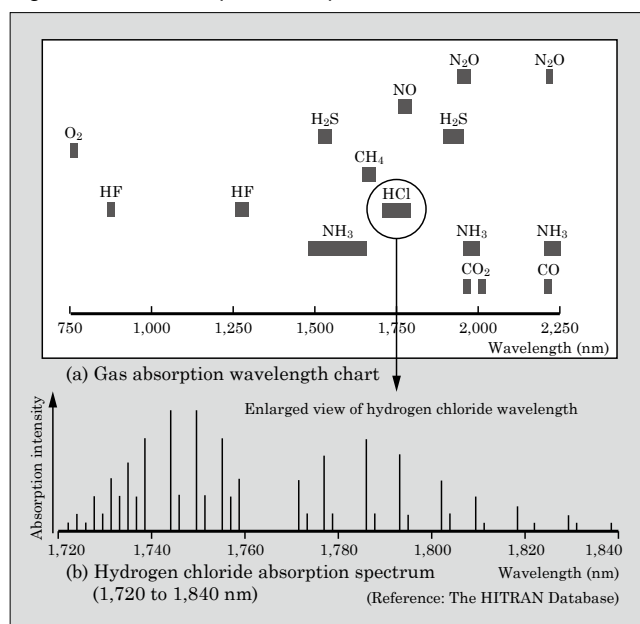
$k$  : Proportionality coefficient

$n$  : Concentration (density) of measurement gas

$L$  : Optical path length

Figure 4 shows the principles of the measurement method. The laser light is approximately a single wavelength of about 10  $\mu\text{m}$  ( $\mu\text{m} = 10^{-12} \text{m}$ ) at half-band-width, but may be frequency modulated by changing the drive current and temperature. By modulating the

Fig.3 Infrared absorption line spectrum



wavelength around the line spectrum of the measurement gas component at a fixed cycle, a signal having a frequency characteristic is obtained, and that signal, having been attenuated and weakened due to absorption, is received as frequency components which are extracted to achieve measurement with good accuracy.

## 4. Features

### (1) Low running cost

The ion selective electrode method requires periodic maintenance, such as the preparation of an absorption solution, to be performed approximately twice a month. With the laser method, however, due to the use of automatic zero point correction based on detection of the absorption line position, zero point stability is excellent and maintenance free operation for six months to a year can be realized. Owing to the low maintenance cost and non-necessity of reagents, running cost has been reduced to approximately 1/5th that of prior methods. Another feature of the laser method is that dead time is eliminated since there is no need to perform periodic automated calibrations.

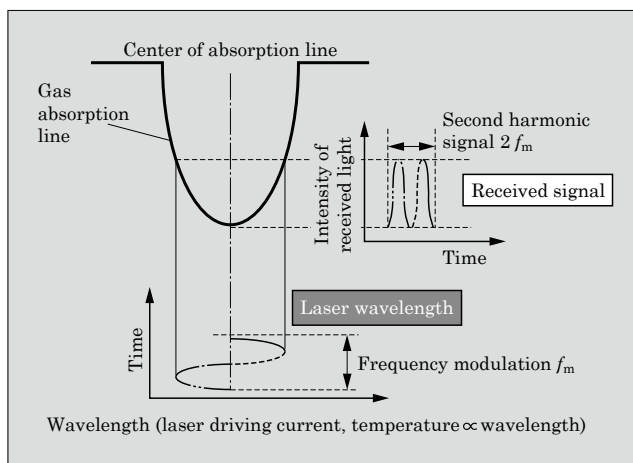
### (2) Low power consumption

With the sampling method, in order to suck in and feed the gas to an analyzer, a dust removal filter, suction equipment, a gas cooling system and the like are required, and to prevent condensation, the sampling pipe must be heated, which requires approximately 50 W/m. On the other hand, with the laser method, the analyzer is mounted directly on the stack, and therefore these components are unnecessary. Moreover, with a small power consumption of 70 VA, the laser analyzer places a low burden on the environment.

### (3) Can be used with exhaust gas containing high dust levels

When gas containing high levels of dust is used with the sampling method, a dust filter or the like is closed for short intervals, during which time a condition occurs in which measurement is not possible. However, with the cross stack laser method, sampling

Fig.4 Measurement principles



is not required and the window surfaces on the transmitting and receiving sides may be constantly being purged with clean air so that exhaust gas containing high levels of dust can be analyzed.

(4) Can be used with control processes

The sampling method has a response time of several minutes in duration (depending upon the length of the sampling pipe). On the other hand, the laser method has a high-speed response of 2 seconds or less, and

by linking the dechlorinization equipment and denitration equipment with more precise control, the amounts of slaked lime used for dechlorinization and ammonia used for denitrification can be reduced.

(5) Measurement is not susceptible to interference from other gases

Measurements made using the ion selective electrode method are susceptible to influence from other halogen substances. On the other hand, since a wide wavelength range is used for measurement with an infrared analyzer, a band-pass filter (optical filter that allows the transmission of only a specific wavelength range) is used in combination to lessen the interference, but measurements made using this method are inherently susceptible to interference from other gases. The laser method uses an extremely narrow wavelength range of 1 nm or less ( $\text{nm} = 10^{-9} \text{ m}$ ). Furthermore, since a wavelength in which other gases are not absorbed is selected, this method is inherently insensitive to interference from other gases.

(6) Highly accurate measurements in regions of low concentration

The hydrogen chloride concentration in the vicinity of a smokestack outlet at an incinerator has a low value of less than 5 ppm, and therefore the measuring device is desired to have low range specifications. This analyzer is capable of measuring in the low concentration region of 10 ppm (when the measuring optical path length is 1 m), and can measure with higher accuracy than the previous methods which had a minimum range of 50 to 100 ppm.

## 5. Specifications

The main specifications are listed in Table 1.

## 6. Example applications to processes

Figure 5 shows an example on an application to an incinerator or industrial waste incineration facility.

(1) Slaked lime injection control based on hydrogen chloride concentration measurement

At the dust collector inlet of an incinerator or industrial waste incineration facility, slaked lime is

Table 1 Specifications of the cross stack laser gas analyzer

| Item                                   |                                          | Specification                                                                                                                                                                                  |
|----------------------------------------|------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Measurement principle                  |                                          | Non-dispersive infrared system (NDIR)                                                                                                                                                          |
| Measuring method                       |                                          | Cross-stack system (path system)                                                                                                                                                               |
| Light source                           |                                          | Near-infrared semiconductor laser                                                                                                                                                              |
| Laser class                            |                                          | Class 1                                                                                                                                                                                        |
| Measurable component and range         | Hydrogen chloride                        | Min. 10 ppm, Max. 1,000 ppm<br>Min. 15 ppm, Max. 1,000 ppm<br>(measurement range when optical path length is 1 m)                                                                              |
|                                        | Ammonia                                  |                                                                                                                                                                                                |
| Detection limit                        | Hydrogen chloride                        | 0.05 ppm<br>0.15 ppm                                                                                                                                                                           |
|                                        | Ammonia                                  |                                                                                                                                                                                                |
| Performance                            | Repeatability<br>Linearity<br>Zero drift | $\pm 2.0\%$ FS<br>$\pm 3.0\%$ FS<br>$\pm 2.0\%$ FS/six months<br>( $\pm 3.0\%$ FS/six months for ammonia range of 20 ppm or less)<br>2 seconds or less                                         |
|                                        | Response time                            |                                                                                                                                                                                                |
| Warm-up time                           |                                          | 90 minutes                                                                                                                                                                                     |
| Allowable angle adjustment             |                                          | 5 degrees or more                                                                                                                                                                              |
| Protection classification              |                                          | IP65                                                                                                                                                                                           |
| Measurable range (optical path length) |                                          | 0.5 to 10 m                                                                                                                                                                                    |
| Measuring gas condition                | Temperature                              | 450 °C max.<br>$\pm 10$ kPa<br>50 vol% or less<br>10 m/s or less                                                                                                                               |
|                                        | Pressure                                 |                                                                                                                                                                                                |
| Ambient temperature                    | Receiver unit                            | -20 to + 55 °C<br>-20 to + 45 °C                                                                                                                                                               |
|                                        | Transmitter unit                         |                                                                                                                                                                                                |
| Power supply, power consumption        |                                          | 100 to 240 VAC, 50/60 Hz, approx. 70 VA                                                                                                                                                        |
| Analog output                          |                                          | 4 to 20 mA DC (550 $\Omega$ )<br>2 points (measurement value, O <sub>2</sub> corresponding value)<br>(optional 4 points max.)                                                                  |
| External I/O                           | Analog input                             | 4 to 20 mA DC, 2 points<br>(optional 6 points max.)<br>12 to 24 V/ 5 to 20 mA DC, 4 points<br>(optional 5 points max.)<br>24 VDC, 1A, 8 points<br>(optional 17 points max.)                    |
|                                        | Contact input                            |                                                                                                                                                                                                |
| External dimensions, mass              | Contact output                           | 180 (W) $\times$ 400 (D) $\times$ 200 (H) (mm), approx. 10 kg<br>240 (W) $\times$ 400 (D) $\times$ 200 (H) (mm), approx. 10 kg<br>240 (W) $\times$ 135 (D) $\times$ 320 (H) (mm), approx. 8 kg |
|                                        | Receiver unit                            |                                                                                                                                                                                                |
| External dimensions, mass              | Transmitter unit                         |                                                                                                                                                                                                |
|                                        | Control unit                             |                                                                                                                                                                                                |

Fig.5 Example of installation at waste incineration facility

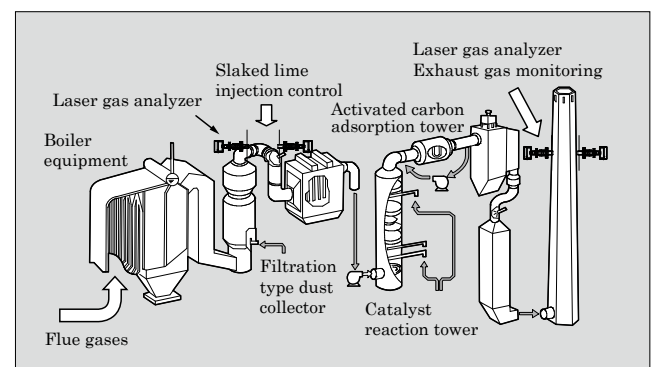
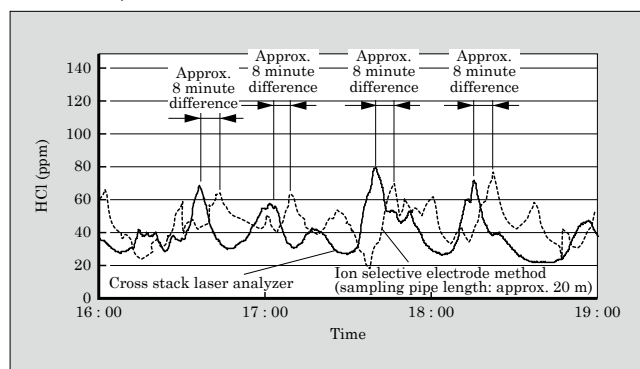


Fig.6 Measurement comparison 1: Cross stack laser analyzer compared to ion selective electrode method (response time)



sprayed in order to reduce the concentration of hydrogen chloride in the exhaust gas. Although dependent upon the type of material incinerated, the automated and continuous measurement of the exhaust gas had been difficult to implement previously due to the adverse conditions of 500 to 2,000 ppm of hydrogen chloride, a temperature between 200 and 400 °C, dust content of 2 to 10 g/m<sup>3</sup> (normal) and moisture of 10 to 20 vol%. The laser method is taking measurements under these types of conditions because purging with clean dry air is performed at 50 to 100 L/min, according to the flow rate of the exhaust gas, to prevent the accumulation of dust and to lower the temperature.

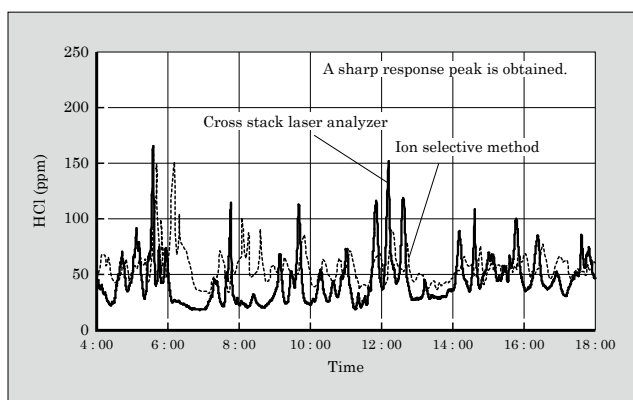
## (2) Hydrogen chloride concentration monitoring in vicinity of smokestack outlet

The exhaust gas from an incinerator or an industrial waste incineration facility must be monitored to ensure that concentration levels do not exceed the prescribed emission levels. The exhaust gas has a hydrogen chloride concentration of 0 to 50 ppm, temperature between 100 and 250 °C, dust content of 200 mg/m<sup>3</sup> (normal) or less, and moisture of 10 to 40 vol%. With a laser analyzer, the exhaust gas is measured as a wet gas concentration (concentration including moisture). It is also possible to set the forecasted moisture concentration and output a dry gas concentration (concentration after moisture has been removed).

## (3) Ammonia injection control for denitrification equipment

Denitrification equipment employing selective catalytic reduction (SCR) that uses ammonia or urea has been installed at large boilers, incinerators and the like. The measuring gas typically has an ammonia concentration of 50 to 200 ppm, a temperature between 300 and 400 °C, dust content of 200 mg/m<sup>3</sup> (normal) or less, and moisture of 10 to 20 vol%. The installation of the laser gas analyzer at the rear of the denitrification equipment enables efficient control to be implemented without excessive injections of ammonia. As a result of this type of control, the exhausting of excess ammonia is reduced and pipe clogging due to the generation of ammonium sulfate ((NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>) is also diminished.

Fig.7 Measurement comparison 2: Cross stack laser analyzer compared to ion selective electrode method



## 7. Field measurement examples

Figures 6 and 7 show examples of measurements in the field.

For Fig. 6, the location at which sampling gas is extracted and the location at which the laser gas analyzer is installed are the same. Both outputs exhibit good correlation, but the results show that the laser analyzer provides an output response approximately 8 minutes earlier than the ion selective electrode method using a 20 m sampling pipe.

In Fig. 7, the output response from the laser gas analyzer provides a steeper peak value than that of the ion selective electrode method. This steep peak is thought to be attributable to the fact that the detector unit is attached directly to the smokestack can reflect instantaneous conditions.

## 8. Postscript

The cross stack laser gas analyzer provides many features not available with conventional sampling methods, such as high speed response, low running cost and maintenance-free operation, and can be used for control and other new applications to meet user needs.

At present, the cross stack laser gas analyzer is adsorptive of hydrogen chloride and ammonia and is being applied to measure gases that are difficult to sample, but through developing such products as an oxygen analyzer for combustion control, a dual-component analyzer for measuring the measurement gas and moisture simultaneously, and so on in the future, Fuji Electric intends to increase its lineup of measurement products having specifications suited to user needs.

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