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e-Front runners

FUJI ELECTRIC REVIEW

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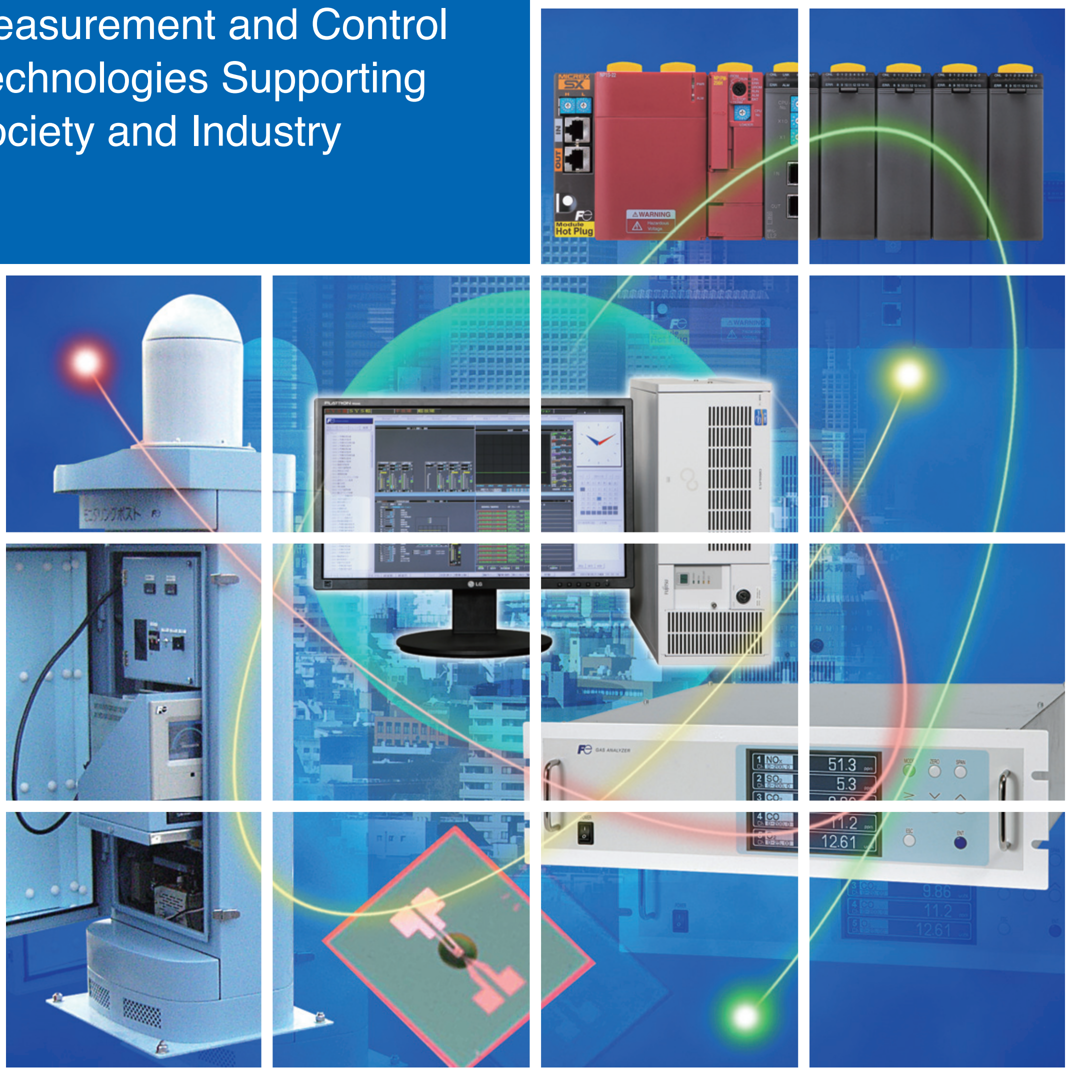
Measurement and Control Technologies Supporting Society and Industry



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1

2012 VOL.58

Measurement and Control Technologies Supporting Society and Industry

CONTENTS

Measurement and Control Technologies Supporting Society and Industry

Supplemental Explanation

Cover photo:

With the goal of realizing a sustainable society, the trends toward energy visualization and energy conservation activities are accelerating. Additionally, the establishment of societal safety and security measures that are able to respond to radioactive contamination, environmental fluctuations and the like on a global scale are sought.

For the purpose of energy conservation as well as safety and security in the social environment and manufacturing fields, Fuji Electric has developed and is supplying products that incorporate measurement technology for various types of sensors, visualization technology for energy and the environment, and system technology for monitoring and control.

The cover photo is an image depicting the coordinated support for society and industry provided by gas sensors for field measurement devices, radiation monitoring posts, gas analyzers, programmable controllers for onsite monitoring and control, and higher-order monitoring systems.

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Current Status and Prospects of Measurement and Control Technologies

Kenichi Kurotani † **Yuji Todaka** †

ABSTRACT

In order to realize a safe and reliable sustainable society, measurement and control technologies are essential. Fuji Electric has developed measurement and control technologies in many fields including power, industrial, water treatment, and commercial fields and achieved good results. In accordance with Japan's New Growth Strategy and Basic Energy Plan, as well as global market and technological developments, we are moving forward with technological development focused on energy and environment. The key for these technologies is to create them smarter, safer, and greener. We are pushing forward with approaches for solutions that achieve the optimal service and operation of energy supply, distribution, and up to the demand side, realize energy conservation, resource conservation, and decrease the environmental burden, and that ensure safety and peace-of-mind.

1. Introduction

Fuji Electric has previously developed measurement and control technology for realizing power savings, automation, higher efficiency and higher reliability in public infrastructure for power, transportation, water treatment, etc., in industrial fields such as for steel, chemical, automotive, electrical and electronic equipment, and in consumer fields for buildings, stores, vending machines, automotive devices, etc., and has realized many pioneering achievements. Aiming to realize measurement and control technology that will contribute to solutions to such social challenges as global warming, declining birthrates and aging populations, and the realization of safety and peace-of-mind, and such management challenges as globalization and increasing competitiveness, Fuji Electric is presently advancing technical development with a focus on the fields of energy and the environment. Additionally, in the wake of the Great East Japan Earthquake, Fuji Electric is attempting to initiate new efforts to realize a sustainable society.

This special issue introduces measurement and control technology for realizing energy conservation and societal safety and security, as well as solutions that use this technology. In this paper, Japanese strategic and global technical trends and issues relating to the manufacturing industry and concerning measurement and control technology, as well as the corresponding efforts by Fuji Electric are described.

† Fuji Electric Co., Ltd

2. Trends and Issues for Measurement and Control Technology in The Global Market

2.1 Japan's New Growth Strategy

In June 2010, the Japanese Cabinet approved the "New Growth Strategy: A Scenario for Revitalizing a Strong Japan" consisting of the following seven strategies.

(a) National Environment and energy strategy based on green innovation
(b) National health strategy based on life innovation
(c) Asian economic strategy
(d) National tourism policy and regional revitalization strategy
(e) Science, technology and information communication strategy
(f) Employment and human resources strategy
(g) Financial strategy

Additionally, in order to promote these initiatives effectively, 21 national strategic projects having particularly strong potential to contribute to economic growth were selected. Of these projects, the following are noteworthy for their potential to contribute to measurement and control technology.

(1) Rapid increase in renewable energy due to adoption of "feed-in tariff"
(2) "Future Environmental City" concept

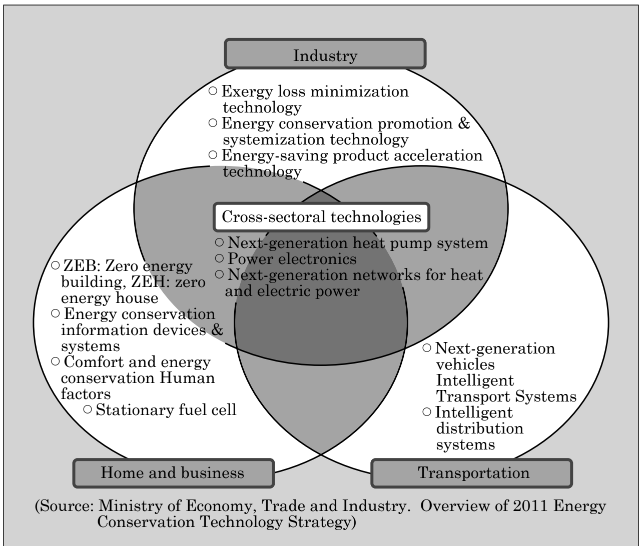
2.2 2011 Basic Energy Plan and Energy Conservation Technology Strategy

In June 2010, a comprehensive review of Japan's Basic Energy Plan was conducted. However, further review is necessary in light of the Great East Japan Earthquake and the accident that it caused at the Fukushima Daiichi Nuclear Power Station. In addition to the basic energy policy of the "3Es" (energy security, environmental protection (global warming prevention), and efficient supply), policies for realizing economic growth centered on energy and for restructuring the energy industry have been newly added. Also, increasing the percentage of self-supplied energy and in the percentage of zero-emission power sources*1, maintaining and strengthening the world's highest level of energy utilization efficiency in the industrial sector, and the like have been set as targets for the year 2030.

In March 2011, the Japanese Natural Resources and Energy Agency established the "2011 Energy Conservation Technology Strategy," which identifies key fields that contribute significantly to energy conservation, an important element of the Basic Energy Plan[4]. Based on a review of all aspects of the previous strategy, policies that exhibit a significant energy conservation effect as a result of the systematizing of various technologies, technologies that contribute to the manufacture and dissemination of products having an extremely high energy conserving effect when used, policies that pursue the development of energy conservation from entirely new perspectives etc. were identified to enable energy conservation from unconventional viewpoints.

Moreover, among the important technologies shown in Fig. 1, in addition to the technologies shown in the industrial sector, home and business sector and transportation sector, power electronics technology, such as high-efficient inverters, and next-generation network technology for thermal and electric power, such as a next-generation energy management system (EMS) for optimizing the regional usage of energy, are cited as technologies that span across sectors, and are expected to contribute with measurement and control technology.

*1: Zero-emission power source: A power source originating from nuclear power or renewable energy such as solar, wind, geothermal, or biomass power.



(Source: Ministry of Economy, Trade and Industry. Overview of 2011 Energy Conservation Technology Strategy)

Fig.1 Key technologies in the 2011: Energy Conservation Technology Strategy

2.3 Trends of measurement and control technologies

Recent trends of measurement and control technologies in the global market are discussed below.

(1) International standardization

Standardization of energy and industrial processes in the measurement and control field is actively being advanced mainly by International Electrotechnical Commission (IEC) standards such as TC8, TC59, T65 and TC95. International standardization is also actively being pursued from the perspectives of electronics, networking, wireless systems for industrial automation, and systems. Smart grid support is actively being advanced primarily by National Institute of Standards and Technology (NIST) in the US in conjunction with IEC. Standardization of wireless systems for industrial automation is being advanced through Wireless-HART from the HART Communication Foundation and SP100 from the International Society of Automation (ISA). As a method of local communication for the remote reading of gas meters, Japan has proposed a multistage radio relay method based on IEEE 802.15.4 g. For the safety of machinery and equipment, standardization in various fields and devices is being advanced with ISO 12100 (machinery safety) and IEC 61508 (functional safety of electrical systems) positioned as upper-level standards, and safety instrumented systems and the like are being introduced in Japan.

For EMS, standardization similar to that of ISO 9000 for quality management and ISO 14000 for environmental management was promoted, and went into effect as ISO 50001 in June 2011.

(2) Sensor technology

From the perspective of safety and security in response to a major earthquake or accident, radiation dosimeters, seismographs and gas detectors, and the like have attracted attention. Additionally, from the perspective of addressing global warming and environmental issues, electric power smart meters, and exhaust gas analyzers for plants and incinerators have also attracted attention. On the other hand, in order to simplify installation and maintenance, long-term and maintenance-free operation with wireless sensors and batteries or self-supplied power are required. To achieve these goals, micro electro mechanical systems (MEMS) (see "Supplemental explanation 1" on page 46) technology is used to achieve miniaturization and power savings.

(3) Control technology

Since the 1990s, model predictive control, neural networks, optimization technology and the like, together with information technology, have been applied to home appliances, automobiles and other such products in industry and society, and have contributed significantly to improved control performance and energy conservation. On the other hand, due to sluggish demand stemming from the collapse of Lehman Brothers, production systems are desired to have the capability to respond to fluctuations in production volume at low cost. As a means for realizing this, the proper adjustment and use of PID controller parameters, together with methods for control performance monitoring, modeling in a closed loop and parameter adjustment are again attracting attention.

(4) Smart grid and smart community technology

Smart grids got their start as next-generation transmission and distribution networks that utilize information and communication technologies. This concept has been extended to the creation of eco-friendly urban spaces (smart communities and smart cities) enabled by smarter electric power, as well as a smarter overall public infrastructure of heat, gas, water, etc. Field tests are being carried out in Japan in such cities as Kitakyushu and Yokohama. Funded by investments that are a magnitude of order larger, smart grid and smart community projects overseas in China, India and the Middle East are moving forward as part of new urban development.

In preparation for a rapid increase in the adoption of distributed power sources such as solar power and wind power in the future, measurement sensors for the fine-grained control of power distribution systems, control technology for control terminals and next-generation power distribution systems, as well as a cluster energy management system (CEMS) regional level energy management system are being developed.

(5) Energy management system (EMS)

Efforts aimed at introducing renewable energy such as solar power and realizing energy savings are progressing. To realize such goals, the overall energy supply and demand must be managed and operated integrally or in a concerted manner, and EMS fulfills that role. In addition to the conventional types of EMS for building and factories, i.e., building EMS (BEMS) and factory EMS (FEMS), development is being advanced for specific applications such as CEMS at the regional level, retail EMS (REMS) for retail distribution, home EMS (HEMS) for homes, etc.

2.4 Changes in the business environment and challenges

Recent changes in the business environment for Fuji Electric's customers, especially in the manufacturing industry, and the accompanying major challenges and needs are described below.

(1) Support of sustainable environment and society

In addition to the energy conservation initiatives traditionally promoted in order to mitigate global warming, even further power conservation is required in Japan. Specifically, in the summer of 2011, each customer within the Tokyo and Tohoku Electric Power service areas was requested to reduce their maximum power consumption by 15% compared to the year 2010. Equipment and device miniaturization and power conservation, which have be promoted previously, the continuous monitoring and improvement of operating efficiency, and the efficient operation of privately owned power generation facilities, including peak shifting and utilization of new energy sources, have become necessary. Moreover, in consideration of new reconstruction in the Tohoku region, efforts must be made to realize a sustainable society rather than merely implement temporary measures. As an effective means for popularizing electric vehicles and plug-in hybrid vehicles (PHVs), there is also a need to move ahead with safe and highly efficient vehicle-side drive control technology as well as establishment of infrastructure such as rapid charging stations. From the environmental perspective, measurement of low concentrations and trace components in gas emissions and waste water from businesses is needed in order to comply with hazardous substance regulations (air pollution, water quality pollution, RoHS*[2], REACH*[3], etc.).

(2) Ensuring high reliability and safety

Field equipment is becoming more and more complex and sophisticated. Meanwhile, in Japan and other developed countries, the experts who carry out field work are aging and retiring one after another, and there is concern about the ability to respond in the event of emergencies. Therefore, equipment is required to be highly reliable and safe, and operation support technology for the early detection of signs of abnormalities, estimation of the service life of facilities and equipment, and so on is anticipated so that preventative measures can be implemented before a failure occurs. Furthermore, in addition to traditional reliability, system availability must be improved, and design technology for enhanced fault-tolerance, earthquake resistance and the like is required. Moreover, tasks must be simplified so that new workers can engage in their work after receiving only short-term training, and facilities and equipment that are safe and can be operated easily even by non-experts are needed. To attain these goals, ensuring safety by providing intelligent functions such as self-diagnosis and functional safety on the equipment side for assisting workers and by monitoring their health and state of consciousness is required.

(3) Support of flexible manufacturing systems

Because of reduced demand and a supply shortage of raw materials and electrical power, the manufacturing industry is being forced to cut back on production or to transfer the production to other sites. Manufacturing facilities and operational control are often designed on the assumption of maximum production

*2: RoHS directive: EU (European Union) restriction on the use of certain hazardous substances in electrical and electronic equipment

*3: REACH: EU (European Union) regulation concerning the registration, evaluation, authorization and restriction of chemicals volume, and if the production volume is limited, energy efficiency may decrease, and the control system stability and control accuracy may not be maintained. In situations with an uncertain outlook, a measurement and control system that supports a flexible production system and that is stable and has hassle-free maintenance is required. Furthermore, production sites and production lines must be able to be built, modified and moved quickly and at minimal cost. For this reason, equipment modularity, generalization and portability are advancing trends. For this purpose, field devices that use less wiring or that are provided with wireless capability, and devices having a plug-and-play function enabling operation simply by connecting equipment are required.

(4) Support of a global business environment

In the manufacturing industry, products designed for key markets must to be supplied to those markets in a timely manner, and the locating of production sites, development sites and business sites near the desired markets is a progressing trend. On the other hand, there is an ongoing trend of production sites being consolidated in countries and regions having low costs, such as low labor cost. In response, technology for the integrated management of distributed sites, global supply chain management, security, the protection of intellectual property and the like has become important. Additionally, because of the intermixing of workers of different cultures, work standardization and work history management must be performed on the basis of a mutual understanding and respect of different cultures, and worksite equipment must be designed with greater levels of safety than in the past.

3. Fuji Electric's Efforts in Measurement and Control Technology

In response to the challenges described in section 2, future measurement and control technology is required to provide solutions that contribute to improving management competitiveness through "visualizing" processes and production, and realizing operation that is "more comfortable, conserves energy and is safe." The trend toward physically distributed and autonomous devices and components is progressing, and meanwhile, system standardization and a seamlessly integrated environment from the perspective of engineering services are required. In accord with these factors, as shown in Fig. 2, Fuji Electric is moving ahead with technical development and product commercialization by working to enhance smartness, safety, and greenness.

Enhanced smartness means to make devices that are smaller and that consume less power, as well as to increase the efficiency of advanced information processing functions for optimal plant operation and the like, and to increase the business and operating efficiency. Enhanced safety can be realized through efforts to ensure safety and security by supplying a functional safety system that supports high reliability design, fault tolerance, and international standards. Enhanced greenness is an eco-friendly initiative that involves the measurement of energy and environmental impact, and efforts to realize energy conservation, resource conservation, and so on. These development and commercialization efforts will be realized based

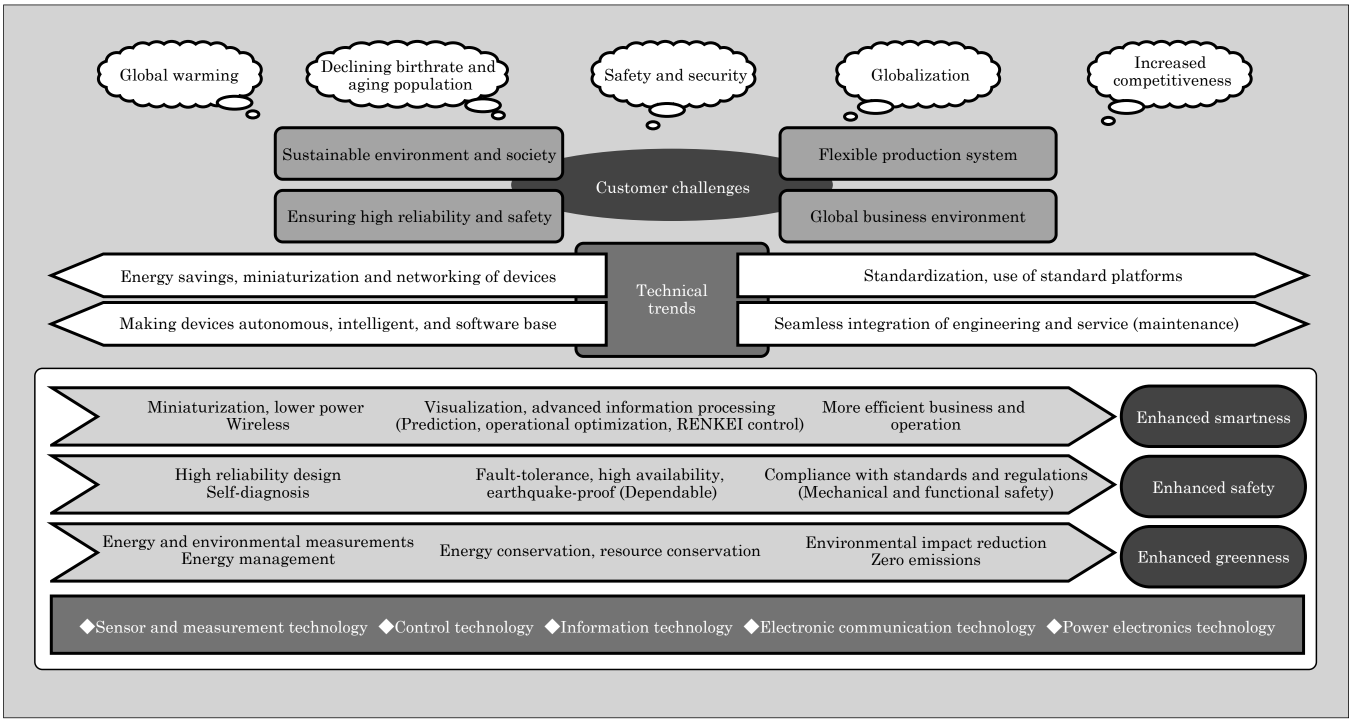


Fig.2 Fuji Electric's targeted measurement and control technology

not only upon sensor and measurement technology and control technology, but also on core technologies such as information technology, electronic communication technology and power electronics technology.

As shown in Fig. 3, Fuji Electric's business areas can be divided into the following three regions: an energy supply (energy creation) side for geothermal power plants, fuel cells and the like; a demand (energy conservation) side for steel, electronic device, machine, food, and chemical industrial fields, retail distribution, internet data centers (IDCs) and the like, and; a distribution side (connection) for linking the supply and demand sides. Product development for optimal and safe operation, extending from the energy supply side to the distribution and demand sides, and for realizing solutions focused on energy conservation, resource conservation and reduced environmental impact is being advanced at each hierarchical level, from devices and modules to component productions, system products and solution products. Additionally, efforts for achieving a "global Fuji Electric" are being advanced more than ever before. In pursuit of "glocal" development that meets the needs of local regions worldwide (globally), Fuji Electric has established development sites in China, the US and Europe to enhance local development.

Specific examples of these efforts are described below.

3.1 Sensor technology

MEMS devices are an effective means for realizing power savings and resource savings in the sensors and actuators used to constitute control systems. Fuji Electric has long been committed to MEMS technology, and has developed and commercialized such products as measurement devices, radiation dosimeters, gas analyzers and the like that incorporate MEMS technology. Recently, Fuji Electric has been working on the development of high-speed and high-sensitivity multi-component gas analyzers, battery-operated methane sensors that can be incorporated into gas alarm unit, high performance vibration sensors for detecting abnormalities or signs thereof in buildings and for diagnosing the integrity of those structures, and vehicle-mounted pressure sensors for use in various types of control applications, and has achieved significant success in realizing miniaturization and power savings.

In the field of radiation measurement, based on case studies at nuclear power plants, an earthquake-proof body surface contamination monitor that will continue to operate even in the case of a magnitude 7 earthquake has been developed in order to ensure greater safety. This device has been installed at the boundaries of radiation controlled areas in nuclear power plants, and measures the surface contamination of radioactive material on the body of a worker exiting the controlled area. Furthermore, for the environmental radiation monitoring equipment, various emergency measures are being implemented so as to allow monitoring and measuring operations to continue even when an earthquake occurs. Also, in recent years, management of pipe wall thickness has become necessary in order to ensure stable operation at power plants, and Fuji Electric has developed a new radiation transmitting-type pipe thickness measurement system. This pipe thickness measurement system utilizes a 3-beam calculation method to improve the measurement performance, and is able to measure a thickness profile through heat insulating material.

3.2 Control technology

Control technologies that perform optimization and

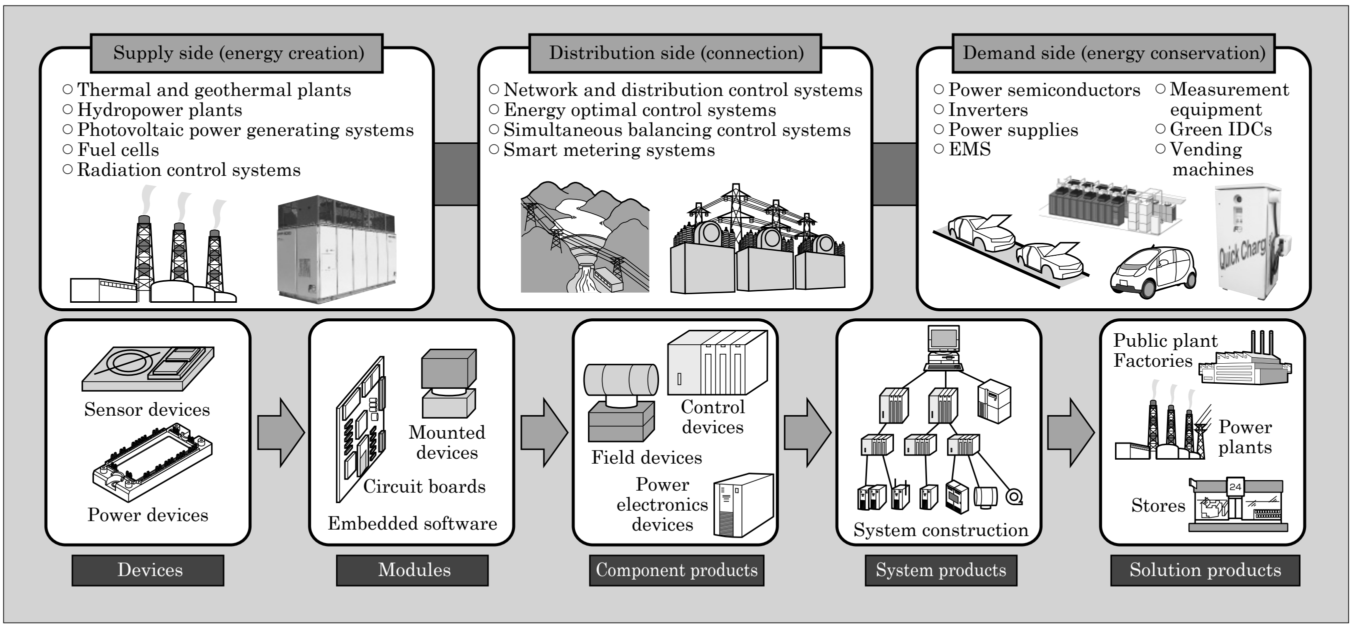


Fig.3 Energy and environment business areas and product hierarchy

that make predictions and diagnoses are core technologies for realizing energy savings and enhanced safety in equipment and plants. Fuji Electric has been engaged in the development of such control technologies for many years as core technologies. Among these, Fuji Electric has focused on PID control technology for single-input, single-output systems, model predictive control technology for multivariable systems, neural network technology for predictive and diagnostic applications, multivariate statistical process control technology, and nonlinear optimization technology for optimizing large-scale complex problems such as power networks. For model predictive control, even further improvement in control performance was realized by implementing the control in a programmable logic controller (PLC) so that the control can be used in applications requiring long-term stable operation, and by employing an external disturbance rejection method using an observer. Moreover, many control systems are said to exhibit control performance degradation and a lack of adjustment due to changes in the characteristics of the controlled object, and in response Fuji Electric has also developed a control performance monitoring function.

3.3 Monitoring and control system

Fuji Electric has delivered its "MICREX-NX" distributed monitoring and control system for medium and large-scale applications to many plants, including steel mills, water treatment plants, chemical plants, etc. With the MICREX-NX, safety instrumented functions and general instrumented functions can be mixed on the same controller and engineering tools. Using this feature, a safety instrumented system for a gas production plant has been built and delivered.

To lower the cost for small and medium-scale applications, Fuji Electric has developed the "MICREX-VieW," a common platform for monitoring and control. With an emphasis on ensuring compatibility with preexisting monitoring and control systems made by Fuji Electric, the MICREX-VieW has been designed as a system that inherits the various assets of existing systems. Moreover, redundancy of the operator stations, databases, control LANs, controllers, I/O units and other various devices that constitute the system is also possible individually. Thus, not only can a highly reliable system be newly constructed, but a system can also be updated gradually in stages with a flexible configuration. For small-scale applications, Fuji Electric has also developed the "MICREX-VieW Compact" system that combines a general-purpose PLC and a programmable display. By generating programs from control function specifications such as instrumentation flow diagrams and logic diagrams created with Visio*4 office automation software, these monitoring and control systems can realize an integrated environment that facilitates engineering work.

In the field of machinery control, which includes control for steel rolling mills, metal processing, printing, packing and the like, high-speed, high-accuracy multi-axis synchronous control systems are required. To realize such drive solutions with a general-purpose PLC, Fuji Electric has developed the "E-SX bus," a proprietary network that enables high-speed, high-accuracy multi-axis synchronous control and large capacity I/O control, and also the "SPH3000MM," a new high-speed CPU module equipped with the E-SX bus.

3.4 Wireless communication technology

For wireless technology, Fuji Electric established a platform that facilitates the development and construction of wireless systems that conform to the ISA 100.11a wireless standard for process automation. ISA 100.11a is a wireless networking standard that combines the highly reliable performance and real-time performance essential in industrial environments. A wireless network system conforming to this standard can be installed at locations in factories or plants where a wired network would be difficult to construct, and may be used for temporary installations during construction or for testing, thereby enabling systems to be constructed with an increased degree of freedom.

Smart metering technology is an important factor for realizing smart communities. Based on technology developed for electric energy meters and remote metering system, smart metering technology capable of bidirectional communication between electric utilities or gas companies and individual consumers is being developed by Fuji Electric. As wireless communication technology for smart metering, a method for multi-stage relay wireless operation with ultra-low power consumption for long-term battery-powered operation has been developed. This method is being advanced for international standardization as IEEE 802.15.4 g.

3.5 EMS platform

Fuji Electric has previously developed EMSs for various uses in the fields of electric power, steel mills, water treatment, retail distribution and so on. A platform that integrates these EMSs of different fields so that CEMS, FEMS, BEMS and REMS can be used with a common mechanism to construct systems efficiently has recently been developed. Through handling various energy models for electric power, heat, gas and the like, this platform enables visualization, energy management and energy conservation RENKEI control. The Web screen supports multiple languages, and systems ranging in size from small-scale systems of a single server to large-scale systems of several tens of servers can be constructed with the same engineering tools.

*4: Visio is a trademark or registered trademark of Microsoft Corporation and its affiliates.

4. Future Outlook

Needless to say, the importance of using renewable energy and of conserving energy will continue to increase in the future, and measurement and control technology will play a large role in the effective and safe implementation thereof.

In present-day measurement and control systems, the integration of engineering is progressing but the engineering work as well as operation and maintenance work still impose a large burden. Development is underway to realize the following types of functions in next-generation systems.

(a) Functionality that, in addition to measuring an object or system to be controlled, also performs data consolidation, and provides easy-to-understand directions without a difficult operation (improved visualization and operating ease in next-generation equipment)
(b) Ability to add, modify and automatically setup devices and functions while the system is running (plug-and-play functionality)
(c) Wireless and self-powered sensors and measurement devices
(d) Control scheme that does not require re-adjustment (maintenance-free control)
(e) Intellectual property protection of software assets, including embedded software

5. Postscript

Fuji Electric's efforts and outlook for measurement and control technology have been described herein based on Japan's strategies for growth and technology relating to energy and the environment, and on global market and technological trends.

To mitigate global warming, a reduction in CO_2 equivalent greenhouse gas emissions worldwide to at least 50% of 1990 levels is needed by 2050. In response to the accident at the Fukushima Daiichi Nuclear Power Plant, each nation is changing their approach to nuclear power and cannot continue with an extension of their current efforts. New measures and policies, including a review of our current lifestyles, must be carried out in order to realize these aims.

With measurement and control technology positioned as a supporting pillar of our energy and environmental business, Fuji Electric intends to contribute to the realization of a safe and secure sustainable society.

Energy Management Solutions to Support Energy Conservation Activities

Naoki Azumaya † **Donghui Xiang** † **Naoto Tatta** †

ABSTRACT

The energy environment that surrounds Japanese businesses is becoming increasingly severe with demands for reductions in energy consumption. Environmental improvements that make day-to-day and continuous energy management possible have become necessary. In order to resolve the many issues that reside in the current state of energy management systems, Fuji Electric is working on energy management solutions that take into consideration both the supply side and the demand side. Energy analysis templates and the energy conservation navigation function based on the MainGATE/PPA process performance analysis package improve operation systems. The energy conservation operation framework contributes to improvements in the customer energy conservation work process.

1. Introduction

With the revision of the "Law Concerning the Rational Use of Energy" (Energy Conservation Law) and the strengthening of regulation and standards such as ISO 50001, an international standard for energy management issued in June 2011, as well as concerns about medium-term tightness in the supply and demand of energy due to a revised national energy policy resulting from the effects of the Great East Japan Earthquake, Japanese companies find themselves surrounded by an environment of increasing demands for lower energy consumption and peak shifting of energy usage.

In the efforts to reduce and peak-shift the energy consumption by companies, limits are already being seen in the effectiveness of individual and local measures, and corporate management needs to be challenged to provide a company-wide environment that supports daily and continuous energy management and improvement.

Among the various energy conservation activities and techniques, this paper focuses on energy management and energy conservation analysis, and categorizes the present challenges. As solutions to overcome these challenges, a framework for energy management solutions provided by Fuji Electric and a newly developed push-type information delivery function known as "energy conservation navigation" are introduced herein.

2. Challenges Facing Energy Conservation Activities

"Energy management" is attracting attention as a key word for energy conservation activities. Table 1 summarizes recommended improvements that were submitted to the Energy Conservation Center, Japan in response to plant energy audits from 1997 through 2005 for various companies. "General management" (mainly energy management) is the most common recommendation, and accounts for one-third of the total. Moreover, if facility operation management, reference value management and the like are included, the improvement recommendations account for more than eighty-percent of the total.

In regards to recent "energy management" activities, attention is focused on the collection of energy supply and consumption data, and on the provision of an information infrastructure to analyze energy savings using that collected data.

It is often observed, however, that the essential energy data cannot be collected, or that the energy data is collected but the various information from measurement values is left as raw data, and is not fully utilized in actual energy conservation management and energy conservation analysis.

In order to improve this situation, solutions are needed to overcome the following three main challenges.

(1) Interdepartmental integrated energy management (1st challenge)

Energy management is typically overseen by an equipment prime mover department that is involved with the energy supply-side, and so the energy management is not integrated with the manufacturing department, business department and the like on the energy demand-side. There is a need for bidirectional integrated supply-demand energy management and energy conservation activities such as energy demand-side operation that is aware of the supply side, and conversely, optimal supply operation whereby the en-

† Fuji Electric Co., Ltd.

ergy supply-side is aware of load fluctuations. With energy management based solely on energy data, this challenge would be difficult to resolve, but by implementing management in accordance with the operating state of the facility and the manufacturing conditions at the energy load-side, effective energy management

Table 1 Recommended improvements based on plant energy conservation audits

Recommended improvement items	Percentage to total number of recommended improvements
General maintenance (5,393 items)	(33.6%)
Energy management system	7.0%
Measurement and recording implementation status	6.1%
Management of amount of energy usage	5.8%
Energy specific unit management of main products	5.2%
Management of device maintenance	4.4%
Load leveling measures	3.2%
Process improvement	1.9%
Air conditioning & refrigeration equipment (2,200 items)	(13.7%)
Energy conservation measures	5.2%
Management of air conditioning & refrigeration equipment operation	5.0%
Management of cooling equipment operation	1.6%
Management of auxiliary operation	1.4%
Cold storage & refrigerating equipment	0.5%
Pumps, fans, etc. (2,249 items)	(14.0%)
Management of pneumatic equipment operation	8.1%
Management of pump & fan operation	4.1%
Installation plans for cogeneration, etc.	1.8%
Boiler, industrial furnace, steam system, etc. (2,830 items)	(17.6%)
Management of boiler & industrial furnace combustion	3.4%
Heat insulation, heat retention and prevention of heat dissipation	2.4%
Management of boiler & industrial furnace operation and efficiency	2.4%
Exhaust gas temperature control, Waste heat recovery	2.3%
Utilization of steam drain recovery	1.9%
Management of steam leaks & heat retention	1.8%
Steam operation management	1.1%
Utilization of waste heat & waste water	1.0%
Optimization of steam piping system	0.6%
Management of heat exchanger operation	0.5%
Load leveling of the steam system	0.2%
Lighting, electrical equipment, etc. (3,380 items)	(21.1%)
Management of lighting equipment operation	6.8%
Management of power receiving facility	5.5%
Management of transforming facility	4.2%
Management of electric motor capacity & operation	3.0%
Management of electric heating equipment and operation	1.6%

(Source: Guidebook on Energy Conservation for Factories. The Energy Conservation Center, Japan)

for improving the energy conservation activities becomes possible.

At the stage in which information sharing and total optimization have not yet been implemented among the various departments, measures are needed uppermost to enable energy management that is aware of the energy load-side and to enable improvement activities.

(2) Creation of mechanism for operation and evaluation directly linked to improvement (2nd challenge)

At the stage in which energy data management is performed on a daily basis but a great deal of time is spent performing that data management, and the energy conservation analysis results and managed data are not yet effectively used for improvement, the creation of a mechanism for operation and evaluation that is directly linked to improvement is needed.

(3) Establishment of business processes for energy conservation activities (3rd challenge)

The collection of energy data has been made easier as a result of advances in measurement technology. The construction of an information system for collecting data will establish a means for energy management, the ultimate objective of which to cycle through the PDCA {Plan (to set targets), Do (to improve), Check (to evaluate), Action (to reconsider)} cycle as part of daily work. The establishment of a method for analyzing the collected data and work processes for energy conservation activities are becoming increasingly important.

3. Fuji Electric's Energy Management

To realize optimal energy management, energy management that visualizes the challenges (performs a factor analysis of the results) involved in integrating energy supply and demand (Fig. 1), and a PDCA cycle for an energy conservation improvement activity process are important. Through constructing an optimal energy management infrastructure, a "mechanism

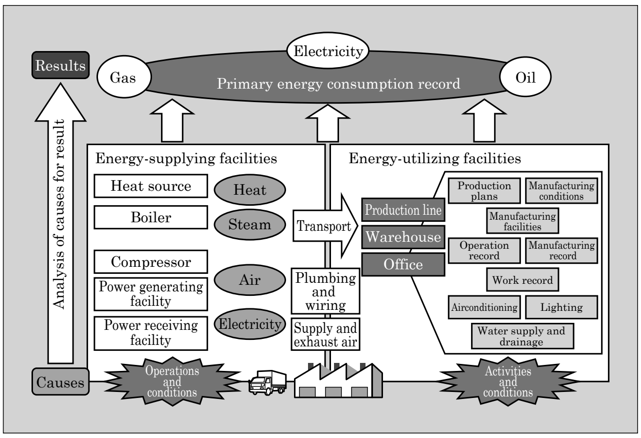


Fig.1 Fuji Electric's "energy management that visualizes challenges"

capable of predictive planning" and a "mechanism capable of carrying out activities" can be provided. The construction of a mechanism for optimal energy management leads to a "visualization of challenges" for energy conservation and countermeasures, and allows the correction of production activities, leading to improved energy operation and energy conservation in accordance with the particular challenge, and the adoption of energy saving devices and control technology, thereby enabling effective evaluations and corrective actions that can be incorporated into daily and regular cyclic energy conservation activities.

In order to realize "energy management that visualizes challenges," Fuji Electric provides an energy management system (EMS) that uses the "MainGATE/PPA" process performance analysis support package.

For the manufacturing industry, the ability to organically combine energy measurement data with operation information about utility facilities and production facilities, production volume, and other manufacturing information, and to perform energy analyses is a major advantage of this system. Moreover, this system can also be used in energy analyses for heat sources, transport dynamics, lighting, electric outlets, air conditioning, and the like for building energy management systems (BEMS) as well.

Moreover, based on the knowledge Fuji Electric has acquired from many years of experience in EMS construction, an "energy analysis template" can be used to construct such a system easily.

For the 1st challenge described above in section 2, Fuji Electric has utilized "energy analysis templates" and MainGATE to realize better visibility of energy management and energy conservation improvement issues with integrated energy supply and demand. For the 2nd challenge, Fuji Electric has developed an "energy conservation function" as a MainGATE add-on function, and has constructed a mechanism for improved operation that directly addresses the challenges. Additionally, for the 3rd challenge, Fuji has prepared an "energy conservation operational framework" that aims to improve customer energy conservation work processes.

3.1 Energy analysis templates

Energy analysis templates support energy conservation in terms of the three perspectives of "energy consumption analysis," "facility/system control analysis" and "facility/system performance analysis" in order to spiral up energy conservation activities. By systematizing the work sequence and points to be visualized in the course of carrying out the management, the templates help to visualize the energy management work processes.

(1) Energy consumption analysis

By organizing energy management flow diagrams from various perspectives, such as energy summaries for each hierarchical layer and summaries for each application (area, process, facility), and by analyzing each load pattern and the energy share of each load time interval, important targets that promise to exhibit a large improvement effect can be identified. Templates for this use are provided.

(2) Facility/system control analysis

Comparative analysis of the energy status of important targets and their respective operating states can lead to improvement of the important targets. Templates for reassessing operation control according to the load, reviewing optimal control methods, and the like are provided in order to transition from individual optimization to total optimization.

(3) Facility/system performance analysis

Through visualizing key performance indicators (KPI) such as the standalone operating efficiency of energy supply facility and the system efficiency of group control facility, the operation of facility having high standalone operating efficiency can be prioritized so as to lead to an improvement in total system efficiency. Templates are also provided that enable the continuous analysis of production volume fluctuations and energy consumption as a result of specific energy consumption (see Supplemental Explanation 2 on page 46) management on the energy usage-side.

Energy analysis templates from these three perspectives are interrelated and are incorporated in Fuji Electric's "MainGATE/PPA" energy management system. "Energy consumption analysis" enables the user to focus on problem locations, "facility/system control analysis" enables identification of factors that contribute to the problems and "facility/system performance analysis" enables operation evaluation directly linked to improvement.

Through activities based on these perspectives, energy conservation activities can be enhanced. Fig. 2 shows examples of the energy analysis templates.

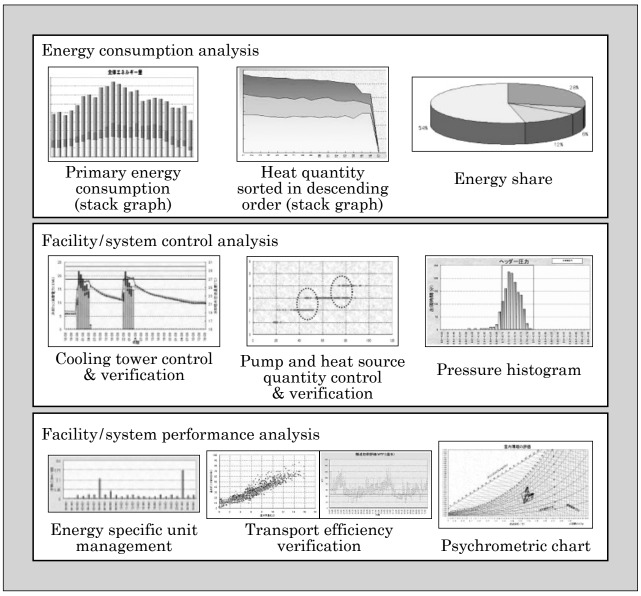


Fig.2 Examples of energy analysis template

Additionally, the MainGATE/PPA package was developed based upon the concept of EUC (end user computing), and when installed, it facilitates the addition of content and performance of maintenance by end users themselves, and provides powerful support for continuous energy conservation activities in accordance with the "energy analysis templates."

3.2 Energy conservation navigation function

To date, Fuji Electric has utilized energy analytic techniques and the MainGATE/PPA from the three perspectives of "energy consumption analysis," "facility/system control analysis" and "facility/system performance analysis" to provide customers with solutions for improving their energy conservation activity cycles. However, there are limits to the human resources and time resources that customers have available for analytic work, and in recent years, in order to discover additional energy conserving items, an environment that supports more efficient energy conservation analysis is sought.

In response to such customer needs, an analysis support environment known as the "energy conservation navigation function" has been developed as an add-on feature to the MainGATE/PPA. This energy conservation navigation function allows relevant energy conservation knowledge of experienced energy managers to be shared and the analytic workload to be streamlined.

(1) Concept

The energy conservation navigation function periodically monitors the status of energy supply and demand in terms of the three perspectives described above in section 3.1, and configures "scenarios" that lead to "awareness" of the relevant issues and that are used to discover energy conservation issues automatically.

Through performing scenario monitoring in real-time, energy consumption factors such as facility deterioration and abnormal behavior, load fluctuation factors, control factors, external factors can be detected in a timely manner, and the energy utilization state can be improved.

In a number of scenarios, in the case of specific energy consumption management, for example, the specific energy consumption may be affected by the operation of energy-consuming facility that exhibits energy usage characteristics uncorrelated to fluctuations in production volume, and by work fluctuations due to human intervention.

The energy conservation navigation function can be used to register scenarios related to the specific energy consumption so that the correlation between the specific energy consumption and the operation state of fasility can be monitored. By automatically specifying the point in time when the specific energy consumption becomes greater than the average value, and then extracting the facility operation status during that same time band, facility that degrades the specific energy consumption and that does not contribute to the production can be identified. Based on the findings of the energy conservation analysis, scenarios for which automatic monitoring is possible can be organized and registered so that facility operation states can be suggested with awareness of the appropriate energy utilization for the manufacturing floor.

(2) Functions

The energy conservation function is an add-on to the MainGATE/PPA, and consists primarily of the following two functions. Fig. 3 shows the relationship among energy conservation functions.

(a) Scenario selection and registration function

With the scenario selection and registration function, a scenario is selected from a list of scenario judgment logic (specific energy consumption evaluation, efficiency evaluation, system loss, comparative judgment, management curve, etc.), and condition setting and management data registration can be carried out according to the selected scenario. Two-stage judgment level settings, reminder messages that correspond to the level, and e-mail message destinations can be registered.

(b) Periodic scenario monitoring and energy conservation advisory action function

This function performs the real-time monitoring of registered scenarios at an appropriate period, and sends a reminder message if the scenario judgment condition is satisfied. Additionally, this function displays a list of energy conservation advisory actions, and outputs an energy conservation analysis template graph that can be used to specify the energy fluctuation factors corresponding to the scenario. Fig. 4 shows the extraction of outstanding values of the specific energy consumption, and specifies the operation time (fluctuation factor) of fluctuating facility affected by the specific energy consumption.

The energy conservation navigation function, through performing real-time monitoring of a variety of KPI, specific energy consumptions and operation control conditions, and comparing a normal energy supply and demand scenario to the actual re-

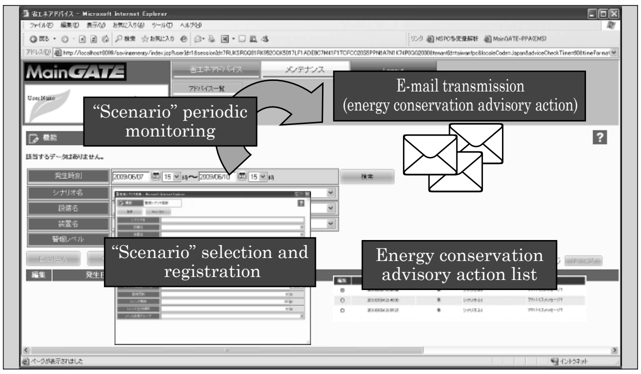


Fig.3 Relationship among energy conservation navigation functions

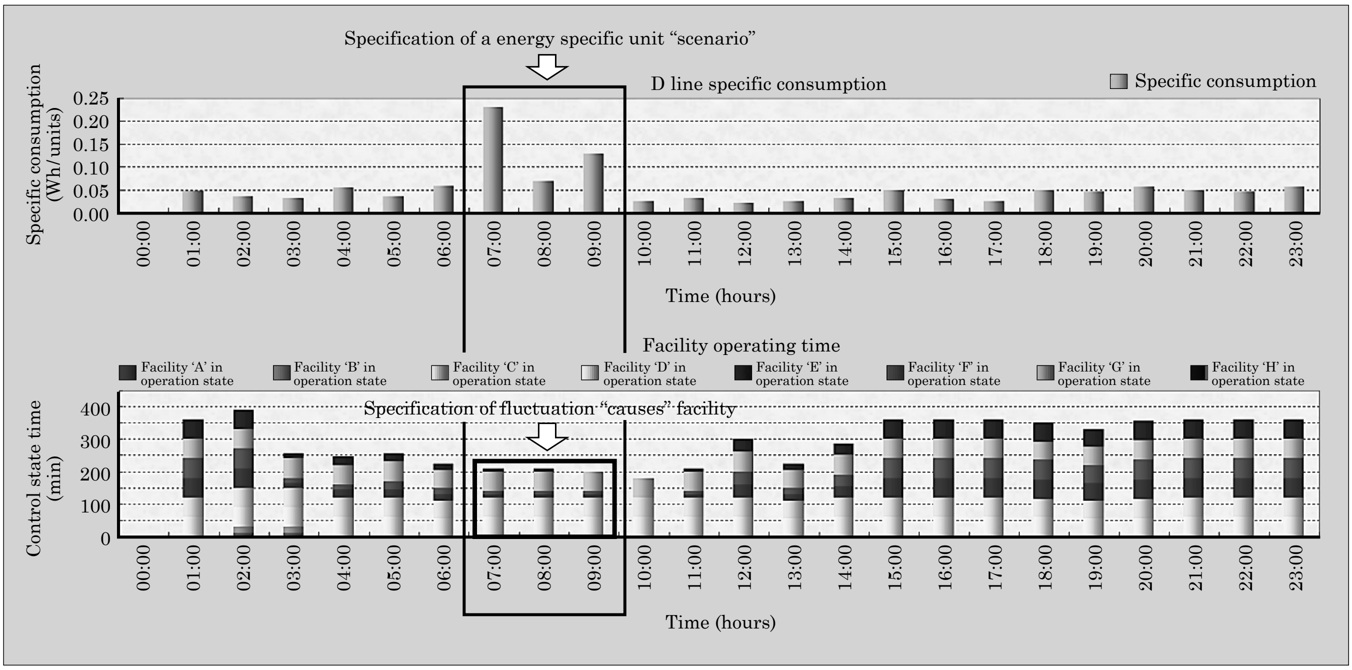


Fig.4 Example of automatic monitoring by energy conservation navigation function

sults, provides energy conservation factors (awareness) and leads to daily improvements.

The various scenarios in the energy conservation navigation function are provided with energy conservation know-how and are also converted into templates, so that they can easily be introduced into customer energy conservation activities.

3.3 Framework for energy-conserving operation

Based on experience in energy conservation and EMS construction, Fuji Electric has systematized the energy analysis templates and energy conservation activity perspectives, management standards, viewpoints and the like, and has entered analysis evaluation specifications into a database to create a database of energy conservation know-how (Fig. 5).

Additionally, based on the workflow of ISO 50001, an international standard for EMS, in each of the various phases of system installation, analysis, revision and so on, customer energy conservation activities and system operation support workflow have been systematized as an energy conservation activity PDCA cycle.

The "energy conservation operational framework" begins with an overall image of the framework, and in accordance with the facility and operation categories shown in Fig. 5, classifies and organizes pre-operation advance preparation materials, perspectives for energy conservation activities, analysis and evaluation specifications that extract effective measurement locations, and examples of energy conservation.

By applying the energy conservation framework to customer energy conservation activity cycles, energy waste can be detected easily and an operation standard for efficient energy management can be provided.

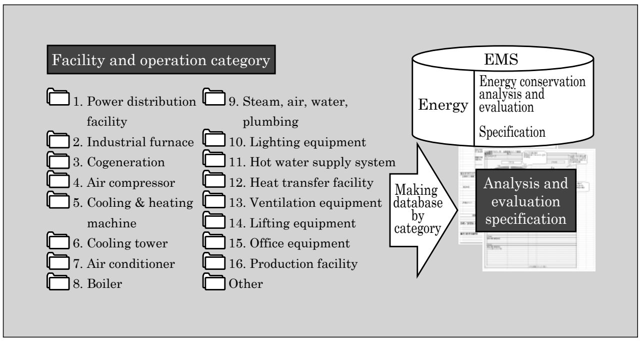


Fig.5 Energy conservation know-how database (Analysis and evaluation specification)

4. Postscript

This paper has introduced Fuji Electric's energy management solutions that support energy conservation activities. Upon this foundation, Fuji Electric aims to build a next-generation EMS that achieves "total optimization of energy supply" and "total optimization of energy consumption" by organically combining renewable energy, electrical storage facilities, heat storage facilities, and utility facilities, for which demand is expected to increase.

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(1) Guidebook on Energy Conservation for Factories. The Energy Conservation Center, Japan, 2008.

“MICREX-VieW” for Small and Medium-scale Monitoring and Control System Platforms in Energy & Environmental Fields

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ABSTRACT

Fuji Electric has supplied distributed monitoring and control systems to various fields. Recently, we have developed the monitoring and control system platform “MICREX-VieW” and its derivative “MICREX-VieW Compact”, which expand the range of applications for small and medium-scale systems and maximize compatibility with our existing systems. They feature high reliability through redundancy, resource inheritance for existing systems, automatic generation of control software by specification definition, and cost performance improvement due to the platform technology. They feature packages and templates for various fields and can be applied to broad fields including power generation plants, garbage incinerator plants, and food plants.

1. Introduction

Fuji Electric has supplied many distributed control systems (DCS) to power plants, petroleum plants, chemical plants, water treatment plants and the like for use in the energy and environmental fields. Fig. 1 shows the product line of distributed control systems provided by Fuji Electric. The “MICREX-NX” DCS provides high reliability through redundancy, and by leveraging its advantageous ability to realize safety instrumented functions and general instrumented functions with the same controller and engineering environment, is increasingly being used in applications to large-scale safety instrumented plants and the like.

Recently, Fuji Electric has developed the “MICREX-VieW” monitoring and control system platform for small and medium-scale applications that provides high reliability and maximizes compatibility with our existing systems.

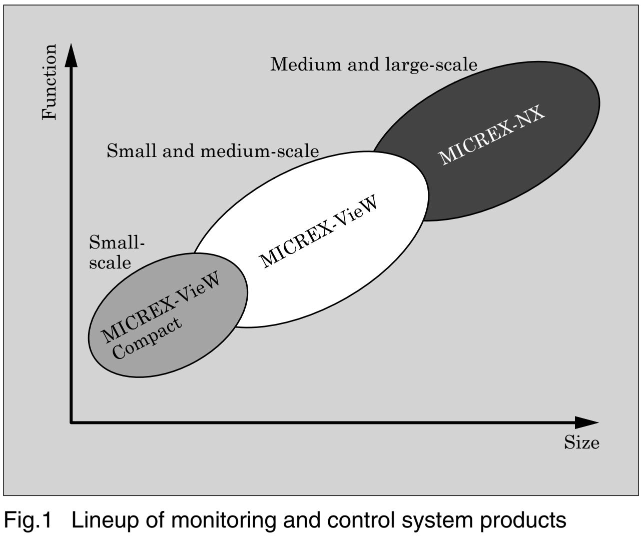

Fig.1 Lineup of monitoring and control system products

† Fuji Electric Co., Ltd.

The MICREX-VieW is a system that realizes high cost-performance by integrating operation and support system platforms and sharing hardware and control software. Additionally, the MICREX-VieW is a sustainable system capable of maintaining and inheriting various assets of existing systems, and flexibly supporting customer plans for equipment updating. For small-scale applications, Fuji Electric has developed the “MICREX-VieW Compact” small-scale monitoring and control system which is based upon the MICREX-VieW and configured from a programmable operation display (POD) and a general-purpose programmable logic control (PLC). This paper introduces features and application examples of the MICREX-VieW, the MICREX-VieW Compact, and their integrated support system.

2. “MICREX-VieW” Small and Medium-Scale Monitoring and Control System Platform

2.1 Overview

The “MICREX-VieW” small and medium-scale monitoring and control system platform targets small to medium-scale plants, and allows redundancy of such components as the controller, network and human machine interface (HMI) to realize an optimal level of high reliability that meets customer needs. Use of the MICREX-VieW at the time of plant updating enables the maximum utilization of customer assets and the updating of plant equipment to be accomplished according to customer needs with the minimum investment. Moreover, in terms of operation and maintenance, the MICREX-VieW enhances plant visualization with minimal engineering cost and reduces the lifecycle cost of the entire plant.

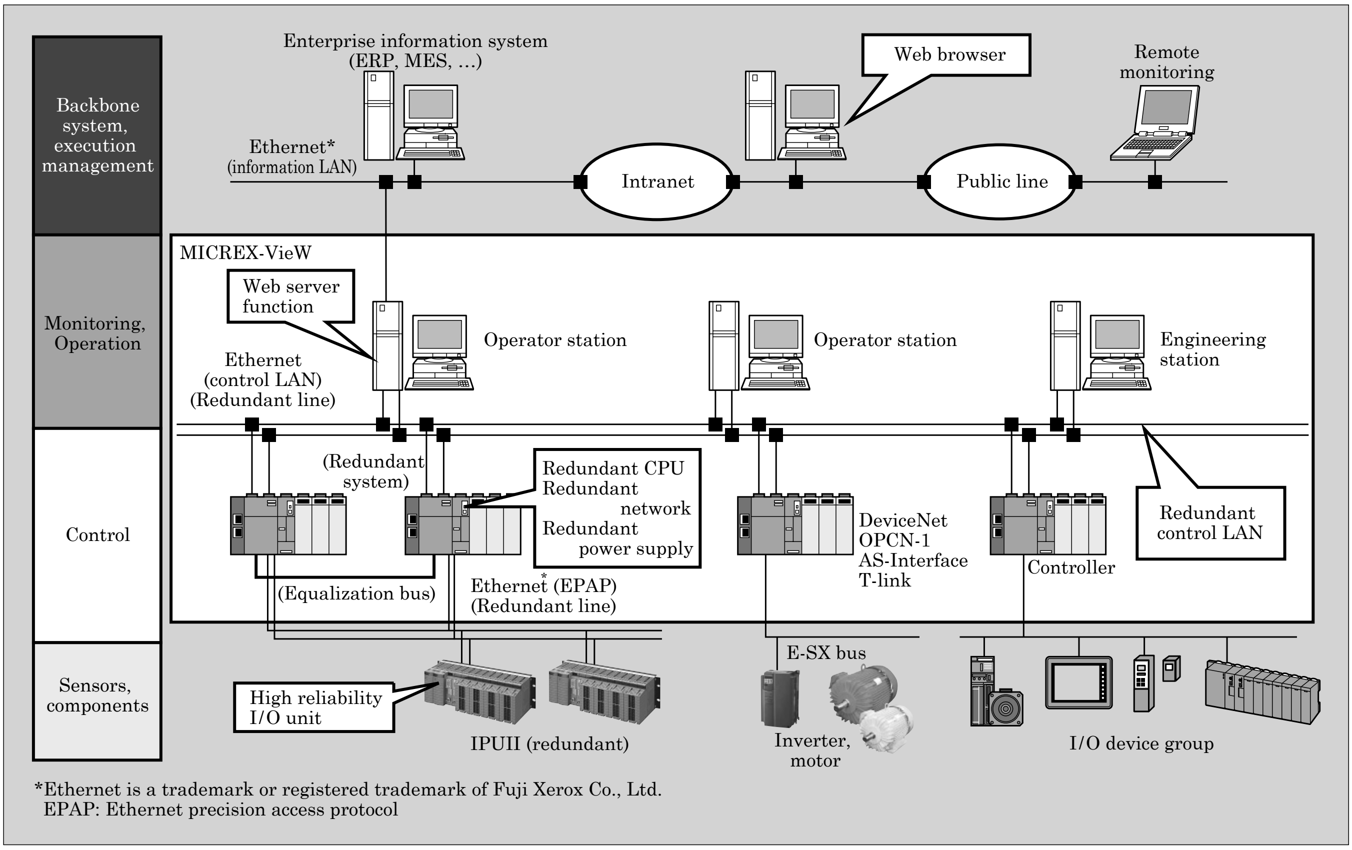

Fig.2 MICREX-VieW system configuration example

2.2 Features

(1) Highly reliable system that supports stable operation

Figure 2 shows an example configuration of the MICREX-VieW system. With the MICREX-VieW, because components such as the operator stations, database, control LAN, controller CPU module, power supply, communication modules, I/O transmission path, I/O unit and the like can be made redundant as necessary, the optimal high reliability system can be built to realize stable operation. Additionally, all component elements of the I/O unit, i.e., the power supply module, bus interface module, internal bus, and I/O module (analog I/O module, digital I/O module) can also be made redundant.

In the case where an I/O module fails, the system can continue to operate while only the failed I/O module is isolated (fail-soft operation), and then after the failed I/O module has been replaced, recovery from the fail-soft operation can be carried out.

(2) Hardware downsizing

The controller unit has combined Fuji Electric's PLC miniaturization and cost-lowering technology with the high reliability and control technology cultivated with DCS. The result is an approximate 70% reduction in size compared to the prior model.

(3) Inheritance of various assets of existing systems

The updating of an existing DCS system is often performed in piecemeal fashion, i.e., in stages according to the schedule of the customer. With the MICREX-VieW, interfaces to existing equipment are available for the HMI, controller and I/O unit so that these new units can be intermixed and used with other various units of an existing system. Accordingly, the HMI, controller and I/O unit can be updated independently in MICREX-VieW without having to modify the existing application software. Thus, updating can be performed in stages, with the HMI updated first, and followed by the controller and finally the I/O unit, for example. The plant monitoring screens of an existing system have typically been created with supervisory control and data acquisition (SCADA) software such as InTouch*1, iFIX*2 and Citect*3, and a single system may have than 100 such screens. The MICREX-VieW is configured such that varieties of SCADA software can be used as add-ins to the HMI platform so that the existing screen software can be ported without modification.

(4) Visualization of equipment operating conditions, interlock, circuit status

*1: InTouch is a trademark or registered trademark of Invensys plc, USA
*2: iFIX is a trademark or registered trademark of General Electric Company, USA
*3: Citect is a trademark or registered trademark of Ci Technologies Pty. Limited, Australia

With Fuji Electric's DCS, equipment operating conditions and sequence conditions can be automatically generated from the control specification into the controller program by using the automatic conversion tool "HEART-BELIEVE." The resulting generated software can be monitored on an engineering station. With the MICREX-VieW, the operating conditions, interlock and circuit state, and the like generated with HEART-BELIEVE can be displayed automatically on an operator station, so that monitoring can be performed as part of the usual operation. Individual monitoring screens can be linked freely from the plant monitoring screen (see Fig. 3).

(5) Visualization from remote location

A remote monitoring function enables the monitoring screen of an operator station to be displayed and operated as-is from an office other than the monitoring room or from an offsite location, thereby making possible the remote visualization of the plant state.

An automatic email sending function can be used to acquire the alarm state and the plant state, thereby making possible unattended operation of the plant. Additionally, through coordinating with remote monitoring at Fuji Electric's call center, trouble can be responded to rapidly.

(6) High-level monitoring and control function

(a) Model predictive control (MPC)

Model predictive control, previously being only realizable on a PC or other dedicated device, has been implemented in the controller of the MICREX-VieW. As a result, MPC is easier to apply, has a higher level of reliability and can contribute to long-term stabilized control and labor-savings.

(b) Control performance monitoring (CPM)

In cases where adjustment is insufficient or, because of age-related deterioration or the like, the dynamic characteristics of the object to be controlled fluctuate and the control performance deteriorates, the true control performance of the plant may not be demonstrated. A control performance monitoring function has been developed to detect such deteriorations in the control performance. By monitoring the control performance and detecting deterioration in that performance, the control can be readjusted and device maintenance performed in order to realize stable operation.

(c) Precise synchronization control

The "E-SX" bus, a high-speed synchronous control bus, has been developed. The throughput has been improved significantly, and high-precision multi-axis motion control can be performed for up to 8 axes at a control period of 0.25 ms.

(d) C language application software

C language application software can be installed in the CPU module to realize higher level control functions and information processing functions.

3. "MICREX-VieW Compact"

3.1 Overview

The "MICREX-VieW Compact" (VieW Compact) can be used to configure a compact monitoring and control system at the lowest possible cost. As shown on the left side of Fig. 4, the minimum configuration consists of a combination of only the programmable

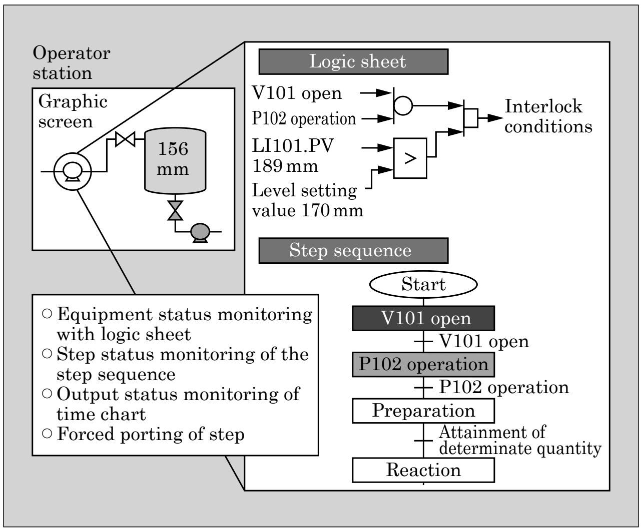

Fig.3 Visualization of equipment operating conditions, interlock, circuit status

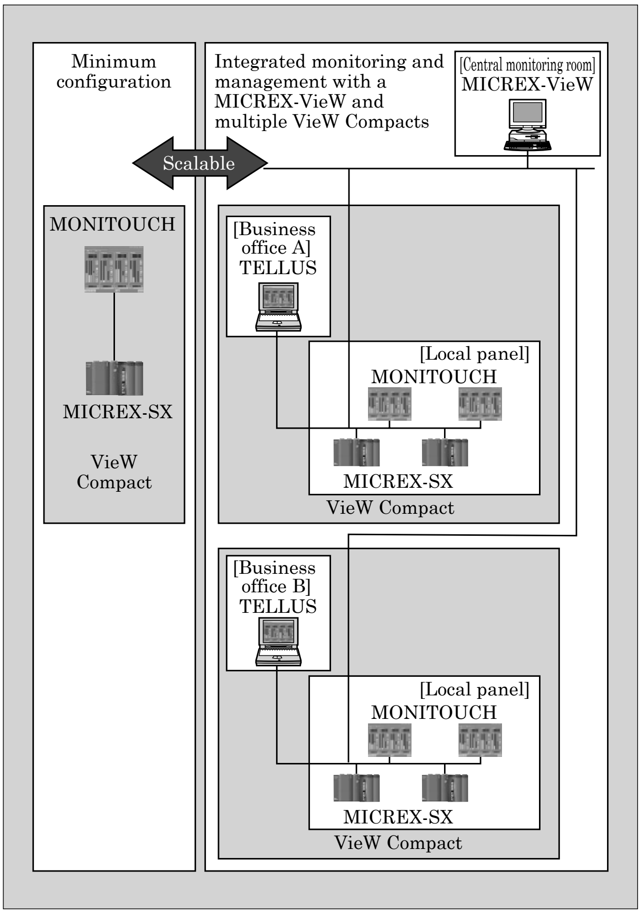

Fig.4 Scalable system configuration example

display “MONITOUCH” and the general-purpose PLC “MICREX-SX,” and is ideally suited for updating single loop controllers and the like. Moreover, flexible scalability allows for easy coordination with the MICREX-VieW system. Additionally, because of a common shared platform with the MICREX-VieW system, the aforementioned high-speed monitoring and control function can also be implemented in the VieW Compact.

3.2 Features

(1) Compatible package

The VieW Compact system can be used for electrical control and instrumentation control. For instrumentation applications, the View Compact is equipped with internal instruments (PID controller position-type output, PID controller velocity-type output, proportion computing unit, integrator, etc.) and input processing functions (temperature and pressure compensation, dead time generation, moving average, linearization, etc.), which are software packages in common with those of the MICREX-VieW of the host system. Variable gain and sample PI control, which have a proven track record with Fuji Electric's single loop controller, can also be supported. By implementing optimal control with diverse functions, the VieW Compact can be used to reduce energy consumption, and applied to control systems, such as for boilers that reduce the emissions of substances harmful to the environment, or other types of control.

(2) Scalable system structure

With a configuration that is scalable according to the size of the control system and the application, the VieW Compact can be applied to plants and equipment optimally. The system can be used in scalable, i.e. the number of devices per PLC is selectable from 2 to 32, and it can provide various configurations from the smallest system having a 1:1 ratio of standalone PLC and programmable operation display, to large system with multiple PLCs, and configurations combined with the host system. Additionally, by installing “TELLUS”, the same screen as shown on the programmable operation display can be displayed and manipulated on a PC, so that monitoring and operations can be performed from a business office and the like (Fig. 4).

Depending on the scale, 48 K steps or 256 K steps can be selected for the PLC. Additionally, high-reliability redundant controllers are also supported. The programmable operation display has excellent environmental durability and is suitable for onsite installation. Display screens are available in 8-inch, 10-inch, 12-inch and 15-inch size variations, and can be selected as necessary.

A VieW Compact used in a small-scale plant may easily be enlarged in the future corresponding to an expansion of the monitoring and control operations. Flexible scalability is also supported, such as subsequent add-on installation of the VieW Compact to an existing monitoring and control system such as the MICREX-VieW for the purpose of localized onsite monitoring and control.

4. Integrated Support System

4.1 Overview

The integrated support system is able to integrally manage support tools and application software, which previously existed separately for each device. This system aims to reduce the total cost of ownership (TCO) through engineering for high quality and improved maintainability (Fig. 5).

4.2 Features

(1) Integrated support system

With the integrated support system, the execution of unified operations such as batch backup with a single action, and the integrated management of application software for each tool have the net effect of reducing human error. As shown in Fig. 5, a system configuration diagram can be created, and a support tool for each device can be activated from that screen. Moreover, because the automatic generation of system definitions, device adjustment, network start-up, diagnosis, maintenance, etc. can be performed at a single location from the system configuration diagram, maintainability is improved.

(2) Compliance with international standard

Support tools for the controller comply with the IEC 61131-3 (JIS-B3503) international standard and can be used worldwide. Applications can be created using ladder language (ladder diagrams), function block diagram (FBD) language, structured text (ST) language, instruction list (IL) language, and sequential function chart (SFC) language.

(3) Automatic generation of control software according to specification description

HEART-BELIEVE is a tool for creating control function specifications such as instrumentation flow diagrams, interlock block diagrams (IBD) and the like

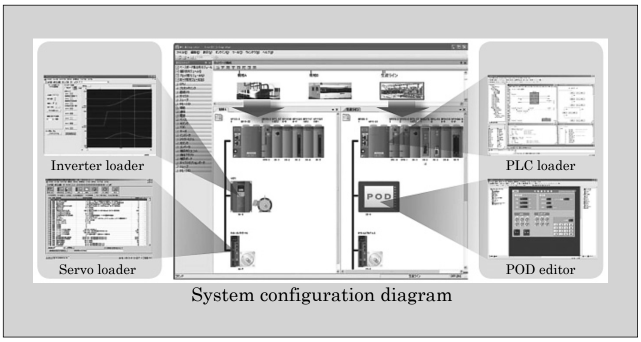

Fig.5 Integrated support system

4: Visio is a trademark or registered trademark of Microsoft Corporation, USA and its affiliates by using Visio[4] general-purpose office automation software. By automatically generating control application software for the controller from the created control function specifications, the engineering work efficiency can be improved and high quality application software can be realized. Moreover, the creation and editing of specifications can be accomplished easily by dragging and dropping function symbols.

The control function uses a platform independent model (PIM) that can continue to operate even if the platform changes. Additionally, by developing platform specific models (PSMs) for required platforms, a structure that supports multiple platforms can be built. Because platforms ranging from PLCs for small-scale systems to DCS controllers for large-scale systems are supported, the range of possible applications is wide (Fig. 6).

In accordance with the control function specifications, the state during operation with a PLC can be monitored and engineering work, ranging from the creation of specifications to onsite adjustment, operation and maintenance, can be comprehensively supported.

(4) Simulation function that runs on a PC

A simulation tool that can execute simulation of a system connected with multiple HMIs and controllers has been developed for use on a single PC (Fig. 7).

By testing the created application software together with an HMI as a system, without using actual devices, the quality of the application software can be improved prior to actual physical testing.

Additionally, by combining the simulation function with a plant simulator or an apparatus simulator, simulations that closely resemble an actual plant or equipment are possible.

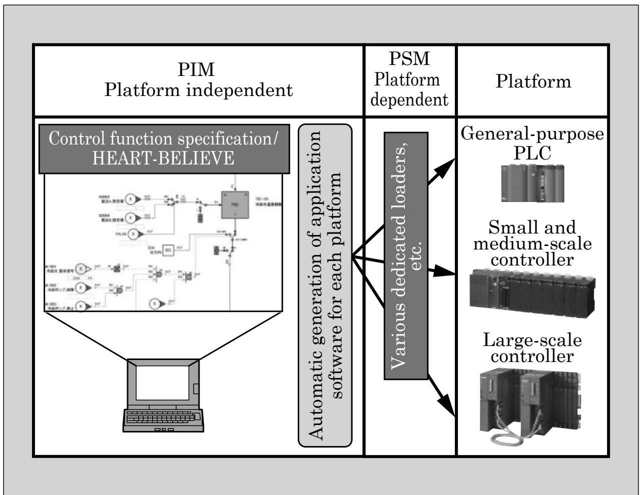

Fig.6 Platform independent application software generation

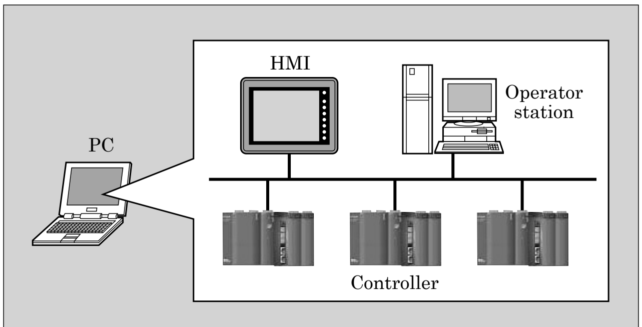

Fig.7 Combined simulation of HMI and multiple controllers

5. Application Examples

The MICREX-VieW and the VieW Compact can be used as control systems for various types of small and medium plants. Several examples of applications to the energy and environment fields are presented below.

5.1 Monitoring and control system for geothermal power plant

With the aim of establishing a low carbon society and in consideration of the problem of electric power shortages, geothermal power plants are attracting attention as a renewable energy source. Geothermal power plants have much lower CO_2 emissions than thermal power plants that use fossil fuels such as oil and coal, and in terms of global environmental protection, are an excellent method for generating power. A geothermal power plant captures geothermal steam from a steam producing well, and rotates a steam turbine to generate electricity.

Figure 8 shows an example of the MICREX-VieW applied to a geothermal plant monitoring and control

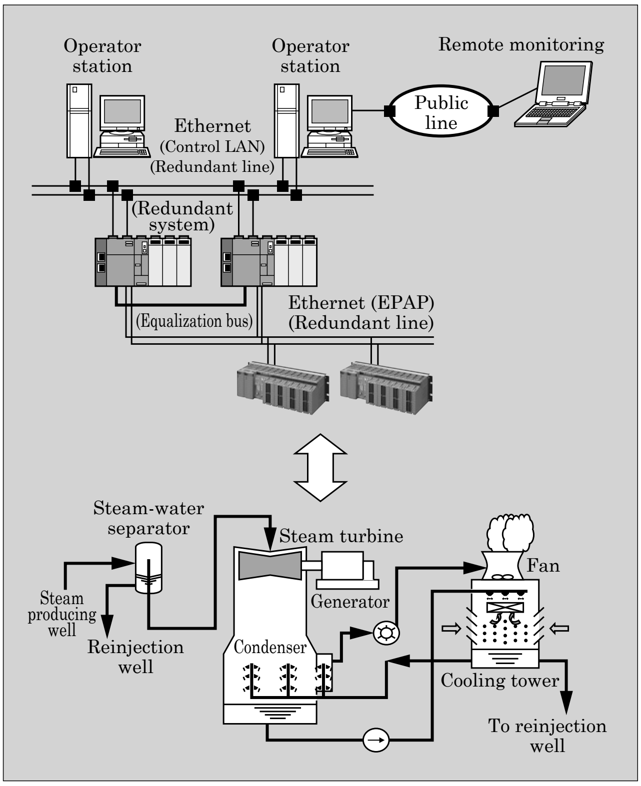

Fig.8 Geothermal power plant monitoring and control system

system. The steam flow rate from the steam producing well and the pressure are controlled with this system, and high reliability is required. The system is configured using redundant operator stations and controllers for high reliability. Additionally, because operation during the nighttime is unattended, the automated e-mail sending function of the MICREX-VieW is used to transmit process error signals and the like. The MICREX-VieW is also provided with a function for switching between multiple languages and is ideal for applications overseas where many geothermal power plants exist.

5.2 Monitoring and control system for waste incineration plant

A waste incineration plant is a plant that incinerates municipal waste, and in addition to controlling the combustion, must also limit the generation of dioxins and the emission of toxic gas to within regulated levels. The MICREX-VieW is equipped with automatic combustion control (ACC), and through implementing optimal control for an incineration plant, is able to minimize the generation of dioxins and the amount of sulfur oxide (SO_x) and nitrogen oxide (NO_x) emissions released into the atmosphere. The MICREX-VieW also contributes to the effective utilization of energy by monitoring and controlling the power demand, performing selective trip coordination and the like, and selling electric power back to the power companies.

Further, one characteristic of waste incineration plants is that compatibility with existing applications is strongly required at the time when updating the control system. Because the software of the MICREX-VieW has a high level of compatibility, the amount of engineering work can be reduced. Moreover, HMIs, controllers and I/O units can be gradually updated in piecemeal fashion so as to minimize the plant downtime (Fig. 9).

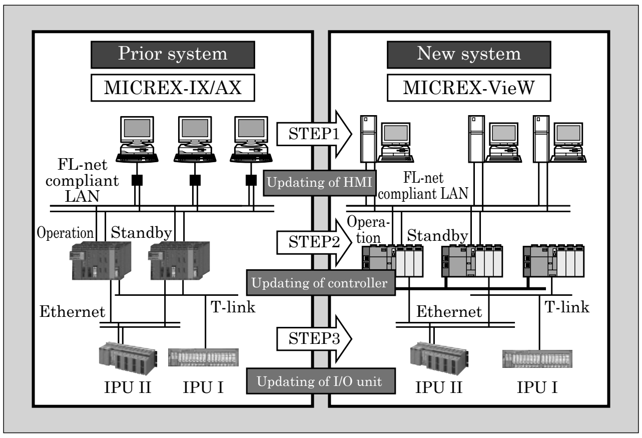

Fig.9 Gradual updating of a waste incineration plant management and control system

5.3 Management, monitoring and control system for food plant

A food plant is a type of batch plant in which control functions center on batch sequences in the manufacturing process and sequence control in cleaning process and the like.

In the food plant management, monitoring and control system shown in Fig. 10, brand management and sequence control for manufacturing processes is performed with the MICREX-VieW and Fuji Electric's "FLEXBATCH" brand management system, and schedule management, results management and the like are performed with the combination of a host system manufacturing execution system (MES) and a traceability system.

In the food industry, in response to social conditions concerning food and an increase in citizen awareness of food safety, manufacturing management and quality management in a plant must be implemented rigorously and information management is needed. A traceability system, in conjunction with a MES and a monitoring and control system, associates raw material number with manufacturing and shipping lot numbers to realize history management of the food manufacturing processes.

In the event of a defective product such as due to contamination, the history management mechanism can be utilized to issue instructions rapidly to recover products from consumers or to stop selling the products, thus supporting the provision of safe food to consumers.

5.4 Updating the control apparatus in a small-scale facility

The following is an example in which the VieW Compact is used for updating an existing single loop controller in the control apparatus of a small-scale facility or turbine, boiler or the like (Fig. 11).

Utilizing the advantageous feature whereby existing single-loop controllers can be gradually updated

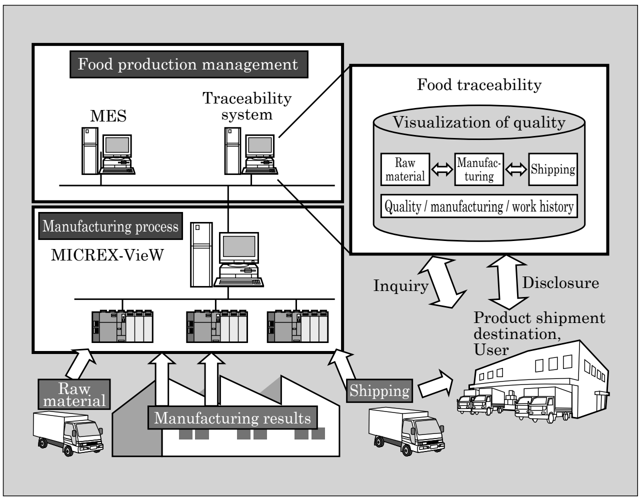

Fig.10 Management, monitoring and control system for food plant

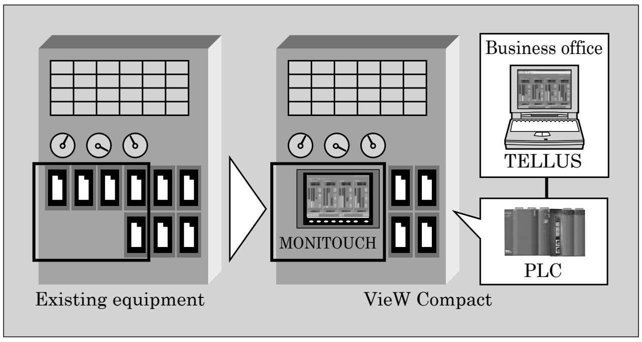

Fig.11 Updating of control equipment in small-scale facility

in stages of several units at a time, five single-loop controllers were updated at first. Housing a high-reliability redundant PLC inside the existing panel and mounting the MONITOUCH programmable operation display on the surface of that panel provides high-performance operation without any sense of unfamiliarity compared to the existing equipment. In consideration of the amount of engineering work needed and the post-operation support maintenance, HEART-BELIEVE was used for the PLC software.

Plant and equipment visualization can be enhanced by installing TELLUS in a notebook PC located in a business office and establishing a configuration in which monitoring is possible.

6. Postscript

This paper has presented an overview and descriptions of the features of the small and medium-scale monitoring and control system platform "MICREX-VieW" and its derivative "MICREX-VieW Compact" for use in the fields of energy and the environment. Fuji Electric intends to continue to supply high performance, high quality systems and solutions through responding accurately to customer needs for asset inheritance, gradual updating in stages, improved maintainability and the like, and aiming to further increase customer satisfaction.

“E-SX Bus” & “SPH3000MM” Promising High-speed, High-precision Motion Control

Eiji Nishimura † **Toshiyuki Nishiwaki** † **Kazuhito Nagatsuka** †

ABSTRACT

In the plant control and machine control fields, further improvements in quality and the stabilization and streamlining of operations are required. Fuji Electric has developed the high-speed/high-precision synchronou s“E-SX Bus”, a backbone bus for configuring control system, and the high-speed/high-performance “SPH3000MM” CPU module to execute applications. These enable high-speed and high-precision motion control while also making it possible to flexibly expand applications up to large-scale systems with numerous I/O points. As application examples, high-speed and high-precision motion control has been achieved in multi-color printing machines and steel/iron plant systems.

1. Introduction

In the field of plant control for iron and non-ferrous material production, paper manufacturing and so on, and in the field of machinery control for metal processing, printing, packaging and so on, higher quality and operational efficiency are required. In order to achieve these goals, while maintaining the ease of system construction and engineering based on general-purpose controller, a high-speed and high-precision control system that can be built flexibly according to the control target is needed.

For high performance machinery, for example, applications that combine sequence control for controlling a variety of inputs/outputs and multi-axis motion control (see supplemental explanation 3 on page47) that require high-precision synchronization must be easy to build. Such applications must acquire data from sensors at a period of several hundred microseconds, and control multiple actuators synchronously with precision of 1 microsecond or less. Large plants typically have control periods ranging from several microseconds to several tens of microseconds, and often have more than 10,000 inputs and outputs, and control systems have traditionally been realized by connecting multiple controllers in a networked configuration which increases costs.

Thus, to realize high-speed high-precision motion control functionality based on general-purpose controller technology and to support large systems having numerous inputs and outputs, Fuji Electric has developed the high-speed high-precision synchronous “E-SX” bus as a backbone bus for controllers and the “SPH3000MM” high-speed high-performance CPU module for running applications. This paper describes features and presents application examples of the E-XS bus and the SPH3000MM.

† Fuji Electric Co., Ltd.

2. Overview of Systems That Use The SPH3000MM

Fuji Electric’s “SPH3000MM” CPU module equipped with an E-SX bus is an important component for implementing high-speed high-precision motion control and for realizing large control systems. The SPH3000MM is positioned as the top-level model of Fuji Electric’s “MICREX-SX” series and has the following features:

(a) High-speed computations: Top speed of 9 ns per instruction
(b) Capable of synchronous control among 32-axial drive machines with accuracy within ±1 µs
(c) Dual processing engines enable synchronous execution of application programs
(d) High-speed I/O with 25 µs response speed
(e) Large I/O capacity up to 4,096 words×2 systems

An example system configuration for motion control is shown in Fig. 1.

(1) High-speed, high-performance CPU module

The new CPU module can be mounted on an existing baseboard, and used with a conventional SX bus or in a multi-CPU module configuration. Furthermore, because the CPU module has two processing engines and is equipped with a dual-system E-SX bus to which high-speed I/O devices and drive control devices can be connected, application programs can be run simultaneously for sequence control and motion control.

(2) “SX-Programmer” support tool

Support for the creation of application programs for sequence control and motion control of multiple CPU modules, the setting of system definition parameters, fault diagnosis, monitoring operation, and so

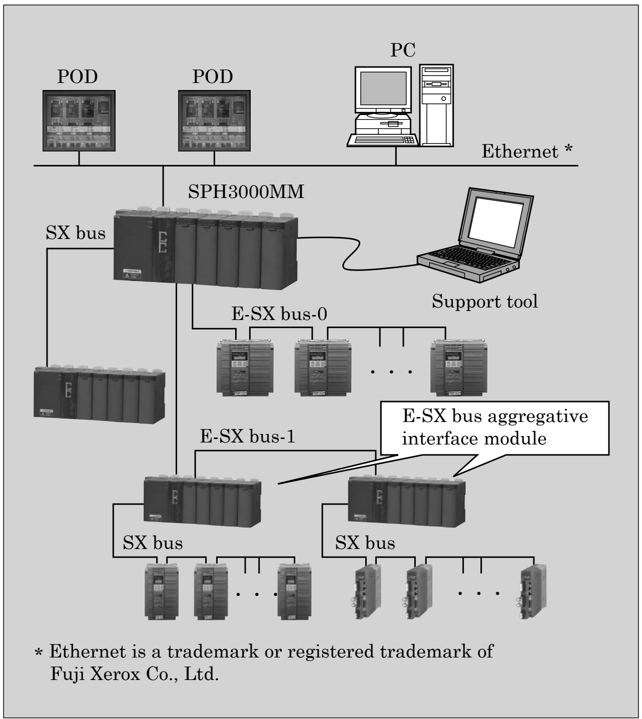

Fig.1 Example system configuration for motion control

on can be provided by a single IEC 61131-3 compliant support tool "SX-Programmer" (2 models: Expert and Standard).

(3) I/O devices and drive control equipment

Having a 25 µs response performance which is faster than before, the E-SX bus supports connections to digital/analog inputs and outputs and other I/O devices such as high-speed counters and encoders, as well as drive control devices such as inverters and servo amplifiers. Furthermore, with an E-SX bus aggregative interface module, the extensive lineup of I/O devices and communication devices for the SX bus can be utilized via the E-SX bus.

3. Features of The "E-SX bus" That Realizes High-Speed, High-Precision Synchronous Communication

The "E-SX bus" utilizes 100 Mbit/s Ethernet*1 technology in its physical layer, and is a hybrid-type motion control bus that realizes a high-speed and high-precision synchronous communication function that are necessary for drive solutions, a large capacity I/O data transfer function, a message communication function and a loopback function. The E-SX bus has the following features.

(1) Scalability

The E-SX bus can flexibly support various systems, ranging in size from small to large, and with a total length of up to 1 km, is capable of connecting up to 238 stations separated by up to 100 m, with a maximum input/output size of 4,096 words (8 times greater than before).

(2) High-speed, high-precision synchronization

When connected to 32 input and output devices, the E-SX bus is capable of high-precision synchronous control with accuracy within ±1 µs.

(3) Large input and output data capacity

In consideration of the runtime required for applications, the data capacity has been increased to 4 times the prior capacity, and at the fastest control period of 0.25 ms, 67 words of input and output data can be processed, or in the case of a control period of 1 ms, 512 words can be processed. Up to 4,096 words can be processed at a control period of 3 ms, and the E-SX bus is well-suited for application to large plants having many inputs and outputs.

(4) Highly efficient transmission protocols

The transmission protocols have evolved from Fuji Electric's proprietary SX bus and have been greatly improved. In addition to the cyclic I/O refresh communication protocol and message communication protocol, a system management protocol for control commands, initial processing and the like is also provided.

These transmission protocols are realized with a high-density integrated circuit (LSI) developed by Fuji Electric, and achieve an effective data transmission efficiency of greater than 70%.

(5) Degenerate continuous operation and wire breakage detection

The E-SX bus uses a configuration (daisy chain connection) that does not require a hub or the like. Other features of the E-SX bus include a function for supplying power from the bus to other stations and a loopback function for times when there is a broken wire. As a result, even if devices are powered-off, wires break, or other bus errors occur, degenerate continuous system operation will be possible whereby, by excepting some system functions, the system will continue to operate. The E-SX bus is also provided with a RAS function for identifying broken wire locations, which improves the ease of maintenance when replacing equipment.

4. Characteristics of The "SPH3000MM" High-Speed High-Performance CPU Module

(1) High-speed high-precision control and large capacity memory

The new CPU module employs a multi-engine architecture as shown in Fig. 2. A system manager and two processing engines are connected through a synchronous bus equipped with a distributed shared memory access function. The processing engine, in combination with high compression compiler technology, realizes a maximum execution performance of 9 ns/instruction. Control period error is less than ±1 µs, and control can be realized with less fluctuation than

*1: Ethernet is a trademark or registered trademark of Fuji Xerox Co., Ltd.

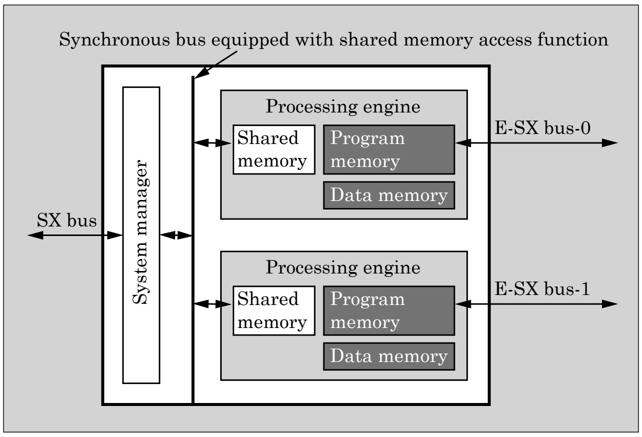

Fig.2 SPH3000MM multi-engine architecture

with prior models.

Additionally, the memories for programs and user data are separate for each processing engine, and substantial applications can be constructed with a large program memory (max. 512 K steps with 2 systems) and a large data memory (max. 4,096 words with 2 systems).

(2) Separation of processing engines and functions between the 2 systems

The processing engines are connected to an internal synchronous bus, and the execution period is synchronized to within ±1 µs among the processing engines. Accordingly, even in cases where 32 I/O devices are connected to the E-SX bus of each system, the output timing among systems can be synchronized within ±3 µs. Furthermore, in the case of the maximum control rate of 0.25 ms, multi-axial motion control can be implemented for up to 8 axes (4 axes×2 systems).

The exchange of data among processing engines is carried out in the background via a shared memory space in order to maintain synchronization. Thus, the exchange of data among the two engines, which is typically performed frequently, can be accomplished with great ease and users are able to create distributed applications without regard to process synchronization. In addition, by distributing the sequence control and motion control functions and running them on two processing engines in parallel, the processing time can be reduced easily.

Furthermore, with two systems of processing engines, by setting one processing engine to a period that is an integer multiple of the other engine, a high-speed motion control application program as well as an equipment control application program, which handles large amounts of data and has a slower control cycle, can be run on a single CPU module.

Thus, flexible systems can be constructed by utilizing the distributed processing function in accordance with the control object.

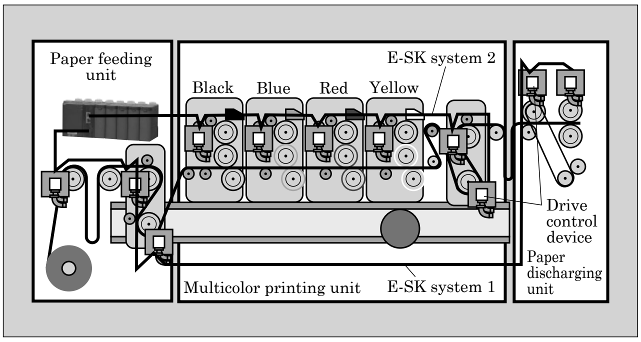

Fig.3 Example of multicolor printer

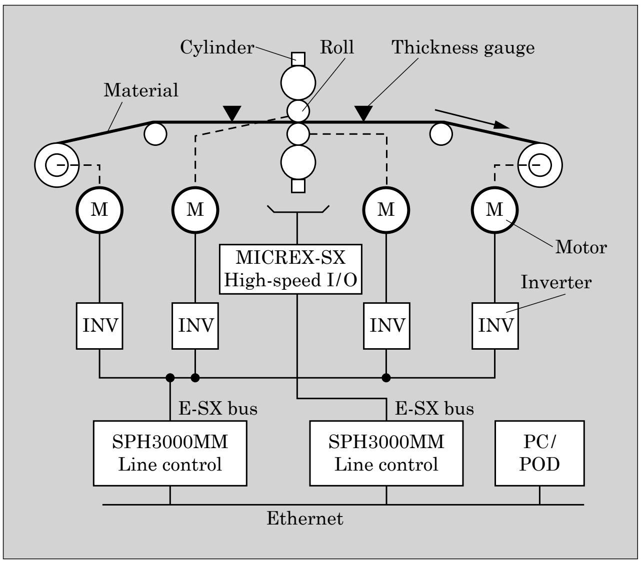

Fig.4 Example of mill pressure control system

5. Application Examples

(1) Application to a high-speed high-precision motion control system

Multi-color printing is an example of an application in which high-speed high-precision synchronous motion control is required. With a minimum configuration of the motion control system, an 8-axial synchronous system can be realized with 4 axes per system and a control period of 0.25 ms, and with a general-purpose controller, motion control can be realized with the maximum speed and precision. During the 0.25 ms control period, 0.12 ms of run time can be ensured for the application program, and high-precision positioning control such as interpolation control can be implemented.

Figure 3 shows an example of a multi-color printer. By performing high-precision synchronization of a vertical axis that controls paper feeding, multi-color printing, paper discharging and other processes with respect to a virtual main axis, high-resolution color printing without print unevenness can be processed quickly. To realize the required printing accuracy (within 0.015 mm) at a printing speed of 300 m/min, the synchronization accuracy must be within 3 µs.

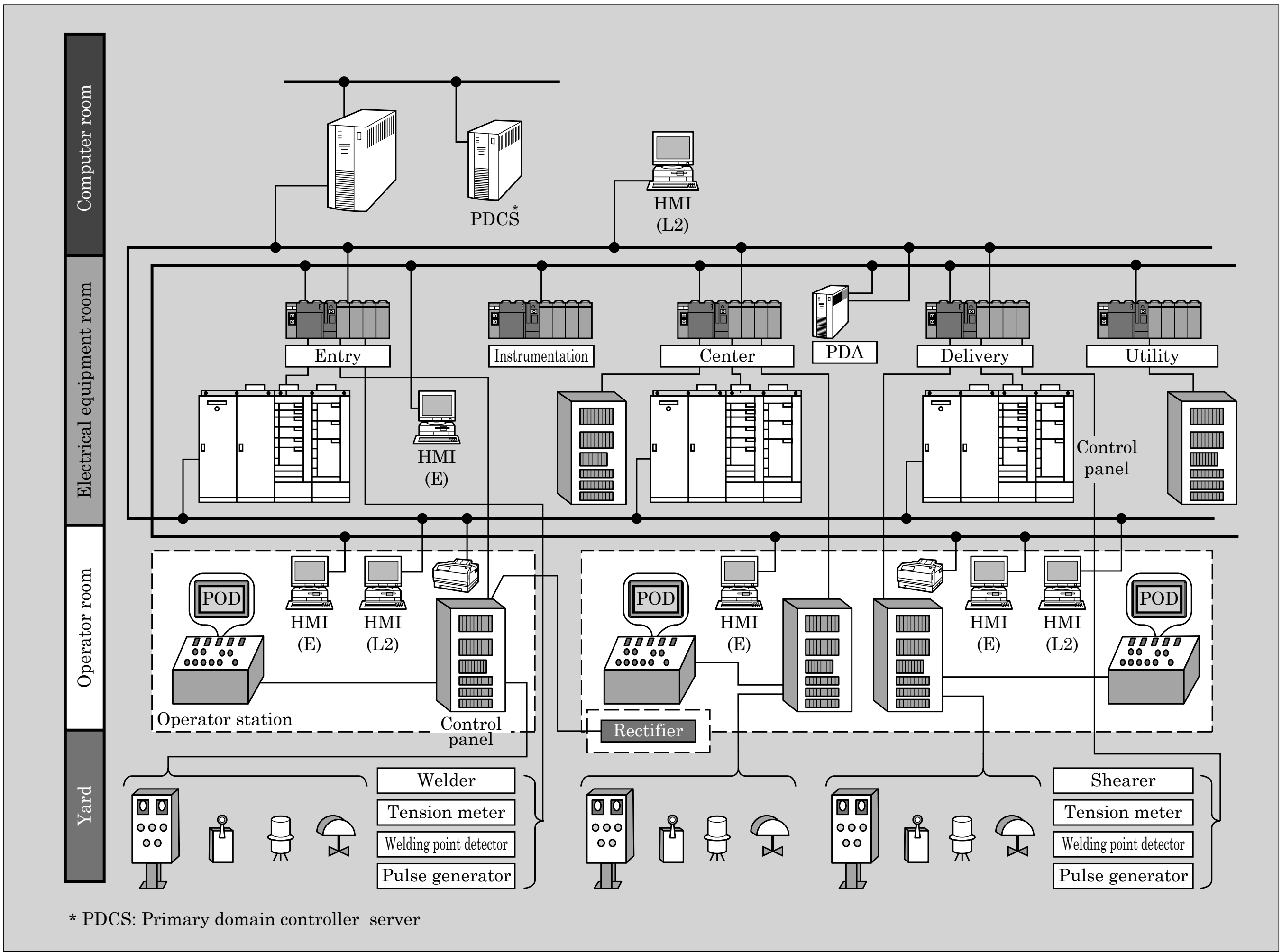

Fig.5 Example of control system for iron process line

With the SPH3000MM, by using one system for the virtual main axis and the paper feeding and discharging units, and another system for the multi-color printing unit and so on, application programs that flexibly separate the functions of customers' equipment and that realize high-speed high-performance synchronization can be constructed easily.

(2) Application to a steel plant system

A steel plant control system is a large-scale system configured from many detectors and actuators, as well as equipment for their control, operation and monitoring. Of these component parts, high-speed performance is especially required of the electric control system, which includes electric motors and solenoid valves.

(a) Application to mill rolling force controller

A mill rolling force controller is a device that uses an apparatus known as a mill (a rolling mill), consisting of multiple rollers, to control materials such as steel, copper or aluminum to a predetermined thickness (Fig. 4).

Material discharged from the upstream side is rolled according to the position of the rollers and the tension applied to the material as it passes through the mill. Because the state of the material passing through the mill changes from moment to moment, controlling the material to a predetermined thickness requires that the state of the material and the equipment be measured with various sensors, and that the mill be controlled to an optimal state. Various control methods have been proposed, and the extent to which information from the sensors can be accurately incorporated is critical to the realization of these methods. Requirements for control equipment are as follows.

(i) High-speed and reliable input from detector (Magnescale, absolute encoder, etc.)
(ii) High-speed processing, high-speed period
(iii) High-speed synchronous output of instructions to actuator

Previously, these requirements were met by using a dedicated control device, narrowing down the control functions and increasing the processing speed.

The SPH3000MM, with its high-speed processing performance, coupled with the high-speed high-precision synchronization function as well as the high-speed input/output capability for detectors and actuators provided by the E-SX bus, enables advanced control functions to be realized easily while maintaining high-speed performance with few restrictions.

(b) Application to the control system for a process line

A process line is a facility for processing iron and nonferrous materials such as by heating, acid washing, plating, coating and so on. In the case of a large-scale system, a process line may consist of drive units for driving several hundred electric motors, numerous solenoid valves, detectors and monitoring devices; and the control system may have a control period of several tens of milliseconds, and the number of inputs and outputs may exceed 10,000 points (Fig. 5).

Requirements for such a system are as follows.

(i) Scalability according to system size
(ii) High-speed connectivity with distributed equipment
(iii) Easy connectivity with third-party equipment

With the SPH3000MM, an optimal configuration can be assembled for the required control performance of systems ranging in size from small to large. Furthermore, in addition to the E-SX bus, conventional buses (P/PE link, T link) and open buses (FL-net, PROFIBUS-DP*2, etc.) are also supported, and thus, systems that mix older model devices and third-party equipment can be easily connected.

*2: PROFIBUS-DP is a trademark or registered trademark of PROFIBUS User Organization

6. Postscript

Controllers equipped with the SPH3000MM CPU module and the E-SX bus can be used to construct various types of high-speed, high-precision and large capacity motion control systems. It is the authors' hope that the content described in this paper will contribute to the manufacture of high quality products required by various plant systems and machinery and to the realization of stable and efficient operation.

To resolve the challenges facing manufacturing sites, the authors intend to continue to expand the range of applications of controllers.

"ZP Series" of Small, High-sensitivity Infrared Gas Analyzers

Yuki Masunaga † Hideyuki Konishi † Kozo Akao †

ABSTRACT

Fuji Electric provides two types of infrared gas analyzers: small single beam types with a simple construction, and double beam types that have high sensitivity but are large and require complicated adjustments, and has developed a small, high sensitivity infrared gas analyzer with a single beam. By creating a measuring section with higher sensitivity and employing sample switching (SSW), the analyzer achieves low density measurements that surpass the double beam measurement range. The analyzer can be used in a wide range of applications from metal heat treatments and monitoring applications for biomass-/waste-related generated fuels that require high density measurements, to low density exhaust gas monitoring and monitoring impurities in pure gases that require low density measurements.

1. Introduction

Fuji Electric's gas analyzers have been used extensively in various industries for applications involving the measurement of gas concentrations, such as for combustion control, emissions gas monitoring and process control in various plants. In these applications, infrared gas analyzers are used to measure nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO) and carbon dioxide (CO_2) concentrations, and are used as environmental monitors to measure the combustion exhaust gases emitted from various industrial furnaces including garbage incinerators, boilers, steel production plants, cement production plants, and for the monitoring and control of gases inside furnaces.

With recent advances in control technology for combustion furnaces and incinerators and advances in techniques for removing toxic substances, the concentrations of NO_x, SO_2 and CO_2 in exhaust gases are tending to decrease. Thus, the purpose of measurement, in addition to the conventional goal of controlling and monitoring exhaust gas, is often to prove that exhaust gas is not being emitted or is at low concentrations, and the ability to provide stable measurements of low concentrations of gas is increasingly sought.

Overseas, particularly in emerging nations such as China and India that are experiencing remarkable economic growth, large markets have been created in this field. To promote the widespread usage of gas analyzers overseas, performance improvements, as well as standardization and simplification of the usage methods are needed.

This paper describes Fuji Electric's new type of gas analyzer that realizes high performance and ease of use. Representative application examples are also discussed below.

2. Product Overview

Fuji Electric's lineup of infrared gas analyzers include small single-beam types having a simple construction, and double-beam types that have high sensitivity but are large and require complex adjustments. Figure 1 shows the structure of the measurement unit of a single-beam type, and Fig. 2 shows the structure of

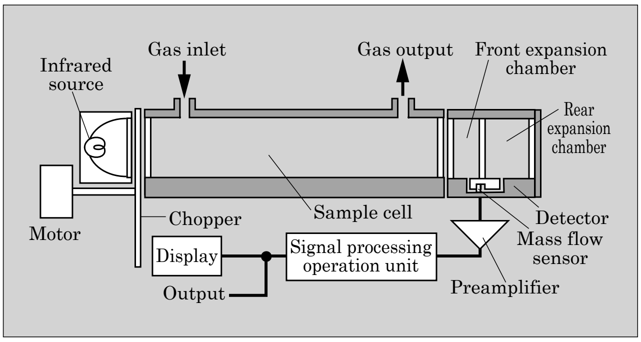

Fig.1 Configuration of single-beam type measurement unit

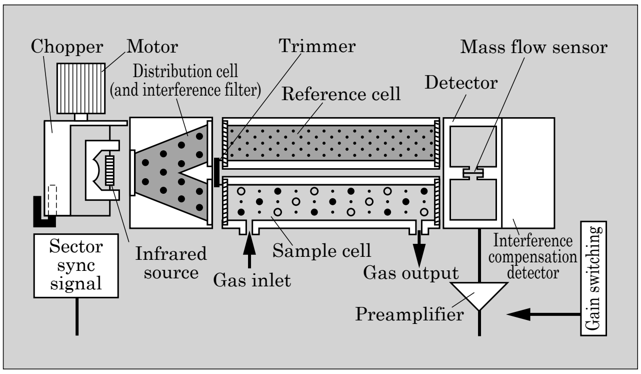

Fig.2 Configuration of double-beam type measurement unit

† Fuji Electric Co., Ltd.

the measurement unit of a double-beam type.

Fuji Electric has newly developed the “ZP series” of small high-sensitivity infrared gas analyzers which aim to achieve performance superior to that of the conventional double-beam type.

By increasing sensitivity of the measurement unit and adopting a method of sample switching, Fuji Electric successfully developed an analyzer that achieves improved stability, is capable of measuring low concentrations and is easy to use. Additionally, component parts were made standardized so as to create a flexible product lineup able to support requirements for measurements ranging from low to high concentrations.

3. External Appearance and Specifications

Figure 3 shows the external appearance and Table 1 lists the main specifications of the ZP series. The series is provided as a general-purpose model (model: ZPA) that covers the conventional single-beam measurement range (0 to 200 ppm), a high-end model (model: ZPB) that covers the conventional double-beam range (0 to 50 ppm), and a low concentration model (model: ZPG) that enables measurement of even lower concentrations of 0 to 5 ppm.

4. Product Features

(1) Small-size, high sensitivity measurement

The thickness of the sensor film of the mass flow sensors used in the detectors of conventional infrared gas analyzers was reduced to improve detector sensitivity. Moreover, the smaller size and increased sensitivity of the measurement unit enabled the single-beam minimum measurement range (conventionally 0 to 200 ppm) to be reduced to 0 to 5 ppm, which is a 40-fold improvement.

With the smaller size of the measurement unit, even when equipped with a sample switching function

Fig.3 Appearance of “ZP series”

Table 1 Main specifications of the ZP series

Item	ZPA	ZPB	ZPG
Measurement principles and measured components	NO, SO_2, CO_2, CO, CH_4: Non-dispersive infrared absorption method, O_2: Selected from among magnetic, galvanic cell and custom zirconia methods		
Measurement method	Standard	Sample switching	
Range ratio	1:10 max.		
Minimum measurement range	NO : 0 to 200 ppm SO_2 : 0 to 200 ppm CO_2 : 0 to 100 ppm CO : 0 to 200 ppm CH_4 : 0 to 500 ppm	NO : 0 to 50 ppm SO_2 : 0 to 50 ppm CO_2 : 0 to 50 ppm CO : 0 to 50 ppm	NO : 0 to 10 ppm SO_2 : 0 to 10 ppm CO_2 : 0 to 5 ppm CO : 0 to 5 ppm
	O_2: 0 to 5 vol% (in the case of magnetic or custom zirconia methods)		
Maximum measurement range	NO : 0 to 5,000 ppm SO_2 : 0 to 10 vol% CO_2 : 0 to 100 vol% CO : 0 to 100 vol% CH_4 : 0 to 100 vol%	NO : 0 to 5,000 ppm SO_2 : 0 to 5,000 ppm CO_2 : 0 to 25 vol% CO : 0 to 5,000 ppm	NO : 0 to 100 ppm SO_2 : 0 to 100 ppm CO_2 : 0 to 50 ppm CO : 0 to 50 ppm
	O_2: 0 to 100 vol% (in the case of the magnetic method)		
Warm-up time	4 hours	2 hours	
External I/O	Analog output DC4 to 20 mA, 550 Ω or less, 12 points Analog input 0 to 1 V, 1 point Contact output 24 V DC, 1 A 15 points max. Contact input 12 to 24 V DC, 5 to 20 mA 9 points max.		Same as the left, 4 points max. Same as the left, 1 point Same as the left, 15 points max. Same as the left, 6 points max.
Power supply/ power consumption	AC100 to 240 V		
	50/60 Hz, approx. 100 VA	50/60 Hz, approx. 120 VA	50/60 Hz, approx. 100 VA
Dimensions (mm)	483 (W) × 418 (D) × 132.5 (H)		
Linearity	±1.0%FS or less		
Repeatability	±0.5%FS or less (0 to less than 200 ppm is ±1.0%FS or less)		
Drift (zero point)	±2.0%FS or less per week (total of NO & SO_2 drift for no more than 0 to 500 ppm is ±2.0%FS or less per day)	±0.5%FS or less/week	
Drift (span)	±2.0%FS or less/week		
Response speed (90% response)	30 seconds or less		

(described below) is installed, the size remains the same as that of a conventional single-beam analyzer and the volume is less than one-half that of a conventional double-beam analyzer (see Fig. 4).

(2) Cancellation of zero point drift

Previously, low concentration measurements using a single-beam type analyzer incurred significant drifting of the zero-point due to the effect of ambient temperature changes, contamination inside the measurement cell and the like, and in order to maintain stability (refer to "Zero-point drift performance" (Explanation 4 on page47)), measurements were limited to the range of 0 to 200 ppm. With the ZP series of products, however, a sample switching method is used and stable measurements can be obtained even when measuring low concentrations.

Figure 5 shows the configuration of the sample switching method.

In the sample switching method, a sample gas and a reference gas corresponding to a zero gas are switched at a certain period, introduced to the measurement unit, and alternatively measured to obtain measurements while continuously monitoring the zero-point. As a result, in principle, the drift of the zero-point is cancelled. Fig. 6 shows the mechanism for cancelling the zero-point drift. The measured values correspond to "concentration amounts," and even if the zero-point drifts, only the change in output is seen, and therefore the amount of drift is negligible.

Consequently, stable measurements can be obtained even in the vicinity of the zero-point.

(3) Simple maintenance

Because a single-beam is used, there is no need for the optical balance adjustment that is required with the double-beam method. Additionally, the measurement unit has a simple structure that facilitates maintenance such as cell cleaning.

(4) Product series that supports a wide range of measurements

The ZP series is suitable for a wide range of applications ranging from the monitoring of metal heat treatments and of the generation of fuel from biomass and waste where measurement of high concentrations of gas is required to the monitoring of low concentrations of exhaust gas, the monitoring of impurities in pure gas, and so on where measurement of low concentrations of gas is required.

5. Application Examples

Application examples that use this analyzer are introduced below.

In actual-use scenarios, pre-treatment equipment provided with dust removal and dehumidification functions must also be used. Table 2 lists main application examples and models of the ZP series.

(1) Thermal power boiler

Figure 7 shows an example of the application of an analyzer in a thermal power station.

Thermal power plants generate electricity by combusting various types of fuel such as heavy oil, coal and natural gas to boil off steam in a boiler, thereby causing a turbine to rotate and generate electricity. Gas analyzers are used to measure O_2 and CO levels for the control of boiler combustion, to measure pre- and post-NO_x levels of equipment for the control and monitoring of NO_x removal equipment that removes nitrogen

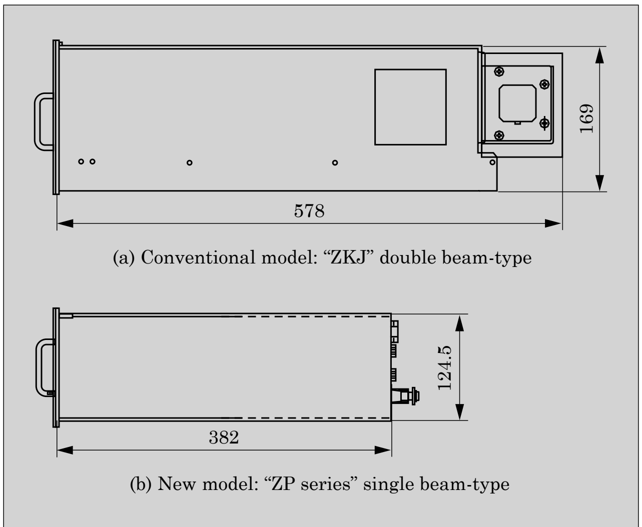

Fig.4 Comparison of conventional and new models (side view drawings)

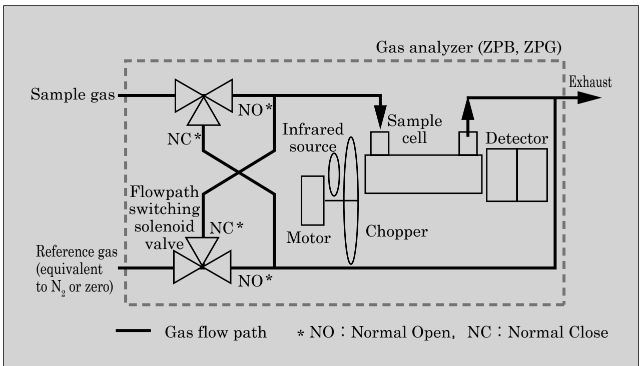

Fig.5 Configuration of sample switching method

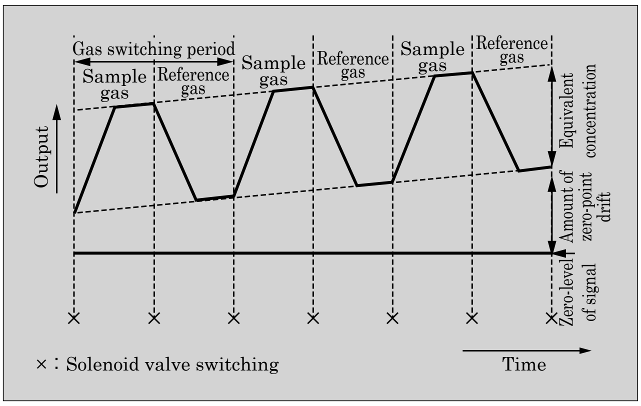

Fig.6 Mechanism for cancelling zero-point drift

oxides from exhaust gas after combustion, and to measure NO_x, SO_2 and O_2 levels for monitoring exhaust gas discharged from chimneys. In recent years, as a result of improvements in desulfurization and denitration processes and higher quality raw materials, the exhaust gases discharged from chimneys have become cleaner, and NO_x and SO_2 levels have decreased to about 10 ppm.

Table 2 Main application examples and models of the ZP series

Market & Business sector	Target	Components and range* to be measured		Model
Waste incin-eration	Pollution monitoring (Exhaust gas measurement)	NO_x SO_2 CO CO_2 O_2	0 to 50...200 ppm 0 to 50...500 ppm 0 to 50...1,000 ppm 0 to 10...20 vol% 0 to 10/25 vol%	ZPB
	Incinerator combustion control	CO O_2	0 to 1,000 ppm 0 to 5.....25 vol%	ZPA
Iron and steel	Pollution monitoring (Hot oven, boiler exhaust gas measurement)	NO_x SO_2 CO CO_2 O_2	0 to 50...200 ppm 0 to 50...500 ppm 0 to 1,000 ppm 0 to 10...20 vol% 0 to 10/25 vol%	ZPB
	Hot oven, boiler combustion control	CO O_2	0 to 1,000 ppm 0 to 5.....25 vol%	ZPA
	Desulfurization/denitrification equipment monitoring and control Monitoring of gas generated by blast furnace, monitoring of gas generated by converter, monitoring of gas generated by coke oven, monitoring of vacuum degassing	CO CO_2 O_2	0 to 20...100 vol% 0 to 10...50 vol% 0 to 1.....25 vol%	ZPA
Cement produc-tion	Pollution monitoring (Exhaust gas measurement)	NO_x SO_2 O_2	0 to 100 ppm 0 to 100...1,000 ppm 0 to 10/25 vol%	ZPB
	Gas monitoring inside a kiln, coal grinder outlet, etc.	CO O_2	0 to 2,000 ppm 0 to 5.....10 vol%	ZPA
Heat treating furnace	Heat treating furnace atmosphere monitoring and control	CO CO_2 CH_4 O_2	0 to 20...25 vol% 0 to 1.....5 vol% 0 to 10...30 vol% 0 to 1.....10 vol%	ZPA
Electric power	Pollution monitoring (Exhaust gas measurement) Oil boiler	NO_x SO_2 O_2	0 to 50...1,000 ppm 0 to 50...2,000 ppm 0 to 10/25 vol%	ZPB
	Pollution monitoring (Exhaust gas measurement) Gas turbine	NO_x O_2	0 to 10...100 ppm 0 to 10/25 vol%	ZPG
Gas supply	Product monitoring, impurity monitoring	CO CO_2	0 to 5.....10 ppm 0 to 5.....10 ppm	ZPG

* : NO_x is converted into NO with a converter and then measured as NO with an analyzer

In addition, gas boilers and gas turbines that use natural gas as fuel and have relatively lower CO_2 emissions have been watched closely, and concentrations of these emissions have been reduced to even lower levels.

With the sample switching method, the ZP series that is capable of stable low-concentration measurements, is able to meet market needs for the measurement of such low concentrations.

(2) Iron and steel industry

Figure 8 shows an example of the application of analyzer in an ironworks.

In iron and steel plants, CO, CO_2 and O_2 concentrations are monitored, where CO gas concentrations are measured for the purpose of combustion control of various types of furnaces such as blast furnaces, converters, and coke ovens and for the recovery of exhaust gas, and O_2 concentrations are measured in order to prevent explosions, and so on. Concentrations are measured in the ranges of 0 to 100% for CO, 0 to 50%

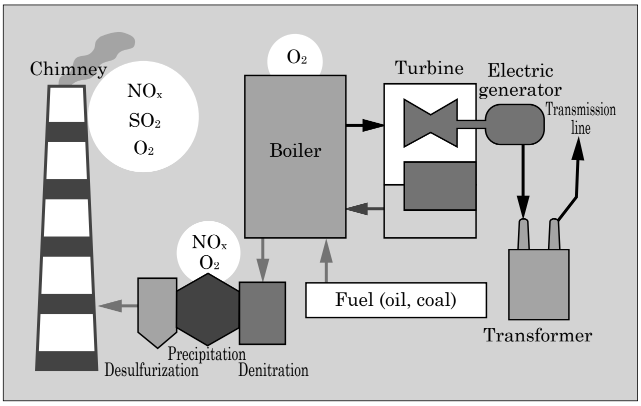

Fig.7 Example application of analyzer in a thermal power station

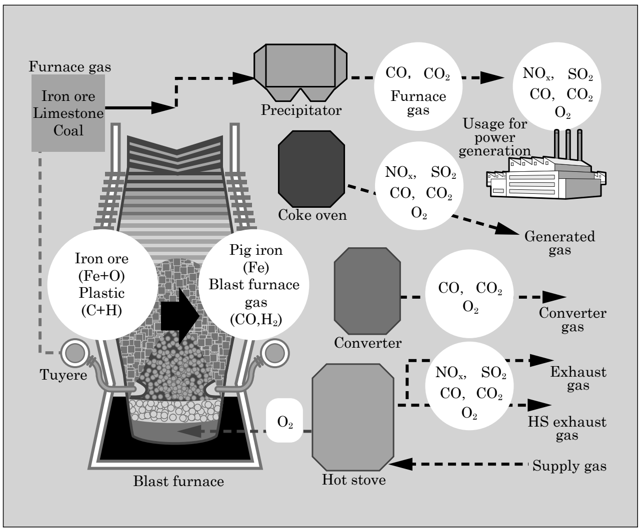

Fig.8 Example application of analyzer in an ironworks

for CO_2, and 0 to 25% for O_2.

Additionally, in order to conserve energy, the exhaust gases from these furnaces are typically used as fuel to generate electrical power that is provided to the plant. Here, NO_x and SO_x are measured to monitor combusted exhaust gas, which is used as a fuel for generating electricity.

All of these measurements involve low emissions levels of around 10 ppm, and therefore, the capability to measure low concentrations is needed.

The ZP series supports measurements ranging from low to high concentrations of furnace gas. Accordingly, the ZP series provides significant merits in terms of management and maintenance since the maintenance parts are standardized and there is no need to learn how to operate various types of analyzers.

(3) Cement production process

Figure 9 shows an example of the application of analyzer in a cement manufacturing process.

In the manufacture of cement, the raw materials of limestone, clay, silica, iron oxide and gypsum are dried and are then injected into a grinder where they are pulverized.

These materials are then placed into a cyclone, mixed uniformly and stored in a silo. The mixed materials are heated by a preheater and then baked by a burner in a rotary kiln to form clinker. The clinker is cooled and then pulverized again, and a separator is used so that the clinker powder particles are of uniform size. The control of the cement plant requires combustion control inside the rotary kiln, safety monitoring of the coal that forms the fuel for firing, and pollution monitoring of the exhaust gas. Combustion control is an especially important factor for determining the quality of the cement.

To control combustion in the rotary kiln, CO, CO_2 and O_2 are measured and to monitor exhaust gas pollution of the overall plant, NO_x, SO_2, CO, CO_2 and O_2 are measured

(4) Waste treatment plant

Fuji Electric's gas analyzers have been used successfully in many applications in waste treatment plants. Fig. 10 shows an example application of analyzer in a waste treatment plant.

In a waste treatment plant, gas analyzers are used to monitor emissions generated by the incineration of waste.

The components to be measured are NO_x, SO_2, CO and O_2. CO levels are measured as a reference value for preventing the generation of dioxins from incineration, and the CO concentration is usually limited to several ppm. With the installation of exhaust emission cleaning equipment, NO_x and SO_2 are reduced to levels ranging from about several ppm to several tens of ppm. Thus, the ZP series, which is capable of measuring low concentrations, can be used effectively.

Biomass power generation using fermented waste has attracted attention recently, and analyzers are also used to monitor the generation of CO_2 and methane (CH_4).

(5) Gas supply equipment

In semiconductor and petrochemical plants, gas purification and supply equipment is installed for such gases as nitrogen, argon and oxygen. Devices are attached to this equipment for monitoring CO_2 and CO impurities contained within the supplied gas. These impurities affect the quality of products made in the plant and their manufacturing processes, and stable measurement of the purity levels is required. The targeted gases, CO and CO_2, are to be measured in the range of 0 to 5 ppm or to 10 ppm, and the ZP series of analyzers is suitable for this application.

(6) Air quality measurement

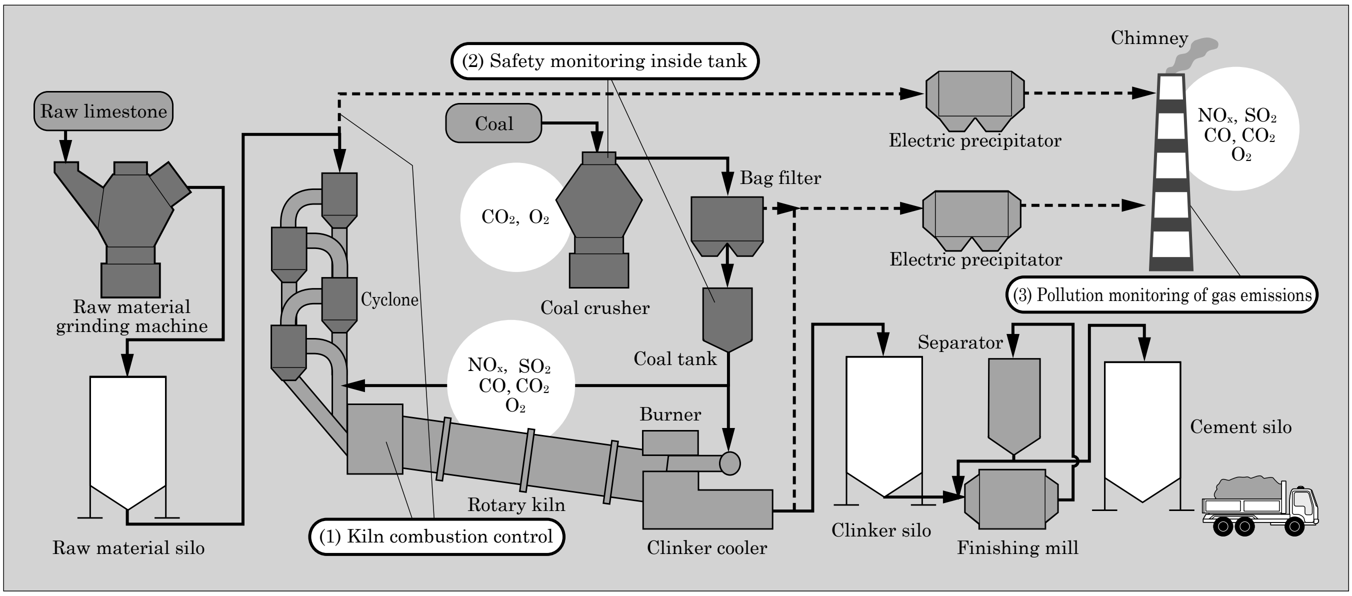

Fig.9 Example application of analyzer in a cement manufacturing process

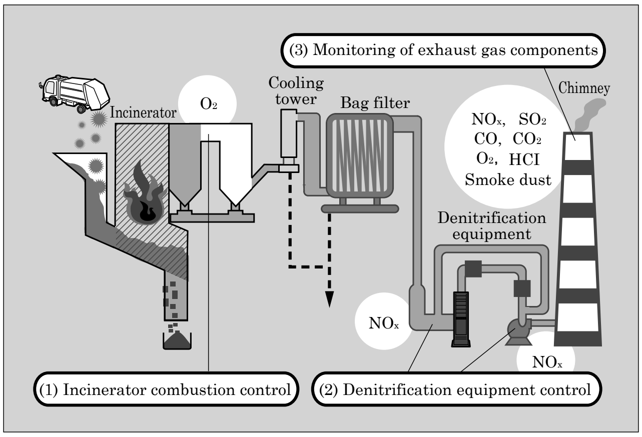

Fig.10 Example application of analyzer in a waste treatment plant

Recently, attention has focused on preventing global warming which is caused by greenhouse gases. Greenhouse gases include CO_2, CH_4 and the like. Infrared CO_2 meters are being used for the purpose of long-term observation of the global environment. The ZP series, with its excellent long-term stability, is well suited for the long-term continuous measurement of CO_2 in the atmosphere.

6. Postscript

The ZP series of compact, high-sensitivity infrared gas analyzers use single infrared beam, improved sensitivity and zero-point drift cancellation to achieve the capability for measurement of low concentrations. Additionally, the handling of all the ZP series equipment has been standardized. The products introduced herein are suitable for use in a wide range of applications for combustion control and exhaust gas measurement in various plants. Fuji Electric has developed the measurement unit of this series to create a line of products.

In the future, Fuji Electric intends to develop gas analysis equipment optimized for these applications, such as by pre-treating the reference gas, and to advance the commercialization of explosion-proof products in order to expand the range of applications.

Applied MEMS Micro-vibration Sensors and Structural Health Monitoring

Satoru Sakaue † Hironobu Yao † Takeshi Suzuki †

ABSTRACT

After the Great Hanshin-Awaji Earthquake, interest has been increasing for earthquake disaster prevention awareness and building safety. As a new field of measuring devices, Fuji Electric has created a prototype vibration sensor module that applies MEMS (Micro Electro Mechanical Systems) technology. This vibration sensor is capable of continuous micro-vibration measurements of around 0.1 Gal. It can detect not only damage by earthquakes, but also the alteration of strength in a building caused by age-related deterioration, so it can be applied to structural health monitoring that includes continuous micro-vibration measurements. We are also considering applications in high-frequency/high-acceleration ranges for motor diagnostics.

1. Introduction

Since the Great Hanshin-Awaji Earthquake in 1995 in Japan, disaster awareness regarding earthquakes and concern for building safety has heightened, and in recent years, there has been an increased in the application of structural health monitoring (SHM) to diagnose the health and safety of buildings. Servo acceleration sensors used primarily for this purpose have the excellent characteristics of high detection sensitivity to extremely low-frequency acceleration, and can be used to measure micro-vibrations constantly at high resolution. The extremely high price of these sensors, however, has been one factor preventing them from coming into widespread use. On the other hand, although lower cost sensors that use micro electro mechanical system*1 (MEMS) acceleration sensor devices have been developed, they have not yet been used in applications for constant micro-vibration measurement, which is necessary for SHM. Fuji Electric is engaged on developments ranging from sensor devices that apply MEMS technology to vibration sensor capable of 3-axis constant micro-vibration measurement. This paper introduces SHM and then describes MEMS micro-vibration sensors and their applications.

2. Structural Health Monitoring

SHM is a technology, having been researched and developed at universities and the like in recent years, for installing sensors in new construction and existing structures in order to diagnose their structural performance based upon response waveforms. SHM technology is able to utilize the response to unfelt earthquakes, which have a relatively high frequency of occurrence[(1)], and to constant micro-vibrations (on the order of 0.1 to 0.5 Gal*2), in order to diagnose the performance of structures (having a resonance frequency in the range of about 0.1 to 20 Hz) and in the case of potential damage from large earthquakes (ranging from several hundred to 2,000 Gal), typhoons and the like, to estimate automatically the extent of that damage.

In addition, by accumulating data continuously, the deterioration of a structure due to aging can be understood, and this information can be used when making decisions about maintenance. In contrast to surface or partial inspections such as periodic visual inspections or ultrasonic inspections, SHM allows the status of the entire structure and locations of defects to be estimated. Fig. 1 shows the SHM sequence. With SHM, sensors are installed in the structure to measure

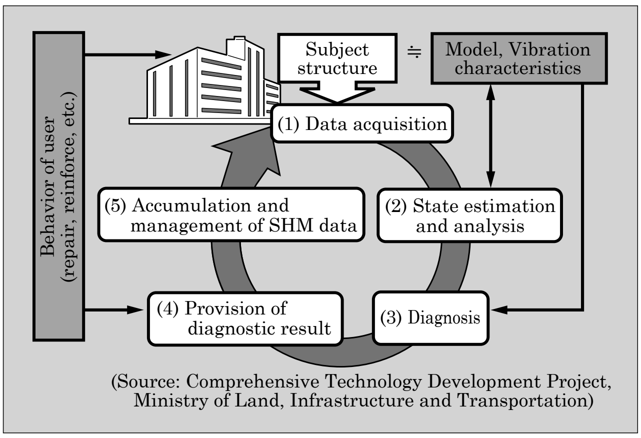

Fig.1 SHM sequence

*1: See MEMS supplemental explanation 1 on page46

*2: Gal is a unit of acceleration, and is defined as 1 Gal= 0.01 m/s^2

† Fuji Electric Co., Ltd.

Table 1 Assumed objective of SHM service

Building life cycle	Service objective
Design, construction, sales	Verification of structural characteristics based on measurement data
Building management	Diagnosis of building deterioration during normal times
Repair, reinforcement	Presentation of necessity and timing of large-scale repair and seismic strengthening
	Presentation of effect of large-scale repair and seismic strengthening
Disaster	Rapid determination of damage status immediately after disaster
	Prediction of structural impact in response to predicted earthquake motion at site
Purchase and sale	Presentation of age-related deterioration of building performance
	Evaluation of asset value based on measurement data
Change of use, etc.	Pre-measurement and post-evaluation of structural impact that accompanies a change of use
Discontinuing usage, Rebuilding	Presentation of service life based on measurement data

(Source: Comprehensive Technology Development Project, MLIT)

the acceleration (or velocity, displacement, etc.) of the structure, and transmit the data to a server to manage. From the transmitted acceleration data, the vibration mode of the structure is analyzed, and based on the computed natural frequency and the like of the structure, a diagnosis is made and the results are displayed. Using the diagnostic results obtained by SHM, the various services shown in Table 1 can be provided for each phase of the life cycle of the building.

In this way, with SHM, the acceleration due to unfelt earthquakes and constant micro-vibrations is measured to understand the shaking of the overall structure. Therefore, the vibration sensors used with SHM are required to have a high resolution of at least 0.01 Gal, and a high-precision time synchronization function of 1 ms or less among the sensors installed in the structure.

3. MEMS Vibration Sensor

3.1 Vibration sensor

To make possible the constant measurement of micro-vibrations, as is required for SHM, a MEMS 3-axis acceleration sensor device, having sensitivity in the low-frequency and low acceleration regions, and its peripheral circuitry were developed and a prototype was built. Fig. 2 shows the appearance of the vibration sensor, Fig. 3 shows the appearance of the MEMS 3-axis acceleration sensor, and Fig. 4 shows a cross-sectional schematic of the sensor device.

The MEMS 3-axis acceleration sensor device is capacitive, and as shown in Fig. 4, detects the displacement of a movable electrode in response to a change in

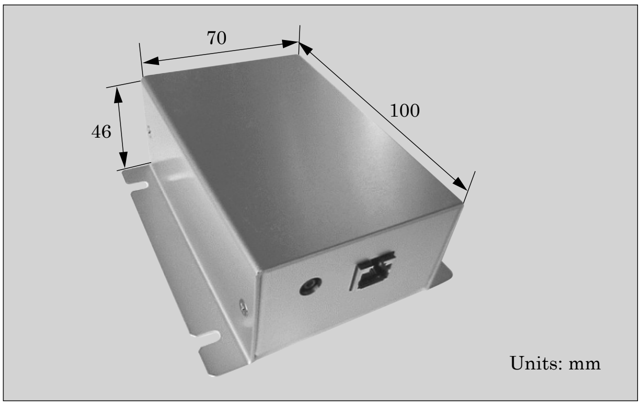

Fig.2 Vibration sensor appearance

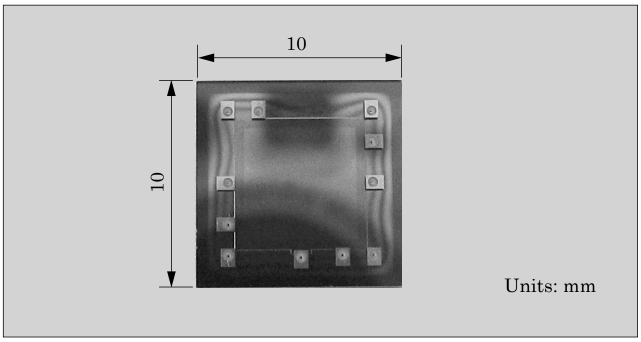

Fig.3 Appearance of MEMS 3-axis acceleration sensor device

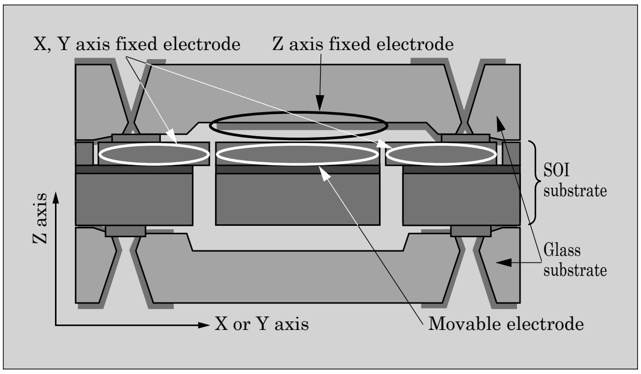

Fig.4 Cross-sectional schematic drawing of sensor device

acceleration as a change in electrostatic capacitance. Displacement along the X and Y axes is detected as a change in electrostatic capacitance between a movable electrode and a fixed electrode formed on a silicon on insulator (SOI) substrate, and displacement in the Z axis is detected as a change in electrostatic capacitance between the movable electrode and a fixed electrode formed on a glass substrate.

Figure 5 shows the structure of a vibration sensor and Table 2 lists the development target specifications of these vibration sensors.

As shown in Fig. 5, the vibration sensor uses a low pass filter (LPF) that cuts off signals above 20 Hz and a 24-bit $\Delta\Sigma$ type analog-to-digital converter in each of the 3 axes to realize high resolution of 0.01 Gal. Because clock error exists among the individual vibration sensor CPUs, the PC transmits a time synchronization packet every 10 seconds in order to achieve time synchronization, and in compared to the specification value of 1 ms as the time synchronization error between sensors, an actual error value of less than 0.5 ms has been attained.

In the connection example shown in Fig. 6, vibration sensors are connected via a power over Ethernet (PoE) hub to a personal computer (PC), and powered using an Ethernet*3 LAN cable (Up to 24 sensors may be connected).

3.2 Building measurement example

In order to obtain experience and knowledge regarding the application of vibration sensors to SHM, a field test was conducted by installing vibration sensors on the 1 st and 4th floors of a 5-story building (Fig. 7) located in the same district as Fuji Electric's Tokyo business place, and micro-vibrations were measured constantly. The vibration sensors were positioned in alignment with the long-side direction as the X-direction and the short-side direction as the Y-direction. The measurements obtained included vibrations from an earthquake originating in the Pacific Ocean off the coast of Japan's Tohoku region. Fig. 8 shows the acceleration waveform at the 1 st and 4th floors at the time of the earthquake, and the acceleration waveform of the constant micro-vibrations immediately prior to the earthquake (enlarged view of interval from 0 to 10 s). Additionally, Fig. 9 shows the Fourier spectral ratio of the 1 st and 4th floors before the earthquake, and Fig. 10 shows the Fourier spectral ratio of the 1 st and 4th floors for the time interval from 70 to 100 s when the amplitude is relatively constant during the earthquake. From Fig. 9 and Fig. 10, it can be seen that the natural frequency of the long-side direction (X axis) decreases from 2.21 Hz before the earthquake to 1.95 Hz during the earthquake, and the natural frequency of the short-side direction (Y axis) decreases from 1.90 Hz before the earthquake to 1.66 Hz during the earthquake. In this field test, we were able to measure the natural vibration frequency of a building with the prototype vibration sensors, and to verify the nonlinearity of the amplitude of the natural vibration

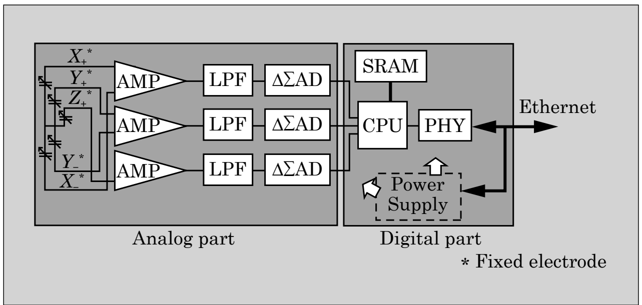

Fig.5 Configuration of vibration sensor

Table 2 Development target specifications of vibration sensor

Item	Specification
Detection direction (number of axes)	3 components (3 axes of X, Y, Z)
Measurement range	±2,000 Gal * (Acceleration: approx. 600 Gal at period of 1 s, and equivalent to Japanese earthquake scale of 7)
Resolution	0.01 Gal
Frequency	0.1 to 20 Hz (structural vibration is primarily 1 to 20 Hz)
Sampling period	100 Hz
AD conversion	24 bit
Time synchronization	1 ms or less
Power source	Supplied by PoE (Power over Ethernet), 48 V, 4 W

* Gal: Unit of acceleration, where 1 Gal=0.01 m/s^2

*3: Ethernet is a trademark or registered trademark of Fuji Xerox Co., Ltd.

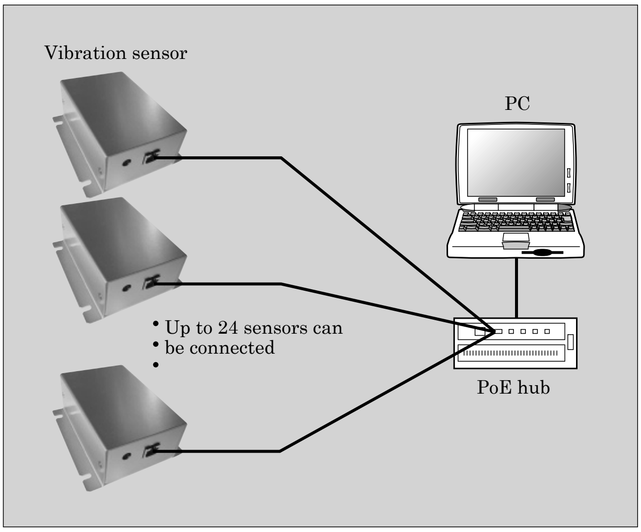

Fig.6 Connection example of vibration sensor

Fig.7 Building with installed vibration sensors

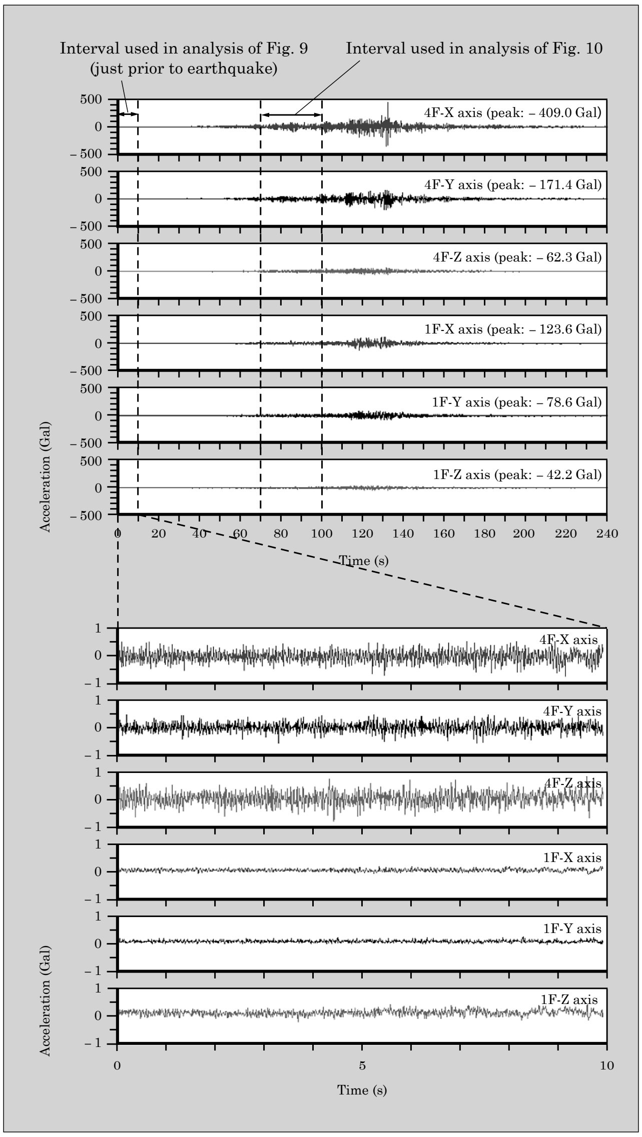

Fig.8 Acceleration waveforms of 1st and 4th floors at time of earthquake

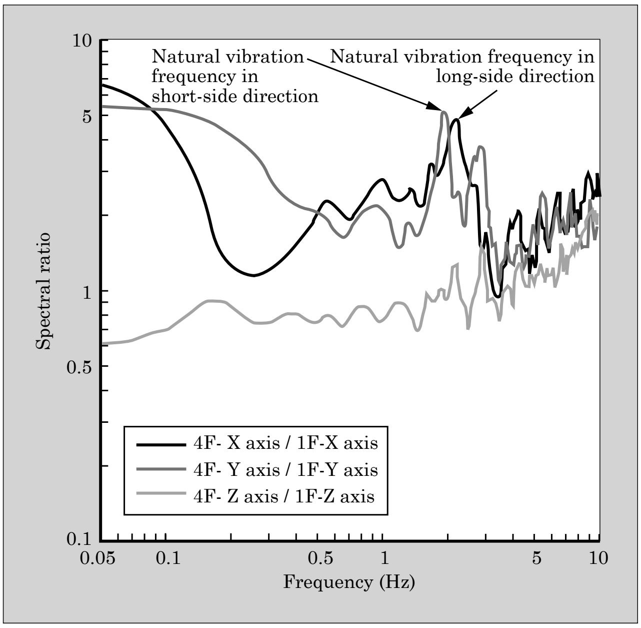

Fig.9 Prior to earthquake (at time of constant micro-vibrations)

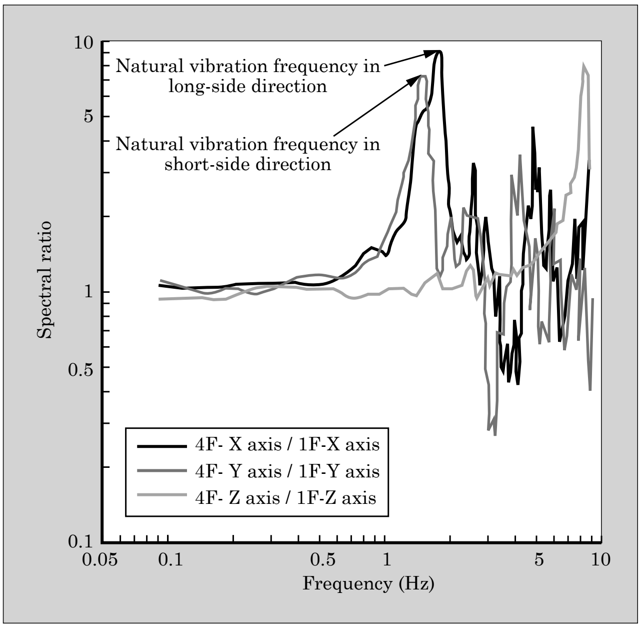

Fig.10 During earthquake (70 to 100 s)

frequency.

The ability to measure vibrations over a wide range from 0.1 to 410 Gal with vibration sensors, and the ability to measure changes in the natural vibration frequency due to changes in the vibrating state of a building were also verified. Damage caused by earthquakes, as well as changes in characteristics such as degraded building strength due to aging-related deterioration, changes in the natural vibration frequency, and so on can be detected, and vibration sensors are considered to be suitable for application to SHM that includes constant micro-vibration measurement.

In addition, vibration sensors can also be used in SHM applications to rail and road bridges.

4. Application to Earthquake Measurement

After the Great Hanshin-Awaji Earthquake of 1995, the National Research Institute for Earth Science and Disaster Prevention began development of a nationwide strong-earthquake observation network in Japan. The result of this construction was the Kyoshin Network (K-NET), a strong-earthquake observation network consisting about 1,000 observatories that cover all of Japan with a grid mesh of about 25 km for the purpose of strong-earthquake research and earthquake disaster prevention. Moreover, in order to realize a higher level of disaster preparedness for earthquakes directly underneath urban areas, which was the lesson of the Great Hanshin-Awaji Earthquake, the Earthquake Research Institute of the University of Tokyo has demonstrated the need for carrying out a detailed evaluation of ground characteristics (from several

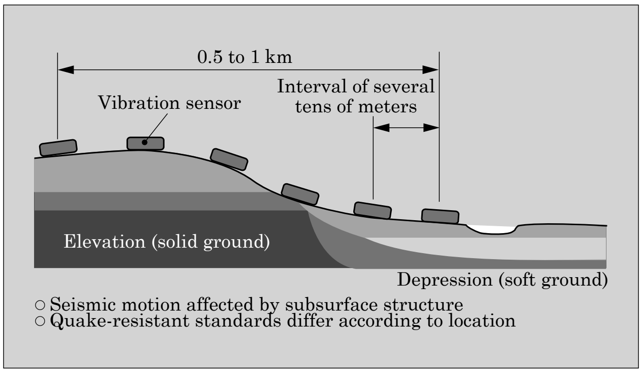

Fig.11 Illustration of ground measurement

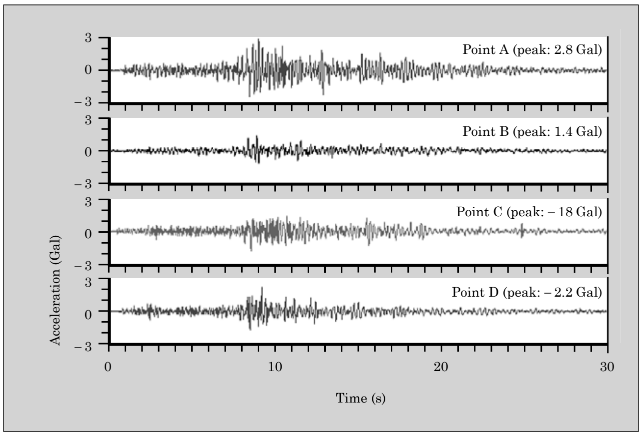

Fig.12 Small-scale earthquake acceleration waveform at Tokyo business place

tens to several hundreds of meters) and to establish disaster prevention criteria for each district through measuring unfelt earthquakes(1) which have a relatively high frequency of occurrence and constant micro-vibrations. Fig. 11 shows an illustration of the ground measurement implementation.

Detailed seismic measurement requires the use of many seismographs. For estimating ground properties, Fuji Electric is studying the application of MEMS-type acceleration sensors which have a cost advantage over the commonly used servo-type acceleration sensors. The specifications required of acceleration sensors for measurement of unfelt earthquakes and constant micro-vibrations are the same as for SHM, that is, high resolution of 0.01 Gal or less and highly accurate time synchronization of within 1 ms among the sensors. For a detailed estimation of ground properties, Fuji Electric installed vibration sensors at 4 locations (points A, B, C and D) in the district of its Tokyo business place, and measured small earthquake acceleration waveforms. Fig. 12 shows the measured acceleration waveforms. Even within the narrow range of these 4 points, which are spaced apart by distances of several tens of meters to several hundreds of meters, the appearance of the vibrations differed, confirming that the manner of shaking was also different.

Table 3 Major challenges in application to SHM and earthquake measurement

Challenge	Solution
Power supply during power outage	○ Built-in battery ○ Change to lower power consumption
Increased cost due to cable installation	Change to wireless technology for cable-free installation
Miniaturization of vibration sensors	Miniaturization of the sensor device and circuit

5. Future Developments

SHM and ground property estimation applications are conventionally in the low-frequency, low acceleration region, but Fuji Electric is attempting to use these applications in the high-frequency, high acceleration region. Fuji Electric is studying the use of vibration sensors to replace commercial vibration diagnostic systems for rotating machines, and also their application to motor diagnostic systems for hybrid and electric vehicles. Fuji Electric possesses the MEMS technology and low-noise circuit technology necessary for sensor development, and that makes possible customization and development from the low frequency, low-speed region to the high-frequency, high-speed region. Additionally, Fuji Electric also intends to address the main challenges for application to SHM and earthquake measurement as shown in Table 3.

6. Postscript

Vibration sensors that use MEMS technology and their applications have been introduced in this paper.

As a result of the prototyping and evaluation of MEMS micro-vibration sensors, application to constant micro-vibration measurement appears to be possible. In the future, Fuji Electric intends to perform detailed evaluations of the performance and applicability of these sensors to performance improvements and structural health monitoring, and to contribute to ensuring building safety.

The authors wish to express their appreciation to Associate Professor Shinichi Sakai of the University of Tokyo Earthquake Research Institute for his advice and guidance concerning the estimation of ground properties.

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(1) "Earthquake Facts and Statistics". USGS. http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php, (Reference 2011-4-21).

Methane Sensor for Cordless Utility Gas Alarms

Takuya Suzuki † Shinichi Soma † Tokumi Nagase †

ABSTRACT

There is a strong desire for utility gas alarms to be made cordless by battery operation. For this reason, the power consumption for methane sensors must be made 1/1,000th or lower than that of current products. Osaka Gas and Fuji Electric have achieved a sensor with this ultra low power consumption by attempting to create a thin membrane and miniaturizing the sensor using MEMS (Micro Electro Mechanical Systems) technology to drive the sensor intermittently to generate heat only at the instant of detection. Currently we are participating in the "Technological Development for a Next-generation Highly-reliable Gas Sensor" project, a New Energy and Industrial Technology Development Organization (NEDO) grant project, and the long-term reliability of the sensor is being verified by large-scale field tests.

1. Introduction

At present, utility gas alarms for home use can be found in approximately 40% of households, but the penetration rate for this market has remained essentially unchanged since 1999. Factors inhibiting greater market penetration include the 100 V AC power specification of existing utility gas alarms and the restriction that the alarms be installed at high locations in a kitchen. Consequently, cordless, battery-powered utility gas alarms are strongly desired. However, because methane sensors must be made to consume very low power that is less than 1/1,000th the power consumption of existing products, the technical challenges for long-term battery power have been extremely high and such technology has been a dream.

Since 1980, Fuji Electric has continued to develop and sell utility gas alarms, and has developed sensors based on semiconductor designs and manufacturing technology that utilizes micro electro mechanical systems (MEMS) technology. This paper introduces a MEMS methane sensor, jointly developed with Osaka Gas Co., that realizes cordless operation in a utility gas alarm.

2. Background

2.1 Prior technology

Semiconductor type gas sensors utilizing tin oxide (SnO_2) as gas sensitive material have been widely used as methane sensors in utility gas alarms. Fig. 1 shows the detection mechanism of this semiconductor type gas sensor. SnO_2 is an n-type semiconductor with electrons as the majority carriers. In a clean air environment, the resistance value increases due to the chemisorption of oxygen, but if a flammable gas such as methane (CH_4) is present, the chemisorbed oxygen reacts with the gas to increase the carrier concentration in the SnO_2 and reduce the electrical resistance. In the case of methane, however, which has low reactivity among flammable gases, the sensor element must be heated to about 400 °C.

Conventional methane sensors, commonly called "sintered body type sensors" or "bulk type sensors" are the mainstream. These sensors, in which gas-sensitive materials consisting mainly of SnO_2 surrounding a metal heater coil are sintered, have reached their limit for reducing power consumption through miniaturization.

2.2 Requirements for cordless utility gas alarms

So that utility gas alarms can be powered by batteries at a realistic cost for the duration of their 5-year lifecycles, the average power consumption of the methane sensor part must be reduced to 0.1 mW or less. (Here, the average power consumption refers to the power consumed to drive the sensor elements and the control circuit.) This reduction in power consumption is

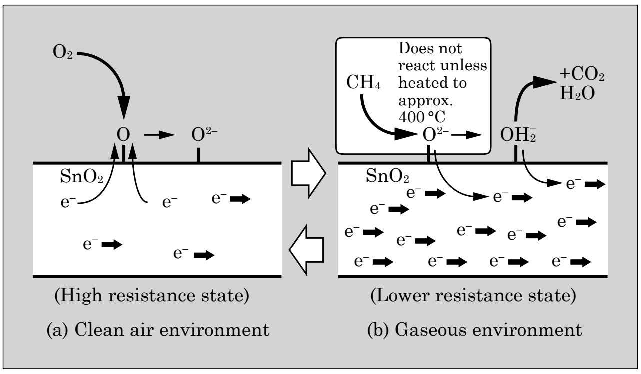


Fig.1 Sensing mechanism of semiconductor gas sensor

† Fuji Electric Co., Ltd.

a novel concept and is 1/1,000th that of existing methane sensors.

While working to realize such ultra low power consumption, basic performance that satisfies the "utility gas alarm inspection regulations" (JIA E001-07) of the Japan Gas Appliances Inspection Association and 5-year long-term reliability are sought.

3. Development of Methane Sensor Having Ultra Low-Power Consumption

3.1 Thinner film gas sensor

Osaka Gas Co. has been researching thin film gas sensors since 1980, and by employing a thin film fabrication technique known as "RF sputtering" and controlling microstructures at the nanometer level, has developed a method for producing SnO_2 thin film having a special "nano columnar structure." Fig. 2 shows a scanning electron microscope (SEM) photograph of this structure. Because gas molecules are able to diffuse between the columnar structures, a high sensitivity is realized and the thin film has the features of stable crystalline particles and sensitivity that remains unchanged over long periods of time.

Osaka Gas has also developed a "thin film methane sensor" having high sensitivity and selectivity to methane by laminating, on top of a columnar-structure SnO_2 thin film, a catalytic thick film through which the combustion-removal of flammable gases such as hydrogen (H_2), carbon monoxide (CO), alcohol and the like is possible.[1]

3.2 Ultra low power consumption by applying MEMS technology

Osaka Gas Co. and Fuji Electric have jointly developed a thin film micro methane sensor based on Osaka Gas's thin film sensor technology and using Fuji Electric's proprietary MEMS technology[2].

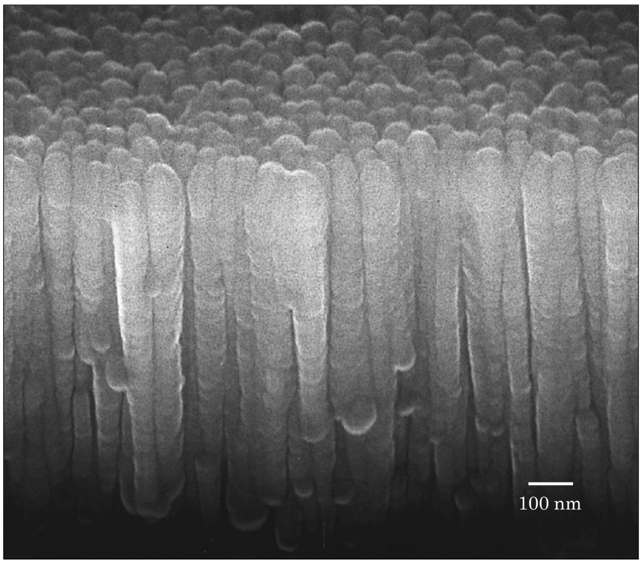


Fig.2 SnO_2 thin film SEM photograph

As shown in Fig. 3, the sensor is constructed with a new structure consisting of a thin film heater, SnO_2 thin film and catalytic thick film formed on top of a thin film diaphragm, and the sensor is intermittently driven and heated only at the time of detection.

Features of ultra low power consumption are as follows.

(1) Spot heating

By forming a thin film heater on a thin film diaphragm having a thickness of several microns, small areas of several hundreds of microns in size, and tending to retain their heat, can be heated.

(2) Short pulse heating

Because SnO_2 thin film, which has a small heat capacity, is formed above a thin film heater, with an electrically insulating layer positioned in between, the thermal responsiveness is good and short pulse heating can be implemented.

(3) Intermittent driving

With the ability to perform short pulse heating, intermittent driving is possible such that heating is performed only at the moment of detection and is stopped at all other times.

Figure 4(a) shows the heater power consumption and Fig. 4(b) shows the gas responsiveness of the newly developed thin film micro-methane sensor. Fig. 4(a) shows the relationship between heater power consumption and surface temperature (center part) at a steady state, and Fig. 4(b) shows the relationship between heater heating time and sensor resistance value when 30 mW of power is supplied to the heater. From these drawings, it can be seen that the heater power

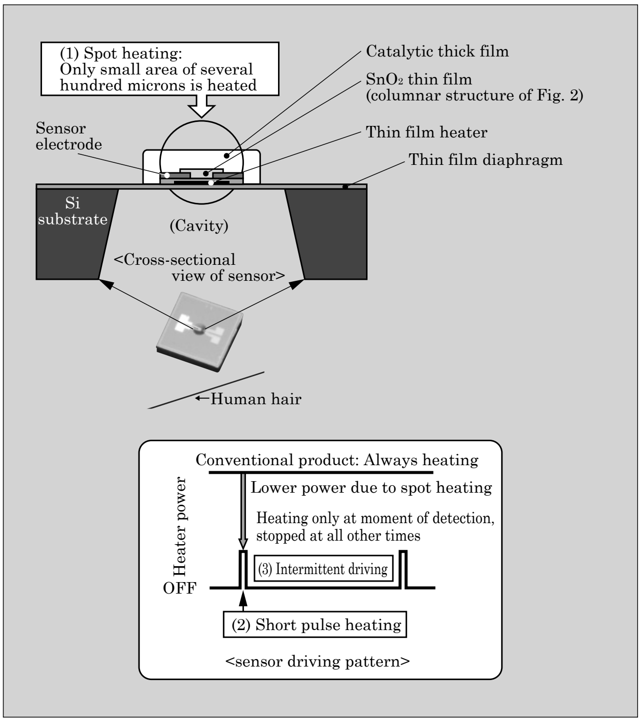


Fig.3 Structure and driving patter of thin film micro methane sensor

necessary for heating the sensor to 400 °C is less than 30 mW, which is low, and that the sensor responds quickly to gas, with methane sensitivity (the change in the sensor resistance value in air) occurring in several tens of milliseconds. Thus, by reducing the power consumed in heating the sensor to 400 °C and enabling short pulse driving by improving gas responsiveness, an average power consumption that is 1/1000th that of existing methane sensors was realized.

Note that in Fig. 4 it can be seen that for a heater heating time of several tens of milliseconds, sensitivity to H_2 and CO is established (when the resistance value in gas is lower than the resistance value in air) but that the H_2 and CO sensitivity diminishes thereafter (with the resistance value in H_2 and CO increasing and approaching the value of resistance in air). This behavior occurs after several tens of milliseconds because H_2 and CO are combusted and removed through the catalytic thick film, and the concentration of gas reaching the SnO_2 surface diminishes.

3.3 Basic performance

A methane sensor for use in utility gas alarms must have high sensitivity to methane, which is a major component of town gas, and also must have selectivity with regard to interfering gases such as H_2 and CO.

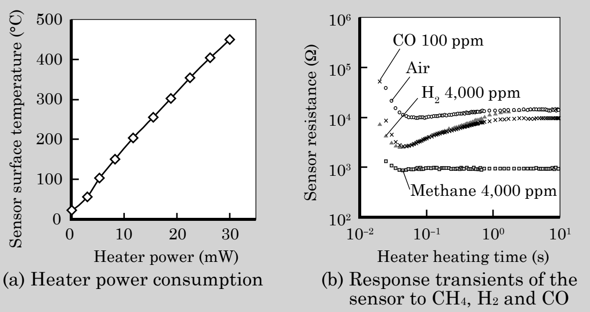
Figure 5 shows the gas sensitivity characteristics of the new developed thin film micro methane sensor. Gas sensitivity is defined as the ratio (Rair/Rgas) of sensor resistance in a clean air environment (Rair) to the sensor resistance in a gaseous environment (Rgas).

From Fig. 5, it can be seen that gas sensitivity increases with respect to methane concentration, and that at the level of 2,000 ppm of methane, the sensitivity is greater than 5, while on the other hand, for H_2 and CO, gas sensitivity is suppressed to rather low levels compared to methane, and therefore the sensor does exhibit sufficient basic performance as a methane sensor for use in utility gas alarms.

4. Long Term Reliability

In addition to exhibiting the basic performance described above, a methane sensor for use in a utility gas alarm is also required to provide long-term reliability with at least a 5-year replacement term.

Fuji Electric is participating in the “Next Generation High Reliability Gas Sensor Technical Development (2008 – 2011)” project sponsored by the New Energy and Industrial Technology Development Organization (NEDO), and aims to establish long-term reliability. In this project, accelerated testing is performed in a laboratory based on large-scale field tests and the data thereof with the aim of realizing a useful service life of at least 5 years. In the large-scale field tests, so that data can be acquired in various types of installation environments, the following factors were considered broadly as conditions of the installation



(a) Heater power consumption

(b) Response transients of the sensor to CH_4, H_2 and CO

Fig.4 Heater power consumption and gas responsiveness of thin film micro methane sensor (responsiveness of sensor resistance in various gas environments)

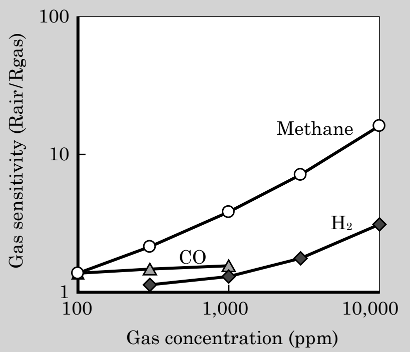


Fig.5 Gas sensitivity characteristics of thin film micro methane sensor

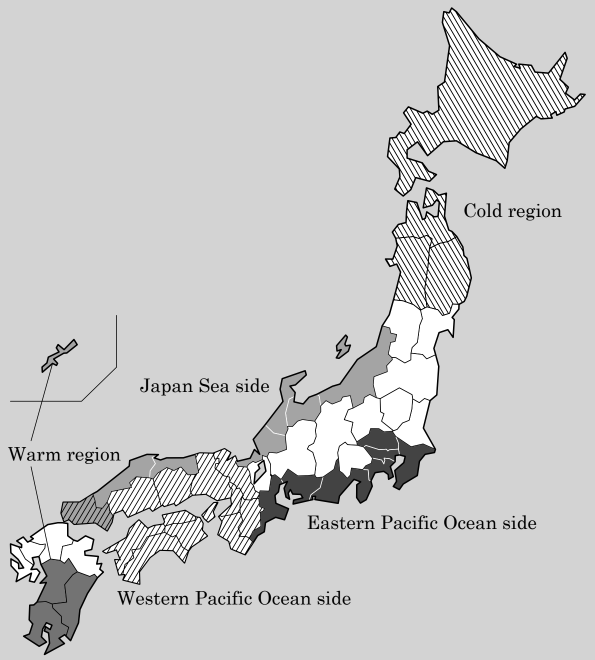


Fig.6 Installation sites of the large-scale field test

site: (1) geographical region (climate), (2) house type, (3) family structure, and (4) year built (building and painting materials). Fig. 6 shows the installation areas of the large-scale field test.

For this large-scale field test, 400, 200 and 60 units were tested in years 2008, 2009 and 2010, respectively, and field data of up to 2.5 years can be acquired so far. Additionally, the construction work for accelerated testing based on the accumulated data is proceeding according to schedule, and by the end of the project, long-term reliability corresponding to a service life of at least 5 years is anticipated.

(a) Existing product (AC power specification) (b) Cordless product (Battery powered)

Fig.7 Appearance of utility gas alarms

5. Application to Utility Gas Alarms

Simultaneous with the development of methane sensors, cordless utility gas alarms that are equipped with such sensors are being studied.

Figure 7 shows the external appearances of existing and cordless utility gas alarms. The cordless product has the same footprint as the existing product, but with a thinner and simple profile. The cordless type utility gas alarm also has the same basic specifications as the existing product, and functions to detect gas leaks, incomplete combustion and fire.

6. Postscript

This paper has introduced a methane sensor for use in cordless utility gas alarms that incorporate MEMS technology, which is an area of expertise of Fuji Electric.

By realizing the early mass production of this sensor and making efforts to popularize utility gas detectors for residential use, Fuji Electric intends to contribute to the safe use of energy.

Some of the research herein was carried out with support from the “Next Generation High Reliability Gas Sensor Technical Development” project of the New Energy and Industrial Technology Development Organization (NEDO) and by collaborative development with the Osaka Gas Co. The authors wish to express their gratitude to all parties concerned.

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Seismic Countermeasures for Environmental Radiation Monitoring System

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ABSTRACT

Environmental radiation monitoring system continually measures and monitors the air absorbed dose rates around nuclear facilities 24-hours a day, 365-days a year. These systems must continue to function even when a disaster occurs such as an earthquake. Fuji Electric takes countermeasures for earthquakes by duplicating transmissions lines with land radio equipment and installing backup power supplies, seismically isolated monitoring posts, and seismically evaluated equipment. Furthermore, we have developed new portable monitoring posts equipped with semiconductor detectors and monitoring cars equipped with the same functions as stationary monitoring posts, and we can supply equipment that makes measuring and monitoring possible without power supplies or transmission lines.

1. Introduction

An environmental radiation monitoring system (outdoor monitoring system) for a nuclear facility measures and monitors air absorbed dose rates around the nuclear facility 24-hours a day, 365-days a year.

The air absorbed dose rates to be measured is data that pertains to the "obligation to notify a nuclear emergency preparedness manager in the case that a radiation dose above the limit specified by a Cabinet Order has been detected near the border of an area where the nuclear site is located" as stipulated in the Act on Special Measures Concerning Nuclear Emergency Preparedness and outdoor monitoring equipment is essential for operation of a nuclear power plant.

Meanwhile, during normal operation, the healthy operating state of a nuclear facility is broadcast via the Internet to the neighboring community as well as to the public at large, and this also has the side of promoting Public Acceptance: social acceptance of nuclear energy policy (PA).

The promotion of nuclear power has gained momentum in the United States, Asia and elsewhere throughout the world because nuclear fuel can be recycled and the amount of CO_2 emissions is low. The situation concerning nuclear energy has been changing, however, as a result of the Great East Japan Earthquake, which occurred on March 11, 2011. Attention is particularly focused on safety measures for nuclear power plants, and outdoor monitoring systems are required to be capable of measuring air absorbed dose rates continuously even in the event of a disaster.

This paper introduces seismic countermeasures so that outdoor monitoring systems will be able to continue their measuring and monitoring activities in the event of an earthquake.

† Fuji Electric Co., Ltd.

2. Overview of Outdoor Monitoring Equipment

An outdoor monitoring system is configured from stationary monitoring posts for measuring the air absorbed dose rate and atmosphere in nuclear facilities (near the border of controlled areas) or outside of the facilities (neighboring communities), a monitoring system for issuing instructions or recording data in a central control room, and a telemeter system for transmitting data. A portable monitoring post which can be transported and installed outdoors and a monitoring car provided with measuring equipment that is able to take measurements while driving are available as ancillary equipment.

3. Seismic Countermeasures

In the event that an outdoor monitoring system is affected by an earthquake, the following types of damage are anticipated.

(a) Severed data transmission line due to landslide
(b) Severed power supply system due to damaged power distribution equipment
(c) Damage to buildings or devices due to shaking by the earthquake

Countermeasures to continue monitoring under these circumstances are described below.

3.1 Transmission channel redundancy

Optical cables are used for transmitting data from the monitoring posts (buildings) to a central control room. In the event that an optical cable is severed, the monitoring function would be lost, however, and therefore a backup system comprised primarily of satellite-based mobile phone lines had been used. However, the optimal form of the wireless unit was reconsidered on the basis of The Niigataken Chuetsu-oki Earthquake that occurred in July, 2007 and in consideration of the conditions at the time of the earthquake. Specifically, the wireless unit is required to:

(a) be unaffected by communication restrictions caused by an overconcentration of phone calls,
(b) have an antenna with low directionality (able to withstand tilting of the antenna due to earthquakes),
(c) be usable under poor conditions such as heavy snow or rain,
(d) be unaffected by obstructions (terrain or trees) as much as possible,
(e) be small in size because the installation site is cramped, and
(f) be rigid and durable.

Since there are no commercially available wireless units that satisfy all of the above requirements, Fuji Electric, in collaboration with a wireless equipment manufacturer, has developed a custom wireless unit for outdoor monitoring systems. This wireless unit is based on a small terrestrial radio device operating in the 400 MHz band, which has a proven track record in applications such as for river management, and has been customized to realize transmission specifications applicable for outdoor monitoring. In addition, to minimize downtime during inspections, we modified the unit so as to allow for the easy replacement of parts that are replaced periodically. The RS-232C standard was adopted for connection to the telemeter equipment, and this standard is also compatible with the previous model of outdoor monitoring system that is in operation.

As of the present date, radio propagation testing of the new wireless unit inside a nuclear power plant had been completed, and the unit is expected to be finished by March 31, 2012. Specifications of the wireless unit are listed in Table 1 and the implementation of the onsite propagation investigation is shown in Fig. 1.

Table 1 Specifications of the wireless unit

Item	Specification
Frequency band to be used	400 MHz band
Oscillation method	Synthesizer
Modulation method	Frequency modulation
Type of radio wave	F2D, F3E
Antenna type	Yagi antenna (400 MHz band, 50 Ω)
Communication method	Half-duplex communication
Coding method	NRZI Equal-length coding
Synchronization method	Asynchronous
Transmission rate	1,200 kbits/s
Code configuration	JIS X5203

3.2 Backup power supply

Power for a monitoring post is supplied via an overhead line from an onsite power distribution unit. In the event that the power distribution unit, electric pole or electric wire become damaged, the power supply will be cut off, and therefore a backup power source is also necessary and has been provided on the side of the building. Fuji Electric ensures the power source operation by using the combination of an uninterruptible power system and an engine generator according to the required backup time and capacity of the equipment. Fig. 2 shows the installed state of the backup power supply equipment.

3.3 Use of seismic isolated building structure

The stationary monitoring post has a building structure as shown in Fig. 3 and is installed on the site of a nuclear facility (near the boundary of a controlled area) or in a neighboring community. Inside the stationary monitoring post building, a radiation detector, measurement assembly, particulate monitor, meteorological monitoring equipment and telemeter equipment are provided. As to prevent damage to the equipment or a collapse of the building due to an earthquake, a seismic isolated building structure has been employed. The structure of the seismic isolation assembly at the base of the building is shown in Fig. 4.

Fig.1 Implementation of onsite propagation investigation

Fig.2 Installed state of backup power supply equipment

3.4 Seismic assessment of installed equipment

A seismic assessment evaluation of the equipment installed in a central control room was performed by means of an acceleration resistance test, and all the equipment was confirmed to be free of problems. Conditions and confirmation methods of the acceleration resistance test (for devices) are listed in Table 2, and Fig. 5 shows the circumstance in which the acceleration resistance test was implemented.

3.5 Portable monitoring post

Portable monitoring posts are measuring devices that can be transported to a measuring site in the event of a disaster or occurrence of a nuclear hazard for which emergency monitoring is required. Portable monitoring posts are required to be lightweight, so that they can be installed manually, and have the equivalent measuring performance as a stationary monitoring post. Fuji Electric has previously supported the elimination of devices, reduction of weight and ensured performance by providing a wide-range measurement model that uses a single NaI (Tl) scintillation detector capable of measuring from the low-dose region (by pulse measurement) to the high-dose region (by current measurement). To accommodate the needs of further weight reduction and long-term operation, Fuji Electric has newly developed a portable monitoring post that uses a lightweight and low-power semiconductor detector.

Specifications of the semiconductor type (latest type) and NaI (Tl) scintillation type (previous type) of portable monitoring posts are compared in Table 3, and Fig. 6 shows the appearance of semiconductor-type.

There are slight differences in the accuracy of dose rate measurment and the energy respones and directional characteristics, but like the previous type, the semiconductor type is capable of measurement of up to 10^5 μGy/h (10^8 nGy/h), which is the dosage rate expected in the event of an accident, and can be used as an alternative measuring system if a stationary monitor-

Fig.3 Appearance of stationary monitoring post (seismic isolated building)

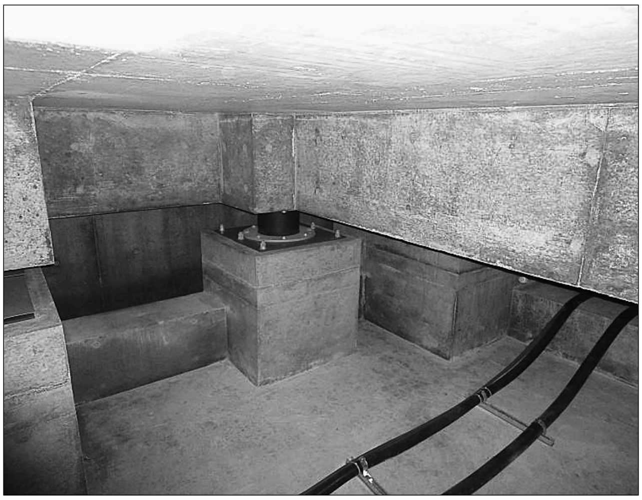

Fig.4 Structure of seismic isolation assembly (base of building)

Table 2 Conditions and confirmation methods of acceleration resistance test (for devices)

Vibration test conditions	Vibration frequency	33 Hz if the resonance frequency is 33 MHz or more The resonance frequency if the resonance frequency is less than 33 MHz	
	Acceleration	Vertical	29.4 m/s^2 (2,940 Gal)
		Horizontal	29.4 m/s^2 (2,940 Gal)
	Direction of vibration	Horizontal (back and forth, left and right), Vertical (along the 3-axis)	
	Vibration time	120 s (each axial direction)	
Items to confirm	○ No damage on devices before and after the test ○ No malfunction or failure before and after the test ○ Within allowable error range before and after the test		

Fig.5 Acceleration resistance test circumstance

Table 3 Comparison of portable monitoring post specifications

Item	Semiconductor type (latest type)	NaI (Tl) scintillation type (previous type)
Detector	Silicon semiconductor detector	NaI (Tl) scintillation detector (wide-range)
Radiation to be measured	Gamma rays	Gamma rays
Measurement range	10^2 to 10^8 nGy/h	Low-dose region: 10 to 5×10^5 nGy/h High-dose region: 3×10^5 to 10^8 nGy/h
Accuracy of dose rate measurement	±20% (0.1 μGy/h or greater, ^{137}Cs reference)	±10% (^{137}Cs reference)
Energy range	60 keV to 3 Mev	Low-dose region: 50 keV to 3 MeV High-dose region: 50 keV or greater
Energy response	±30%, 60 keV to 3 Mev (^{137}Cs reference)	Low-dose region: ±20% (50 to less than 100 keV) ±10% (100 keV to 3 MeV) High-dose region: −50 to +25% (50 to 100 keV) −10 to +20% (100 to 400 keV) ±10% (400 keV to 3MeV)
Directional characteristics	+20%, (0 to ±90°)	+20%, (0 to ±90°)
Display	12.1 inch TFT color LCD	N/A
Data record	Stores per-minute dose rate values for one month	Stores per-minute dose rate values for one week
Data transmission	Ethernet* output (can be combined with satellite-based mobile phone)	RS-232C output

* : Ethernet is a trademark or registered trademark of Fuji Xerox Co., Ltd.

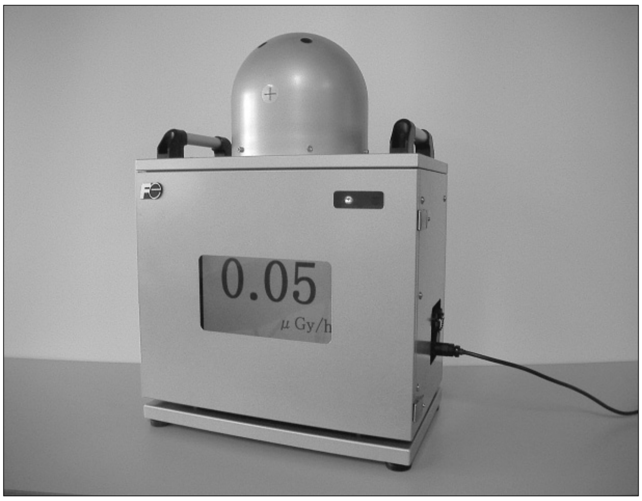

Fig.6 Semiconductor-type portable monitoring post

Fig.7 Appearance of monitoring car

ing post is not available. Moreover, lead-acid batteries and a wireless unit may be installed additionally so as to allow remote measurement and monitoring in locations where there is no power supply or transmission cables. Ethernet output is used for transmitting measurement data, and can be connected to various wireless devices according to the installation environment.

In the system for receiving the measured values, the use of a lightweight and compact notebook personal computer makes possible the flexible and real-time monitoring of measurement values from an off-site center or temporary emergency operation center in the event that the power plant has been affected by a disaster.

3.6 Monitoring car

A monitoring car is a modified cargo truck or minivan equipped with measuring devices. Fuji Electric has developed a monitoring car equipped with a function for measuring specific nuclides such as iodine and using a NaI (Tl) scintillation detector and a measurement unit (provided with a single channel analyzer function), an ionization chamber detector for measuring high-dose regions, and a radioactive particulate measurement device. Previous monitoring cars had limited onboard space and were only equipped with simplified equipment, but this time a larger vehicle was used to realize the same performance and the same functions as a stationary monitoring post with higher measurement precision. Additionally, a wireless unit is used to transmit data to an emergency operation center so that onsite conditions can be grasped in real-time even at a remote site. The monitoring car appearance is shown in Fig. 7 and the interior is shown

Fig.8 Interior of the monitoring car

Fig.9 Appearance of simplified monitoring posts

in Fig. 8.

3.7 Simplified monitoring post

In the event of an earthquake, air absorbed dose rate monitoring is required not only for the communities neighboring a nuclear facility but over a wide range area.

Fuji Electric has developed a simplified monitoring post consisting of a detector mounted on top of a compact enclosure. By providing a single NaI (Tl) scintillation detector capable of measurement from background levels to 10^5 nGy/h and the minimum functions required for monitoring, the price, dimensions and weight of the simplified monitoring post were held down. Also accurate measurement performance is ensured by utilizing components equivalent to those used in the stationary monitoring posts installed at nuclear power plants. Fig. 9 shows the appearance of simplified monitoring posts.

4. Future Efforts

The Great East Japan Earthquake caused unprecedented devastating damage by a tsunami. Stationary monitoring posts are the fundamental type of outdoor monitoring posts. However, in anticipation of various scenarios of damage, portable monitoring posts must also be provided, and performance improvements are the key for promoting their adoption. As an example of a specific initiative, Fuji Electric is in the process of developing a product that employs a semiconductor detector and by replacing heavy lead-acid batteries with lithium-ion batteries or by using solar cells, achieves both further weight reduction and longer term operation. Reducing the cost and furthering the popularization of simplified monitoring posts will promote more precise air absorbed dose rate monitoring around nuclear facilities.

5. Postscript

This paper has described the status to date of seismic countermeasures for outdoor monitoring systems to assure the safety and security of nuclear facilities and especially for nuclear power plants. In the future, by concentrating our efforts on improving the reliability of stationary monitoring posts and developing an emergency monitoring system, Fuji Electric intends to contribute for improving the reliability to utilize nuclear energy.

Supplemental Explanation

Supplemental explanation 1 MEMS

In general, micro electro mechanical system (MEMS) is a generic term for devices such as mechanical components, sensors, actuators, electronic circuits and other such devices that integrate various functions and that are fabricated using semiconductor microfabrication technology. In Japan, this field had previously been known as the micro machine field.

To manufacture MEMS devices, various types of materials are processed, typically silicon (Si) wafers, glass wafers and the like. MEMS devices are fabricated using nearly the same equipment as for large scale integrated (LSI) circuit manufacturing, but MEMS specialized equipment is also necessary for such processes as wafer bonding, deep etching to a depth of several hundred microns, and forming three-dimensional shapes or movable structures, which are not used in LSI manufacturing.

Technology for fabricating MEMS structures includes surface micro-machining for forming laminated structures on the surface of Si substrates or the like, and bulk micro-machining which utilizes deep etching technology to process the Si substrate itself and form structures. Until recently, surface micro-machining, which is similar to the technology used in LSI fabrication, had been the more common but with advances in MEMS-specific process technology such as deep etching and wafer bonding, bulk micro-machining has become more widely used.

Examples of typical MEMS devices include acceleration sensors, pressure sensors, ink jet heads, gyroscopes, and so on.

Supplemental explanation 2 Specific energy consumption

The specific energy consumption is the amount of energy usage divided by “a value closely related to production volume, building floor space or the like,” which provides an energy management index. This index was created under the assumption that energy consumption will increase if the production volume or building floor space increases.

Here, “a value closely related to production volume, building floor space or the like” refers, in the case of a plant, to the number or weight of products manufactured, while in the case of a building, the total floor space is often used. A suitable quantity must be used for each plant or workplace.

As an energy savings index for an entire plant, the specific energy consumption is a numeric value obtained by dividing the total amount of energy by the total production volume. In a plant that manufactures many types of products, however, the total plant production volume cannot be expressed with a single quantity. Even with an energy consumption rate for the entire plant, if the energy management attempts to reduce consumption, the constituent elements will have to be retroactively analyzed and thus the specific energy consumption will ultimately be managed separately for each product and process. In addition, assessment of the individual specific energy consumption for fuel, electric power, service water and other types of energy or their applications, and analysis of their relation to production volume, yield and manufacturing equipment performance is necessary.

Supplemental explanation 3 Sequence control and motion control

Sequence control is defined, according to Japan Industrial Standard (JIS), as "control that proceeds sequentially through various stages of control according to a predetermined order or procedure." Sequence control is applied, for example, to equipment such as building elevators and car wash facilities, food product production lines that require automation, and production line equipment at plants that manufacture automobiles or other products for which a series of operations are performed based on operating instructions.

Motion control uses drive equipment such as servo amplifiers and inverters to implement sophisticated synchronous control of the operation of multiple motors. Motion control is applied, for example, to printers that print by overlaying multiple colors and to packaging machines that need to align locations for adhesion, and in steel plants, to rolling mills for forming uniform material thicknesses, and to the control of servo-presses or other equipment at high speed and with high precision.

In actual factory production lines and at steel plants, control systems are typically realized by combining sequence control and motion control. In such cases, sequence control and motion control had each previously been implemented with their own CPU module, but recently, with the improved performance of microcontrollers and other such devices, sequence control and motion control can be implemented with a single CPU module.

Supplemental explanation 4 Drift performance

Drift performance is a performance indicator that also designates stability, and is a key factor in indicating the performance of gas analyzers. Drift performance is typically discussed in terms of zero drift (stability of the zero point) and span drift (stability of the sensitivity corresponding to the concentration proportionate to the measurement range). These quantities are expressed as the ratio of the zero point or span fluctuation versus the measurement range within a fixed period such as a day, a week, a month, and so on. As the measurement range progresses toward lower concentrations, the drift performance deteriorates relatively, and therefore, improvement of the drift performance presents a challenge.

Drift in an infrared gas analyzer is caused by internal and external factors. The internal factors include fluctuations in the infrared light source intensity and detector sensitivity caused by temperature changes and fluctuations in the supplied power, as well as long-term deterioration of the infrared intensity and changes in the detector sensitivity. The external factors include contamination of the sample cell window and walls by contaminants (such as dust or mist) in the measurement gas.

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