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System Control and Drive Components

Fuji Electric Group

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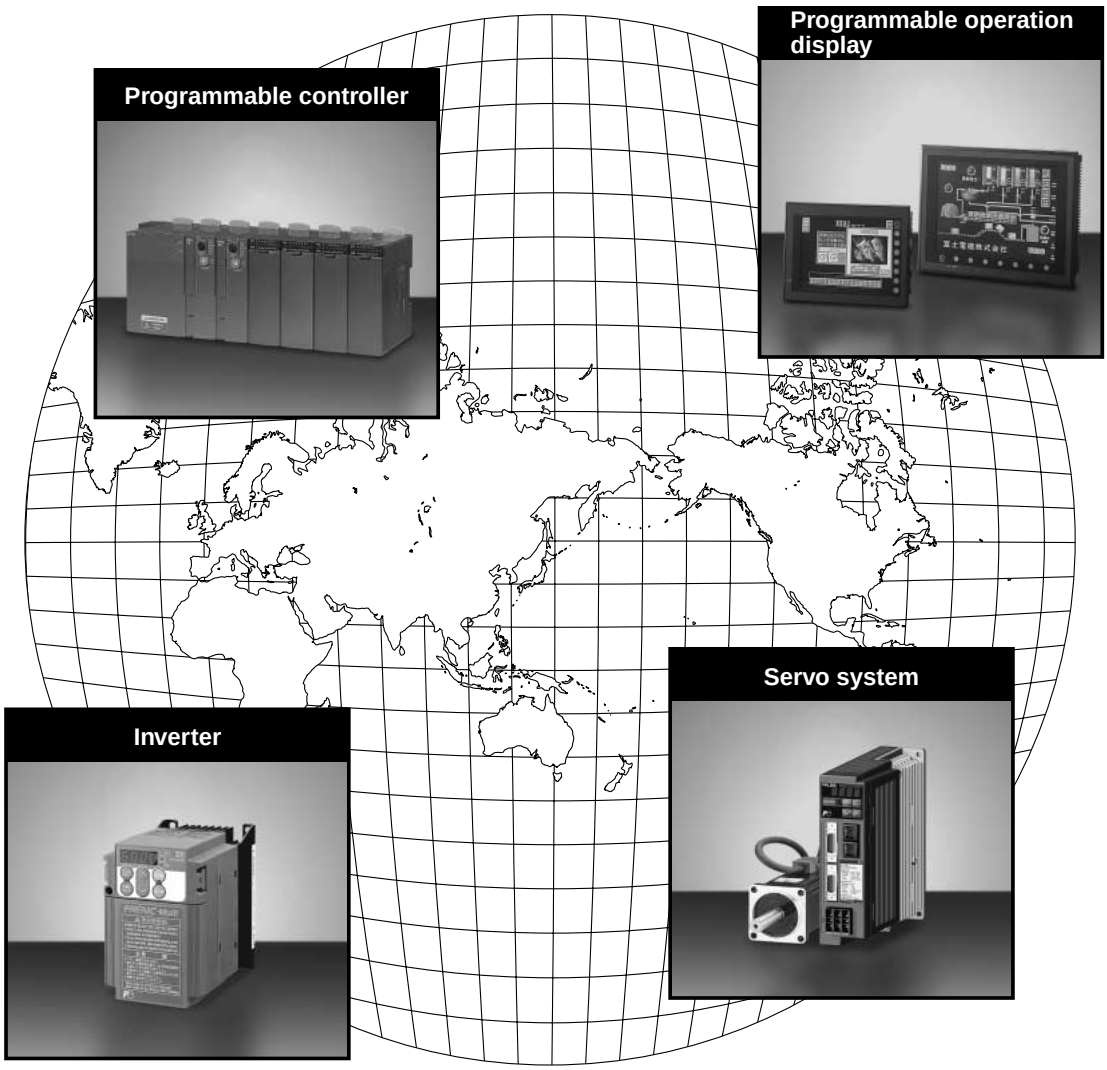

Realizing world's highest class performance in FA and mechatronics fields.

Day by day, leading-edge systems in FA lines and intelligent buildings are becoming more sophisticated. The accurate operation of those systems is supported by Fuji's system components.
To provide products suitable for use throughout the world, both hardware and software of our programmable controllers conform to IEC standards and support various open networks such as Ethernet*1 and DeviceNet*2. Additionally, programming environments support languages suitable for control applications, and various software functions such as speed and position control are combined to facilitate the creation of application programs for large-scale systems.
World's highest class control and drive systems can be constructed by combining our programmable controllers, programmable operation displays, inverters and servo systems.
Fuji Electric provides powerful support for your business as a leader in system control and drive components.

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Fuji Electric's System Control and Drive Components

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CONTENTS

Cover photo:

Today's industrial automation systems face many challenges such as achieving total manufacturing optimization and realizing facility energy-savings. Consequently, system control devices used here are required not only to provide individual functionality and performance, but also to enhance integration capability of the system when combined with these devices.

With expanded application range resulting from enhanced performance and added product lines, as well as the support of open network and standard programming technology, Fuji Electric's core system control devices, MICREX-SX integrated controller, FRENIC general-purpose inverter and FALDIC servo system, continue to evolve into flexible and efficient system components.

The cover photo shows these devices organized by a network for optimal operation.

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Present View and Outlook for System Control and Drive Components

Mitsunori Fukuzumi
Kouetsu Fujita

1. Introduction

The control systems that have realized continuous improvements in such applications as automation of manufacturing system and energy saving of facility operation have been supported by advances in major components, such as drive system devices typified by general-purpose inverters and servo systems, and control, operation and display devices typified by general-purpose programmable controllers (PLCs), and programmable operation displays (PODs).

These system control devices are fundamentally required to exhibit high performance, multi-functionality and low cost as a standalone device, and additionally required to provide expandability and flexibility when integrated into a system configuration. Recently, reliability and safety have become important evaluation criteria when selecting devices with which to construct a system.

This paper describes general technical trends overlooking new technologies of system control devices presented in this special issue and introduces Fuji Electric's corresponding product lines.

2. Technical Trends of System Control Devices

2.1 Technical trends of drive system devices

(1) Performance enhancing technology

Requirements of the drive system include not only motor speed and position control, but also the ability to realize energy savings in the whole system, including load, and high-speed responsiveness, which correlating to a reduction of takt time in consideration of structure of the load machine and rigidity of the part for mounting.

Fuji Electric's servo systems are equipped with vibration suppression control as a fundamental function to increase responsiveness of the whole system. With this function, multi-inertia model that includes model of load machine is stored within servo amp, and compensation is performed to minimize the vibrations of this model in order to realize high-speed response in machinery, such as robotic arm having relatively low rigidity. To utilize the vibration suppression control function, an accurate capture of transfer function of the mechanical system is needed, and for this purpose a servo-analysis function has been developed. The servo-analysis function can analyze resonance frequency and anti-resonance frequency of the mechanical system to facilitate the user's task of parameter setting. Such mechanical system analysis is performed either offline during an initial operating mode that differs from the usual operation, or online during usual operation. Fuji Electric's easy tuning function operates offline to analyze the transfer function of complex mechanical systems and to auto-tune control system parameters optimally for facilitating user settings. Future development of online full auto-tuning function suitable for applications in which the transfer function changes during operation is anticipated, and such development will require a detailed algorithm capable of safe operation and stopping during operating modes other than usual operation.

Meanwhile, inverters for elevator applications are equipped with imbalance load compensation function that suppresses the phenomenon of rollback when an elevator car's mechanical brake is released. This function detects the speed of elevator motor and generates compensating torque in response to abrupt changes of motor speed, and yet there is a need for robust control capable of freely responding to changes of loaded mass of the car or of rope mass due to landings at different floors.

(2) Capacity enlargement technology

In recent years, general-purpose inverters have been advancing toward larger capacities, and Fuji Electric has expanded its product line to include a 400 V input voltage standard converter/inverter series that have a single-unit capacity of 800 kW (stack type) maximum.

In order to increase capacity of inverters having limited input voltage, it is necessary to increase motor current, and for this purpose, appropriate insulated gate bipolar transistor (IGBT) modules and other main circuit parts must be arranged in parallel. Applicable technologies here are current balancing in steady state among devices and equalization of switching speed in transient state. For this purpose, in addition to

uniformity of device characteristics, consideration of wiring inductance and stray capacitance corresponding to device layout is also important. For such kind of design, three-dimensional electromagnetic field analysis and thermal analysis are indispensable, and by using such analysis techniques, twelve parallel connections of 1,200 V/400 A IGBT modules were realized.

(3) Noise reduction technology

Since main circuits of general-purpose inverters and servo amplifier have voltage-type inverter configuration, by controlling DC voltage with pulse width modulation (PWM) control, variable voltage and variable frequency output is obtained. Therefore, increase of noise level cannot be avoided comparing to commercial power supply, and noise-reduction combined with input harmonic current suppression technology is needed. Noise-reduction technology suppresses either generation of noise or transmission and radiation of generated noise. The former reduces voltage change rate dv/dt of switching device used for main circuit or for control power supply. The latter is realized with filter components and case shield material.

Recently, noise reduction technology has been actively researched with the aim of increasing motor reliability. It is known that when a long wire is used to connect inverter with motor, surge voltage will be generated at the motor input terminal. This effect is due to the difference between wire impedance and motor impedance, which generates reflected wave at the motor input terminal and suddenly boosts the voltage higher than inverter output voltage. In some cases, this surge voltage may accelerate the degration of motor insulation. As a countermeasure, surge-suppressing cable containing a function to bypass only high harmonic frequencies that cause reflection, and surge-suppressing unit that can be easily attached to existing motor have been developed.

(4) Main circuit technology

With the introduction of new devices for main circuits, power electronics field has been changing dramatically, and at present, reverse blocking IGBTs are being used in practical applications. One typical application is matrix converter, the main circuit configuration of which is shown in Fig. 1. Two reverse blocking IGBTs are connected in anti-parallel configuration to form bidirectional device, and three of these devices are arranged for each phase to realize matrix converter. This circuit is suitable for applications requiring suppression of power supply high harmonic frequencies and requiring power supply regenerative operation. Fuji Electric is planning to accommodate wide range of applications, beginning with elevator applications. Figure 2 shows example characteristics of a 400 V, 22 kW matrix converter. Both high power factor and high efficiency can be achieved.

2.2 Technical trends of control and operation display devices

(1) Highly efficient programming technology

Fig.1 Matrix converter main circuit

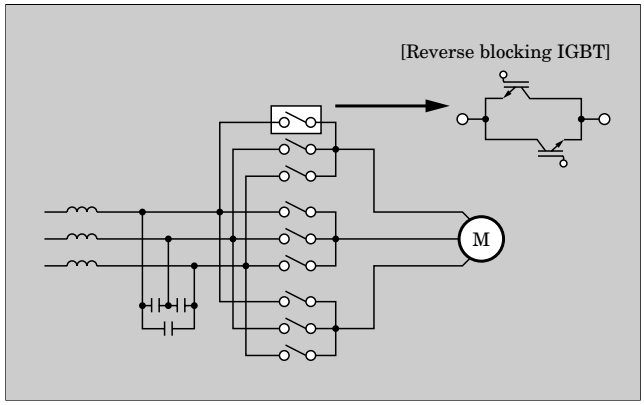
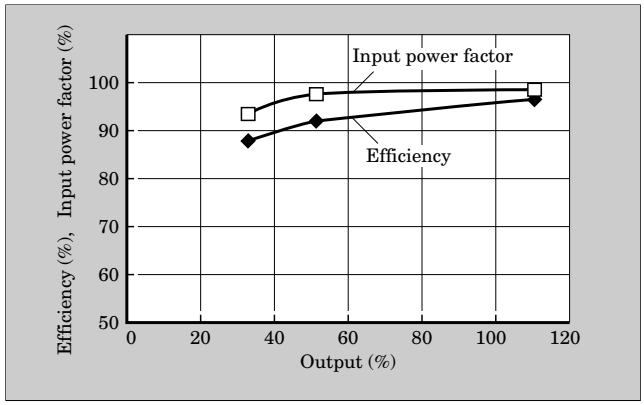


Fig.2 Example of matrix converter characteristics



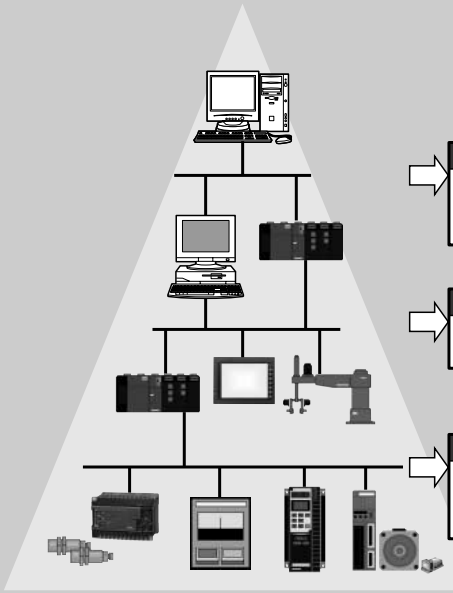
Application programs in controller field are becoming larger in scale and more complex, and improved efficiency for program development is highly sought. Since first being introduced to market, MICREX-SX series of integrated controllers have been provided with SX Programmer Expert programming tool that fully conforms to international PLC programming language standard IEC61131-3. As a result of software reuse, facilitated by the trends toward structured development and modularization of programs promoted by IEC standards, software production has become more efficient. In particular, modular programming structure of function blocks (FBs) have a large effect in increasing efficiency.

Accompanying the widespread penetration of IEC standards, mutual use of application programs among PLCs of different suppliers is becoming desirable. Fuji Electric, in cooperation with PLCopen Japan, is working to realize practical applications of reusable software programs written by different manufacturers and running on different machines using extensible markup language (XML).

(2) Large capacity data processing technology

With their higher performance and greater functionality, application range of PLCs has expanded dramatically. In recent years, in addition to applications in machines and equipment used to configure production systems, demand for PLCs has increased

Fig.3 Network hierarchy of system control components



Plant level
Optimal application for factory equipment and production lines

Controller level
Cooperation between machines and line controllers

Device level
Sense/drive and operation/ display functions for machines/production lines

Open network	Original network	PLC	POD	Inverter	Servo
Ethernet*1		○	○		
ADS-net		○			
Ethernet		○	○		
FL-net		○	○		
	P/PE-link	○			
	LE-net	○			
OPCN-1		○	○		
PROFIBUS-DP*2		○	○	○	
DeviceNet*3		○	○	○	○
Interbus-S				○	
Modbus			○	○	
CANopen				○	
	T-link	○	○	○	○
AS-i		○			
LONWORKS*4		○		○	

∗1 : Ethernet is a registered trademark of Xerox Corp. in the US and other countries.
∗2 : PROFIBUS-DP is a registered trademark of the PROFIBUS User Organization.
∗3 : DeviceNet is a registered trademark of the Open DeviceNet Vendor Association (ODVA).
∗4 : LONWORKS is a registered trademark of Echelon Corp. in the US and other countries.

especially in so-called data-oriented fields, to improve traceability, to manage electricity and water for energy-savings and so on, based on the need for data management of the production items and for compliance with legal regulations. The use of PLCs was originally driven by the need to realize efficient sequence control systems. However, since PLCs are poorly suited for applications requiring the efficient processing of large quantities of data, improved functionality that supports the expanded range of applications is now needed. MICREX-SX supports not only a ladder language for sequence control, but also a structured text language (ST language) and structured data types such as arrays and structures based on IEC61131-3. Even in applications involving a high-level of data processing, MICREX-SX is able to realize a development environment suitable for shop floor locations, where PC is poorly suited, and thereby it has dramatically increased the range of applications. Recently, a new CPU that further improves data processing performance has been added to MICREX-SX series.

(3) Network technology

Figure 3 shows network hierarchy composed of Fuji Electric's system control components. This network technology is compatible with all major open networks worldwide and also supports Fuji Electric's long-established original networks (P/PE-link and T-link). Optimal systems, ranging in size from small-scale systems embedded in machines to large-scale hierarchical distributed systems, can be configured seamlessly.

(4) Higher reliability technology

With the expanded range of applications for PLCs, there is demand for reliability equivalent to that of a plant controller, in other words, the ability to maintain continuous system operation 24-hours-per-day without downtime even when failures occur is required.

Since first being introduced to the market, MICR EX-SX has provided CPU redundancy with a 1-to-1 warm-standby feature. This redundant technology consists of both active and backup systems, and enables continuous operation without system downtime even when CPU malfunction occurs.

New developed LE-net controller level network realizes redundant network through the use of redundant network modules and loop topology (See Fig. 4). Moreover, with hot plug-capable baseboard, MICREX-SX system realizes high reliability class of distributed control system (DCS) at low cost associated with PLC.

(5) Human-machine interface (HMI) technology

Programmable operation display (POD) units were first introduced to the market around 1990. As a highly rated device that enables the creation of operation display screen without requiring any knowledge of programming, PODs continue to remain popular. Originally, PODs were used mainly as replacements for operation display panels which were constructed from switches, LEDs, and so on. However, as a result of improvements in the expressive ability and response speed of screens, a trend toward larger screen sizes, and improved ease of interfacing with various networks, the range of applications is presently ex-

Fig.4 LE-net redundancy

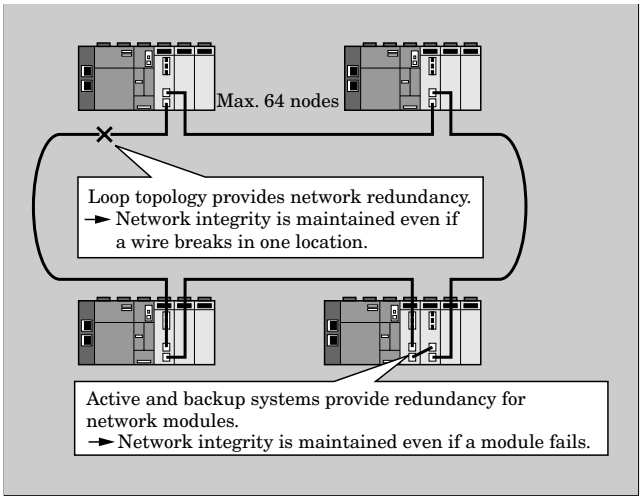
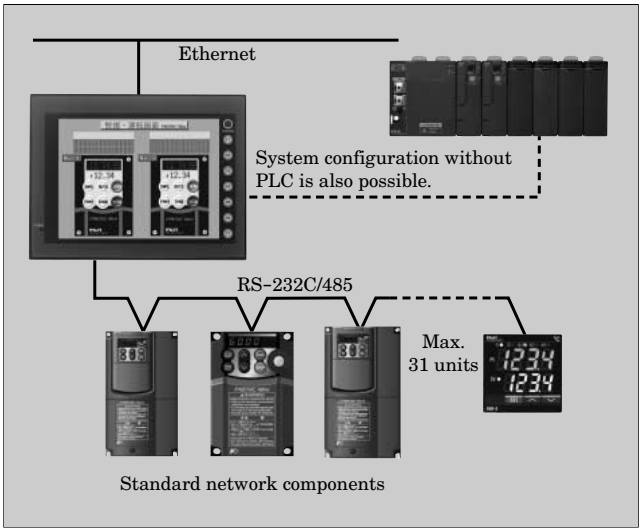


Fig.5 POD connectivity for standard network components



panding to acquisition and more realistic display of production shop floor information, accumulation of production management data, exchange of information through data networks, support of Internet-based services, and so on.

In addition to having port for connection to PLC, Fuji Electric's UG30 POD series is also provided with single-channel serial port that supports various communication protocols. This port can be connected to various components such as a temperature controller or inverter equipped with a communications function, and even if those components are made by different manufacturers, standard protocol can be used to monitor the components or to set parameters (See Fig. 5).

2.3 Environment-friendly technology

Since in recent years, beginning in Europe, there have been increases in the enactment of legal regulations to protect the environment and in the employment of green procurement policies, system control components have also become more responsive to environment. Environmental responsiveness can be accomplished in two ways, by effectively utilizing natural resources through extending the service life of products, and by eliminating environmentally hazardous substances from the materials of which products are made, and then by promoting the reuse of those products. Fuji Electric's system control components actively contribute to these efforts by extending the service lives of electrolytic capacitors and cooling fans, and by using a construction that allows easy component replacement. Moreover, in response to requests for cooperation with green procurement, Fuji Electric will lead the way with its newly developed products but also plans to steadily move its existing products to comply with RoHS directive*5. In particular, since there are many problems associated with the use of lead-free solder on PLC printed circuit board and inside the main circuit module in drive system, Fuji Electric intends to solve those problems through the use of materials having low elastic coefficient, by optimizing the temperature profile of solder bath, and so on.

3. Fuji Electric's System Control Components

Fuji Electric provides an abundant variety of system control components, and these components can be combined in various ways to realize optimal system configurations for a wide variety of applications.

3.1 Inverter product lines

Table 1 lists Fuji Electric's inverter product lines. General-purpose inverter product line is characterized by addition of new models, such as the FRENIC-Eco series and FRENIC-Lift series, for specified applications. These models are provided with optimal performances and features for their intended applications, and are more cost effective and easier to use than previous models. Fuji Electric's newest product, FRENIC-Multi series, is high-performance and compact inverter suitable for wide range of applications, and has been designed as a global product for worldwide use. FRENIC-Multi series also includes several semi-standard series of inverters having built-in filter or various built-in cards, and is capable of accommodating wide range of requests within short lead-time. FRENIC5000G11 and FRENIC5000P11 series have a track record of stable operation, and with a single-unit capacity that can be increased up to 800 kW, they have made significant contributions to the expansion of application range for general-purpose inverters.

FRENIC5000VG7 and FRENIC5000VG7F high-

*5: RoHS directive is restriction on the use of certain hazardous substances in electric and electronic devices.

Table 1 Fuji Electric's inverter product lines

Model type	Series	Supply voltage	Capacity range (kW) 0.1 1 10 100 1,000	Frequency control range (Hz) 100 1,000 10,000	Main specifications
General-purpose inverters	FRENIC -Mini	Single-phase 100 V Single-phase 200 V 3-phase 200 V 3-phase 400 V	0.1 – 0.75 0.1 – 2.2 0.1 – 3.7 0.4 – 3.7	400 400 400 400	Compact inverter ○ 400 Hz max. output freq. ○ Side-by-side mountable ○ Supports global standards (400 V input)
	FRENIC -Multi	Single-phase 200 V 3-phase 200 V 3-phase 400 V	0.1 – 2.2 0.1 – 15 0.4 – 15	400 400 400	High-performance compact inverter ○ Start torque: 200 % ○ Optional card supports PG feedback control ○ Wide variety of models
	FRENIC -Eco	3-phase 200 V 3-phase 400 V	0.75 – (110) 0.75 – (500)	120 120	Inverter for fan and pump applications ○ Energy-savings operation ○ Various functions for HVAC use ○ Long-life design, simple maintenance
	FRENIC 5000G11S	3-phase 200 V 3-phase 400 V	0.2 – 90 0.4 – 800	400 400	High-performance, multi-functional inverter ○ Start torque: 200 % ○ PID control & RS-485 provided as standard equipment ○ Optional card supports vector control
	FRENIC 5000P11S	3-phase 200 V 3-phase 400 V	5.5 – 110 5.5 – 800	120 120	Inverter for variable torque loads ○ PID control & RS-485 provided as standard equipment ○ Control power supply aux. input provided as standard equipment ○ Automatic energy-savings function enables highly effective driving
	FRENIC -Lift	3-phase 400 V	5.5 – (45)	120	Vector-control inverter for elevators ○ Overload capability: 200 %, 10 s ○ Special functions and control for elevators ○ Supports synchronous motors in elevator applications
High-frequency inverter	FRENIC 5000H11S	3-phase 200 V	0.75 – 18.5	1,667	Special high-frequency inverter that utilizes PWM control technology
High-performance vector-control inverter	FRENIC 5000VG7S	3-phase 200 V 3-phase 400 V	0.75 – 90 3.7 – 800	200 200	High-performance vector-control inverter for general industrial use ○ Highly responsive torque and speed control ○ Control options provide full system functionality
Thin inverter	FRENIC 5000VG7F	3-phase 200 V 3-phase 400 V	5.5 – 11 5.5 – 15	200 200	Special thin inverter having a depth of 90mm
Regenerative PWM converter	RHC-C	3-phase 200 V 3-phase 400 V	7.5 – 55 7.5 – 800	50 – 60 50 – 60	Regenerative converter ○ Regeneration with high efficiency ○ Reduced harmonic current input

(110), (500), (45): Under development

performance vector-control inverter series are used in general-purpose industrial applications that require high responsiveness and high-precision torque and speed control. They have also extended their range of applications to include machine-roomless elevators, and are often used in combination with synchronous motors. Meanwhile, the RHC-C series of regenerative PWM converters used in combination with these inverters is also provided with capacity ranging up to 800 kW single-unit capacity as same as inverters.

Table 2 Fuji Electric's servo system product lines

Series	Applicable motor	Capacity range (kW) 0.1 1 10 100	Rated/ max. speed (r/min) 1,000 3,000 5,000	Main specifications
FALDIC-α (1) V type (for pulse train, speed control) (2) L type (for linear positioning) (3) R type (for rotational indexing)	GYC motor (low inertia type)	0.1 – 2	3,000/5,000	(1) Same frequency response: 600 Hz (2) Vibration suppression control can be installed (3) 16-bit ABS/INC shared encoder (4) Serial connection between amp and encoder reduces wiring (5) High-speed serial bus (SX bus) and support of various other buses
	GYS motor (low inertia type)	0.05 – 5	3,000/5,000	
	GYA motor (low inertia type)	0.5 – 2.5	1,500/2,500	
	GYM motor (medium inertia type)	2.9 – 7.5	1,500/3,000	
		11 – 15	1,500/2,000	
FALDIC-β (for pulse train)	GYC motor (low inertia type)	0.1 – 0.75	3,000/5,000	(1) Industry's smallest amp (2) Command follow-up control and vibration suppression control provided as standard equipment (3) Notch filter, servo analysis function (4) 16-bit serial encoder
	GYS motor (low inertia type)	0.05 – 0.75	3,000/5,000	
FALDIC-W (for pulse train, speed control)	GYS motor (low inertia type)	0.05 – 0.75	3,000/5,000	(1) Vibration suppression control provided as standard equipment (2) Easy tuning, servo analysis function (3) Many varieties motors (4) 17-bit serial encoder (5) RS-485 (2 ports), control power supply input
	GYG motor (medium inertia type)	0.5 – 2.0	2,000/3,000	
		0.5 – 2.9	1,500/3,000	
Digital ES motor (for pulse train, speed control)	GRK motor (high inertia type)	0.05 – 3.7	2,000/2,500	(1) Suitable for machines have a large load moment of inertia (2) Motor can be replaced with general-purpose motor (3) Simple setup and operation

3.2 Servo system product lines

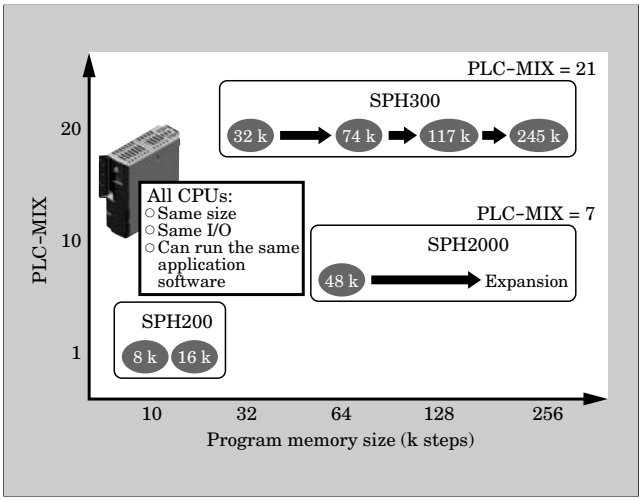
Table 2 lists Fuji Electric's servo system product lines. This product line consists of FALDIC-α series, equipped with a high-performance high-resolution serial encoder, the FALDIC-β series, provided with vibration suppression control as the industry's smallest amp, and the newest model, FALDIC-W series that supports global standards. Moreover, each of these series has been expanded in terms of capacity and rated speed of servomotor. FALDIC-α series has been expanded to maximum capacity of 15 kW, and FAL DIC-W series has added servomotors with rated speeds of 1,500 r/min and 2,000 r/min, to enable selection of optimal servomotor for each particular application.

For servomotor systems, in addition to the product lines listed in Table 2, Fuji Electric also provides the MC8 motion control module for MICREX-SX series. This module enables interpolative control or other high-level position control for up to 8 axes in a servo system.

3.3 Integrated controller product line

Figure 6 shows Fuji Electric's MICREX-SX CPU product line. SPH200, SPH300 and new SPH2000 series are provided to meet various requirements for memory capacity and performance. All CPUs have the same size dimensions, and have the advantageous ability of being able to inherit I/O and application programs completely. As a result, in cases where application capacity is insufficient or scan performance is not full accurate, user can simply upgrade the CPU to the next higher class, without having to modify the I/O or application programs.

Fig.6 MICREX-SX CPU product line



3.4 POD product line

Table 3 lists Fuji Electric's POD UG30 product line. This product line supplies a wide range of POD

Table 3 POD product line

Size	Model		Specifications
12 type	UG530H	V□	TFT 32,768 colors 800×600 dots
10 type	UG430H	V□	TFT 32,768 colors 800×600 dots
		T□	TFT 32,768 colors 640×480 dots
		S□	TFT 128 colors 640×480 dots
8 type	UG330H	V□	TFT 32,768 colors 800×600 dots
		S□	STN 128 colors 640×480 dots
6 type	UG230H	T□	TFT 32,768 colors 320×240 dots
		S□	STN 32,768 colors 320×240 dots
		L□	monochrome 320×240 dots
	UG221H	SR	STN 16 colors 320×240 dots
		LE,LR	monochrome 320×240 dots

Ethernet port and compact flash card interface are provided as standard equipment (except with the UG221).

sizes, from 6 inch type models for simple shop floor operation and to 12 inch type models that provide PC-level display capability.

4. Conclusion

The technical trends and product lines of Fuji Electric's system control components have been described above. In the future, to support system expansion in FA and shop floor applications, system control components are expected to advance toward higher levels of functionality, performance and capacity, and to become focused for particular applications. Moreover, applications are also predicted to expand into the field of information processing, which is replacing PCs, and to become increasingly integrated with management systems.

In the future, Fuji Electric intends to continue to assess these types of trends accurately, and to provide advanced components and tools as a good partner to our customers.

New SPH2000 CPU Combining Sequence Control and Data Processing Capabilities

Hideyuki Odaka
Takayuki Shimokawa
Yuugo Sunaga

1. Introduction

MICREX-SX integrated controller series has been providing many innovative hardware modules suitable to develop optimum manufacturing automation control systems. For example, as CPU module forming the core of a system, MICREX-SX series provides two product lines of SPH200 and SPH300 CPUs, to achieve both lower prices and enhanced performance, capacity and functionality capabilities so that sophisticated, diversified, and complex end-user needs can be satisfied.

In addition to the automation of industrial facilities, recent programmable controller (PLC) applications are branching into new areas such as production status monitoring, traceability control, and energy-saving supervisory control system. In these applications, personal computers are commonly used along with PLCs because PLCs are not well suited for efficient processing of large quantities of data. PLC technology must advance in the areas of enhanced data processing capability and better usability because there are needs to eliminate personal computers. This paper introduces new SPH2000 CPU, which realizes dramatically improved performance of data processing functionality together with conventional PLC sequence-control capability.

2. Overview of SPH2000

2.1 Development concept of SPH2000

Underlying concept behind SPH2000 development was to create a standard OS layer platform for continued use in the future, which had been specifically designed for each module and series in the past. Each PLC functionality is reconstituted in functional sub-layer. The functionality is mounted on the platform so that user's software resources may be reused continuously. Moreover, the standard platform will also evolve into an integrated FA platform that is installed in other control equipment.

2.2 Inheritance of all features of MICREX-SX series

SPH2000 (Fig. 1) inherits all features of MICREX-SX series as listed below.

(1) High-speed control system using the SX bus
(2) Efficient programming and its execution based on IEC61131-3 international standard
(3) Further system cost reduction
(4) Fundamental compliance with CE marking, UL, and marine specifications

2.3 System structure with SPH2000

Since SPH2000 housing is the same as that of the SPH300 type-R (with USB and User-ROM), it can use same SPH modules such as power supply, baseboard, IO, function and communication modules as well as other SX-bus modules. Furthermore, Fuji's UG30 Programmable Operation Display series may also be connected as before.

As programming support tools, both SX-Programmer Standard and SX-Programmer Expert support SPH2000 and provide same development environment to the user as before. SPH2000 achieves full compatibility with application software of SPH200 and SPH300. In this way, user inheritance such as programs and user function blocks can be reused easily.

2.4 Flexible program execution engine

PLC execution engine adopted a general microcontroller in the 1980s, and later custom LSI chips were added to complement functions and performance PLC. Thereafter, the custom LSI chips evolved to larger scale devices in response to the requirement for higher

Fig.1 SPH2000 (baseboard mounting)

performance of PLC program-execution engine together with the advancement of microelectronic technology. As a result, several problems became noticeable, which were increase of investment required for development, rising price of components, and difficulty for design changes relating to the custom LSIs.

Therefore, utilizing recent technical advances of general-purpose microcontrollers, SPH2000 uses a RISC microcontroller (Fig. 2), instead of custom LSIs, as PLC program execution engine, and mounts standardized FA platform (Fig. 3) on general OS.

3. Features of SPH2000

Main specification comparison of SPH200/SPH300 and SPH2000 is shown in Table 1.

3.1 Large capacity memory

Program memory capacity of SPH2000 is 48 k steps that is 3 times larger than that of SPH200, and this capacity is the largest among compact building blocks type small-class PLCs. Data memory capacity, 96 k words, is 3 times larger than that of SPH300 32 k-step entry model, and if even larger memory is required, SPH2000 can use compact flash memory card (CF). In all memory specification of SPH2000, each parameter is equivalent or superior to corresponding parameter of 16 k-step SPH200 or 32 k-step SPH300 models.

In this architecture, program and data memory can be expanded to maximum 256 k steps and 2 M words, respectively.

Fig.2 Circuit diagram

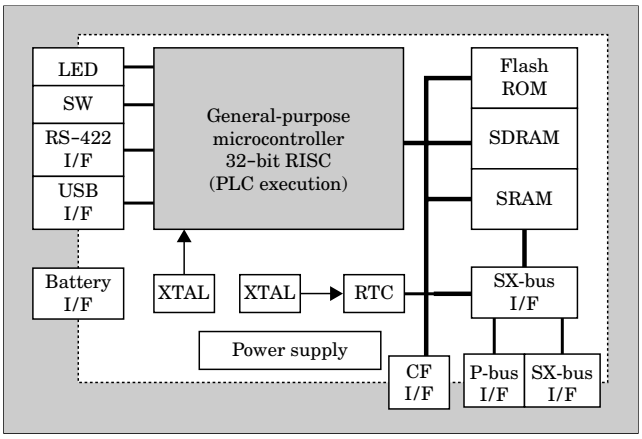
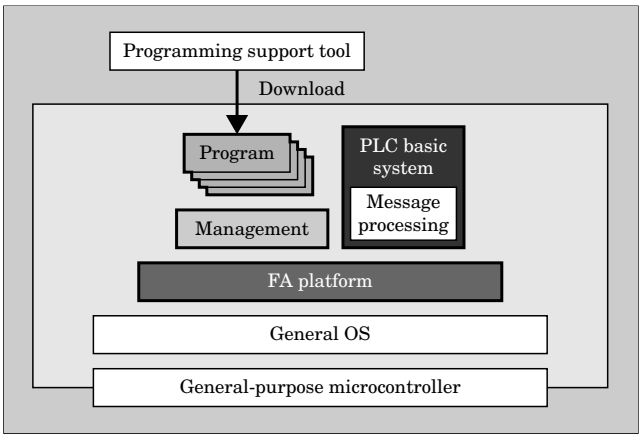


Fig.3 Software structure



3.2 High-speed program execution

Compared with SPH300, which executes each instruction at high-speed, SPH2000 provides very high performance at repeat processing of FOR loops that combine arrays and structures by using structured text (ST) language, or at repeat processing in function blocks (FBs). (In these cases, the repeat process is less than 1 k steps). A comparison of execution time of major instructions is shown in Table 2.

As for SPH2000, Table 2 shows that differences in execution time among various instructions are not very large. Processing time for program management, access time of array or structure, and execution time of FOR loop are not included in this list. The result of practical evaluation test for execution time by a program that has been created by SX-Programmer Expert is described as follows.

(1) Assuring sequence control performance

An evaluation was performed using an 8 k-step program that consists 84 % basic instructions and 16 % application instructions. This program was created according to "Performance reference index for execution processing of programmable controllers" published by Japan Electrical Manufacturers' Association (JEMA), and does not include repeat processing. Figure 4 shows the program summary and execution results.

SPH2000 can execute 8 k-step program in 3 ms. This is 2.5 times higher performance than SPH200. This result also indicates that SPH2000 has twice processing speed as F70S, which is the fastest of MICREX-F series mainly used for general machinery control. Thus, SPH2000 has ample headroom up to required performance.

(2) Achieving high-speed processing of large quantities of data

Figure 5 summarizes program execution results that is addition of 4 k double-word arrays A and B, and storage of the result as an array C, processed in both DINT (32-bit integer data) and REAL (32-bit real data) formats. Data types of arrays A, B and C assigns each operation data type. This case is applicable to repeat processing of less than 1 k steps because 2 line instructions (FOR loop and ADD) is executed 4,096 times.

This result indicates that SPH2000 provides 2.5 times higher performance than SPH300 in both DINT and REAL data processing. Under matching to the repeat processing conditions, SPH2000 demonstrates powerful execution performance. This shows that REAL ALU performance exceeded that of SPH300's

Table 1 Performance specification of SPH200, 300 and SPH2000

Item		SPH200	SPH300	SPH2000
Memory	Program memory capacity	8/16 k steps	32/74/117/245 k steps	48 k steps
	Program steps/POU	4 k steps	8 k steps	8 k steps
	General memory	15/31 k words	32/128/256/512 k words	96 k words
	Retain memory	15/31 k words	30/126/254/383 k words	32 k words
	Instance memory	Total : 15/31 k words 1FB : 256 words	30/126/254/510 k words 1FB : 4 k words	Total : 32 k words 1FB : 4 k words
	Temporary area	Total : 4 k words 1FCT : 4 k words	Total : 8 k words 1FCT : 4 k words	Total : 32 k words 1FCT : 4 k words
	Common memory	–	30/126/254/383 k words	32 k words
External memory	Device	User ROM card	CF (***R only)	CF
	Memory backup function	Indispensable	Indispensable	Selectable
	Auxiliary memory function	N/A	Available	Available
	FB for access		2 FBs	7 FBs
External I/F	Communication I/F	RS-422	RS-422, USB	RS-422, USB
	Multi–CPU	N/A	Max. 8 : Mixture is possible	Max.8 : Mixture is possible
	Redundancy	N/A	Available	N/A
	CPU link modules	Max. 2	Max. 8	Max. 8
	I/O memory	512 words	512 words (extension : 4,096 words)	512 words
	Remote I/O/master module	128 words	512 words	512 words
	Battery backup time (at 25°C)	5 years	32 k steps : 5 years Others : 1.3 years	5 years
Function	Rewriting a program While PLC is running	Only 1 POU		Multiple POUs
	Sampling trace	N/A	Available (74R or more)	Available
	Debugging stop	Available: 1 point		Available: 8 points
	Allotment of execution time	N/A (fixed)	N/A (fixed)	Variable
	Constant scan	N/A	N/A	Available

Table 2 Instruction execution speed

Instruction			SPH300 (Note 1) High speed/ Normal	SPH2000 (Note 2)		SPH 200
				Repetition	Single	
Sequence	Contact		0.02/0.06	0.03	0.19	0.07
	Coil		0.02/0.06	0.13	0.26	0.14
	Timer		0.86/1.06	0.78	2.01	49.7
	Counter		0.78/1.02	0.91	2.49	47.7
Applied	DINT operation	32-bit ADD/SUB	0.08/0.20	0.07	0.37	0.60
		32-bit MULTI	0.10/0.22	0.09	0.49	30.0
		32-bit DIV	1.48/1.58	0.28	0.67	24.0
	REAL operation	32-bit ADD/SUB	0.16/0.24	0.29	0.61	56.0
		32-bit MULTI	0.16/0.24	0.27	0.62	46.0
		32-bit DIV	1.36/1.52	0.38	0.68	96.0

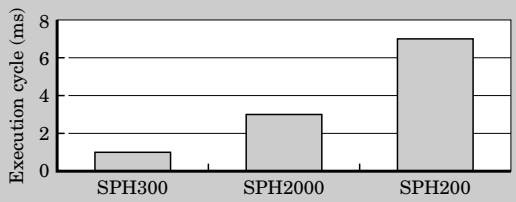
(μs)

Note: 1) The target user data is high speed memory or normal memory
2) In the case of repetition processing (less than 1 k steps) or single processing

Fig.4 Execution time of sequence control

<Ratio of operation>

Instruction	Ratio	Appearance ratio: 1 % or more	
Sequence	84 %	1–bit external input	18 %
		1-bit external output	8 %
		1-bit internal input	30 %
		1-bit internal output	26 %
		16-bit timer	1 %
Applied	16 %	16-bit move	4 %
		16-bit comparison	3 %
		16-bit logical operation	5 %



custom REAL ALU when executing FOR loops, accessing array data and executing addition (ALU: arithmetic logical unit).

(3) Practical programming example

An example of replacing data processing program

Fig.5 Execution time of repeat processing of ST language

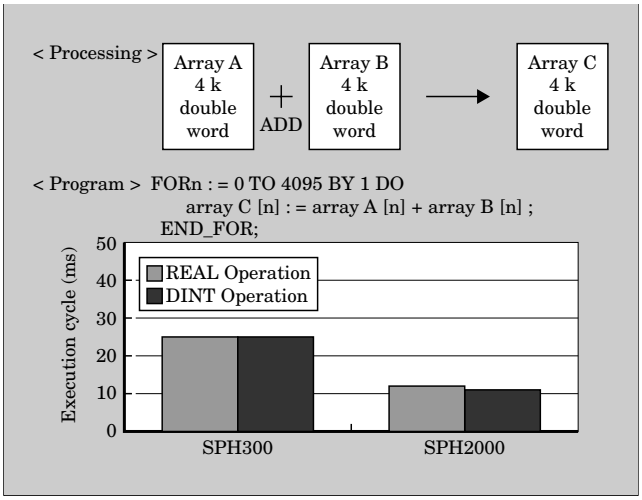
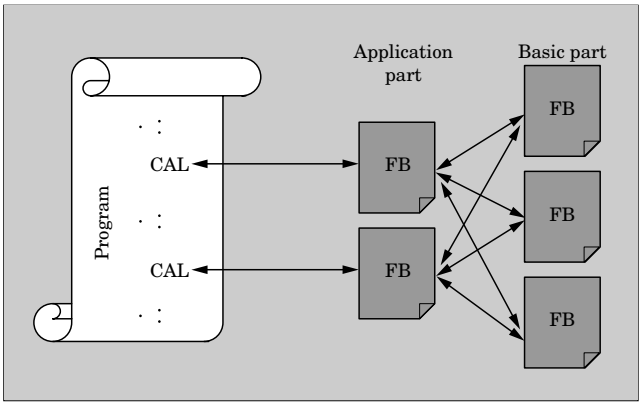


Fig.6 Block engineering



used in a microprocessor-board system with SPH300 and SPH2000 is described below. This program is oriented toward structured programming based on IEC61131-3 international standard, and uses a thorough block-engineering approach.

The result, as shown in Fig. 6, is that original program is divided into layers consisting of groups of smaller basic FBs and groups of application FBs formed from combination of basic FBs, and each FB is repeatedly executed.

Execution time of SPH2000 was about a half of SPH300. Repeatedly executed smaller FBs using block engineering enabled high-speed performance of SPH2000.

3.3 Enhancement of file management function

SPH2000 has a CF-slot as a fundamental function, which permits to connect commercially available CF products as external memory for saving programs and data. CF-related functions of SPH2000 are as follows.

(1) User ROM function

Same as SPH300, SPH2000 has functions to save programs to a CF and to upload programs from a CF to the CPU module itself. Program saving function can be performed, in both cases, when a CF is inserted into the SPH2000 slot or inserted in a personal computer that runs support tool software. Uploading function is performed when the programs in the CPU module differ from the programs saved in the CF.

(2) Auxiliary memory function

As FB variation of reading/writing user files, SPH2000 has additional FBs for append-writing, CSV (records separated by linefeed, values separated by comma) data format conversion, and file deletion (See Table 3).

In current products, when sequentially changing data was required to be saved to CF, the data was first stored in the CPU module memory as sequentially separated block data, and was then stored in CF as different files after that. By using F_APPEND FB, which provides the capability to append data to the same file, the number of files to be stored and management of file names can be reduced.

Moreover, by using F_READ_CSV and F_WRITE_CSV FBs capable of handling CSV text data formats, files stored in CF can be edited directly with general text editors and tools, and the tediousness of dealing with binary data is eliminated.

(3) Enable/disable setting of user ROM function

In previous products, reading/writing user files in CF required storing user programs in CF. In SPH2000, however, user ROM function can be disabled so as to eliminate the necessity for users to store user program in a CF when uploading data from CPU or setting data to CPU through the CF. In this case, user

Table 3 File management FBs

FB	Operation	Note
F_READ	File reading	Existing FB
F_WRITE	File writing	
F_APPEND	Additional writing to an existing file	FB added by SPH2000
F_DELETE	Deletion of specified file	
F_WRITE_CSV_DINT	File writing after BIN → CSV conversion	
F_READ_CSV_DINT	CSV → BIN conversion after file reading	
F_APPEND_CSV_DINT	Additional writing to an existing file after BIN → CSV conversion	

Fig.7 Allocation of execution time

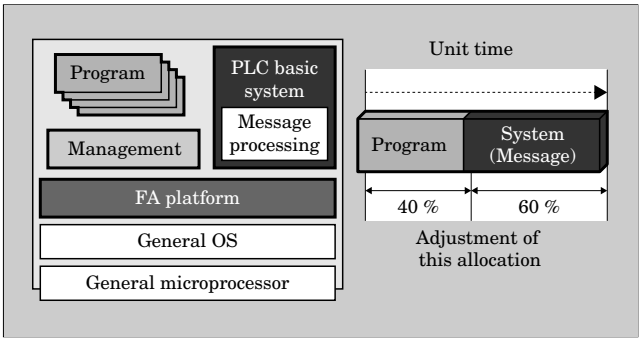
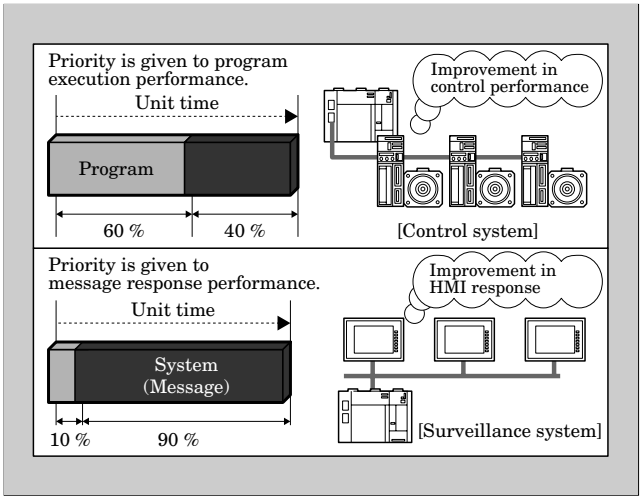


Fig.8 Example of execution time allocation



programs are backed-up in the flash memory of the CPU module.

3.4 Flexible system architecture design

(1) Execution time allocation

Although execution time allocation of user program executing and system processes such as message transferring in unit cycle time, was not adjustable in previous CPU modules, the allocation of those two processes can be set with SPH2000 (See Fig. 7). With this new function, SPH2000 is able to set allocation of execution time, so as to give priority to the execution of user programs to improve control performance or to improve HMI response by prioritizing the performance of message processing, for example, and thus SPH2000 provides greater flexibility in system design suited to the usage of the user (See Fig. 8).

Default allocation of "programs: system = 6:4" is the maximum user program rate at which system can ensure time for the transfer of at least one message within a 1ms-tact setting. Conversely, the minimum allocation rate for user program is "programs: system = 1:9".

(2) Multi-CPU system

SPH2000 and SPH300 can be used to configure a mixed multi-CPU system of up to 8 CPU modules. In response to requirements for load sharing due to increasingly large size of programs and for a functionally-distributed system which assigns each function to a specific CPU, users are able to design system configuration in detail in consideration of cost-performance tradeoffs. For example, users can configure a combined system with SPH300 for highest performance sequence control and SPH2000 for high performance data processing, to leverage the features of each CPU.

4. New Applications for SPH2000

In current PLCs, main focus of application has been sequence control that targets machines and equipment used in the construction of manufacturing and control systems. However, personal computers or microcontroller boards were often needed for data management and monitoring systems which process large amounts of data efficiently.

SPH2000 is able to expand its applications to data processing listed below, and therefore enables reduction of total cost from system construction, startup and operation to maintenance.

(1) Recording of the status of manufacturing machine systems and devices, recording of error status
(2) Individual tracking of products and traceability based on legal regulations
(3) Energy consumption management that is concerned with manufacturing-related consumption such as electricity and water
(4) Data management in an electric power monitoring system
(5) Recording and management of building entrance and exit access
(6) Recording of traffic volumes
(7) Batch comparison of input data from bar code reader, etc.

5. Conclusion

This paper has summarized the features and new applications of SPH2000. Fuji Electric will continue development to provide PLCs that can be quickly applied to increasingly complex and diversified user needs.

New Features of PLC Programming Tools for MICREX-SX Series

Noriyuki Nakama
Koji Fukushima
Daisuke Wakai

1. Introduction

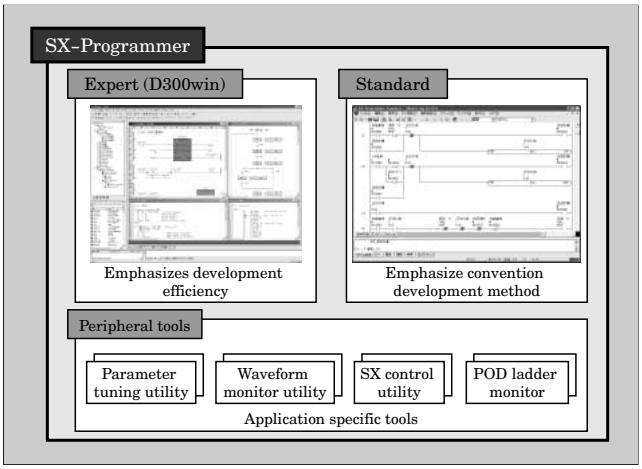
As performance and functionality of machinery and facilities have progressed, controller application software has year-by-year become larger in size and more complex. Meanwhile, shorter software development time is required, therefore controller support system is expected to provide more efficient software development environment.

Figure 1 shows an overview of the programming tools for "integrated controller MICREX-SX series."

(1) SX-Programmer Expert (D300win) (hereafter referred to as the "Expert") aims to improve development efficiency through genuine structured design.
(2) SX-Programmer Standard (hereafter referred to as the "Standard") inherits the conventional ladder programming method and still facilitates structured design, which is a characteristic feature of MICREX-SX series.
(3) Application specific tools efficiently support system startup, operation, and maintenance.

These controller programming tools for MICREX-SX are compatible with various development methods, from conventional ladder programming to genuine structured development, and provide efficient development environment throughout the lifecycle from development, operation, to maintenance. This paper describes the latest progress of these programming tools.

Fig.1 Overview of PLC programming tools for MICREX-SX series



2. SX-Programmer Expert (D300win)

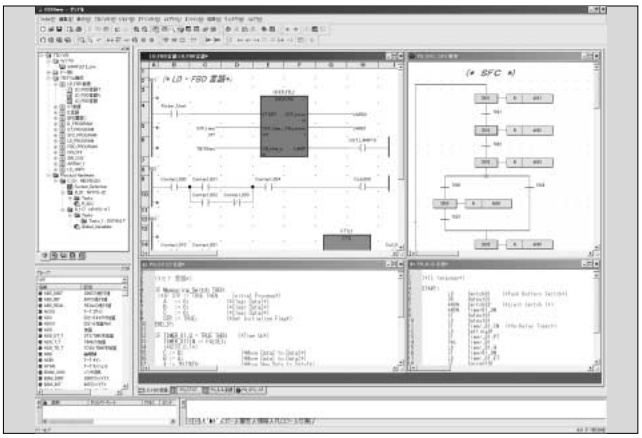
2.1 Overview

The Expert is a programming tool that realizes high level conformity to IEC61131-3 standard programming concept for programmable logic controllers (PLC), and enables genuine structured design. Figure 2 shows a screenshot of Expert programming screen. The Expert can support larger scale and more complexity of recent programs, furthermore it aims to improve development efficiency and management efficiency.

2.2 Enhancement of structured development

Based on IEC61131-3 standard, basic program units are called "program organization units" (POUs). Depending on the increase of POUs, program management becomes more complex as a program is getting larger in size, therefor group-management capability of associated POUs in a tree format has been added. This function can provide hierarchical management of up to 6 tiers, and allows POUs on the tree to be edited with drag and drop operations. As a result, POUs can be classified associated with function units, process units or the like, to enhance further the efficiency of

Fig.2 Programming screen of Expert support tool



structured design. Figure 3 shows a screenshot of this function.

2.3 Large-scale project development support

With increase trend of application software size, it is getting common for several developers to work together for a program development jointly. In such case, management of the concurrent development is complicated, and there is a risk that the development efficiency may decrease as a result of the increase in man-hours necessary for management tasks or due to a management mistake. Thus, multi-user support function has been developed, an overview of which is shown in Fig. 4. This function enables program files to be consistently and exclusively managed with a center server. As a result, it is able to avoid simultaneous changes to the same program from multiple developers, and meanwhile, the historical management of the master program is facilitated.

2.4 Enhanced variable management

Variable programming that does not depend on a PLC memory address is a fundamental concept of the Expert to improve program modularization and reusability. Variable names are often defined with sequential numbers. In such case, as shown in Fig. 5, linking those definitions to spreadsheet software such as Excel*1 is an extremely effective technique. From the beginning the Expert has supported a function to import and export data from and to Excel, and has subsequently added cut and paste operations between a variable definition worksheet and Excel, so that the variable definitions may be used directly. With this functionality, the tasks of defining and managing variables can be implemented with greater efficiency.

*1: Excel is a registered trademark of Microsoft Corp. in the US and other countries.

Fig.3 POU group managing function

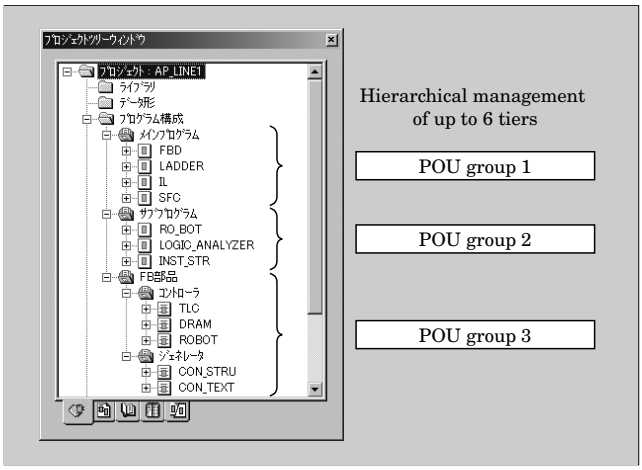


Fig.5 Mutual use of variable declaration between Expert and Excel

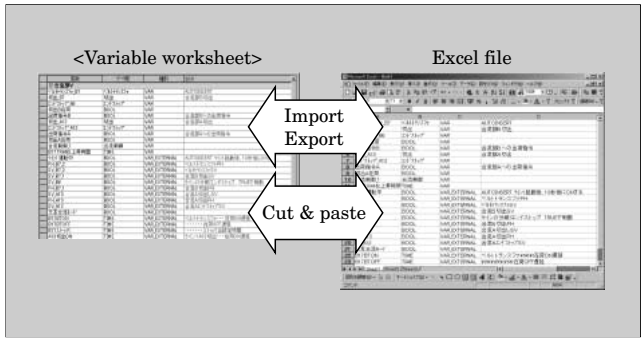
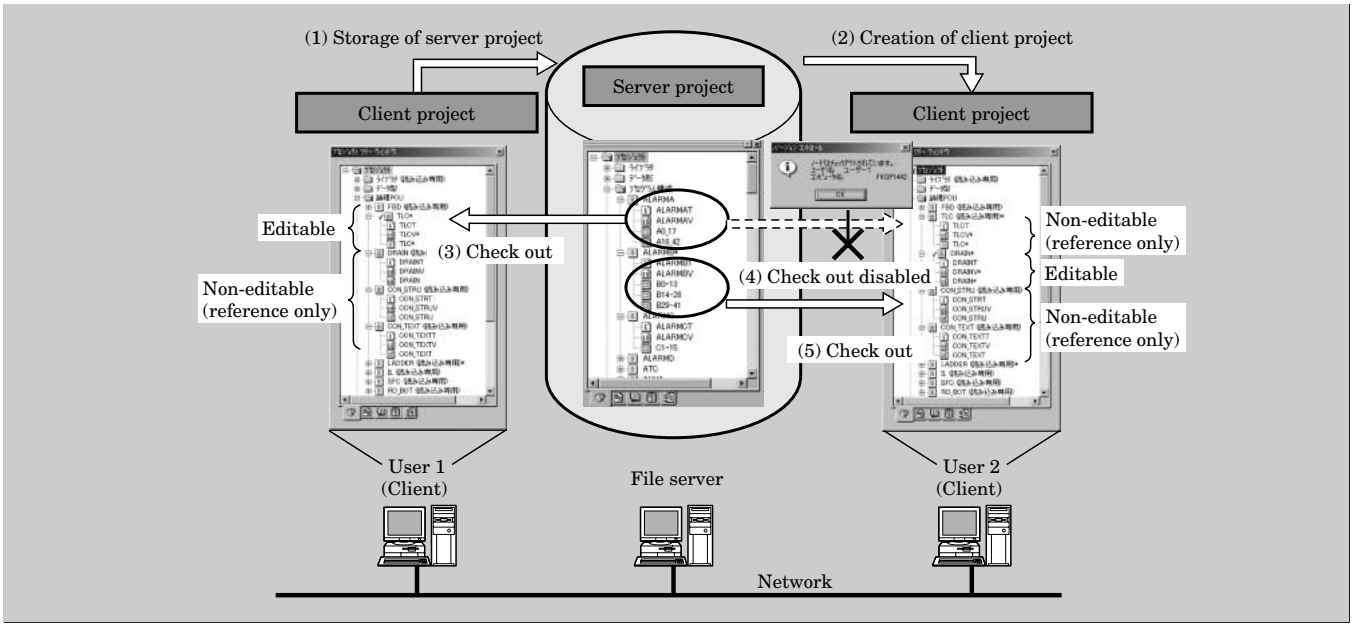


Fig.4 Multi-user support function



3. SX-Programmer Standard

3.1 Overview

The Standard is a conventional-type ladder programming tool that facilitates structured programming. Conventional tool elements, such as scrolling of the whole program area, implementing programming changes while running, uploading with complete restoration and the like are realized without limitation. Meanwhile, function blocks (FBs), structured text (ST) language and the like, which are essential for structured and modular design, can be used with conventional skill. By facilitating the use of structured programming technology on a conventional-type tool, Fuji aims to increase development efficiency with programming methods familiar to major PLC user. Figure 6 shows the programming screen of the Standard.

3.2 Enhancement of structured programming

(1) FB expression

FB is a modular program structure, and its function is essential to improve programming efficiency. As shown in Fig. 7, the Standard uses two types of FB call expression, a conventional data instruction type and a box type. The data instruction type has the advantage of collapsing parameters, but the box type has the advantage of easy understanding correlation between input and output.

(2) Program display

With the Standard, POUs are treated as pages. The display method can be switched between a scroll mode for scrolling through whole program area and a mode for managing whole program structure with a tree configuration. As these two modes reduce barriers to the transition from a conventional programming culture to a structured programming culture, it aims to increase user convenience. Figure 8 shows the program display modes.

3.3 Support of ST language, arrays and structures

The standard provides ST language, optimal for the effective modularization and reuse of program parts, and well suited for describing computational control. Program described by ST language can be modified during uploading or while the PLC is running without limitation. Furthermore, debug functions such as break points and step execution can be used. Arrays and structures are also supported, therefore, it can be applied into instrumentation field, such as

Fig.6 Programming screen of Standard support tool

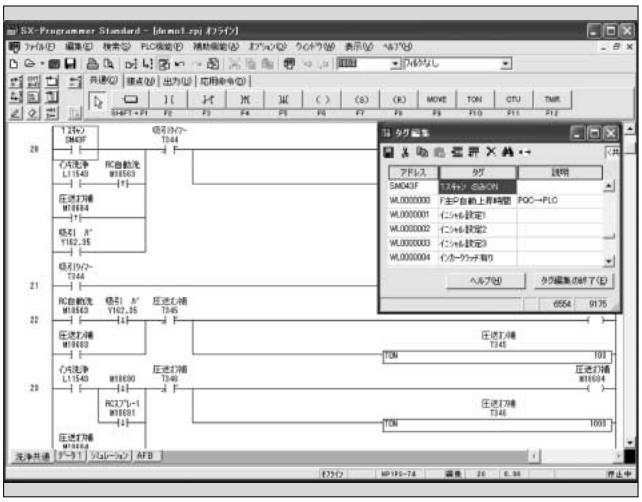


Fig.7 FB expression

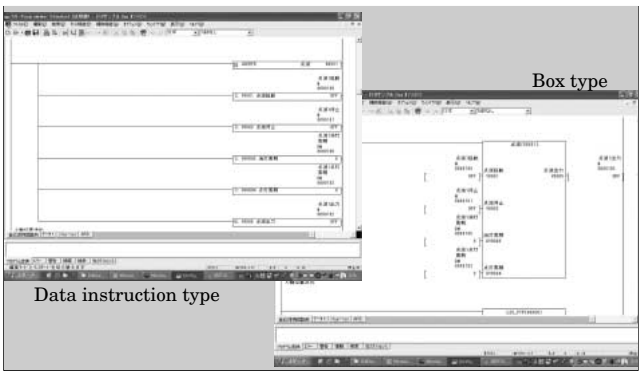


Fig.8 Program display modes

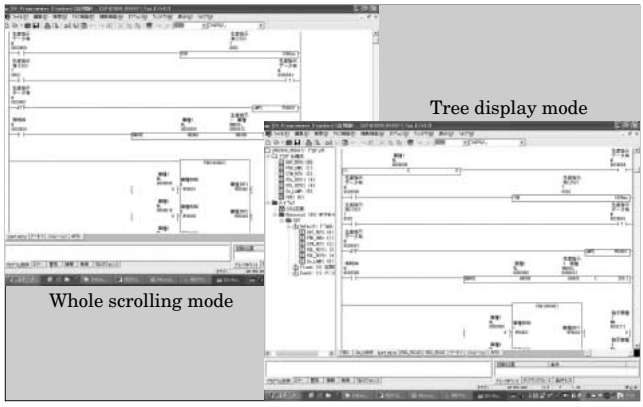
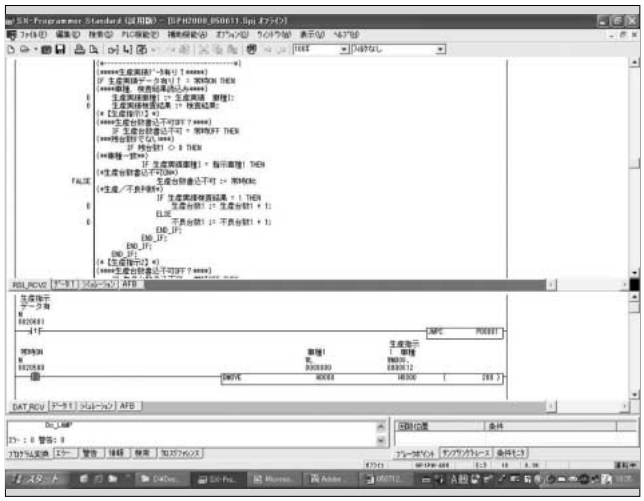


Fig.9 ST programming screen on Standard support tool



temperature control system. Figure 9 shows the ST language programming screen.

3.4 Simulation

Simulation tool, which is provided as a standard function, enables program debugging without having an actual PLC ready. As a result, the logical operation of a program can be verified on a PC. Moreover, as I/O devices such as switches, lamps and the like can be positioned on the screen, it can provide a debugging environment that resembles a control panel. Figure 10 shows an example screenshot of simulation.

4. Application Specific Tools

4.1 Parameter tuning utility

Parameter tuning utility is a software tool that provides a function for tuning and managing operating parameters in instrumentation systems, temperature control systems, and the like. In case of instrumentation systems, management of lots of operating parameters is extremely important. Thus, parameter tuning utility has been developed as a tool for modifying, tuning, performing historical archiving, and saving operation parameters associated with an FB such as PID or other loop control block. Since operation and maintenance workers may not know programming or operation of the Expert, this parameter tuning utility has been developed as a custom tool independent of the Expert. This tool enables consistent management of programs and parameters.

Moreover, since the sheet for tuning and managing parameters is generated automatically from the Expert, there is no need for labor-intensive screen generation tasks. Figure 11 shows a screenshot of the parameter tuning utility.

Fig.10 Simulation screen on Standard support tool

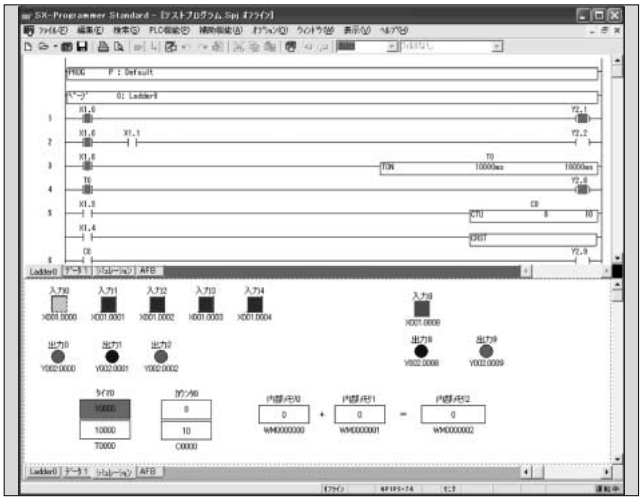
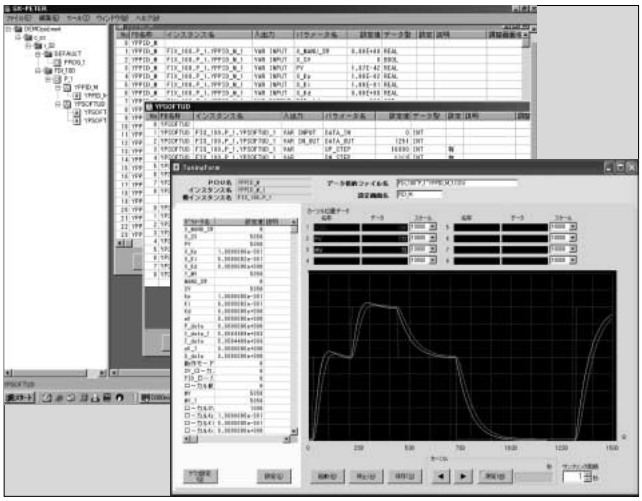


Fig.11 Parameter tuning utility screen



4.2 Waveform monitoring utility

The waveform monitoring utility is a custom tool to display waveforms sampled by a PLC. This tool is capable of segmenting signals, sampling, and then assembling them to generate continuous waveform. In addition, this tool provides various other functions such as merging and superpositioning, which are useful in waveform analysis. Figure 12 shows a screen shot of the waveform monitoring utility.

Fig.12 Waveform monitoring utility screen

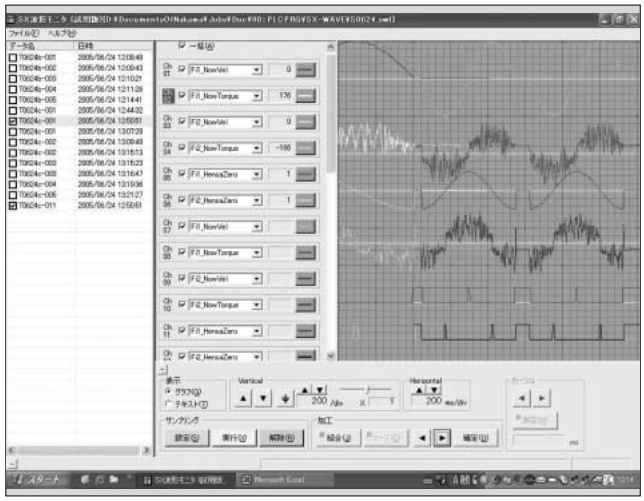
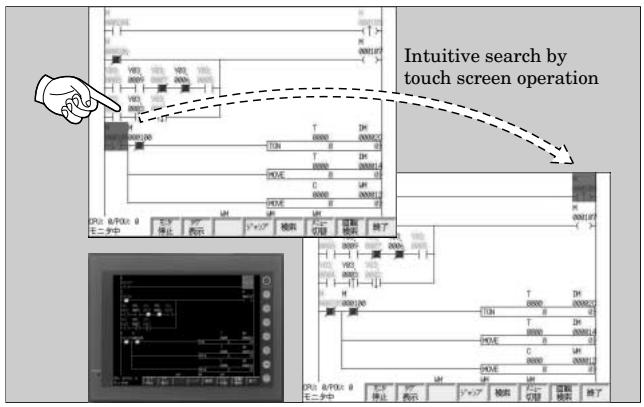


Fig.13 POD ladder display



4.3 POD ladder monitor

POD ladder monitor is a tool intended to facilitate the timely provision of information for the purpose of a primary diagnosis to engineers and maintenance workers, and therefore to reduce the mean time to repair (MTTR) of the system when system trouble occurs in the machinery or facilities. Ladder programs developed with the Standard can be displayed and monitored on programmable operation display (POD) UG series, and intuitive program search can be performed by touching contacts and coils on the ladder diagram. Figure 13 shows a screenshot of the POD ladder monitor display.

5. Conclusion

An overview and summary of the progress in controller support tools for MICREX-SX series has been presented above. In the future, Fuji Electric continues not only to develop each support tool, but also to broaden the scope of tools by enhancing cooperation among the various support tools and computer aided design (CAD) system, and human-machine interface (HMI) tools in order to increase productivity.

Expanded Line of MICREX-SX PLC Components

Yutaka Yatsuda
Yutaka Saitoh
Koichi Ohara

1. Introduction

In recent years, applications for programmable controllers (PLCs) have continued to diversify and evolve, for instance adoption of open standards and progress to multi-functionality. This evolution has been accompanied with relentless marketplace demands on PLCs to support open networks or international standards such as IEC (International Electrotechnical Commission), to acquire industry-specific certifications, and to improve the development efficiency and maintainability of programs capable of supporting larger scale and more advanced systems.

Developed as a "global system component," MICR EX-SX integrated controller has been satisfying marketplace demands since it was introduced to the market. With a focus on the latest family of products, this paper describes the expanded lineup of MICREX-SX components and the status of the acquisition of relevant certifications.

2. Expanded Line of CPU Modules

Figure 1 shows a product map of CPU module models that form the core of MICREX-SX series. Previously there were two product lines of CPU modules, SPH300 series and SPH200 series, but now a newly developed SPH2000 series that uses a general-purpose microprocessor has been added. The product models and functionality of the high-end SPH300 series have been expanded to support a broadening range of applications. In May 2005, 245 k-step model was released, which had the largest program capacity among the SPH300 series, to be capable of supporting even larger-scale systems.

2.1 Features of SPH300 series

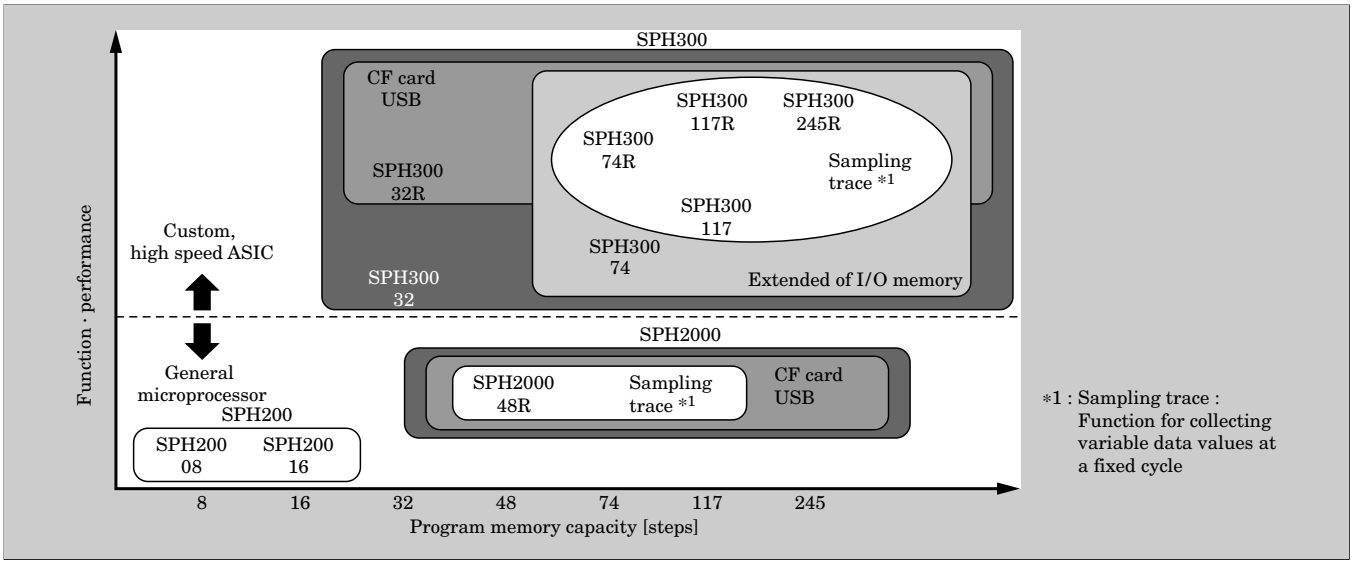
Presently, SPH300 series have two versions of its flagship CPU modules, a standard type and an R-type providing compact flash (CF) cards and USB interface.

Since SPH300 series is equipped with a high-speed processor ASIC optimized for PLC application and realizes, on average, an operational performance of 19,000 instractions per 1 ms, it is suitable for the real-time control of various devices.

2.2 Support of large-scale systems

Simultaneously with the release of 245 k-step

Fig.1 MICREX-SX CPU module product map



model in May 2005, 74 k- to 117 k-step models also expanded their functionality, and in order to facilitate the support of large-scale systems, I/O memory was made expandable from conventional 512-word size to 4,096 words maximum (8 times increase) (See Table 1).

Figure 2 shows an example configuration of conventional large-scale system. In order to construct a large-scale system with I/O memory larger than conventional size 512 words, it was necessary to partition the system into a multiple controller system configuration. As a result, a controller level network module was needed to communicate between controllers as well as CPU module, power supply module, and baseboard, therefore there are problems of increased system cost and a complex system design.

Figure 3 shows an example configuration of large-scale system having an extended I/O memory. The extension of I/O memory resolves the abovementioned problems. Large-scale system having I/O memory of 4,096 words or less on device level network with single-system configuration, thereby minimizes system cost, simplifies system design, and makes it possible for MICREX-SX to replace MICREX-F series large-scale systems.

3. Support of International Standards

In recent years, new standards and regulations concerning electromagnetic interference of electronic devices, prevention of electric fires and shocks, and preservation of global environment have been enacted. Depending on the locality of use and the type of application, PLCs are required to comply with those standards and regulations. MICREX-SX series supports these standards and regulations as a normal feature (See Table 2).

An overview of these standards and regulations, and compliance of MICREX-SX series are presented below.

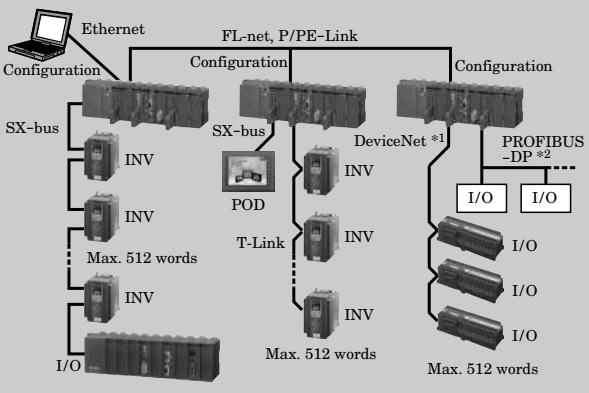
Table 1 SPH300 series extended I/O memory

	32 k-step model (32, 32R)	74 k-step model (74, 74R)	117 k-step model (117, 117R)	245 k-step model (245R)
Conventional I/O memory	512	512	512	–
With extended I/O memory	512	1856	4096	4096

Extended

Units: [words]

Fig.2 Example of conventional large-scale system configuration



*1 : DeviceNet is a registered trademark of the Open DeviceNet Vender Association (ODVA).
*2 : PROFIBUS-DP is a registered trademark of the PROFIBUS User Organization.

3.1 CE marking

PLCs to be distributed and sold within the EU market are required to have a CE marking. The MICREX-SX series displays CE markings as recognition of its conformance with the EMC Directive and Low Voltage Directive, specifically, its conformity with the EMC and safety items of European standard EN61131-2:2003.

3.2 UL

In the US, with the exception of certain specific consumer household products, there is no legally

Fig.3 Example of large-scale system configured with extended I/O memory

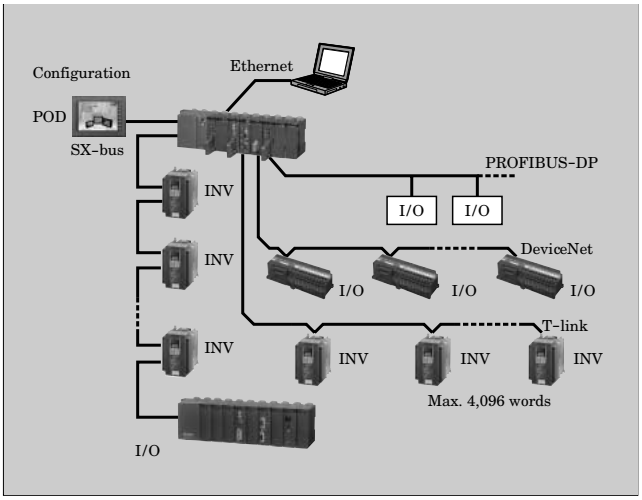


Table 2 Standards supported by MICREX-SX series

Standard/ Regulation		Cert. No. (*1)
CE marking		FIN571306 (*2)
UL		E140422
Marine certification	NK (Nippon Kaiji Kyokai : Japan)	99A107
	ABS (American Bureau of Shipping : USA)	00-Y038419-X
	BV (Bureau Veritas : France)	12082/A2 BV
	CCS (China Classification Society : China)	DBT02720034G
	DNV (Det Norske Veritas : Norway)	A-9402
	GL (Germanischer Lloyd : Germany)	24758-04HH
	LR (Lloyd's Register : UK)	99/10003

(*1) Partially compliant (as of July 1, 2005)
(*2) Declaration of conformity

mandated standard and certification system for the manufacture and sales of products. Therefore UL certification and the UL mark verify the safety of electronic products. UL certification is recognized by most states. MICREX-SX series has acquired UL standard (UL508) certification for industrial control equipment.

3.3 Approval for marine use

Marine-use PLCs must use products certified by a classification society that registers ships. Since MICR EX-SX series has acquired certification from seven out of ten classification societies (NK/ABS/BV/CCS/DNV/GL/LR) officially admitted to the IACS (International Association of Classification Societies), it conforms to most requirements for marine-use.

In response to user requests, Fuji intends to aggressively pursue certification from other classification societies.

3.4 RoHS directive

RoHS*1 directive bans the use of certain hazardous substances [lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyl (PBB), and polybrominated diphenyl ether (PBDE)] in electrical and electronic equipment in the EU market as of July 1, 2006. Due to the end of FY2005, transition is scheduled to comply with this directive gradually.

4. Expanded Line of Communication Modules

Figure 4 shows network hierarchy of MICREX-SX. MICREX-SX supports major open network protocols worldwide, and is additionally equipped with Fuji's original T-link and P/PE-link networks. Thus, these networks enable optimal selection regardless of the network device manufacturer, and provide support for various systems requirement such as minimum cost or replacement of existing system.

Although MICREX-SX network is already extensible, new modules are being developed and the functions of existing modules are being expanded to broaden the range of applications further. Several examples are introduced below.

4.1 LE-net

As systems have trended toward larger scale and greater sophistication in recent years, demand for decentralized control system has been increasing. To meet this demand, an original network named LE-net has been developed.

Decentralized control is characterized by a masterless distribution of the processing load and easy implementation of system changes. LE-net realizes these characteristic features at low cost, with easy connectability, and a simple protocol.

LE-net network topology supports either multidrop or loop arrangements. Since communication is still kept with a loop topology, even if network cable becomes disconnected, it enables highly reliable systems to be constructed at low cost (See Fig. 5).

LE-net is positioned as one of the main controller networks connecting PLCs in the future, and is targeting applications in systems requiring high reliability within the fiercely cost-competitive FA industry.

4.2 Standard 2-channel RS-232C communication module

Standard communication protocol is widely used in the marketplace, and new 2-channel RS-232C product is released as one of the general-purpose communication module lineup. This module provides customers with a wider selection of available devices, increases the number of supported networked devices, and contributes to lower total cost of SX system (See Fig. 6).

*1: RoHS: restriction on the use of certain hazardous substances in electric and electronic devices.

Fig.4 MICREX-SX supported network

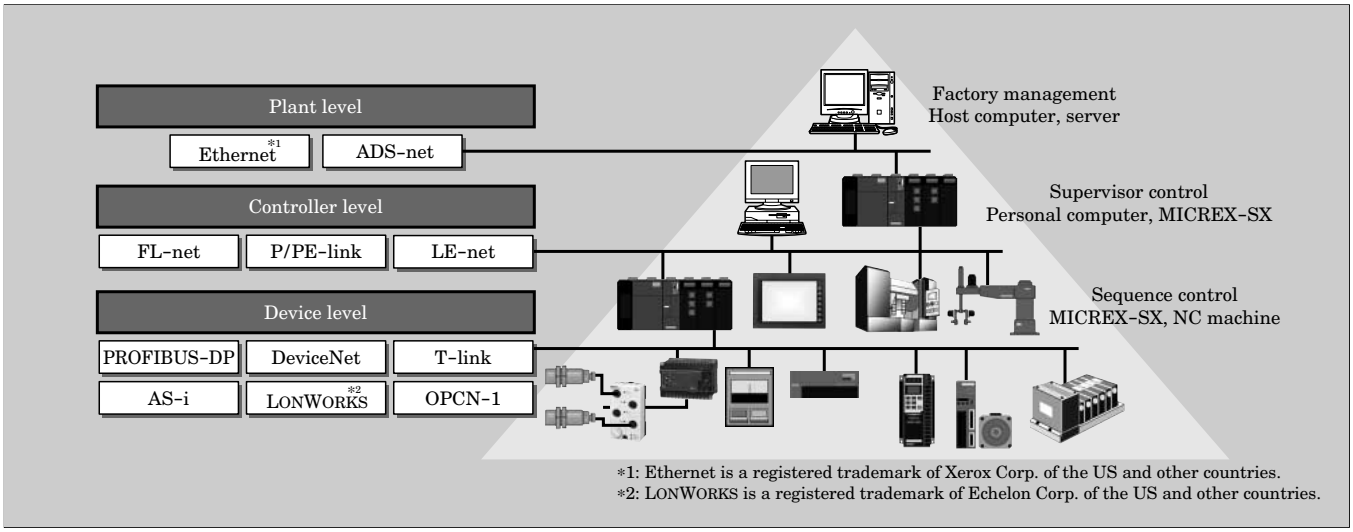


Fig.5 LE-net topology

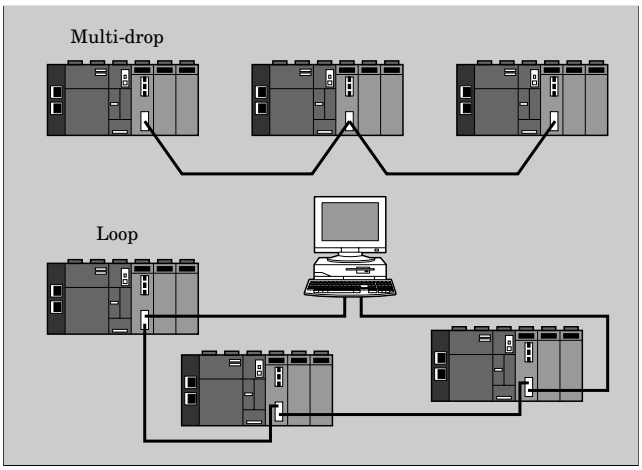
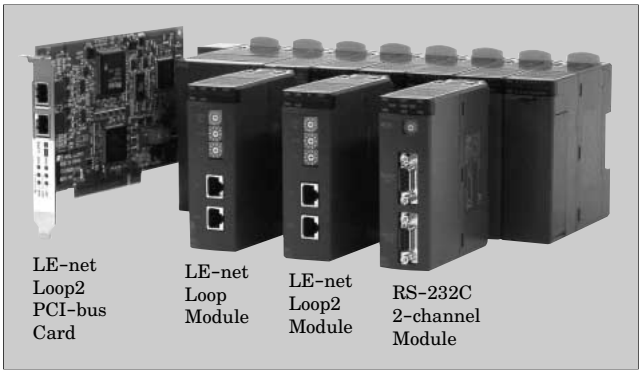


Fig.6 LE-net family of products and the RS-232C 2-channel module



5. Expanded Line of Analog Modules

NR2 series of I/O terminals has been expanded with the following four analog models that support OPCN-1 open network standard: (1) 8-channel analog voltage input, (2) 8-channel analog current input, (3) 4-channel analog voltage output, and (4) 4-channel analog current output.

5.1 Support of multi-channel analog measurement

Since analog I/O terminals did not exist, an SX bus expansion system or an assembled-type expansion system was used in order to construct an analog multi-channel system, as shown in Fig. 7. In this type of configuration, maximum 336 analog channels could be realized per system.

Figure 8 shows an example system configuration using analog I/O terminals. Here, the combination of analog I/O terminals with an I/O memory extension function of the CPU module realizes maximum 1984 channels per system configuration. Therefore, it can provide multi-channel data logging system at low-cost.

Fig.7 Example of conventional analog system configuration

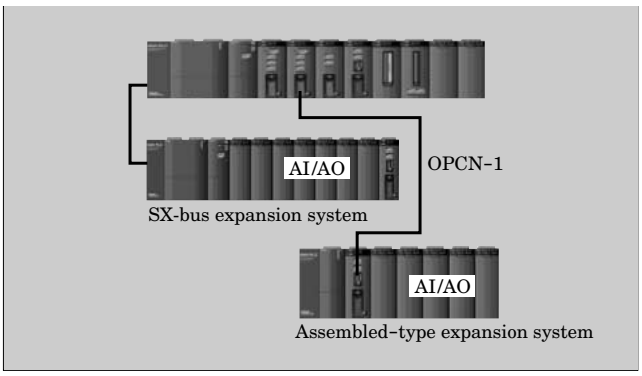
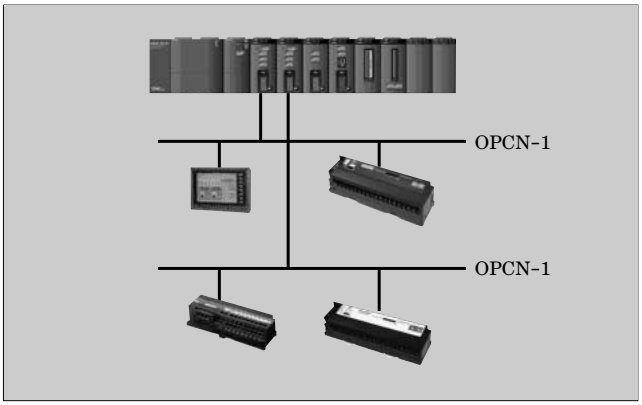


Fig.8 Example system configuration using analog I/O terminals



5.2 Improvement of analog performance

Since these analog I/O terminals realize performance improvements such as: (1) the smallest installation footprint in the industry, (2) 250 μs/channel high-speed A/D and D/A conversion, (3) ±0.1 % high accuracy, they support precision measurement control. Additionally, user interface is improved and range setting, a basic analog parameter, can be implemented from the front panel DIP switch.

6. Conclusion

The latest expanded line of MICREX-SX components and the status of certification acquisition for these components have been presented herein. A diverse variety of PLC functions and model types will be required in the future to meet the demands of increasingly globalized marketplace. Programming tools for MICREX-SX support five programming languages that conform to IEC standards, and when used in combination with the MICREX-SX family, they enable support flexible application programming in various fields. In the future, Fuji Electric intends to provide optimal systems that leverage the advantages of SX series.

FRENIC-Multi Series General-purpose Compact-size Inverters

Osamu Shiokawa
Norio Hirai
Toshiya Ito

1. Introduction

With recent background of increasing demand in general-purpose inverter market such as powerfulness for conveyance machines and energy-savings for fan and pump applications, there are growing needs to improve performance and multi-functionality for small and medium-size variable-speed inverter applications, as well as to reduce size and cost.

Newly developed FRENIC-Multi series is Fuji Electric's core line of general-purpose inverters. So that these inverters are suitable for use in any industry or application field, FRENIC-Multi series has been designed to have high performance, multi-functionality, improved environmental friendliness, ease of maintenance, and use, enhanced protection functionality, harmonization with peripheral equipment, conformance to overseas standards, etc., and is positioned as a global product for wide range of uses throughout the world.

This paper introduces these features.

2. Environment Harmonization Design

2.1 Conformance to RoHS directive

As a result of the enforcement of WEEE*1 and RoHS directives*2 of European Union (EU), the concept of environmentally harmonized products are spreading throughout various countries in the world. Although general-purpose inverters are currently exempt from RoHS directive, due to rising environmental awareness in the marketplace, FRENIC-Multi series will not exceed specified content levels of six limited hazardous substances [lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyl (PBB), and polybrominated diphenyl ether (PBDE)]. Also, client who requests compliance with green procurement are recently increasing, therefore Fuji Electric is preparing so that we can respond quickly in case the information of existence and content of any of those six hazardous substances is requested.

∗1: WEEE is Waste Electrical and Electronic Equipment.

∗2: RoHS directive is restriction on the use of certain hazardous substances in electric and electronic devices.

2.2 Long-life design of limited-life parts

In previous models, periodic replacement of DC bus capacitors, electrolytic capacitors on the printed circuit board, and cooling fan was recommended every 3 to 7 years, as these parts have a limited service life. Since these parts were designed to have longer service lives and their layouts were optimized in FRENIC-Multi series, to prolong the equipment maintenance cycle time, their designed lives extended to 10 years under the conditions of 40°C inverter ambient temperature and 80 % continuous load operation. Also, in order to prevent incidents of sudden equipment stoppage, service life information can be viewed on keypad display, and when some parts approach the end of its service life, warning signal is output as a transistor-level signal that is sent to upper-level controller or the like to encourage part replacement before any problems occur.

3. Abundant Model Varieties

Figure 1 shows the appearance of FRENIC-Multi series, and Table 1 lists the varieties of models in this series. Newly developed FRENIC-Multi series succeeds previous FVR-E11S series and adds 11 kW and 15 kW models to 3-phase 200 V and 400 V series, and offers a wider range of capacities.

Additionally, models with built-in pulse generator (PG) feedback card, built-in electromagnetic compatibility (EMC) filter, and built-in RS-485 card have been developed as semi-standard series in order to provide wider user selection. Figure 2 shows an example of the model with built-in RS-485 card.

4. High Performance and Multi-functionality

4.1 Dynamic torque-vector control (with flux estimation)

Dynamic torque-vector control is a control method based on an equation that describes induction motor voltage. In this method, output current and motor constants are used to calculate the optimal output voltage command value and estimated slip value in real-time to enable high-speed response and stable operation in response to abrupt load changes.

Fig.1 Appearance of the FRENIC-Multi series

Table 1 Model varieties of the FRENIC-Multi series

Model type		Varieties	
Standard		3-phase 200 V	0.1/0.2/0.4/0.75/1.5/2.2/3.7/5.5/7.5/11/15 kW
Semi-standard	Built-in EMC filter	3-phase 400 V	0.4/0.75/1.5/2.2/3.7/5.5/7.5/11/15 kW
	Internal PG feedback card		
	Internal RS-485 card	Single-phase 200 V	0.1/0.2/0.4/0.75/1.5/2.2 kW

Fig.2 Internal RS-485 card

FRENIC-Multi series adds the functions of flux axis difference compensation based on the estimated flux and excitation current compensation by means of flux regulator to enable stable output for large starting torques of 200 % or greater. Moreover, an online tuning function can be used to perform primary resistance compensation and secondary resistance compensation to minimize speed fluctuation that is accompanied with motor temperature change.

Fig.3 Speed vs. torque characteristics

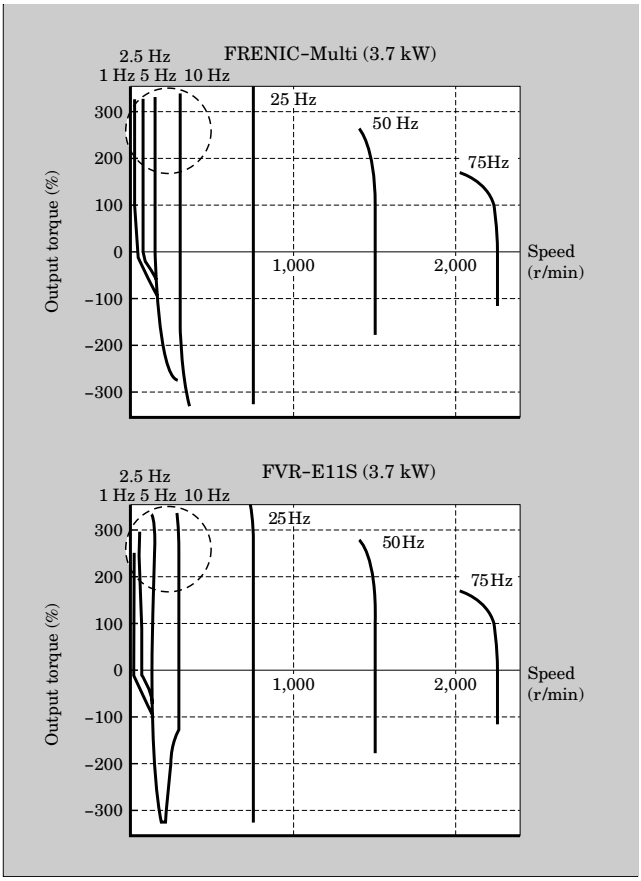


Fig.4 Step load response

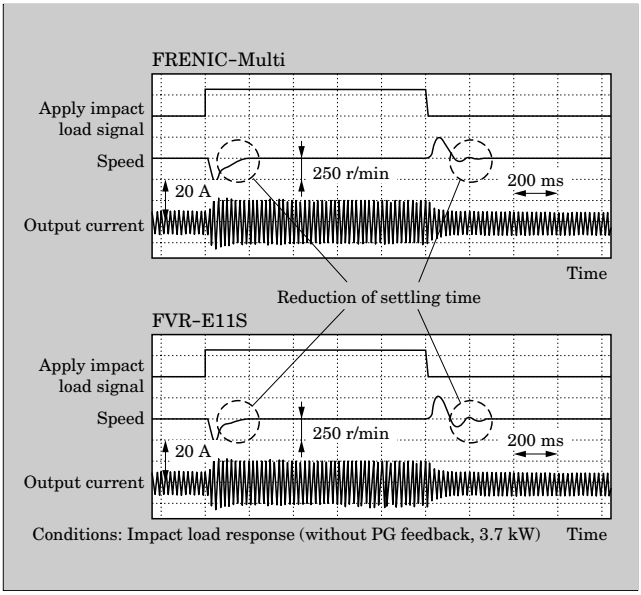


Figure 3 shows the speed versus torque characteristics and Fig. 4 shows the step load response characteristics of FRENIC-Multi compared to FVR-E11S. In the low-speed region, FRENIC-Multi series is capable of stable torque output over a wide range, and even in response to step loads, FRENIC-Multi series exhibits

Fig.5 Regenerative avoidance control

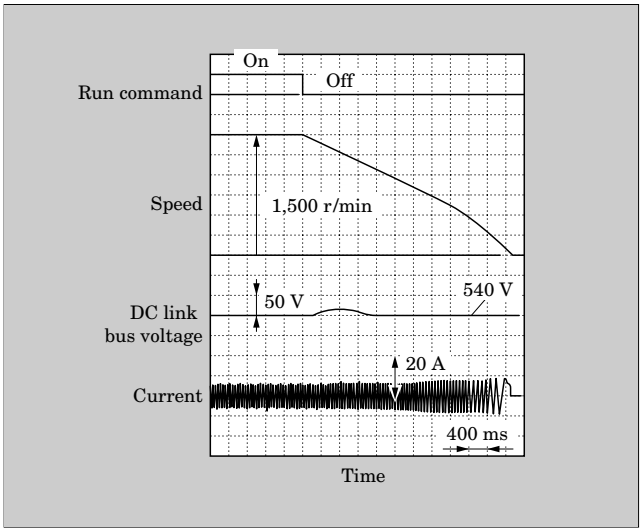
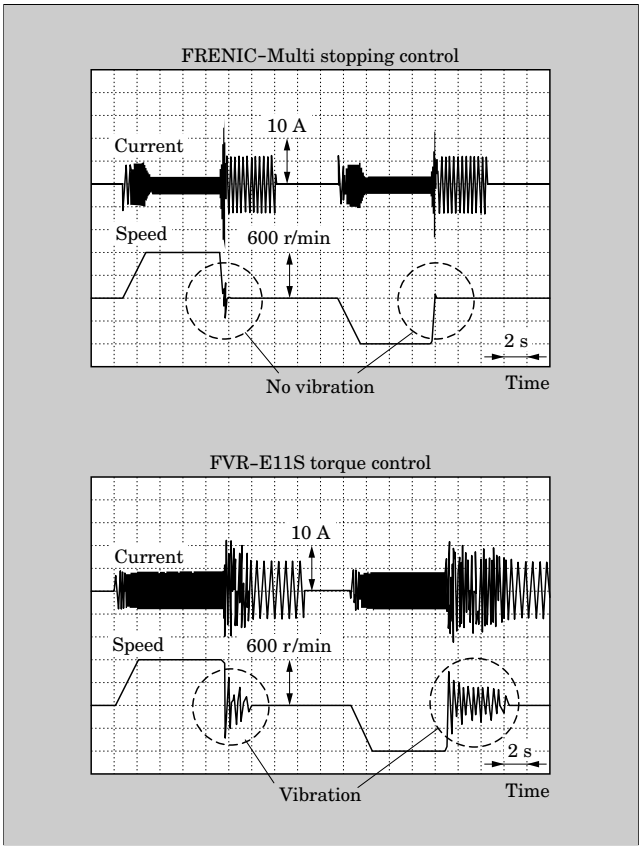


Fig.6 Control to stop characteristics



less fluctuation in motor speed and shorter settling time to recover the original speed.

4.2 Regeneration avoidance control

With FRENIC-Eco series inverters for fan and pump applications, regeneration avoidance control regulating DC link bus voltage to constant value is used where DC link bus is monitored during deceleration, and the deceleration time is automatically extended if the voltage is greater than a certain value. On the other hand FRENIC-Multi series, uses a highly responsive torque limiting method well suited for horizontal and vertical conveyance applications. With torque limiting method, braking torque is calculated instantaneously, and if it reaches the suppression level, deceleration time is extended automatically to prevent tripping due to overvoltage.

Figure 5 shows an example of regeneration avoidance control characteristics. By detecting the braking torque and controlling the output frequency, voltage increases of DC link bus are suppressed.

4.3 Overload stop function

Because sudden load changes are detected based on changes of torque or output current, inverter can provide any one of the following operations.

- ○ Coast-to-stop
- ○ Deceleration stop
- ○ Control to stop

Control to stop is an essential function for horizontal and vertical conveyance. It decelerates the motor based on the torque estimated by the torque limit method, and after deceleration operation is switched to current control from torque limit, generates a holding torque and waits to apply the brake.

Figure 6 shows characteristics of this control to stop operation function. FRENIC-Multi series maintains a constant torque after hit-and-stop, and in contrast to FVR-E11S series, motor rotational characteristics are free from vibration.

4.4 Brake signal for vertical conveyance

In vertical conveyor systems, in order to prevent work-piece from falling, a mechanical brake is usually applied to hold the work while conveyor is stopping.

With FRENIC-Multi series, a transistor-level brake signal output is provided, and brake signal apply/release timer, braking signal released frequency/current, and brake signal injection frequency are added to function codes. Combination of these settings with starting frequency, starting frequency holding time, stop frequency, and stop frequency holding time, enable optimal system configuration that does not burden drive system or brake for vertical conveyance applications.

Figure 7 shows an example of timing chart for the brake signal.

4.5 Torque and current limiting operation

Since FRENIC-Multi series is equipped with two limiting methods of torque limiting (drive and braking), current limiting, optimal limiting operation can be selected in accordance with each system. Torque limiting regulates actual torque, therefore it is best suited for protecting drive system. Current limiting regulates output current and can be used for thermal

Fig.7 Timing chart for brake signal

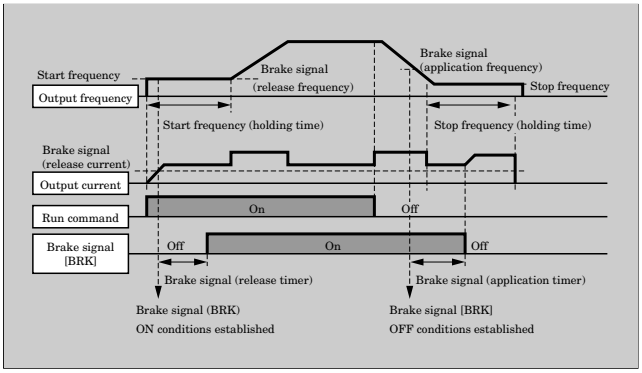
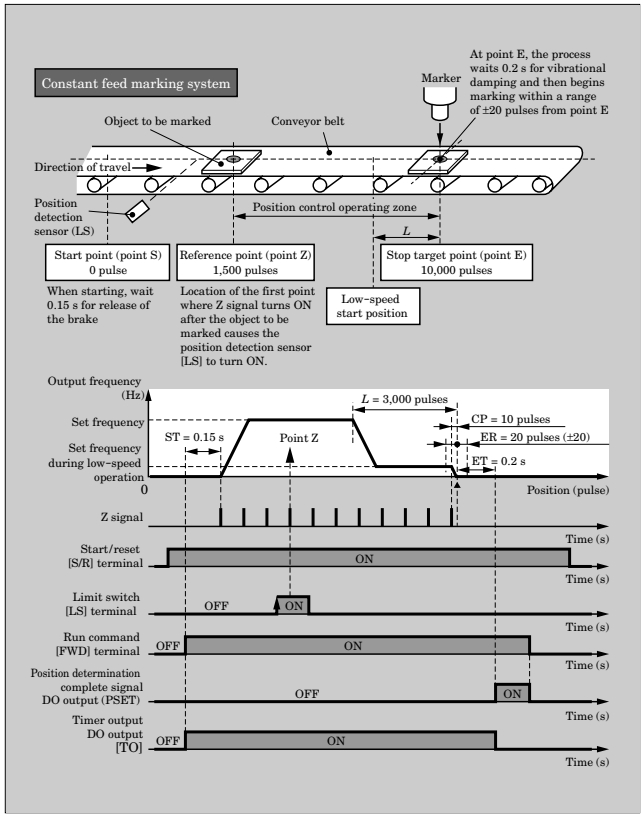


Fig.8 Timing chart for position control



protection of the motor and system, and for load limiting.

4.6 PG feedback control

For the first time in the inverter industry, Fuji has developed optional PG interface control for lower-end models, which was originally developed for high-end models. Installation of PG interface card in FRENIC-Multi series enables use of the following functions and has significantly expanded the range of applications.

(1) Speed control based on PG feedback

Since speed control is more accurate than slip compensation control based on estimated torque, and speed control based on PG feedback is expected to improve positioning accuracy of conveyance machines and measurement accuracy of measurement machines.

(2) Position control based on pulse detection

PG feedback control application to conveyance machines makes it possible to control work position. Position control signal terminals and function codes are provided so that sophisticated position control system can be configured with ease. Figure 8 shows an example of a timing chart of position control. In this example, constant feed marking system controls conveyor feed rate at constant value after detecting the passage of work piece on the conveyor.

(3) Frequency setting using pulse train

Pulse train from control device such as programmable controller can be used to set frequency. Moreover, following operation can be performed by inputting pulse signal from the PG attached to main motor.

4.7 Maintenance functions

Following maintenance information of the inverter can be monitored via keypad or by data transmission.

(1) Capacity of DC bus capacitor
(2) Cumulative operation time of electrolytic capacitors on printed circuit board
(3) Cumulative operation time of cooling fan
(4) Cumulative inverter operation time

As FRENIC-Multi series was designed with attention to peripheral equipment, monitoring of the following information is additionally provided to facilitate equipment maintenance.

- ○ Cumulative motor operation time
- ○ Number of times motor has started

The above information provides a guideline for the user to replace consumable parts related to equipment operation. By implementing preventative maintenance, trouble-free and stable system operation can be achieved.

5. Simple Operation, Simple Wiring, Space Savings

5.1 Removable keypad

With previous FVR-E11S series, keypad was attached to the inverter unit with screws. However, with FRENIC-Multi series, the keypad can be easily removed with simple one-touch operation. Additionally, when a rear cover, which is packaged with the inverter is attached to the keypad, it can be mounted on the control panel of the enclosure, to enable remote operation. In case of remote operation, keypad and inverter connection is possible with commercially available LAN cable (straight cable for 10BASE-T/100BASE-TX) by one-touch connection.

5.2 Removable interface board

Interface board is designed to be removable in order to simplify wiring operations. Optional PG interface card and the RS-485 communication card

have similar dimensions and are installed in the same way as the standard interface board, so that various optional specifications can be supported by only replacing the standard interface board with an optional card.

5.3 Side-by-side mounting

When several numbers of inverters are used, space-saving design of control panel is allowed by the side-by-side mounting of multiple inverters (of 3.7 kW or less).

6. Conclusion

Features of high-performance and compact FRENIC-Multi series inverters have been described. All inverter models in this series are intended for use in general applications, throughout the world, and were developed by incorporating Fuji Electric's proprietary technology and techniques. In the future, Fuji Electric intends to apply its performance and functions of FRENIC-Multi series to various machine and equipment, and to expand the range of applications.

FRENIC-Eco Series Inverters for Fan and Pump Applications

Takashi Nakanishi
Yasushi Kondo
Osamu Mizuno

1. Introduction

Reflecting the growing awareness of global environmental conservation throughout the world in recent years, and as represented by the enforcement of Kyoto Protocol, there is a demand for energy savings and conservation in order to reduce CO_2 emissions that cause global warming. In fan and pump applications in heating, ventilation and air-conditioning systems (HVAC) and the like, substantial energy savings have been realized through the use of inverters. In such applications, the use of inverters is already widespread, and marketplace requirements for improved functionality and higher performance have recently increased.

In response to those requirements, newly developed FRENIC-Eco series was specifically designed for fan and pump applications, and realizes improved ease-of-use with the most suitable functions, performance and options for use with fans and pump, as well as compact size and low cost by optimized design using semiconductor devices in the main circuit. Moreover, since FRENIC-Eco series is environmentally friendly and complies with standards for example designed for long-service life and low noise, and conforming to EU's RoHS directive*1, it is positioned as global product that can be used throughout the world.

This paper describes the features of FRENIC-Eco series.

2. Abundant Model Varieties

Figure 1 shows the appearance of FRENIC-Eco series, and Table 1 lists its model varieties.

To provide wide range of capacities for use in applications ranging from home-use pumps to ventilation systems in tunnels, 3-phase 200 V series from 0.75 to 75 kW and 3-phase 400 V series from 0.75 to 220 kW were developed as standard models. In addition to these standard models, a series with built-in DC reactor for suppressing harmonics in power supply, a series with built-in electromagnetic compatibility (EMC) filter for reducing electromagnetic noise, and a waterproof (IP54) series for use in wet environments (such as pump applications) have also been developed as semi-standard models.

To simplify maintenance, Fuji Electric has also developed inverter support loader software that enables function code setting, operation monitor, test run, and the like on PC.

To improve ease of use, optional interface cards such as LONWORKS*2, DeviceNet*3, RS-485, and relay output as well as, optional multi-function keypad

Fig.1 Appearance of FRENIC-Eco series

Table 1 Variety of FRENIC-Eco series models

Item	Varieties	
Standard Type	3-phase 200 V	0.75 to 75 kW (90 to 110 kW)
	3-phase 400 V	0.75 to 220 kW (280 to 500 kW)
DC reactor (DCR) built-in type	3-phase 200 V	0.75 to 75 kW
	3-phase 400 V	0.75 to 75 kW
EMC filter built-in type	3-phase 200 V	0.75 to 15 kW
	3-phase 400 V	0.75 to 15 kW
Waterproof type (IP54 enclosure)	3-phase 200 V	0.75 to 45 kW
	3-phase 400 V	0.75 to 90 kW

( ) are intended to be lineup in series.

*1: RoHS directive is restriction on the use of certain hazardous substances in electric and electronic devices.

having built-in copying function with improved operation and display capabilities, and external cooling attachment moving rear heat source to outside the control panel to reduce panel size have been developed.

3. Environmental Design

3.1 Energy-savings operation function

Previous energy-savings operation function used a control method that minimized motor loss in accordance with load condition. Newly developed FRENIC-Eco series, however, utilizes a new control method that minimizes both amount of electric power consumed by the inverter itself (inverter loss) and the motor loss. Figure 2 compares characteristics of "inverter + motor" efficiency vs. motor output when using previous method, new method of energy-savings operation, and no energy-savings operation. New method is capable of achieving energy savings in several percent greater than that in previous method.

3.2 RoHS compliance

Even though general-purpose inverters are presently excluded from the EU's RoHS directive, FRENIC-Eco series is steadily advancing toward conformance with RoHS directive in consideration of growing environmental awareness in the marketplace.

3.3 Noise reduction including peripheral devices

By insulated gate bipolar transistor (IGBT) switching in main circuit and field-effect transistor (FET) switching in control power supply, inverter generates conducted noise that travels through stray capacitance with respect to ground and radiated noise that travels as electromagnetic waves, and these may cause incorrect operation in other peripheral devices. FRENIC-Eco series implements the following measures to reduce noise generation.

(1) Reducing voltage fluctuation (dv/dt) of main circuit's IGBT
(2) Use of a structure that cuts off noise conduction path of control power supply FET
(3) Use of a structure that reinforces chassis ground shield

Additionally, the product line has been expanded to include semi-standard series having built-in EMC filter, which conforms to EU's EMC standard (EN61800-3).

3.4 DC reactor built-in type

FRENIC-Eco models with built-in DC reactor (0.75 to 75 kW) are added as to semi-standard series. Since models of motor ratings 22 kW and below also contain built-in zero-phase reactor and capacitive filter, they conform to 2004 version of "Public Building and Construction Standards" issued by Japan's Ministry of Land, Infrastructure and Transport. Models of motor ratings 30 kW and above can conform to that standard by adding zero-phase reactor.

3.5 Easier maintenance

In order to reduce maintenance labor involved in replacing parts of already installed equipment, all limited life parts used in inverter are designed to have an optimal layout (heat countermeasure) and selected from long life parts, to achieve longer design service life. Table 2 lists design service life of various parts in case of 40°C inverter ambient temperature and 80 % load condition of inverter rated current.

Moreover, by storing and displaying following maintenance information to keypad or by sending it to upper-level system, enhance of equipment reliability and simple maintenance can be performed.

- ○ capacitance of main circuit
- ○ cumulative operating time of electrolytic capacitors on printed circuit board
- ○ cumulative operating time of cooling fan
- ○ cumulative operating time of inverter
- ○ cumulative operating time of motor
- ○ number of times started

3.6 Easy replacement of cooling fan

As cooling fan used in FRENIC-Eco has long life, it

*2: LONWORKS is a registered trademark of Echelon Corp. in the US and other countries.

*3: DeviceNet is a registered trademark of the Open DeviceNet Vender Association (ODVA).

Fig.2 Efficiency with and without energy-savings operation function

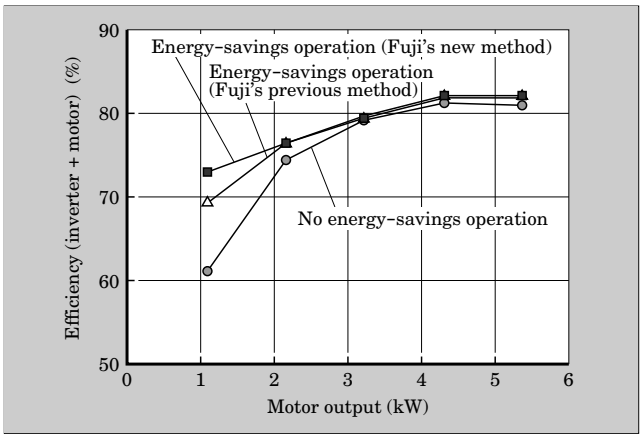


Table 2 Design service life of aging parts

Part name		Design service life
Main circuit capacitor		10 years
Electrolytic capacitor on the printed circuit board		10 years
Cooling fan	30 kW or below	10 years
	37 kW or above	7 years

Load condition : 80 % of output rated current
Ambient temperature : 40°C

has low likelihood of requiring replacement. Moreover, its structure allows easy replacement in the case of failure.

7.5 to 30 kW models can be replaced with simple one-touch operation, and 37 kW and larger models can be replaced from the front panel of the inverter, without removing inverter from control panel. Figure 3 shows cooling fan replacement procedure.

4. Optimal Functions for HVAC

4.1 Current output of analog monitor

Previously, information such as output frequency or output current was 0 to 10 V analog voltage output signal. With newly developed FRENIC-Eco series, such information can also be output as a 4 to 20 mA current signal, which is commonly used as instrumentation signal. Therefore, even in cases where control line wires are long and 4 to 20 mA is required, there is no need for an external device such as a voltage-current converter.

4.2 PID control function

In fan and pump applications, tasks such as control of temperature, flow rate, and pressure are performed by proportional, integral, derivative (PID) function of inverter or by an external PID regulator. Since newly developed FRENIC-Eco series is equipped with enhanced PID control function that supports multiple mode of manual speed commands, alarm output function, low water-flow stop function, and an anti-reset windup function that prevents PID control overshoot, it is suitable for various fan and pump applications. Figure 4 shows a block diagram of PID control function.

4.3 Commercial switching sequence

For fan and pump applications, inverter often operates on commercial power supply mode at or near the commercial frequency, and drives in cases where its frequency is required less than commercial frequency, to improve efficiency. Moreover, in cases where it is not possible to stop equipment that is using inverter, operation may be continued by changing over to commercial operation when inverter issues an alarm stop or fails.

In these cases, the changeover between commercial and inverter operation was traditionally implemented by external sequence control circuit outside the inverter. Since FRENIC5000G11S/P11S series housed a portion of that external circuitry inside the inverter, it simplifies external sequence circuit. As FRENIC-Eco series additionally provides automatic changeover internal sequence to commercial operation in response to an alarm stop initiated by inverter protection function, it enables further simplification of external circuitry.

4.4 Pick-up function

FRENIC-Eco series is equipped with pick-up function that uses high-speed current control function same as in FRENIC-Mini series. With this function, even when idling fan, turning by natural convection or the like, is started by inverter, smooth pick-up is possible regardless of motor's direction of rotation.

Figure 5 shows characteristics of idling motor started by pick-up function.

4.5 Power monitor function

Monitoring information of amount power consumption (kW), cumulative power consumption (kWh) and cumulative power rates (price in local currency per

Fig.3 Replacement of cooling fan (7.5 to 15 kW)

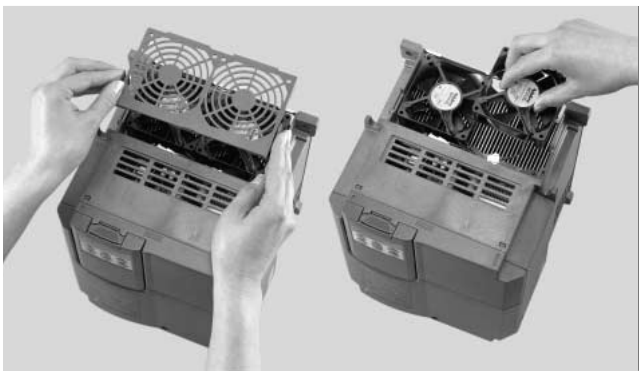


Fig.4 Block diagram of PID control

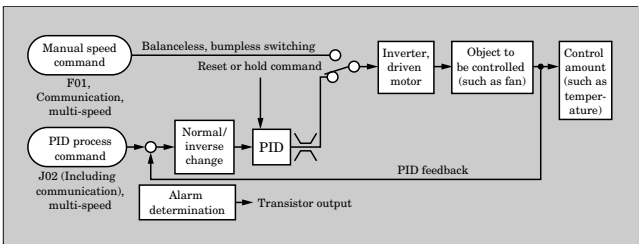
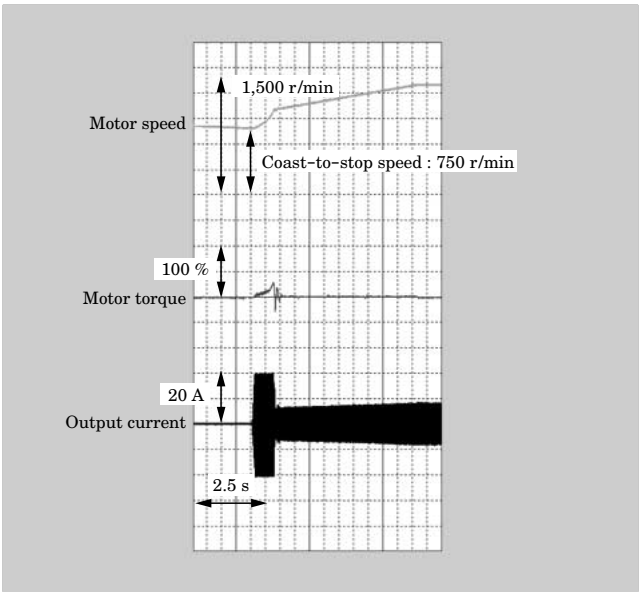


Fig.5 Characteristics of a motor started by the pick-up function



kWh) is displayed on keypad, or is transmitted to an upper-level system to enable power monitoring of whole system consisting of other devices such as inverters.

4.6 Analog input monitor function

By analog input monitor function provided in FRENIC-Eco series, where signals such as flow rate or temperature in air conditioning equipment are connected to the inverter's analog input pins, and conversion factors to convert those signals into physical values such as temperature and pressure are preset, those values can be displayed synthetically on the inverter's keypad or transmitted to an upper-level system, without requiring the use of dedicated flow meters or pressure gages.

5. Options

5.1 Multi-function keypad

FRENIC-Eco series is provided with a keypad as standard equipment, and this keypad provides the capability for remote operation. As an option, multi-function keypad featuring a backlight liquid crystal display (LCD) and large 5-digit 7-segment light-emitting diode (LED) display is also available. Figure 6 shows the appearance of this multi-function keypad. Special features of multi-function keypad are listed below.

(1) Can be attached to inverter unit instead of standard keypad (allows remote operation via a LAN cable)
(2) A "REM/LOC" switch key makes it possible to switch between remote operation via external operation commands, or local operation with inverter unit
(3) Can store and read out function codes for up to 3 inverters
(4) Communication debug function enables testing and verification of transmission data

Fig.6 Appearance of multi-function keypad

(5) Capable of information display up to the last 4 generated alarms, and capable of setting and verifying function code data

5.2 Network options

To communicate with upper-level controller, Fuji Electric provides interface cards that support LONWORKS and DeviceNet. Since LONWORKS is well suited for building networks, it realizes flexible system

Table 3 Functions of inverter support loader software

Name of function	Description
Function code setting	Reading, editing and comparison of function code data, term searches, user settings, etc.
Operation monitor	I/O monitor, system monitor, alarm monitor, meter display
Multi-monitor	Simultaneous monitoring of two or more inverters
Test run	○ Run/stop and frequency setting can be entered at the loader for starting test run. ○ Monitoring of the operation status (such as the output frequency)
Real-time trace	Arbitrary data can be monitored in real time.
Other	Communications setting, connection setting

Fig.7 Function code setting screen

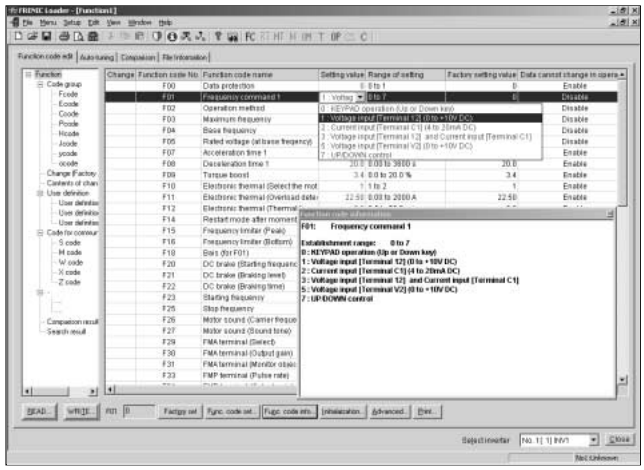
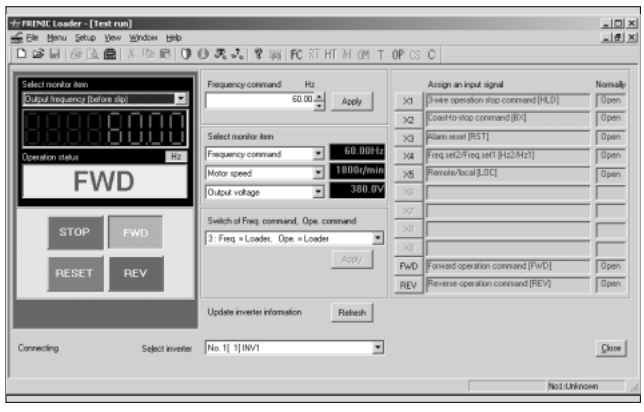


Fig.8 Test run screen



for building's internal control such as air conditioning. In the future, Fuji Electric intends to provide interface cards that support various other networks such as PROFIBUS-DP*4 and CC-Link*5.

5.3 Inverter support loader software

Inverter support loader software that runs on Windows*6 is available to support function code setting, operation monitoring, test runs and the like.

Table 3 lists function of the inverter support loader software, Fig. 7 shows an example screenshot of function code setting, and Fig. 8 shows an example screenshot of test run.

6. Main Circuit Technology

FRENIC-Eco series uses suitable main circuit semiconductor devices matched to variable torque characteristic of fan and pump applications.

Moreover, smaller size and lower cost are realized through the use of newly developed low-thermal resistance metal circuit board (7.5 to 15 kW), where ceramic circuit board was used internally in the past, and the use of power module that integrates the converter unit and inverter unit previously separated.

Additionally, electromagnetic analysis and simulation techniques were used to design internal bus bar that connects main circuit's IGBT and capacitor. Since as a result, shape of the internal bus bar and layout of IGBT device and the main circuit's capacitor are optimized, it enables inductance reduction of the internal wiring and a uniform distribution of current, and realization of more compact size and lower cost for snubber circuit and main circuit's capacitor.

7. Conclusion

Features of FRENIC-Eco series inverter for fan and pump (variable torque load) applications have been described above. These inverter models feature enhanced functions and performance for fan and pump applications in order to achieve significant energy savings, and are specifically-designed products that will develop further use of inverters. Looking ahead to future trends of fan and pump market, Fuji Electric intends to continue to create products that satisfy the needs of the marketplace.

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*4: PROFIBUS-DP is a registered trademark of the PROFIBUS User Organization.

*5: CC-Link is a registered trademark of the CC-Link Association.

*6: Windows is a registered trademark of Microsoft Corp. in the US and other countries.

FRENIC-Lift Series Inverters for Elevating Machinery

Tetsuya Nomura
Hiroaki Kato

1. Introduction

In elevator industry, system is transitioning from geared elevators that use standard induction motors to gearless elevators that use synchronous motors. Gearless elevators has already got the majority of new construction starts in Japan, and demand for their use is also increasing in rapidly growing markets in China and Europe. Inverters that drive gearless elevators are required to be small, thin, to have high overload capacity, and to deliver high performance and high functionality.

In consideration of these circumstances, Fuji Electric has newly developed FRENIC-Lift series inverters designed specifically for elevator machinery. This paper introduces the features of FRENIC-Lift series.

2. FRENIC-Lift Specifications and Features

FRENIC-Lift series was developed to provide powerful and high-performance inverters as well as easy-to-use. Input voltage is 3-phase 400 V, and output capacity ranges from 5.5 to 22 kW. Figure 1 shows external appearance of 11 kW model. Functionality is enhanced with the provision of many custom functions for elevator machinery, including the well-established vector control with speed sensor.

2.1 Hardware configuration for powerful and optimized elevator machinery

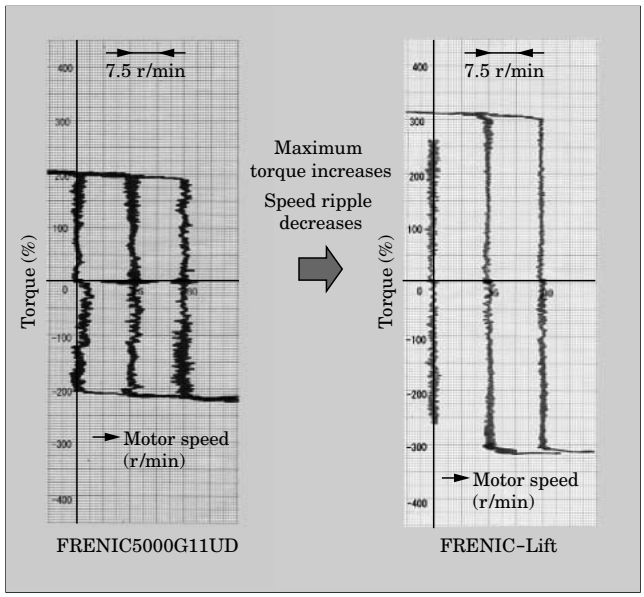
2.1.1 High overload capacity

Since maximum torque is needed during acceleration and deceleration for elevator-related applications, an ample overload capability is important. Moreover, required load inertia (at the motor shaft) of recently popularized gearless elevator is larger than that of geared elevator, and a larger torque is needed during acceleration and deceleration.

With FRENIC-Lift, specified thermal design based on operating pattern of elevator and lower generated loss due to the use of next-generation insulated gate bipolar transistor (IGBT) chip enabled the realization of 200 % – 10 s overload capacity. This value is significant improvement from the 150 % – 10 s overload capacity of previous model (FRENIC5000G11UD).

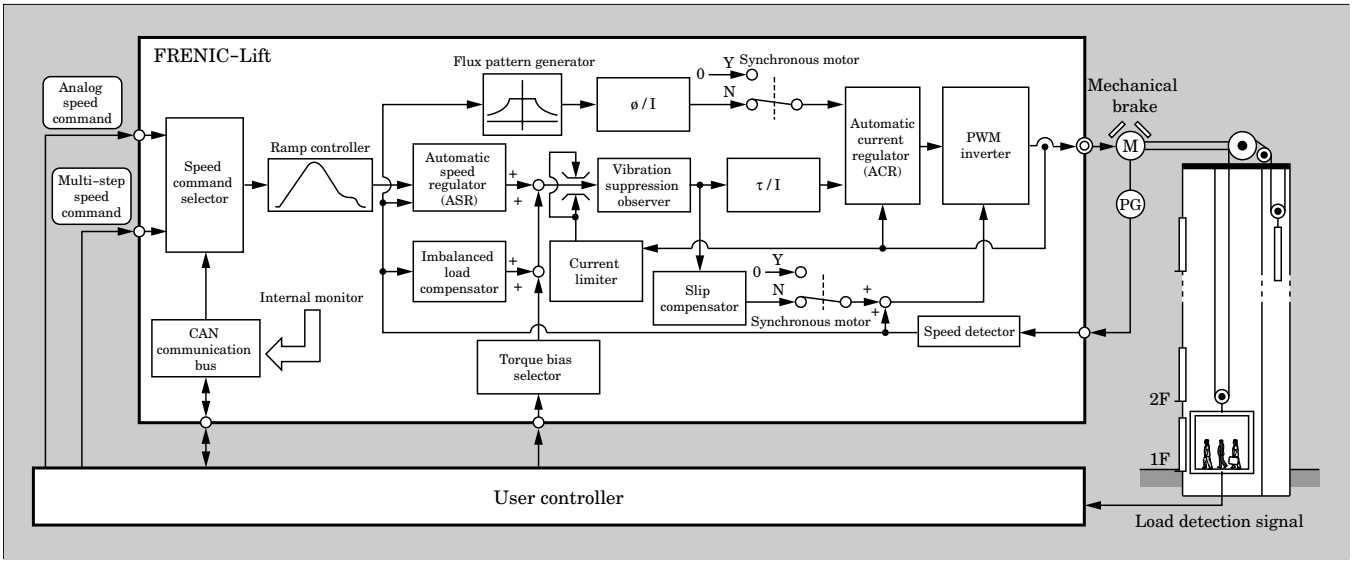
Fig.1 External view of FRENIC-Lift series

Fig.2 Speed vs. torque characteristics (at low speed)



Consequently, FRENIC-Lift series is well suited for applications for which prior models could not be used due to their limited overload capacity such as relatively high-speed elevators and gearless elevators

Fig.3 Control block diagram



having large load inertia (at the motor shaft).

Figure 2 shows speed vs. torque characteristics at low speed. Compared to FRENIC5000G11UD, it can be seen that FRENIC-Lift has larger torque and lower speed ripple, and is thereby capable of powerful and stable operation.

2.1.2 Internal encoder interface and braking circuit

Encoder interface and braking circuit are provided as standard equipment. As a result, it is attachable to the small space compared with previous models.

2.1.3 Safety function

Safety function is provided whereby, regardless of operating state, when dedicated control input (EN terminal) is turned OFF, inverter output is cutoff immediately and motor drive is stopped reliably. The process by which drive output is cutoff in response to this function is implemented by hardware, which operates much faster than software processing. Additionally, since output cutoff circuit is equipped with functions for stopping the motor drive reliably even in the case of partial malfunction and for delivering information outside about the malfunction, it realized enhanced safety feature.

2.2 High-level control performance

2.2.1 Greater riding comfort by improved control response

With FRENIC-Lift, control response has been improved significantly with use of higher-speed automatic current regulator (ACR). Figure 3 shows a block diagram of FRENIC-Lift control system, and Fig. 4 shows speed response characteristics of FRENIC-Lift and the FRENIC5000G11UD.

With improved control response of FRENIC-Lift, elevator car vibration (vertical) has been reduced compared to previous models, and a vibration characteristic less than 0.10 m/s² (p-p) was achieved in actual gearless elevator (See Fig. 5).

Fig.4 Speed response characteristics

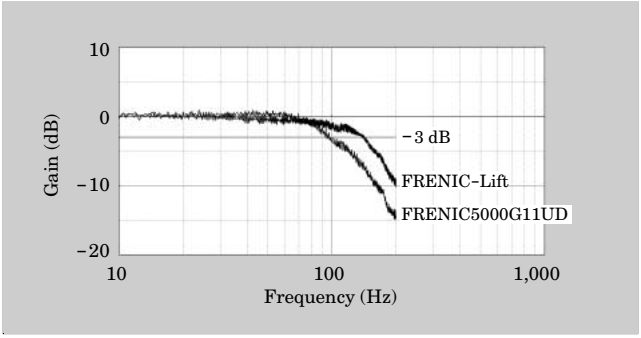
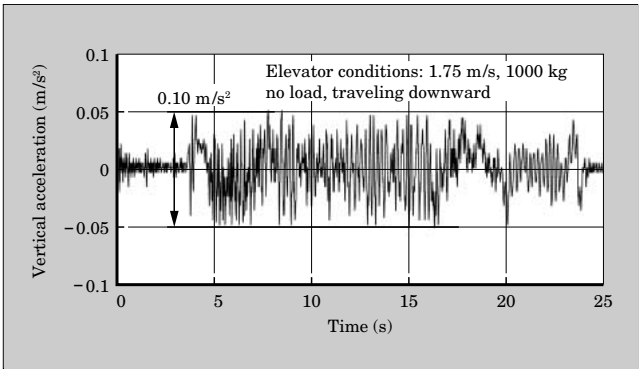


Fig.5 Car vibration (vertical)



2.2.2 Reduced rollback when brake is released

Unless elevator provides torque compensation in response to load imbalance between weight of car (with load) and counterweight, rollback will occur when mechanical brake is released.

Typically, a signal from load detector attached to elevator car has been used to calculate necessary amount of torque to inverter so as to reduce the occurrence of rollback when the mechanical brake is released. FRENIC-Lift, however, is equipped with imbalanced load compensator to calculate and provide

Fig.6 Reduced rollback when mechanical brake is release

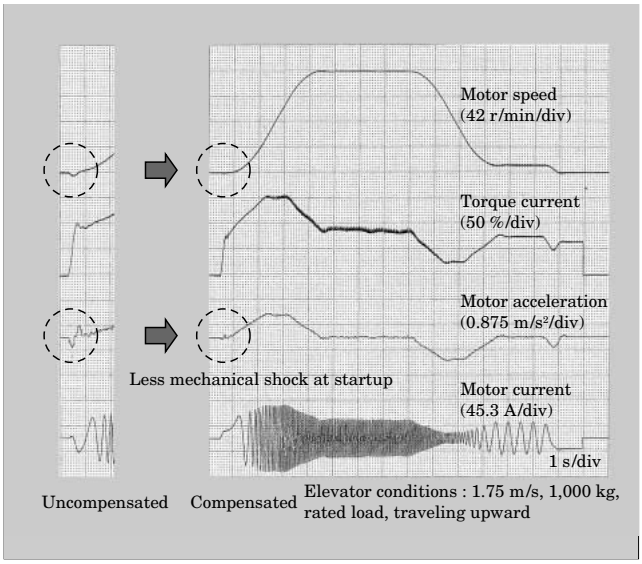
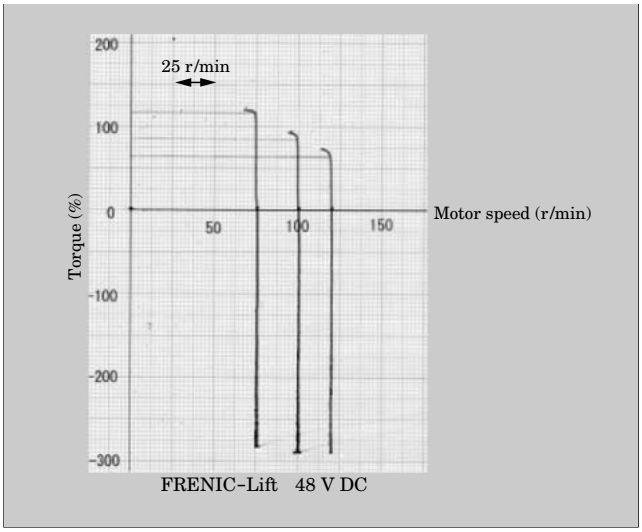


Fig.7 Torque characteristics during battery operation



necessary amount of torque compensation.

Figure 6 shows characteristic data of imbalanced load compensator. Data on the left is "uncompensated" and data on the right is "compensated." The phenomenon of rollback when mechanical brake is released can be checked with vibration of motor acceleration. Compensated data shows no fluctuation in motor acceleration, and it can be seen that the imbalanced load compensator mitigates the phenomenon of rollback.

Because load detector is unnecessary with this function, elevator system can be simplified and reduce its cost. When renewing an elevator, for example, imbalanced load compensator is very effective to realize smooth operation even in elevators not equipped with load detector.

2.2.3 Application for gearless elevators (option)

For synchronous motors, an optional interface is available that supports "EnDat 2.1 serial interface encoder" and "4-bit gray code and U V W 3-bit code parallel interface encoders," which are used often in elevator industry. Additionally, offset tuning function of magnetic pole position is also provided to adjust the magnet pole position offset values automatically.

As a result, set-up work for gearless elevator is simplified.

2.3 Functions suited for elevator applications

2.3.1 Standard CAN bus interface

Controller area network (CAN) bus is a highly reliable network having a track record of many successful applications. Moreover, due to low protocol overhead and high-speed communication capability of CAN bus, high-speed response can be achieved that is approximately 10 times RS-485 communication performance used in conventional general-purpose inverter.

Because CAN bus is provided as standard interface, inverter control can be realized via communication lines, and as a result, less wiring is possible.

2.3.2 Optimization of operating cycle

Generally, just prior to landing elevator (the car is approaching loading position), it travels at a low-speed known as creep speed to reach the landing position accurately. However, FRENIC-Lift is equipped with creepless operation function that operates when the elevator is landing. When receives a positioning signal as an external command, this creepless operation function generates speed command pattern to move the elevator from that time to just the specified distance, and then to stop the elevator. Therefor it can eliminate the need for creep speed operation.

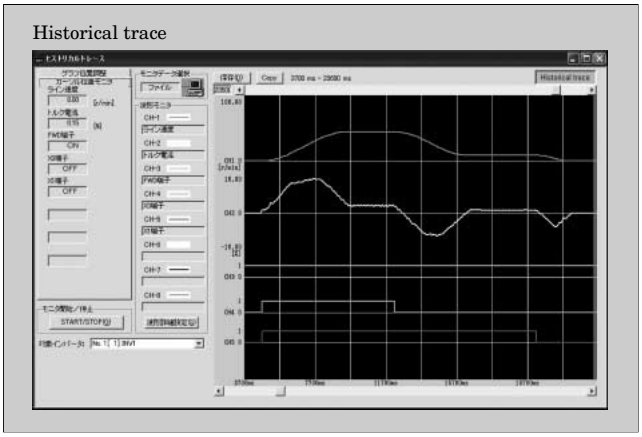
This function enables optimized operating cycle of an elevator.

2.3.3 Battery operation characteristics

Figure 7 shows speed vs. torque characteristics during battery operation. The battery voltage is 48 V DC. When in the braking mode, even during battery operation, stable operation with at least 200 % torque is possible.

Additionally, during battery operation, an uninterruptible power supply (UPS) or the like may be used as an auxiliary power input to inverter control circuit. Since UPS output voltage matches the voltage of the power distribution system, it often differs from the voltage at the motor power inputs (3-phase power supply). For example, in the case where 3-phase power supply is 380 V and the power distribution system voltage is single-phase 220 V, a voltage drop of more than 40 % will occur at time of changeover to the UPS. Fuji Electric's general-purpose inverters only guarantee proper operation for up to 15 % drop in power supply voltage. However with FRENIC-Lift, design of the DC-DC converter load has been optimized to guarantee proper operation during this type of wide voltage variation. By reducing DC-DC converter load during battery-powered operation, 400 V series inverter can allow 200 V control power input during a power failure.

Fig.8 Trace function



2.4 Ease of use

2.4.1 Trace function

Windows*1-compatible FRENIC loader enables trace function that is capable of monitoring such waveforms as inverter's internal reference speed and reference torque, etc.

Trace function allows for real-time traces, which display the current state as a continuous waveform, and historical traces, which display waveforms before and after when trigger conditions are met (See Fig. 8).

Because this function allows parameters to be adjusted during test runs, maintenance, waveform monitoring, and the like, operation efficiency is improved and set-up time is reduced.

2.4.2 Environment-friendly functions

Since elevators are public facility, the level of acoustic noise emitted from an inverter's cooling fan when elevator is stopped, may be undesired in some cases. With FRENIC-Lift, the conventional cooling fan control has been improved such that, as long as the inverter's heat sink temperature does not rise, the cooling fan will not operate. As a result, not only reduction of acoustic noise from the cooling fan, but also extension of service life of cooling fan is performed.

Additionally, since inverters are installed in relatively severe environments such as inside an elevator control console, machine room, or the like, a dust-protecting fan is used to improve the capability of the inverter against such environments.

2.4.3 Other functions

An elevator control system consists of user controller, inverter and peripheral circuitry. FRENIC-Lift series is system-oriented, and is equipped with many convenient functions.

One of such function is providing door open-close control signal. This signal equipped on inverter side make it easy to control the elevator door when the elevator has landed.

Another convenient function is selection of positive or negative logic for each I/O signal. The decision of whether each signal is normal ON, or abnormal ON, depends on the type of control signal and the system design. With FRENIC-Lift, all I/O signal active logic can be switched easily with the parameter settings.

3. Future Outlook

3.1 Global standard conformance

Fuji Electric intends to conform with EC directive (CE mark) required in the European markets, and the UL standards and cUL certification required in the North American markets. Furthermore, although inverters are presently exempt, in consideration of the growing sense of environmental awareness in the market, Fuji Electric is also making preparations to facilitate conformance with RoHS directive*2.

3.2 Product series expansion

In the future, Fuji Electric plans to develop a large-capacity 400 V series and a 200 V series.

4. Conclusion

Features of FRENIC-Lift series inverters for elevator machinery have been presented. Fuji Electric intends to continue to develop inverters that meet the needs of the market and to incorporate insights from end users to create even better products in the future.

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*1: Windows is a registered trademark of Microsoft Corp. in the US and other countries.

*2: RoHS directive is restriction on the use of certain hazardous substances in electric and electronic devices.

FALDIC-W Series Servo Systems

Akihiro Itou
Kayo Tsuzaki
Atsushi Narita

1. Introduction

The range of applications for servo systems has recently been expanding to include the field of general industrial machinery, such as conveyance machinery, printing machinery, textile machinery, injection molding machinery, and to the field of semiconductor manufacturing equipment, to achieve better mechanical performance and thereby improve productivity in these fields. In addition to the prior requirements for high performance and high precision, availability for severe operating environments and easy setup and maintenance are also required.

Responding to these marketplace requests, Fuji Electric has newly developed FALDIC-W series (hereafter referred to as "W series"), as a continuation of its FALDIC-α series and FALDIC-β series high-performance servo systems. W series servo system is equipped with vibration suppression control to improve performance and precision, and International Protection Code IP67 motor to support use in severe operating environments. Moreover, easy-tuning function and centralized parameter management function are provided to increase user's easy-of-use and to simplify setup and maintenance work.

Specifications and features of this new servo system are described below.

2. Basic Specifications

Figure 1 shows external appearance of W series.

W series consists of three model types: a low inertia model having 3,000 r/min rated speed, and two middle inertia models having 2,000 r/min and 1,500 r/min rated speeds. Basic specifications of these

Fig.1 Appearance of FALDIC-W series

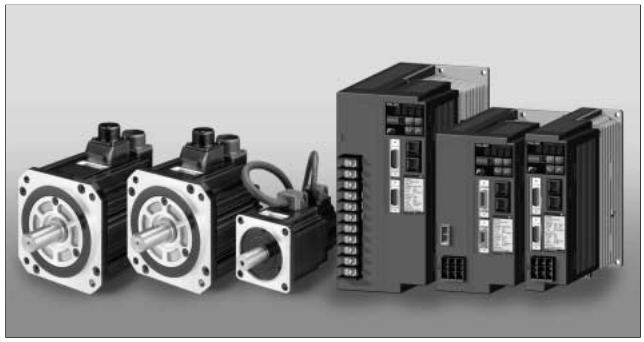


Table 1 Servomotor specifications

Item \ Model	GYS□□□DC2-T2△					GYG□□□CC2-T2△					GYG□□□BC2-T2△		
	500	101	201	401	751	501	751	102	152	202	501	851	132
Rated output (kW)	0.05	0.1	0.2	0.4	0.75	0.5	0.75	1.0	1.5	2.0	0.5	0.85	1.3
Rated torque (N·m)	0.159	0.318	0.637	1.27	2.39	2.39	3.58	4.77	7.16	9.55	3.18	5.41	8.28
Max. torque (N·m)	0.478	0.955	1.91	3.82	7.17	7.2	10.7	14.3	21.5	28.6	9.50	16.2	24.8
Rated speed (r/min)	3,000					2,000					1,500		
Max. speed (r/min)	5,000					3,000							
Moment of inertia $\times 10^{-4}$ (kg·m^2)	0.0192	0.0371	0.135	0.246	0.853	7.96	11.55	15.14	22.33	29.51	11.55	15.15	22.33
Rated current (A)	0.85	0.85	1.5	2.7	4.8	3.5	5.2	6.4	10.0	12.3	4.7	7.3	11.5
Max. current (A)	2.55	2.55	4.5	8.1	14.4	10.5	15.6	19.2	30.0	36.9	14.1	21.9	34.5
Altitude at location of installation	Indoor: 1,000 m or less												
Ambient temperature, humidity	–10 to +40°C, 90 % RH or less (no condensation)												
Resistance to vibration (m/s^2)	49					24.5							
Mass (kg)	0.45	0.55	1.2	1.8	3.4	5.3	6.4	7.5	9.8	12.0	6.4	7.5	9.8

Table 2 Servo amplifier specifications

Item \ Model			RYC□□□D3-VVT2					RYC□□□C3-VVT2					RYC□□□B3-VVT2		
			500	101	201	401	751	501	751	102	152	202	501	851	132
Applicable motor rated speed (r/min)			3,000					2,000					1,500		
Applicable motor output (kW)			0.05	0.1	0.2	0.4	0.75	0.5	0.75	1.0	1.5	2.0	0.5	0.85	1.3
Input	Main power	No. of phases	Single phase				Single phase, 3-phase	3-phase					Single phase, 3-phase	3-phase	
		Voltage	200 to 230 V AC −10 to +10 % (single phase)												
			200 to 230 V AC −15 to +10 % (3-phase)												
		Frequency	50/60 Hz												
	Control power	No. of phases	Single phase												
		Voltage	200 to 230 V AC −10 to +10 %												
		Frequency	50/60 Hz												
Output	Control method		IGBT PWM sine wave operation												
	Carrier frequency		10 kHz												
	Overload capability		300 % / 3 s												
	Control method		Regenerative braking applied to intermediate DC circuitry, regenerative resistor installed externally												
Feedback			Incremental 17-bit encoder (17-bit resolution per revolution)												
Control function	Control function		Position control, speed control, torque control												
	Max. frequency of input pulse string		1.0MHz (differential input), 200 kHz (open collector)												
	Frequency response		600 Hz (at $J_L = J_M$)												
	Position analysis function		2^{17} (= 131,072) / revolution												
Environment	Location of installation		To be installed indoors, an altitude of 1,000 m or less, at a location free from dust, corrosive gas or direct sunlight. To conform with European standards: pollution degree = 2, overvoltage category Ⅲ												
	Ambient temperature		−10 to +55°C												
	Ambient humidity		10 to 90 % RH (no condensation)												
	Resistance to vibration (m/s^2)		4.9												
	Resistance to impact (m/s^2)		19.6												
Applicable standards			Conforms to UL/cUL (UL508c), CE marking (low voltage directive EN50178)												
Mass (kg)			1.0					1.5			2.5		1.5		2.5

model types are presented below.

2.1 Servomotor specifications

Table 1 lists basic specifications of servomotor. W series consists of total 26 models, configured from 3 different types of rated speeds and output capacities, and either with or without a brake.

In order to support wide range of applications, motor (except for shaft area and connector area) in all models has dustproof and waterproof construction that conforms to International Protection Code IP67.

New middle inertia models, achieves 2.5 to 3.5 times inertia moment as same rated speed prior models. The result is improved suitability for applications involving machinery which have relatively large ratio of load inertia moment or have low rigidity, and thus broader range of applications is available for the servo system.

2.2 Servo amplifier specifications

Table 2 lists basic features of servo amplifier. W series is provided with a control function that allows switching among following three types of control: position control, speed control and torque control.

Since all wiring connectors are arranged on the front and bottom panels of the amplifier to enable side-by-side installation, it realizes 400 W in compact size of 45 mm (W) × 160 mm (H). Moreover, control power source is provided to backup sensor position in case main power is cut off during emergency, and thereby it eliminates return to origin action.

3. High Performance

3.1 Vibration suppression control

Shorter takt times are increasingly demanded in order to improve productivity. W series uses Fuji Electric's proprietary vibration suppression control function, inherited from FALDIC-β series, to achieve a takt time reduction. The vibration suppression control function can reduce vibrations of machinery having low rigidity, such as tip of robotic arm using multi-inertia machine model housed in the servo amplifier. In recent years, applicable range of vibration suppression

control is increasing due to demand of shorter takt times by suppressing mechanical vibration in applications such as LCD glass panel conveyor lines, for example.

Prior to using the vibration suppression control function, mechanical vibration frequency is set as a parameter. Up to four different frequencies can be set to support machinery in which vibration frequency changes due to operation or object being conveyed. Servo analysis function that analyzes specific vibrating frequencies of the machine is also provided to simplify user's task of setting the frequency. To simplify the user's operation, PC loader tool can be used to instruct the servo amplifier to perform automated analysis operation and then to display the analysis results on PC screen. The parameters may then be set directly from the display screen.

3.2 Improved response with model torque computation function

In response to requests for shorter takt time machine operation, W series is equipped with a model torque computation function. Model torque computation calculates amount of torque needed for particular command, thereby it increases tracking performance and reducing settling time for that command. As a result, W series is suitable for application such as die bonder, that is one of the semiconductor-manufacturing equipment in which high performance is required.

3.3 17-bit serial encoder

The motor of W series is equipped with a newly developed serial encoder to provide stable rotation at slow speeds. This encoder has a resolution of 17 bits (corresponding to 131,072 pulses), and sends data to the amplifier through high-speed serial interface. Reduction of rotational speed fluctuation realized smooth mechanical operation and high-speed response.

4. Simplified Setup

4.1 Centralized parameters management

When using a servo system, various parameters must be set in accordance with machinery characteristics. Setting of parameters is accomplished via serial communication interface, which previously has been implemented as point-to-point communication between upper-level controller and the servo system. When using multi-axis servo system for mass-produced machinery, manual setting becomes time consuming because communication cables must be changed for each servo system. Moreover, mistakes tend to occur, such as the incorrect parameter setting.

With W series, node numbers are used to identify a servo system for communication. W series is also equipped with two RS-485 interface ports to support multi-drop communication with multiple servo systems. Figure 2 shows a conceptual drawing of multi-drop connection. A maximum 31 servo systems can be connected to one upper-level controller, and communication with any servo system is possible by specifying the appropriate node number, without having to replace any communication cable. As a result, during system setup, setting of parameters can be carried out automatically from the upper-level controller, thereby it reduces required setup time and prevents setting mistake.

4.2 Pattern operation

When setting up the total system, even if a servo system is installed to a machine, the system will not operate unless upper-level controller such as programmable controller issues the appropriate command. Therefore, no operation will occur until the upper-level controller completes such preparatory tasks as verifying the load factor of the servo system in accordance with the operating pattern, and adjusting operation-related parameters.

W series is equipped with a pattern operation function that automatically performs reciprocal operations. Figure 3 shows a conceptual drawing of pattern operation. Pattern operation accepts the stroke and speed parameters according to a pattern to enable combination action with mechanical system by means of repeated reciprocal operation, even in cases where

Fig.2 Multi-drop connection

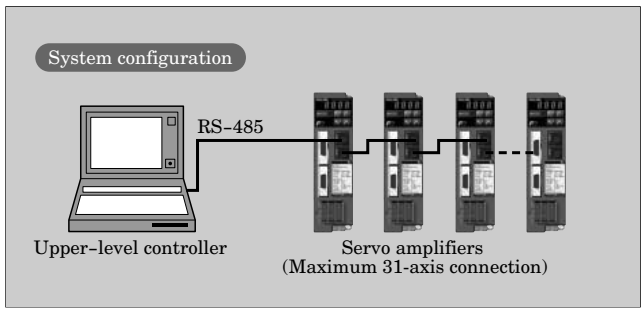
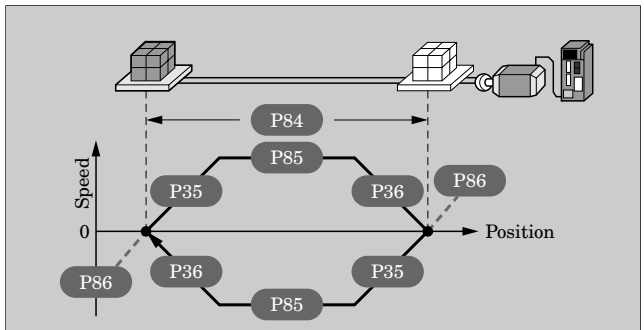


Fig.3 Pattern operation



<Description of pattern operation>
○ In the figure, P□□ indicates the parameter number.
○ Accelerates at acceleration time (P35), moves by stroke setting (P84) amount at speed setting (P85), decelerates at deceleration time (P36), stops for duration of timer setting (P86), and then similarly returns to the start position.
○ This reciprocating operation is repeated.

there is no upper-level controller. By monitoring each motor during operation, overload level, motor suitability, operation pattern suitability and the like can be assessed early on, without affecting by completion degree of upper-level controller. Moreover, use of the easy tuning function to perform adjustments and operational verification reduces required setup time.

4.3 Easy tuning

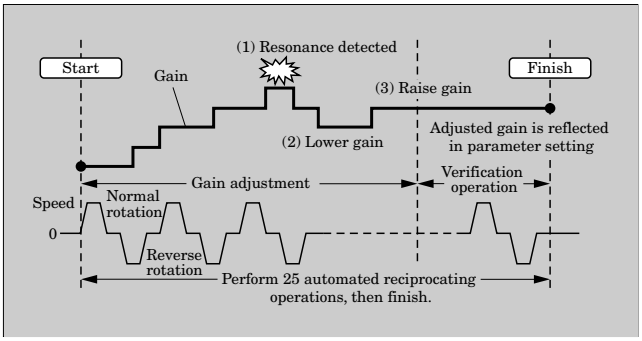
With conventional auto-tuning, relevant parameters are computed automatically according to gain and ratio of load inertia. Ratio of load inertia is estimated automatically, and user sets the gain itself. Machine's response is determined by the gain adjustment, and in cases where machine vibrates at its resonance frequency, adjustment-related expertise and experience are needed to reduce the gain and adjust various parameters.

In W series, instead of requiring the user to make such adjustments, easy tuning function is provided for gain adjustment. Figure 4 shows the operation of the easy tuning function. The easy tuning function operates automatically to increase the gain according to servo system operation pattern suited for tuning. If resonant vibration is detected, the easy tuning function automatically decreases the gain, sets a notch filter, and then increases the gain again. When the easy tuning operation is completed, gain value is reflected on the parameter setting, and subsequent normal operation is performed using this gain setting. This gain adjustment is extremely easy to implement, the user simply presses a button to activate the easy tuning function and the adjustment is performed entirely by the servo system.

4.4 Z-phase offset

During setup, origin sensor attached to the machine have to set machine's origin position. Therefore this origin position and the Z-phase servomotor reference position require position matching. Normally, such positional adjustment is implemented by mechanical coupling between the machine's shaft and the

Fig.4 Easy tuning operation



servomotor's output shaft. However in recent years, the range for this adjustment has become extremely narrow due to the smaller sizing of machines, and the man-hour cost for adjustment work which is the burden on the user have been increasing.

W series, however, is equipped with Z-phase offset function that electronically adjusts Z-phase output position. With Z-phase offset function, electrical Z-phase position is set by simply moving the machine to a location where a Z-phase signal is desired and then activating an automated adjustment function. As a result, the task of Z-phase positional adjustment can be eliminated.

5. Conclusion

Features and specifications of FALDIC-W series have been presented. W series was designed to support a wide range of applications with increased variety of motors, and dramatically improved performance.

In the future, Fuji Electric intends to advance conformance with EU's RoHS directive*1 that regulates the use of chemical substances, and to strive to satisfy user expectations.

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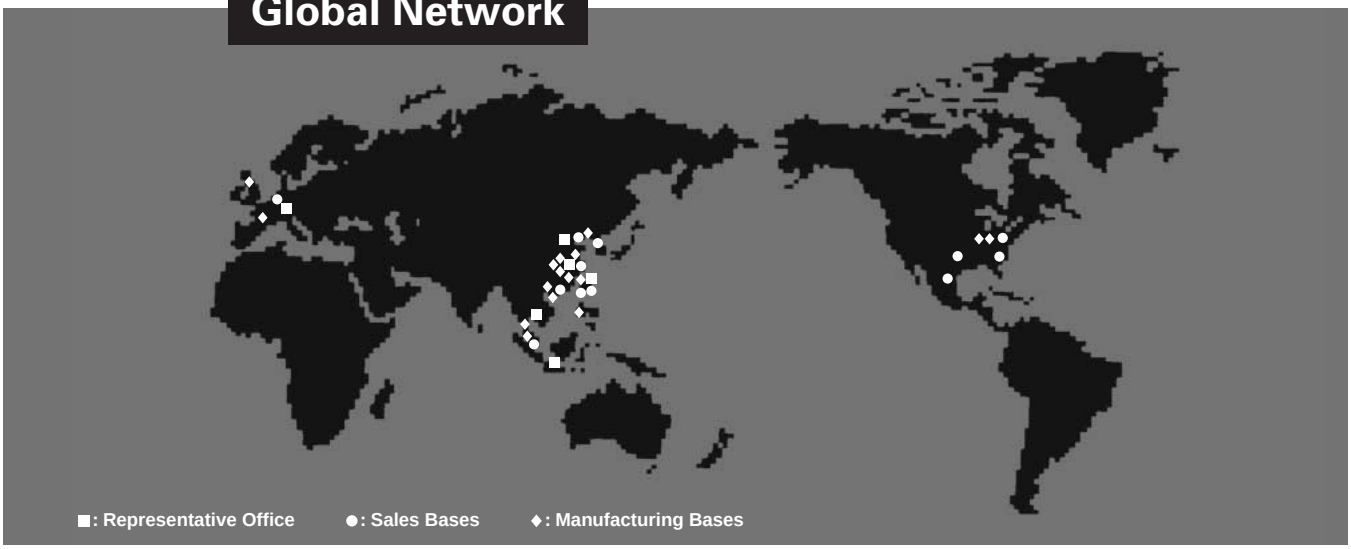
*1: RoHS directive is restriction on the use of certain hazardous substances in electric and electronic devices.

Global Network



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