Latest Technology for General-purpose Inverters and Servo Systems

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1. Introduction

In the industrial sector, the range of applications for general-purpose inverters and servo systems is expanding, and equipment and machinery trends are toward miniaturization, energy savings, labor savings, higher speed and higher accuracy. In recent years, in response to efforts to design safety systems that use risk assessment, not only is good performance required, but a simple configuration and ease-of-use that will lead to lower total costs for system development and maintenance are also requested.

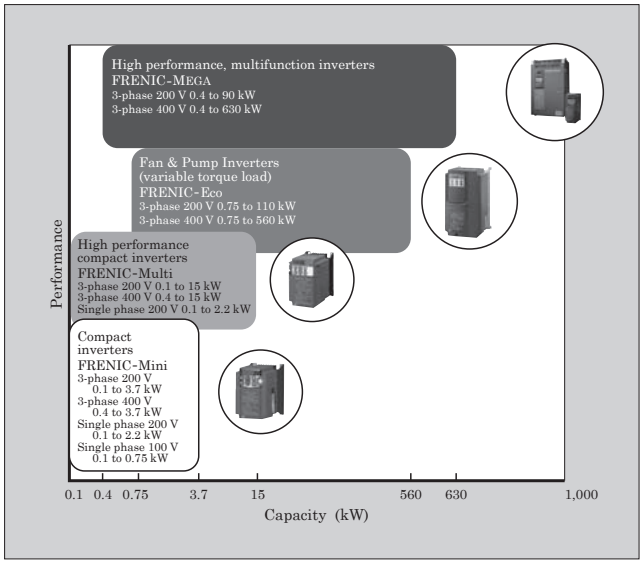
Responding to these requests and trends, the latest technologies have been incorporated into these general-purpose inverters and servo drive systems, and application examples thereof, are introduced herein.

2. Fuji Electric's Product Lineup

2.1 General-purpose inverters

Figure 1 shows Fuji Electric's product lineup of general-purpose inverters.

Fig.1 Fuji Electric's product lineup of general-purpose inverters



Fuji Electric provides four series of general-purpose inverters: FRENIC-Mini, FRENIC-Multi, FRENIC-Eco and FRENIC-MEGA.

The product lineup is described briefly below.

(1) FRENIC-Mini Series

Compact-type inverter series for the simple variable speed control of small capacity motors of 3.7 kW or less

(2) FRENIC-Multi Series

High-performance, compact-type inverter series for the general variable speed control of small and medium capacity motors of 15 kW or less

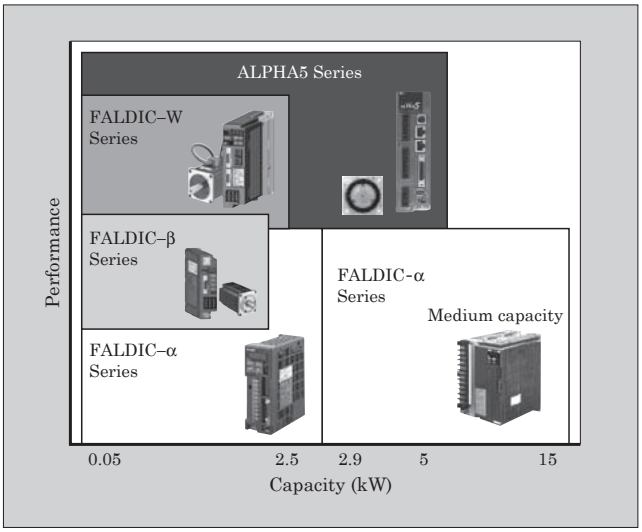
(3) FRENIC-Eco Series

Application specific inverter series with enhanced functions for air-conditioning applications that use fans, pumps and HVAC (Heating Ventilation and Air Conditioning) equipment for applications that target control of variable torque load of 560 kW or less

(4) FRENIC-MEGA Series

General-purpose inverter series provided with highest-class of vector control, and high performance and multi-functionality that support various applications of 630 kW or less

Fig.2 Fuji Electric's product lineup of servo systems



† Fuji Electric Systems Co. , Ltd.

2.2 Servo systems

Figure 2 shows Fuji Electric's product lineup of servo systems.

The FALDIC-α Series, FALDIC-β Series, FALDIC-W Series, and the ALPHA5 Series which is presently the main model, are available.

With capacities of 0.05 to 5 kW, a frequency response of 1,500 Hz, and the industry's highest level of performance, the ALPHA5 Series is suitable for a wide range of applications.

3. Latest Technology and Application Example

3.1 General-purpose inverters

(1) Synchronous motor drive system

A high efficiency synchronous motor drive system that combines a permanent magnet type synchronous motor (PM motor), and a dedicated inverter for PM motor driving is described below. A PM motor has a higher efficiency and contributes more to reducing CO_2 emissions and increasing energy savings than an induction motor.

(a) FRENIC-MEGA Series for PM motor driving

This series of dedicated inverters for PM motor driving utilizes sensor-less vector control, which has a track record of success, and realizes highly accurate torque control and speed control, as well as highly efficient operation, without the use of sensors for the PM motor.

Figure 3 is a block diagram of the sensor-less vector control system.

Features of sensor-less vector control are described below.

(i) Highly accurate torque control and speed control

A position and speed estimator that uses a voltage equation model of the PM motor estimates the rotor speed and magnetic pole position from a voltage reference value and a current detection value. The torque is calculated from precise estimates of the rotor speed and magnetic pole position, and highly accurate torque control and speed control is realized.

(ii) Highly efficient operation

Highly efficient operation is realized by using a magnetic flux reference calculator and a current reference calculator to control the torque with respect to the current so that the magnetic flux is always at its maximum value.

At speeds greater than the base speed, the terminal voltage (induced electromotive voltage proportional to the speed) of the PM motor becomes larger than the maximum output voltage of the inverter, and the terminal voltage cannot be controlled to the desired value. As a result, the current cannot be controlled properly and stable operation of the motor is difficult to achieve. With the FRENIC-MEGA Series, magnetic flux is controlled such that the terminal voltage of the PM motor does not exceed the maximum output voltage of the inverter, and therefore higher efficiency and greater stability can be realized than with the conventional control method.

(iii) Auto-tuning (offline)

To realize sensor-less vector control and high efficiency operation, the electric constants of the PM motor (armature resistance, inductance and induced electromotive voltage) must be known. The FRENIC-MEGA Series has a function for measuring these electric constants automatically.

For each regulator, an offline auto-tuning function automatically sets control parameters to optimal values based on measured values of the electric constants. The user is no longer required to perform the troublesome task of setting parameters, and a system having maximum efficiency can be realized easily.

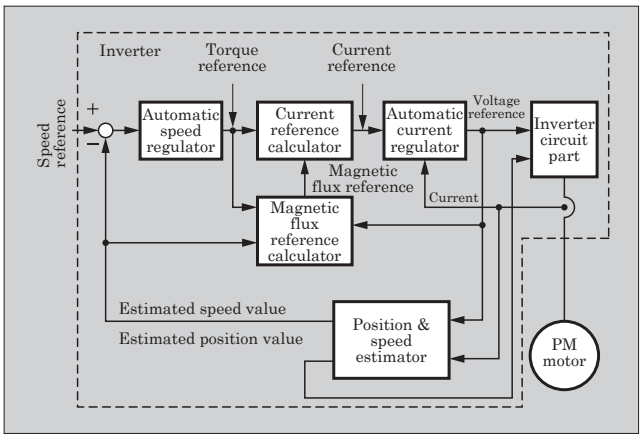
Moreover, this offline auto-tuning function also enables the sensor-less driving of special PM motors, such as those having high-speed specifications.

(b) PM motors

(i) Standard PM motor

PM motors have no field loss and therefore generate a low amount of heat. For this reason, PM motors can realize less total loss than an induction motor, and the volume of the stator core can be reduced, the required cooling capability can be decreased, and the frame size can be made smaller than a standard induction motor. Fuji Electric's standard PM motors use a frame that is 1 to 2 sizes smaller than that of a standard induction motor, and realize a significantly smaller size and lighter weight with a 35% reduction in volume on average and a 40% reduction in mass on average. Accordingly, a machine in which a standard PM motor is installed is also able to realize smaller size and

Fig.3 Block diagram of PM motor sensor-less vector control



lighter weight.

Moreover, a standard PM motor by itself has an efficiency corresponding to the 1E3-level prescribed by IEC 60034-30 and is able to contribute more than an IE1-level standard induction motor to the reduction of CO_2 emissions and to the realization of greater energy savings.

The product lineup extends across a wide range, from 0 to 90 kW for the 3-phase 200 V series, and 11 to 300 kW for the 3-phase 400 V Series, and Fuji Electric sells two product lines, one without a sensor and one with a sensor.

Figure 4 shows the external appearances of the FRENIC-MEGA Series and a standard PM motor,

(ii) High efficiency PM motors

Seeking to maximize the low-loss advantage of PM motors, high efficiency PM motors that achieve IE4-level efficiency values are introduced below. Another advantage of this product is that it has the same frame size as a standard induction motor. In the case where a standard induction motor used in an existing plant facility or machine is to be replaced with a PM motor, the smaller frame size of the aforementioned PM motor requires that the installation base for the motor must be modified or the design of the machinery changed, and therefore the motor cannot be replaced easily. This extra work can be eliminated by using the same size frame as the standard induction motor. The high efficiency PM motor realizes a greater reduction in CO_2 emissions and greater energy savings than a standard PM motor, and can easily replace a standard induction motor.

These advantages have been well received, and about 30 standard induction motors of 75 kW and 22 kW capacities in existing pump and existing air-conditioning equipment at a certain customer's plant were updated with a combination of a high-efficiency PM motors and the FRENIC-MEGA series of inverters for PM motor driving. As a result, electric utility fees were reduced by more than 30 million yen annually and CO_2 emissions were reduced by more than 1,000 tons, and the sequential planned replacement of equipment is progressing.

Fuji Electric's product line of high efficiency PM motors consists of a 3-phase 200 V series of 11 to 90 kW capacity and a 3-phase 400 V series of 11 to 160 kW capacity, and these products are sold without a speed sensor.

Fig.4 Appearance of FRENIC-MEGA Series for PM motor driving, and a standard PM motor

(2) Inverter that satisfies category 3 of the safety standard EN 954-1

In Japan, there is a history of providing users with thorough safety training, and of isolating hazards and pursuing intrinsic safety at each plant to ensure safety and prevent accidents. A recent international trend, as prescribed in the international safety standard ISO 12100 (Safety of machinery -- Basic concepts, general principles for design) and the like, is to take into account risk probability and the impact thereof, and designs that limit risk up to an allowable range are a rapidly growing trend.

Inverters for driving machinery and equipment are no exception. It is strongly request that the main inverter unit be provided with functions adapted to the relevant safety standards, and safety standard compliance is particularly strict in Europe. Inverters that satisfy EN 954-1 are introduced below.

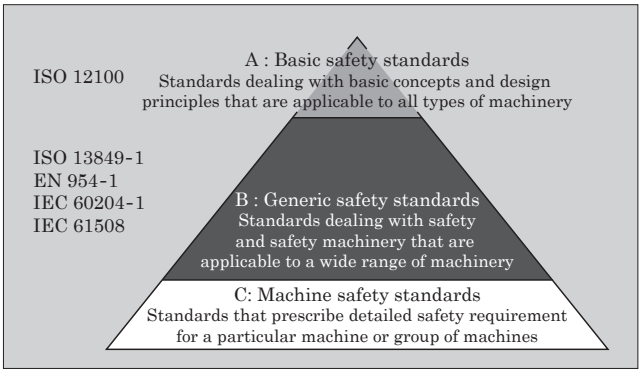
(a) Safety standard system

As shown in Fig. 5, the safety standards for machines are organized into three categories: (A) Basic safety standards, (B) Generic safety standards, and (C) Machine safety standards.

The "Safety of machinery -- Basic concepts, general principles for design" (ISO 12100/JIS B 9700) and other affiliated safety standards are known as "Basic safety standards" (category A standards) and deal with basic concepts and design principles that may be used commonly among all types of machinery.

EN 954-1 (Safety of machinery - Safety related parts of control systems, general principles for design), IEC 61508 (Functional safety of electrical/

Fig.5 Safety standard categories



electronic/programmable electronic safety-related systems) and the like are known as "Generic safety standards" (category B standards) and pertain to safety regulations applicable to all machinery in a specific field and to safety equipment. The generic safety standards are referenced from "Machine safety standards" (category C standards) which are detailed safety standards for specific machines.

(b) Applicable safety standards

EN 954-1 category 3 and IEC 60204-1 (Safety of machinery, Electrical equipment of machines, General requirements) stop category 0 are applied as safety standards to the FRENIC-Multi and the FRENIC-MEGA series.

When a safety signal is input to the dedicated safety terminal, the inverter turns off the torque (removes power) and conforms to stop category 0 (uncontrolled stop), i.e., "Stopping by immediate removal of power to the machine actuators."

In order to apply these safety standards, the following features are provided.

- ○ Removal of power can be implemented with hardware only, without using software
- ○ The hardware removal circuit has a dual-system redundant design

Figure 6 shows schematic drawing of the safety circuit configuration.

(c) User benefits from the use of safety standard-compliant inverters

As shown in Fig. 7, if an inverter does not support the safety standards, then in order to realize machinery that complies with EN 954-1 category 3, redundant contactors must be provided at the output of the inverter so that the safety function will not be compromised even if one of the contactors is contact welded. On the other hand, by using a safety standard-compliant inverter provided with redundancy functions for the hardware implementation of the power removal function and the removal circuit, the output-side contactor and the redundant safety circuit become unnecessary, and a safety circuit can be realized with a configuration that is essentially the same as that of a conventional circuit.

Furthermore, EN 954-1 will expire at the end of 2009 and will be replaced with ISO 13849-1 as a harmonized standard. ISO 13849-1-compliant products are planned to be sold during 2009.

(3) FRENIC-MEGA inverter series with built-in positioning control and vibration suppressing control

Inverters used in conveyor and transportation machinery and provided with positioning control and vibration suppressing control functions that are based on full-closed control are introduced below.

As shown in Fig. 8, in the case where an inverter is used in a conveyor requiring positioning control, semi-closed control is generally implemented. A position signal from an encoder attached to the motor shaft is input to a PLC of the upper level system or to a user-developed controller board, and position detection is performed and a frequency reference signal is sent to the inverter. If error due to wheel slippage of the moving object or the like cannot be ignored, a measure to improve the positional accuracy is employed wherein a laser distance sensor is used concurrently and a distance signal is input to the upper level system. The upper level circuit must contain a counter unit and a read circuit for receiving two detection signals, and as a result, such a system becomes more expensive. Moreover, the system cost increase further in the case where a servo is used, an encoder is provided on the

Fig.7 Examples of machines equipped with safety functions

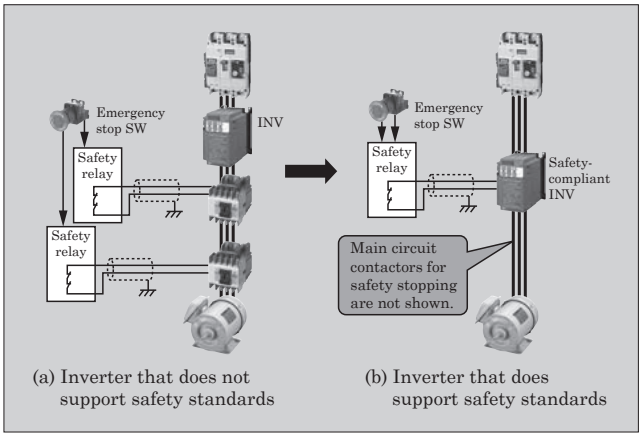


Fig.6 Schematic drawing of the safety circuit configuration

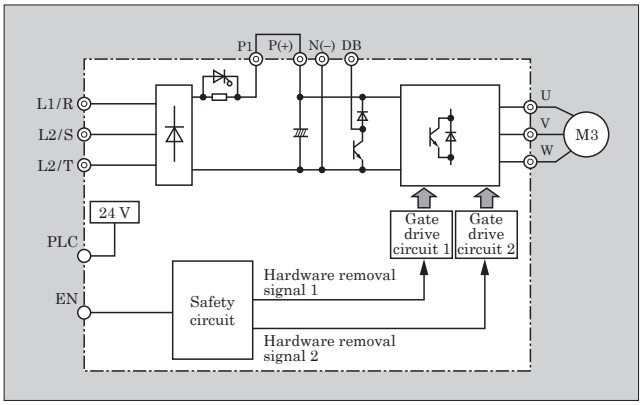


Fig.8 Example of conventional positioning control system (Semi-closed control)

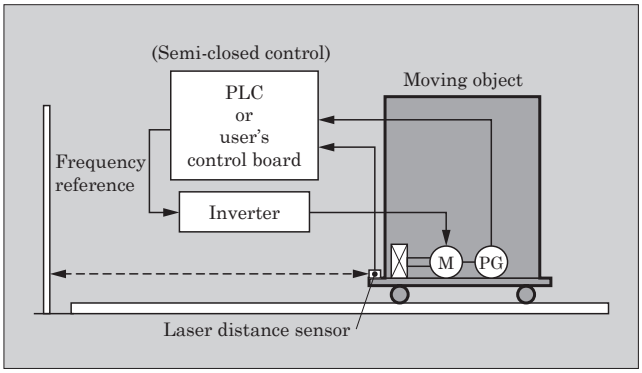


Fig.9 Example of positioning control system based on FRENIC-MEGA (full-closed control)

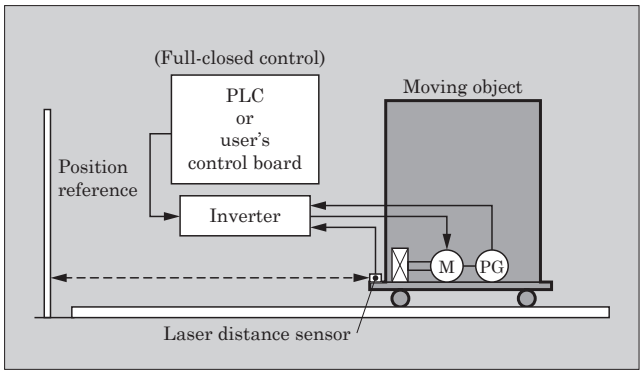
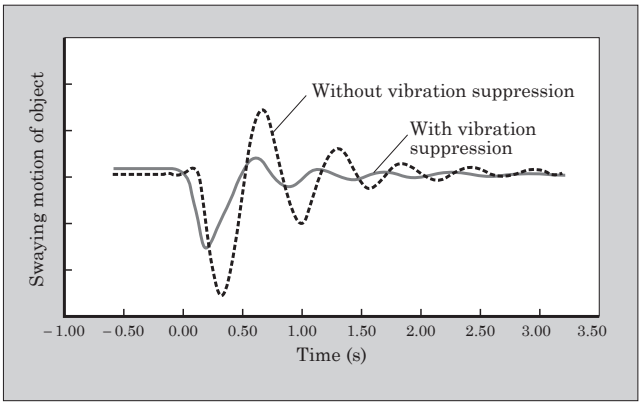


Fig.10 Comparison of results of vibration suppression measurement data



conveyor side and full-closed control is utilized.

In order to resolve these issues, as shown in Fig. 9, some of the conventional servo technology is incorporated into the inverter to provide the following control methods.

(a) Incorporating the servo's positioning control function

A positioning control function, which has been used successfully with servo equipment, is partially incorporated in an inverter to realize extremely low-cost positioning control. Basic functions are described below.

(i) Positioning control is implemented based on the target position setting data (number of pulses) and the deviation of the detected position signal

(ii) Equipped with a return to origin function, over-travel processing, position preset function and the like

(iii) Equipped with various I/O signals such as an enable/disable positioning control input, a position data selection input, a positioning completed output, over-travel detection, etc.

(b) Full-closed control based on laser distance sensor

In a system that improves positioning accuracy through the concurrent use of a laser distance sensor, full-closed control can be realized in an inverter by inputting the laser distance sensor signal directly to the inverter without passing through the upper level system, enabling the configuration of a low-cost and accurate system. This application is promising for devices for which, until now, an inverter provided insufficient performance and a servo provided excessive performance.

Figure 9 shows an example positioning control system based on a FRENIC-MEGA series inverter.

(c) Vibration suppression control

Because of shorter takt times, large-scale conveyors and the like must be able to start and stop with quick acceleration and deceleration, and be capable of high-speed operation. When stopped, operation of the next process starts after waiting for convergence of the vibration generated in a moving body, and therefore takt time increases. As a means for reducing this vibration, vibration suppression control that devises a speed pattern with the PLC of the upper level system is being developed by users. However, parameters such as the size, height and hardness of a moving object, and the height and weight of a load have a large effect but have been difficult to adjust.

Based on the successful track record of vibration suppression control in servo equipment, vibration suppression control that is effective even for the vibration of a moving object has been developed. The result leads to reduction in conveyor takt time and enables some users to slow the pace of their plans for developing vibration suppression control.

Figure 10 compares the results of measured data of the vibration suppression control.

Thus, by providing inverters with a positioning control function and implementing full-closed control and vibration suppressing control, the range of applications for inverters in conveyors is expected to expand further.

3.2 Servo systems

Application examples of servo systems having a simple configuration and that have achieved a total cost reduction are introduced in paragraphs (1) and (2) below. Then, in paragraph (3), the positioning function of a control system that uses the ALPHA5 to meet customer specification requirements is introduced.

(1) Application to blanking machine for paper aprons

A simple control system that combines an @E.Terminal and a servo system is introduced below.

(a) Overview of the conventional system

A paper apron-type blanking machine is used to produce the paper aprons often worn to protect one's clothes from becoming soiled by grease or food while dining at a Japanese yakiniku (barbecue-style) restaurant or the like. Figure 11 shows a sketch of the configuration of this system. In each machine, a two-axis servo system is used to drive a feed roll and

a cutter roll. The feed roll driving causes material to be delivered at a constant speed, and synchronized to this speed, the cutter roll operates a cutter part synchronously to perform the predetermined blanking operation. Because aprons for adults and children have different cutting dimensions, the system has been generally configured with a control system that employs motion control capable of adapting to changes in only the settings. Figure 12 shows the configuration of a conventional control system.

The system is configured from Fuji Electric's MONITOUCH panel, a motion controller and a servo system (two axes).

In a conventional system, before the machinery can be setup, the software program for the positioning control module has to be generated with a custom loader, and other tasks, such as the adjustment of servo system parameters, also has to be implemented with the custom loader. Consequently, due to program development and debugging constraints, a significant amount of time was required for startup.

(b) Configuration of system using an @E.Terminal

Figure 13 shows the configuration of a control system using an @E.Terminal.

As can be seen in the figure, the system can be constructed with a simple configuration since motion control can be realized with simple settings without the need for software program development.

Figure 14 shows the work flow – from meetings about the specifications through the completion of combination testing. By using the @E.Terminal and its built-in motion contents function, there is no need to master the use of a motion-related loader or to create motion programs. In this case, significant time savings was realized compared to a conventional control system.

(c) Features of a system that uses am @E.Terminal

(i) Realization of wire savings and space savings

Four functions, i.e., the motion function, operation and display function, sequence function, and networking function, are integrated, and excellent wire-savings and space savings are realized so as to enable "one-touch" wired connection to a control device.

(ii) Realization of motion control with simple settings

Motion operations such as complex synchro-

Fig.11 Block diagram of blanking machine for paper aprons

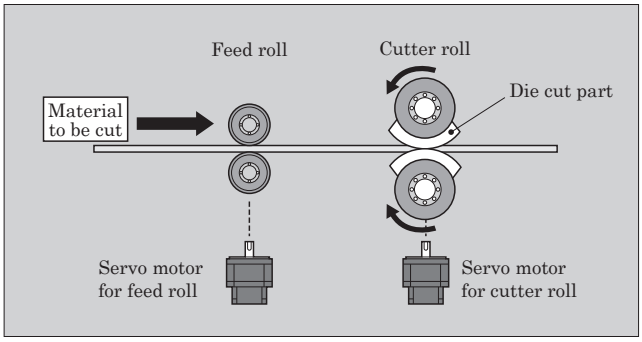


Fig.12 Configuration of conventional control system for blanking machine

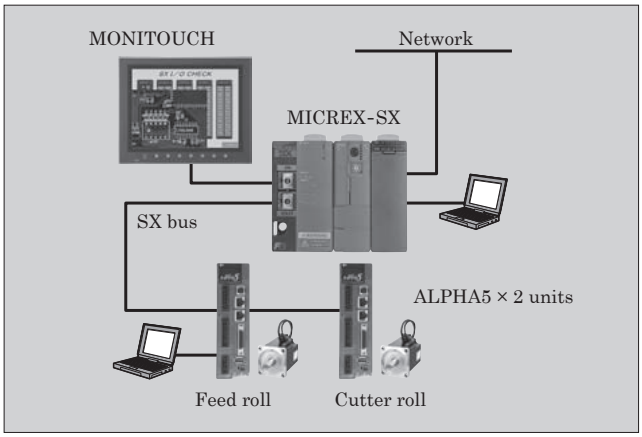


Fig.13 Configuration of new control system for blanking machine

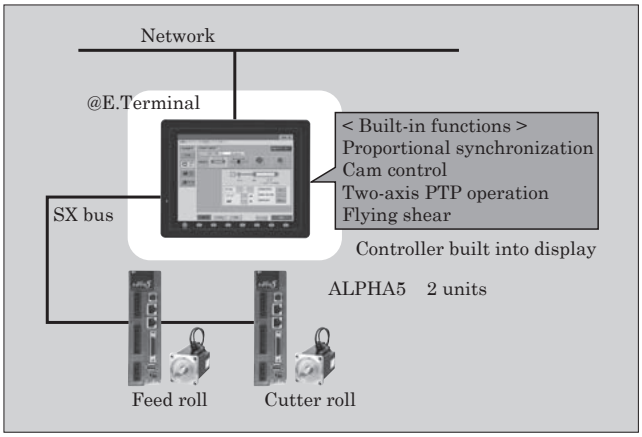
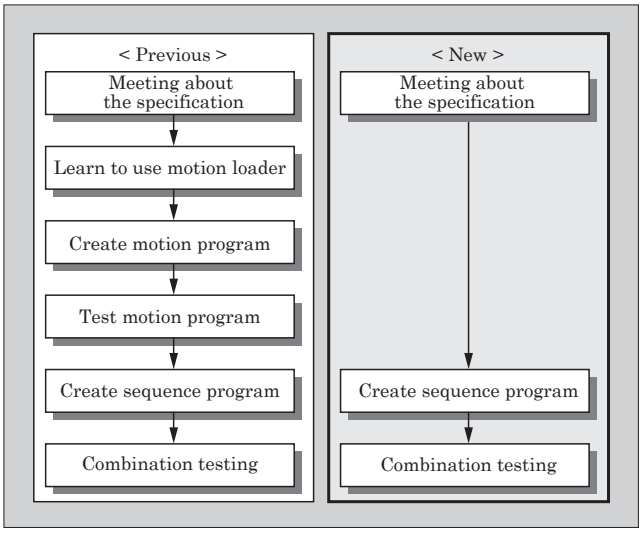


Fig.14 Work flow through the completion of combination testing



nous control can be realized easily, simply by setting the @E.Terminal screen with the motion operation for each axis.

(Example: PTP, proportional synchronization, flying shear, rotary shear, etc.)

(iii) Easy adjustment and maintenance

The @E.Terminal is provided with the required screens for servo parameter changes, waveform sampling, failure diagnosis, error history and the like so that adjustment and maintenance can be performed onsite without having to use a servo loader.

(2) Application to sizing and cutting machine

An example application of a servo system having a built-in positioning control function that leads to lower total costs is introduced below.

(a) Overview of the conventional system

A sizing and cutting machine cuts material (steel, fabric, paper, film, etc.) in units of a preset length. Ordinarily, a single-axis servo system is applied to a single machine, and used to drive the delivery of materials. Various machines, from small-scale to large-scale, are available according to the type of material.

Figure 15 shows the system configuration for a conventional sizing and cutting machine.

When the PLC receives a start signal, in accordance with the cut length and other data set by the MONITOUCH, and as a result of the pulse signal from the positioning control module, control is implemented such that the servo system operates in proportion to the preset values.

(b) Configuration of system using ALPHA5 Series with built-in positioning control function

Figure 16 shows the configuration of a system using Fuji Electric's ALPHA5 Series.

The ALPHA5 servo system series is equipped with a positioning control function. Since the MONITOUCH and servo amp are linked via the Modbus RTU (RS-485) communications function, there is no longer a need for the positioning control module. This implementation results in wire-savings and an extremely simple and low-cost configuration.

(c) Features of system using ALPHA5 with built-in positioning control function

(i) Positioning control function according to the application

The positioning control function provided as a standard feature of the ALPHA5 allows 15 points of positioning data to be registered internally. Furthermore, acceleration and deceleration times can be set separately for each type of data, thereby enabling usage in various ways according to the application.

(ii) Equipped with Modbus RTU (RS-485) communications function

The Modbus RTU (RS-485) communications function is provided to enable the external setting of positioning control data and modification of parameters. This communications function is an open network, and therefore various upper level devices such as PCs, PLCs, touch panels and the like can be connected easily.

(iii) Fuji Electric's positioning of a control system that uses the ALPHA5 to meet customer specification requirements

The two application examples described above both had new system configurations. In conventional implementations, all motion controls have

Fig.15 Conventional configuration of system for sizing and cutting machine

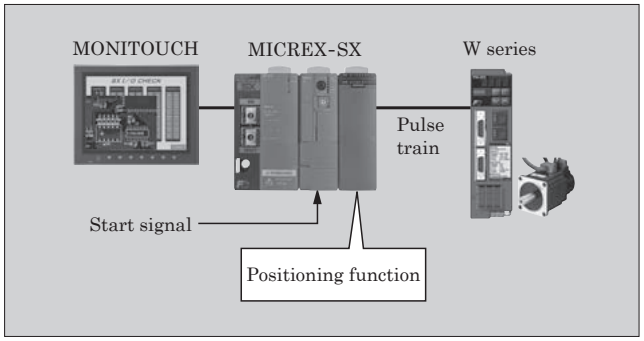


Fig.16 New configuration of system for sizing and cutting machine

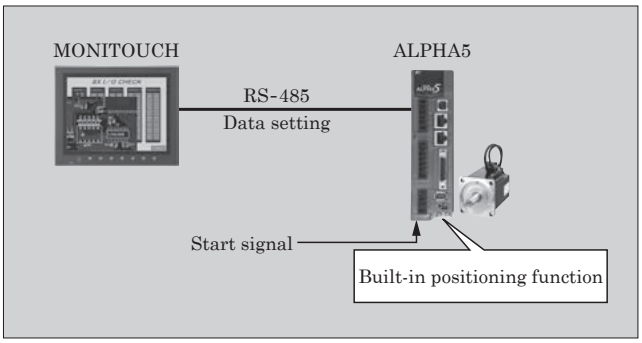
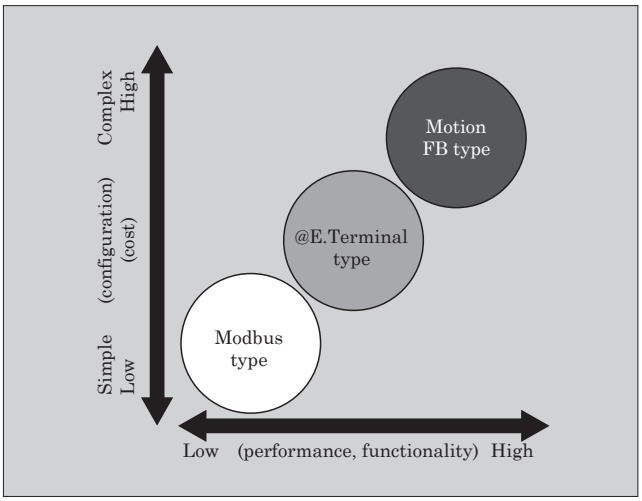


Fig.17 Fuji Electric's positioning of control systems to meet customer specification requirements



been implemented using motion function blocks in motion controllers, but each control function can be separated according to customer specification requirements by using ALPHA5.

Figure 17 shows Fuji Electric's positioning of control systems to meet customer specification requirements.

4. Postscript

The latest technology and application examples of general-purpose inverters and servo systems have been discussed. Fuji Electric intends to continue to accurately assess the latest needs and to manufacture products that incorporate technology to meet those needs.

Reference

(1) Rotating electric machines-Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code).