

FUJI ELECTRIC REVIEW

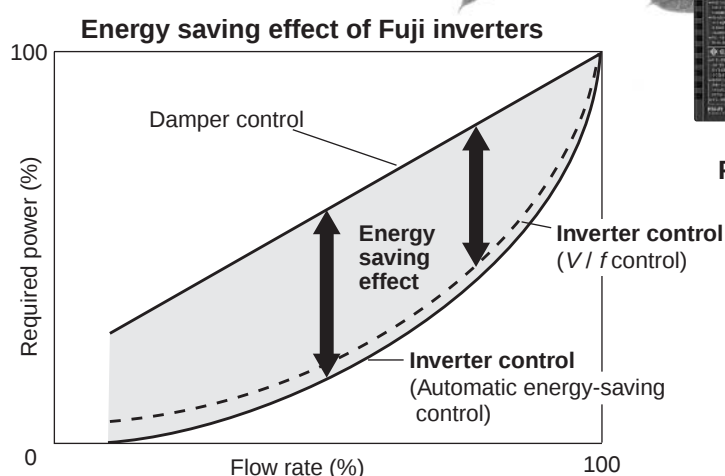


2000 VOL.46

General-Purpose Inverters and
Servo Systems



Let's Give Priority to Environmental Preservation.



Calculation example
 Motor output : 1x15kW
 Flow rate : 85% 2,000h and 60% 2,000h(in total, 4,000h / y).

Energy saving effect : 25,200kWh / y
CO₂ reduction : 3,024kg / y

Economical energy saving with Fuji inverters and high-efficiency motors

A demand for reduction in environmental load is currently more and more intense. Fuji Electric realizes advanced energy-saving air-conditioning and pumping systems. The "inverters" optimally control operation corresponding with work and the "high-efficiency motors" powerfully operate with less power consumption. The efficiency of machines is improved and electricity charge is reduced. In addition, the low-noise, low-vibration design gives workers a comfortable environment. Fuji Electric offers energy-saving systems friendly to environment, management, and people.

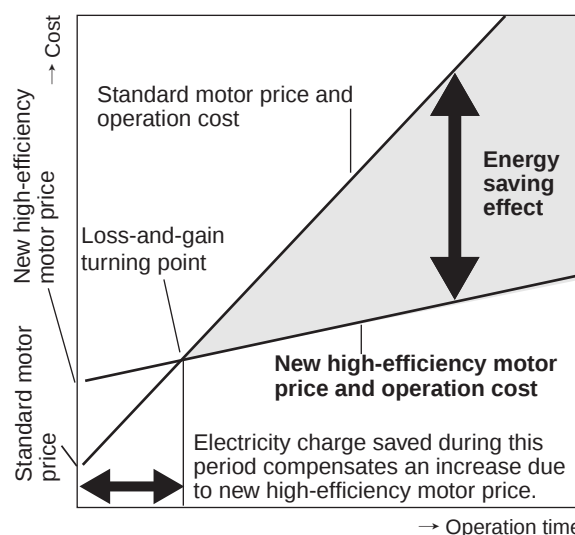


Fuji Inverter 11 Series

Fuji High-Efficiency Motor



Economics of Fuji high-efficiency motors



Calculation example
 A 30kW 4-pole totally enclosed externally ventilated motor operated at 200V, 50Hz, 100% load and 4,000h / y.

Energy saving effect : 8,900kWh / y
CO₂ reduction : 1,068kg / y

Energy-Saving Drives with Fuji Electric Inverters and High-Efficiency Motors

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General-Purpose Inverters and
Servo Systems

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Cover Photo:

Variable-speed drives such as general-purpose inverters and servo systems are widely used in all industrial fields and contribute to automation, reduction in labor, improvement in performance, and energy saving.

Fuji Electric prepares ample series of general-purpose inverters and servo systems and is making efforts to use the latest technology and improve performance by bringing out a new model at intervals of several years. This enables every customer to select a type of good cost performance suitable for his need.

In the cover photo, the new, small, high-performance, quickly responding general-purpose inverter and servo system are superposed upon a background showing part of the main circuit diagram of a general-purpose inverter, giving the image of up-to-date technology.

Views on the Technology for General-Purpose Inverters and Servo Systems

Masaru Yamazoe
Shinobu Kawabata
Shigefumi Kurita

1. Introduction

Variable-speed motor drives such as general-purpose inverters and servo systems have contributed to the downsizing of machines and equipment, energy saving, automation, and reduction in labor. From applications in many fields, plenty of new needs have been brought forth, including increased response speed for high-performance drives and size and price reduction for standard drives. Common new needs for all drives are: compliance with international regulations against noise and harmonics, production of systems for controlling many pieces of equipment by serial data transmission, and prolonged life span as well as provision of a life expectancy prediction function to facilitate equipment maintenance.

This paper describes the latest technologies to meet these new needs at low cost and Fuji Electric's products that incorporate these latest technologies.

2. Trends of the Latest Technologies

The requirements of inverters and servo systems have diversified as the application range has expanded. The range of technologies to satisfy these demands is so wide that this paper describes the latest technologies according to their classification such as power circuits, control circuits, sensors, advanced functions, downsizing, and systematization.

2.1 The latest power circuit technology

The effort to satisfy demand for reduction in the size of inverters and servo amplifiers can be called a war on loss. The insulated-gate bipolar transistor (IGBT) that contributes 50 to 70% of the power circuit loss has made great progress, followed by the fourth-generation IGBT in which collector-emitter saturation voltage ($V_{CE(sat)}$) has been greatly reduced by using trench-gate and non-punch-through technologies. The application of new devices is expected to reduce loss further. The intelligent power module (IPM) has been used for power circuit modules with the aim of reducing size, improving protective functions, and reducing cost.

On the other hand, the use of a high switching frequency (10 to 15kHz) to reduce motor noise has become commonplace, resulting in a noise problem with the peripheral equipment. A method to solve this problem has been established by drive technology that suppresses switching voltage variation to about 5,000V/ μ s. With regard to the DC-DC converter for control power, another noise source, the adoption of quasi-resonance switching is expected to solve the problem. Figure 1 is an example of radiation noise measurement to demonstrate the effect of noise suppression technology. Reduction by 15 to 20dB is observed particularly in the band of 30 to 50MHz.

Further, another requirement of the power circuit is the suppression of input power line harmonic. The power supply circuits of general-purpose inverters

Fig.1 Example of radiation noise measurement

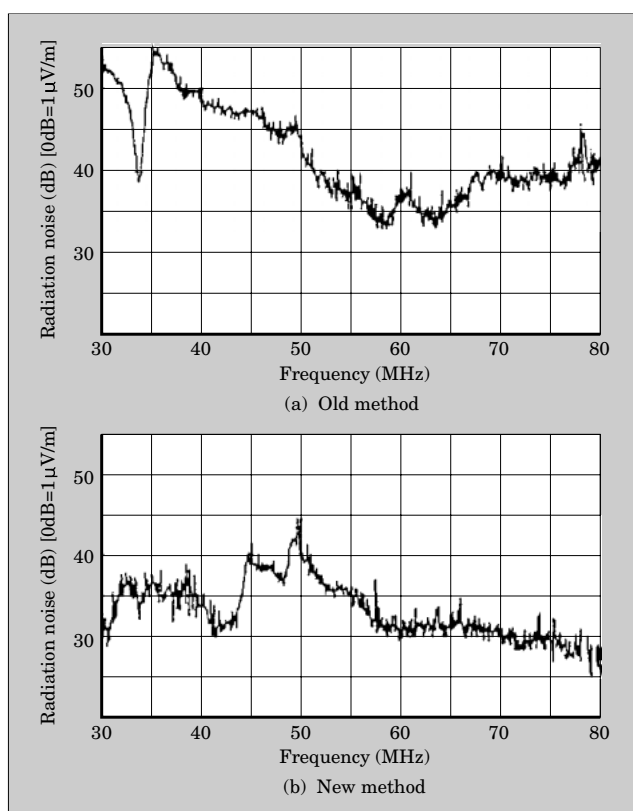
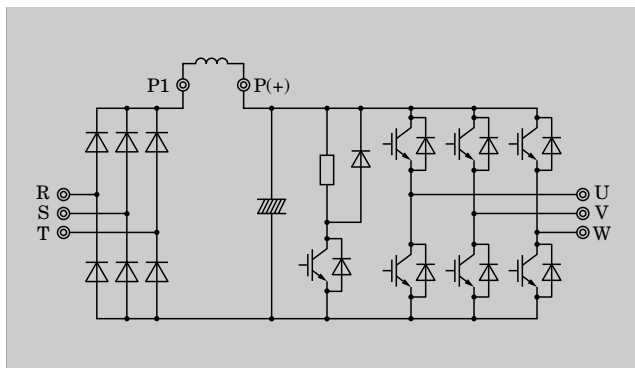


Fig.2 Power circuit diagram of a general-purpose inverter



mainly use diode rectifiers, and it is known that this causes harmonic current in the power supply. A regulation in Japan, “Guideline of limits for harmonics emissions on general-purpose and household electric appliances,” was issued in 1994, and we are faced with the necessity of harmonic suppression. Fuji Electric equips all types of apparatus, including compact inverters, with “DC reactor connection terminals” as standard for economical suppression of harmonics (Fig. 2).

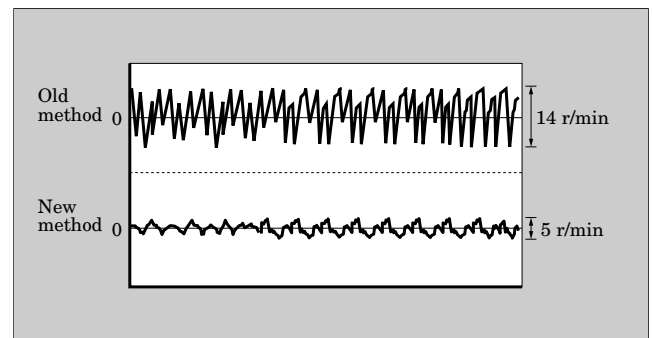
2.2 The latest control technology

Quick response and high performance are strongly required not only by servo systems but also by general-purpose inverters, and Fuji Electric has developed products to meet these requirements. One factor enabling the realization of high-speed control is the advance in microprocessor performance. In inverters several generations ago, the use of 16-bit microcomputers meant high speed. Recently, 32-bit RISC (reduced instruction set computer) processors have greatly raised processing speed, and control data processing speed has more than doubled. In servo systems, operations formerly processed with software have been processed with hardware through utilization of application specific integrated circuits (ASICs), for example, and the control period has been made about 10 times faster. Consequently, response characteristics of the total control system have greatly improved, and a high-speed response approximately 5 times faster than before has been realized with the speed control system.

From the viewpoint of the control method, it has become expected that vector control be used for general-purpose inverters. In high-performance types of apparatus, vector control with pulse generator (PG) feedback is made possible by mounting a simple optional circuit board. Now, high-performance vector control can be offered at low price.

The performance of vector control depends on how accurately driven motor constants are comprehended. A standard tuning function for measuring motor constants has been installed for this purpose, and on-line tuning to detect the variation of motor constants due to temperature changes during operation has been

Fig.3 Example of rotational irregularity measurement (at 1Hz, no load)



used in addition to off-line tuning while the equipment is halted.

In servo systems, real-time tuning technology for load inertia has been developed, enabling a proper control response that corresponds to the load.

Fuji Electric has developed an original torque vector control for the control system of general-purpose inverters and has improved control performance. As the application range has widened, higher accuracy of torque operation in the region of low-speed operation has been anticipated. The performance of low-speed control has been improved by performing iron loss compensation in consideration of motor hysteresis loss. With regard to the rotational irregularity that sometimes caused problems in the low-speed region, inverters have been greatly improved by applying compensated control to the output voltage distortion that causes irregularity.

Figure 3 shows measurement of the rotational irregularity of a 3.7kW motor operated at 1Hz with no load. The component at six times the output frequency is greatly reduced.

2.3 The latest sensor technology

In servo systems, the rotary encoder as well as high-speed data processing and high-performance systems are essential factors that control the total system performance. The 16-bit encoder is currently most common for the requirement of high resolution and high performance. To avoid a pulse frequency increase due to increased resolution, serial data transmission has come to be used for connection between encoders and servo amplifiers in place of the former parallel data transmission system.

2.4 Advanced function technology

Recently, market needs for maintenance functions have increased. In recent mechanical equipment that use many electronics devices, there is the fear that device failure will lead to failure of the whole equipment. To avoid this, advice on maintenance and inspection prior to the failure of each individual device is expected.

Fuji Electric has developed inverters having a

Table 1 List of Fuji Electric inverter model types and series

Model type	Series	Supply voltage	Capacity (kW)					Frequency control range (Hz)			Main advantages
			0.1	1	10	100	1,000	100	1,000	10,000	
General-purpose inverters	FVR-S11	Three-phase 200V	0.1	0.75				120			Inverters for simple variable-speed drive ◦Three types of volume tuning, terminal-board signal control, and serial-transmission control available
		Single-phase 200V	0.1	0.4				120			
	FVR-C11	Single-phase 200V	0.1	2.2				120			Compact inverters ◦PID control equipped as standard ◦Frequency setting volume equipped as standard.
		Three-phase 200V	0.1	3.7				120			
	FVR-E9	Single-phase 100V	0.1	0.75				400			General-purpose inverters ◦Starting torque: 200% ◦RS-485 equipped as standard ◦PID control equipped as standard
		Single-phase 200V	0.1	2.2				400			
		Three-phase 200V	0.1	3.7				400			
		Three-phase 400V	0.4	3.7				400			
	FRENIC 5000G11	Three-phase 200V	0.2				90	400			High-performance, multifunctional inverters ◦Starting torque: 200% ◦RS-485 equipped as standard ◦PID control equipped as standard ◦Auxiliary control power supply equipped as standard ◦High-performance vector control with the optional card and a PG-mounted motor
		Three-phase 400V	0.4				400	400			
	FRENIC 5000P11	Three-phase 200V		5.5			110	120			Exclusively for variable torque loads ◦PID control equipped as standard ◦Auxiliary control power supply equipped as standard ◦RS-485 equipped as standard ◦High-efficiency operation by the automatic energy-saving function
		Three-phase 400V		5.5			500	120			
	FRENIC 5000H2	Three-phase 200V	0.75				22		5,000		For superhigh-speed motor drive
General-purpose vector control inverters	FRENIC 5000VG5	Three-phase 200V	0.75				90	120			High-performance vector control inverters for general industries ◦Quick-response speed control ◦Torque control
		Three-phase 400V		3.7			220	120			
Inverters for machine tool spindle drive	FRENIC 5000MS5 M5 V5	Three-phase 200V	0.75				22	270			Inverters for machine-tool spindle drive ◦M5 (torque vector control without PG) ◦V5 (vector control with PG) ◦Converter separated (dynamic or regenerative braking selectable)
		Three-phase 200V		1.5			45	270			
Regenerative PWM converters	RHC	Three-phase 200V		7.5			55	50	60		Regenerative converters ◦High-efficiency regeneration ◦Reduction in input harmonic current
		Three-phase 400V		7.5			400	50	60		

□ (Under development)

function to measure the electrostatic capacity, operation time, and ambient temperature of deteriorating component parts and predict their life expectancy. These inverters have been well received.

With regard to the function of operating a high-inertia load, smooth operation without any shock is required when restarting after an instantaneous power interruption or when drawing into inverter operation a blower being rotated by external wind. Technology has been developed to produce self-oscillation based on proper positive feedback from the control when starting the inverter and to predict the rotating speed from

its frequency. Because this method can predict speed, including the rotating direction, it has the advantage of being able to start an inverter without a shock irrespective of the current rotating direction, forward or reverse.

2.5 Downsizing technology

Downsizing technology has rapidly advanced in general-purpose inverters, and this trend excludes neither the amplifiers nor motors of servo systems.

(1) Downsizing of inverters and servo amplifiers

Cooling technology is very important for the down-

Table 2 List of Fuji Electric servo system series

Series	Motors	Capacity (kW)			Max. speed (r/min)			Main advantages
		0.1	1	10	2,000	3,000	4,000	
FALDIC- α ①L-type (for linear positioning) ②R-type (for rotational positioning) ③V-type (for speed control)	GRC motors (low-inertia, cubic type) GRS motors (low-inertia, slim type)	0.1	1.5			3,000/5,000		①Frequency response at 500 Hz, top-level in the industry ②Two low-inertia motor types are selectable as either a cubic type with min. axial length or a slim type with min. diameter ③Amplifier types (V, L, and R) prepared for different uses ④Reduction in wiring by serial transmission between the encoder and amplifier ⑤High-speed serial bus connection between Fuji Electric's PLC and the amplifier
		0.03	1.5	5.0 (Under development)		3,000/5,000		
FALDIC-II ①L-type (for linear positioning) ②R-type (for rotational positioning) ③V-type (for speed control)	GRH (medium-inertia) motors GRK (high-inertia) motors	0.3	2.7			3,000		①Frequency response at 100 Hz ②Medium-inertia motors used, high rigidity compliant ③Model types (V, L, and R) prepared for different uses ④Reduction in wiring by serial bus connection between Fuji Electric's PLC and the amplifier
		0.05	3.7			2,000/2,500		
FALDIC-IM	MPF series motors (exclusive-use induction motors)		2.2	37		1,500/2,000		①Positioning of a large machine ②Frequency response at 80 Hz ③Reduction in wiring by serial bus connection between Fuji Electric's PLC and the amplifier
Digital ES motors (for speed control)	GRK (high-inertia) motors	0.05	3.7			2,000/2,500		①Applied to machines that handle loads with large moment of inertia ②Speed control and pulse train positioning possible ③Motors are interchangeable with standard motor

sizing of inverters and servo amplifiers. Aluminum die-cast cooling fins were formerly the mainstream; however, caulked fins and brazed fins have come into use due to their efficient cooling. Also, technologies for parts integration and high-density mounting have greatly contributed to downsizing. Future technical problems to be tackled are technologies for bare-chip mounting and advanced system LSI (large-scale integration).

(2) Downsizing of motors

It is an important to be able to reduce the size of servomotors without reducing efficiency. Main technologies for reducing servomotor size are: ① use of rare-earth magnets, ② improving the coil filling, and ③ cooling technology using high heat-conductive resin molding. As the result of these technical developments, the motor has reduced its volume to about one third of the former type.

2.6 Systematization technology

As general-purpose inverters advance in performance and servo systems increase in response speed, there is a growing demand for system compatibility so that upper-level programmable logic controllers (PLCs) can be connected by serial data transmission.

General-purpose inverters are equipped with RS-485 as a standard function; however, there is demand for compatibility with not only Fuji Electric's private link but also open bus systems. There are different

types of open bus systems depending upon the industry and district, and the goal of technical development is make it easier to connect an inverter to an open bus system.

To utilize most effectively the greatly improved high-speed response of servo amplifiers, they can be connected to the PLC by a high-speed serial bus. This bus is of a 25MHz, 3V drive type, and noise suppression technology is fully utilized to realize high-speed control for servo systems.

3. Fuji Electric's Product Lines

Fuji Electric provides diverse product lines ranging from inverters for very simple speed control to servo systems for high-response, high-precision positioning control. Therefore, it is possible to select the most economical product for each use.

The product series are described below.

3.1 Inverter product lines

Table 1 shows Fuji Electric inverter model types and series.

In the group of general-purpose inverters, the inverters are undergoing a model change to the 11 series, and in addition, the simplest variable-speed inverter "FVR-S11S" series has newly been added to facilitate the use of inverters in fields that formerly abandoned inverter use for economic reasons.

The main type “FRENIC5000G11S/P11S” series is equipped with an auxiliary control power supply, PID (proportional, integral, and derivative) control, and RS-485 serial data transmission as standard. These were formerly optional items. The wide reduction of rotational irregularity in the low-speed region and the function of life expectancy prediction are worthy of special mention.

In addition, because high-performance vector control is made possible by using the optional card and motors with PG, the G11S series has greatly expanded its application range.

3.2 Servo system product lines

In servo systems, both servo amplifiers and motors have realized drastic reduction in size and high performance by using innovative technologies. This enabled Fuji Electric’s servo systems to be utilized in the fields of high-speed response where servo systems had not been used, such as multiple-axis machine tools, robots, semiconductor manufacturing equipment, and electronic parts processing machines, and greatly expanded the application range.

Table 2 shows the Fuji Electric servo system series. The new “FALDIC- α ” series servo system has been added. This new series has realized the top-level high-speed response in the industry by reducing the motor size and the moment of inertia.

This new series, along with the three series of: the “FALDIC-II” series that improve mechanical rigidity by combination with a motor of medium moment of inertia, the “FALDIC-IM” series that covers the range of medium and large capacities, and the “digital ES

motor” series that is easy to use and suitable for building economical systems, have formed a powerful four series system.

On the other hand, servo systems are generally used in combination with positioning control equipment. Therefore, to comply with comparatively simple positioning systems, a series of “servo amplifiers with built-in positioning function” that can internally register 100 steps of position data have also been provided. In the case of multi-axis advanced-function positioning control, the use of the “advanced-function module” of Fuji Electric’s PLC (MICREX series) is recommended.

4. Conclusion

The trends of variable-speed drive systems toward small size, high performance and multiple functions have continued, and technical developments in line with these trends has been touched on. As for new trends, from the viewpoint of “user friendliness,” the automatic tuning of control constants and small, easy-to-operate inverters have been introduced. From the viewpoint of the environment, noise suppression technologies for power circuits and control power supply circuits have been introduced, and from the viewpoint of higher reliability, a trend such the life expectancy predicting function, has been described.

These new items are in their beginning stages and will require further efforts in the future. Please directly inform Fuji Electric of your needs, including items other than the above, from the standpoint of an actual user of variable-speed drive equipment. We appreciate your cooperation.



Latest Control Technology in Inverters and Servo Systems

Takao Yanase
Hidetoshi Umida
Takashi Aihara

1. Introduction

Inverters and servo systems have achieved small size and high performance through the progress of semiconductor devices with high intention and low power consumption. Among these devices, the high performance microprocessors used for control possess high computing power that enables complex and minute operation, thereby enhancing the intelligence of the equipment.

In addition, highly integrated ASICs (application specific ICs) enable the process sharing between software and hardware to shift optimization to the hardware side, and realize higher performance of the equipment.

In this paper, an overview of the latest control technology in inverters and servo systems is introduced.

2. Inverter Control Technology

Because of the advanced control technology for output voltage and the state estimation algorithm for induction motors, the latest control technology is realizing a greater range of speed control and smooth rotation with small torque ripple and high speed response. At present, Fuji Electric is developing a technology in which performance and convenience will be further improved based on the above mentioned technology, and as a part of such development, the “torque control accuracy improvement technology” and the “free run speed estimation technology” are intro-

duced here.

2.1 Torque control accuracy improvement technology

The main factors of torque error in the inverters, iron loss of the induction motor and thermal drift of the equivalent circuit parameters can be enumerated. For applications in which high accuracy is required, compensation of the control error through these factors is necessary. Details of the compensation technology are described below.

(1) Iron loss compensation

The iron loss of the silicon steel sheet used in the induction motor causes power and torque loss that is not negligible when performing accurate control within an error of several percent. An example equivalent circuit that accounts for iron loss is shown in Fig. 1. The iron loss consists of eddy current loss and hysteresis loss. Since the eddy current loss can be expressed through a linear resistance, it is easily considered for analysis of a control system and can be compensated simply. On the other hand, since the hysteresis loss has a non-linear characteristic depending upon the flux level, it has not been given much consideration in the past. However, as the speed range becomes wider, the hysteresis loss affects torque accuracy greatly at low speed.

Figure 2 shows schematically the relation between frequency, the eddy current loss component and the

Fig.1 Equivalent circuit of induction motor (single phase)

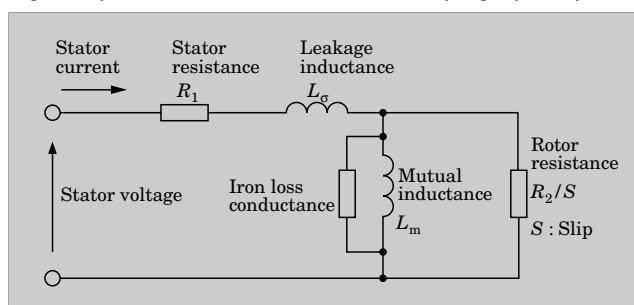


Fig.2 Iron loss component of stator current vs. primary frequency (constant flux)

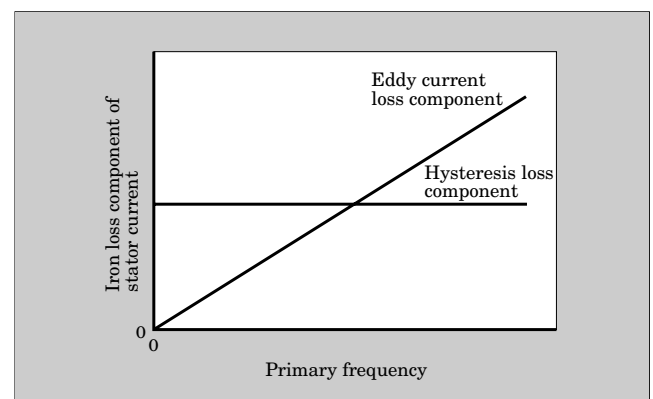


Fig.3 Characteristics of torque calculation

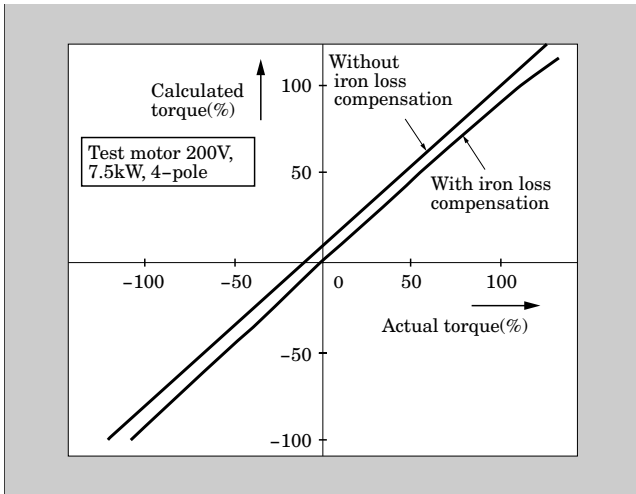
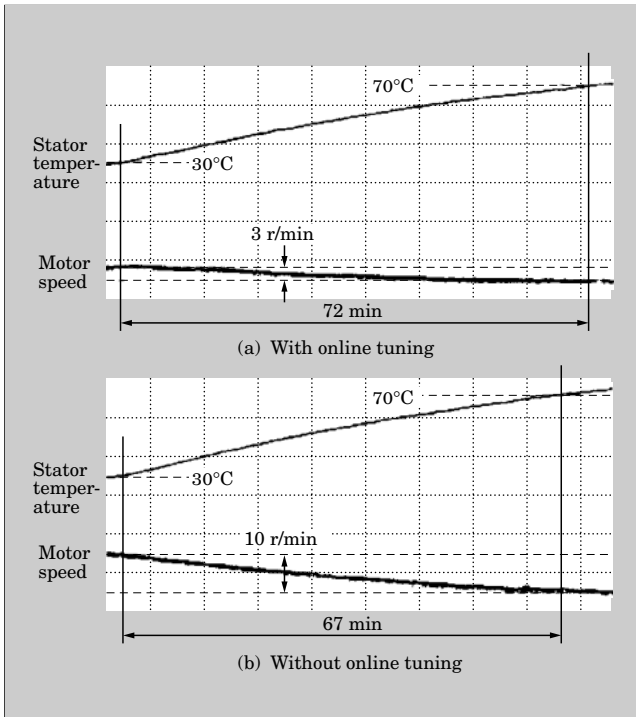


Fig.4 Effect of online tuning

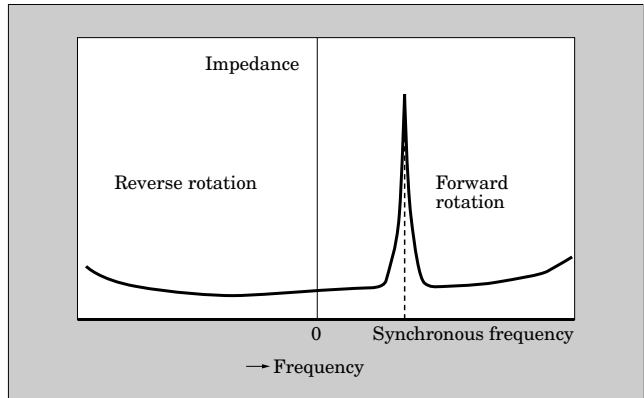


hysteresis loss component in the iron loss converted into torque current. Since the magnitude of the hysteresis loss component does not depend upon frequency, it has a significant effect at low speeds. Figure 3 shows a torque calculation result at 5Hz in which the iron loss is compensated with consideration of the hysteresis loss component. The iron loss compensation improves the torque calculation accuracy, and contributes notably to the improvement of calculation at low speed.

(2) Online tuning

The parameter of the induction motor equivalent circuit that shows the largest variation during operation is rotor resistance. Because the magnitude of slip frequency of V/f controlled induction motors is propor-

Fig.5 Frequency characteristics of induction motor impedance



tional to the rotor resistance, if the rotor resistance changes due to the temperature rise during loaded operation, the speed also varies. In order to maintain constant speed regardless of temperature rise, the function of online tuning is required. Here, a tuning method is described that utilizes the property that stator resistance varies almost proportionally to rotor resistance.

In the case of induction motor, the following relation exists between stator resistance R_1 , magnetizing current i_{1d} and their setting values R_1^* and i_{1d}^* .

$$\frac{R_1}{R_1^*} = \frac{i_{1d}^*}{i_{1d}} \quad \dots\dots\dots (1)$$

The slip frequency is proportional to R_2/i_{1d} (R_2 : rotor resistance). Therefore, when the slip frequency is compensated according to the following equation, the speed can be maintained constant even if R_2 changes.

$$\hat{R}_2 = R_2^* \left(\frac{i_{1d}^*}{i_{1d}} \right)^2 \quad \dots\dots\dots (2)$$

$\hat{R}_2$: Compensated rotor resistance

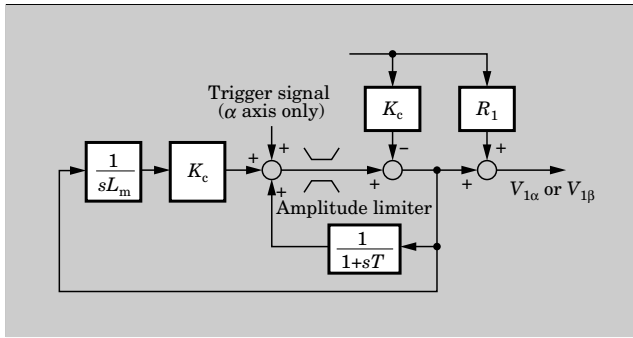
Figure 4 shows the comparison of the powering condition. This online tuning method enables an improvement in speed drift to about 1/3 in spite of the simplified calculation.

2.2 Free run speed estimation technology

The induction motor sometimes enters a free run condition due to the instantaneous power interruption or external force. If a speed sensor is not provided as in the case of V/f control, when the inverter starts while the motor is rotating, the rush current might cause an emergency stopping of the inverter or the torque shock. In order to start smoothly, the frequency should be set to the optimum estimated free run speed of the motor when starting the inverter. A free run speed estimation method that utilizes self-excited oscillation is introduced below.

Figure 5 shows the impedance characteristics of induction motor. The impedance of the induction motors becomes maximum at the synchronous frequency (zero slip). Utilizing this characteristics, by means

Fig.6 Structure of controller (one phase)



of appropriate positive feedback through control of the microprocessor and the inverter, self-excited oscillation occurs near the synchronous frequency and speed estimation is possible. Figure 6 shows a control block diagram (stationary frame α , β axis) for self-excited oscillation. With the control, the inverter can excite the induction motor near the synchronous speed regardless of the motor speed by supplying the reactive power needed by the induction motor.

Figure 7 shows the current waveform of the induction motor at the self-excited oscillation, and Fig. 8 shows an example of the speed detection result. The free run speed is detected precisely over the entire speed range including forward rotation, reverse rotation and the stop. Because this method of free run speed estimation allows frequency detection including rotational direction, the realization of non-shock starting without abnormal torque in either forward rotation or reverse rotation is possible.

3. Latest Servo System Control Technology

“Small sizing of the motor” and “auto-tuning of control parameters” can be listed as trends of the latest servo system technology.

In contrast, servo control technology has the following themes.

- (1) Achievement of minimum response time corresponding to a small moment of rotor inertia.
- (2) High gain control achieves robustness for disturbance, high stability and low rotational fluctuation during small motor inertia.
- (3) Auto-tuning system achieves the performance of (1) and (2).

The high speed control response of (1) which can achieve the minimum response time and the achievement of the high gain control of (2) have the same meaning for the control technology.

To achieve high speed control response, improvement of low speed performance with a high resolution rotary encoder is indispensable. At low speed and stand still, non-negligible shaft vibration caused by resolution of the rotary encoder occurs, and the magnitude of vibration is nearly in proportion to the control response. A high resolution rotary encoder is

Fig.7 Waveform of α , β axis current in case of self-excited oscillation

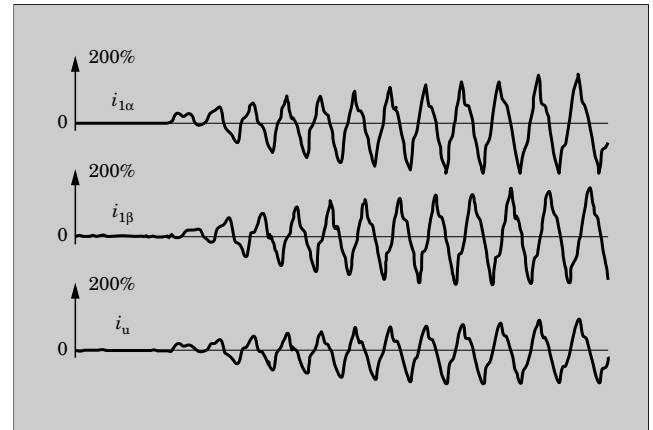
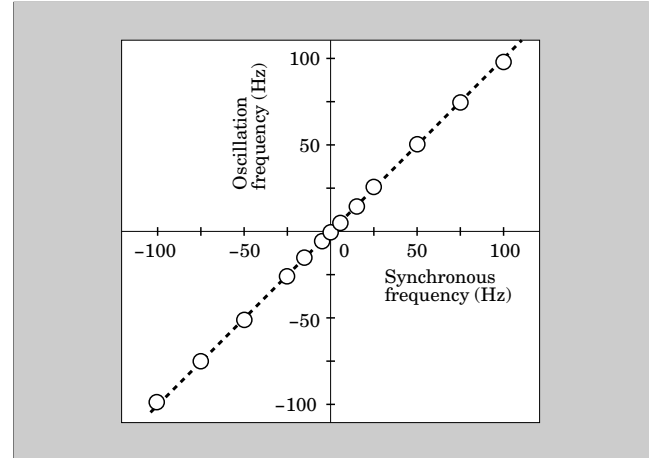


Fig.8 Relation between rotor speed and oscillation frequency



necessary in order to realize both the high speed control and the low vibration.

Low speed performance improvement that uses high speed control response and a high resolution rotary encoder, and a novel method of auto-tuning technology are introduced below.

3.1 High response speed control

To achieve high speed control response the following two items were developed.

- Hardware for current control
- Application of a high speed RISC (reduced instruction set computer) processor to the servo control

The control period can be shortened by performing the current control calculation with a hardware algorithm, instead of calculating by software as in the past. In addition, the speed control calculation period can be shortened by reducing the calculation time by utilizing a high speed RISC processor as well as the hardware for current control.

As a result, a speed control response of 5 times faster compared to the past has been achieved. Figure 9 shows frequency characteristics of the speed control response. It can be seen that the -3 dB point of cutoff

Fig.9 Frequency characteristics of speed control

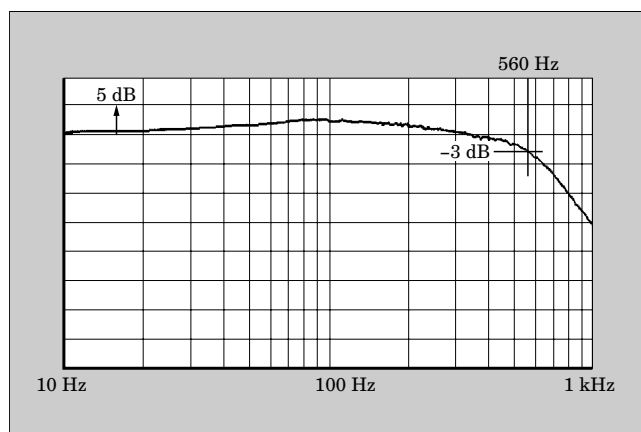
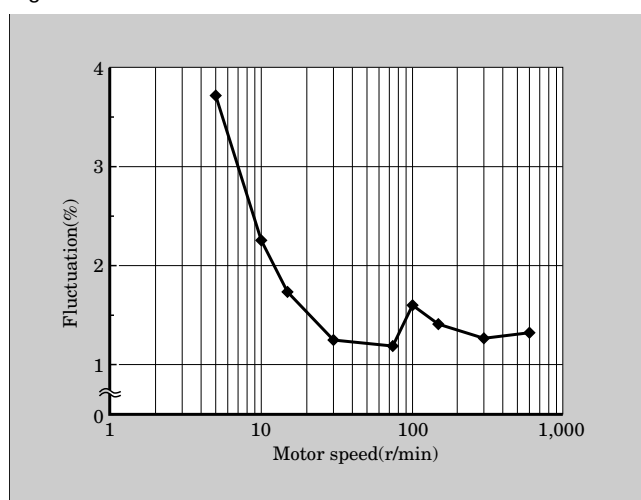


Fig.10 Rotational fluctuation characteristics



frequency indicates 560Hz.

Figure 10 shows the rotational fluctuation characteristics. It is clear that low fluctuation of 4% or less is achieved throughout the whole range. Since the response of 500Hz can be obtained, by heightening the control gain the rotational fluctuation can be restricted.

Figure 11 shows the settling time of positioning. Acceleration and deceleration of up to 1,000r/min are each performed for approximately 25ms, and the settling time from zero speed to signal-on of positioning completion is 2ms or less. Achievement of such high speed positioning is attributable to the speed control response of 500Hz.

3.2 Improvement of low speed characteristics by high resolution rotary encoder

A 16-bit serial communication interface rotary encoder (corresponding to 16,384 pulses) has been newly developed. By using this encoder to control feedback, low speed performance is dramatically improved. Figure 12 shows a comparison of shaft vibration during a 1r/min command operation. Both waveforms are for the conditions of no load and tuned

Fig.11 Settling time of positioning

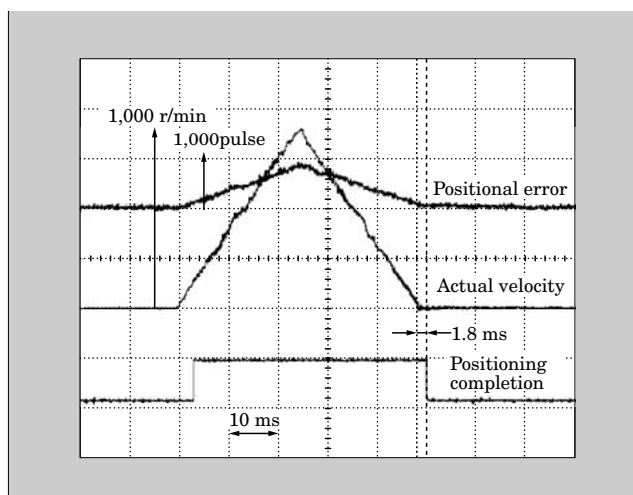
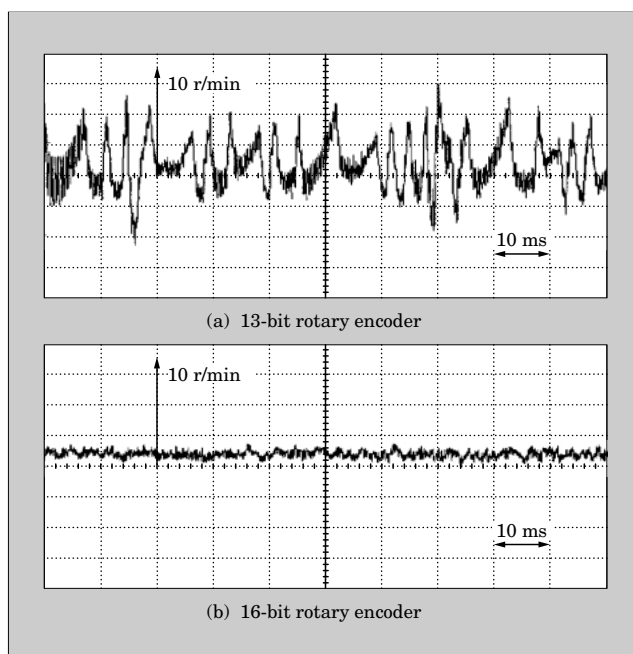


Fig.12 Comparison of shaft vibration



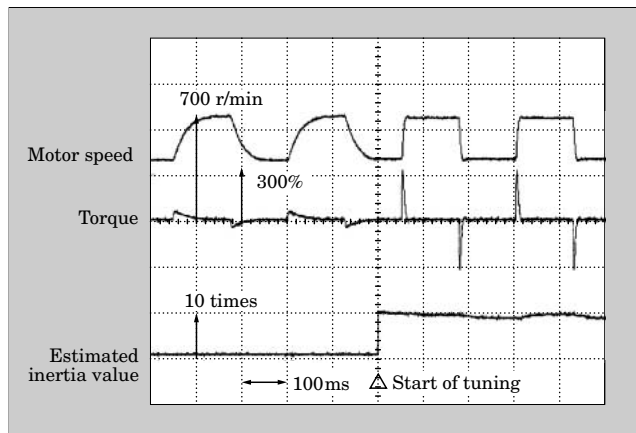
500Hz response. With the 13-bit rotary encoder, shaft vibration of 12r/min (p-p) is generated due to ripple of the detected velocity caused by the low resolution. In many cases, this vibration induces mechanical resonance or acoustic noise. From this viewpoint, it is understood that obtaining a 500Hz response using a 13-bit rotary encoder is not practical. On the other hand, with the 16-bit rotary encoder, only a small amount of 1.5r/min (p-p) vibration is generated, solving the vibration problem.

3.3 Novel auto-tuning method

A novel auto-tuning method that tunes servo control gain instantaneously based on estimated load inertia is introduced here.

Figure 13 shows an example of the inertia estimation waveform, and speed and torque response wave-

Fig.13 Real-time auto-tuning action waveform



forms. When the total inertia value is 10 times the motor inertia, the initial value of inertia is estimated as unity. When real-time auto-tuning is started at point $\triangle$ mark, the inertia is instantaneously estimated

correctly. Since the appropriate control gain is set in real-time based on the estimated inertia value, it is clear that the response of motor speed after the start of tuning becomes approximately 10 times faster.

Thus, through high speed and high accuracy of the tuning action, instantaneous adjustment of various machines is possible, and the range of applications for these machines can be extended.

4. Conclusion

As the latest control technology, the improvement of torque control accuracy of the inverter, initial speed estimation technology, high speed response control of the servo system, improvement of low speed characteristics by the high resolution rotary encoder and a novel auto-tuning method have been introduced above.

We are endeavoring further development of novel functions and high performance in response to market demands.

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# Modern Hardware Technology in Inverters and Servo Systems

Yoshihiro Matsumoto  
Seiji Shinoda

## 1. Introduction

With the popularization of variable speed drive systems for electric motors, including general-purpose inverters, have come great advances such as smaller size, lighter weight, lower price, higher performance with diversified functions, and improved quality. As a result, the volume of a 750W general-purpose inverter, for example, has decreased to 1/10 or less of the volume of the initial product. Behind the scenes of these developments have been remarkable advances in hardware technology due to application of high performance microprocessors, development of power semiconductor devices and cooling technology, etc.

Recently, the higher frequency switching for downsizing and lighter weight of the inverter have generated noise that may trigger a malfunction of the peripheral equipment, and this has caused a new problem. Desired hardware technology has also become diversified since communication functions are demanded along with networking capability.

This paper introduces the hardware technology of modern general-purpose inverters and servo systems.

## 2. Recent Main Circuit Technology

### 2.1 Power devices

In a general-purpose inverter and servo system, power devices generate most of the heat, and the loss thus generated accounts for 50 to 70% of the overall system loss.

The performance of IGBT (insulated gate bipolar transistor) elements, chiefly used as power devices, also has advanced greatly over the past ten years. The fourth generation IGBT has now been developed (Fig. 1) using technologies of the trench gate IGBT and the planer-type micro-machined NPT (non-punch through) -IGBT. The saturation voltage between collector and emitter  $V_{CE(sat)}$  has been decreased to about 1.6V in the 600V class, and about 2.3V in the 1,200V class.

Moreover, because this IGBT is used at higher-frequency switching of about 10 to 15kHz, the loss due switching is so large that it accounts for 50 to 70% of

the generated loss of the IGBT. Therefore, to decrease the switching loss, the on/off switching of voltage and current has been as abruptly as possible. This is the main cause of noise generation from the inverter and the servo system. When actually used in the field, this generated noise has caused peripheral equipment to malfunction.

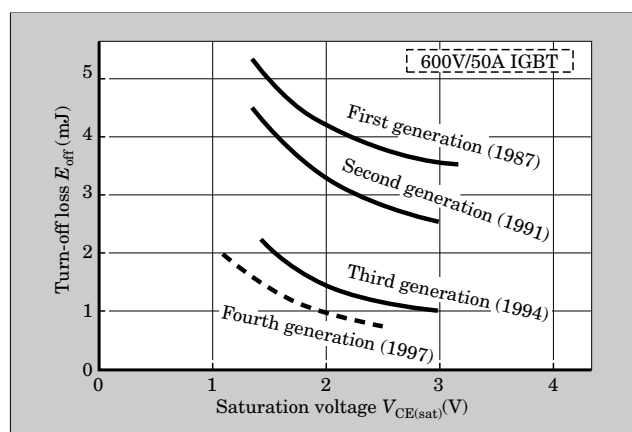
By limiting the voltage change rate  $dV/dt$  of this switching to about 5kV/ $\mu$ s on average in the FRENIC5000G11/P11 series of general-purpose inverters and the FALDIC- $\alpha$  series of servo systems that Fuji Electric has developed, the generated noises are suppressed to a lower value.

### 2.2 Intelligent power module (IPM)

Because the treated energy is large, the rectifier diodes and IGBT elements that compose the main circuit exert a significant influence on any damage due to usage or power-supply circumstances where a general-purpose inverter or servo amplifier have been setup. Therefore, it is strongly required to enhance reliability and protective functions of the main circuit unit.

In general, the system was designed so that the inverter apparatus side, where the IGBT modules compose the main circuit, may actuate protection by detecting the output current of the inverter apparatus or the current of the DC circuit. This protection circuit

Fig.1 Evolution of IGBT trade-off



was installed outside the IGBT modules.

In addition, if the system is to provide overcurrent detection for each IGBT element to protect the IGBTs and improve reliability, IPMs with built-in protection circuits must be used.

In the FRENIC5000G11/P11 series of general-purpose inverters that has been developed by Fuji Electric, IPMs are utilized for all systems of 22kW or less, in order to enhance the protection and reliability of the main circuit.

Especially for capacities of 5.5kW or more, the system adopts a protection method using the junction temperature detected by a measuring element directly

buried in each IGBT element. This method achieves secure temperature protection compared with the previous indirect protection method that estimated the junction temperature from that of the cooling fin.

Table 1 compares the protective functions of the conventional model using standard IGBT modules with those of the new model using IPMs.

### 2.3 Dedicated power modules for inverters

In the pursuit of downsizing and cost reduction of the inverter apparatus, a technical limit is encountered especially for small capacity models when using only rectifier diodes or IGBT general-purpose modules. Therefore, it is necessary to utilize dedicated power modules containing as many essential functions as possible.

Fuji Electric has developed the FRENIC5000G11/P11 series of general-purpose inverters and the FALDIC- $\alpha$  series of servo systems, which exclusively use amplifiers with dedicated power modules based on IPM technology.

Figure 2 shows the internal circuit diagram of the dedicated power module.

As a structural feature, the power module has integrated the main circuit terminal block connected with the external power supply and the electric motor.

The copper wiring bars that had been used up to now for each connection were almost eliminated, and the apparatus was greatly simplified.

Current detection was an important factor in the integration with the terminal block.

Although Hall CTs that use Hall elements are generally used to detect the current, they must be inserted between the IGBT output and terminal block, and, in this case, integration becomes difficult from the viewpoint of sizing.

Table 1 Comparison of protective functions

| Protective functions                                                                       | FRENIC5000G9 (standard IGBT)                                                                                                                                                                     | FRENIC5000G11 (IPM)                                                                                                                                                                             |
|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overload                                                                                   | ○<br><ul style="list-style-type: none"> <li>Overcurrent protection by output current detection</li> <li>Indirect junction temperature protection by detecting cooling fin temperature</li> </ul> | ◎<br><ul style="list-style-type: none"> <li>Overcurrent protection by output current detection</li> <li>Direct junction temperature protection by detecting IGBT element temperature</li> </ul> |
| Output short-circuit and ground fault                                                      | ○                                                                                                                                                                                                | ○                                                                                                                                                                                               |
| Arm short-circuit (malfunction by noises)                                                  | ×                                                                                                                                                                                                | ○<br>Overcurrent protection for each IGBT element                                                                                                                                               |
| Influence of damage on external circuits such as control power supply, drive circuit, etc. | Extended damage of IGBT due to damage of peripheral circuits                                                                                                                                     | Minimized damage compared with that of standard IGBT                                                                                                                                            |

Fig.2 Internal circuit diagram of dedicated IPM (50A, 600V)

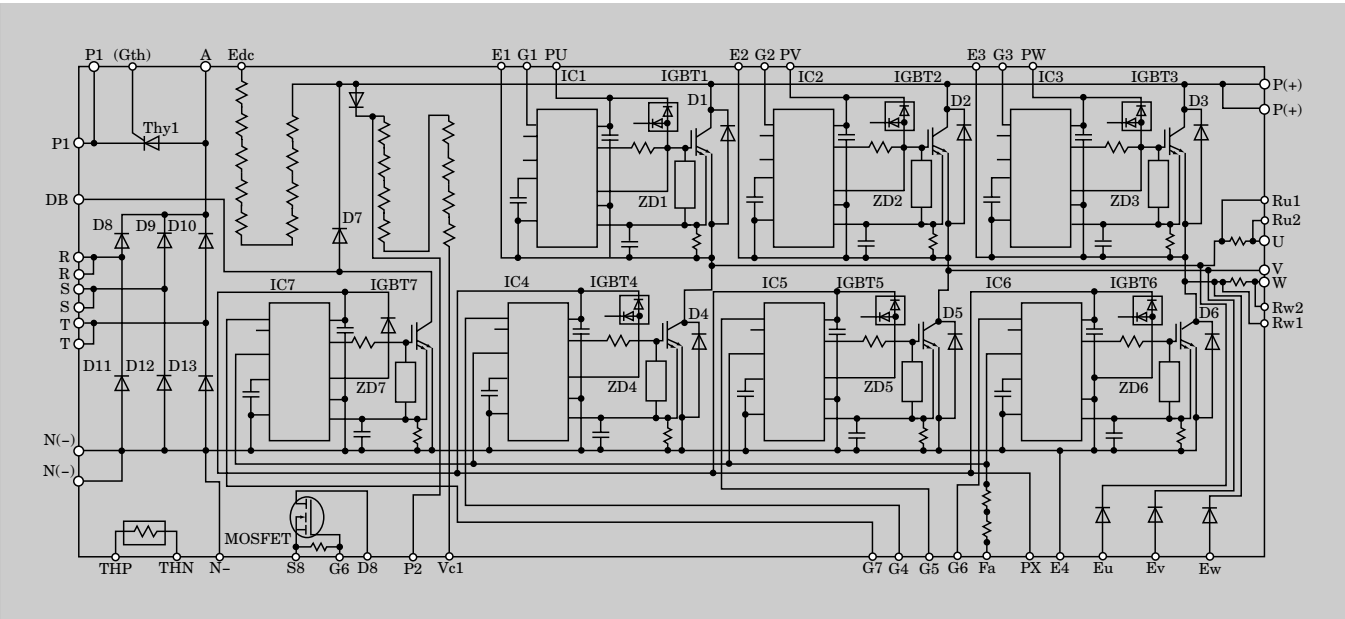


Fig.3 Integrated power modules and terminal blocks

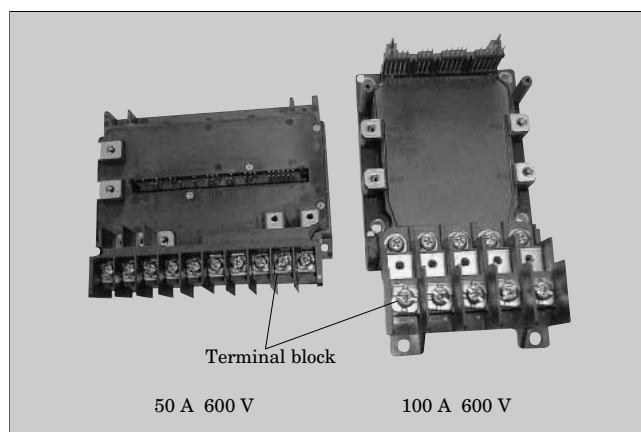
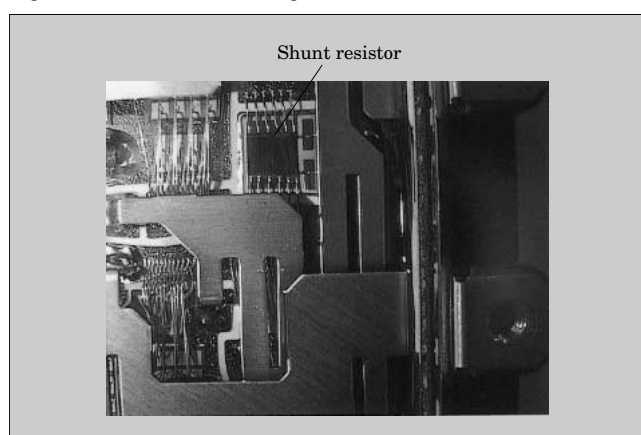


Fig.4 Shunt resistor with high thermal conduction



Fuji Electric has utilized a 10mm square shunt resistor in its dedicated IPMs to achieve an integrated structure of the power module and terminal block for models up to 200A/600V (Fig. 3 and Fig. 4).

## 2.4 Cooling technology

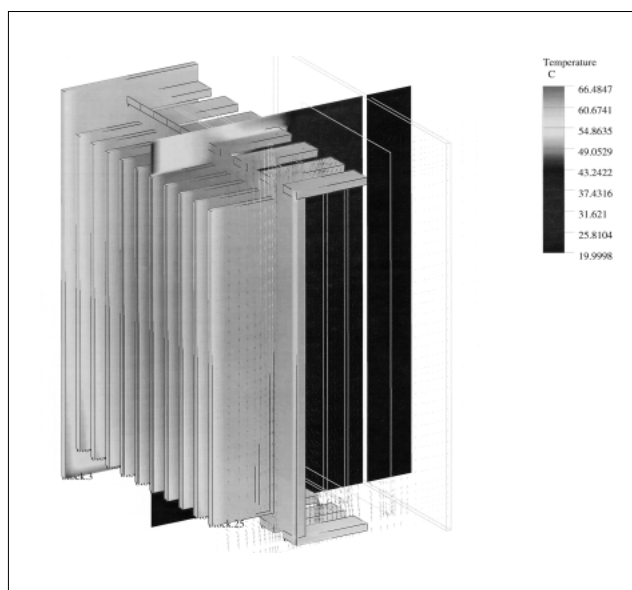
The conversion efficiency of the inverter apparatus is approximately 95%, and the remaining approximate 5% is loss. For instance, a loss of approximately 1kW will be generated in an inverter apparatus of 22kW output. The cooling technology basically determines the downsizing.

The natural air method of cooling is applied to the smallest capacities of 750W or less, and forced air cooling is generally used for capacities of more than 750W. With forced air cooling, the amount of wind from the cooling fans is the key factor when enhancing the cooling capability by increasing the rotation speed of fans. Direct current drive fans of 5,000r/min or greater are being used at present.

Increasing the surface area of the cooling fins as much as possible, fins with a narrower rib pitch are especially effective for forced air cooling. Cooling fins with a pitch of 4mm or less are currently applied by using caulking and brazing technology.

Repeated temperature testing consumes a great

Fig.5 Example of thermal simulation results



deal of time when designing apparatus, and the arrangement of components has been optimized while tests are repeated many times.

However, Fuji Electric has recently introduced simulation technology. Simulation is used for verification before implementation, such as to examine the shape of the cooling fins or simulate the mutual interference of heat in order to setup the inverter apparatus.

Figure 5 shows an example of actual analyzed results of the servo amplifier using thermal simulation. It is anticipated that thermal simulation technology will further develop in the future.

## 3. Recent Control Circuit Technology

General-purpose inverters and servo amplifiers are used as actuators in the field of industrial machinery. Therefore, their required performance and functions are often demanded directly from the machinery itself. For instance, shortening the time required to start and stop the electric motor can reduce the operating hours of each machine. Moreover, processing accuracy of the machinery improves by decreasing rotational fluctuation of the electric motor and enhancing its positioning accuracy. Consequently, neither ultra low-speed processing nor correction process is needed. The performance of the control circuit plays a significant role in improving the performance of the apparatus. Some of the control circuit technology is introduced here.

### 3.1 Speed-up of operation

The installed microprocessor is responsible for internal processing in recent general-purpose inverters and servo systems. Software is necessary of course. Although there is some difference in the inverter and the servo amplifier, high-speed operation processing of

the feedback system and sequential processing of the functional parts are necessary for the position adjustment, speed and current systems.

So far, most of such processing was executed with one microprocessor to satisfy product requirements for downsizing and cost reduction.

However, to implement basic performance improvements strongly demanded by the marketplace such as high-speed rotation, high-speed response, and high accuracy, there is the need for operations such as observers that are compatible with estimated control and turbulence, in addition to making the operation cycle and operation speed of the feedback adjustment system much higher.

In order to deal with such an increase in operation load, Fuji Electric utilized a RISC (reduced instruction set computer) type microprocessor with processing speed of approximately 30MIPS (million instructions per second). Fuji Electric has also responded to the problem by shifting those tasks which demand more high-speed operation to hardware by using ASICs (application specific ICs).

### 3.2 Shift to hardware processing

Along with higher integration of ASICs, it has become possible for operation processing to shift from software to hardware. That is, it has become possible to speed up operation processing with ASIC hardware, avoiding a significant cost increase and greatly improving the product performance.

Here, three examples where processing was shifted to the hardware for performance improvement are described.

#### (1) Voltage control by pulse width compensation

A key technology for the general-purpose inverter is to obtain an ideal output voltage even for low speed and to achieve smooth electric motor drive. Conventionally, although the voltage distortion caused by the nonlinear performance of switching devices such as IGBTs has been compensated by the software, the processing speed has not always been sufficient.

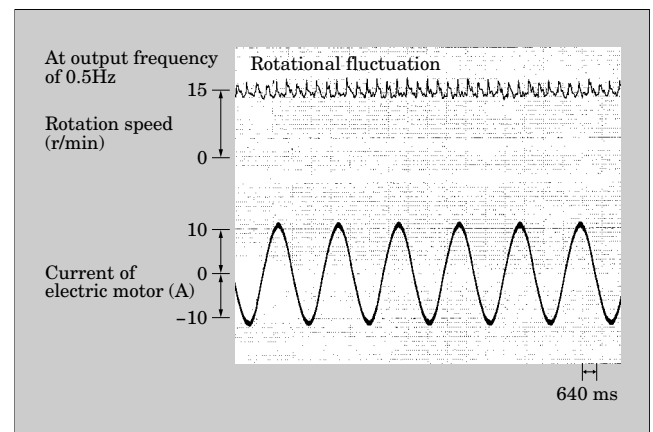
This technology detects shifting in the IGBT switching timing and compensates the switching pulse width. An ASIC is used for timing processes of 1 $\mu$ s or less. Application of this technology makes the low-speed current waveform more closely resemble an ideal sinusoidal wave. Figure 6 shows the rotational fluctuation and output current waveform of an inverter at 0.5Hz. This waveform is an almost ideal sinusoidal.

#### (2) Digital voltage control

This is an example of a feedback control that detects the output voltage for the purpose of controlling the output voltage of the general-purpose inverter as described above.

Containing an operation circuit that performs three-phase adjustment such that the detected output voltage agrees with the instructed voltage, the system performs all processing with ASICs, from the adjusting

Fig.6 Rotational fluctuation and current waveform



operation to PWM (pulse width modulation) processing. By using ASICs, it is possible to perform operation processing in a cycle of several tens of  $\mu$ s.

Ideal voltage control is made possible through high-speed operation processing and the detection of the output voltage.

#### (3) Digital current control

The servo amplifier controls positioning, speed, and current.

The current control requires the highest speed operation, and its performance determines the response of positioning and speed control. So far, however, this control has been implemented in software, because it requires a complex adjuster operation.

By implementing all these current control operations with an ASIC, the operation cycle has speeded up by approximately a factor of ten. This system has achieved a frequency response of 500Hz or more for the speed control loop.

Product performance has been improved through an appropriate paradigm shift to ASIC control.

### 3.3 High-resolution of pulse encoder

The feedback control in the servo amplifier needs a signal from the pulse encoder attached to the electric motor axle or the mechanical system to know the rotation of the electric motor.

The pulse encoder outputs a predetermined number of pulses to the electric motor per rotation. Currently, the output of several thousand pulses per rotation is common in the general industrial machinery field, excluding some super-precision machining equipment.

However, the pulse output within a fixed time (100 to several hundred  $\mu$ s) decreases as the rotation of the servomotor approaches low-speed. Therefore, the rotation of the servomotor cannot accurately be detected on the servo amplifier side, and problems such as low-speed axle vibration occur.

The performance of machinery has continued to be enhanced, and tens of thousands of pulses per rotation or more is being required in general industrial machin-

ery.

On the other hand, because the output pulse frequency for high-resolution response enters the MHz region due to high-speed rotation, transmission of the pulse train signals becomes difficult. A recent measure implemented between the pulse encoder and servo amplifier is to exchange positioning information detected from the electric motor, while synchronizing at the operation cycle of the servo amplifier, using serially transmit numerical values.

Fuji Electric has implemented its original serial transmission format for Manchester code on an ASIC, resulting in high frequency transmission.

### 3.4 Field networking

To issue operational instructions to multiple general-purpose inverters and servo systems installed in machinery, and to collectively manage operational situations and internally set data, the networking of high-ranking control equipment with inverters and servo systems is becoming increasingly common.

Such networking only requires one serial communication cable to wire each piece of equipment. In conventional I/O wiring, each signal (each function) required its own separate wire. Networking can dramatically decrease the necessary wiring, leading to downsizing of the control board.

However, the currently existing methods of networking are many and diverse, and are adopted by certain countries, regions, industrial equipment manufacturers or fields of application.

Because of this situation, there are various movements by local regions throughout the world to standardize their own method. On the other hand, because of advantages and disadvantages of each method, it is difficult for the user to choose only one system as the standard networking method for their own equipment.

Table 2 lists some typical types of networks.

Moreover, the servo amplifier is responsible for increasing the speed and accuracy of the machinery. In addition, a multi-axle servomotor installed in a machine must not be allowed to operate with a time delay in response to a high-ranking instruction. In particular, complete synchronization of each axle is demanded

Table 2 List of various networks

|                                         |
|-----------------------------------------|
| RS-485 (HL)                             |
| Modbus RTU                              |
| Modbus Plus                             |
| Profibus DP                             |
| Interbus S                              |
| JPCN1                                   |
| Device Net                              |
| T-link (original link of Fuji Electric) |
| SX-bus (original link of Fuji Electric) |

for track control implemented processing applications.

Because some time difference is inevitable when transmitting instructions by serial communication between each piece of networked equipment, positioning shifts are likely to result among the machine axles. To suppress such shifts to an allowable level, it is necessary to exchange the information of positioning instructions at an extremely fast cycle. A dedicated network with transmission speeds of about 10MHz or more is necessary.

Thus, the performance of the servo amplifier is influenced by the networking method, and many servo system makers are currently striving to develop and find applications for their original networking methods.

## 4. Conclusion

This paper described the modern hardware technology of inverters and servo systems. Since these products are indispensable in the industrial machinery field, high functions and high performance are always required, and, especially in recent years, the manufacture of environment-friendly products has also been demanded.

In the future, the authors will continue efforts to establish a product design technology that considers not only performance and functions, but also adapts to the environment and is concerned with simplified waste disposal and product recycling.



# Recent Servomotor Technology

Kenji Endo  
Akihide Mashimo  
Terufumi Shimizu

## 1. Introduction

The trends toward compact-size and high-speed response of semiconductor manufacturing equipment and electronic parts machining equipment have increased in recent years. For this reason, the demand for compactness to save space and for low inertia to achieve high-speed response is increasing for the servomotors that drive these types of equipment.

Fuji Electric has been working on the development of an element technique for several years to achieve compact servomotors, and has successfully realized such a servomotor which is ranked as the top level compact unit in the business world. An overview of this achievement is described below.

## 2. Application of Rare Earth Magnet

A rare earth magnet is formed by sintering several

minute powdered metals that contain rare earth elements such as Nd (Neodim) and Sm (Samarium). As shown in Fig. 1, the magnetic characteristics of rare earth magnets have improved remarkably in recent years, thus enabling the generation of a strong magnetic field comparable to that of an electromagnet.

From early on, Fuji Electric challenged itself with the permanent magnet rotating machine, known for its difficulty, and since then has manufactured and delivered devices that utilize rare earth magnets such as the world's fastest gas turbine driving generator and the world's largest capacity torque machine for driving a coal mine conveyor.

Rare earth magnets include the Nd type, Sm type and Pr (Prasceodim) type, and each type has certain advantages and disadvantages. For this servomotor, an Nd type magnet was utilized because of its abundance as a natural resource, progress in mass production, and significantly improved characteristics.

The stability of magnetic force of an Nd type magnet was confirmed by placing the magnet by itself in air, which is magnetically the most severe condition, and then by leaving it in a 100°C environment for 1,000 hours. Even after these tests, no deterioration was observed as shown in Fig. 2.

Reliability of the magnet was secured by improving the magnet's rather inadequate mechanical strength with modifications to the support mechanism and by making it less susceptible to rust with the application

Fig.1 Improvement of magnet characteristics

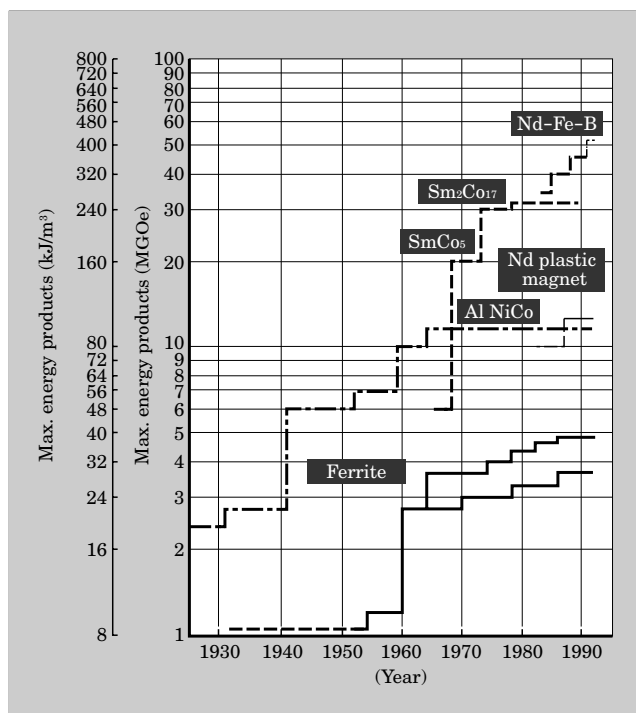


Fig.2 Deterioration of magnet characteristics

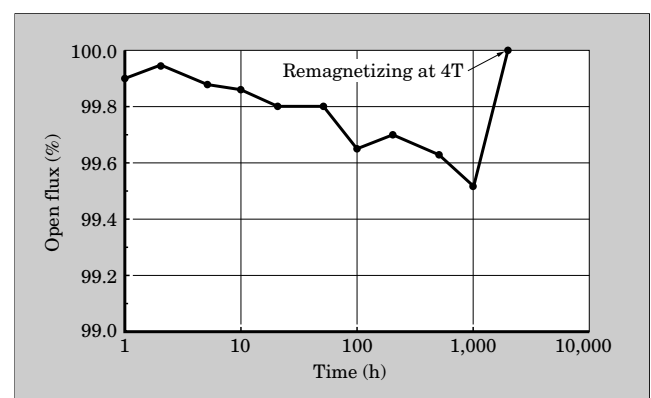
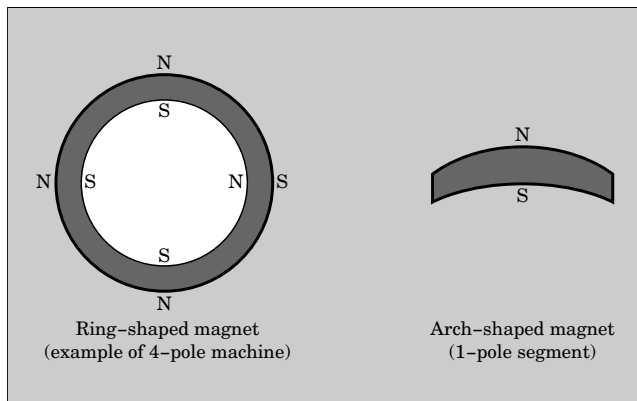


Fig.3 Ring-shaped magnet and arch-shaped magnet



of a resin coating.

The permanent magnet is shaped as a small simple ring or arch, as shown in Fig. 3, and is adhered and fixed to the surface of a solid rotor core that has been cut out together with the shaft. This simple construction has the advantage of being able to become magnetized after the magnet is fixed in place, aiming to improve the mass-productivity.

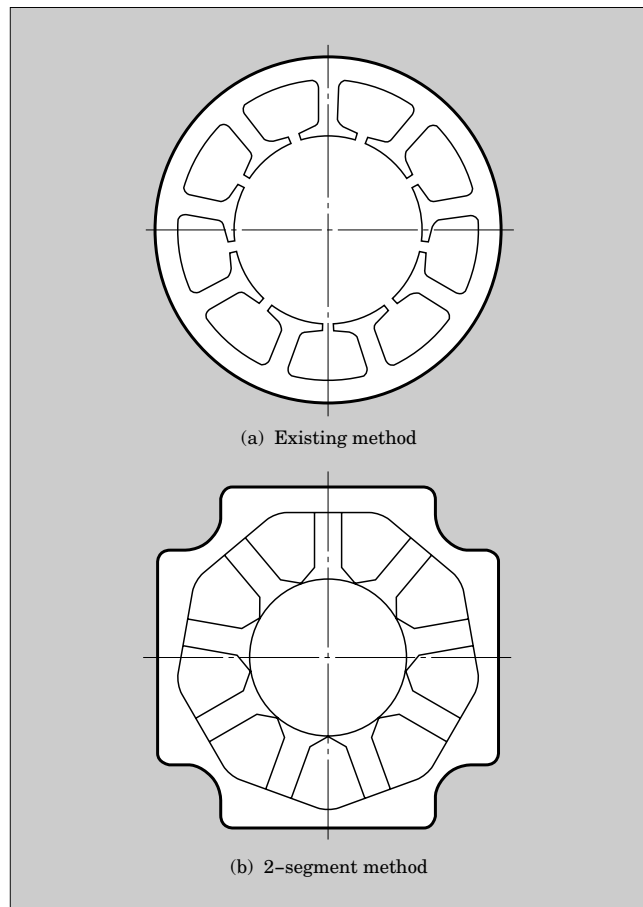
This method, using a small arch-shaped magnet, has been applied to large diameter units whose size exceeds the manufacturing limit of ring-shaped magnets. Based on application of magnetic field analysis that accounted for the advantageous ability to freely modify its sectional configuration, a configuration with minimum cogging torque was selected. As a result, the cogging torque could be reduced to 1/3 that of existing magnets.

### 3. Improvement of Coil Filling Ratio

In existing electric motors, as shown in Fig. 4 (a), the coil must be automatically inserted from an inconvenient angle and position into a slot located on the inner diameter side of the armature, resulting in only about a 50% filling ratio. Consequently, the current feeding per unit peripheral length was inadequate, leading to low torque density. In addition, there were a number of gaps in the slot which interfered with the discharge of coil heat through the core and further restricted the current feeding. Therefore, a method was utilized in which the core is segmented and after tightly winding the coil while keeping the slot portion wide open, the core is assembled into a solid construction. However, because the core is an important part that transmits magnetic flux and supports the construction, segmentation of the core must be prepared carefully, otherwise severe problems with characteristics and strength will result.

One of the methods applied to this electric motor is called the 2-segment method, shown in Fig. 4 (b). In other words, the inner core is shaped like a gear composed of teeth and bridges that connect the teeth, and a bobbin, made of resin on which the coil has been

Fig.4 Shape of armature core



wound, is attached to each tooth. This assembly is fitted into a ring yoke, forming the completed armature core. The fitting clearance at each tooth between outer and inner cores must be maintained as even as possible to obtain better characteristics.

The bridge is a vital part for the nonstructural support of the inner core, and is also effective in regulating the ripple torque that results from interference between the magnetic flux and teeth. However, excessively increasing its thickness in expectation of these effects will result in unnecessary bypass of the magnetic flux between poles, thus decreasing the usage percentage of the magnetic flux.

The optimum bridge configuration, which has a high magnetic saturation, was evaluated and determined using 2-dimensional static field FEM (Finite Element Method), instead of the conventional analysis method. Figure 5 shows an example of magnetic flux passing over the bridge. The method was not only useful in determining the optimum configuration but was also greatly effective in specifying the permissible manufacturing tolerances and the relation between core dispersion and cogging torque as shown in Fig. 6.

### 4. High Thermal Conductive Resin Mold

Because the thin bridge portion is not strong

Fig.5 Analysis of magnetic flux distribution

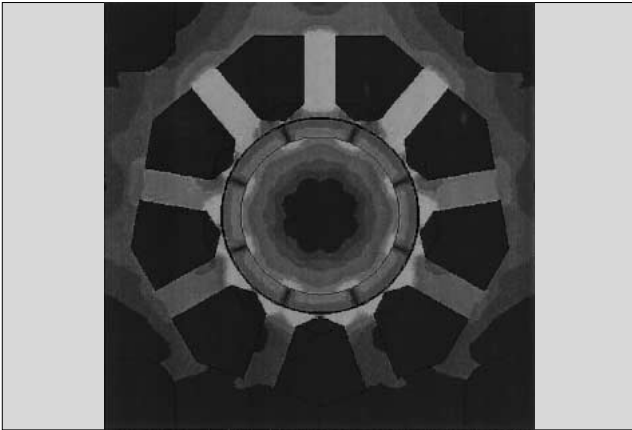
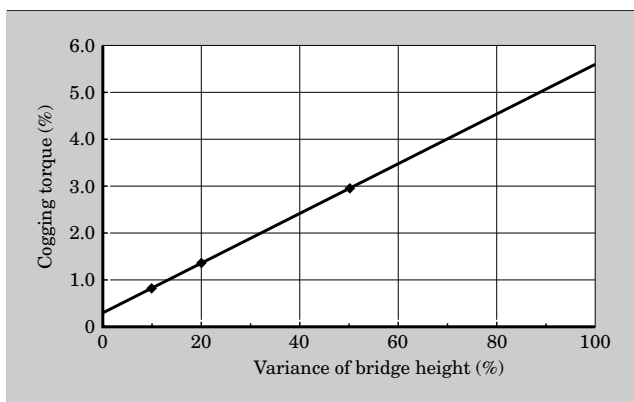


Fig.6 Core dispersion vs. cogging torque



enough by itself to support the core structure, the core, into which coils have been inserted, needs to be molded in resin to achieve stronger construction. To protect the coil and core in a severe environment, the molding resin must have high thermal conductivity in order to reduce anti-environmental characteristics and to lower the coil temperature. On the other hand, the molding resin needs to be highly fluid (low viscosity) to minimize damage to the coil during molding and to allow the resin to fill down into small areas of the coil.

In general, unsaturated polyester BMC (Bulk Molding Compound) is widely used as the molding resin for molded motors. However, further improvements have been made to oil resistance and thermal conductivity, and a new resin that allows low-pressure molding was developed and applied in order to satisfy the above requirements.

Although characteristics differ for improving thermal conductivity and resin flow by adding inorganic filler, a thermal conductivity higher than that of generally applied resin and a lower molding pressure were achieved by selecting a filler with optimum average particle diameter and optimum particle distribution.

As shown in Fig. 7, the water-soluble machining oil resistance, necessary when a motor is used for metal processing machines, is also better than that of

Fig.7 Machining oil resistance of mold plastic

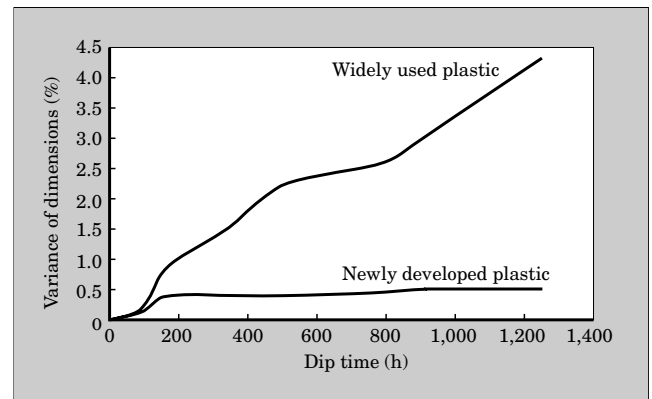
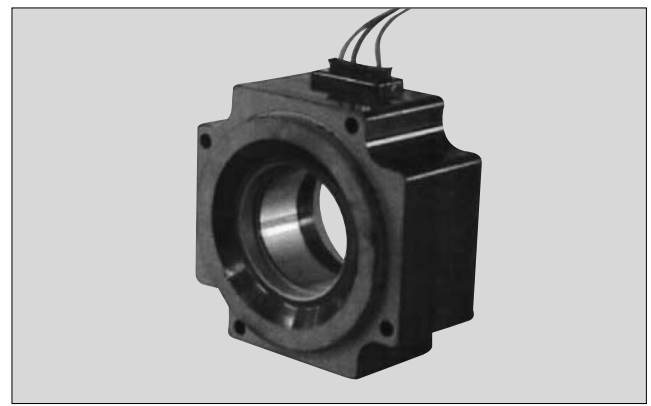


Fig.8 Molded core



general-use resin. No cracking was observed on the new resin, neither after a  $-20^{\circ}\text{C} \leftrightarrow +130^{\circ}\text{C}$  heat cycle test on a resin-molded 750W electric motor core, nor in the results of tests performed afterward. Therefore, it is safe to say that excellent non-cracking characteristics have been achieved compared to general application resin where cracks occur at less than 10 cycles.

An example of the model 2-segment core with coil inserted and molded in resin is shown in Fig. 8. Both cores are firmly coupled by filler resin, and both bobbin and coil are tightly stored in their slot, thus demonstrating the significant effect of the improved environmental characteristics and cooling function. In this example, the coil filling ratio has exceeded 80%, far surpassing the above goal.

## 5. Frameless Construction

For small power units that utilize a 2-segment core, a sturdy armature can be constructed with only a laminated core, and therefore further compactness can be realized by eliminating the aluminum or other type of frame. The external shape of the core, which is square and fixed in place at its 4 corners with run-through bolts, allows convenient handling and storing. Although the material of the laminated core itself is susceptible to corrosion, application of the previously mentioned resin mold to the rear of the core resulted in

Fig.9 Existing type (left) and newly developed type (right)

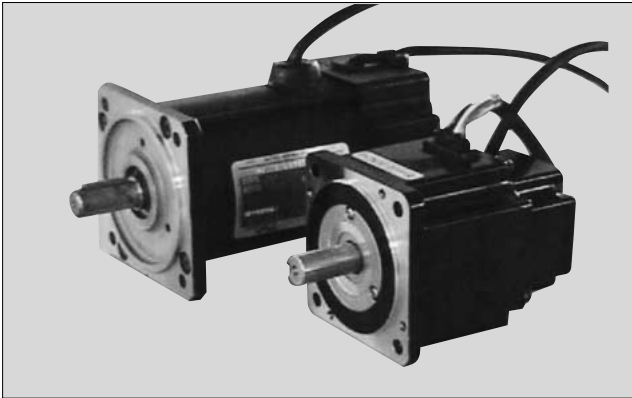
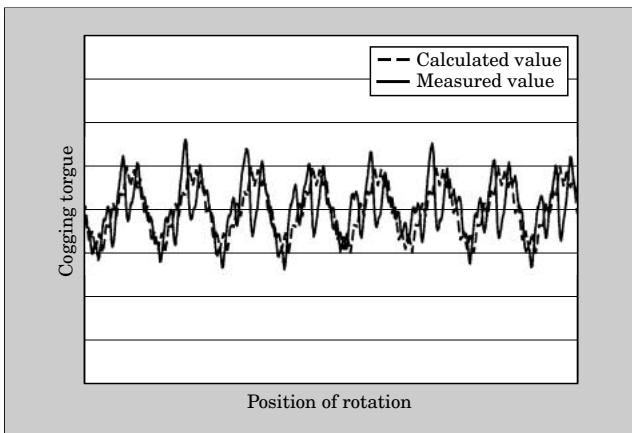


Fig.10 Waveform of cogging torque



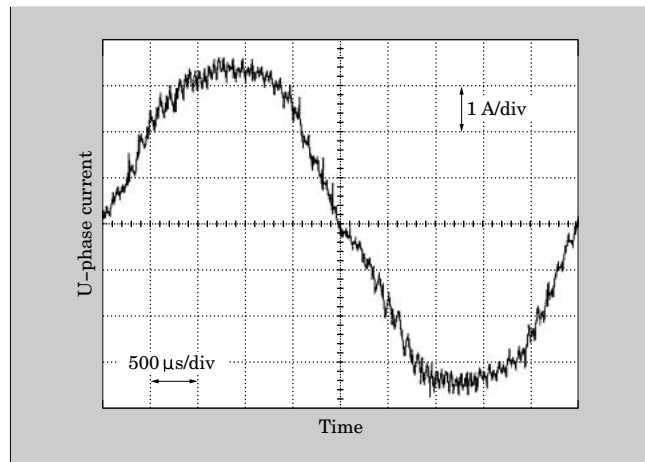
an excellent surface coating with luster and anti-corrosion characteristics.

## 6. Cooling Technique

The improvement of magnetic density by using a rare earth magnet will lead to increased core loss, and the generation of a large current by a tightly wound coil will result in increased copper loss. On the other hand, an over-heated rare earth magnet may possibly cause de-magnetization, and enamel wire, molding resin and encoder at the shaft end have their own temperature limits expectively. Therefore, measures were carried out to achieve the operation of each part at an appropriate temperature by compensating the increase of loss density with a well-designed cooling mechanism.

For this reason, a thermal network was compiled which shows the heat source and heat transmission in details, and by assigning appropriate material values, analysis was performed for numerous cases. Heat flow was controlled by, among other things, providing a heat rejection mechanism between the servomotor and encoder. This is in contrast to the aforementioned high thermal conductivity resin, but achieves a construction where there is only natural heat discharge and no over-heating area at the specified loaded condition,

Fig.11 Waveform of current



regardless of the angle at which a servomotor is operated.

## 7. Model Unit and Measured Result

Figure 9 shows a model unit and an existing 400W unit, side by side. Considerable compactness was achieved to realize the top-level high power density servomotor in the business world.

The cogging torque wave while the terminal is opened is shown in Fig.10 along with the predicted value of the design. There is a difference of amplitude. Nevertheless, similarity of the waveform is remarkably good, verifying the excellency of the analysis accuracy.

Figure 11 displays the current waveform during inverter driven operation. Although high harmonic current due to the 10kHz carrier is observed, the noise at 5,000r/min is 50 dB and the vibration is only 2μm even under such conditions. Therefore, significantly improved characteristics were achieved compared with the existing unit.

The temperatures of the coil, magnet and encoder during servo-amp driven operation are all within the permissible values even under the condition where harmonic current increases loss. Thus, it was verified that the thermal transmission mechanism with a combination of various materials functionates as expected.

## 8. Conclusion

The top-level compact servomotor was achieved with the support of radical new materials such as a rare earth magnet and high thermal-conductive resin, and with the use of a high level analysis method represented by the Finite Element Method. Applying the technologies cultivated during this development work, the authors intend to carry out further research and to continue to contribute novel servomotors to the market.

# Recent Encoder Technology

Kouetsu Fujita  
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Yuji Matsuzoe

## 1. Introduction

The encoder, a type of angle detection sensor, has greatly advanced with the trend toward higher performance servo systems.

This trend is driven by demand for drastically improved resolution, and 16-bit (corresponding to 16,384 pulses) encoders are now appearing in the market instead of encoders with 2,048 pulses, which had been the standard up to the present.

Such being the background, special features of the recent encoder are as follows.

- (1) Realization of small and high resolution encoder
- (2) Standard provision of absolute function
- (3) Economy of cables by adopting serial transmission
- (4) Provision of intelligent function

## 2. Improvement of Optical Encoder Performance

### 2.1 Improvement of resolution

There are two methods, mechanical and electrical (interpolation), to realize a drastic improvement in encoder resolution.

The mechanical method improves resolution of the encoder by increasing the number of the slits of the revolving slit disk. For this purpose, the width of a slit must be as small as possible, requiring high precision machining and assembling of the element parts.

Recently there are several electrical methods to achieve high resolution, one of which is to realize high

resolution by electrically interpolating the approximate quasi-sinusoidal wave shaped A and B signals from the photo detectors, as shown in Fig. 1.

### 2.2 High accuracy

This section explains technical matters related to the realization of high accuracy in the method shown in Fig. 1. This method is required to reduce distortion of the 2 quasi-sinusoidal waves shape as small as possible in order to improve the position accuracy.

For this purpose, it is necessary to analyze and optimize LED (light emitting diode), the slit disk, the characteristics of the photo detector and the effect of the relative positioning of such components that compose the detective part.

It is possible to analyze the effect of such parameters on the distortion of 2-phase signals by a simulator as shown in Fig. 2. This simulator photographs, with a CCD camera, the intensity distribution of light that passes through the slit disk, and then calculates the photoelectric current generated by each photo detector from this image data.

Figure 3 shows the result of analysis of the change of 2-phase signal outputs where the distance between the slit disk and the photo detector is a parameter. It is possible from this analysis, showing the distortion factor and the amplitude, to design the most appropriate distance between the slit disk and the photo

Fig.1 Example of achieving high resolution

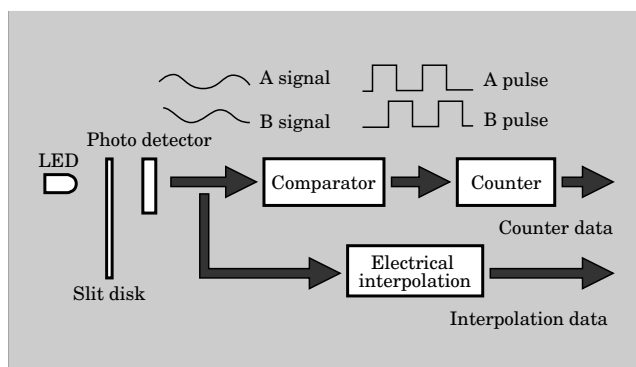


Fig.2 Simulator for analyzing optical system

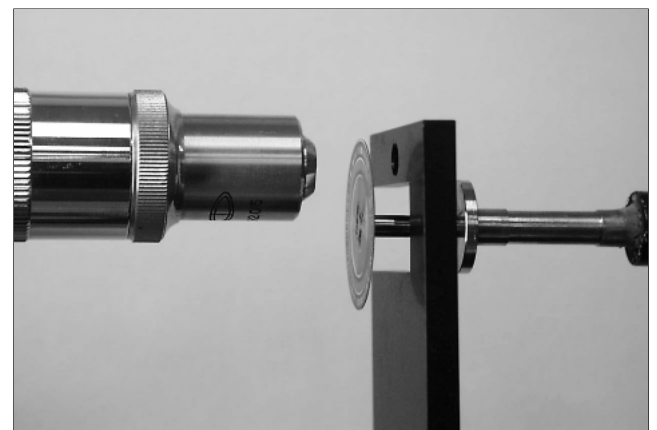


Fig.3 Simulation results

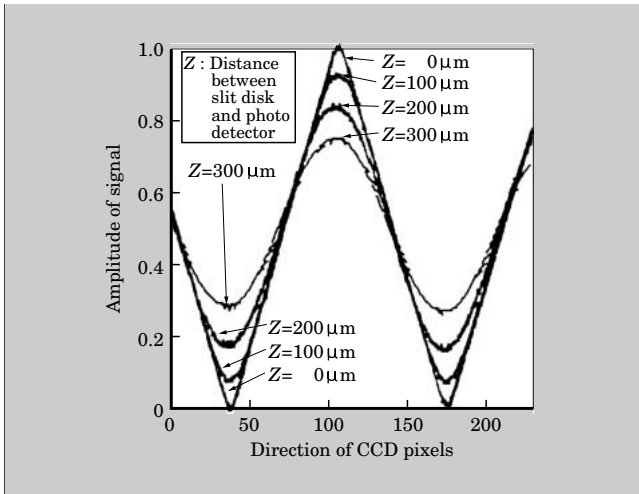
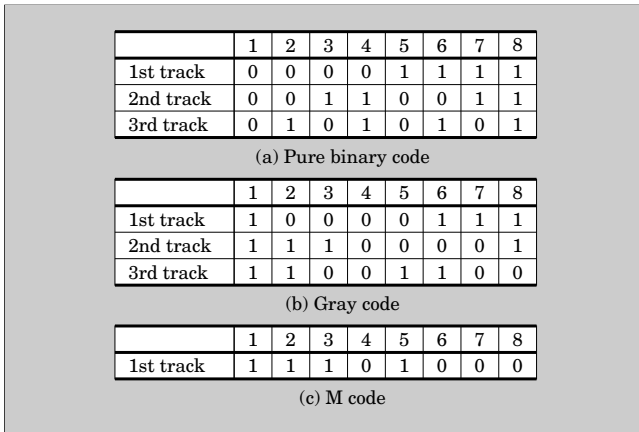


Fig.4 Code pattern (3 bits)



detector.

### 2.3 Absolute encoder

The absolute encoders were only utilized in a limited range of applications because of their handling difficulty and high cost due to their complicated construction. Recently, absolute encoders, which do not require an origin return operation, have become necessary for applications where origin return operation is difficult, such as in a multiple robot or unmanned factory. In order to realize the absolute encoder it is necessary to provide a position detection (to absolutely detect a position in one revolution) and a revolution number detecting function (to detect the number of revolutions). The position detection must continue operation even if the servo-amplifier does not receive electricity, in which case the batteries installed outside of the encoder shall supply electricity to the encoder. For this reason, it is required that the position detection part consumes low electric energy, and recent encoders are provided with a permanent magnet to detect the revolution number magnetically.

Generally, the typical performance is indicated by the resolution of the position detecting function.

Fig.5 Configuration of gray code system and data conversion

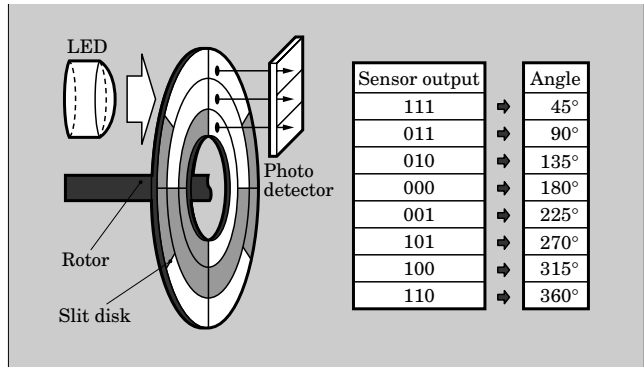
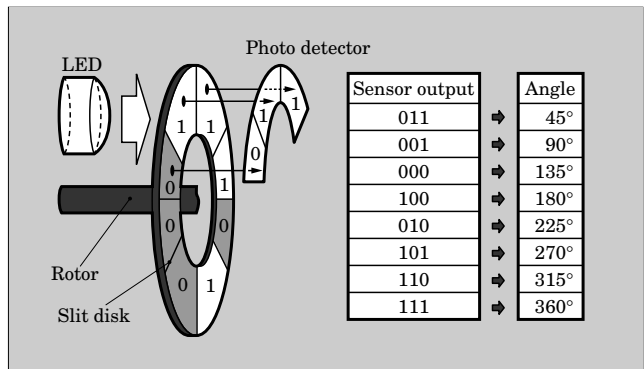


Fig.6 Configuration of M code system and data conversion



Therefore, the algorithm to detect the absolute position by the position detecting function affects the overall composition and performance of the encoder. There are two methods used in recent encoders to detect the absolute position.

#### (1) Gray code system

Figure 4 shows various code patterns of the absolute encoder. Gray code is different from the pure binary code shown in Fig. 4 (a), and more than two (inclusive) codes do not change at the same time as shown in Fig. 4 (b).

Three slit disks, each provided with a grating consisting of permeation portions corresponding to "1" and covering portion corresponding to "0", are arranged concentrically, and three photo detectors, facing the disks, are arranged in a row in the radial direction as shown in Fig. 5. The disadvantage of this method is that it is difficult to reduce the radius.

#### (2) M code system

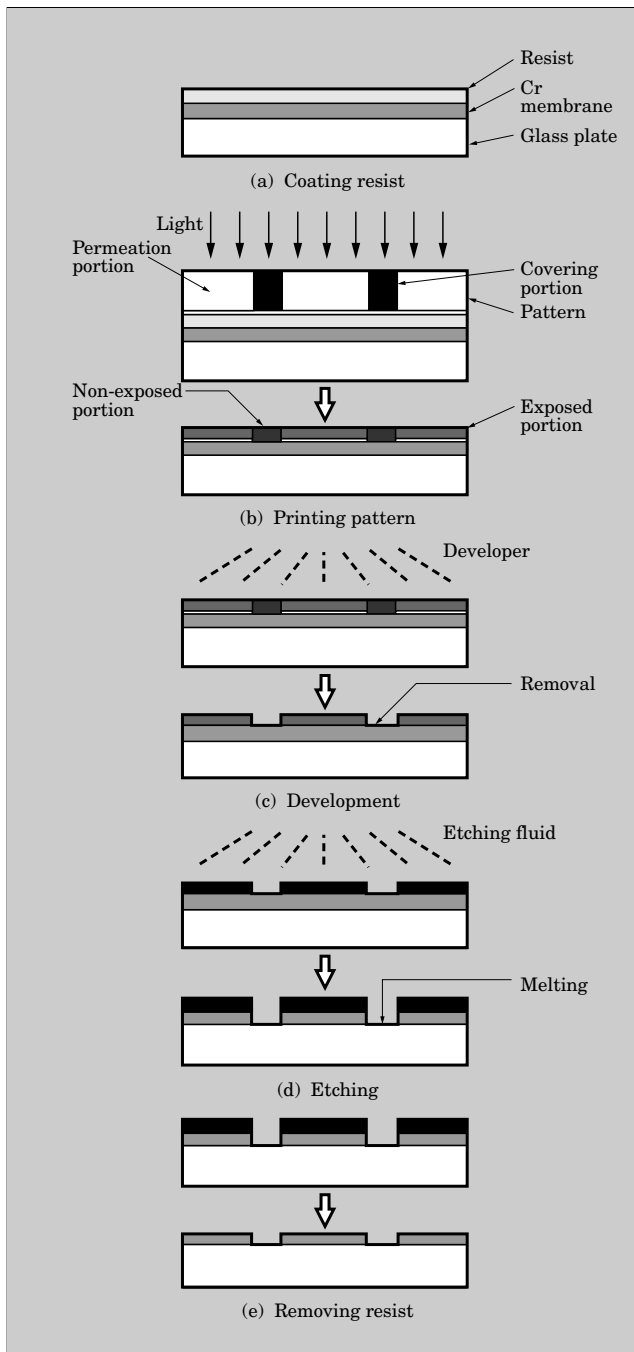
M code is a random number code constructed from a simple rule and consists of  $2^n$  combinations of "1" and "0" data per one cycle as shown in Fig. 4 (c).

Since there is only a single piece of data, given by a series of 1s and 0s from any particular position, there exist  $2^n$  unique data values, along the periphery.

Figure 6 shows the encoder with an M code slit disk.

In this case, it is easy to achieve a small radius, since the photo detectors are arranged along the circumference.

Fig.7 Photoetching process



### 3. Element Technology of Optical Encoder

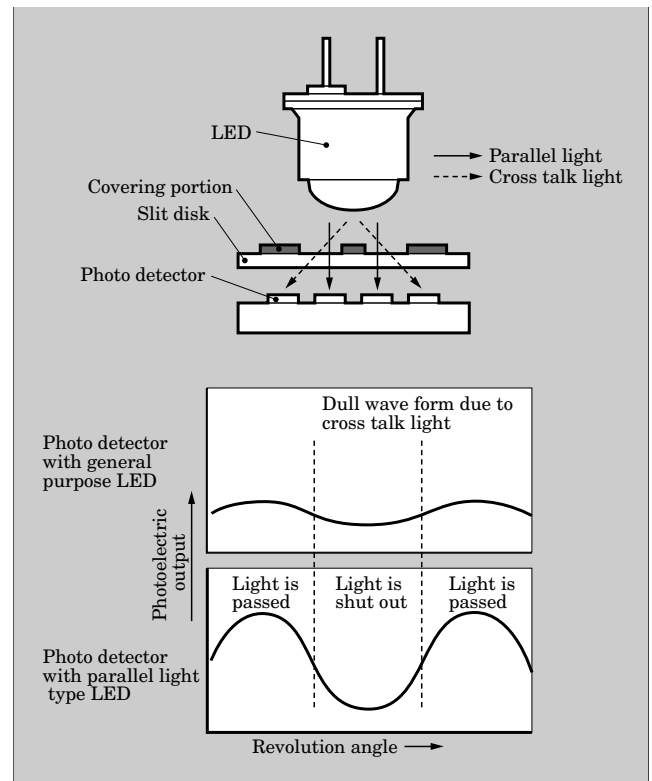
#### 3.1 Photo detector

The photo detector is a transducer that converts a light signal, passing through the slit disk, into an electrical signal, and typically consists of a photo diode and phototransistor.

The photodiode is constructed such that light is applied to its p-n junction, and its main features are quick response, linear light-current characteristics, low noise, etc.

The phototransistors are a combination of a photo-

Fig.8 Effect of cross talk



diodes and a transistors for amplification integrated into a single unit. Its advantage is that it can generate a large signal, equal to the photoelectric current of the photo diode multiplied by the amplification factor of the transistor. Its disadvantages include slow response and different light-photoelectric characteristics depending on each phototransistor.

To compensate for these disadvantages, recent encoders use semiconductor wafers, on which a photo-diode and a phototransistor are mounted, so that an appropriate encoder may be used corresponding to the specifications of the light signal.

#### 3.2 Slit disk

The hot etching method is generally used to manufacture the slit pattern, and the manufacturing process for a glass slit disk differs from that for a metal slit disk.

The pattern of the glass slit disks is manufactured in the following process as shown in Fig. 7: (a) coat the Cr spattered glass surface with the resist membrane, (b) print the pattern, (c) develop, (d) etch, and (e) remove the resist membrane. A glass slit disk made by this method has advantages of excellent etching accuracy and high resolution, as well as disadvantages of vibration and shock susceptibility and high cost.

In the case of a metal slit disk, the metal slit disks are directly etched and therefore the etching accuracy is not as high as that of the glass slit disk and is not suitable for high resolution. However, it does have advantages of high resistance to vibrations and shocks

Table 1 Serial transmission codes (electrical/mechanical specifications)

| System<br>Evaluation item | RS-232C                 | RS-423                   | RS-422                   | RS-485                    |
|---------------------------|-------------------------|--------------------------|--------------------------|---------------------------|
| Transmission speed        | To 20 kbps              | To 300 kbps              | To 10 Mbps               | To 10 Mbps                |
| Transmission distance     | To 15 m                 | To 600 m                 | To 1,220 m               | To 1,220 m                |
| Transmission operation    | Unbalanced              | Unbalanced               | Balanced                 | Balanced                  |
| Maximum connection        | 1 driver/<br>1 receiver | 1 driver/<br>10 receiver | 1 driver/<br>10 receiver | 32 driver/<br>32 receiver |

and low cost. Recently the film slit disks have been developed to improve the disadvantages of both types mentioned above.

### 3.3 LED

LEDs for the encoder are provided by the various manufactures. When selecting LEDs, the following points shall be considered.

#### 3.3.1 Parallel light characteristics

The cross communication (talk) light component will lower the signal-to-noise ratio as shown in Fig. 8 and reduce the detection accuracy.

Hence, an LED that emits a wide range of parallel light is preferable.

#### 3.3.2 Light intensity vs. temperature characteristics

The light intensity of an LED per unit of forward current is lowered by temperature rise. For this reason, it is necessary to flow a larger forward current at high temperature than at normal temperature in order for the photo detector to output a constant photoelectric current.

The increase of the forward current of the LED shortens the life of the LED exponentially. Therefore, LEDs, for which the light intensity reduction due to temperature rise is small, are utilized to realize longer life of the encoder.

#### 3.3.3 Uniformity of illumination

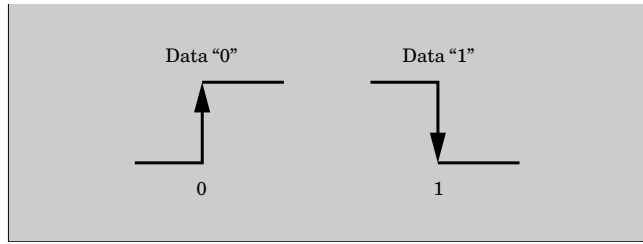
The photoelectric current of the photo detector varies if the uniformity of illumination is uneven. Especially in the case of the encoder, which achieves high resolution by electrically interpolating the sinusoidal wave shaped output signal from the photo detector, the distortion of A and B signals prevents accuracy from improving. For this reason, LEDs with highly uniform illumination are utilized.

### 3.4 Construction

Encoders are classified as ① shaft type, ② hollow shaft type, ③ modular type, etc., according to their method for mounting on motors and method for securing the revolving part. Each type has a different construction.

Of these types, the hollow shaft type is becoming dominant due to such reasons as encoder miniaturiza-

Fig.9 Manchester code



tion and ease of replacement.

The hollow shaft type encoder is provided with a shaft whose center is hollow. The motor shaft can be inserted into the hollow shaft of the encoder to achieve a shorter length in the shaft direction than that of shaft type. In addition, it is easier to mount and replace the hollow shaft type encoder than modular type encoders.

On the other hand, it is necessary to pay special attention to heat and shock resistance characteristics, since all parts of the encoder are susceptible to heat and shock directly transmitted from the motor.

## 4. Encoder and Servo-Amplifier Communication, Intelligent Function

### 4.1 Communication between encoder and servo-amplifier

Regarding the communication between the encoder and the servo-amplifier (herein after referred to as "encoder communication"), the customary pulse transmission system to transmit A · B · Z signals in parallel cannot meet the requirement of high resolution, since the transmission frequency is limited. On the other hand, the resolution is not limited fundamentally by the transmission frequency and the cable between the encoder and the servo-amplifier can be minimized to transmit the position data in serial.

In the case of serial transmission, absolute position data is transmit in real-time, resulting in drastically improved reliability of the transmission line for correctness of the position, compared with the pulse transmission system. Therefore, it is general trend of recent high resolution encoders to adopt a serial transmission system between the encoder and the servo-amplifier.

### 4.2 Serial transmission system

High speed transmission of several megabits/second is required as the communication cycle of the encoder largely affects the response characteristics of the servo system. Because the length of the transmission line can reach 100m at maximum, it is necessary to pay special attention to the voltage drop and noise along the transmission line.

Standard mechanical and electrical specifications for serial transmission are shown in Table 1. RS-422 and RS-485 can be said to be suitable for encoder communication from the viewpoints of transmission

Fig.10 Serial communication block diagram

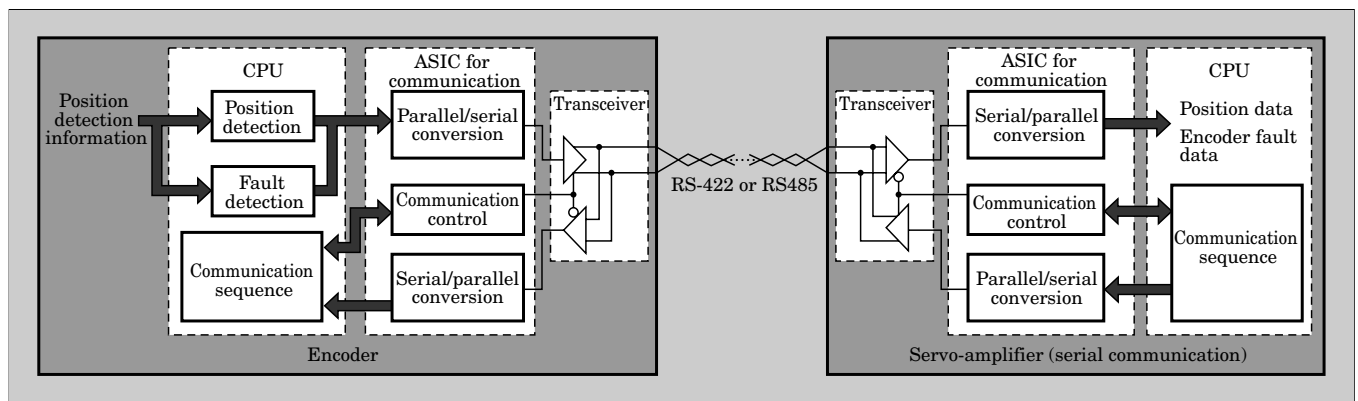


Table 2 Self-diagnosis

| Function                 | Summary                                                                                                         |
|--------------------------|-----------------------------------------------------------------------------------------------------------------|
| Motor type and output    | Informs servo-amplifier of motor type (verifies whether it matches servo-amplifier type)                        |
| Abnormal communication   | Detects a disconnection of transmission line, CRC (cyclic redundancy checks) error, etc. at the servo-amplifier |
| Overheat                 | Informs the servo-amplifier of higher temperature than the setting value in the encoder                         |
| Abnormal number of pulse | Informs the servo-amplifier when the number of pulses per one revolution differs from the design number         |

speed, transmission distance and adoption of a balanced transmission system with noise resistant characteristics. Manchester code is usually applied for its excellent transmission efficiency and high transmission speed. This code is a two value code, and indicates an upward edge as “0” and a downward edge as “1” as shown in Fig. 9.

In addition to the ordinary position signal, cyclic redundancy check data is transmit also to improve the reliability of transmission.

#### 4.3 Configuration of encoder communication system (an example)

To implement a serial transmission system it is necessary to process a huge number of digital signals to convert the position detecting data received in parallel from the optical system. In order to achieve such complicated processing with small number of components in a small space, CPUs (central processing units) and ASICs (application specific ICs) are utilized.

Figure 10 shows a block diagram of the serial communication system, including the servo-amplifier. The CPU of the encoder detects the position as well as faults from various signals detected by optical sensors and other sensors, and carries out the sequential

processing of the communication from the servo-amplifier. An ASIC for communication converts the data of the CPU and that of the transceiver from parallel to serial format and controls communication to the servo-amplifier based on the sequential demand of communication from the CPU. The transceiver converts the input/output signals to RS-422 or RS485 signal levels. It is also necessary to provide the servo-amplifier with a system that includes a transceiver, ASIC for communication and CPU to respond to the encoder’s system. The servo-amplifier receives position data and fault data from the encoder, and controls the operation sequence of the whole system.

#### 4.4 Intelligent encoder

By mounting a CPU and ASIC on an encoder, it is possible to provide an encoder with multiple functions. Hence, the encoder and servo-amplifier are provided with a self-diagnosis function as the position detector, which communicates RAS (reliability, availability and serviceability) information to the servo-amplifier, enabling the servo-amplifier to control the servomotor quickly and safely. Table 2 shows an example of self-diagnosis functions. These functions improve dramatically the RAS function of the position detector.

#### 5. Conclusion

This paper describes encoder technology corresponding to a high performance servo-system applied to various manufacturing equipment, including machine tools, semiconductor manufacturing equipment and industrial robots. Because it is anticipated that demand for higher resolution will continue, Fuji Electric will apply the latest optoelectronics technology and micro-technology for photo detectors and slit patterns to develop a low cost and high reliable encoder as well as achieve higher resolution.

# FRENIC5000G11S/P11S Series, the Latest General-Purpose Inverters

Hiroyuki Yonezawa  
Yasuaki Hachisu  
Hirokazu Tajima

## 1. Introduction

Supported by a wide-range of users, the development of general-purpose inverters over the past ten years has been remarkable. The standard series began with simple  $V/f$  control, and now has achieved high performance with controls for magnetic flux, torque and efficiency. Consequently, general-purpose inverters can be used in applications that previously required dedicated inverters.

The FRENIC5000G9S/P9S series had satisfied market needs as the highest-class inverters with regards to function, performance, quality and price. However, due to the enlarged application range, still higher performance is required. The FRENIC5000G11S/P11S series being introduced here is the latest product series, and uses the most advanced technology.

## 2. Main Features and Specifications

Table 1 shows the basic specifications, and main features are described below.

### (1) Powerful control with dynamic torque-vector control

A RISC (reduced instruction set computer) processor is utilized as the CPU (central processing unit) to improve the response and control calculation speed of important input signals for stopping accuracy and positioning. If a frequency of 0.5Hz has been set, high starting torques of 200% for 22kW or less and 180% for 30kW or more can be achieved. High-speed torque limiting for stopping with a stopper and a press to avoid regenerative braking, etc. are equipped as standard. The inverter can be utilized in a wide range of applications such as a rapidly changing load with trip-less control.

### (2) Wide range of model configurations

The FRENIC5000G11S series is for general industry and the FRENIC5000P11S series is for squared torque load such as fans, pumps, etc. The FRENIC 5000G11S series includes a 200V system ranging from 0.2kW to 90kW and a 400V system ranging from 0.4kW to 400kW. The FRENIC5000P11S series includes a 200V system ranging from 5.5kW to 110kW

and a 400V system ranging from 5.5kW to 500kW. Compared with the conventional series, these series have a wide capacity range provided by enhanced capacity of the unit construction. Therefore, inverters can be selected as appropriate for a particular application.

### (3) Environment-friendly inverter

To increase the range of noise suppression measures, a review of heat loss reduction and cooling design for inverters of 30kW or more was performed, and the upper limit of the carrier frequency has been raised. Measures such as utilization of a half-resonant type low-noise control power supply system and soft switching to suppress  $dV/dt$  of the IGBT (insulated gate bipolar transistor) in the main circuit reduce the effect of noise to peripheral devices such as sensors. Furthermore, in the low carrier mode, which is effective against noise, tone change by a non-periodic carrier frequency can soften the grating noise. The inverter is equipped with terminals for connecting a DC reactor that can suppress higher harmonics, and is equipped with a European EMC (electromagnetic compatibility) compliance filter.

### (4) Circuit configuration

Figure 1 shows the circuit configuration. A newly developed control technology using a digital AVR (automatic voltage regulator) and newly designed gate array improved the output waveform of the inverter, and decreased motor wow to 1/2 that of conventional units. In inverters of 1.5kW or more, an auxiliary control power supply is equipped as standard, and error output signals can be maintained even if the main circuit power supply is interrupted. For the main circuit, a dedicated IPM (intelligent power module) was developed, improving the reliability for short-circuit protection, etc.

### (5) Compliance with international standards

To comply with international markets, the inverter has been approved by UL (America), cUL (Canada), TÜV (Germany) and CE marking (Europe). The keypad panel supports 6 languages: Japanese, English, French, German, Italian and Spanish. Chinese is also supported as an option.

### (6) Abundant functions

Table 1 Basic specifications

| Item                                             |                                   |                                                                    | FRENIC5000G11S                                                                                                                                                                                                                                                                        |                                              | FRENIC5000P11S                  |                                              |
|--------------------------------------------------|-----------------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|---------------------------------|----------------------------------------------|
| Output ratings                                   | Rated capacity                    | 200 V series                                                       | 0.2 to 22 kW                                                                                                                                                                                                                                                                          | 30 to 90 kW                                  | 5.5 to 22 kW                    | 30 to 110 kW                                 |
|                                                  |                                   | 400 V series                                                       | 0.4 to 22 kW                                                                                                                                                                                                                                                                          | 30 to 400 kW                                 | 5.5 to 22 kW                    | 30 to 500 kW                                 |
|                                                  | Voltage                           | 200 V series                                                       | 3-phase 200 V/50 Hz 200 V, 220 V, 230 V/60 Hz                                                                                                                                                                                                                                         |                                              |                                 |                                              |
|                                                  |                                   | 400 V series                                                       | 3-phase 380 V, 400 V, 415 V, (440 V)/50 Hz 380 V, 400 V, 440 V, 460 V/60 Hz                                                                                                                                                                                                           |                                              |                                 |                                              |
|                                                  | Overload capability               |                                                                    | 150% of rated current for 1 min                                                                                                                                                                                                                                                       |                                              | 110% of rated current for 1 min |                                              |
| 200% for 0.5 s                                   |                                   |                                                                    | 180% for 0.5 s                                                                                                                                                                                                                                                                        |                                              |                                 |                                              |
| Rated frequency                                  |                                   | 50, 60Hz                                                           |                                                                                                                                                                                                                                                                                       |                                              |                                 |                                              |
| Input ratings                                    | Phases, Voltage, Frequency        | 200 V series (3-phase)                                             | 200 V to 230 V, 50/60 Hz                                                                                                                                                                                                                                                              | 200 V to 220 V, 50Hz<br>200 V to 230 V, 60Hz | 200 V to 230 V, 50/60 Hz        | 200 V to 220 V, 50Hz<br>200 V to 230 V, 60Hz |
|                                                  |                                   | 400 V series (3-phase)                                             | 380 V to 480 V, 50/60 Hz                                                                                                                                                                                                                                                              | 380 V to 440 V, 50Hz<br>380 V to 480 V, 60Hz | 380 V to 480 V, 50/60 Hz        | 380 V to 440 V, 50Hz<br>380 V to 480 V, 60Hz |
|                                                  | Voltage/frequency variations      |                                                                    | Voltage: +10 to -15%, Frequency: +5 to -5%                                                                                                                                                                                                                                            |                                              |                                 |                                              |
|                                                  | Momentary voltage dip capability  |                                                                    | When the input voltage is 165 V (400 V series: 310 V) or more, the inverter can be operated continuously. When the input voltage drops from the rated voltage to below 165 V (400 V series: 310 V), the inverter can be operated for 15 ms. The smooth recovery method is selectable. |                                              |                                 |                                              |
| Output frequency                                 | Adjustment                        | Maximum frequency                                                  | 50 to 400 Hz                                                                                                                                                                                                                                                                          |                                              | 50 to 120 Hz                    |                                              |
|                                                  |                                   | Base frequency                                                     | 25 to 400 Hz                                                                                                                                                                                                                                                                          |                                              | 25 to 120 Hz                    |                                              |
|                                                  |                                   | Range of output frequency                                          | 0.1 to 400 Hz                                                                                                                                                                                                                                                                         |                                              | 0.1 to 120 Hz                   |                                              |
|                                                  |                                   | Carrier frequency                                                  | 0.75 to 15 kHz (different depending on capacity)                                                                                                                                                                                                                                      |                                              |                                 |                                              |
|                                                  | Accuracy                          |                                                                    | Analog setting: $\pm 0.2\%$ of maximum frequency (at $25\pm 10^{\circ}\text{C}$ )<br>Digital setting: $\pm 0.01\%$ of maximum frequency (at $-10$ to $+50^{\circ}\text{C}$ )                                                                                                          |                                              |                                 |                                              |
|                                                  | Setting resolution                |                                                                    | Keypad panel setting: 0.01 Hz (99.99 Hz or less), 0.1 Hz (100 Hz or more)<br>Analog setting: 1/3,000 of maximum frequency, link setting: 1/20,000 of maximum frequency, 0.01 Hz                                                                                                       |                                              |                                 |                                              |
| Control                                          | Control method                    |                                                                    | V/f control, dynamic torque vector control , vector control with PG (G11S only)                                                                                                                                                                                                       |                                              |                                 |                                              |
|                                                  | Torque boost                      |                                                                    | Automatic torque boost, manual torque boost,                                                                                                                                                                                                                                          |                                              |                                 |                                              |
|                                                  | Starting torque                   | 200% (22 kW or less) (at dynamic torque control)                   |                                                                                                                                                                                                                                                                                       | 50%                                          |                                 |                                              |
| 180% (30 kW or less) (at dynamic torque control) |                                   |                                                                    |                                                                                                                                                                                                                                                                                       |                                              |                                 |                                              |
| Braking                                          | Braking torque (not using option) | 150% (0.75 kW or less)                                             | 10 to 15%                                                                                                                                                                                                                                                                             |                                              | 20%                             | 10 to 15%                                    |
|                                                  |                                   | 100% (7.5 kW or less)                                              |                                                                                                                                                                                                                                                                                       |                                              |                                 |                                              |
|                                                  |                                   | 20% (22 kW or less)                                                |                                                                                                                                                                                                                                                                                       |                                              |                                 |                                              |
| Enclosure (IEC60529)                             |                                   | IP40                                                               | IP00                                                                                                                                                                                                                                                                                  | IP40                                         | IP00                            |                                              |
| Cooling method                                   |                                   | Natural cooling (0.75 kW or less),<br>Fan cooling (1.5 kW or more) |                                                                                                                                                                                                                                                                                       | Fan cooling                                  |                                 |                                              |

A PID (proportional, integral and differential) function, which performs feedback control for temperature control with a fan or pressure and flow rate control with a pump, is equipped, and the changeover sequence to a power distribution line is partly integrated into the inverter to simplify peripheral circuitry. Furthermore, many new functions are provided such as the following: a function that continues operation by consuming inertia energy of the motor and load at a power failure, a function that decelerates and stops the motor, an automatic energy-saving function to operate the motor at minimum loss, and a function to switch a fan on and off depending on the temperature of the cooling fins.

Since serial transmission (RS485) capability is equipped as standard, system compatibility with various open buses (optional) is facilitated.

By installing a PG (pulse generator) feedback card,

real vector control is possible, and the inverter can be used in even higher performance applications.

### 3. Control System

The control system developed for FRENIC5000G11S/P11S, including operation characteristics will be described below.

#### 3.1 Dynamic torque-vector control

Fuji Electric's original "dynamic torque vector control" system was newly developed and features remarkably improved dynamic characteristics compared to conventional "torque-vector control".

The system configuration is shown in Fig. 2. By detecting output voltage of the inverter and making the voltage a sinusoidal wave with the digital AVR, a small rotational fluctuation of about 5r/min (p-p) is

Fig.1 Circuit configuration

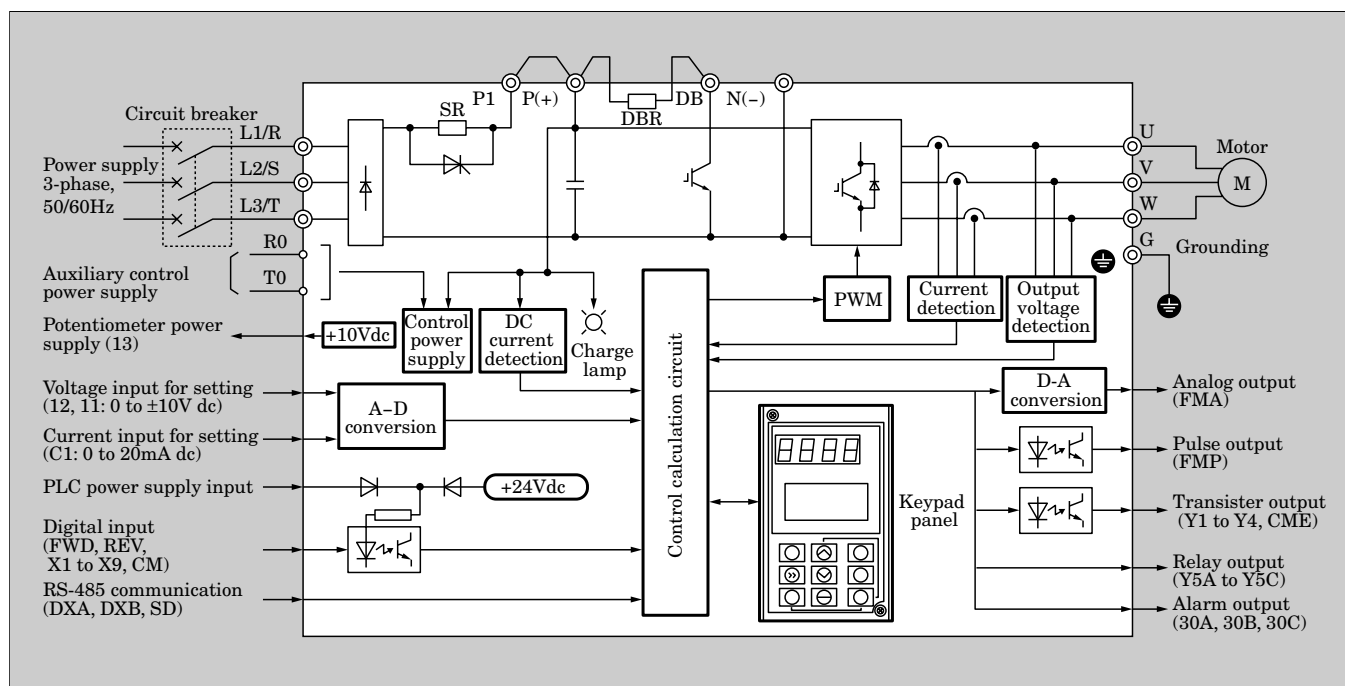


Fig.2 System configuration

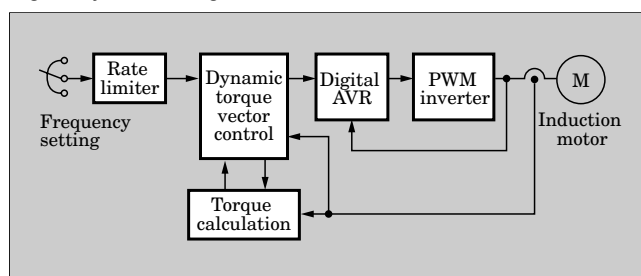
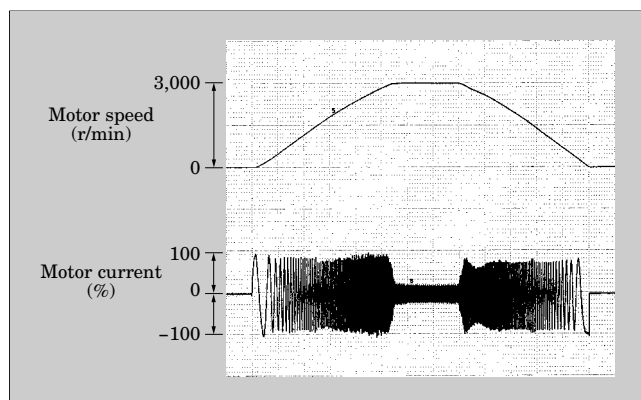
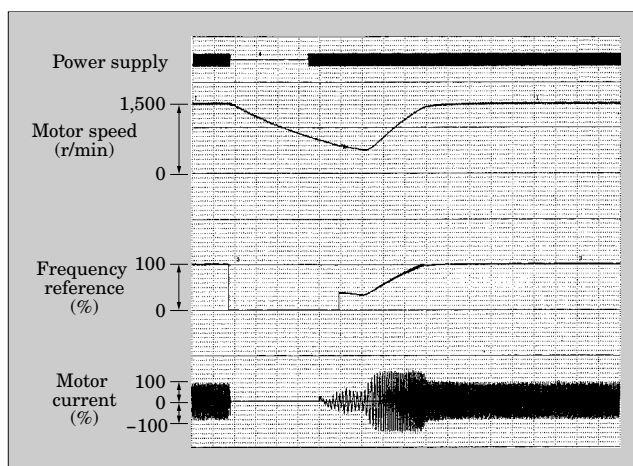


Fig.3 Acceleration/deceleration characteristics



realized at 1Hz operation. The torque calculation accuracy is improved with this digital AVR and accurate torque calculation becomes possible even at the ultra low speed of 0.5Hz. With dynamic torque-vector control, the stability and response are also improved at acceleration/deceleration and rapid load change.

Fig.4 Operation characteristics after an instantaneous power interruption (flying start)



### 3.2 Acceleration and deceleration characteristics

Figure 3 shows acceleration and deceleration operation characteristics using a torque limiting function. The torque limiting function operates immediately after the start of deceleration, and the speed variation and current overshoot are suppressed. Since a new torque limiting method is utilized in which the deviation between the torque limit value and generating torque in the motor is made to be zero, the acceleration and deceleration time can be shortened.

With this function, machine tools, which require reduced gear noise and the shortest acceleration and deceleration, and conveyance machinery, which require high-frequent operation, can be smoothly accelerated and decelerated or forward and reverse operated.

Fig.5 Motor speed vs temperature variation

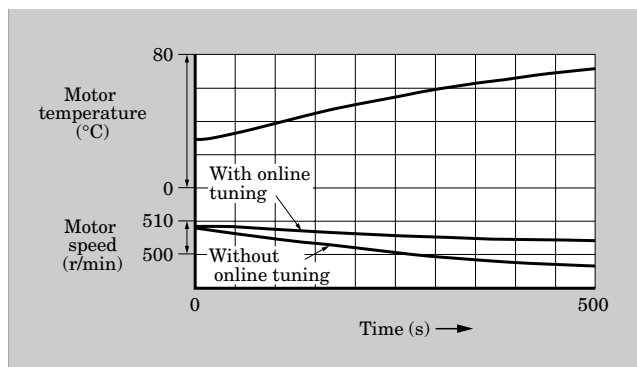
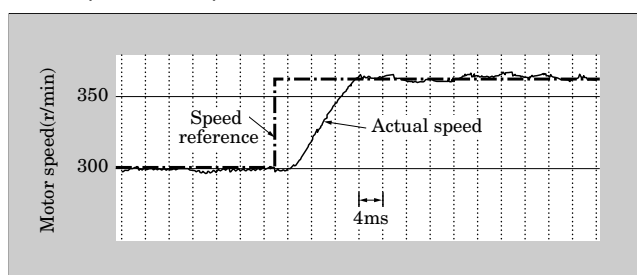


Fig.6 Response at step speed setting (Vector control using speed sensor)



### 3.3 Flying start

The control system is equipped with a flying start function whereby a free-running motor can be smoothly restarted without shock.

This function detects the rotating speed and direction by self-excited oscillation of the motor and inverter that is induced by positive feedback of the motor current. Figure 4 shows operation waveforms in the case of restarting after an instantaneous power interruption. The operation smoothly restarted without rush current.

Since the speed can be correctly detected even if the rotating direction is reversed, this function can be used effectively to start the reverse rotating fans.

### 3.4 Auto-tuning function

Various motors are used with general-purpose inverters. Control constants must be adjusted to correspond to the motor in use to effectively utilize the ability of dynamic torque-vector control. Therefore, in addition to the conventional off-line auto-tuning function, the control system is also equipped with a new on-line auto-tuning function that adjusts the control constants according to changing motor constants during operation. Figure 5 shows operation characteristics when using the on-line tuning function. Even if the motor slip fluctuates due to temperature change, it is possible to maintain an approximately constant rotating speed. This facilitates applications such as fluid mixing machines, commercial-use washing machines, etc.

Fig.7 Appearance of keypad panel



### 3.5 Vector control with speed sensor

Vector control with speed sensor can be realized by installing a "PG feedback card" in the main body of a motor with PG. Since this can control the torque, application to printing machines, winding machines, etc. are possible. In Fig. 6, a waveform of the response at step speed setting is shown. The response to an input signal is only several milliseconds due to the high-speed CPU.

## 4. Keypad Panel

The keypad panel has been refined and made more usable than previous models. Its operability not only succeeds that of previous inverters, but is also backward compatible with other inverters. Figure 7 shows the appearance of the keypad panel, and its features are described below.

#### (1) LED/LCD display

The LED display can selectively display 13 types of data such as settings, output frequency, current, voltage, power consumption, and data at the PID control. The LCD display is enlarged and is provided with an operation guide display for manual-less operation. A scrolling display is used for explanation of the operation keys.

#### (2) Operation keys

The number of operation keys has increased from the conventional keypad panel, and with these keys, the motor can be operated in forward and reverse directions from the keypad panel. Furthermore, changeover of jogging mode and changeover of operation command (terminal/keypad panel) can be performed by key operation on the keypad panel, eliminating the need for changeover in a remote control room.

#### (3) Frequency setting

The frequency setting is displayed in the LED display part, but the value can be also set as a process value (e.g. pressure) during PID control, in addition to frequency or line speed, and the control value of the object to be controlled can be recognized at a glance.

(4) Abundant functions

The following functions can be set with this keypad panel in addition to the operation functions, monitoring functions and function setting functions.

(a) I/O check (tester function)

In addition to the analog/digital input and output tester function of the conventional inverter unit, the input and output of the option card can also be checked.

(b) Maintenance

To verify operation status of the equipment, maximum current, r.m.s current and average braking power can be checked from the operation patterns.

Accumulated operation time, inverter internal temperature, maximum current and DC link circuit voltage can be displayed and verified as maintenance information for the equipment. In addition, the life expectancy information of inverter components that wear out, such as the

main capacitor, capacitor mounted on the printed circuit board and cooling fan, can also be displayed.

(c) Copying function

A function to copy function data is provided in the keypad panel, and can be simply set up.

## 5. Conclusion

In this paper, we have presented an overview of the general-purpose inverter FRENIC5000G11S/P11S newly introduced to the market. This inverter has characteristics and functions that considerably exceed those of conventional inverters, and can be applied to a wide range of applications. We, at Fuji Electric, will continue to improve inverter characteristics and functions, including application to new fields, and to develop general-purpose inverters in response to market needs.



# FVR-C11S/S11S Series, the Compact Inverters

Kazuhiko Imamura  
Takao Ichihara  
Osamu Shiokawa

## 1. Introduction

General-purpose inverters are becoming widely used in the fields of energy saving fan-pumps, labor-saving or automation applications for industrial machines and consumer-related products. The low-capacity fan or mini-conveyor markets, characterized by light loads and variable speeds, which had been slow to adopt the general-purpose inverter because of its cost and size, has begun to use the inverters, to standardize the specifications of 50/60Hz machines and to replace magnetic contactors with contact-less devices in the main circuit. Consequently, new demand for these inverters has appeared.

In recent years, the way of dealing with environmental protection has become important. Therefore, higher harmonic reducing measures and the realization of low-noise are becoming more important for the tasks of general-purpose inverters. In order to respond to these needs, Fuji Electric has developed this new FVR-C11S/S11S series of compact type inverters.

## 2. Special Features and Specifications

An external view of the FVR-C11S series is shown in Fig. 1, and the FVR-S11S series is shown in Fig. 2.

Fig.1 External view of FVR-C11S series



## 2.1 Common features and specifications of the FVR-C11S/S11S series

### 2.1.1 Introduction of separate input and output wiring of the main terminals

For purposes of compatibility with the installation and operation of the conventional FVR-C9S series, the same attaching dimensions are employed, the separate wiring style of the main terminal as shown in Fig. 3 is utilized, and a terminal for the power factor correcting DC reactor and two ground terminals (main power supply side, motor side) are equipped as standard features. With this equipment, the wiring arrangement of upper-input and lower-output can be employed, therefore making the wiring work easier and simpler.

Further, in order to realize greater convenience for installation in cubicles, a rail-mounting base is optionally equipped on devices rated at lower than 0.75kW. Consequently the device can be fixed or loosened on the 35mm IEC compliance rails with a simple one-touch operation.

### 2.1.2 Consideration of the environment

In consideration of the environment, the following items have been adopted.

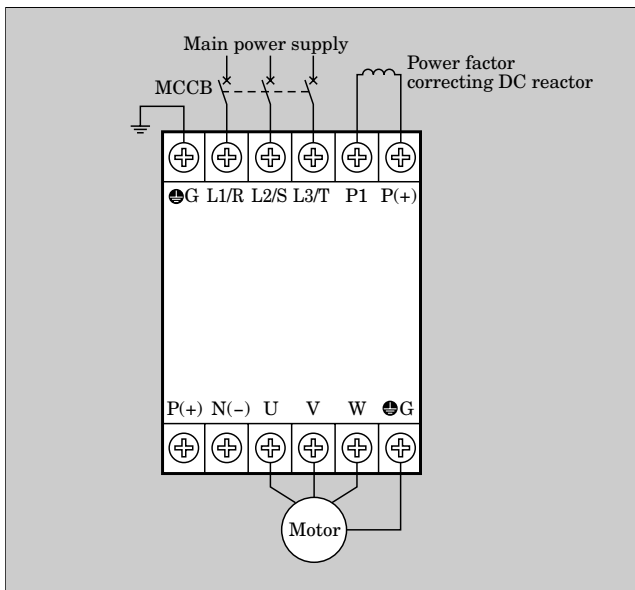
#### (1) Realization of low noise

IGBTs (insulated gate bipolar transistors), a source of noise, shall be controlled by soft-switching control which has a voltage change rate ( $dv/dt$ ) less than 5kV/ $\mu$ s, and consequently the noise shall be limited. Further, for the FVR-C11S series, a quasi-resonance

Fig.2 External view of FVR-S11S series



Fig.3 Main circuit terminal of FVR-C11S/S11S series



type switching IC is utilized in the DC-DC converter, and the generated noise shall be minimized by aligning the switching-timing with the instant of minimum voltage between the drain and source of the switching MOSFET (metal-oxide-semiconductor field-effect transistor). Thus, the noise-influence to surrounding devices such as sensors is decreased drastically.

#### (2) Easy classified disposal

As environmental protection measures, lightweight products (max. 10% less than conventional products) are realized and the number of parts (max. 20% less than conventional products) is minimized. Further, the metal-insert molding in plastics is discarded, and thus, the construction was designed with consideration for ease of classified disposal.

#### 2.1.3 Worldwide compatibility

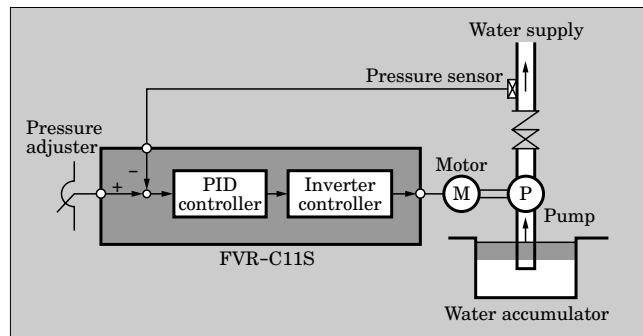
In order to cope with foreign markets or indirect exports attached to some equipment, it is necessary for the inverter to comply with foreign safety standards or the like. For that purpose, the standard models of this series conform to the UL/cUL standard and the EN standard (CE marking).

### 2.2 Features and specifications of the FVR-C11S series

Compared with the conventional FVR-C9S series, the new FVR-C11S series is enhanced with the additions of a PID (proportional, integral, derivative) control function, accumulated operating time display for maintenance, on-off control of the cooling fan, and increased functionality adopting programmable input terminal. In addition, operation by serial communication (RS-485) is possible as an option. Furthermore, the function codes are standardized within the 11 series and improved for easier understanding.

We would like to introduce here some additions and improvements compared to the conventional FVR-C9S series.

Fig.4 Application of FVR to pump system



#### 2.2.1 PID control function

For fans and pumps, the most suitable PID-control is adopted in order to maintain a smooth and stable rate of flow in accordance with the variation of pressure. In the case of the FVR-C11S series, this function is installed in the inverter as a standard so that the feedback signal from the sensor can be input directly to the inverter. In this manner, the external PID-controller required by the conventional inverter has become unnecessary, and consequently this new inverter is more economical.

Figure 4 shows an example of a constant pressure control system that utilizes an inverter. Pressure in the water supply system is detected by a sensor, and that pressure is controlled by means of inverter control of the pump speed to always be constant, regardless of variations in the supply pressure. In the low rotating speed range where water supply is less, the pump load becomes small and a big energy-saving effect is obtained.

#### 2.2.2 Accumulated operating time

By indicating the accumulated operating time of the inverter, the time for replacing electrolytic capacitors and other components that wear out can easily be estimated and consequently maintenance ability improved.

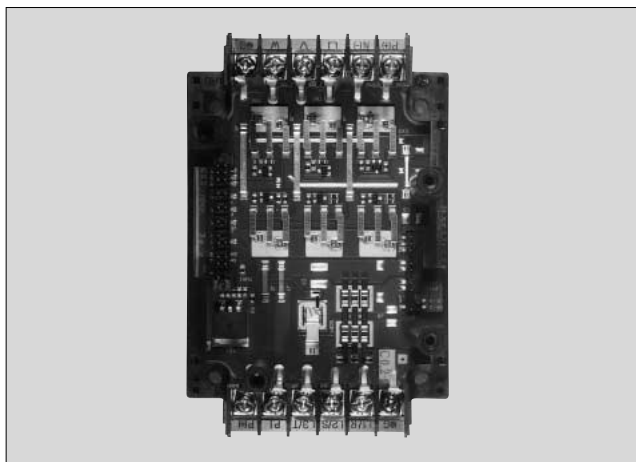
#### 2.2.3 ON/OFF control of cooling fan

Based on the relation between the heat sink temperature and operating state of the inverter, an ON/OFF control was employed in which a cooling-fan rotates only when necessary. In this manner, the life of the cooling fan was prolonged, noise decreased and greater energy saving was realized.

#### 2.2.4 Terminal function can be selected for increased functionality

The number of control circuit terminals in a small-size inverter such as the FVR-C11S series is limited by size constraints. On the other hand, a wide variety of terminal functions are requested by the user. Therefore, if limited to fixed functions, the general-purpose usefulness will be lost. For this reason, the X1, X2, X3-terminals of the FVR-C11S have multiple functions and many functions can be selected from a few terminals. A total of eight terminal functions such as

Fig.5 External view of Power Module



coast-to-stop command, external alarm, alarm reset, multi-step frequency, etc. can be selected.

### 2.2.5 Rush current reducing circuit is equipped on all types

In order to prevent the welding of contacts in a magnetic contactor by rush current at the moment of power circuit closing, a rush current reducing circuit is equipped on all inverters in this series as a standard. As a result, inverters thus equipped can utilize smaller magnetic contactors, compared to unequipped inverters.

## 2.3 Features and specifications of the FVR-S11S series

### 2.3.1 Three types of inverters are available for different applications

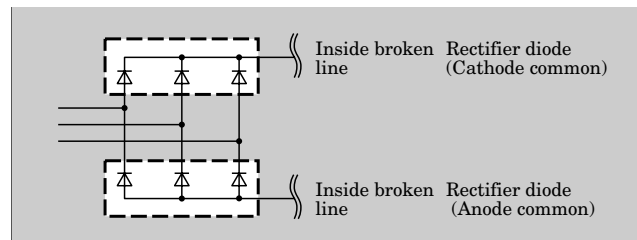
Although functions of the FVR-S11S series are limited, the following three inverter types are available according to user requests. Consequently, supply of a low cost and optimally suitable inverter is possible.

- (1) A volume type inverter (FVR-S11S-V) that sets the frequency by adjusting the volume on the inverter front and operates with turning · reversing · stopping switches.
- (2) A terminal type inverter (FVR-S11S-S) that sets the frequency by an external 0 to 5V input and operates according to the ON/OFF input of the control terminal.
- (3) A serial communication type inverter (FVR-S11S-C) that operates according to RS-485.

### 2.3.2 Simple setting of functions

This inverter series can set the following: high carrier frequency and low carrier frequency switching, torque boost, acceleration/deceleration time, base frequency, and maximum frequency including electronic thermal overload relay which protects the overload of motor. In the case of V and S type inverters, these functions can be set easily with a switch or by adjusting the volume. In the case of the C type inverter, these items can be set directly from a personal computer or programmable controller via RS-485 communication.

Fig.6 Circuit configuration of converter in FVR-C11S/S11S



## 3. New Technology Adopted in the FVR-C11S/S11S Series

### 3.1 Connection without aluminum wire bonding

The parts of a semiconductor chip such as transistors or diodes of the main circuit have been electrically connected hitherto by aluminum wire bonding technology to comprise the circuit. With this method, the substrate can be freely designed however there is a limit on how much the production time can be decreased. Therefore, Fuji Electric developed an original chip with an electrode that can be soldered, different from conventional bonded chip.

Figure 5 shows an external view of a power module in which the chip has been soldered to a metal bar directly. By adopting this new method, production time has been decreased and bonding that is more reliable than the conventional one has been realized.

### 3.2 Development of the diode chip rectifier

The general-purpose inverter has a converter in which alternative current is once converted into direct current. In the case of 3-phase input as shown in Fig. 6, this inverter is comprised of 6 diodes. In order to decrease the space occupied by parts and pursue economy, we integrated the circuit shown in the broken line of Fig. 6 into a single part, and developed a Fuji Electric original diode chip rectifier. There are two types of chips, one is the upper arm side (cathode common) and another is the lower arm side (anode common). Because of this development, smaller total equipment size and improved reliability with non-bonded connections are expected.

## 4. Conclusion

An overview of the compact type inverter FVR-C11S/S11S series has been presented.

We expect that this series will satisfy many users with its low noise operation by the utilization of a quasi-resonance type switching IC, etc. and wide variety of functions made possible.

We will continue to make efforts to develop products gentle for the environment such as by adopting lead free solder, and to realize further improvements which correspond to the needs of the market.

# FALDIC- $\alpha$ Series, the Compact and High Performance Servo Systems

Hiroyasu Arakawa  
Takashi Sakiyama  
Tsutomu Niimi

## 1. Introduction

In the market for AC servo systems, easier operation, ability to interface with various high-end devices, installation of serial encoders, enhancement of environment-proof construction, and compliance with overseas safety standards are increasingly being required in addition to smaller size, higher response and a higher degree of accuracy than had been required in the past.

The newly developed FALDIC- $\alpha$  series is an improved version of the conventional FALDIC-II series and has been introduced to the market with the goal of

creating new demand.

This paper presents an overview of the FALDIC- $\alpha$  series including its specifications and features.

## 2. Features

Figure 1 shows an external view of the FALDIC- $\alpha$  series and Fig. 2 its system configuration.

The main features are described below.

### 2.1 Higher performance

#### (1) Higher speed response

A frequency response of 500Hz (five times the previous frequency) and positioning settling time of 5ms or less were realized by using a control LSI for high-speed calculation in the current control loop and a 32-bit RISC-CPU (reduced instruction set computer-central processing unit).

#### (2) Utilization of 16-bit serial encoder

Utilization of a 16-bit serial encoder achieved resolution eight times the previous resolution. Higher accuracy and stabilized control was obtained at low speeds.

#### (3) Reduction of rotational fluctuation

Rotational fluctuation was reduced to one tenth of

Fig.1 External view of the FALDIC- $\alpha$  series



Fig.2 System configuration of the FALDIC- $\alpha$  series

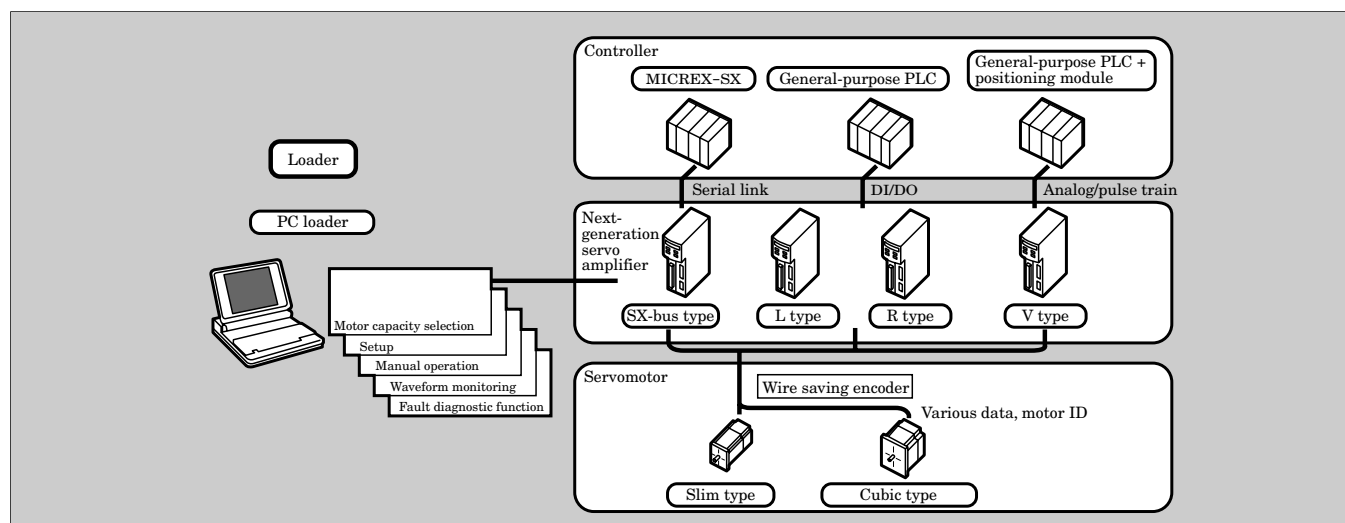


Table 1 Fundamental specifications of servo amplifiers

| Type                   |                                | RYS□□□○○-V○○                                            | RYS□□□○○-L○○                                                  | RYS□□□○○-R○○           | RYS□□□○○-OS○                     |
|------------------------|--------------------------------|---------------------------------------------------------|---------------------------------------------------------------|------------------------|----------------------------------|
| Main application       |                                | Speed control                                           | Linear positioning                                            | Indexing               | Speed control/linear positioning |
| Input power            | Voltage                        | 200 to 230V +10 to -10%                                 |                                                               |                        |                                  |
|                        | Frequency                      | 50/60 Hz                                                |                                                               |                        |                                  |
| Control specifications | Control system                 | Totally digitized sinusoidal wave PWM current control   |                                                               |                        |                                  |
|                        | Carrier frequency              | 10kHz (5kHz for some range of capacity)                 |                                                               |                        |                                  |
|                        | Feedback                       | 16-bit serial encoder                                   |                                                               |                        |                                  |
|                        | Speed control range            | 1 : 5,000                                               |                                                               |                        |                                  |
|                        | Frequency response             | 500 Hz                                                  |                                                               |                        |                                  |
|                        | Overload capacity              | 3s / 300%, 1.5s / 450%                                  |                                                               |                        |                                  |
|                        | Positioning resolution         | 16-bit (equivalent to 16,384 pulses)/revolution         |                                                               |                        |                                  |
|                        | Position control               | Absolute/incremental (selectable)                       |                                                               |                        |                                  |
| Control function       | Speed control                  | ○                                                       | ○                                                             | ○                      | ○                                |
|                        | Torque control                 | ○                                                       | —                                                             | —                      | ○                                |
|                        | Pulse train                    | ○                                                       | ○                                                             | ○                      | ○                                |
|                        | Point-to-point positioning     | —                                                       | ○                                                             | ○                      | ○                                |
|                        | Homing                         | ○                                                       | ○                                                             | ○                      | ○                                |
|                        | Positioning by external marker | ○                                                       | ○                                                             | ○                      | ○                                |
|                        | Interface specifications       | Input                                                   | No. of contacts                                               | 8 (DI/DO type)         | 21 (DI/DO type)                  |
| Analog command         |                                |                                                         | 2 channels (DI/DO type)                                       | 1 channel (DI/DO type) | —                                |
| Pulse input            |                                |                                                         | 1 channel (open collector/differential input: both available) |                        |                                  |
| Output                 |                                | No. of contacts                                         | 5 (DI/DO type)                                                | 10 (DI/DO type)        | 2 (DI/DO type)                   |
|                        |                                | Analog monitor                                          | 2 channels                                                    |                        |                                  |
|                        |                                | Pulse output                                            | 1 channel (differential output)                               |                        |                                  |
| Environment            | Temperature/humidity           | -10 to +55°C, 10 to 90% RH (free from dew condensation) |                                                               |                        |                                  |
|                        | Location/altitude              | Indoor, clean atmosphere, 1,000m or less                |                                                               |                        |                                  |

its previous value due to progress in electromagnetic field analysis technology and the reduction of motor cogging torque based on high precision machining, and higher response and higher resolution of the encoder as mentioned above.

## 2.2 Improvement in user interfaces

### (1) Development of personal computer loaders

Fuji Electric developed a loader for personal computers to support servo systems from setup to maintenance, realizing facilitated operation and maintenance.

## 2.3 Flexibility

### (1) Standard installation of wire-saving absolute (ABS) encoder

ABS encoders have been provided in the FALDIC- $\alpha$  series as a standard to eliminate the inconvenience of initial positioning (homing action) when power is turned on. This results in a wire-saving absolute system including wiring of lithium batteries contained in servo amplifiers by serial communication.

## 3. Specifications

### 3.1 Servo amplifier

The FALDIC- $\alpha$  series was intended for a capacity

range of 30W to 5kW. Servo amplifiers for servomotors up to 1.5kW are already being commercially produced, and higher capacity servo amplifiers will be introduced successively.

Table 1 shows the fundamental specifications of servo amplifiers, which are classified into the following four types.

#### (1) V type

The V type is capable of positioning operation with pulse train input, speed control operation with analog voltage input, and torque control operation.

#### (2) L type

The L type incorporates a linear positioning function in the servo amplifier, allowing positioning only with on/off signals from a high-end controller.

#### (3) R type

The R type is for rotor indexing applications, such as an ATC (automatic tool changer) or an index table.

#### (4) SX type

The SX type performs various types of motion control through high-speed serial communication with Fuji Electric's new type programmable controller (PLC) MICREX-SX.

### 3.2 Servomotor

Miniaturization of the servomotors was realized by

Table 2 Cubic motor specifications

| Motor type<br>Item                                       | GYC101DC1-S                                                       | GYC201DC1-S | GYC401DC1-S | GYC751DC1-S | GYC102DC1-S       | GYC152DC1-S |
|----------------------------------------------------------|-------------------------------------------------------------------|-------------|-------------|-------------|-------------------|-------------|
| Rated output (kW)                                        | 0.1                                                               | 0.2         | 0.4         | 0.75        | 1                 | 1.5         |
| Rated torque (N · m)                                     | 0.318                                                             | 0.637       | 1.27        | 2.38        | 3.18              | 4.78        |
| Rated speed (r/min)                                      | 3,000                                                             |             |             |             |                   |             |
| Max. speed (r/min)                                       | 5,000                                                             |             |             |             |                   |             |
| Max. torque (N · m)                                      | 0.955/1.43                                                        | 1.91/2.87   | 3.82/5.73   | 7.17/10.7   | 9.55/14.3         | 14.3/21.5   |
| Moment of inertia(kg · m <sup>2</sup> )×10 <sup>-4</sup> | 0.0583                                                            | 0.216       | 0.412       | 1.21        | 3.26              | 4.51        |
| Rated current (A)                                        | 1.0                                                               | 1.5         | 2.6         | 4.8         | 6.7               | 9.6         |
| Max. current (A)                                         | 3.0/4.5                                                           | 4.5/6.8     | 7.8/11.7    | 14.4/21.6   | 20.1/30.2         | 28.8/43.2   |
| Winding insulation class                                 | B                                                                 |             |             |             | F                 |             |
| Operation duty                                           | Continuous                                                        |             |             |             |                   |             |
| Enclosure protection                                     | Totally enclosed, self cooling (IP55)                             |             |             |             |                   |             |
| Connection terminals (motor)                             | with cables 0.3m long and connectors                              |             |             |             | Cannon connectors |             |
| Connection terminals (encoder)                           | with cables 0.3m long and connectors                              |             |             |             | Cannon connectors |             |
| Temperature detection                                    | N/A (detected by servo amp.)                                      |             |             |             |                   |             |
| Mounting                                                 | Mounted with flangesIMB5 (L51), IMV1 (L52), IMV3 (L53)            |             |             |             |                   |             |
| Shaft                                                    | Cylindrical shaft with a key                                      |             |             |             |                   |             |
| Painted color                                            | N1.5                                                              |             |             |             |                   |             |
| Detector                                                 | 16-bit serial encoder (absolute system: servo amp with a battery) |             |             |             |                   |             |
| Vibration                                                | V5 or less                                                        |             |             |             | V15 or less       |             |
| Location/altitude                                        | Indoor / 1,000m or less                                           |             |             |             |                   |             |
| Ambient temperature/humidity                             | -10 to +40°C / 90% RH or less (free from dew condensation)        |             |             |             |                   |             |
| Vibration resistance                                     | 49m/s <sup>2</sup> (5G)                                           |             |             |             |                   |             |

<Note> Values indicated to the right of the backslash ("/) in the Max. torque and Max. current rows represent values when combined with servo amplifiers one class higher in series.

the adoption of new technologies, such as high-performance cylindrical or circular-arc segment magnets, segment cores, densely embedded windings using regular windings, and resin molds or resin casts.

Installation of 16-bit wire saving serial encoders enabled smaller size, higher-speed response and a higher degree of accuracy.

The FALDIC-α series contains two different shapes of servomotors. The shape may be selected depending upon the application, installation space and other requirements.

The FALDIC-α series has improved environmental resistance as a standard to comply with IP55, and can optionally be made to comply with IP67. This series was developed with the goal of obtaining certification from overseas standards such as CE marking and UL standard, adding to the completeness of the product line.

Table 2 shows cubic motor specifications of 1.5kW or smaller capacity units. A series of servomotors with capacity ranging from 2 to 5kW is planned to be introduced successively.

### 3.3 ABS encoder

The standard mounting of encoders on servomotors was developed based on the following concepts.

(1) Higher resolution and lower vibration of motors

When using 13-bit encoders, the adjustment of

internal constants of a servo amplifier to realize a response of 500Hz causes a large amount of vibration in the servomotor, leading to mechanical resonance and noise.

Therefore, by utilizing 16-bit encoders whose resolution is as much as eight times that of 13-bit encoders for feedback control, detection ripples in the low-speed range were suppressed and control stability at low speed was dramatically improved.

(2) Standard installation of wire-saving ABS encoders

ABS encoders are installed in the FALDIC-α series as a standard to eliminate the inconvenience of initial positioning (homing action) when power is turned on or when power is restored after a power failure. The FALDIC-α series allows lithium batteries, whose serviceable life is more than five years under normal operating conditions, to be incorporated into servo amplifiers for data backup. Super capacitors are incorporated into the encoders to retain absolute data for at least one-hour even when power is turned off during maintenance work.

Table 3 shows the general specifications of encoders installed in the FALDIC-α series, and Fig. 3 their external view.

(3) Automatic identification of motor ID (type)

There are two series of motors, slim and cubic types. To utilize most effectively the performance of the motors, it is essential to operate each type with the

Table 3 Specifications of 16-bit ABS encoders

| Item                             | Specifications                                                   |
|----------------------------------|------------------------------------------------------------------|
| Resolution/revolution            | 16 bits/revolution                                               |
| Multiple turn data               | 16 bits (=65,536 revolutions)                                    |
| Data communication specification | RS-485                                                           |
| Communication speed              | 4M bits/sec                                                      |
| Max. rotation speed              | 6,000r/min                                                       |
| Backup                           | For five years with optional lithium battery                     |
| Short time backup                | For one hour with super capacitor                                |
| Storage temperature              | -20 to +85°C                                                     |
| Operation temperature            | -10 to +85°C                                                     |
| Humidity                         | 90%RH or less (free from dew condensation)                       |
| Allowable vibration              | 5G                                                               |
| Allowable shock                  | 50G                                                              |
| Fault detection                  | Overload, overheat, overvoltage, abnormal number of pulses, etc. |

appropriate constants. Servo amplifiers read and identify the motor type from serial data transferred from the encoders. This allows the motors to be operated with the most appropriate constants (already stored in advance), eliminates the need for input of the motor type and reduces the time for setup.

### 3.4 High performance

#### (1) Realization of high-speed response

Figure 4 shows the control block diagram of the FALDIC- $\alpha$  series. The CPU is comprised of a RISC-CPU, a newly-developed exclusive LSI, a control LSI and a serial PG (pulse generator).

External interface signals are input to and output from the control LSI through the connector CN1. Communication with the 16-bit serial encoder is performed through a serial PGLSI and the connector CN2 using a pair of signal cables.

In the FALDIC- $\alpha$  series, to achieve improved frequency response, digital processing is performed on the current control loop, which consists of an ACR (automatic current regulator), a PWM (pulse width modulator) and a current detector. Software processing is performed by the RISC CPU on the speed control loop, which consists of an ASR (automatic speed regulator), a feedback pulse processor and an APC (automatic position controller).

Figure 5 shows the frequency response of the FALDIC- $\alpha$  series and Fig. 6 its step response. Adoption of the RISC-CPU and realization of high-speed computing in the current control loop and speed control loop with a dedicated LSI result in a frequency response of 500Hz.

The ASR shown in Fig. 4 is provided with a real-time automatic tuning function that permits real-time optimizing adjustment of servo system parameters according to load conditions of the mechanical system during setup and actual loaded operation.

Fig.3 External view of an encoder



#### (2) Realization of smooth control at low speed

Recently, among requirements for servomotors, the most attention has been given to achieving smooth rotation at low speed, because this greatly affects the workmanship of finished products.

As described earlier, a combination of high-performance cylindrical magnets and segmented magnets is utilized for the FALDIC- $\alpha$  series. The core shape and the accuracy of segmentation and fitness exert a great effect on fundamental motor characteristics such as the induced electromagnetic voltage and cogging torque.

By optimizing materials, magnet shapes and sizes, cores and windings and by balancing the combination of magnetic loading and electrical loading through utilization of magnetic field analysis technology, rotational fluctuation in the FALDIC- $\alpha$  series has been reduced to 10r/min, one tenth as large as that of conventional motors. Figure 7 compares rotational fluctuation in the FALDIC- $\alpha$  series to that of conventional motors.

### 3.5 User support tool (PC loader)

This user-support tool runs on Windows\* 95 and has been developed with the aim of improving the efficiency of tasks required of users, such as selection of motor capacity, setup, commissioning and maintenance.

Figure 8 shows a PC screen display of a real-time trace used during setup and maintenance, allowing real-time monitoring of waveform signals such as speed and torque and logic signals such as RUN through external selection. This tool is also provided with a historical trace function that allows the monitoring of phenomenon before and after a trigger point under the condition of triggering by a certain signal change.

In addition, this tool is provided with a diagnostic function to analyze trouble that occurs during commissioning and maintenance and to indicate countermeasures to resolve the problem, leading to a reduction in restoration time.

\* Windows : A trademark of Microsoft Corporation

Fig.4 Control block diagram of the FALDIC- $\alpha$  series

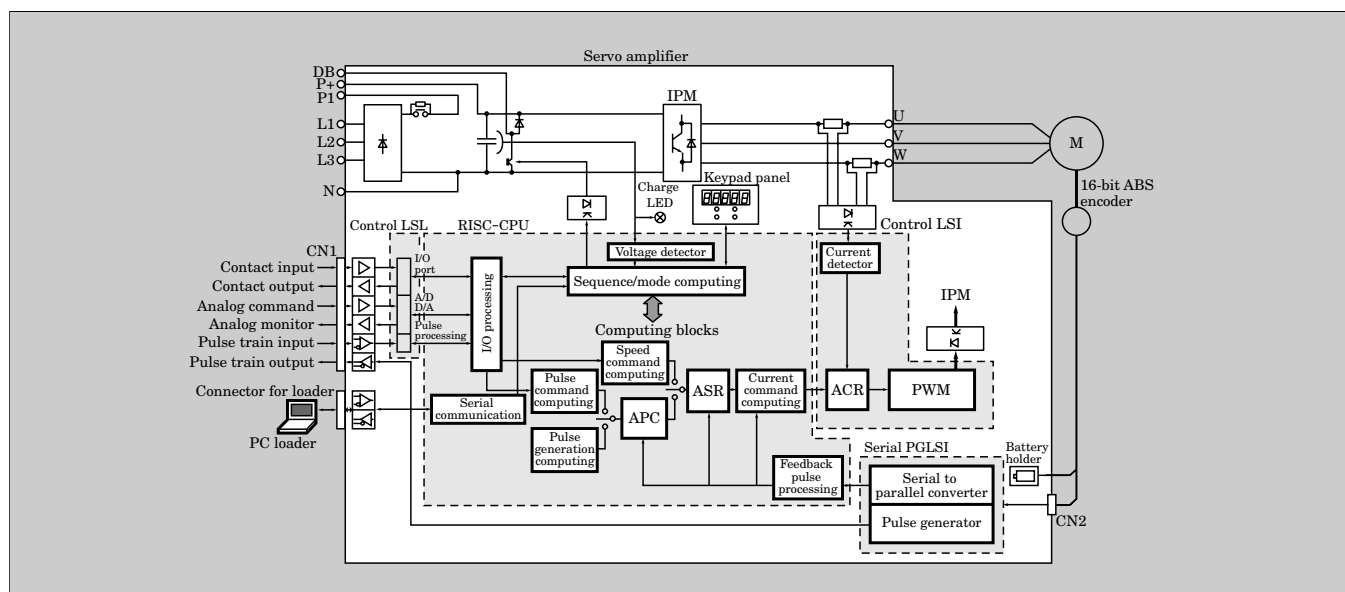


Fig.5 Frequency response

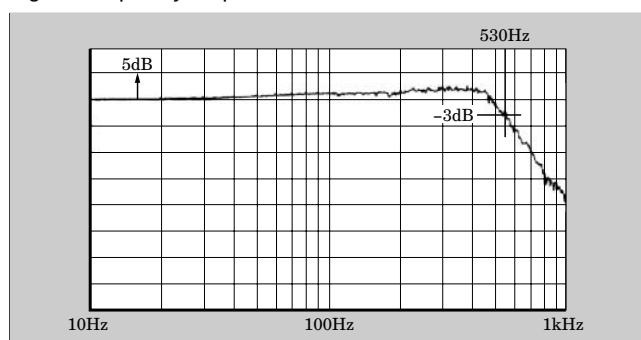
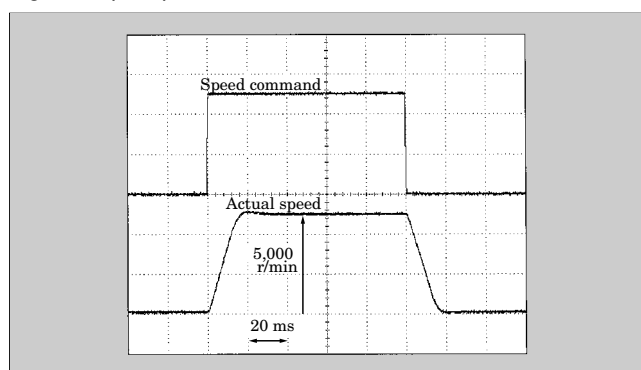


Fig.6 Step response



#### 4. Conclusion

This paper presented an overview of the FALDIC- $\alpha$  series. Fuji Electric is capable of supplying the market with an easy-to-use service system enabled by smaller-size, higher-performance motors and servo amplifiers, standard-equipped high-resolution 16-bit ABS encoders to eliminate homing action and an improved user-support function with PC loaders.

Fig.7 Rotational fluctuation characteristic

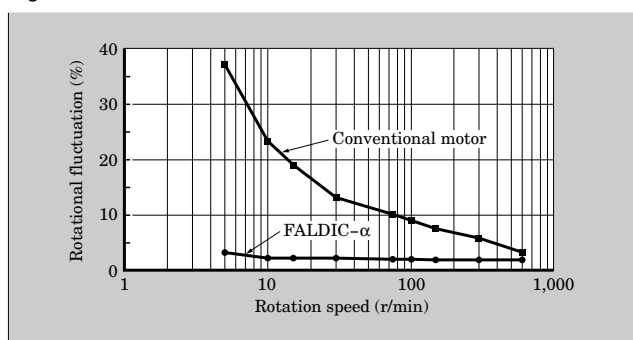
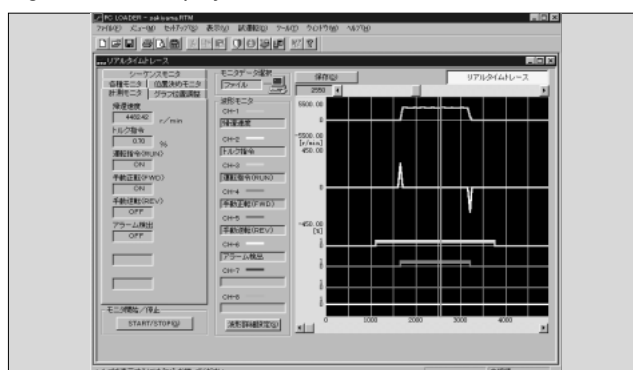


Fig.8 Screen display of real-time trace



Fuji Electric is determined to increase the capacity of the FALDIC- $\alpha$  series and to offer the series in a wider variety of shapes, such as a slim type and highly rigid type.

Fuji Electric is also determined to do its best to achieve system flexibility of the FALDIC- $\alpha$  series by pursuing higher precision positioning with encoders of improved resolution, higher performance in the extremely low speed range and improved interface functions for compatibility with open networks.

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