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MITSUBISHI ELECTRIC ADVANCE

Factory Automation Edition

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●Vol. 90/June 2000 Mitsubishi Electric **ADVANCE**

Factory Automation Edition

CONTENTS

Our cover shows several key components representative of the gathering wave of motor-drive equipment for factory automation: inverters (the FA-A500 Series, upper left), servos (the MR-J2S Series, upper right), and NC drive equipment (the MDS-B Series, lower right). Mitsubishi Electric pulls together the full range of individual technologies into close and synergistic product development. The corporation's accurate grasp of market needs is behind several major advances that promise to greatly expand the range and scale of applications. Motors are as vitally important as the means used to drive them, and closely linked development projects are currently under way.

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Overview

The Future of Motor Control in Factory Automation

*by Keiji Matsumoto**

Inverters and servos are typical of motor-drive equipment that has developed as clean, efficient and highly effective means of controlling and transforming motive power, and they have made significant contributions to factory automation. While this equipment owes much to technical progress, particularly in micro- and power electronics, there also appears to be a virtuous circle at work: market needs first encourage well-matched developments in device technology and products, and the new products in turn stimulate additional demand.

New products that have been recently introduced demonstrate an accelerating move towards miniaturization, higher performance and more sophisticated functions. Again, as enterprises become borderless, there is an increasingly urgent need to cope with the demands of globalization and to find solutions for environmental problems. This edition of "*Advance*" introduces the new technologies and products demonstrating these trends.

Motor-drive equipment comprises key components for the future improvement of productivity, and more and more of these components will be found within our factories. In seizing this opportunity, Mitsubishi Electric attaches great importance to achieving the highest possible mechanical performance, and to combining environmental friendliness with the sophistication that also ensures user friendliness. We are committed to developing the next-generation devices that will enable us to provide products satisfying our customers' needs.

**Keiji Matsumoto is General Manager of the Factory Automation Engineering Dept.*

FREQROL F500 Series Energy-Saving Inverters for Fan and Pump Motor Drives

*by Hisao Sakurai and Masahiro Kimata**

Mitsubishi Electric has developed Freqrol F500 and F500L Series inverters supporting energy-efficient operation of fan and pump motors. An optimum excitation current control program improves motor efficiency under the low-torque conditions that typify these applications. The inverters are commercially available.

The new inverters place a priority on energy efficient operation. Fig. 1 shows a photo; Table 1 lists the specifications. The inverters also offer simpler operation, reduced maintenance and low-noise design. The motors are certified to comply with both domestic and overseas safety standards.

Second-Order Deceleration Torque Patterns
The inverters' variable-frequency control program offers constant and second-order deceleration torque patterns. The latter brings the output voltage below the level of fixed-torque patterns, which conserves energy by matching the motor output with the second-order deceleration loads typical of fans.

Intelligent Energy-Saving Control
In the early nineties, the company introduced a microprocessor-based current monitor loop that tracks motor energy and minimizes the inverter output voltage. This function is suited to constant-speed operation and augments the benefits of second-order decleration patterns.

Fig. 1 Freqrol FR-F500 and F500L inverters for fan and pump control.

Table 1 Specifications of FR-F500/FR-F500L Inverters

Capacity	0.75 ~110kW/200V 0.75 ~ 375kW/400V		
Frequency range	0.5 ~120Hz		
Control methods	PWM control over a high carrier frequency, variable-frequency control, optimum excitation control		
Functions	Switchable cooling fan, PID control, 7-level speed control, simple setup mode, sink-source switching		
Parameter units	Models	FR-DUO4 (standard)	PU04 (optional 8-language support)
	Input	Up/down keys	10 key pad
	Display	—	Backlit LCD
	Copy	Yes	Yes
Options	Serial ports (one RS485 port is standard), 12-bit parallel port, analog outputs, relay output, communication packages including CC-Link, Profibus-DB and DeviceNET(TM)		
Construction	NEMA compliance	NEMA1 compliant for capacities of 22kW and under	
	Removable terminal lugs	Usable for all power capacities	
	Cooling fan	Replaceable cassette type	
	DCL connection	Available for all capacities	
Safety certification	UL, CUL, EN		

**Hisao Sakurai is with the Nagoya Works and Masahiro Kimata with Energy & Industrial Systems Center.*

Optimum Excitation Control

The optimum excitation-current control program modifies the basic variable-voltage control mode. The function monitors the motor current and modulates the output voltage boosting the induction motor efficiency in the low-torque region typical of fan and pump motor applications.

Fig. 2 shows a block diagram of the function. Maximum efficiency in induction motors operation under constant first-order flux conditions occurs when the effective and reactive components of the first-order current (I_q and I_d) are equal. First, the three-phase first-order current signal is represented by two current vectors: the excitation current (the d axis) and the torque current (the q axis). I_d and I_q are then used with the motor output frequency ω_1 to determine the appropriate first-order voltage levels $V1d$ and $V1q$ from the following relations:

$V1d = K1 \times i_d$ .... (Eq. 1)

$V1q = K2 \times i_q + K3 \times \omega_1 \times I_0^*$ .... (Eq. 2)

where $K1$ and $K2$ are the first-order resistance compensation gains for the d and q axis components, respectively, $K3$ is the excitation voltage gain and I_0^* is the excitation current command.

The second term in Eq. 2 corresponds to the control voltage provided that the motor voltage-frequency (V/f) quotient for the q axis is constant. Under this constraint, the following voltage control commands reduce to the following:

$V1d = 0$ .... (Eq. 3)

$V1q = K3 \times \omega_1 \times I_0^*$ .... (Eq. 4)

The motor input power P is given by:

$P = V \times I$

$= V1d \times i_d + V1q \times i_q$

$= K1 \times i_d^2 + K2 \times i_q^2 + K3 \times \omega_1 \times I_0^* \times i_q$

... (Eq. 5)

The first-order angular velocity ω_1 is determined by the target velocity ωr^* and the slip rate ωs as follows:

$\omega_1 = \omega_r^* + \omega_s$.. (Eq. 6)

$\omega_s = K4 \times i_q$ .... (Eq. 7)

where $K4$ is the slip rate multiplier.

Substiting Eq. 6 and 7 into Eq. 5 yields the values of the losses associated with the excitation

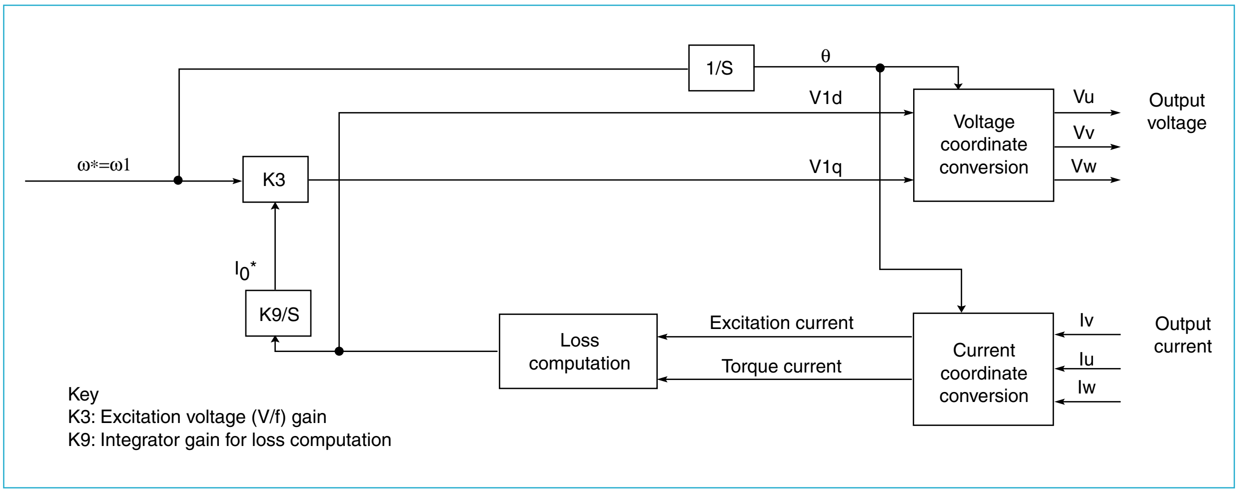


Fig. 2 Block diagram of optimum excitation control mode.

(d-axis) current and the torque (q-axis) current as follows:

$$P1_d = K5 \times I_d^2 \quad \text{(Eq. 8)}$$

$$P1_q = K8 \times I_q^2 \quad \text{(Eq. 9)}$$

where $K5$ is the loss compensation coefficient for the d axis and $K8$ the loss compensation coefficient for the q-axis.

The following expression suggests that the excitation current $I_0{}^*$ will be a minimum when

$$P1_d = P1_q.$$

$$I_0{}^* = (K9 / S) \times (P1_q - P1_d) \quad \text{(Eq. 10)}$$

where $K9$ is the integration gain and S is the integration time constant.

Eqs. 8 and 9 give the d- and q-axis loss components and Eq. 10 the excitation current command $I_0{}^*$. The values for Eq. 10 are chosen to equalize the loss components of Eqs. 8 and 9, maximizing motor efficiency.

Fig. 3 shows a comparison of motor efficiencies. The advantage of the new control mode over previous inverter control systems is especially pronounced in the low-torque region.

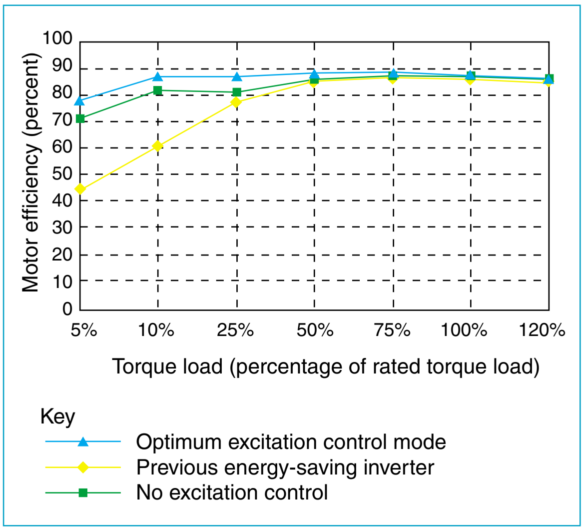


Fig. 3 Motor efficiency curves for FR-F520-3.7k inverter driving 3.7kW four-pole motor at 60Hz.

Other Advances

Two parameter-setting modes are provided. The simple mode displays only essential parameters. Tools are provided to simplify management of parameter sets. Maintenance has been simplified by removable terminal connectors and a replaceable cooling fan cassette. PWM control implemented over a high carrier frequency reduces inverter noise. CC-Link, DeviceNet(TM) and Profibus-DP packages support networking. The I/O terminals allow sink-source switching. The inverters can operate from 240 and 480V supplies and comply with UL, CUL and EN standards.

By reducing motor power consumption, these energy-saving inverters contribute to lower production of the greenhouse gases responsible for global warming. ❑

FR-E500 Series Compact High-Performance General-Purpose Inverters

*by Wataru Ikeshita and Shinzo Tomonaga**

FR-E500 series general-purpose inverters offer industry-leading performance and reliability in a compact form factor. Their features include open networking support, simpler operation and maintenance, and multinational safety standards compliance. An example is shown in Fig. 1.

Mitsubishi Electric has developed a single module containing all major inverter components: the microprocessor implementing motor control and protection functions, gate-drive circuit, the power circuit and sensors for monitoring bus voltage and output current levels. This design permits smaller inverter dimensions than are possible using off-the-shelf power modules.

Integrating the power devices with control circuitry into a single module required design to expel dissipated heat and to provide sufficient electrical isolation between the power and control circuits.

Mitsubishi Electric has pursued a systems approach to design of power, control and physical construction. Components that impact inverter size include low-loss low-VCE power devices, power module technologies, microprocessors, peripheral LSIs, cooling fan and motor design. The module plant that manufactured the devices is an affiliate of the inverter manufacturing line.

Fig. 1 An FR-E500 series inverter.

Electrical Isolation

North American and European safety standards require isolation of the power circuit from the user interface circuitry. An insulated high-speed serial communications link between the two microprocessors that control the main circuit and user interface permits aggregation of the devices in a single module (Fig. 2) without an insulated power circuit. The connector in the figure is linked by a cable to the user interface board (not shown).

Thermal design

Smaller module dimensions make it critical to design the system to minimize the junction temperature rise in the power devices. The devices were bare-chip mounted on high heat-dissipating insulation board. Simulations were conducted to optimize the positioning and arrangement of the power devices, thickness of the insulation board and heat-sink base, and the thickness and spacing of the heat-sink fins.

In previous modules, power devices were placed close together, creating heat concentrations inconsistent with optimal cooling design. More uniform distribution of heat is achieved in

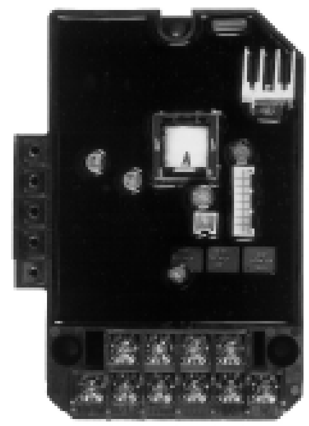


Fig. 2 The custom-developed inverter module.

**Wataru Ikeshita and Shinzo Tomonaga are with the Nagoya Works.*

the new module by potting the entire module in epoxy resin. This reduces the maximum temperature rise in power devices by as much as 30%, boosting reliability.

Insulation Design

Insulating capabilities of the power board have been augmented by slitting the board where better insulation is required and filling the slits with epoxy resin. This avoids the conventional tradeoff between insulation distance and board size, allowing the board area to be reduced by 30%. The printed-circuit board is shown in Fig. 3.

Drive Performance

FR-E500 series inverters are designed to maximize motor drive output. Ripples in torque and speed stem from errors in motor output voltage and inaccurate measurement of the output current. Better output voltage control and more accurate current detection yield gentler transitions in rotation speed and torque levels and smoother operation at low speeds. Voltage control is subject to errors related to delays imposed by the short-circuit protection interval.

Fig. 4 shows the output current detection system. The Hall-effect current sensor and DC current transformer of previous systems is replaced by a non-insulated output current detection scheme using a shunt resistor that reduces de-

Fig. 3 The printed-circuit board for the power circuit.

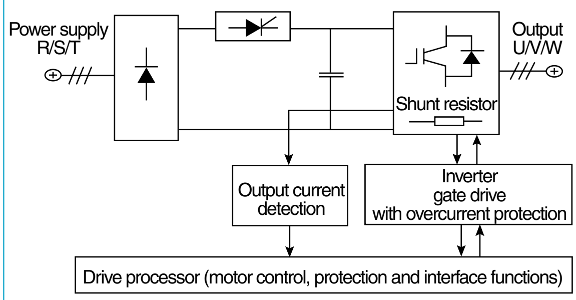
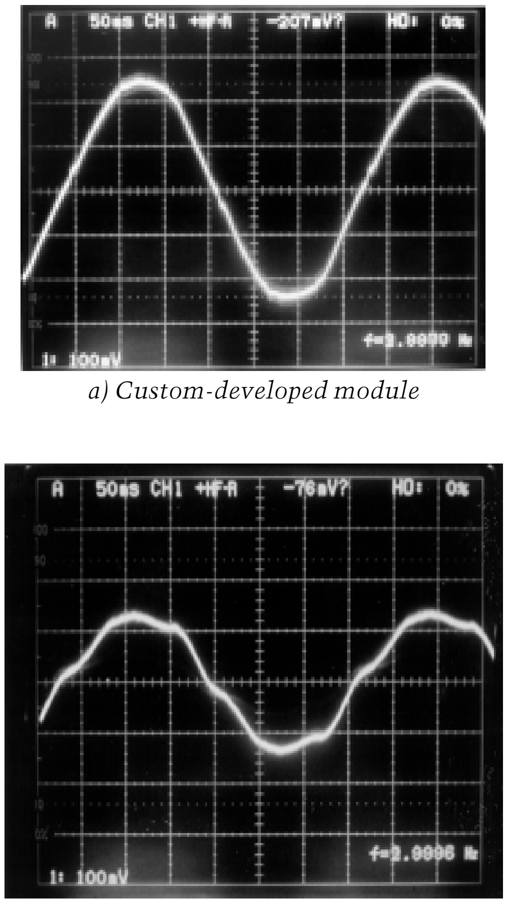


Fig. 4 The current control system.



a) Custom-developed module

b) Commercial module

Fig. 5 Output current waveforms.

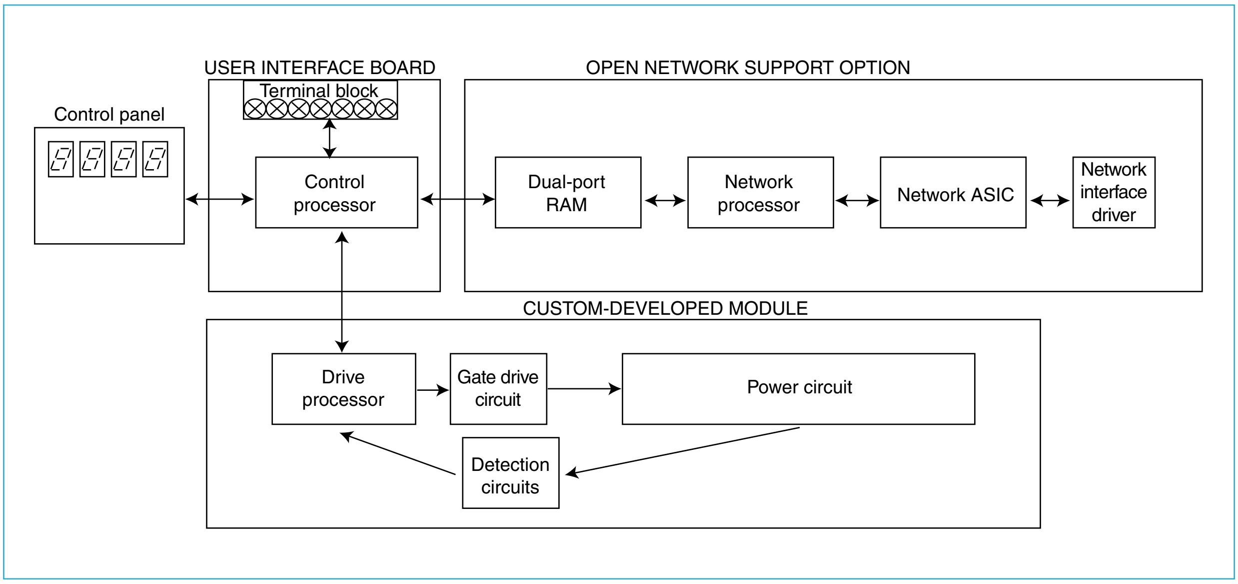


Fig. 6 Control circuit configuration.

tection delay. The drive control processor uses this fast, accurate current feedback to implement fast motor control with integrated short-circuit protection.

Output voltage control performance has been dramatically improved. Fig. 5 shows 3Hz output current waveforms when a 14.5kHz carrier frequency is used, comparing a commercially available inverter module with the Mitsubishi developed prototype.

These improvements in voltage and current control permit 150% torque output at the low speed of 1Hz.

Supplemented with our offline autotuning functions, these capabilities are sufficient to implement general-purpose flux vector control applications with motors from various vendors including installations with longer wiring runs.

Control Technology

Fig. 6 shows the basic configuration of the control system. The inverter control processing is distributed among three independent microprocessors: a control processor that handles the user interface, a drive processor that controls and protects the power devices and a network processor that implements network connectivity.

This design better distributes the computing load so that the system can sustain higher performance levels. The control and network processors are connected by dual-port RAM. The software for the network processor can be selected to suit the desired networking standard, which can include Profibus-DP, Device Net(TM) or CC-Link.

The detachable control unit is linked to the inverter using an RS485 connection. The connector also accommodates the Model FR-PU04 parameter unit or user configured computer system as top-level controller.

The cassette-mounted cooling fan provides ready access to replaceable components. Fan life is extended by operating the fan motor only when necessary.

Standard products support 240V and 480V power connections and meet UL, cUL and EC certification requirements.

These compact, modular general-purpose inverters set new standards for performance and reliability. They provide open networking support, simpler operation and maintenance, and comply with multinational safety standards. ❑

New Technologies in MR-J2 "Super" Series General-Purpose AC Servos

*by Yasushi Ikawa and Tetsuaki Nagano**

Mitsubishi Electric has developed MR-J2 "Super" series general-purpose AC servo amplifiers. The "Super" series offers superior response and encoder resolution than the base series while maintaining backwards compatibility. The new series also features an improved autotuning function.

General-purpose AC servo amps are used in a wide variety of positioning, speed-control and tension-control applications that include semiconductor manufacturing equipment, component inserting and mounting machines and machine tools. Applications have broadened as servo performance has improved.

Mitsubishi Electric launched MR-J2 series servo amplifiers in 1995. These popular units offered adaptive filtering, realtime autotuning capabilities, compact dimensions, and EC and UL safety certification.

The "Super" series offers faster response, superior encoder resolution and improved autotuning abilities while maintaining backwards compatibility with the original product line.

Fig. 1 shows a "Super" series servo amp with a servo motor. Table 1 lists servo amps and Table 2 motor products. The interface and form factor are unchanged, permitting swap-in upgrading of previous models.

Fig. 1 MR-J2 "Super" series servo amp and motor.

Improved Response

Improving the frequency response of the velocity control loop is the principal means of reducing the time required for the servo to execute a motor axis movement. Our previous servos have implemented software control of position, speed and current. In the "Super" series these functions are implemented in a 32-bit RISC processor with on-chip DSP functions. The new processor performs these calculation in one fourth of the time previously required so that the motor does not remain idle while waiting for calculations to be completed.

Fig. 2 shows the frequency response of the velocity control loop, which achieves 550Hz. This performance, combined with a highly rigid slider mechanism, enables positioning accuracy of ±10μm within a 1ms settling time.

Increased Encoder Resolution

Shortening the time taken to perform speed control calculations results in a proportional drop in the resolution of the velocity-feedback signal; furthermore, the conventional AB phase pulse-count method suffers from signal attenuation at high motor speeds. These factors can undermine posi-

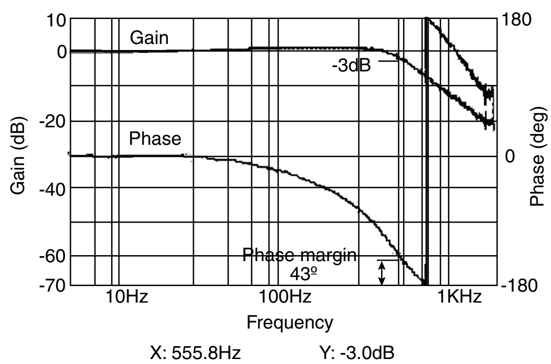


Fig. 2 Frequency response of velocity-control loop.

**Yasushi Ikawa and Tetsuaki Nagano are with the Nagoya Works.*

Table 1 Servo Amplifiers

Type designation (all beginning "MR-J2S-")	10A	20A	40A	60A	100A	200A	350A
Output power	100W	200W	400W	600W	1KW	2KW	3.5KW
Power supply	3-phase, 200~230VAC, 50 or 60Hz; 1-phase 230VAC, 50 or 60Hz						
Control system	Sinewave PWM current control with position and velocity control functions and adaptive filtering						
Frequency response of speed control loop	550Hz						
Autotuning	Realtime						
Protective functions	Automatic shutoff in response to overcurrent, overvoltage, motor overheating, overload, undervoltage, overspeed and excessive droop pulses						
Control modes	Position, velocity, torque						
Position control capabilities							
Max. input pulse frequency	500pps for differential receiver circuit, 200pps for open collector circuit						
Resolution	131,072 pulses/revolution						
In-position control range	0~±10,000 command pulses						
Velocity control capabilities							
Control range	1:5,000 (1:2,000 with external analog speed setting)						
Command input	0~±10VDC (rated speed)						
Torque control capabilities							
Command input	0~±8VDC (maximum torque)						
Structure	Open						

Table 2 Servo Motors

Type	Features	Rated speed	Output
HC-MFS	Small power, ultralow inertia	3,000rpm	50~750W
HC-KFS	Small power, low inertia	3,000rpm	50~750W
HC-SFS	Medium power, medium inertia	1,000rpm	800W~3kW
		2,000rpm	500W~3.5kW
		3,000rpm	500W~3.5kW
HC-RFS	Medium power, low inertia	3,000rpm	1~2kW
HC-UFS	Medium power, flat type	2,000rpm	750W~2kW
	Small power, flat type	3,000rpm	100~750W

tioning reliability. This pulse-count implementation also entails complicated motor assembly and adjustment procedures.

As an alternative method of maintaining accuracy during high-speed operation, we have increased the axial position encoder resolution by a factor of 16—from 8,192 to 131,072 pulses/revolution—in all of our motors. This improvement is accomplished without a change in the physical encoder mechanism; instead, a microprocessor interpolates the signals to resolve angle-increment data accurately even during high-speed operation.

High Level Realtime Autotuning

The "Super" series features a more sophisticated realtime autotuning function than the original

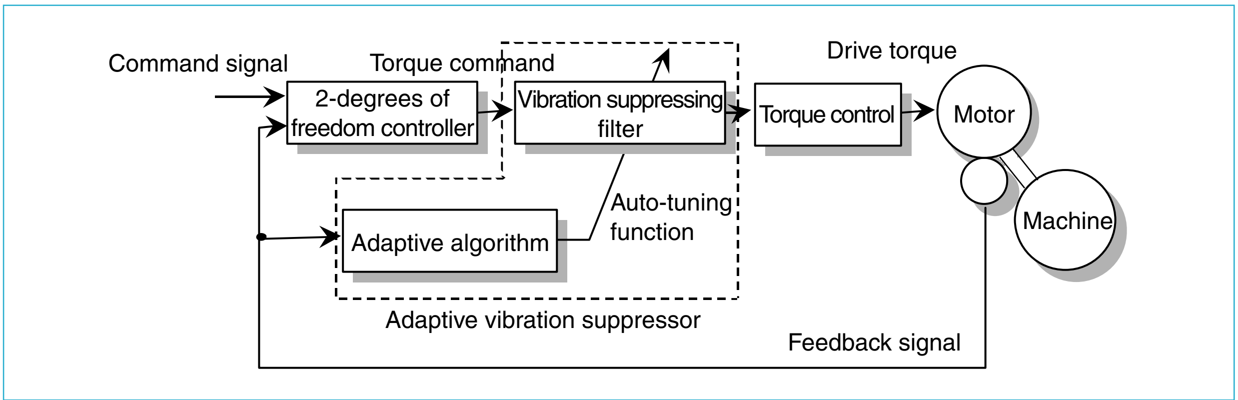
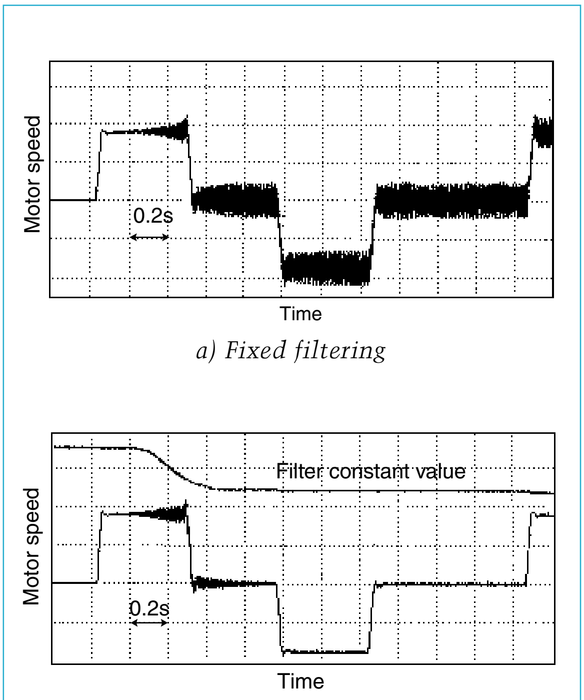


Fig. 3 Block diagram of adaptive vibration suppressor.

series. The load inertia estimate is much more accurate, expanding the range of applications for which the autotuning function is suited. This function is treated in depth in the Technical Highlights section of this issue.



a) Fixed filtering

b) Adaptive filtering

Fig. 4 Vibration suppression.

Adaptive Vibration Control

All mechanical systems have a resonant frequency associated with their stiffness. This makes it difficult to secure the required mechanical response without vibration when using higher gains. These resonances are typically damped by incorporating notch filters for the particular control parameter, but this approach addresses neither the individual variations among machines, nor the changes that occur in a given machine over time.

The "Super" series has a much improved adaptive vibration control system. Fig. 3 shows its configuration. The adaptive filter adjusts its characteristics in realtime to minimize the resonant frequency component of the feedback signal: the filter coefficient changes in response to the level of ringing. This adaptive character enables the filter to track changes in the machine's resonant frequency over time and under various load conditions. Its dynamic character largely eliminates the need for adjustment. Fig. 4 shows how dramatically this adaptive filtering scheme reduces ringing in response to speed changes when a motor drives a lead-screw drive table.

The MR-J2 "Super" series servos contribute to better performance of the entire mechanical system. Development plans call for increases in capacity and emphasis on positioning capabilities. ❑

A Fast, High-Accuracy Linear Servo System

*by Mitsuyasu Kachi and Kazuhiko Tsutsui**

Linear motors promise to extend the high-speed drive capabilities of machine tools. Mitsubishi Electric has developed a high-gain linear servo drive system that is dramatically faster and more accurate than conventional-motor servo systems. The system's faster positioning response reduces manufacturing times, while enhanced positioning accuracy reduces surface roughness by a factor of three, often eliminating the need for subsequent finishing processes.

Fig. 1 Linear servo motor.

Linear motor drive systems promise to overcome the performance limitations of conventional motor drive systems. Mitsubishi Electric has been developing linear motor drive systems for several years targeting leading-edge manufacturing applications. This article reports on the company's linear motor servo system.

Fig. 1 shows the company's LM series, which includes seven linear motors. Fig. 2 shows the servo drive panel, Fig. 3 the basic system configuration.

Fig. 2 High-gain servo drive.

Servo drive Model MDS-B-V14L enables dramatically faster positioning using the new linear motors. This technology base was used to develop two servo drives for conventional rotary motors: Models MDS-B-V14 and MDS-B-V24. A linear scale used to provide data for position and speed feedback loops. Applications requiring use of relative linear scales can be supported using the standard linear scale with Model MDS-B-HR high-resolution scale interface unit and Model MDS-B-MD magnetic detector.

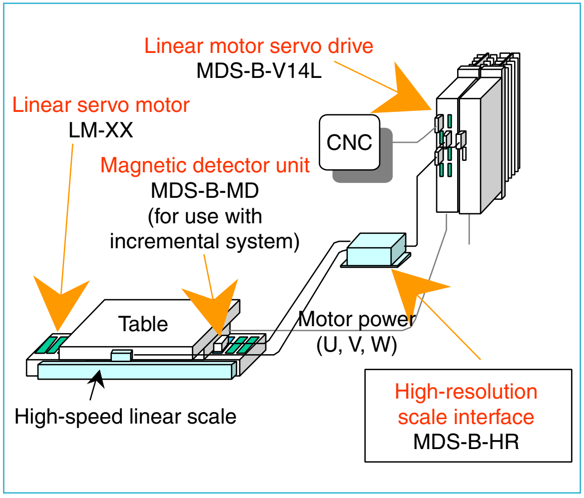


Fig. 3 Basic system configuration.

Technology Issues

IMPROVED DYNAMIC RIGIDITY. Linear-motor drive systems can operate a linear mechanism such as a table directly, without the intermediary of a ball screw drive or similar mechanical transformer required with a rotary motor. The simpler mechanism has the disadvantage of lower dynamic rigidity because the motor is directly affected by the reactive forces of machining.

SUPPRESSION OF MECHANICAL RESONANCES. Linear motor systems are more subject to me-

*Mitsuyasu Kachi and Kazuhiko Tsutsui are with the Nagoya Works.

chanical resonances than conventional drives because they are designed for higher speeds and accelerations than conventional systems and because the feedback loops for both speed and position are based on motion of the machine edge.

IMPROVED TRACKING ACCURACY DURING HIGH-SPEED MACHINING. It is difficult to maintain positioning accuracy during high-speed machining due to the large reaction forces involved.

GREATER MOTOR COOLING POWER. With the linear motor mounted directly on the table, heat released by motor operation can lead to undesired thermal expansion effects in the table and workpiece.

Servo Gain and Frequency Response

Higher servo gain addresses the first three issues. Higher servo gain in Model MDS-B-V14L was achieved by a combination of hardware and software improvements, along with shorter lag times for each of the control loops that help improves suppression of mechanical resonances.

Model MDS-B-V14L features original high-speed processing circuitry capable of performing computation-intensive current loop control alongside mechanical resonance suppression. The frequency response of the current loop has been improved by a factor of three, yielding a two to threefold improvement in the frequency response of the velocity and position loops for the motor operating in isolation.

This fast processing, coupled with a fast ADC and automatic conversion circuits quadruples the processing power available for the current loop, giving this servo the shortest current-control processing delay in the industry, with improved frequency response in the velocity and position control loops as well.

Software improvements have trimmed the lag time between current detector output and PWM output to 10μs. The lag time between the velocity feedback to the voltage command for the PWM has also been reduced.

Effects of High Gain Servo Drive

Fig. 4 shows the accuracy of a circular path traveled using a high-gain servo drive. Improved frequency response in the current, velocity and position control loops reduces surface roughness by a factor of three during low-speed movement

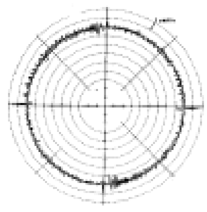
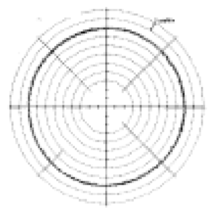
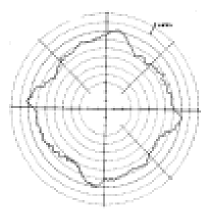
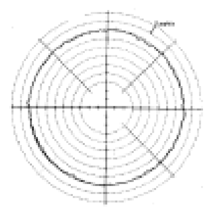
	Previous amplifier (MDS-B-V1)		High-gain amplifier (MDS-B-V14)	
Position loop gain	47 rad/s		100 rad/s	
Medium speed	F3m/min		R100mm(1μm/div)	
Accuracy	1.7μm		0.5μm	
Spike size	2.3μm		0.5μm	
High speed	F50m/min		R100mm(2μm/div)	
Accuracy	4.9μm		1.1μm	

Fig. 4 Improvements in high-gain servo drives.

Table 1 Technical Advances and the Issues They Resolve

Issue	Solution	Improvement
Dynamic rigidity	Reduce lag time in servo control processors; increase resolution of position and velocity feedback data	* Twofold improvement in dynamic rigidity * Threefold increase in current loop frequency response * Two- to three-fold increase in velocity and position loop frequency response * 12.5 fold increase in velocity and position feedback resolution
Suppression of mechanical resonance	Reduce lag time in servo control processors; improve mechanical resonance filtering	
Tracking accuracy at high feed speeds	Solved by higher gain (above)	* Threefold reduction in surface roughness * Fourfold improvement in tracking accuracy at high feed speeds * Fourfold reduction in shape distortion
Linear motor cooling design	Larger radiation area, review of thermal propagation path	* Temperature rise at motor attachments reduced by half

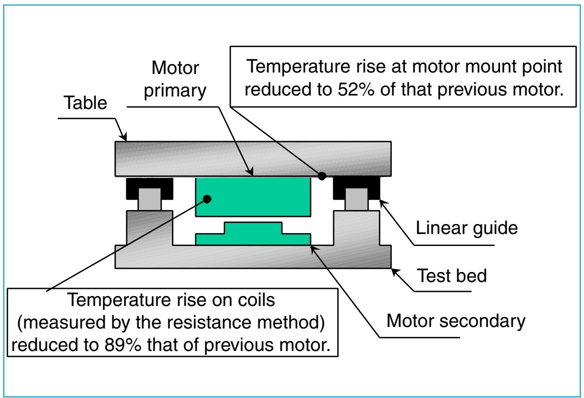


Fig. 5 Temperature rise test for a linear servo motor.

and reduces tracking error during high-speed operation by a factor of four. These improvements confirm the promise of linear motor servo drive systems.

Powerfully Cooled Linear Servo Motor

Further increases in accuracy and productivity of numerically controlled linear-motor servo systems will require better cooling and more even temperature distribution near the motor coils, see Fig. 5.

Mitsubishi Electric has developed and evaluated an enhanced cooling design that reduces the coil temperature rise (determined by the resistance method) 11% below a previous motor design while halving the temperature rise on the table surface near the motor attachments.

Table 1 summarizes the project's technical accomplishments. An early version of the linear servo system presented here was used by Toyoda Machine Works,Ltd., in a system that earned one of the Nikkan Kougyou Newspaper's top-ten awards in 1998. This article marks the launch of commercial products using linear servo technology. Mitsubishi Electric is committed to continued increases in the performance of these systems and further cost reductions. ❑

Energy-Saving Induction Motors

*by Hitoshi Yoshino and Yuji Kurata**

Mitsubishi Electric has developed Super Line Eco-Series three-phase induction motors to meet needs for improved control and energy savings. In addition to achieving the highest efficiency in the industry, the inverter-controlled motors offer enhanced capabilities for fixed-torque low-speed operation, extended bearing life, and excellent performance under humid conditions.

Fig. 1 Super Line Eco-Series motors.

Fig. 1 shows two of the motors. The totally enclosed fan-cooled designs feature outputs of 0.2~55kW and frame sizes from 63M to 225S. Two-, four- and six-pole designs are available. Four-pole designs are available with outputs to 45kW.

The motors offer the world's highest efficiency, exceeding the efficiency recommendations of both domestic JEMA and US EP Act standards for 200V motors. The frames for all models are made from welded steel plate that contributes to higher efficiency while reducing size and weight. Advanced inverter torque vector control permits the motors to operate continuously under fixed-torque conditions at speeds as low as one-tenth of rated speed.

The motors are designed to function reliably under conditions of high humidity. Bearing life has been extended by two factors: a harder bracket material reduces creep by a factor of four compared to previous motors, while the predicted grease life has been boosted by a factor of 2.5.

The average motor noise is 3dBA below previous motors with vibration amplitude under 15µm. The motor mount design follows industry standards to facilitate retrofitting and upgrading.

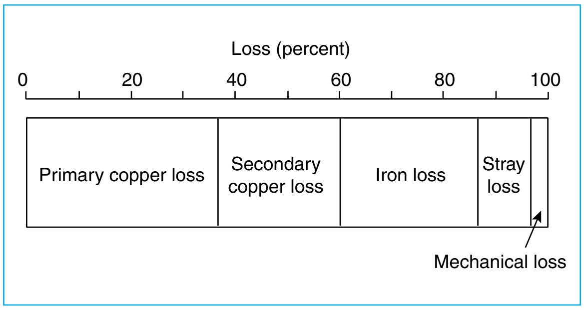


Fig. 2 Loss components for a totally enclosed fan-cooled 3.7kW 4-pole 200V 50Hz motor.

Technology for Efficiency

Fig. 2 illustrates the components of energy loss in induction motors. They include primary resistance losses in the copper rotor windings, secondary (stator) resistance losses, magnetic energy dissipated in the motor's iron components, various mechanical losses and stray losses. The following paragraphs describe how total losses have been reduced by 20~30%, leading to the highest efficiency in the industry (see Fig. 3.)

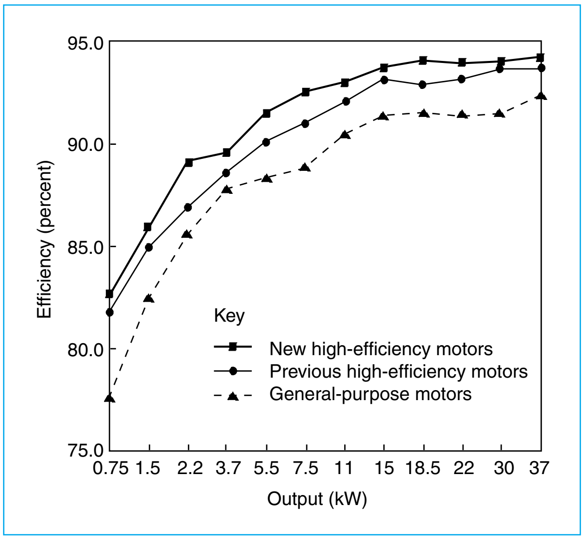


Fig. 3 Efficiency comparison for Mitsubishi Electric 4-pole, 200V, 50Hz motors using the circle diagram method (JIS C4207)

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PRIMARY AND SECONDARY RESISTANCE LOSS. Reductions in electrical resistance are the key to minimizing these losses since the power dissipated in a conductor is expressed as I^2R, where I is the current and R the electrical resistance. Resistance losses have been cut by 10~30% through two improvements.

First, a high-flux-density low-loss laminate iron core material was developed, boosting the flux density in the magnetic flux passageway and especially in the slot. Second, a new winding machine packs slot windings closer together, while a new winding method has reduced the winding length and coil end length.

IRON LOSSES. These losses are the result of energy dissipated when the motor's rotating magnetic field is applied to the stator core. The low-loss, high flux density material developed for the status core reduces motor size while boosting efficiency. Fig. 4 shows the relationship between power loss and magnetic flux density for conventional and new core materials.

The original welded steel frame system used for all models weighs less than comparable cast frames without the efficiency tradeoff and power factor shortcomings of nonmagnetic aluminum frames.

STRAY LOSSES. Stray losses are the losses that remain after the primary (copper) and secondary losses, iron losses and mechanical losses are accounted for. The largest factor in stray losses is harmonic energies that are generated when the motor operates under load. Some of these energies are dissipated as currents in the copper windings, harmonic flux components in the iron components, leakage in the laminate core, and eddy currents in the rotor and stator.

Stray losses were reduced by 50% through extensive mathematical simulations and prototype tests that determined the optimum slot combination ratio, air gap length and rotor skew.

MECHANICAL LOSSES. These losses include friction in the motor bearings and windage losses of the cooling. A low-loss fan and other measures minimize their effects.

Ruggedizing

WINDINGS DURABILITY. The motor windings are coated with a specially developed fast-curing varnish that mechanically anchors the windings while maintaining insulation performance in damp or dusty environments. The varnish also resists heat. This improved protection permits

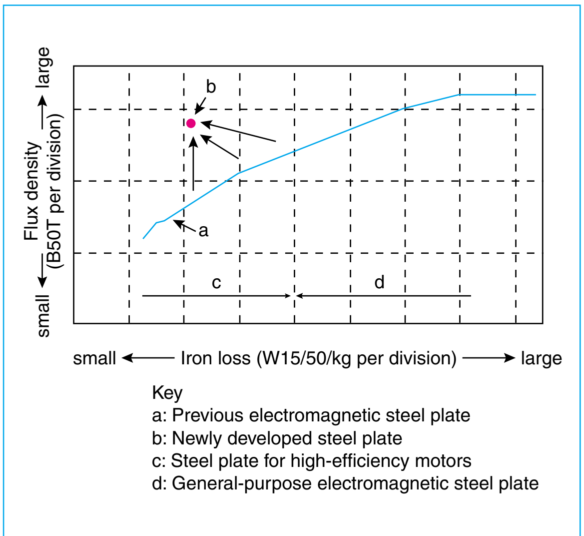


Fig. 4 Iron loss vs. magnetic flux density for electromagnetic steel plate.

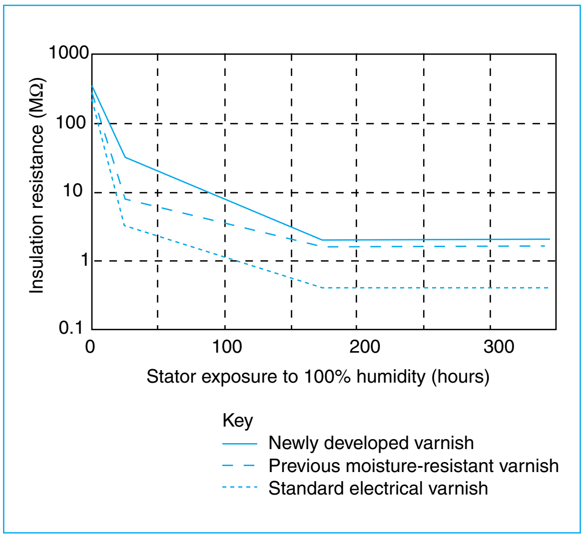


Fig. 5 Insulation performance under damp, dusty conditions.

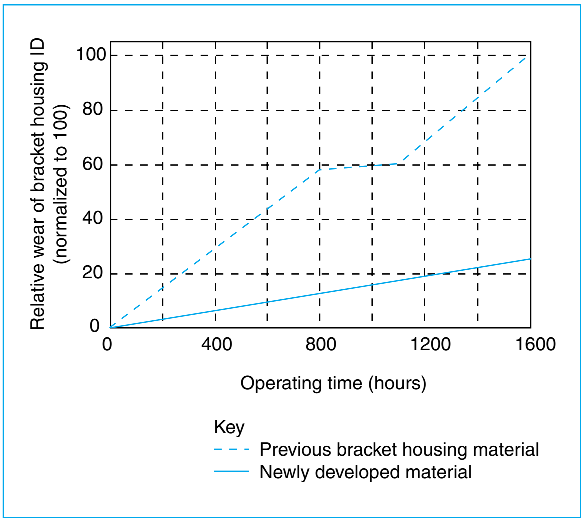


Fig. 6 Creep measured in bracket housing.

standard-specification motors to be applied in tropical environments. Fig. 5 shows the results of environmental stress testing on insulation performance. The test consisted of exposing a 4-pole 3.7kW stator to a high level of dust in an atmosphere of 100% humidity. Insulation resistance was measured periodically.

MOTOR BEARINGS. A new low-friction grease was developed for the motor bearings. Thanks to its improved heat resistance and lower abrasion torques, the grease permits bearings to operate 2.5 times longer between servicings. A harder material used for the bracket housing reduces creep. Fig. 6 shows the test results. Wear in a 4-pole 3.7kW motor was deliberately accelerated by attaching an unbalanced weight to the shaft end and operating the motor continuously. Creep measurements were taken periodically.

The new motors were designed for reduced environmental impact over the entire life cycle: The energy cost of frame fabrication is lower. Improved environmental durability and longer service intervals reduce maintenance costs. And finally, the compact and lightweight design uses materials sparingly, reducing the costs of transport and decommissioning. ❑

Interior Magnet Permanent Motors & Drive Technologies

*by Toshiyuki Kaitani and Hiroki Matsubara**

This report introduces the magnetic and mechanical design of interior permanent magnet (IPM) motors, and describes an original sensorless drive control system. The motors exhibit excellent torque-speed characteristics over a 1:10 operating region while tests at 7,200rpm indicate good torque-load response. Since a large portion of the electrical power used in manufacturing is spent driving electric motors, improvements in motor efficiency are essential to reducing power use. There is also a continuing demand for motor size and weight reductions. The IPM motors described here offer advances on both of these fronts.

Motor Design

Fig. 1 shows the rotor design of a typical IPM motor. The torque T on the d-q axis, which is fixed with respect to the rotor magnets, is given by the following:

$$T = Pn \cdot [\Phi a \cdot iq + (Ld - Lq)\, id \cdot iq] \quad \text{................ Eq. 1}$$

where Pn is the number of pole pairs; Φa is the magnetic-flux leakage; id and iq are the d- and q-axis components of the armature current; and Ld and Lq are the d- and q-axis components of the armature self-inductance.

The first term expresses the magnetic torque, the second term the reluctance torque caused by the inductance differential. Our smaller, lighter, more efficient design derives from effective use of the reluctance torque component.

IPM motors offer many advantages over induction motors:

- Overall efficiency is higher, since the rotor losses are close to zero.
- Effective use of the reluctance torque maintains high efficiency at both low- and high-speed extremes.

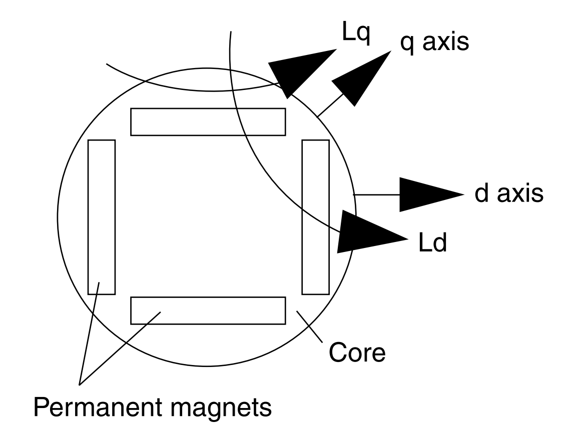


Fig. 1 Basic elements of an IPM motor.

- The smaller losses permit a reduction in motor thermal capacity, leading to lower size and weight.
- The smaller motor size reduces the moment of inertia, raising frequency with which speeds can be changed.
- Use of flux weakening control based on salient pole behavior supports a wider range of speeds at any given output level.

IPM motors are also superior to surface permanent magnet motors: Use of salient pole behavior permits sensorless control with benefits of reliability, tolerance of environmental extremes, and simpler maintenance. Further, embedding the magnets in the rotor core yields a simpler, stronger mount that supports high operating speeds.

Design Methodologies

Extensive magnetic flux analysis was performed to optimize the motor's magnetic circuit, while structural analysis was used to improve the mechanical design. The stator incorporates high-density winding and manufacturing technologies.

Leakage flux components appear between the permanent magnets embedded in the magnetic core material. This has been minimized by thinning the core material between the magnets so that saturation occurs. Saturation limits the flux magnitude.

The core material must serve as a secure mechanical anchor for the magnets while also providing the desired magnetic behavior. This requires a tradeoff between the core's structural and magnetic properties.

Fig. 2 shows the magnetic flux distribution of a typical IPM motor. The motor shape was designed to optimize magnetic characteristics and thereby minimize use of permanent mag-

**Toshiyuki Kaitani and Hiroki Matsubara are with the Nagoya Works.*

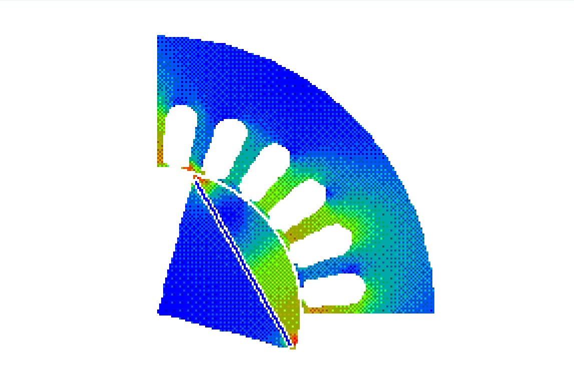


Fig. 2 Magnetic flux distribution.

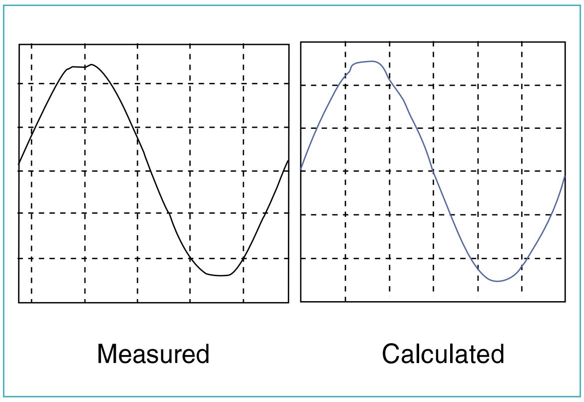


Fig. 3 Back EMF waveform.

net material—one of the motor's more costly components. The design also reduces the cogging torque.

Fig. 3 shows the predicted and measured back EMF waveforms, indicating a high degree of analytical accuracy. The ability to predict the EMF waveform accurately has made it possible to achieve a sinusoidal waveform that minimizes loss.

Sensorless Drive Technology

Synchronous motors generally employ a position sensor to support position-based control algorithms. The authors have introduced a sensorless position sensing method for this application. The system permits use of an inverter control system sharing the variable-speed operation and easy implementation of inverter-controlled induction motor drive systems.

The voltage formula for IPM motors is given by the following:

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} R+pLd & -\omega Lq \\ \omega Ld & P+pLq \end{bmatrix} \begin{bmatrix} id \\ iq \end{bmatrix} + \begin{bmatrix} 0 \\ \omega\Phi a \end{bmatrix} \quad \text{... Eq.2}$$

where Vd and Vq are the d and q components of the terminal voltage, ω is the electrical angular velocity, R is the armature resistance and p represents the differential operator d/dt.

The Vd and Vq values are the sum of one term proportional to the current and another term proportional to the motor speed. Sensorless operation is achieved by controlling Vd and Vq as follows:

$$\begin{aligned} Vd &= Kd \cdot id + Vcd \\ Vq &= Kq \cdot iq + Kv \cdot \omega_1 + Vcq \end{aligned} \quad \text{.......................... Eq.3}$$

where Kd and Kq are the resistance compensation gain for the d- and q-axis, Kv is the back EMF voltage compensation gain, Vcd and Vcq are the stabilizing voltages for the two axes, and ω_1 is the output frequency.

The speed compensation term ω_T is calculated from the torque transients when a speed command ω^* is applied, so that the following expression for ω_1 yields results in stable motor operation:

$$\omega_1 = \omega^* + \omega_T \quad \text{...... Eq.4}$$

The speed fluctuation ratio can be held to zero without sensor-based control by synchronizing the motor rotation speed with the output frequency and zeroing ω_T under constant torque conditions.

Estimating Rotor Position at Standstill

Achieving smooth startup of synchronous IPM motors requires a known initial rotor position. A system was developed that can make this determination over a brief interval immediately preceding motor startup. Fig. 4 shows its accuracy.

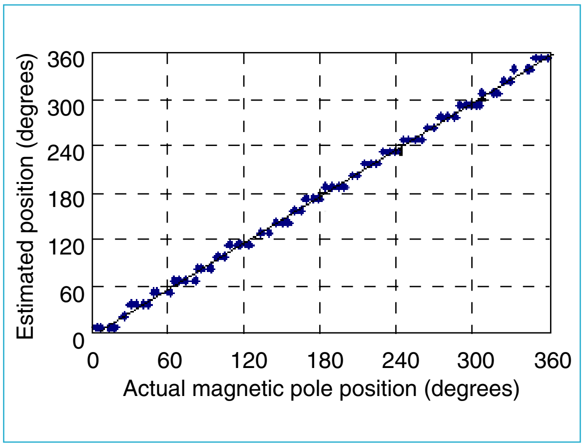


Fig. 4 Motor position detection at standstill.

Performance Evaluation

Fig. 5 shows the motor torque *vs.* speed characteristics for a 7,200rpm motor. The motor exhibits excellent torque availability from 720~7,200rpm, the typical 1:10 operating region.

Fig. 6 shows the motor's speed and torque response when 100% step torque loads are applied during 7,200rpm operation. The motor exhibits excellent stability.

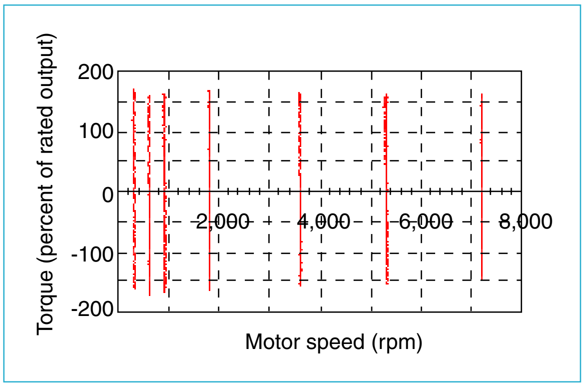


Fig. 5 Torque vs. speed characteristics.

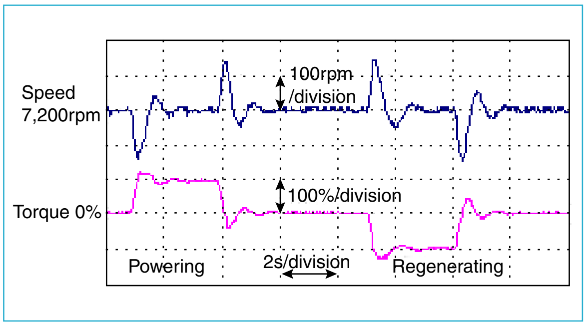


Fig. 6 Motor response to torque loading.

Work is continuing toward developing still smaller, more powerful and more efficient motors, and applying these technologies in commercial drive products. ❑

HS Series Intelligent Servo Motors

*by Yoji Tsutsumishita**

Mitsubishi Electric has developed intelligent servo motors with built-in amplifiers for 200W to 2kW applications with MELDAS numerical control equipment. This approach has the advantages of smaller power distribution panels, self-cooled design, lighter infrastructure (no hydraulic or air lines) less wiring and lower energy use with reduced environmental impact while offering higher accuracy and enhanced functions.

AC servo systems are getting smaller even as their performance improves. In the smaller amplifiers, size reductions appear to be limited only by the mounting area for the connectors and switches.

Although servos are increasingly used in manufacturing systems, hydraulic and pneumatic equipment is still widely used. We feel that the use of electric motors will further increase, reflecting environmental concerns, energy efficiency concerns, and desire for more general utility in manufacturing equipment.

Fig. 1 HS series intelligent servo motors: left 750W, right 200W.

A significant issue for buyers seeking to upgrade an existing line is the additional installation space for a servo amplifier. To facilitate this changeover Mitsubishi Electric has developed intelligent servo motors—motors with integrated servo amplifiers. The company has developed eight motors with capacities of 200W~2kW that operate under MELDAS numerical control equipment. A 0.75kW and a 0.2kW unit are shown in Fig. 1.

The power panels can be smaller, since they do not need to accommodate the amplifiers. A single cable carries power and signal wiring for each motor. A manufacturing line could install the motor in a line without modifying the existing power panel. Typical specifications are listed in Table 1.

Table 1 Specifications

	Low inertia			Medium inertia				
Model	HS-MF23	HS-RF43	HS-RF73	HS-SF52	HS-SF53	HS-SF102	HS-SF103	HS-SF202
Rated output	200W	400W	750W	500W	500W	1kW	1kW	2kW
Rated speed (rpm)	3,000	3,000	3,000	2,000	3,000	2,000	3,000	2,000
Max. torque (N.m)	1.92	3.18	5.67	11.8	8.82	21.6	16.7	41.7
Moment of inertia ($kg.cm^2$)	0.089	0.8	1.5	6.6	6.6	13.6	13.6	42.5
Encoder resolution (pulses/rev)	8,000	100,000						
Encoder method	Absolute position detection							
Power supply	200~230VAC single phase	200~230VAC 3-phase						
Mounting area	60 x 60mm	100 x 100mm	100 x 100mm	130 x 130mm	130 x 130mm	130 x 130mm	130 x 130mm	176 x 176mm
Dimensions (L x H)	178 x 101mm	204 x 174mm	222 x 174mm	232 x 216mm	232 x 216mm	257 x 216mm	257 x 216mm	277 x 267mm
Construction	Fully enclosed with passive cooling							

**Yoji Tsutsumishita is with the Nagoya Works.*

System Configuration
Fig. 2 compares conventional and intelligent-servo-motor-based NC systems. Use of intelligent servo motors saves space in the control panel and simplifies wiring. A single interface board installed in the NC equipment reliably implements communications with the motors. The board can register ID numbers to facilitate logging.

Motor Construction
Rotor and stator designs were taken from HC series motors that use high-performance magnets and high-density winding to achieve their high-performance within compact dimensions. The encoder and amplifier are manufactured as a single unit that can be removed from the motor for storage. The unit includes power modules and boards for overall control, encoder processing and main circuit control. Motor construction is shown in Fig. 3.

Providing sufficient power dissipation was a central design issue because the unit was to be enclosed and only passive cooling provided. We reduced the temperature differential between the chassis and board-mounted components by using silicone gel sheets: One was placed between the power circuit's electrolytic capacitor and the chassis. Another was placed atop an aluminum plate to provide a heat-conductive path for the microprocessor and power devices in the switching power supply. The aluminum plate provides shielding between the power and control electronics while dissipating heat from the control electronics to the chassis and atmosphere.

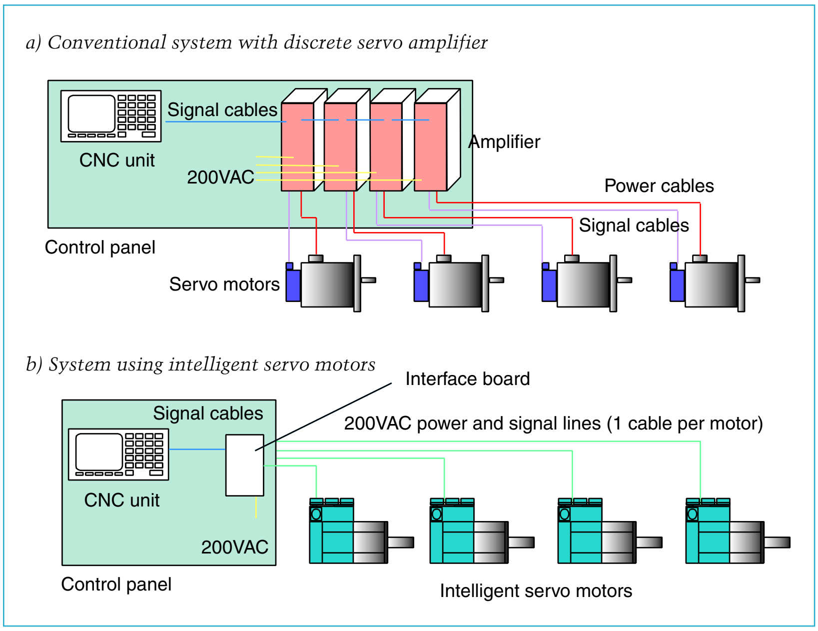


Fig. 2 System configurations.

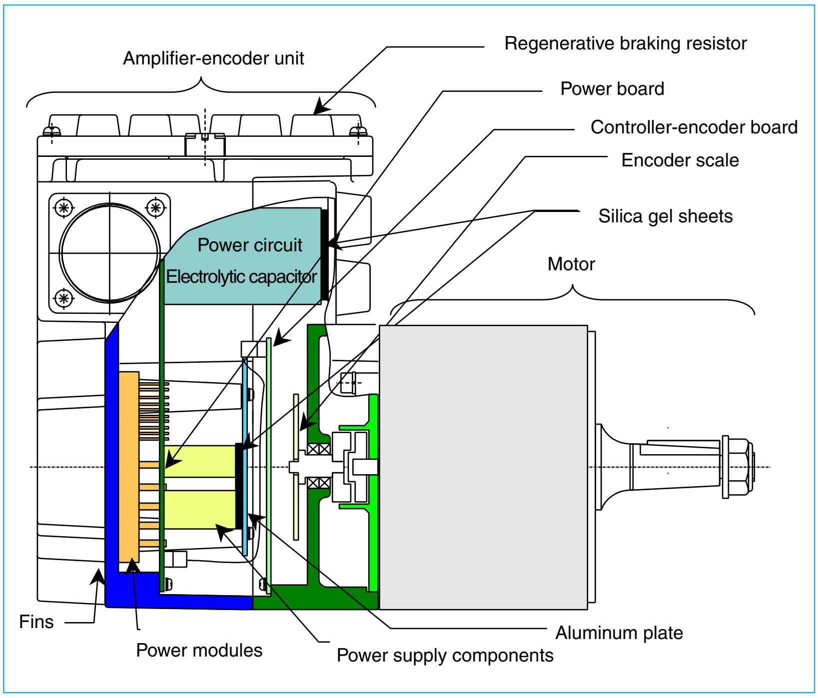


Fig. 3 Motor construction.

Future Developments
We believe intelligent servo motors will become increasingly popular as their designs advance. Fewer components in the motor encoder and amplifier circuits will lower prices and increase reliability. More product variants will expand markets in general-purpose servo control and auxiliary motor-drive applications for NC systems. Lower losses and better thermal design will contribute to reliability and increase motor capacities. Simple cabling and small installation space will give intelligent servo motors significant advantages over discrete amplifier systems. Finally, we can expect new functions that build on the advantages of an integrated motor and amplifier. ❑

Autotuning Technologies for General-Purpose AC Servo Systems

*by Yasushi Ikawa and Hidetoshi Ikeda**

Mitsubishi Electric has developed a new realtime autotuning technology for its MR-J2 "Super" series AC servo amplifier line. The servos also feature an automatic gain scan function that helps to minimize positioning time.

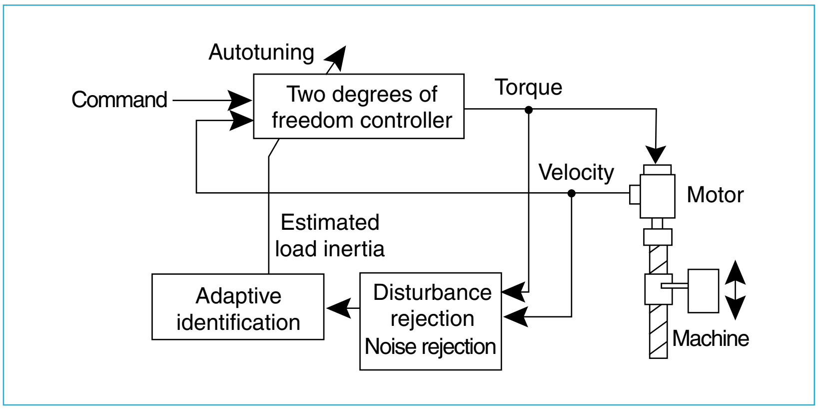
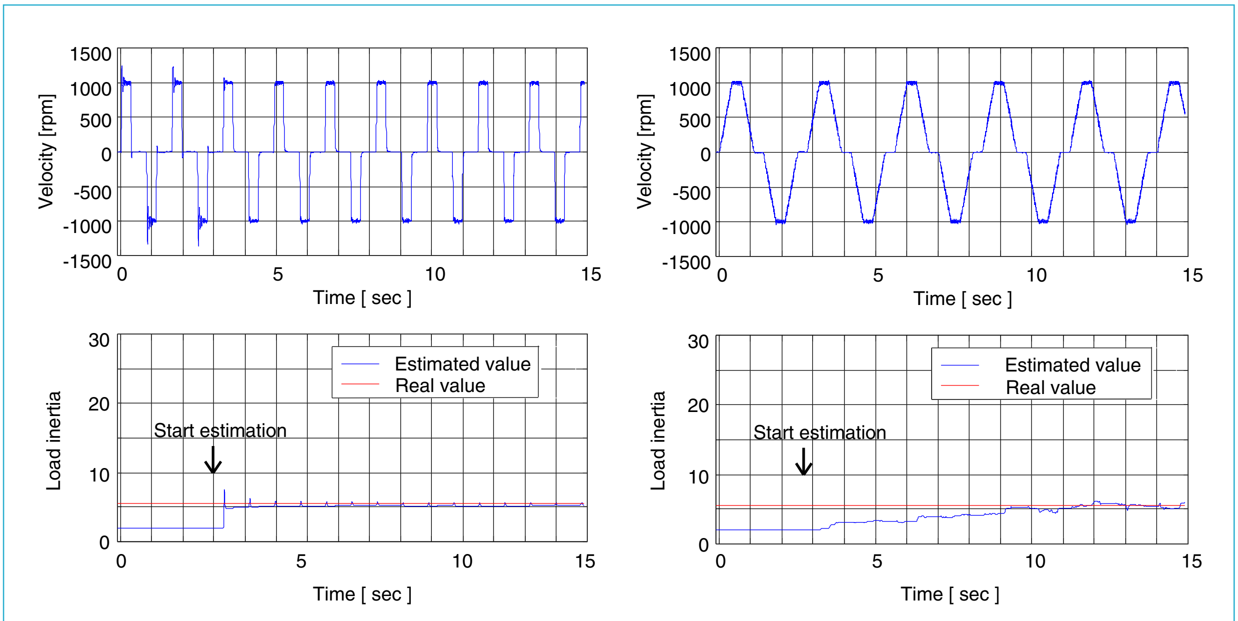


Fig. 1 Block diagram.

AC servo applications have expanded from machine tools into semiconductor manufacturing equipment, component placement systems, robots, and work transport systems, where they have raised the bar on systems requiring torque, speed or positioning control. A potential cost in implementing servo systems is the time needed to tailor the servo gain parameters to the mechanical system. An automatic adjustment system would be preferable. In 1999, Mitsubishi Electric launched its MR-J2 "Super" series servo amplifiers with realtime "autotuning" technologies the company developed to achieve this goal. High-rate positioning operations are sensitive to settling-time issues. The company has also developed a gain-scanning function that automatically seeks suitable gain settings with the minimum settling time.



(a) Operate to high acceleration and deceleration *(b) Operated to low acceleration and deceleration*

Fig. 2 Hi-level realtime auto-tuning

**Yasushi Ikawa is with the Nagoya works and Hidetoshi Ikeda with the Industrial Electronics & Systems Laboratory.*

Realtime Autotuning Function
Automatic gain setting is possible provided that the load's mechanical inertia can be known. Specifically, a rapid and precise system for inertia measurement would maintain suitable gain settings even when the mechanical inertia changes—for example when using a different tool head, or driving workpieces of different weights. Inertia is more difficult to measure at the small acceleration values where mechanical friction and variable linkage tolerances result in an SN ratio that is unacceptably high. Previous attempts at automatic tuning required narrow constraints on the application, and a more robust and accurate alternative was needed. We have succeeded in developing a realtime autotuning function that can operate under low-acceleration conditions, despite friction, other sources of noise torques, or while lifting against gravity. Fig. 1 shows the basic operating principle. Use of statistical techniques combined with an adaptive identification algorithm and other enhancements has achieved highly accurate inertia determinations for a wide range of mechanical systems and operating conditions. Fig. 2 shows evaluation of a lead-screw with friction torque above the rated 15% that is lifting a load against gravity. Fig. 2a shows performance with a torque valued at 55% of rated torque, favorable conditions for inertia measurement. The slight initial overshoot disappears once autotuning is completed, yielding precise control. The inertia estimation is also accurate and stable in Fig. 2b where the applied torque is just 1.5%, despite the friction and gravity loads. This sensitivity improves the reliability of the self-tuning capabilities while broadening their usefulness.

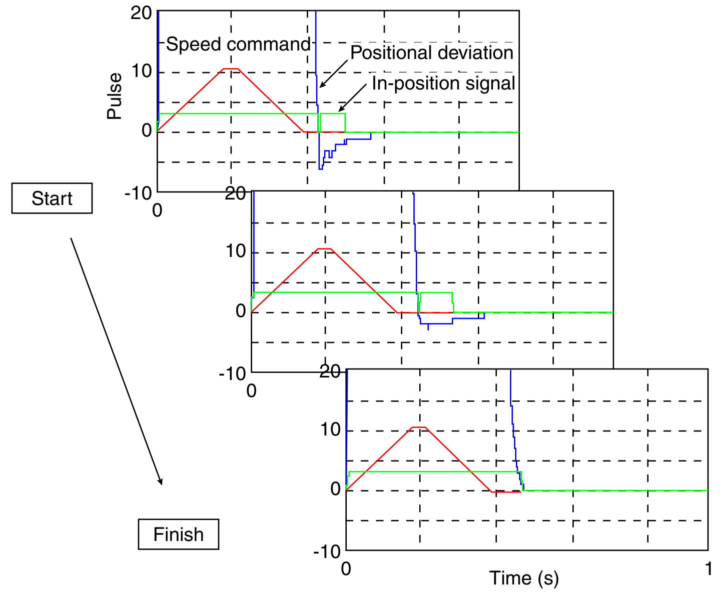


Fig. 3 Gain-scan results.

Gain Scan Function
This proprietary scan algorithm repeats a positioning operation while incrementing the gain level until the settling time exceeds the target value. Positioning performance is maximized by setting the highest gain consistent with the required settling time. No special test pattern is needed: the testing can be performed using routine movement patterns. When linked with the results of frequency response analysis by the company's "machine analyzer" the gain scan range can be constrained, leading to more rapid determination of optimum gain settings. Fig. 3 shows the results of such a gain scan.

This high-level realtime autotuning function promotes the spread of servo-control technology by permitting manufacturers to introduce servo equipment without the time-consuming manual setup previously required. Mitsubishi Electric will continue to develop resonance suppression technologies and plans additional application-specific performance improvements. ❑

FR-S500 Series Compact General-Purpose Inverters

Mitsubishi Electric has launched FR-S500 series compact general-purpose inverters with a control panel that reduces operator manipulation time by 50% compared to previous systems. A digitally encoded dial facilitates setup and operation. Tactile detents in the dial mechanism permits rapid setting of running frequency and parameter values. Simple, key-operated mode changeover is provided and, in default mode, access is restricted to the 12 most commonly used parameters, simplifying operation for those who many never need to access the full range of parameters provided for by the series.

Product power capacities are:

100V	Single phase	100W~750W
200V	Single phase	100W~1.5kW
200V	Three phase	100W~3.7kW

Proprietary torque-enhancement technologies boost torque at a 6Hz output frequency to 150% of rated output for applications requiring high torque at low speeds. With 15 speed settings, a 4~20mA speed input interface and PID control, the series approaches the performance of high-end inverters.

The FR-S520-0.1kW General-Purpose Inverter

Mitsubishi Electric's well-received "Soft-PWM" technologies reduce audible motor noise and EMI. The standard configuration includes in-rush current suppression with options for a DC reactor to suppress power-supply harmonics and a specially designed EMI filter.

All models are 128mm high with a cooling fan design for easy replacement.

Models are available with or without RS485 interface. This interface provides for control by the corporation's FR-PU04 control panel or by computer.

Sink and source connections can be selected by connector switch. The models satisfy UL, cUL and CE requirements. ❑

MR-J2 "Super" Series General-Purpose AC Servo Amplifiers

While retaining backward compatibility with the company's popular MR-J2 series products, the "Super" series offers enhanced functions and performance with 50W~3.5kW capacities available for 200V supplies and 50~400W for 100V supplies. Customers can choose between A-type models with general-purpose pulse-train and analog interfaces and B-type models fitted for SSCNET, the company's proprietary high-speed realtime networking system. Both types are available as of February 2000.

A 32-bit RISC microprocessor with DSP functions calculates position, speed and current commands four times faster than the MR-J2 series, raising the frequency response of the velocity control loop to 550Hz. An absolute encoder delivering 131,072 pulses per revolution improves both positioning and speed-control accuracy.

The autotuning function of the "Super" series has a new algorithm for measuring the load's moment of inertia that is suitable in a wide range of applications.

"Super" Series Servo Amplifiers with the Servo Motors they Control

"Super" series servo amplifiers can be used with small-capacity HC-MFS series motors as well with newly developed HC-KFS series motors. HC-KFS motors share the dimensions of HC-MFS motors while providing triple the motor inertia to better suit applications involving large mechanical inertia or low machine rigidity.

System setup is faster thanks to newly developed computer software including a "machine analyzer" tool that analyzes a system's mechanical characteristics using the servo as an exciter and detector. A gain-scan function, also utilizing the servo, identifies parameters for optimal positioning performance and settling time. ❑

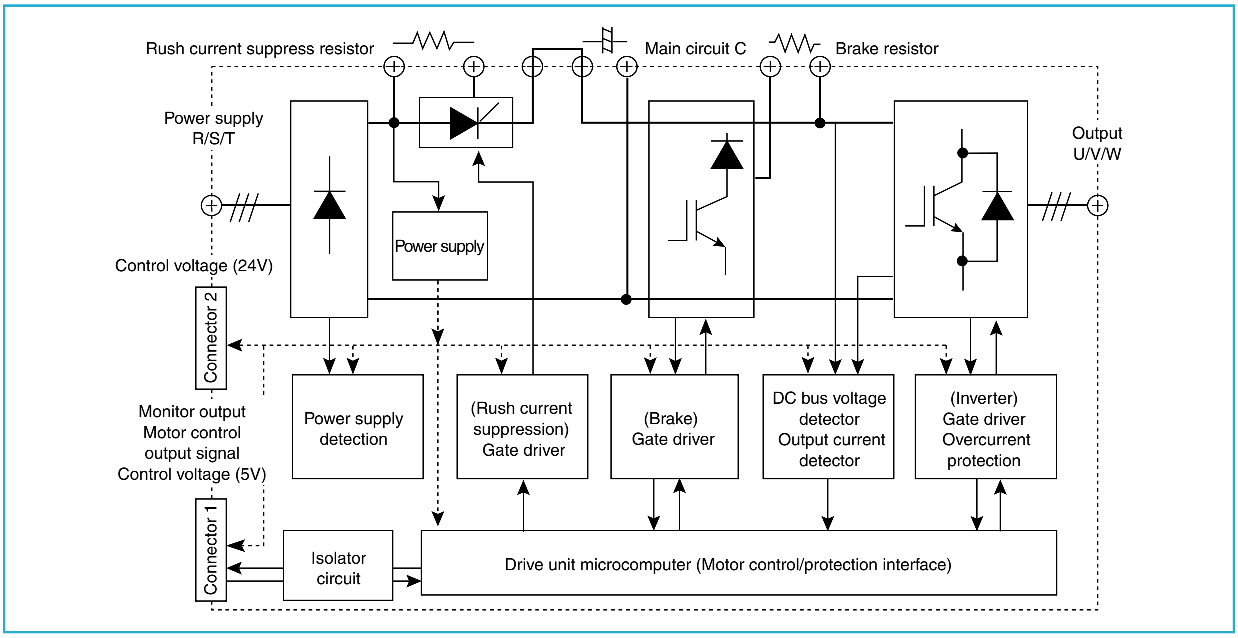
Compact Inverter Technologies

Compact inverter equipment requires lower switching losses and better thermal design. Fine-patterned IGBTs that cut switching losses by 20% and dedicated module construction with improved thermal design help reduce the size of Mitsubishi Electric's inverter products.

Switching loss is reduced by improving power-device characteristics, in this case IGBT turn-on voltage and switching characteristics. Recently, we have launched a "fourth generation" fine-patterned IGBT. The new device reduces switching losses by about 20%. The simpler drive circuitry of IGBTs also contributes to small equipment size. The figure shows the power circuit block diamgram.

A second key innovation is a power module that forms an integral part of the chassis. The power components are mounted on thermally conductive insulating board. Bare-chip mounting is used to boost integration scale. The resin casing can be molded to accommodate specialized components or chassis mounting hardware. The module is potted in an injected insulating resin that maintains insulation.

Thermal design is especially important in general-purpose servo applications where power dissipation may be high. Narrow-pitch cooling fins for the application were designed with the aid of a CAD-based heat-flow analysis. Space has also been saved by replacing some of the photocouplers with high-voltage ICs. ❑

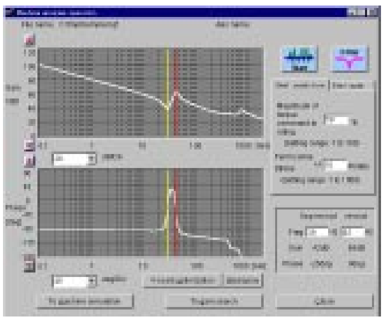


Dedicated power-module construction

"Machine Analyzer" Tailors Servo Amp Notch Filters

Mitsubishi Electric has developed test software that measures the resonant modes of servo system at frequencies up to 1kHz providing information needed to configure notch filters. The system uses only a servo amp, motor, and personal computer; mechanical oscillators and FFT scopes and are not required.

When servo amplifiers are used to control machine-tool systems, they risk exciting resonant modes of the system causing undesired mechanical oscillation. Exciting the higher frequency modes can destabilize the control system, interfering with accurate position control. The problem is typically addressed by analyzing the mechanical resonance modes of the system and using notch filters to reduce the amplifier gain at the corresponding frequencies.



A typical display for machine analyzer operation

The test software sends commands for pseudorandom torque patterns that excite the mechanical system. The speed and torque signals generated during the test are analyzed to map frequency characteristics. The data can be viewed as a graphic display and provides a model for evaluating the effect of various gain settings intended for a production system. ❑

MITSUBISHI ELECTRIC OVERSEAS NETWORK (Abridged)

Country	Address		Telephone
U.S.A.	Mitsubishi Electric America, Inc.	5665 Plaza Drive, P.O. Box 6007, Cypress, California 90630-0007	714-220-2500
	Mitsubishi Electronics America, Inc.	5665 Plaza Drive, P.O. Box 6007, Cypress, California 90630-0007	714-220-2500
	Mitsubishi Consumer Electronics America, Inc.	2001 E. Carnegie Avenue, Santa Ana, California 92705	714-261-3200
	Mitsubishi Semiconductor America, Inc.	Three Diamond Lane, Durham, North Carolina 27704	919-479-3333
	Horizon Research, Inc.	1432 Main Street, Waltham, Massachusetts 02154	617-466-8300
	Mitsubishi Electric Power Products Inc.	Thorn Hill Industrial Park, 512 Keystone Drive, Warrendale, Pennsylvania 15086	412-772-2555
	Mitsubishi Electric Manufacturing Cincinnati, Inc.	4773 Bethany Road, Mason, Ohio 45040	513-398-2220
	Astronet Corporation	37 Skyline Drive, Suite 4100, Lake Mary, Florida 32746-6214	407-333-4900
	Powerex, Inc.	Hills Street, Youngwood, Pennsylvania 15697	412-925-7272
	Mitsubishi Electric Research Laboratories, Inc.	201 Broadway, Cambridge, Massachusetts 02139	617-621-7500
Canada	Mitsubishi Electric Sales Canada Inc.	4299 14th Avenue, Markham, Ontario L3R 0J2	905-475-7728
	Mitsubishi Electronics Industries Canada Inc.	1000 Wye Valley Road, Midland, Ontario L4R 4L8	705-526-7871
Mexico	Melco de Mexico S.A. de C.V.	Mariano Escobedo No. 69, Tlalnepantla, Edo. de Mexico	5-565-6269
Brazil	MELCO do Brazil, Com. e Rep. Ltda.	Av. Rio Branco, 123, a 1507, 20040, Rio de Janeiro	21-221-8343
	MELCO-TEC Rep. Com. e Assessoria Tecnica Ltda.	Av. Rio Branco, 123, a 1507, 20040, Rio de Janeiro	21-221-8343
Argentina	MELCO Argentina S.R.L.	Florida 890-20º-Piso, C.P. 1005, Buenos Aires	1-312-6982
Colombia	MELCO de Colombia Ltda.	Calle 35 No. 7-25, Oficinas No. 1201/02, Edificio, Caxdac, Apartado Aereo 29653, Bogotá	1-287-9277
U.K.	Mitsubishi Electric U.K. Ltd.	Travellers Lane, Hatfield, Herts. AL10 8XB, England	1707-276100
	Apricot Computers Ltd.	3500 Parkside, Birmingham Business Park, Birmingham, B37 7YS, England	21-717-7171
	Mitsubishi Electric Europe Coordination Center	Centre Point (18th Floor), 103 New Oxford Street, London, WC1A 1EB	71-379-7160
France	Mitsubishi Electric France S.A.	55, Avenue de Colmar, 92563, Rueil Malmaison Cedex	1-47-08-78-00
Netherlands	Mitsubishi Electric Netherlands B.V.	3rd Floor, Parnassustoren, Locatellikade 1, 1076 AZ, Amsterdam	20-6790094
Germany	Mitsubishi Electric Europe GmbH	Gothaer Strasse 8, 40880 Ratingen	2102-4860
	Mitsubishi Semiconductor Europe GmbH	Konrad Zuse Strasse 1, 52477 Alsdorf	2404-990
Spain	MELCO Iberica S.A. Barcelona Office	Polígono Industrial "Can Magi", Calle Joan Buscallà 2-4, Apartado de Correos 420, 08190 Sant Cugat del Vallés, Barcelona	3-589-3900
Italy	Mitsubishi Electric Europe GmbH, Milano Office	Centro Direzionale Colleoni, Palazzo Perseo-Ingresso 2, Via Paracelso 12, 20041 Agrate Brianza, Milano	39-60531
China	Shanghai Mitsubishi Elevator Co., Ltd.	811 Jiang Chuan Rd., Minhang, Shanghai	21-4303030
Hong Kong	Mitsubishi Electric (H.K.) Ltd.	41st Floor, Manulife Tower, 169 Electric Road, North Point	510-0555
	Ryoden Holdings Ltd.	10th Floor, Manulife Tower, 169 Electric Road, North Point	887-8870
	Ryoden Merchandising Co., Ltd.	32nd Floor, Manulife Tower, 169 Electric Road, North Point	510-0777
Korea	KEFICO Corporation	410, Dangjung-Dong, Kunpo, Kyunggi-Do	343-51-1403
Taiwan	MELCO Taiwan Co., Ltd.	2nd Floor, Chung-Ling Bldg., No. 363, Sec. 2, Fu-Hsing S. Road, Taipei	2-733-2383
	Shihlin Electric & Engineering Corp.	No. 75, Sec. 6, Chung Shan N. Rd., Taipei	2-834-2662
	China Ryoden Co., Ltd.	Chung-Ling Bldg., No. 363, Sec. 2, Fu-Hsing S. Road, Taipei	2-733-3424
Singapore	Mitsubishi Electric Singapore Pte. Ltd.	152 Beach Road #11-06/08, Gateway East, Singapore 189721	295-5055
	Mitsubishi Electric Sales Singapore Pte. Ltd.	307 Alexandra Road #05-01/02, Mitsubishi Electric Building, Singapore 159943	473-2308
	Mitsubishi Electronics Manufacturing Singapore Pte. Ltd.	3000, Marsiling Road, Singapore 739108	269-9711
	Mitsubishi Electric Asia Coordination Center	307 Alexandra Road #02-02, Mitsubishi Electric Building, Singapore 159943	479-9100
Malaysia	Mitsubishi Electric (Malaysia) Sdn. Bhd.	Plo 32, Kawasan Perindustrian Senai, 81400 Senai, Johor	7-5996060
	Antah MELCO Sales & Services Sdn. Bhd.	3 Jalan 13/1, 46860 Petaling Jaya, Selangor, P.O. Box 1036	3-756-8322
	Ryoden (Malaysia) Sdn. Bhd.	2nd Fl., Wisma Yan, Nos. 17 & 19, Jalan Selangor, 46050 Petaling Jaya	3-755-3277
Thailand	Kang Yong Watana Co., Ltd.	15th Floor, Vanit Bldg., 1126/1, New Petchburi Road, Phayathai, Bangkok 10400	2-255-8550
	Kang Yong Electric Co., Ltd.	67 Moo 11, Bangna-Trad Highway, Km. 20 Bang Plee, Samutprakarn 10540	2-312-8151
	MELCO Manufacturing (Thailand) Co., Ltd.	86 Moo 4, Km. 23 Bangna-Trad, Bangplee, Semudparkarn 10540	2-312-8350~3
	Mitsubishi Elevator Asia Co., Ltd.	Bangpakong Industrial Estate, 700/86~92, Moo 6 Tambon Don Hua Roh, Muang District Chonburi 20000	38-213-170
	Mitsubishi Electric Asia Coordination Center (Thailand)	17th Floor, Bangna Tower, 2/3 Moo 14, Bangna-Trad Highway 6.5 Km, Bangkawe, Bang Plee, Samutprakarn 10540	2-312-0155~7
Philippines	International Elevator & Equipment, Inc.	Km. 23 West Service Road, South Superhighway, Cupang, Muntinlupa, Metro Manila	2-842-3161~5
Australia	Mitsubishi Electric Australia Pty. Ltd.	348 Victoria Road, Postal Bag No. 2, Rydalmere, N.S.W. 2116	2-684-7200
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