ISSN 1345-3041

MITSUBISHI ELECTRIC

Dec. 2005／Vol.112

# ADVANCE

Latest Technologies of Factory Automation (FA) Devices and Mechatronics


MITSUBISHI ELECTRIC
Changes for the Better

Dec. 2005 / Vol. 112
MITSUBISHI ELECTRIC
# ADVANCE
*Latest Technologies of Factory Automation (FA) Devices and Mechatronics*

**Cover Story**

In the field of factory automation (FA) devices and mechatronics, we have been working on the development of new products that respond in a timely manner to changes in market needs.

The following papers introduce our representative new products that have been born of our R&D efforts to achieve greater reliability, high-speed synchronized networking, high-speed responsivity, submicron high-precision processing, and so forth.



• **Editorial Inquiries**
*Keizo Hama*
Corporate Total Productivity Management & Environmental Programs
Fax 03-3218-2465

• **Product Inquiries**
*Tomoyuki Sugai* (p2-7, p11-16)
Automation & Motion Control Systems Sect.
Overseas Marketing Dept.
Industrial Automation
Fax 03-3218-6820

*Minoru Ueda* (p17-22)
EDM Marketing Manager
Industrial Automation Machinery Dept.
Industrial Automation Machinery Marketing Division
Fax 03-3218-6822

*Toshihiro Yonehara* (p8-10)
AC Drives & LVS Systems Sect.
Overseas Marketing Dept.
Industrial Automation
Fax 03-3218-6821

*Kazuhiro Tobinaga* (p23-28)
Laser Marketing Manager
Industrial Automation Machinery Dept.
Industrial Automation Machinery Marketing Division
Fax 03-3218-6822

## CONTENTS

### Technical Reports



***Mitsubishi Electric Advance*** is published on line quarterly (in March, June, September, and December) by Mitsubishi Electric Corporation.

# *Overview*

Author: *Akira Sugiyama**

In recent years, the environment surrounding Japan's manufacturing industry has been undergoing major changes. Such changes include the diversification of user needs and the need to respond quickly and flexibly to low-volume high-variety production runs, production-line changeovers, and the installation and relocation of equipment and facilities. Also, automation is being promoted in order to compete with low-cost production by numerous low-wage workers in China and elsewhere, as well as the trend toward even higher capacity utilization rates. Moreover, companies are striving to achieve greater compliance with safety and environmental standards, which are attracting growing interest internationally, to meet the demand for easier handling, maintenance and diagnostic capabilities of machinery and equipment in view of the graying of production departments and increasingly unskilled shop-floor workers.

This feature issue examines a group of new products and industrial processing machines having new added values: servo products and high-performance motors, both of which have been developed by accurately identifying changes in market needs for factory automation (FA) equipment and can boost productivity; energy-efficient inverters; programmable controller systems developed to eliminate system downtime; and displays with an entirely new architecture destined to become a global standard.

Mitsubishi Electric Corporation is committed to contributing to the development of the world's manufacturing industry as a comprehensive FA equipment manufacturer by raising the competitiveness of our powerful FA equipment such as programmable controllers, servos and inverters and also by improving compatibility among such equipment. Through such efforts, we aim to meet the increasingly sophisticated and global needs of production worksites.

**Executive Officer, Group President - Factory Automation Systems*

# New AC Servo Amplifier "MR-J3 Series"

Authors: *Tomohiro Miyazaki*[*] and *Masanori Ozaki*[*]

## Article Introduction

A new series of general-purpose AC servo amplifier has been developed. The "MR-J3 series", has incorporated advanced control capabilities that able to maximize the best advantage from the machinery. This paper introduces control functions that have been beefed up MR-J3 series and the newly developed high-speed synchronous servo system network dubbed SSCNET III.

Fig.1 AC servo amplifier MR-J3B & servo motor HF-KP

## 1. High-speed High-precision Control That Adapts Itself to Mechanical Characteristics

A basic way of controlling machinery at high speed with high precision is to raise control gain. However, by raising the control gain, the machine might generate mechanical vibrations. For the reason, that every machine usually has a few vibration mode. Such vibrations will hinder the machine from operating in higher speed and better precision.

From servo control viewpoint, these mechanical vibrations can be divided into three categories. The first category are vibrations of high frequency in the range of several hundred Hz or above. The characteristic of this vibration is normally initiated by a raise in control gain. Once the control system starts to vibrate in this vibration mode, it becomes unstable and impossible to control.

The second category are low frequency vibrations ranging from several Hz to approximately 100 Hz. In this vibration mode, the control system will not vibrate even when the control gain is increased. However, the control system might generate residual vibrations at the time of stopping/positioning, hence, the settling time becomes longer.

The third category represents a low-frequency vibration mode that poses a problem with machinery of extremely high load/motor inertia moment ratio together with low mechanical rigidity. In this case, vibration itself is not likely to pose any problem. However, the gain becomes small at low frequency, as a result, the machine becomes receptive to disturbance and unable to achieve high precision.

In order to suppress these mechanical vibrations, it is necessary to apply appropriate control methods commensurate with the characteristics of such mechanical vibrations. To cope with these categories of mechanical vibrations, we have developed "Adaptive filter II," "Advanced vibration suppress control" and "Robust disturbance compensation control" to be equipped into the MR-J3.

## 2. Advanced Vibration Suppress Control

Advanced vibration suppress control is designed to suppress the vibrations in Category 2 above. It is effective in suppressing residual vibrations at the time of settling during positioning operation.

The MR-J3's control block diagram with Advanced vibration control illustration is shown in Fig. 2. The

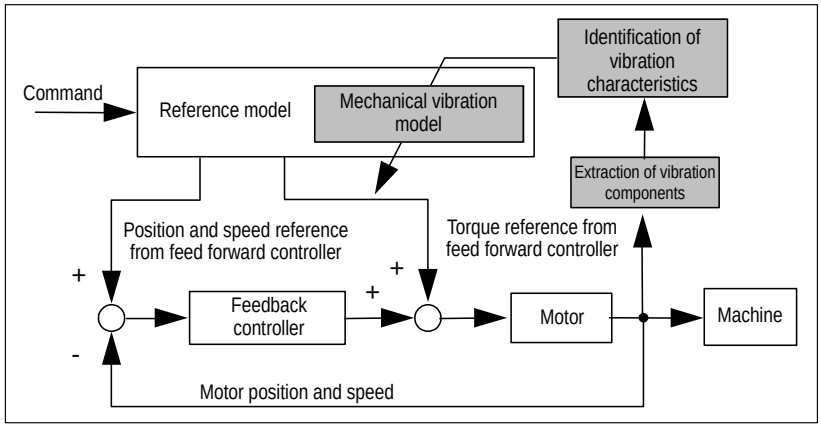



Fig. 2 Block diagram of advanced vibration suppress control

*Nagoya Works

primary control method of the MR-J3 is model adaptive control. In this method, the motor is driven in such a manner that the tip of the given machinery moves together with the reference model applied.

Under Advanced vibration suppress control, it uses a mechanical vibration model from reference model to generate a drive pattern that prevent the tip of machinery from vibrating, thereby suppressing any residual vibration. Advanced vibration suppress control can extract vibration components from actual motor movements. It identifies the vibration characteristics of the machinery in real time, and automatically make adjustment to the mechanical vibration model.

## 3. Robust Disturbance Compensation Control

The Robust disturbance compensation control is designed to suppress the mechanical vibrations in Category 3 above. It is particularly effective in increasing the synchronization precision of large load inertia machines such as printing presses and packing machines.

In the case of machines with large load inertia and low rigidity, it is almost impossible to sufficiently raise gain at low frequency using conventional control methods. It is because the gain became larger at high frequency than at low frequency, as a result, the control systems will become unstable. For this reason, such kind of machines was susceptible to disturbance and unable to obtain sufficient precision.

The Robust disturbance compensation control has been designed to stabilize and suppress disturbance for such machines. A Disturbance suppression controller has been added to the conventional controller as shown in Fig. 3. Since the Disturbance suppression controller enhances responsibility for disturbance only, it is not necessary to raise conventional controller's gain considerably and it is possible to greatly reduce the effects of disturbance while retaining stability.

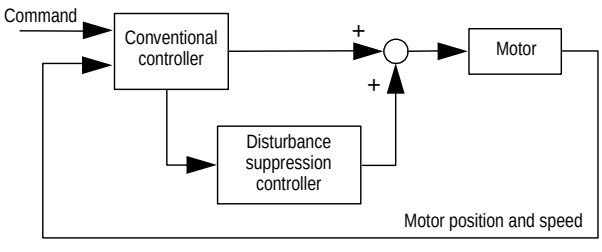



Fig. 3 Block diagram of robust disturbance compensation function

## 4. Adaptive Filter II

When a given machine has a mechanical resonance at a high frequency, (in the range of several hundred Hz and above.) increase control gain will cause the control system to oscillate in this vibration mode and subsequently lose control. In order to overcome the mechanical resonance, it is common practice to insert a machine resonance suppression filter into the control loop to prevent oscillation. Adaptive filter II is a function that automatically set this machine resonance suppression filter in real time.

Figure 4 shows the configuration of Adaptive filter II. It extracts mechanical resonance components that contained in the torque command, determines their frequency, and automatically adjusts the parameter of the machine resonance suppression filter accordingly.

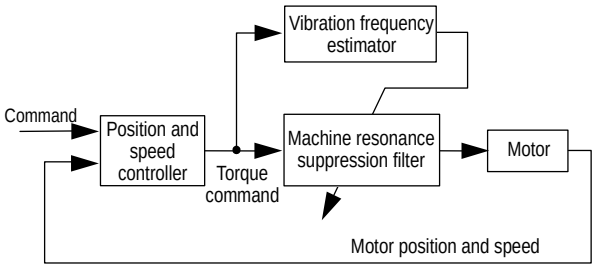



Fig. 4 Block diagram of adaptive filter II

## 5. Servo System Network SSCNET III

The SSCNET III is a high-speed synchronous network using an optical fiber cable. The Mr-J3B servo amplifier is connected to Q173HCPU or Q172HCPU motion controller via SSCNET III (See Fig. 5). As for the communications specifications of SSCNET III, it can control up to 8 axes per system with the transmission rate of 50 Mbps and command communications period of 0.4 ms. If the command communications period set to 0.8 ms, control of up to 16 axes per system is possible. (In the case of the conventional SSCNET, the command communications period was 3.5 ms.) The maximum station-to-station cable length between the controller and the servo amplifier is 50 meters. With maximum of 16 axes per system, a maximum overall cable length of up to 800 meters is possible. (In the case of conventional SSCNET, the maximum overall cable length was only 30 meters.) Since long-distance wiring has become possible, it is possible to locate the controller's control panel and drive units far apart and spread widely in a large-scale facility or a large-scale production line. This, in turn, will shorten the cable between amplifier and motor in machines where there is a relatively large amount of wiring.

As for the servo adjustments, a servo setting and support tool, MR Configurator can be used over SSCNET III, just simply connect a personal computer to the motion controller makes it possible to perform controller settings and servo parameters of all the connected axes to SSCNET III. The aforementioned control functions can also be made with ease using the GUI of MR Configurator.

In conclusion, this paper has introduced MR-J3's control capabilities and Servo system network SSCNET III on machinery performance enhancement as a total system. We will continue our best efforts to develop products that meet future market needs.

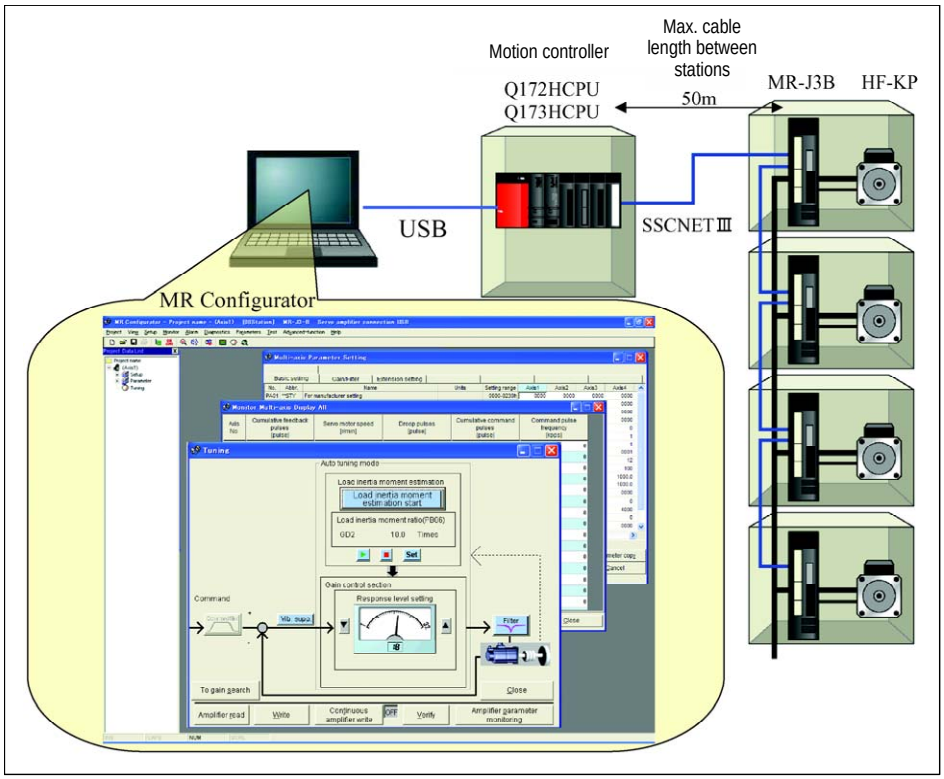



Fig. 5 Servo system network SSCNET III

# *Small-sized, High-efficiency Servomotor "HF Series"*

Authors: *Takashi Miyazaki*[*] and *Tomohiro Kikuchi*[*]

## Article Introduction

In recent years, reduced dimensions, higher speed and higher performance are required of servomotors that are to be incorporated into industrial machinery. To address these requirements, we at Mitsubishi Electric Corporation have commercialized "HF-series" AC servomotors featuring compatibility between reduced dimensions and high performance. The reduced dimensions and enhanced performance of these HF-series products have been realized through the use of our unique proprietary "joint-lapped core" construction, a high-density winding technology, and a control method designed to obtain the best possible servomotor performance characteristics. This paper describes the downsizing technology and the performance enhancement technology we have used in developing the HF-series servomotors, along with their outstanding features. Figure 1 shows the external appearance of the HF-series servomotors.

Small-capacity low-inertia:
HF-KP series

Small-capacity ultralow-inertia:
HF-MP series

Medium-capacity medium-inertia:
HF-SP series

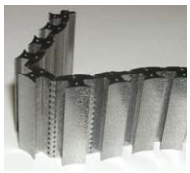
Fig. 1 Small-sized, high-efficiency servomotor "HF Series"

## 1. Adoption of Joint-lapped Core

In the case of the conventional HC-series servomotors, we employed our unique proprietary chain-type separate cores (chain-type "Pokipoki" cores) and thereby achieved one of the industry's smallest dimensions. For the HF series we have developed this time, we adopted joint-separated cores (joint-lapped cores) that have been developed as an advanced type of the above-mentioned Pokipoki cores. The external appearance of a joint-lapped core is shown in Fig. 2. In making the joint-lapped core, lamination is performed in a cylindrical form inside a progressive die at a speed comparable to the speed at which conventional integrated-type cores are punched. (See Fig. 2 (a).) Taking a look at the joint portion of the core, it is lapped at each predetermined thickness. At the center of the rotation of that lapped portion, protrusions and grooves are formed. These acts pile up and it becomes like a hinge. By opening this hinge portion, it is possible to bend the core in the opposite opening direction. (See Fig. 2 (c).)

(a) Ring-shaped die-cut core

(b) Opened core



(c) Bent in the opposite direction

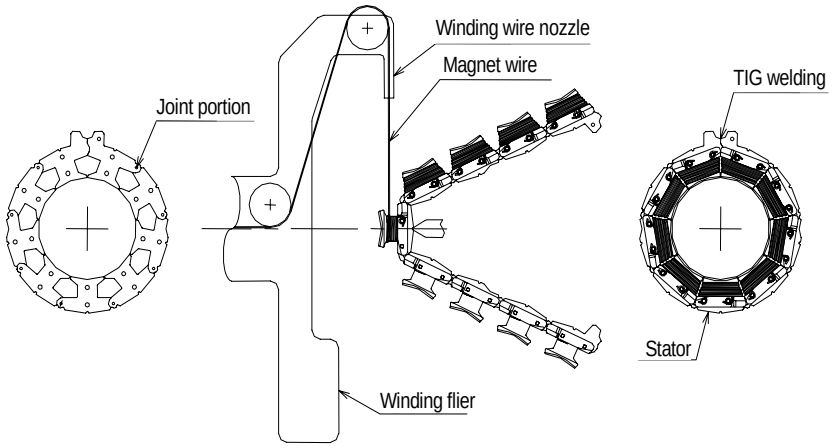
Fig. 2 The joint-lapped "Pokipoki" core

Thanks to this construction, it is possible to secure winding work areas that are more spacious than those of the rectilinear chain-type separate cores. As a result, high-speed, high-density winding using a flier winding machine or the like is possible. Figure 3 shows the condition of winding to the joint-lapped core. As to the method by which the stator is made, the core in a circular form as shown in Fig. 3 (a) is opened and bent in the opposite direction, and the winding is performed on each protrusion as shown in Fig. 3 (b). Then, the core is formed back into the circular form again as shown in Fig. 3 (c).

## 2. Small-sized Absolute-value Encoder

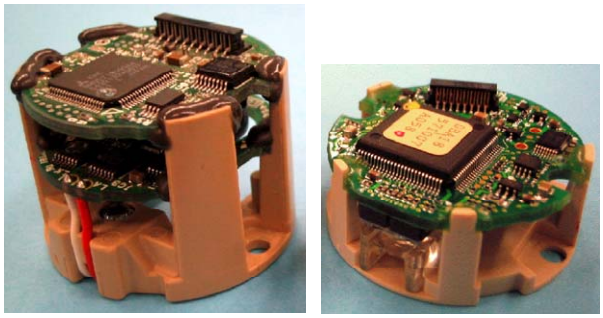
HF-series servomotors are each equipped with a newly developed small-sized optical absolute-value encoder. Our conventional encoder and newly developed encoder are shown in Fig. 4. For use in these newly developed encoders, the number of printed circuit boards has been reduced from two to one due to the thorough optimization of circuits and by means of our software technology. Furthermore, by capitalizing on our optical-system design technology, we have developed a phototransmitter-photoreceiver module, and a fold-back prism arrangement. Thanks to these

*Nagoya Works




(a) Stator core (b) Winding conducted by flier on reverse-bent core (c) Ring-shape formation (by welding)

Fig. 3 Winding for the joint-lapped "Pokipoki" core



Conventional encoder Newly developed encoder

Fig. 4 Encoder

technologies, we have stepped up resolution from 17 bits/rev (131,072 pulses/rev) to 18 bits/rev (262,144 pulses/rev), while at the same time achieving downsizing by cutting the lengthwise dimension approximately in half compared to that of our conventional encoder.

## 3. Reduction in Cogging Torque

Because of their rotor construction using permanent magnets, AC servomotors are equipped with torque pulsation called cogging torque even when they are not being energized. Since cogging torque acts as an extraneous disturbance factor on a servo system, it is desirable to minimize it as much as possible to achieve higher performance and reduced torque ripples. In order to reduce this cogging torque, we performed three-dimensional electromagnetic field analyses when the HF series was in the design stage. Through these analyses, we have performed analysis-based optimizations for not only magnetic circuitry on a plane in the direction of rotation but also magnetic circuitry in the direction of the shaft. Moreover, we have newly considered the effects of presswork and the like on the magnetic properties of magnetic steel sheets. As a result, we have realized high-precision simulations that more closely match actual servomotors.

What is more, the joint-lapped core adopted this time was prepared by performing core stamping in a circular form and opening the circular-shaped core, then conducting winding and thence forming the core into a circular form again as shown in Fig. 3. Therefore, we were able to increase the precision of the inner diameter of the stator compared with that of the conventional chain-type separate core that was prepared by bending a rectilinear-shaped core into a circular form. This procedure has enabled us to reduce variation in cogging torque caused by limited precision.

These analyses and manufacturing technologies have in combination reduced cogging torque to about half of what it used to be.

## 4. Enhancement of Rotational Speed and Torque

By virtue of our reappraisal of the magnetic and electrical characteristics of HF servomotors and the adoption of a control method designed to obtain the best performance from the servomotors to be used with MR-J3 series servo amplifiers, the HF-series servomotors have gained speed over their predecessors as follows: from HC-KFS/MFS series' 4,500 rev/min to HF-KP/MP series' 6,000 rev/min; and from HC-SFS series' 2,000 to 3,000 rev/min to HF-SP series' 3,000 rev/min. What is more, the degradation of torque during high-speed operation has been reduced, and a torque characteristic maintaining high torque well into the high-rev range has been achieved. Figure 5 comparatively shows the torque characteristics of HF- and HC-series servomotors.

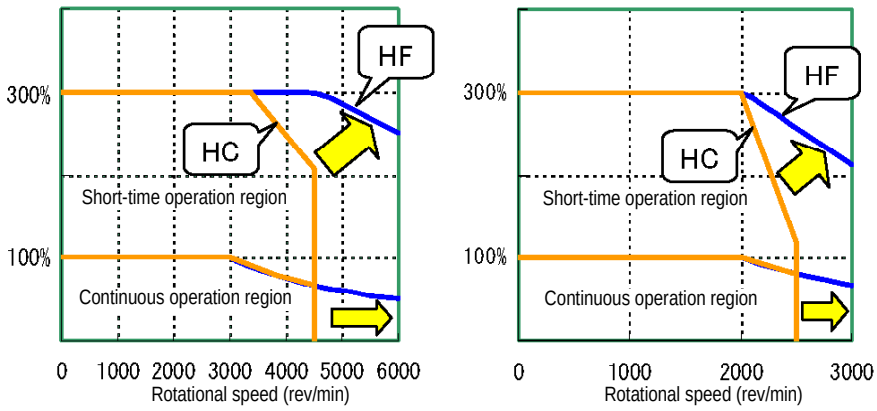



Fig. 5 Torque characteristics

## 5. Enhancement of Environmental Resistance

As servomotors find their way into an increasing range of applications such as food machinery and machine tools, there are increasing instances where water and/or chemical solutions fall directly onto servomotors. Given this situation, enhancing the environmental resistance of servomotors is desirable.

In the case of the HF series, we no longer use the sealing materials (liquid packing) and rubber plate-like packing materials that used to be employed in part-to-part junctions, and employ an O-ring-sealed construction instead. On account of this design change, precision has been enhanced by surface-to-surface contact between parts while reliability has been increased through the decreased swelling and corrosion of sealing parts in the face of chemical solutions. In this way, HF-KP/MP-series small-capacity servomotors have an IP65 waterproof rating (except the opening through which the shaft passes), while HF-SP medium capacity carries an IP67 rating (except the opening through which the shaft passes).

Moreover, the HF-KP/MP series features a connector coupling arrangement that permits power-supply and encoder connections to be made by means of the connectors on the side of the motor housing. Including its connectors engaged, the motor housing is structurally designed to meet the IP65 standard. What is more, the connectors that are to be engaged with the motor are structurally designed to permit the user to change the cable exit orientation. Thanks to this construction, using optional cables marketed by our company, the user can choose between cable exit orientations, either on the load side or on the side opposite to it, and can thus have a high degree of flexibility in wiring.

The HF-series servomotors have achieved downsizing and enhanced performance by incorporating our unique proprietary manufacturing technologies and the latest in analysis technology and control technology. With the commercialization of the HF series, we are determined to roll out the technologies used for the HF series to other models in the future, while at the same time making efforts to broaden the HF series.

# *Next-generation Energy-saving Inverter "FR-F700 Series"*

Authors: *Yasuhiro Shiraishi** and *Katsushi Ikeda**

## Article Introduction

To address energy-saving needs, we have developed FR-F700-series inverters for use with fans and pumps.

For incorporation into the FR-F700 series inverters, we have made improvements over optimum excitation control to achieve energy savings. Each FR-F700 series inverter is also equipped with an energy-saving monitor that allows the user to see the effect of energy savings being made. In addition, the series has excellent maintainability and environmental immunity.

## 1. Product overview

The FR-F700 series offers many different capacities spread across its broad product lineup: it consists of 17 different models with capacities ranging from 0.75 kW to 110 kW rated at 200 V, as well as 29 different models ranging from 0.75 kW to 560 kW rated at 400 V.

Optimum excitation control and other functions that are well suited for fan- and pump-powering applications are incorporated. The major features are as follows:

(1) Further promotion of energy efficiency savings
(2) Easy operation and simple maintenance
(3) Consideration given to the environment

## 2. Incessant pursuit of energy savings

### 2.1 Improvement of optimum excitation control

Optimum excitation control was first adopted into the FR-F500 series and proved to be effective in achieving large energy-saving effects. In the case of the FR-F500 series, control was implemented in such a manner that d-axis loss and q-axis loss have become nearly the same as each other. Although this method achieved considerable energy-saving effects in the course of constant-speed operation, sufficient energy-saving effects could not be obtained at acceleration/deceleration because of low responsivity. Given this situation, in the case of the FR-F700 series, we have optimized gain in loss minimization operation and added vd*, a d-axis voltage command term, in order to improve responsivity so that an energy-saving effect may be obtained even during acceleration/deceleration. Figure 2 shows a block diagram of optimum excitation control.

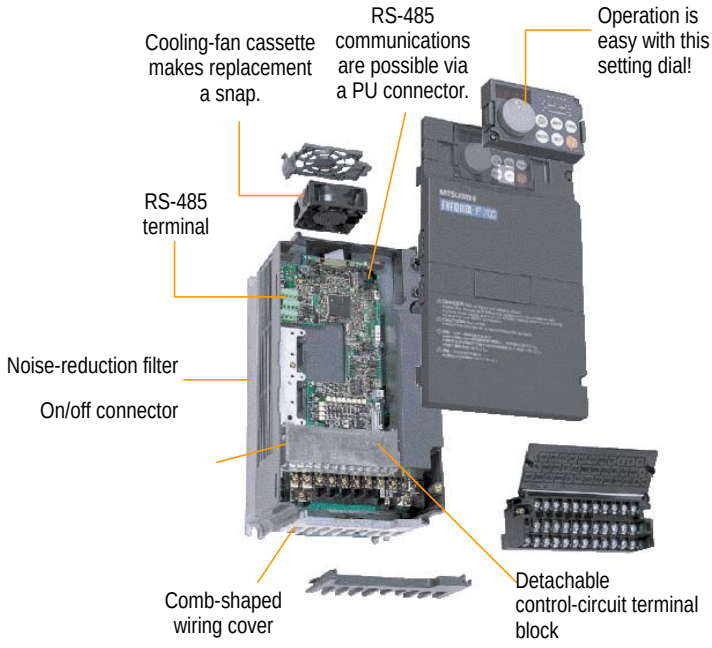



Fig. 1 Basic composition

*Nagoya Works

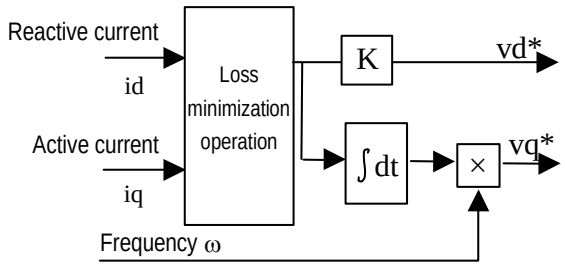



Fig. 2 Block diagram of optimum excitation control

As a result, over current was no longer generated during steep acceleration/deceleration even without limiting the amount of voltage compensation during such acceleration/deceleration and it has resulted in improved energy savings. Figure 3 shows an example of a comparison between the FR-F500 series and the FR-F700 series in terms of energy savings.

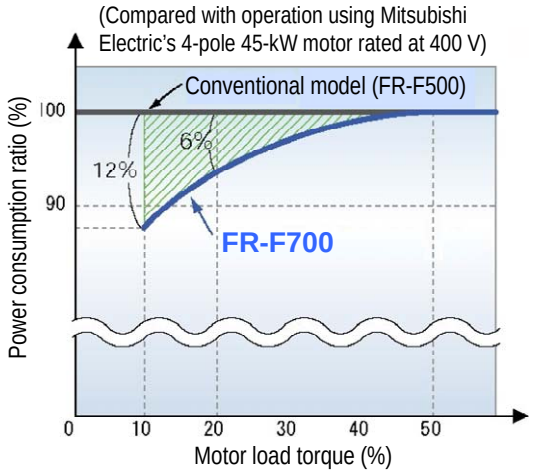



Fig. 3 Comparison of motor power consumption at acceleration-deceleration

### 2.2 Energy-saving monitor function

We have overcome the challenge of conventional optimum excitation control in the ways discussed above and achieved further enhanced energy-saving control. What is more, each FR-F700-series inverter is newly equipped with an energy-saving monitor that enables the user to keep track of energy savings actually being achieved under excellent control.

The energy-saving monitor stores information in its memory on amounts of power that would be consumed if a given load is run directly off a wall outlet without an inverter for use as "estimated values." In addition, the monitor compares actual readings of power being consumed by this load while being powered by the inverter with these "estimated values," and then indicates the obtained differences that serve as an indication of energy savings achieved. Figure 4 shows an example of discharge damper control. With respect to damper control, energy savings made under the control of the inverter are given as a percentage, with the rated output of the motor being 100%. With an appropriate parameter having been set, the energy-saving monitor can convert savings into an electricity charge, an average savings value per unit hour, or the like. It can also indicate an integrated value and an annual projection value. These monitor values can not only be displayed on the control panel that is provided as standard equipment but also put out in the form of an analog voltage and the data over a communications network to allow the user to conveniently monitor energy savings elsewhere.

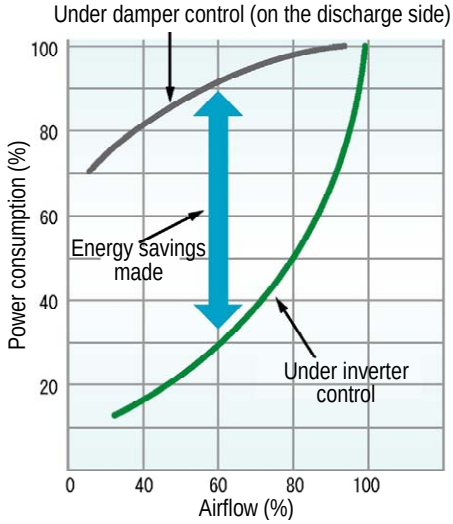



Fig. 4 An example of characteristics of the blower

## 3. Enhanced maintainability

### 3.1 Enhanced longevity of life-limited parts

Long-life parts have been used for such life-limited parts as cooling fans, main-circuit capacitors and control-circuit capacitors in order to achieve a design life of ten years (at an ambient temperature of 40°C at a current of approximately 80% of the rated current of Mitsubishi Electric's standard 4-pole motor). Particularly with the cooling fans, we have succeeded in achieving unprecedented longevity by making improvements to the grease, bearings and the like.

### 3.2 Life diagnostic function

The life diagnostic function performs self-tests on the life-limited parts to determine their degree of deterioration. It prevents problems before they occur by issuing an alarm when a given part approaches the end of its lifespan. The FR-F700 can run diagnostics on the following four kinds of parts: (1) Main circuit capacitor, (2) Control circuit capacitor, (3) Inrush current limit circuit, and (4) Cooling fan. The degree of deterioration of each of these parts can be read out by means of an inverter parameter for various deterioration-monitoring purposes. When a predetermined level is reached, the diagnostic function outputs an alarm signal that can be received and acknowledged by the user via appropriate output terminals or over a communications network.

## 4. Ease of operation

In order to achieve ease of operation on the control panel that is provided as standard equipment, we have adopted a setting dial that has been well received by FR-S500- and FR-F500J-series inverter users. By having increased the responsivity speed with which communications are exchanged between the control panel and the inverter at all times, we have achieved removable, smooth and speedy operability.

## 5. Enhanced environmental resistance

In consideration of the environment, the incorporation of EMC (electromagnetic compatibility) filters has made it possible for our inverters themselves to meet the European Union's EMC Directive (for 2nd environment) without having to install EMC filters in control cabinets. (See Fig. 5)

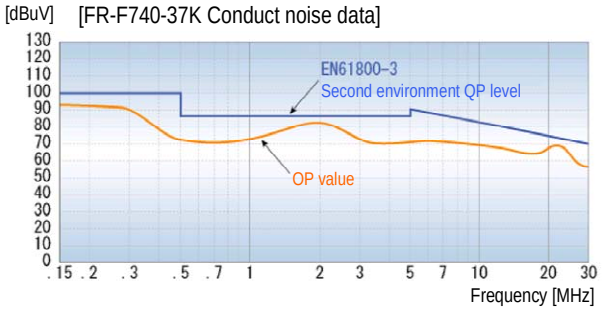



Fig. 5 Conduct noise data

In order to meet incessant industry demands for further improved inverters featuring bigger energy savings, greater environmental immunity and improved ease of operation, we are determined to further step up our research and development efforts.

## Bibliography

FREQROL - F500 Series Energy-saving Inverters for Fans and Pump Motor Drives, written by Hisao Sakurai, Masahiro Kimata, and Yoshihiro Nagataki, Mitsubishi Electric Technical Report, 73, No. 9

# MELSEC-Q Series Redundant System

Authors: *Hiroshi Nishiyuki*[*] and *Keisuke Shiotani*[*]

## Article Introduction

In recent years, the need to enhance facilities' reliability through the use of programmable controllers has been on the increase in various fields, most notably in the field of instrumentation systems. To address this need, we have developed the MELSEC-Q series (hereafter referred to as the Q series) Redundant System, enabling its applicability to be expanded to systems that are required to ensure a higher degree of reliability.

## 1. Basic Q-series redundant system configuration

Figure 1 shows an example of a basic Q-series redundant system configuration. Configuration-wise, the two redundant CPU modules are installed on their respective base units and a connection is made between these CPU modules using the tracking cable. This setup has made it possible to accomplish redundancy for the CUP modules, the power supply modules, the base units and the network, thereby realizing enhanced system-wide reliability.

As for the I/O of the Q-series redundant system, use is made of the MELSECNET/H remote I/O network to achieve flexible system construction thanks to the distributed placement of inputs/outputs and also to enable the diversification of system risk. Furthermore, in order to enhance the reliability of remote stations, redundancy has been made possible for their power supply modules.

When building a high-reliability system, it is necessary to not only enhance reliability through the redundancy of hardware but also achieve excellent operability and maintainability (by which mishandling/operator errors on the shop-floor are prevented).

To this end, since there is a need for the capability to handle the two redundant CPU modules as a single CPU, we have added a range of convenient functions such as a function to simultaneously write to both the control and standby systems at program change time and a function to enable monitoring operation equipment (HMI) to automatically switch over to the new active-duty control system after completion of system switching.

On the maintenance front, it has become possible to decrease the number of spare parts by using already-existing Q-series units/modules as much as possible, thereby achieving the highest possible degree of commonality and compatibility. What is more, we have also incorporated the ability to bulk copy control-system programs and data at module change time.

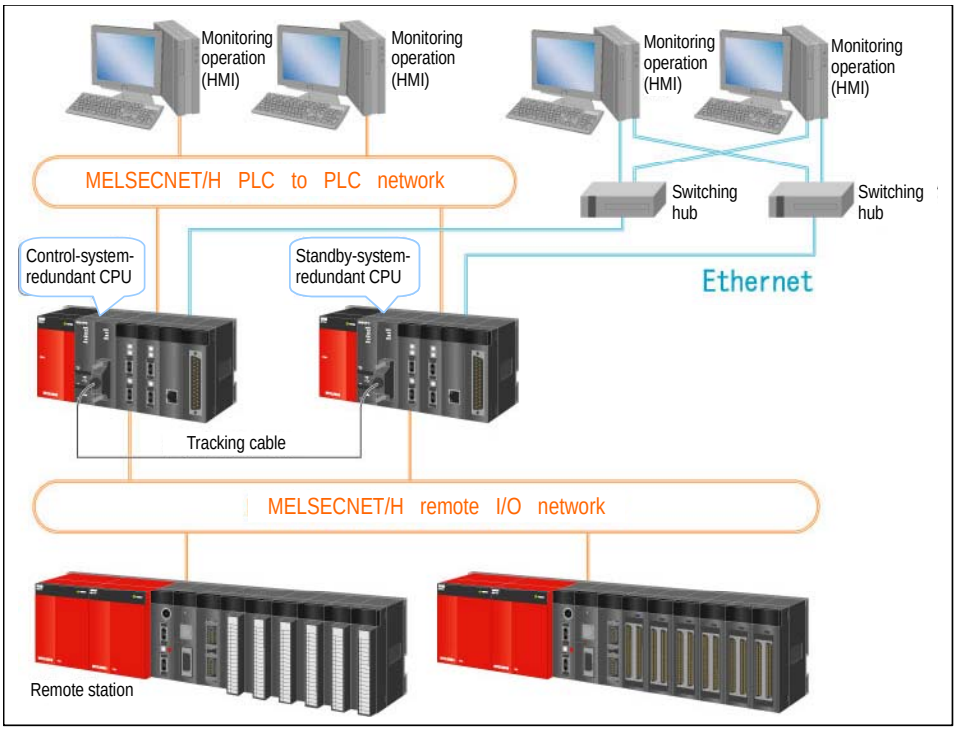



Fig. 1 Basic MELSEC-Q-series redundant system configuration

*Nagoya Works

## 2. Redundant CPU

As for the redundant CPU that becomes the nucleus of any Q-series redundant system, we have achieved ease of replacement, enhanced tracking performance, shortened the time required to recover from an error, achieved ease of operation, reduced physical size, and so on, to reflect market needs for the current Q4ARCPU. To achieve the above features, we have newly developed a tracking communications function using the hardware of the MELSEC Process Control (QnPHCPU) as a basis. The tracking communications function is a function designed to keep both CPUs in agreement with each other in terms of operating state by transmitting control data from the control-system-redundant CPU to the standby-system-redundant CPU at all times in anticipation of possible system switchover.

The tracking communications function becomes the nucleus of the system that determines the reliability and performance of the system. We introduce the technologies that we have applied toward achieving the function as follows:

(1) In order to physically separate the redundant CPUs (base units), an external connection is required by means of a cable or the like. In addition, it is necessary to enhance the reliability and speed of the tracking communications function while, at the same time, achieving small physical size, a feature to be inherited from the Q series. Toward this end, we adopted a serial communications scheme in implementing the tracking communications function, thereby reducing the number of signal lines and connector dimensions. For data communications, we employed general-purpose Ethernet technology and newly created a dedicated signal with which to perform inter-CPU communication state diagnostics to achieve compatibility between enhanced performance and increased reliability. For information, we have capitalized on serializer/deserializer IC chips for serial communications.
Figure 2 shows an abbreviated block diagram of the redundant CPU.

(2) To enhance tracking communications performance, we have implemented a dedicated DMA controller within an FPGA. On top of this, we have also implemented our proprietary protocol hardware-wise in order to realize processing with which to automatically sort and route tracking communications data to appropriate destination storage locations, as well as processing with which to re-send tracking data in the event of a reception packet error or upon detecting a response timeout on the sending-side CPU. In this manner, we have implemented the tracking function without incurring a performance penalty as a controller.

## 3. Network

As control systems grow very large in scale and become computerized, redundant systems, including network systems, are growing in importance. Given this situation, we have made it possible to build redundant systems, including information-level Ethernet modules and control-level MELSECNET/H modules.

### 3.1 Information network module

In the event that an Ethernet module detects a bend or a break in a communications line, the information network module performs a system swap in conjunction with the redundant CPU, thereby enabling uninterrupted communications and non-stop operation.

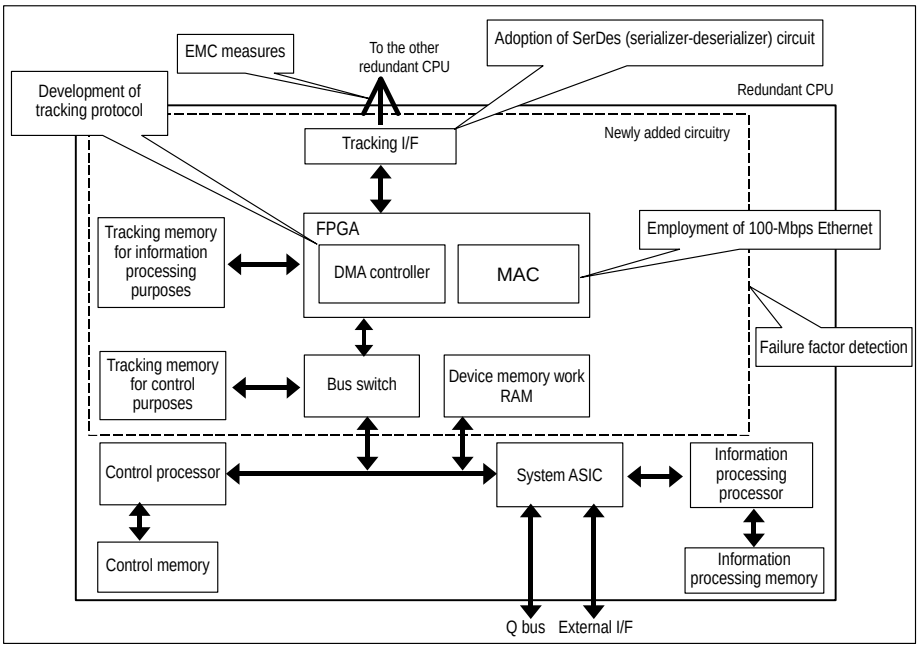



Fig. 2 Abbreviated block diagram of the redundant CPU

### 3.2 Control network module

One important feature of the MELSECNET/H module is high-speed cyclic transmission. We have achieved the redundancy of this cyclic transmission through the use of a pairing function. To be more specific, a station (a control station or standby station) to be paired is designated beforehand so that this station can step in to take over the responsibility of performing data transmissions from the control system in the event that the control system goes down. By virtue of the tracking communications function and the pairing function, it has become possible to build a dual-redundancy system, including a network, without the need for any special consideration at a user program. (See Fig. 3)

In conclusion, also into the future, we are committed to developing products that can contribute to the enhancement of the added value of user systems and equipment by listening to voices in the market well. In parallel with this, we are also determined to make efforts to expand the range of applications for programmable controllers.

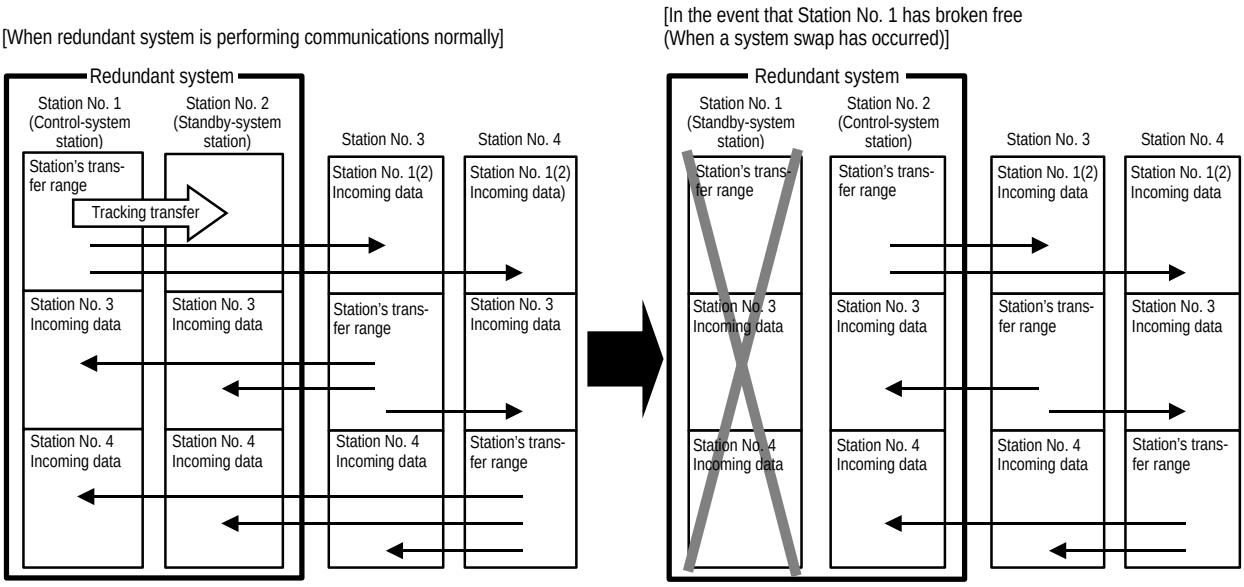



Fig. 3 Conceptual rendering of pairing and tracking

# *Programmable Graphic Operation Terminal "GOT1000 Series"*

Authors: *Kengo Mizusawa*[*] and *Takeyoshi Kondo*[**]

## 1. Foreword

To meet increasingly diversified user needs, we put on the market a range of new programmable graphic operation terminals under the designation "GOT1000 series" in July of 2004. This paper introduces the product features of the GOT1000 series, the technologies we applied to this series, and our future efforts.

## 2. GOT1000 series

In the course of developing the GOT1000 series, we have strengthened basic functions and performance in our relentless pursuit of meeting universal needs for displays such as "high responsivity, the capability to display beautifully, and ease of use." In addition, to meet a variety of market needs, we incorporated new features including a USB transparent function (which can be accessed via a USB port provided on the front), a multichannel function, and an advanced alarm function.

## 3. Product lineup

The GOT1000 series comes in two different versions. One version consists of full-spec models (15", 12.1", 10.4" and 8.4" in screen size and XGA to VGA in resolution) under the model name GT15. They are capable of network communication and covering a wide range of applications. The other is a standard model (5.7" in screen size and QVGA in resolution) under the model designation GT11. This model features a broadened range of basic functions to allow standalone use.

## 4. Thorough strengthening of the capability to meet universal needs for displays

### 4.1 High-speed responsivity

We have enhanced the computation performance of the GT15 by adopting a 64-bit-processing super-scaler RISC (Reduced Instruction Set Computer) chip operating at 200 MHz. In addition, we have increased the speed at which to draw two-dimensional geometric objects by incorporating a proprietary graphic accelerator of our company, Mitsubishi Electric Corp., featuring our high-speed memory access technology. On the communications front, we have inherited the legacy of high-speed communication afforded by a MELSEC Bus connection and incorporated a 115.2-kbps high-speed serial interface in all models as standard equipment by placing importance on high-speed responsivity when a programmable logic controller (PLC) or a microcomputer of a make other than Mitsubishi Electric Corp. is connected.

For use in the GT15, we have established an architecture that is oriented toward high-speed responsivity from the viewpoint of "computation," "drawing," and "communication." As a result, the GT15 has achieved high-speed monitor performance that is more than 4 times faster than that of the GOT-A900 series.

### 4.2 High-quality display

The GT15 has a pallet of 65,536 colors and supports display in the JPEG file format, making it possible for the user to easily create and display highly effective troubleshooting screens by making use of images taken with a digital camera and the like.

One noticeable feature of the GOT1000 series is its ability to "beautifully display text without the user having to worry about layout technicalities" by virtue of the adoption of high-quality fonts, most notably the use of TrueType[*1] fonts that come preinstalled on every Windows[*2] version as well as through efforts to expand the range of font variation in terms of typeface variety and font size.

### 4.3 Large-capacity user memory

The GT15 comes equipped with a large 9 MB of standard memory, expandable up to 57 MB (as opposed to up to 3 MB with the GT11), making it possible to use plenty of image data that is indispensable for displaying effective troubleshooting screens.

## 5. New functions to improve work efficiency and shorten downtime

### 5.1 Contribution to enhanced work efficiency

Into the GOT1000 series, we have incorporated a variety of new functions in order to increase the user's work efficiency and design flexibility.

(1) Increased degree of freedom in system design (Enhanced provision for connections with equipment)

*1 Outline font technology, licensed to Microsoft Corp., that has been widely used as a standard Windows system font since Windows 95.
*2 Name of one of Microsoft Corp's OS series

*Nagoya Works *Himeji Works

In addition to the enhanced ability to connect to a PLC and a microcomputer, the GOT1000 series realized direct connections with a motion controller, servo amplifier, inverter, and temperature controller. Further, we have developed a multichannel function that enables multiple connections to equipment.

(2) Screen design made easy with greater flexibility (afforded by a layer function)
As a solution to performing screen design with greater efficiently and flexibly, we have developed a layer function that permits the user to define the upper-lower relationships of objects to be placed on a base screen and later display thus-prepared objects in layers while maintaining these relationships intact (See Fig. 1). Using this function, the user can arrange objects on top of each other and thereby make effective use of the available display area.

(3) Speeding-up of debugging and boot-up operation (through the use of USB connection)
Compared with the GOT-A900 (using RS232), the GOT1000 series has a shortened screen transfer time by a factor of 20 thanks to its USB download function. What is more, by virtue of the USB transparent function using a front-mounted USB port, transferring screen data and ladder, and implementing ladder monitoring and diagnostics are performed only by connecting the GOT1000 to a personal computer using a USB cable. (See Fig. 2)

### 5.2 Contribution to reducing downtime

In order to increase the user-performed troubleshooting success rate and shorten downtime, we have developed an advanced alarm function that has the following three salient features:

(1) Multiple alarm monitor settings (up to 255 settings) have been made possible. The number of alarm

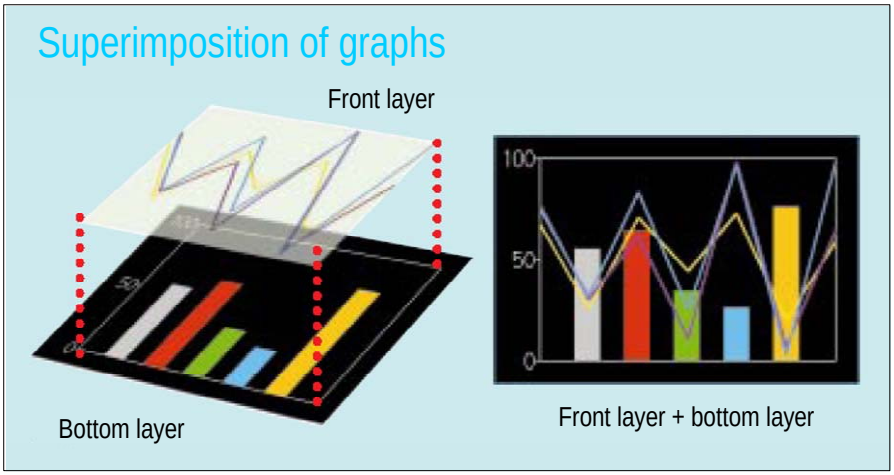



Fig. 1 Layer function

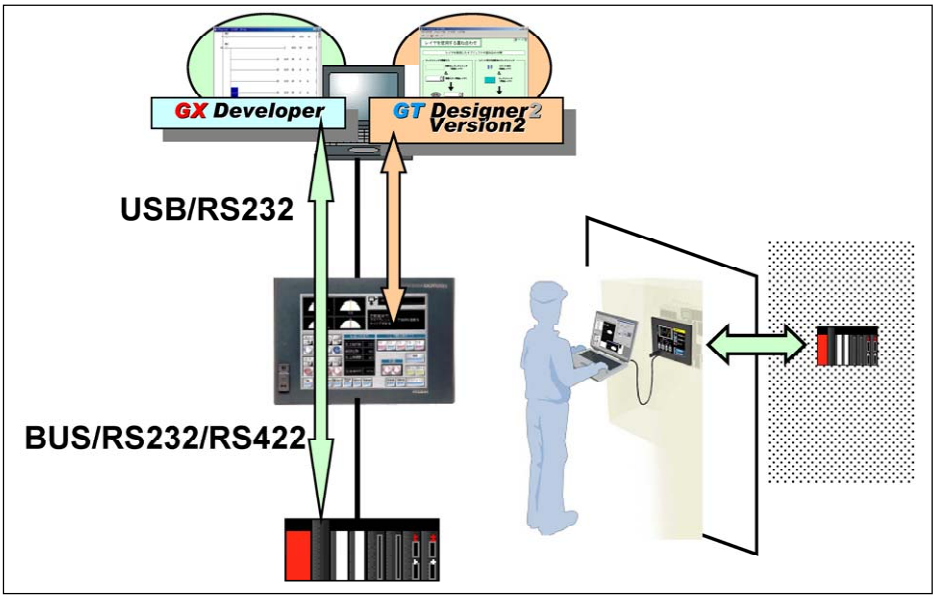



Fig. 2 USB download function and USB transparent function

monitor points has been expanded to a maximum of 32,767 per setting, making it possible for the user to implement layered-alarm-structure management in keeping with the composition of his/her system no matter how large it may be in scale. Thanks to this expansion, alarm information can be presented in a collective manner or on an equipment-by-equipment basis to help facilitate determining the cause of trouble.

(2) An easy-to-understand four-step alarm notification display consisting of “upper-layer alarm” display, “intermediate-layer alarm” display, “general alarm” display and “detailed screen” display has been realized. (See Fig. 3) A variety of search functions powerfully support the operator in taking quick control of the situation and in making quick decisions.

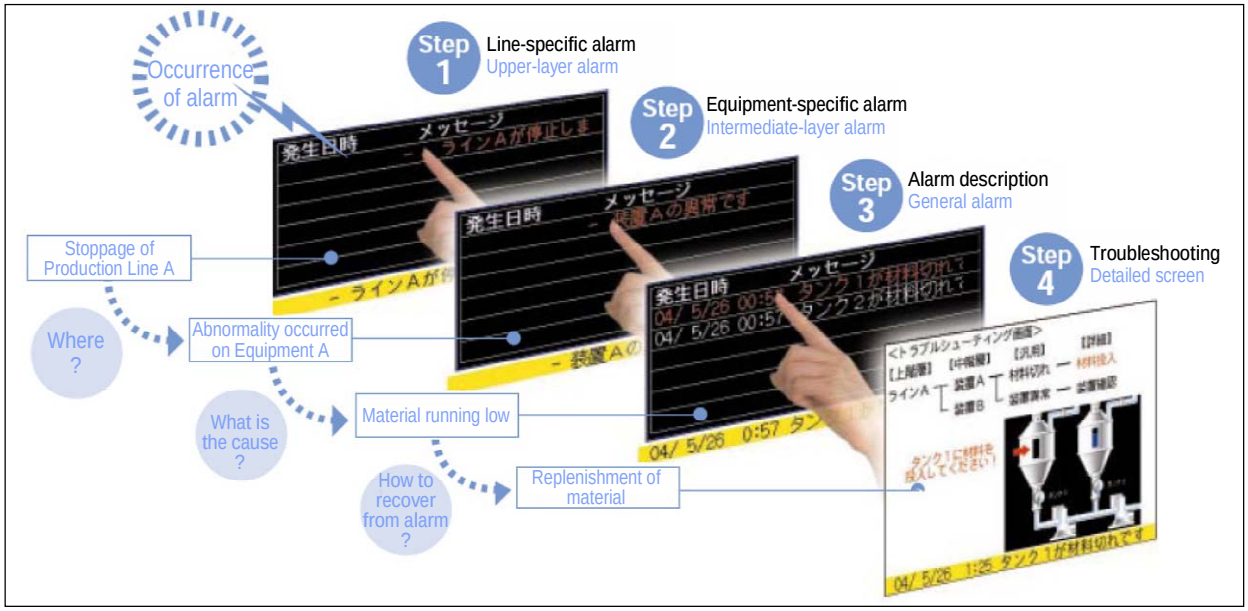



Fig. 3 4-step alarm notification (Advanced alarm function)

# New-design WIRE EDM "FA-S Series"

Authors: *Yoshinori Saigusa*[*] and *Ryougo Koba*[*]

## Article Introduction

The new FA-S wire electric discharge machine has been developed by making improvements and enhancements to its predecessor model in terms of performance and specifications. The promotion of standardization has resulted in cost reductions in excess of cost increases that were caused by improvements made in the specifications. As a consequence, the selling price of the FA-S could be set below that of the predecessor model and could be positioned as a world-strategic machine in an affordable price range. This paper introduces the latest technologies incorporated in the FA-S series and examples of work conducted using it.

## 1. Features of the FA-S Series Wire Electric Discharge Machines

Figure 1 is a photograph of an FA-S series machine, while Table 1 shows the basic product specifications of the series. Descriptions of equipment, circuitry, and adaptive control, all of which have been incorporated into the FA-S as standard equipment, are provided in the sections that follow.

Fig. 1 Externals of the FA10S/20S wire electric discharge machine

Table 1 FA10S/20S basic specifications

| Item | FA10S | FA20S |
|---|---|---|
| Max.workpiece dimensions (W×D×H) [mm] | 800×600×215 | 1050×800×295 |
| Max. weight of workpiece [kg] | 500 | 1500 |
| Dimension of table [mm] | 590×514 | 780×630 |
| Axis movement amount (X×Y×Z) [mm] | 350×250×220 | 500×350×300 |
| Axis movement amount (U×V) [mm] | ±32×±32 | ±75×±75 |
| Wire diameter [mm] | ϕ0.1 to 0.3 | ϕ0.1 to 0.3 |
| Outside dimension (W×D×H) [mm] | 2300×2175×1930 | 2580×2770×2100 |
| Dielectric fluid control | Inverter control (16 steps) | Inverter control (16 steps) |
| <Standard equipment><br>• Soaking specification<br>• Automatic wire threader<br>• Dielectric fluid temperature control unit<br>• XY axis linear scale<br>• Automatic lubrication unit<br>• Long stroke T/C (*1) | <Remarks><br>(*1) Only for FA20S | |

(1) Provision to handle thin wire newly added as standard

In recent years, when metal molds have been moving toward increasingly finer geometries, there have been growing calls to reduce the diameter of the wire to be used in wire electric discharge machines. To address such needs, an automatic wire threader capable of handling fine wires measuring 0.1 and 0.15 mm across, which was an option of previous models, has been added to the FA-S series as standard equipment for micromachining purposes.

(2) Provision to enable high-precision machining

The FA-S series is outfitted with X- and Y-axis linear scales as standard equipment to ensure stable positioning accuracy for extended periods of time. In addition, it is also equipped with "all-axis (X, Y, Z, U, V) high-precision, absolute-value control." In the event of a power outage during machining, this control feature enables the FA-S to resume and continue high-precision discharge-machining operation upon restoration of power from where it left off.

(3) Provision to enable high-quality machining of

*Nagoya Works

large-angle tapers

Also in the case of taper equipment, a long-stroke taper unit designed to increase the UV stroke to ±75 mm from ±32 mm, which used to be the norm, has been mounted as standard equipment. By virtue of this, the FA20S, which is often used for machining considerably thick plates, is capable of performing taper cutting up to 15 degrees with a slab thickness of 260 mm. Furthermore, by using a new-type diamond die capable of large-angle taper cutting up to 45 degrees and a new control method, a new option (angle master) that enables high-quality machining up to 45 degrees has been made available. With the help of this option, the FA20S is now capable of taper cutting up to 45 degrees and 40 mm in slab thickness without leaving streaks.

Figure 2 is an example of a workpiece that has been worked on using the angle master.

(4) Fine finish circuit without a device for insulation

There have been options with which to realize a machined surface roughness of less than 2 μm $R_y$. However, such options were burdened by a number of constraints, such as the need to place an insulating jig on top of the surface plate and perform workpiece setups at a place other than the surface plate. However, the "fine finish circuit without a device for insulation" mounted on the FA-S series as standard equipment can achieve a surface roughness of 1.5 μm $R_y$ under the most favorable conditions with the workpiece placed directly on the surface plate. This has resulted in not only enhanced ease of setup but also enhanced ease of introduction of automation for such purposes as automatically changing workpieces by means of industrial robots.

Figure 3 shows an example of workpieces that have been machined using "the fine finish circuit without device for insulation."

(5) Various kinds of adaptive control

PM control is a type of adaptive control designed to maximize machining efficiency while preventing the wire from breaking by optimizing machining conditions through automatic determination of the thickness of work along with changes in this thickness. In the case of PM4 control, a function has been newly added to control the flow rate of dielectric fluid being jetted out to the location where the workpiece is being worked on, in keeping with changes in the thickness of the slab. Since the cutting speed reductions required for corners (where the wire tends to break) can be reduced to a minimum, a 20-percent increase in machining speed has become possible.

In the case of work whose thickness changes in the course of cutting, finish-machining used to be a difficult job because level differences tend to develop or streaks tend to be left in places where the slab thickness abruptly changes, requiring rework to be performed later on. In contrast to this, the FA-S series addresses this difficulty by incorporating SL control, a function that is very effective in reducing level differences on to-be-finished surfaces of work whose thickness varies abruptly. With SL control, it is possible to reduce level differences that used to measure approx. ±3-7 μm to less than ±2 μm. By virtue of this control, high-precision machining and automation of parts with complex geometries such as stair-step shapes can be performed.

(6) Approach to reducing running costs

Reductions in running costs directly translate into increases in the user's profit, which, in turn, constitute great requirements. The FA-S has achieved running cost savings of up to 40 percent compared with its predecessor through the incorporation of new technologies with which to reduce power consumption and the wear and tear of its parts. As a representative example, we consider power consumption reduction technology. In the case of the predecessor series, a dielectric fluid temperature control unit (e.g. a cooler) was installed in the circuitry responsible for supplying dielectric fluid to the locations being worked on. In order to supply cooled dielectric liquid to in-between electrodes in this manner, a large-sized, high-wattage feed pump (P1) was required. What is more, since liquid temperature control had to be turned on at all times even when machining operation is not in progress, the cooled liquid was circulated through by-pass circuitry all the time. The power consumed by this continuously running pump

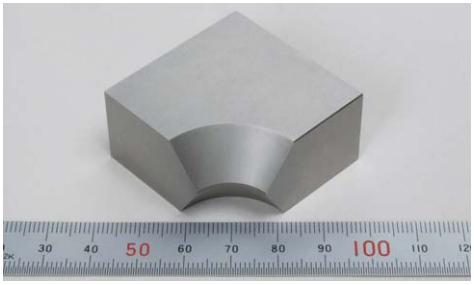



Fig. 2 Processing sample of angle master

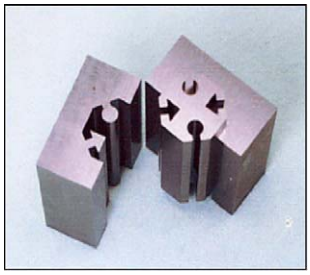


Fig. 3 Processing sample of a fine finish circuit without a device for insulation

(P1) was greatly responsible for worsening running costs. Given this situation, in the case of the liquid circuit adopted on the FA-S, the cooler was installed in a closed circuit and an inverter-powered pump whose operation is controlled by pressure was used for P1. As a result, a small-sized circulation pump (P7) for liquid temperature control has become the sole remaining pump that stays energized at all times. Since P1 can now be energized only when needed and only for the required lengths of time, the overall power consumption of the machine has decreased by one-half.

## 2. In Conclusion

We have introduced the FA-S-series wire electric discharge machines and the new technologies that have been incorporated into them. The FA-S series represents our world-strategy machines for high-performance general-purpose wire electric discharge machines for which the highest sales volume can be expected in the market at the present time, and they are being watched with keen interest as next-generation standard machines in the market. Also into the future, we are committed to continually meeting market needs, while, at the same time, working on the development of new technologies and products to open up new market areas.

# New-design Die-sinking EDM "EA12V"

Authors: *Toshihiro Enya*[*] and *Naka Sakakida*[*]

## Article Introduction

We have developed the "EA12V" high-performance die-sinking EDM targeted at a broad range of users, from those involved with cold-forged dies to those concerned with dies for fine-pitched subminiature connectors. In order to address diverse machining needs, we have mounted a newly developed power supply as standard equipment, which has made the EA12V a cut above its predecessors in machining performance. Furthermore, we have adopted a mechanism construction and features that make the EA12V easier to use.

## 1. Major Features of the EA12V Die-sinking EDM

Figure 1 shows an external view of the EA12V, while Table 1 shows its basic specifications.


Fig. 1 General view of EA12V

Table 1 Machine specifications

| Working tank type | | Elevating tank type |
|---|---|---|
| Working tank internal dimensions (W×D×H) | [mm] | 850×600×350 |
| Maximum workpiece dimensions(W×D×H) | [mm] | 800×550×250 |
| Maximum workpiece weight | [kg] | 700 |
| Table size (W×D) | [mm] | 700×500 |
| XYZ-axis machining range | [mm] | 400×300×300 |
| Maximum electrode weight | [kg] | 50 |
| Machine unit dimensions (W×D×H) | [mm] | 1325×2050×2365 |
| Dielectric fluid tank capacity (initial) | [L] | 340 (400) |
| Type of power supply | | FP80V |
| Control specifications | | C21EA-2 |

### 1.1 Incorporation of the FP80V high-performance power supply as standard equipment

We have developed the FP80V ultra-high-performance power supply and installed it in the EA12V as standard equipment in order to work on a variety of workpieces. Conventionally, an optional power supply was used to work on tungsten carbide. Now, such hard-to-machine material can be worked using the EA12V equipped with standard specifications alone. Furthermore, in parallel with the optimization of the length of the feeder to supply power to the electrode and the workpiece, machining performance has been significantly enhanced compared with that powered by the conventional power supply. What is more, the power consumption of the new power supply is approx. 20 percent lower than that of the conventional power supply.

### 1.2 Enhanced mechanical rigidity and precision

We have implemented the optimum design of the mechanism structure using the latest analysis tools. As a result, we have raised the mechanical resonant frequencies of the EA12V to higher than those of its predecessors, thereby achieving an increase in mechanical rigidity.

To meet high-precision machining needs, we have installed linear scales on all X-, Y- and Z-axis drive arrangements as standard equipment to enhance the machine's static accuracy. In addition, in order to reduce thermal displacements of the machine proper caused by temperature changes in the vicinity of the machine, we have covered the entire machine with sheet metal, as shown in Fig. 1, to structurally prevent outside air from coming into direct contact with the structure of the machine. On top of this, the incorporation of a displacement temp. compensation system as a standard feature has reduced heat-caused displacements by more than half for all axes compared with the predecessor models, thereby making it possible to stably maintain high mechanical precision for extended periods of time.

### 1.3 Realization of savings in space

We have installed a dielectric fluid tank behind the machine to hold dielectric fluid and thereby united the tank to make it an integral part of the machine. Furthermore, we have optimized the external dimensions of the new power supply and achieved savings in space

*Nagoya Works

by 10-percent reductions in both width and depth directions and by a 20-percent reduction in the footprint compared with the predecessor models.

### 1.4 Reductions in setup time

The working tank is designed in such a way that three of its sides (front, right, and left) move up/down automatically in order to increase the number of working-tank height settings (preset fluid levels), each of which can be automatically established. Thanks to this, it has become possible to set the height in finer increments and in shorter lengths of time. Since the working tank can be opened in the three directions, operator accessibility to the machine table has been enhanced and a structure that enables work to be carried into and removed from the machine table with the help of a hand lifter has been provided. These structural contrivances have resulted in enhanced workability in setups and changeovers.

### 1.5 Adoption of new dielectric fluid circuit

By capitalizing on the adoption of a new dielectric fluid circuit, we have newly incorporated a "high flow mode" in which to instantaneously flush away sludge that has been generated in course of machining operation. In this mode, fluid is supplied on a high-flow basis from the rear of the working tank to create a flow of the fluid. Under the action of this flow, sludge that has been generated in large amounts during coarse machining is removed to stabilize machining operation. Furthermore, during ordinary machining, the operator can adjust the liquid flow rate to his/her liking; he/she can turn off the high flow mode and proceed with machining operation in medium flow mode or stop the fluid flow by manually making a fine adjustment with the hand-operated valve when working on an elaborate electrode or the like that is highly susceptible to the effect of liquid flow.

Moreover, as shown in Fig. 2, we have newly incorporated a "fluid conditioning mode" since, when it is necessary to perform high-precision machining, it is necessary to bring the temperature of the machine into agreement with that of the fluid by circulating the temperature-controlled dielectric fluid inside the working tank after completion of work setup. By virtue of this "fluid conditioning mode," it has become possible to bring the temperature of the table, jigs and so on to that of the temperature-adjusted dielectric fluid beforehand by circulating the fluid only around the table while the operator is working on work setup.

Added to this, we have newly installed a liquid circuit dedicated to a manual cleaning operation to wash away any sludge that has been deposited around the work after completion of the machining operation.

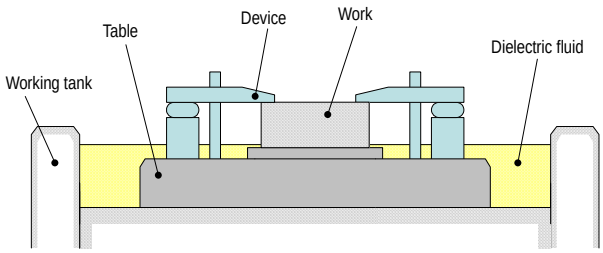



Fig. 2 Concept chart of fluid conditioning mode

### 1.6 Enhanced filtering efficiency

To efficiently remove cuttings generated in course of machining, we have added two filters as standard. We have reduced their mesh diameter and increased the effective filtering area that can actually collect sludge. Compared with their predecessors, these filters can now trap finer sludge and now have a longer lifespan before replacement.

### 1.7 Enhanced maintainability

Sections requiring maintenance such as filter replacement, supply/draining of lubrication oil, cleaning of the filter at the air inlet, and replenishment of the lubricator have been collectively installed onto the rear of the machine for enhanced workability. What is more, we have installed a pressure gauge next to the working tank to let the operator check the gauge from the front at any time and give him/her an approximate idea of when to replace the filters. We have also made structural provision to change the two filters one by one in order to permit the operator to perform a filter-changing operation without having to stop the machine.

### 1.8 Provision for introduction of automation

In order to meet recent years' automation needs, we have made provision to enable the EA12V to work in concert with automated electrode/work replacement systems such as Work Pal and Work Master. In addition, installing the power supply on the left-hand side of the machine makes it possible for the user to configure an automation system in which a single robot controls two EA12Vs units, arranged on the right and left. Through the use of such additional equipment, it is possible to significantly increase the uptime of the machine.

## 2. Example of a Machined Workpiece

Figure 3 and Table 2 show an external view of a workpiece processed with the EA12V and the results of the processing, respectively. This processing represents an example of a sample prepared by high-speed processing of tungsten carbide. This sample has the shape of a hexagon die and undergone electric discharge machining down to a depth of 10 mm. When preparing this sample, we realized high-speed coarse processing (1.0 g/min. max.) using the standard power supply. This processing speed is approx. 1.6 times the

speed of the predecessor models. Better yet, the wear of electrodes has decreased by approx. 30 percent, making it possible to reduce the required number of electrodes per processing.

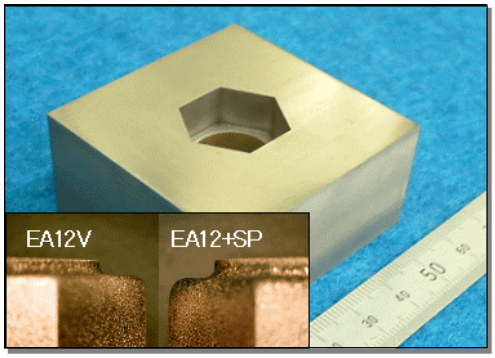



Fig. 3 General view of processing case

Table 2 Result of processing case

| *EA12V EDM Sample* | |
|---|---|
| Work | G8 (tungsten carbide) |
| Electrode | CuW two |
| Undersize | 0.120-0.020 mm/side |
| Time | 36 min |
| Accuracy | –0.008 to –0.002 mm |
| Roughly | Ry: 11.701 Ra: 2.709 |

In conclusion, the EA12V we have developed this time has won a distinguished JSIM award presented by the Japan Society of Industrial Machinery Manufacturers at the 35th Machine Industry Design Award. With this award as an incentive, we are committed to developing machines that satisfy the increasingly high demands of mold builders.

## Bibliography

(1) The latest FA equipment and industrial processing machinery by Toshihiro Enya *et al*., Mitsubishi Technical Report 3 No. 3 Vol. 79 2005

# A Compact High-power Diode-pumped Solid-state Laser (ML45LS)

Authors: *Shuichi Fujisawa** and *Toshiaki Watanabe**

## Article Introduction

We introduce the ML45LS, a new generation of diode-pumped solid-state laser which is an upgrade of our conventional product series. The output power of the ML45LS is set to 4.5 kW, which is the most practical value for high-power laser applications. The ML45LS is designed to be user-friendly based on our experience with practical production lines using our conventional lasers.

## 1. Background of Development

Diode-pumped solid-state lasers, which use a semiconductor laser for the pump source, are recently attracting attention as a solution to the problems of efficiency and maintenance costs associated with the conventional lamp-pumping scheme. When a semiconductor laser is used as a pump source, the efficiency can be dramatically improved by matching the wavelength of the semiconductor laser to the absorption band of the laser. Furthermore, the lifespan of the pump source typically exceeds 10,000 hours, which is an order of magnitude longer than the life of the discharge lamp.

The ML45LS, illustrated in Figure 1, can generate the laser power of 4.5 kW, which is the most practical power for demanding applications, and is designed with ultimate usability for the user in terms of high reliability, space-saving footprint and ease of maintenance. The ML45LS can be used for a wide variety of high-power laser applications, such as high-speed welding and deep penetration welding.


Fig. 1 Diode-pumped solid-state laser ML45LS

## 2. Basic Configuration

Table 1 lists the specifications of the ML45LS, and Fig. 2 shows the configuration of the oscillator. The ML45LS can generate an output power of 4.5 kW with its four cavities arranged in series, each of which functions as the basic unit of a diode-pumped solid-state laser. The laser beam that is emitted from the oscillator is coupled to a step-index-type optical fiber with a core diameter of 600 μm and then delivered to the desired destination. All key components of the ML45LS, from diode modules to cavities and power supplies, have been developed in-house. Therefore, customers can be assured of supreme reliability throughout all stages, from production to quality control.

Table 1 Specifications of ML45LS

| Type | | ML45LS | Note |
|---|---|---|---|
| Oscillation wavelength | | 1.064 μm | |
| Oscillation mode | | CW | Continuous pumping by diode lasers |
| Max. output power | | 4,500 W | At the amplifier output |
| Optical fiber | | 600 μm | Step Index (SI) type |
| Dimensions | W | 2,400 mm | Excluding projections |
| | D | 800 mm | |
| | H | 1,600 mm | |
| Weight | | 2,500 kg | Typical weight including cooling water |
| Max. electrical input | | 58 kVA | |

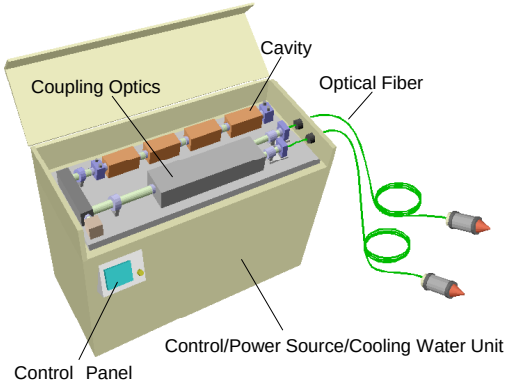



Fig. 2 Configuration of ML45LS

## 3. Technical Features

For the ML45LS, we developed a unique homogeneous pumping technology (CIDER scheme: Close-coupled Internal Diffusive Exciting Reflector

*Nagoya Works

scheme) to improve oscillation efficiency, the configuration of which is shown in Figure 3. In the CIDER scheme, a YAG rod is placed in a cylindrical diffusive reflector. Pumping lights from a diode laser are confined in the reflector and recycled for the pumping of the YAG rod.

Consequently, an electrical-to-optical efficiency of 18% has been achieved, which is, to our knowledge, the highest efficiency for rod-type YAG laser products.

In addition, for the ML45LS, we greatly reduced the dimensions of the oscillator body to be incorporated by newly developing a cavity with an output power rating of 1 kW or more. For the power source unit, we more than doubled the output capacity without increasing the physical volume of the unit by adopting a new scheme that incorporates our proprietary small-sized IPM (Intelligent Power Module). As a result, a footprint of 1.9 $m^2$ (for the oscillator main body), which is among the world's smallest for a 4-kW-class high-power solid-state laser, has been achieved.

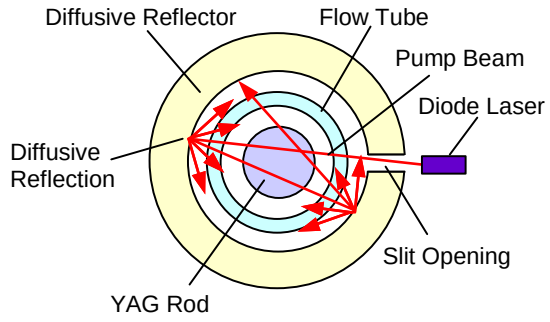



Fig. 3 Cross-sectional view of CIDER pumping configuration

Regarding the diode module, which is a key component for reliability, we also employ an in-house product, whereas many other oscillator manufacturers purchase diode modules from dedicated manufacturers.

These diode modules have been developed based on our wealth of expertise and technologies, ranging from thermal fluid mechanics for cooling the modules to quality control techniques, accumulated in mass-producing semiconductor lasers for consumer electric/electronic equipment.

## 4. Ease of Maintenance

To keep the oscillator normal and safe, more than 300 operating conditions such as output power, temperatures of various components, state of beam shutter and so on, are monitored.

Information on the states of the oscillator can be easily checked using the operation screen as shown in Figure 4, which is invaluable for daily and periodical maintenance.

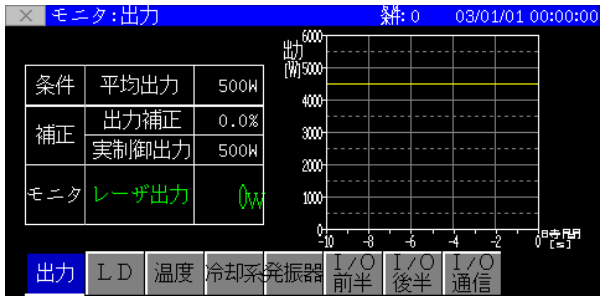



Fig. 4 Control panel display (Power monitor window in Japanese)

Remote monitoring via LAN or telephone lines is also possible as an optional specification.

In principle, the oscillator can be accessed from the front for maintenance, including daily checks by users and advanced checks by our service engineers through site visits.

In addition, the main components have been designed to be unit-to-unit replaceable. Not only optical components such as the cavities and beam shutters, but also the power source unit, control unit, and cooling water unit can be replaced from the front.

For external control of the ML45LS, CC-Link (Control & Communication Link) connection, which provides high-speed networking, is available as an optional specification in addition to the standard I/O connection. The CC-Link connection not only drastically reduces wiring but also allows sophisticated remote control of the oscillator such as specifying an output power and reading out error codes.

## 5. Applications

The ML45LS is already widely used in production, particularly in the automotive industry, ranging from the stitch or continuous welding of automotive bodies to tailored-blank welding and continuous welding of formed pipes.

Because of the nature of wavelength, the YAG laser has higher potential for laser processing compared to the $CO_2$ laser. Furthermore, since the wavelength of the YAG laser is one-tenth of that of the $CO_2$ laser, the laser beam can be delivered through optical fibers, which is a major advantage of the YAG laser. Moreover, the absorption ratio of metals is larger and interference of plasma induced by laser irradiation is less than that of $CO_2$ lasers.

Figure 5 shows the welding characteristics of the ML45LS.

Currently, laser-processing technologies using the ML45LS are actively being studied to extend the scope of applications to outside of the automotive industry, such as railroad vehicles, the steel industry, and precise welding of electric equipment.

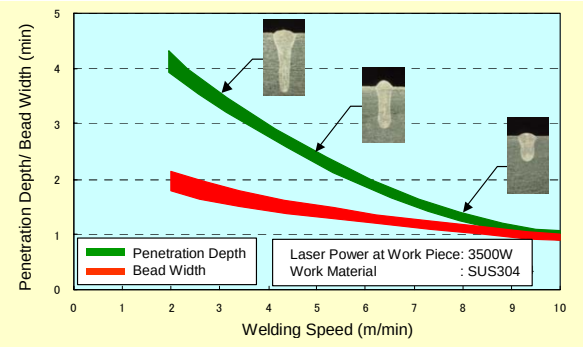



Fig. 5 Welding characteristics of ML45LS

We consider the ML45LS to be a practical industrial tool for a wide variety of applications taking advantage of its excellent features such as one of the world's smallest footprints and ease of maintenance. We will continue to develop products tailored to users' needs so that diode-pumped solid-state lasers become commonplace in various fields of manufacturing, while concurrently extending our lineup of oscillators and laser processing technologies.

# *New Laser Processing Machine for PCB Drilling "ML605GTW-5150U"*

Authors: *Masashi Naruse*[*] and *Kenichi Ijima*[*]

## Article Introduction

Printed circuit boards (PCBs) for IT equipment including personal computers and mobile phones have been becoming denser in step with the growing functionality of such equipment. Given this situation, PCB hole counts have been on the increase year after year. In the PCB drilling process, reductions in hole diameter and increases in precision and productivity have become major challenges to be addressed.

Furthermore, new laser drilling technologies are being sought in connection with changes in PCB material as well as changes in the ways that PCBs are bored due to changes made to PCB manufacturing processes.

To address such needs, we have developed the ML605GTW-5150U laser-drilling machine equipped with two $CO_2$ laser heads capable of drilling two workpieces (panels) at a time (hereafter referred to as the GTW). Figure 1 shows the outward appearance of the GTW. This paper introduces the major features of the GTW.

## 1. GTW Features

### 1.1 Simultaneous drilling of two workpieces

Figure 2 shows the arrangement of the processing heads, while Table 1 shows the specifications of the GTW. As opposed to its predecessor model equipped with a single head, the GTW is outfitted with two heads in order to perform the simultaneous drilling of two PCBs. Thanks to the dual-head configuration, significant savings can now be achieved in per-PCB table travel time, work load/unload time, alignment mark read

Fig. 1 Photograph of ML605GTW-5150U

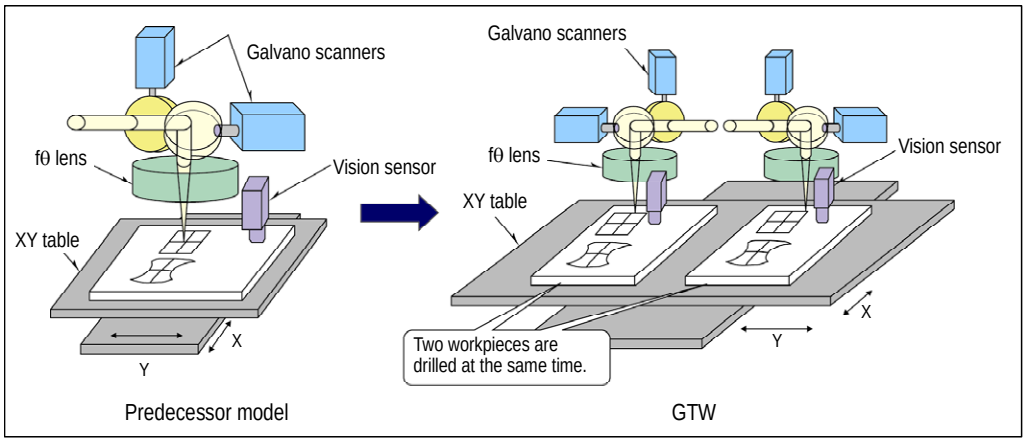



Fig. 2 Configuration of the processing head

*Nagoya Works

Table 1 Specifications of the GTW

| Item | | | Specification |
|---|---|---|---|
| System | Outer dimensions (in mm) | Laser-drilling machine (Resonator + controller + L/UL) | 4100W×2550D×2270H (incl. signal tower) |
| | | Cooling unit | 1540W×670D×1765H |
| Laser-drilling machine | XY table | Workpiece dimensions (mm) | 620×560 |
| | | Max. feed speed (m/min) | 50 |
| | Galvano scanner | Scanning freq. (1-mm pitch) | 1400×2 |
| Resonator | Laser type | | $CO_2$ laser |
| | Output power (W) | | 150 |
| | Pulse freq. setting (Hz) | | 10 to 6200 |

time and so on. We have adopted our proprietary simultaneous beam-splitting technology to bifurcate the laser beam to the two heads, enabling drilling of two workpieces at the same time.

### 1.2 High-speed galvano scanners

The galvano scanners are the optical parts responsible for performing high-speed high-precision positioning inside the processing heads as shown in Fig. 2. The galvano scanners we have developed this time are characterized by their enhanced drilling speed, made possible by increasing hole-to-hole pitch travel speed. As a result, compared with the predecessor model, an increase of from 1200 Hz to 1400 Hz with 1-mm pitch travel or from 1600 Hz to 1800 Hz with micropitch travel has been achieved.

### 1.3 High-output high-frequency resonator

Commensurate with the increase in the speed of the galvano scanners, the need to increase the resonator's beam pulse frequency also arises. We have, therefore, achieved an increase in output power by developing a new high-frequency inverter unit. Compared with the predecessor model, the rated output power has been increased by 1.5 times from 100 W to 150 W, while the resonation frequency has been raised by a factor of more than 1.2 from 5.0 kHz to 6.2 kHz. What is more, the prolongation of mirror life and an improvement in pulse stability have been achieved.

### 1.4 Optical control technology

We have developed an energy-up unit. Thanks to this unit, it has become possible to collect and condense a laser beam with high density and control beam/mode shaping. An example of the effects of using the energy-up unit (which is available as an option) is shown in Fig. 3. In the case of conformal processing, when there was a misalignment between the center of the laser beam and the center of a to-be-etched hole, there were cases where some resin remained in the laser-etched hole. Now, with the help of the newly developed energy-up unit, it has become possible to produce excellent laser-drilled holes even when there are such misalignments.

## 2. Example of a laser-drilled hole

Figure 4 shows an example of a hole laser-drilled in a package board. Since the taper of the drilled hole has increased to 75 percent, the hole diameter at the bottom has increased and, as a result, it has become possible to decrease the hole diameter at the top to 55 μm. Figure 5 is an example of copper direct proc-

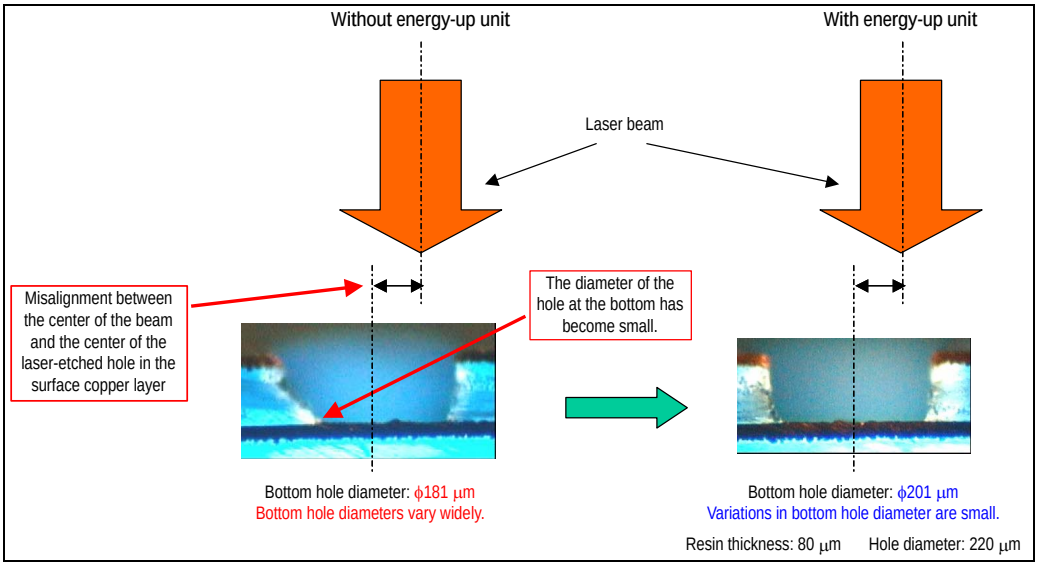



Fig. 3 Case with effect of energy-up unit

essing of a motherboard (FR-4). As can be seen from this, an improvement in circularity has been achieved.

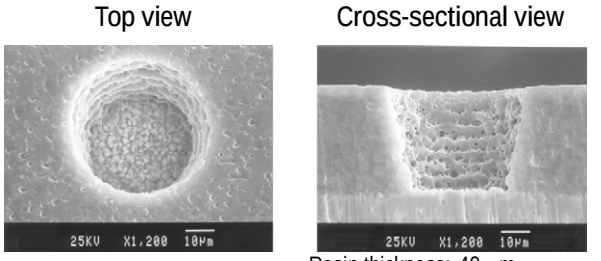



Fig. 4 Hole processing on the package PCB

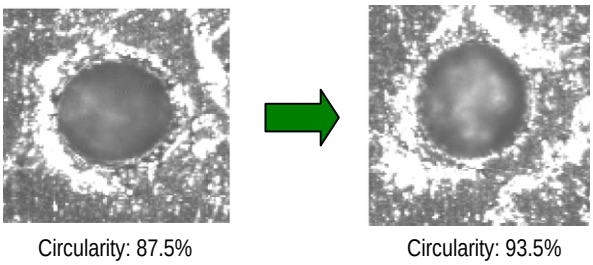



Fig. 5 Copper direct processing (FR-4)

We have so far introduced the ML605GTW-5150U $CO_2$-laser, 2-head, 2-workpiece drilling machine that brings high productivity. With the evolution and proliferation of IT, portable terminal equipment is becoming more sophisticated in functionality and is decreasing in size. Given this situation, PCBs are expected to become denser still. Where the drilling of PCBs is concerned, $CO_2$ lasers are very much in the mainstream. However, as downsizing proceeds further, the adoption of third- or fourth-harmonic YAG lasers is considered to increase. It is, therefore, necessary for us to make stepped-up R&D efforts at developing such YAG lasers for further increased productivity.


MITSUBISHI ELECTRIC CORPORATION