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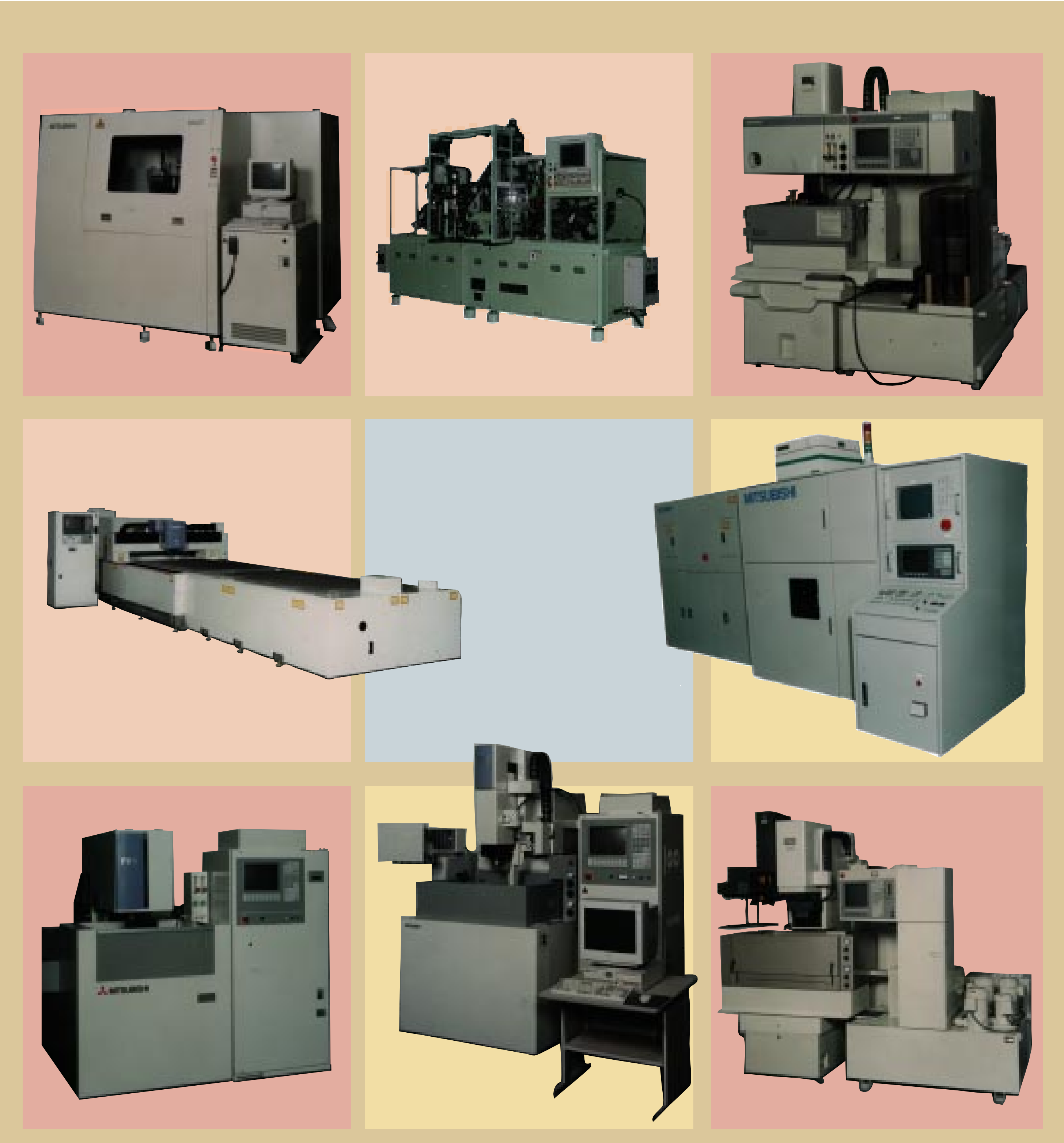
MITSUBISHI ELECTRIC ADVANCE



MITSUBISHI ELECTRIC

A Quarterly Survey of New Products, Systems, and Technology

●Vol. 81/Dec. 1997 Mitsubishi Electric **ADVANCE**

New Frontiers of Mechatronics in Manufacturing Processes Edition

CONTENTS

Our cover is a montage of representative models from our range of industrial processing equipment. They represent revolutionary advances in industrial processing at the borderline between mechanical and electronic technology known as "mechatronics," using the spectacular progress being made in electronics to meet the increasingly severe demands for high precision, uniformly high quality and higher productivity in many sectors of industry, including automotive engineering.

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Foreword

The Character and Roles of Electrical Machining

*by Takahisa Masuzawa**

The technologies of the milling and grinding machines that have been a familiar sight in factories ever since the industrial revolution are now being supplemented by non-traditional methods of processing based on quite different principles and approaches developed in recent years. These methods were developed specifically to perform processing impossible, either in principle or in practice, with conventional methods.

An example of this is the dies for die-cast molding, which are made of tempered steel. These dies could not be ground to shape using tools made of the same tempered steel, so they had to be machined *before* being tempered. The deformations that occurred as a result of the tempering process had to be corrected in a subsequent process that was both difficult and time-consuming. Then came the innovation of electrical-discharge machining (EDM).

EDM uses the repeated generation of small electrical “spark” discharges to create instantaneous localized high temperatures that melt and disperse the material being machined, independent of its degree of hardness. This enables the direct, high-precision processing of tempered steel. Again, because there is no need to rotate the workpiece or the jigs and tools, complex three-dimensional shapes including sharp corners, virtually impossible to create with conventional machining, rapidly became possible. This method has been widely adopted in machine shops and is indispensable in producing dies, etc.

Many such non-traditional methods use electrical energy, for example laser-beam, electron-beam, ion-beam and electrolytic methods. Their operating principles are fundamentally different from conventional methods of milling, etc. that remove material by force, and this gives them an overwhelming advantage in certain applications. We have seen how this is so for EDM; laser-beam processing makes a similar use of heat. Because it uses no force, it is readily used to cut thin sheets that have already been shaped without deforming them, something impossible using conventional methods. While it may not provide quite the same high precision as EDM, it is extremely fast, making it ideal for mass production.

Naturally, these electrical methods can also be used for normal materials and common shapes, an area where they come into competition with conventional methods. Which method will be selected in a particular application generally depends upon technical issues and resources. Currently, a large proportion of such applications are handled by conventional milling and other machinery, but the inroads being made by electrical methods are too large to be ignored.

Most important, however, are the large inherent advantages of these methods, and they alone offer the prospect of responding to the future needs of the factory shop floor. With current moves towards more sophisticated materials and more severe machining requirements, for instance in amorphous materials, fiber-reinforced materials, micro-processing, and in the high-speed production of small lots of multiple product variants, electrical methods are becoming increasingly important. As the technologies improve, the processing systems that employ them will also find wider applications in contention with conventional methods. ❑

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Extending the Limits of Machining Technology

*by Mitsuo Yonetani and Tamio Takawashi**

This report reviews advances in three specialty machining technologies: electrical-discharge machining, laser processing and electron-beam processing. These methods have extended the limits of manufacturing technology and are contributing to dramatic innovations in product development and manufacturing capabilities.

Electrical-Discharge Machines (EDMs)

Electrical-discharge processing has found extensive use in die-manufacturing for high-precision forging, casting, molding and stamping applications in the automotive, electric and electronics industries.

DIE-SINKING EDMs. A major advance in machining quality has been achieved by suspending fine silicon particles in the dielectric fluid. The silicon particles improve the dielectric performance, yielding hard die surfaces that resist abrasion and corrosion, and are free of the heat-induced surface cracks and arcing discoloration that accompany the use of conventional dielectrics. In addition, maximum tool area under mirror finishing has increased to $100cm^2$, and this capacity increase can be utilized for productivity enhancement.

Other problems of die-sinking EDMs are the delays and cost of manufacturing the specially shaped copper or graphite electrodes required to transfer a specific pattern to a workpiece. These factors are especially noted in dies for miniature electronic components, since the complicated electrode shapes and patterns require numerous machining operations. Low-wear machining conditions spread the cost over a larger number of dies, but only at the expense of somewhat lower machining speeds.

Mitsubishi Electric has developed a technique using copper pipe electrodes to produce the same sorts of shapes as die-sinking EDMs without the cost and trade-offs of specialty electrode manufacture. An “electrical-discharge scanning” process controls the pipe electrode under high-wear conditions for faster machining. Accuracy is maintained by measuring and compensating for electrode wear in realtime, which yields die quality comparable to die-sinking EDMs (Fig. 1) and vastly superior to that achieved with a simple copper rod.

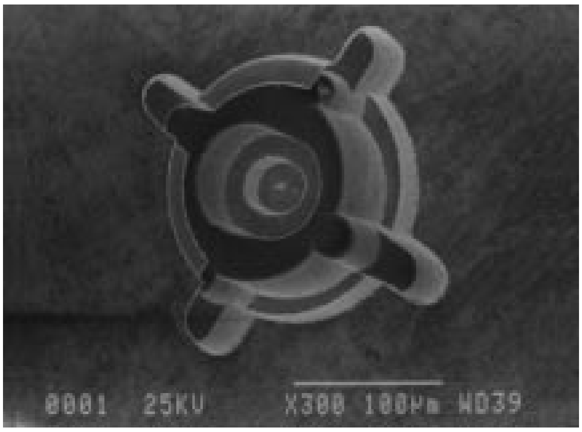

Fig. 1 A tiny die used in electronic component manufacturing.

WIRE-CUT EDMs. Better performance, functionality and cost effectiveness are bringing wire-cut EDMs into competition with mechanical die-production processes, especially in the semiconductor and electronic component industries with their demands for high-quality, high-precision and short product development cycles.

Wire-cut EDMs can produce high-precision dies for stamping IC lead frames with greater consistency than mechanical processing. The corporation has developed wire-cut EDM technologies for this application including an antielectrolysis power supply that minimizes surface stress and reduces the thickness of the stressed layer in both first-cut and finish machining, and an ultrasmooth surface finishing power supply (FSII) that yields a surface finish comparable to the best mechanical processes (Fig. 2).

The next generation of high-precision wire-cut EDMs is incorporating highly rigid structural members, precise wire tension control, discharge monitoring and control, and other advanced technologies that promise even wider use of wire-cut EDM processing in semiconductor and electronic component manufacture. We expect to see continued improvements in

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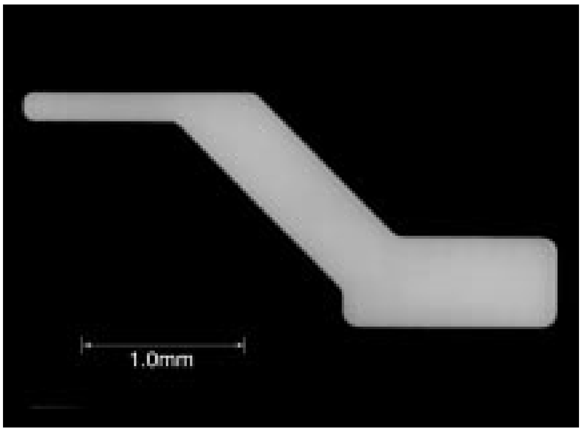

Fig. 2 An example of ultraprecise die machining by the FSII EDM power supply.

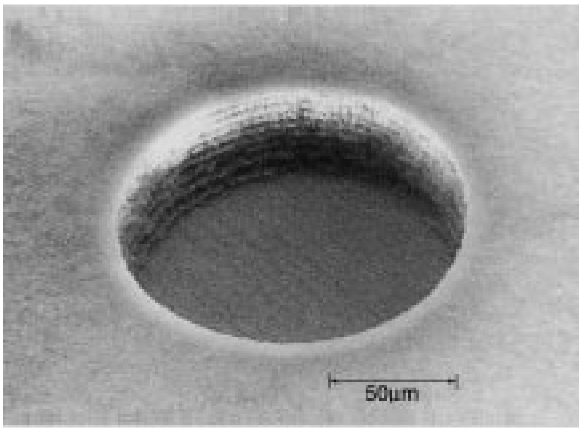

Fig. 3 Blind via hole processing by a short-pulse CO_2 laser.

precision, cost and processing speed in the future.

Laser Processing Machines

Recent increases in processing speed make laser processing machines increasingly practical for cutting shapes out of sheet metal. Laser processing machines are beginning to replace the several hundred thousand turret-head stamping machines currently used in Japan, and can serve as the basis for a cost effective sheet-metal processing cell.

Internationally, demand for three-axis laser processing machines is high due to strong investment in high-productivity equipment, particularly in large-scale sheet-metal forming operations where minimizing die production costs is essential.

Laser-based welding and surface treatment processes are also being developed for the specialty processing niche that accounts for about 10% of the market.

The corporation is now producing CO_2 lasers, high-output solid-state yttrium aluminum garnet (YAG) lasers and excimer lasers that perform cutting, welding and hole-drilling on micromachining scales beyond the capabilities of mechanical processing. Development continues in the areas of laser oscillators, control systems and peripheral technologies to support even wider applications.

SHORT-PULSE CO_2 LASER PROCESSING MACHINES. Advanced CO_2 laser technology is being applied to hole drilling in printed-circuit boards (PCBs). To help shrink the PCBs used in compact information equipment, 300µm-diameter through holes and blind via holes are being introduced (Fig.3). The corporation has developed a high-speed laser drilling system for producing these holes using a three-axis orthogonal CO_2 laser with high peak power and short pulse duration, a special optical system and a high-speed, ultraprecise table drive. The system can drill holes in conventional glass-epoxy PCB materials with minimal thermal effects. This solution is more general than drilling by photochemical reaction, which requires a special PCB material. Continued improvements in the laser drilling system are expected to lead to wider applications and fine-pattern processing capabilities approaching the minimum hole diameter for the optical wavelength.

HIGH-OUTPUT SOLID-STATE LASER PROCESSING MACHINES. YAG lasers are being applied to welding applications previously performed by CO_2 lasers. Conventional YAG lasers have a practical output ceiling of about 100W. Higher outputs cause thermal distortion to occur in the YAG rod, resulting in a large spot size that slows deep welding operations. The corporation has broken through this barrier by developing a

200W YAG laser suitable for deep welding and cutting. The laser minimizes thermal effects by more uniformly exciting the YAG rod and introducing technology that eliminates focusing errors associated with thermal lensing effects.

EXCIMER LASER PROCESSING MACHINES. Excimer lasers efficiently produce light in the ultraviolet region. Because of the high photon energy involved, excimer lasers can directly cut the chemical bonds of a polymer material in a procedure known as ablation processing without the thermal effects experienced when using a CO_2 or YAG laser. The short wavelength also allows better focusing, with a minimum spot size in the tens-of-microns range for fine-pattern processing. The promise of excimer lasers must be balanced against the high running cost per unit of energy output.

The corporation is currently studying the use of holograms with excimer lasers because holograms can create patterns without masking the beam. By boosting the effective light utilization by a factor of five to fifty, this technique allows the use of much smaller laser equipment for the same application.

Electron-Beam Processing Machines
Electron-beam processing offers small spot diameter, high speed and high positioning accuracy, and numerous potential applications in electronic component and ceramic package manufacturing are currently under investigation. Although the immediate goal of high productivity is somewhat hampered by a requirement for processing under vacuum, extremely low operation cycle times have been achieved utilizing an electron-beam processing machine fitted with a continuous evacuation system. Productivity has been enhanced by developing a beam deflection system capable of processing multiple workpieces in a single pass. Applications of electron-beam processing are poised to expand from a strong automotive base into precision electronic components.

Owing to technologies such as those listed above, Mitsubishi Electric's line of advanced processing machines continue to receive high praise for performance from various industries. ❑

The Latest Technologies for Die-Sinking EDMs

*by Koji Akamatsu and Atsushi Taneda**

Mitsubishi Electric has introduced several new technologies for its VX and EX series of die-sinking electrical-discharge machines (EDMs). The FP power supply for the EDMs uses solid-state power circuits for reduced size and power dissipation. A silicon powder-mixed EDM system has been developed that yields a smooth finish, and fuzzy-logic adaptive control technology achieves stable, high-speed processing.

Resistorless Solid-State Power Supply

The FP power supply features a Mitsubishi-developed low-loss switching control system for regulating the peak discharge current. The system dramatically improves the power efficiency of the VX and EX die-sinking EDMs. Fig. 1 shows the efficiency improvement of the resistorless power supply circuit. The resistorless circuit reduces the internal dissipation of conventional circuits by about 80% and reduces the total power consumption by half. In addition, current feedback control in the power supply yields stable, reproducible machining performance. The power supply is half the size of previous units, and its lower dissipation reduces thermal effects on the EDM equipment. Lower dissipation also allows the use of indirect cooling, which gives the benefit of enhanced reliability.

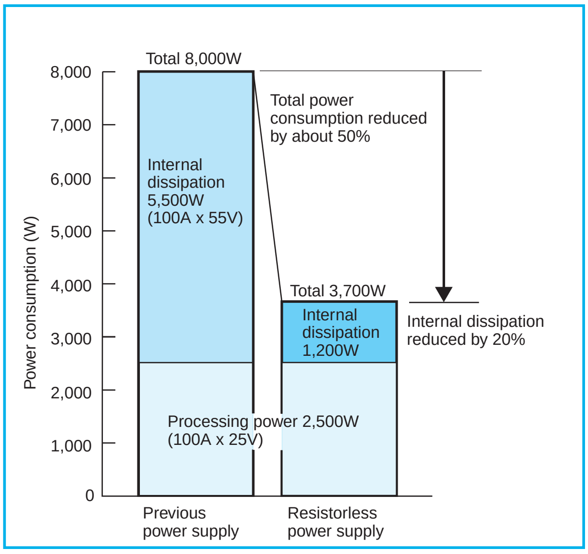

Fig. 1 Power consumption of EDM power supplies.

Machining with a Silicon Powder Suspension

Fig. 2 shows the VPX10 EDM which utilizes dielectric fluid with a silicon powder suspension. Use of silicon powder in the dielectric fluid makes it possible to perform rapid machining to a surface roughness of better than 1μmR_{max}. This process requires a special machining tank fitted with an agitator and a special dielectric fluid supply unit. The agitator maintains a stable concentration of silicon, which has a specific gravity three times that of the dielectric fluid. The agitator sprays the dielectric fluid through small holes and uses the kinetic energy of the fluid to carry the powder. CAE software was used to model the three-dimensional fluid flow in the tank, and the nozzle placement and throughput were optimized to hold variations in silicon powder concentration to half that of previous units.

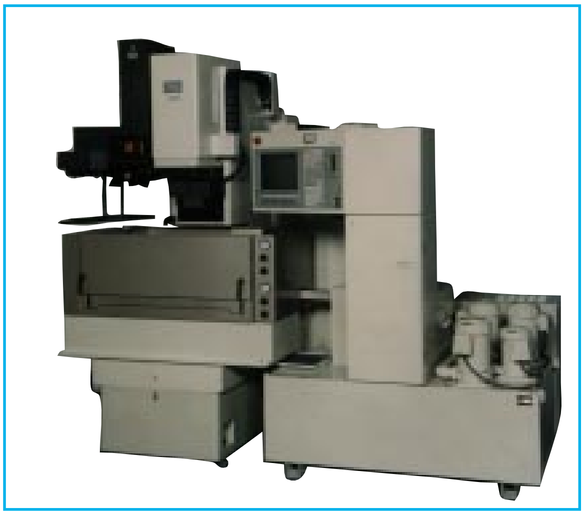

Fig. 2 The VPX10 EDM for silicon powder-mix machining.

Bridge Elimination Circuit

Silicon powder can result in surface pitting of complicated shapes during first-pass machining when sludge trapped in the machining gap causes a short circuit from the electrode to the workpiece (Fig. 3a). Fig. 4 shows the magnetic

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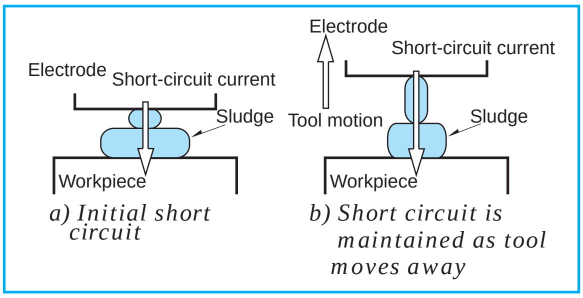

Fig. 3 Short-circuited machining gap.

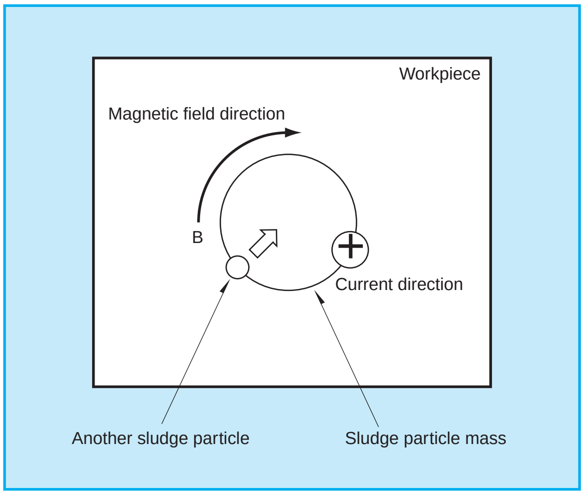

Fig. 4 Magnetic field created in the machining gap by a short circuit.

field that surrounds this current. The field tends to move the sludge toward the central axis, maintaining the short circuit even as the tool separates from the workpiece (Fig. 3b). This continued concentrated discharge causes pitting.

The FP power supply has a function that prevents sludge concentration during short-circuiting. When a short circuit continues for a certain period, a brief current pulse is applied to blow out the sludge and clear the short circuit. This function increases machining speed and improves the surface finish.

A Machining Application Using Suspended Silicon Powder

Fig. 5 shows a cold-forging die produced by an EDM utilizing suspended silicon. Hand polishing is unnecessary, and the absence of cracks and pits extends die life.

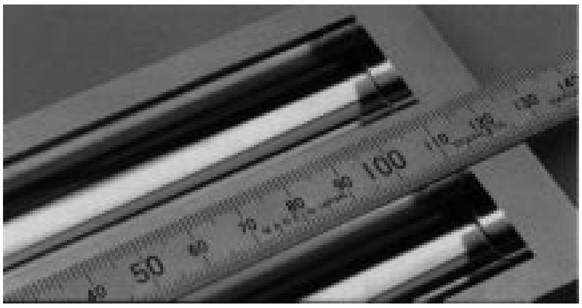

Fig. 5 An SKD61 cold-forging die machined by the VPX10 to a surface roughness of 0.8µmR_{max} using a copper tool. Machining time is six hours with oil dielectric fluid and 3.7 hours with mixed silicon powder.

"Fuzzy Pro" Adaptive Control System

This control systems consists of three new sensing functions and a digital control unit that incorporates the know-how of a skilled operator (Fig. 6).

The first function is a machining area sensor that automatically detects the area of the surface under processing.

The second is a machining stress sensor. Processing depths are generally less than the target value when the processing area is large, especially in finishing passes. This occurs as a result of play that develops when the mecha-

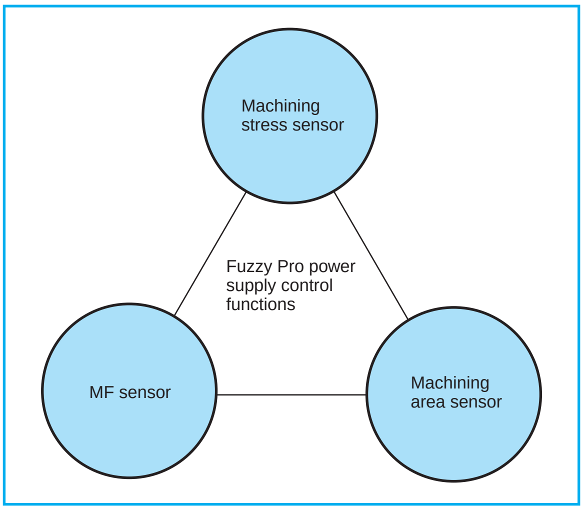

Fig. 6 The "Fuzzy Pro" power supply.

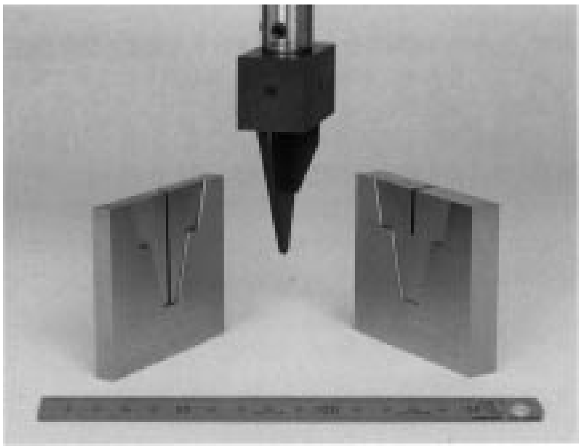

Fig. 7 A ribbed die and the graphite electrode used to produce it.

nism executes a jump movement while the dielectric fluid is adhesively coupling the tool and workpiece. The control unit has a machining stress sensor that detects and compensates for these forces.

The third function is an MF sensor that distinguishes between “good” pulses that contribute to processing and “bad” pulses that cause arcing and surface discoloration by checking the presence of harmonic components in the voltage waveform of the discharge pulses.

Fig. 7 shows a die with a thin, deep rib pattern typical for molding lightweight plastic structures and the graphite electrode used to form it. Graphite EDM tools can produce thinner ribs than any other method. The FP power supply supports stable machining, achieving results comparable to copper machining without bridging problems even in deep rib sections.

Improvements in EDM machining performance make this technology an increasingly attractive alternative to mechanical fabrication. ❑

An Electrical-Discharge Scanning Machine

*by Masaru Shinkai and Toshio Suzuki**

Electrical-discharge scanning is a new electrical-discharge machine (EDM) process in which a simple pipe-shaped electrode is used to form complicated shapes with high precision in a scanning process that resembles mechanical processing. This technique dramatically reduces fabrication costs by eliminating all the steps involved in the design and manufacture of specially shaped electrodes. Electrical-discharge scanning is also better at forming intricate shapes than shaped tools. The technology is suitable for manufacturing dies for semiconductor fabrication equipment, finely detailed dies and components for micromachine research.

Basic Principles

In conventional electrical-discharge machining, the shape of the electrode is transferred to the workpiece, requiring a substantial investment in tool design and manufacture. The tool must be manufactured to the same high accuracy desired of the finished product and the cost of production may be as much as half the die manufacturing cost. The time required for tool manufacture also impacts production scheduling.

Electrical-discharge scanning uses precise control of simply shaped tools to generate the desired profile, eliminating the cost of specially fabricated tools. Fig. 1 shows Mitsubishi Electric's electrical-discharge scanning machine, ED-Scan 8E. Fig. 2a shows how the scanning process works. The bottom of a rotating pipe is used to perform the machining, removing material from the workpiece layer by layer until the desired shape is formed (Fig. 2b). The scanning process removes 10~100µm per scan in first-pass mode and 1~10µm per scan in finishing mode.

Fig. 2c shows the process for conventional contour machining using the side of a cylindrical tool. Low-wear machining conditions are used to prolong the tool life, but wear causes rounding of the bottom of the electrode. Electrical-discharge scanning, in contrast, uses high-wear machining conditions, which speeds production and maintains the tool's sharp edge, while a Z-axis feed automatically advances the electrode as it wears for extremely accurate processing. The Z-axis feed is corrected by periodic depth measurements.

Fig. 1 ED-Scan 8E.

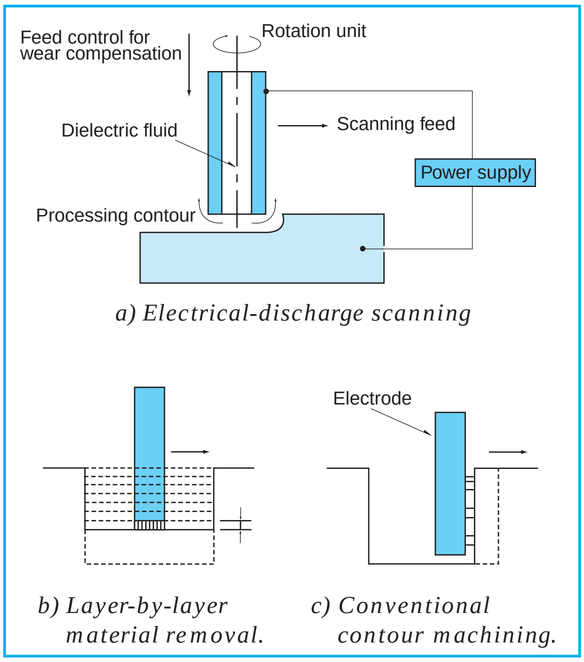

Fig. 2 Principles of electrical-discharge scanning.

*Masaru Shinkai and Toshio Suzuki are with the Nagoya Works.

Features of the Electrical-Discharge Scanning Process

Electrical-discharge scanning offers many advantages over previous EDM processes. Table 1 lists these advantages, along with weaknesses of the scanning process. The greatest merit of the process is that it eliminates the electrode fabrication step and can produce finer shapes than are possible with a conventional tool. Most of the weaknesses of the process can be eliminated through process improvement and advances in CAM performance.

Table 1 Features of Electrical-Discharge Scanning

Advantages
Eliminates specialty tool design and production costs
Finer machining than conventional EDM shaping processes
No electrode wear considerations
Excellent bottom-surface flatness
Uniformly smooth finish over large areas
Processing time is easily estimated
CAD data for the die design can be converted directly to NC data
No dielectric fluid processing considerations
Disadvantages
Sometimes slower than shaped-electrode EDM processes
Not yet suitable for curved surfaces
Poor precision on side-wall angles more than 10° from vertical

Table 2 Applications of Electrical-Discharge Scanning

Application area	Practical examples
Semiconductor manufacture	Die plate relief for IC frame punch and die, stripper plate relief for IC frame punch and die, IC lead frame punch, other components for semiconductor production
Micromolds	Molds for subminiature connectors, small gears, watch parts, switch components, etc.
Precision dies for stamping	Micro punches, die plate relief
Dies for aluminum window frames	Aluminum extrusion die relief
Printing	Lettering on molds and dies
Component production	Precision component fabrication
Micromachines	Components for micromachines

Table 2 lists applications. The technology is already building a track record in die production for semiconductor manufacture.

Fig. 3 shows a test-manufactured mold for a stepped microgear. The diameter is 1.2mm at the outer teeth, 0.72mm at the inner teeth and 0.1mm across the central shaft. The deepest part of the die is 270µm below the surface level. In the conventional approach, a wire-cut EDM would be used to create the stepped structure, which would then be shaped in additional passes using other tool shapes. In this case, however, the required electrodes are too small to fabricate reliably. The new process allows CAM data to be converted to the desired mold in a single step with processing accurate to 5µm.

Features of ED-Scan 8E

The ED-Scan 8E has an automatic changer for the tool and a tool guide that supports different electrode diameters for optimum first-pass and finish machining. These enable the system to automatically perform first-pass machining at high currents with a large-diameter tool and finish machining at low currents with a small-diameter tool.

Another significant advance in the ED-Scan 8E is the new SS power supply circuit, which doubles finishing speed, bringing it closer to the finishing performance of shaped-electrode machining. High-speed power switching de-

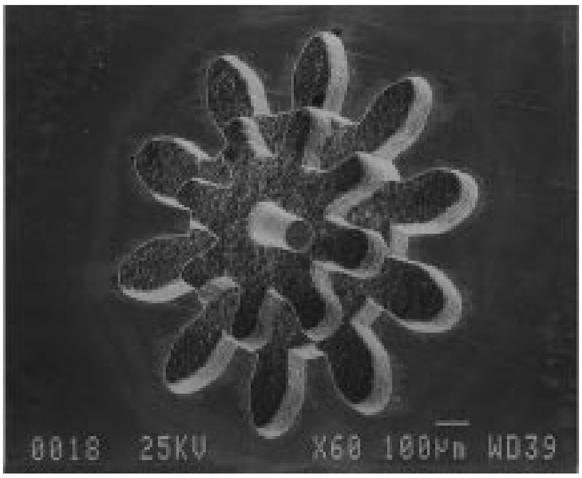

Fig. 3 A test-produced microgear mold.

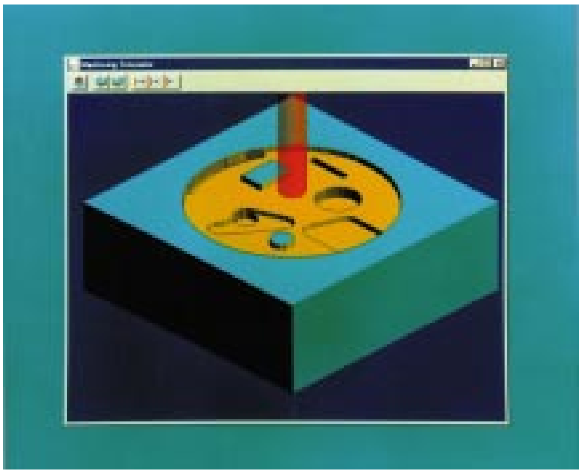

Fig. 4 Shape simulation.

vices in the SS circuit speed finishing by reducing the gap voltage rise time, while a short-circuit suppression circuit improves the stability of the finishing process.

CAM Software

Mitsubishi Electric has developed an ED-Scan/CAM package to convert die-shape information and process parameters into numeric controller (NC) instructions for the scanning process. ED-Scan/CAM runs on a personal computer under the Microsoft Windows 95 operating system. The shape data, supplied in DXF format, can be created using general-purpose CAD software. The NC data includes instructions for scanning, tool changes and electrode wear measurement. The software also offers a three-dimensional graphic simulation of the workpiece shape that the operator can use to visually verify the NC data. Programming is faster since shape data errors can be easily spotted and corrected. Fig. 4 shows a shape simulation.

By eliminating costly electrode fabrication steps, electrical-discharge scanning brings new possibilities to EDM processing, extending the advantages of this technology over mechanical die-fabrication techniques. ❑

FX Series General-Purpose Wire-Cut Electrical-Discharge Machines

*by Makoto Tanaka and Seiji Sato**

Mitsubishi Electric has developed the FX Series of wire-cut electrical-discharge machines (EDMs) for the expanding EDM market. The series features automated machining achieved through incorporation of the low-wire-breakage "PM2" power-control system, a moving-column tool transport mechanism for simpler more accurate operation, improved aesthetic design and a number of other innovations.

Background

Wire-cut EDMs are extensively used in die-making and many other manufacturing fields because they can make fine cuts that are impossible with other machine tools and they rarely cause stress damage. The current EDM market is emphasizing cost-effective general-purpose equipment capable of fast, efficient cutting. Fig. 1 is a photograph of the FX20 wire-cut EDM, developed to meet these needs. Alongside basic performance, the FX Series provides automated operation, simplified setup, an improved user interface, and enhanced aesthetic design.

Fig. 1 A photograph of the FX20 wire-cut EDM.

The PM2 Power Control System

Wire breakage is perhaps the largest factor in the reduction of EDM machining efficiency. It can be minimized by using the correct machining energy to suit workpiece contours and thickness. The PM2 features an adaptive control system that utilizes machining status and workpiece thickness information to dynamically optimize the first-cut machining power and other parameters as machining proceeds, thereby minimizing the incidence of wire breakage.

Poor electrolyte flow around step shapes and at workpiece edges can also lead to unstable machining and wire breakage. The control system detects concentrated discharge and short circuits that occur under these conditions and reduces the machining power automatically.

Overall machining speed is improved since the power control system selects maximum machining speed whenever the electrolyte flow is sufficiently stable.

Fig. 2 shows a stair-shaped workpiece that can be machined automatically by the PM2 power control system. The system automatically optimizes machining even at difficult locations; at the stair section where workpiece thickness changes, at the workpiece edge and wherever there is a long distance to the upper electrolyte nozzle. Fig. 3 shows the machining time improvements using the automated power control function.

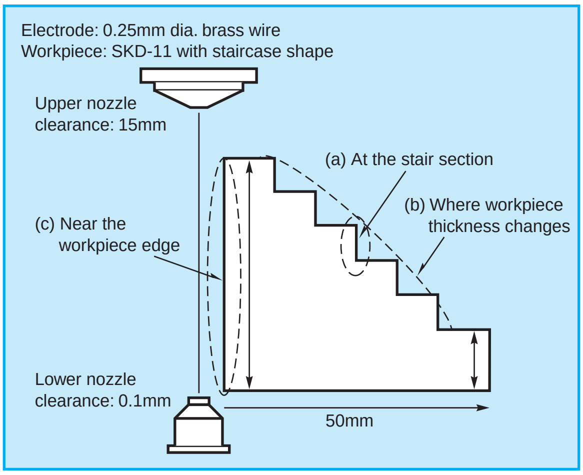

Fig. 2 Issues in machining a stair-shaped workpiece.

User Interface

The FX20 has an easy-to-use user-interface monitor screen (Fig. 4) that allows the operator to automate control of first-cut and finish machining. The operator simply selects first-cut or finishing

**Makoto Tanaka and Seiji Sato are with the Nagoya Works.*

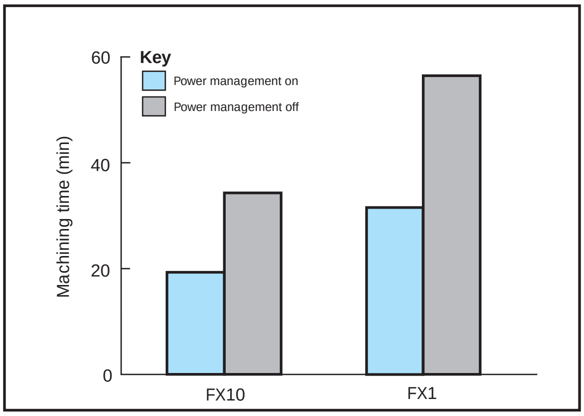

Fig. 3. Effect of power management on machining times for a stair-shaped workpiece.

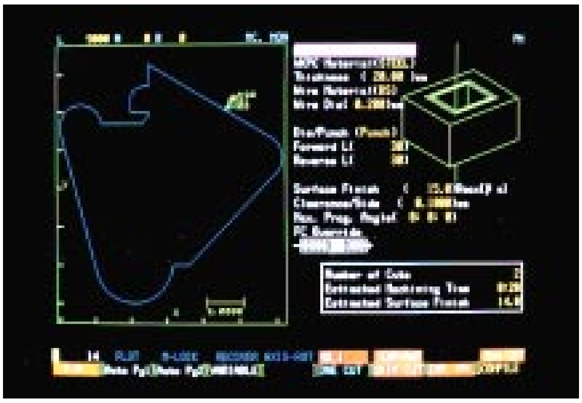

Fig. 4 The power monitor screen.

mode and specifies the final surface roughness. The system then automatically selects the number of passes, offset values and other machining conditions. All operations from NC program entry and verification to calculating the machining time and monitoring and managing the machining process are easily accomplished, allowing even a first-time user to create finely finished products.

Operability Improvements

The most labor-intensive tasks in EDM use are preparatory operations—attaching, aligning and removing the workpiece. The corporation redesigned the door to the machining tank for space savings, easy opening and the recovery of leaked electrolyte. Larger models have a motorized door, and all models have an automatic door-lock mechanism to prevent operator error. A mechanism for automatically cutting and recovering the wire electrode assists operation and maintenance.

Construction

The moving column mechanism facilitates workpiece setup and reduces the equipment size by eliminating the need for an XY table drive. The moving column moves the wire electrode tool along the X and Y axes relative to a workpiece and table that are fixed in place.

The moving column mechanism eliminates two key factors responsible for static and dynamic positioning errors: flexing of loaded structural members and changes in the mass of the workpiece and electrolyte.

The flexing errors are predictable and compensated while the moving column mechanism and machining head are maintained at a constant mass, ensuring inherent immunity to the effects that changing electrolyte and workpiece mass would have on table movement precision.

The frame members of FX Series wire-cut EDMs were designed using state-of-the-art CAE technology. The members were analyzed indi-

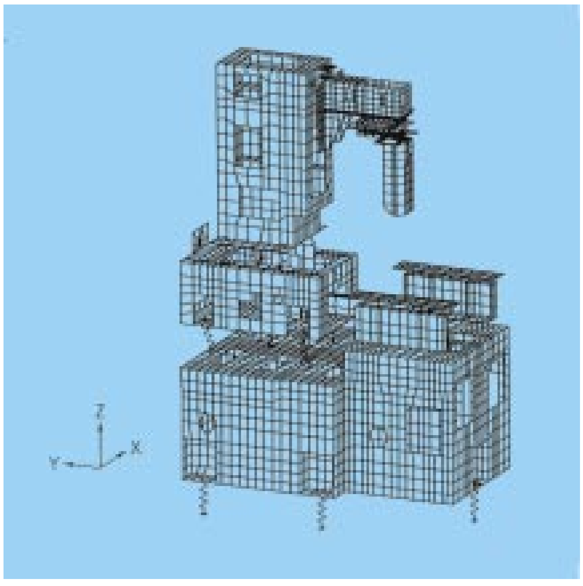

Fig. 5 A vibration mode analysis model.

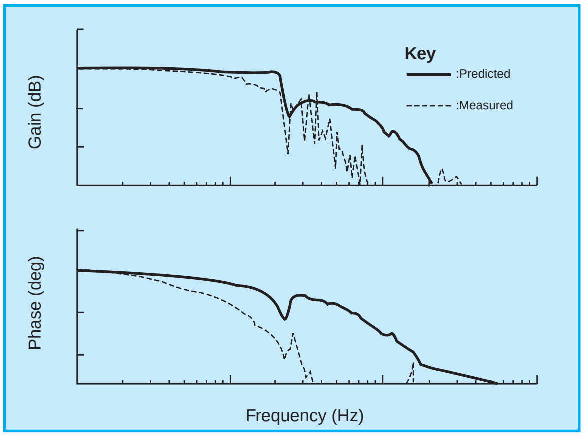

Fig. 6 Positioning loop dynamic analysis results.

vidually for local problems, and then the entire structure was tested for static and dynamic properties that could affect right-angle movements and corner shapes.

We performed a dynamic analysis to determine vibration modes of the structural members as the basis for servo-system resonance studies. The simulations were conducted on workstations with the structural member vibration mode analysis model feeding the drive system model used in the servo-system analysis. Fig. 5 shows the analysis model and Fig. 6 the predicted and measured results. Good matching was achieved in the low-frequency region, and these findings will be used to develop future mechanisms with even better dynamic properties.

Overall Design

Believing that the good performance of our FX Series wire-cut EDMs deserved a functional and aesthetically pleasing overall design, we developed a simple, futuristic design with an ergonomic user interface and special unit cover that provides enhanced safety.

The performance and design of the FX Series are earning Mitsubishi Electric EDMs an excellent reputation worldwide.❑

Machining Technologies for Highly Precise Wire-Cut Electrical-Discharge Machines

by Takeshi Yatomi and Yutaka Terada*

Mitsubishi Electric has developed the DWC90PA wire-cut electrical-discharge machine (EDM) to meet the high-end die-machining requirements of the semiconductor and precision electronic component industries. DWC90PA, which uses water as the machining fluid, is ready to compete head-to-head with the grinding processes in the production of dies for stamping IC lead frames and other ultrahigh-precision machining applications.

Trends in Dies for IC Lead Frames

IC lead frame technology needs to keep pace with increases in IC integration scale, pin count, pin pitch and smaller package sizes. Lead frames are produced by etching or stamping, with stamping widely used for mass production of devices with up to about 240 pins. Dies for stamping are generally formed in sections by grinding in a time-consuming and labor-intensive process. The wire-cut EDM offers the advantages of manufacturing dies as a single piece, more rapid production, increased automation and tighter lead pitches.

Mitsubishi Electric is leading these advances with the DWC90PA wire-cut EDM (Fig. 1), which features extraordinary machining accuracy, surface finishing and highly automated operation.

Fig. 1 The DWC90PA wire-cut EDM.

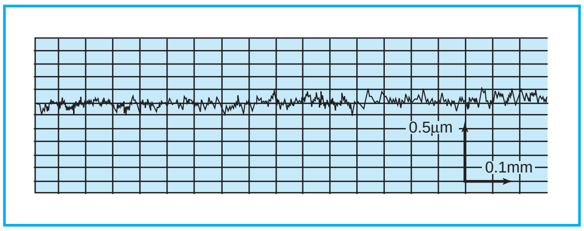

Fig. 2 Surface roughness measurement data.

Features

SURFACE FINISH TO 0.3µmR_{max}. Dies for IC lead frames require extremely high precision and a smooth surface finish for better longevity. To compete with grinding, wire-cut EDMs need to provide a high-quality surface finish comparable to grinding without the surface cracking or heat damage that often accompanies electrical-discharge machining.

The corporation has developed a high-frequency AC power supply capable of stable machining at extremely low power levels, and which achieves extremely smooth and stress-free finishes with a surface roughness of 0.3µmR_{max}. Fig. 2 shows the roughness measurements of surfaces finished using a wire-cut EDM and Fig. 3 a scanning electron micrograph of an EDM-finished surface. This finish is comparable to grinding and provides the same long stamping life at blade portions of the die.

HIGH SHAPING PRECISION. The DWC90PA employs an automated gap control system to achieve the high precision required for machining lead frame dies. Digital gap control technology yields more accurate shapes, better control response and wider safety margins. Small-radius corners and narrow slits are more accurate and are finished smoothly. Also significant, this EDM offers a stable very-low-power finishing mode. Unstable autoexpansion machining and corner points have been improved through effective digital gap control.

*Takeshi Yatomi is with the FA Systems Planning & Administration Department and Yutaka Terada with the Nagoya Works.

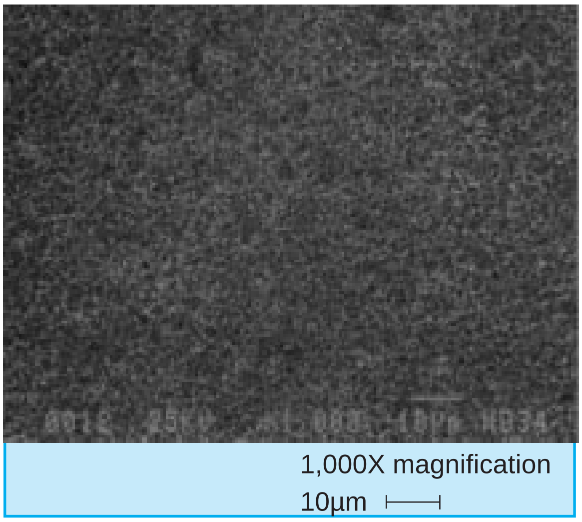

Fig. 3 Electrolytic corrosion on workpiece surface.

HIGHLY RIGID STRUCTURE. The table drive employs a 0.1µm linear-scale drive closed-loop control system that provides uniformly precise positioning while highly rigid special castings for the structural members prevent thermal shocks from affecting accuracy. Fig. 4 shows an illustration of a circular sample machined to highlight feed and structural errors. The 20mm-thick SKD-11 plate was machined into a 20mm diameter cylinder with an accuracy of 1.5µm.

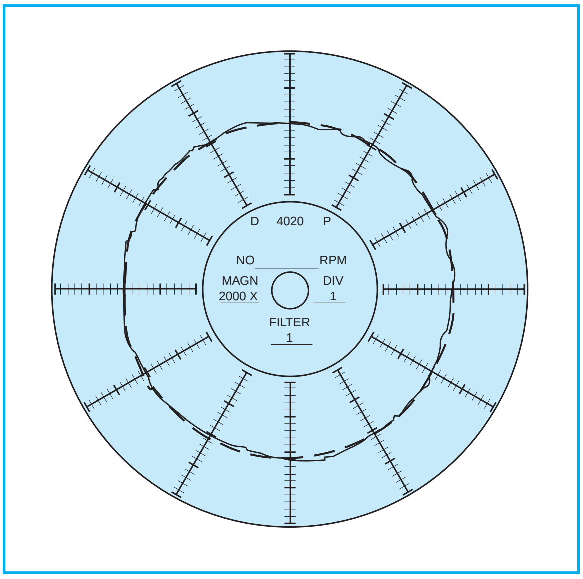

Fig. 4 Example of true circle machining.

A specially designed lower-arm assembly protects the inner arm from external pressure. The lower arm, which runs from the column to the interior of the machining tank, employs a dual structure made of carbon-fiber reinforced plastic. The external arm receives the small forces that come through the feeder wire and from the flow of water in the machining tank, preventing small displacements that would otherwise affect the inner arm and the lower guide it supports.

UNSUPERVISED MACHINING WITH NARROW-GAUGE WIRE. The DWC90PA can automatically thread wire gauges as small as 0.05mm. An automatic fine-hole search function and a small-diameter jet nozzle can automatically feed the electrode wire through starting holes as small as 0.3mm.

Machining Tests

We used a DWC90PA equipped with these new technologies to test machine small slits typical of an IC lead frame. We machined a 9mm-thick hard alloy workpiece using a 0.1mm dia. brass wire electrode. The high-precision gap control system was used for the first through sixth passes, and finish machining was performed in the seventh and eighth passes. The machining time was 35 minutes, and the final surface roughness 0.5µmR_{max}. We produced 0.16mm slits, which is close to the smallest resolution available using 0.1mm wire.

Fig. 5 shows the results of measuring parts of

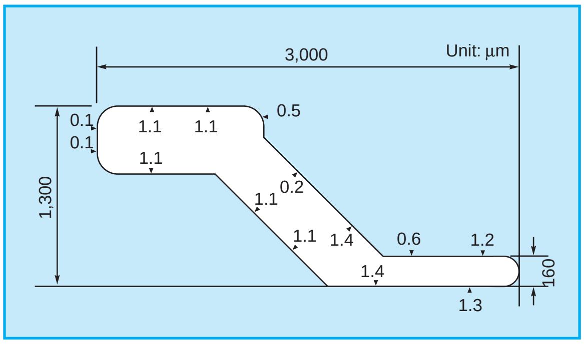

Fig. 5 Lead frame shape accuracy measurements.

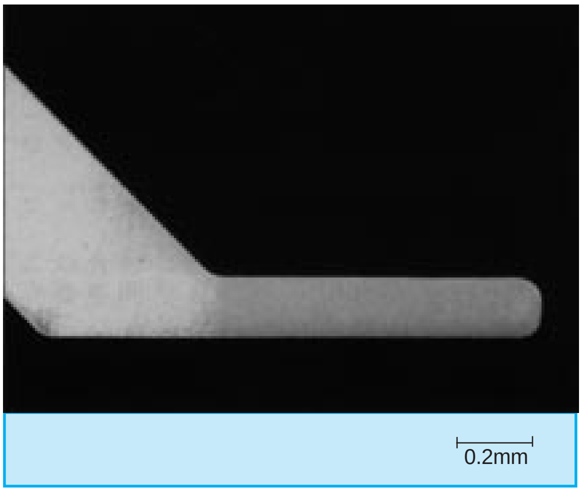

Fig. 6 Detail of a lead frame.

an IC lead frame. Fig. 6 shows an enlarged image of the lead end. The shape error is within 1.4µm with surface roughness under 0.5µmR_{max} and no stress damage.

Advances in power control and the table drive system, combined with an improved structural design, give the DWC90PA the ability to produce dies for lead frame stamping with accuracy and durability on a par with the best grinding processes, yet with substantial labor savings and largely automated operation. ❑

The LXP Series CO_2 Laser Processing Machine

by Mitsunobu Oshimura*

Demand for productivity improvements in CO_2 laser processing machines is high now that steel-plate processing applications have expanded from specialty fabrication to quantity production. This article introduces Mitsubishi Electric's newly developed LXP Series CO_2 laser processing machine and reports on state-of-the-art laser processing technologies.

The LXP Series Laser Processing Machine

International competition is forcing down prices for manufactured goods. High-precision machine shops using CO_2 lasers stand to benefit from productivity enhancements supporting small-lot manufacture of numerous product variants. Mitsubishi Electric has developed a flying optical system with three-axis control for the LXP Series, the corporation's newest line of CO_2 laser processing machines for faster, more accurate processing. Fig. 1 is a photograph of a typical model.

Fig. 1 The ML3015LXP-4030D CO_2 laser processing machine.

The LXP Series operates at a feed speed of 60m/min, double the rate of previous Mitsubishi laser processing machines. It can also cut a 10mm dia. hole to within 50µm in 1mm plate at a rate of 8m per minute—60% faster than its predecessor.

The LXP Series features an X-axis with two driving units, each with a ball screw and rotating nut, which are controlled simultaneously. Faster processing was achieved using a CAE-optimized mechanical system, a more powerful control microprocessor and a new high-accuracy control algorithm. Faster laser response has been achieved through use of a digital laser oscillator control system, and the laser optics have been upgraded. The LXP Series also has an alternating pallet loader that allows a workpiece to be mounted on one pallet while another workpiece on a second pallet is being processed. Fig. 2 illustrates the LXP Series productivity improvement in cutting 1000 pieces from nine 1,220 x 2,440 x 1mm SECC (zinc-coated steel) sheets.

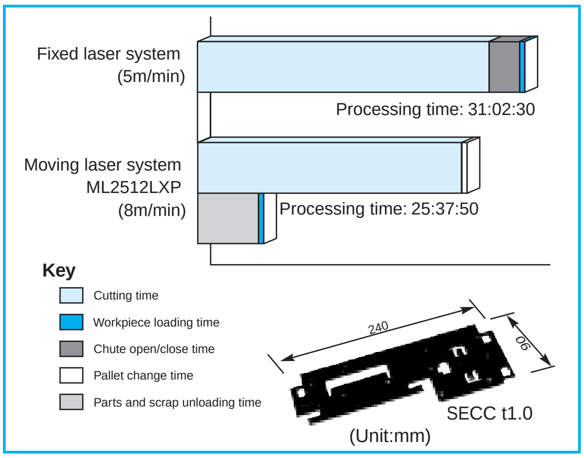

Fig. 2 Productivity comparison for 1,000 of the items shown in the inset photograph.

CO_2 Laser Oscillator

Mitsubishi Electric's CO_2 laser oscillator features a silent-discharge, three-axis cross-flow resonator design; an output sensor and control loop that keeps the output level within 1%; and gas-tight construction that lowers running costs. The newly developed D Series adds sev-

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eral enhancements.

First of all, the oscillator emits most of its beam load in the low-order TEM01 component, providing a high output suitable for cutting mild steel plate up to about 12mm thick. This beam load cuts more efficiently and operation is more stable due to a lower thermal load on the optical components.

Second, an output response three times faster than previous laser oscillators was achieved by matching the control program of the microprocessor-based controller to oscillator performance curves.

Third, the laser oscillator offers continuous output up to 3kW and peak output of 4kW, providing power for high-speed piercing.

Fourth, a new system has been adopted to prevent heat from causing distortion in the oscillator's internal optical components. This prevents variations in beam mode and shape,

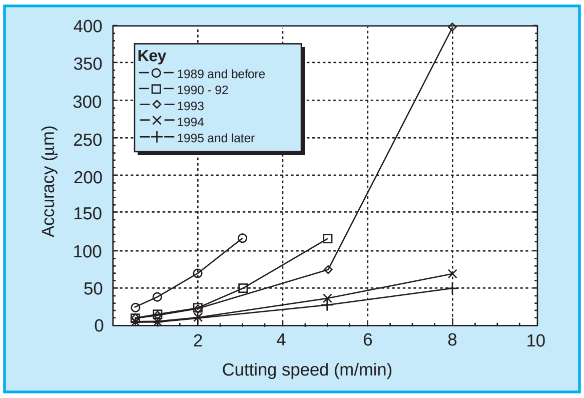

Fig. 3 Improvements in accuracy vs. speed for 10mm dia. holes in a 1mm SPCC (mild steel) sheet.

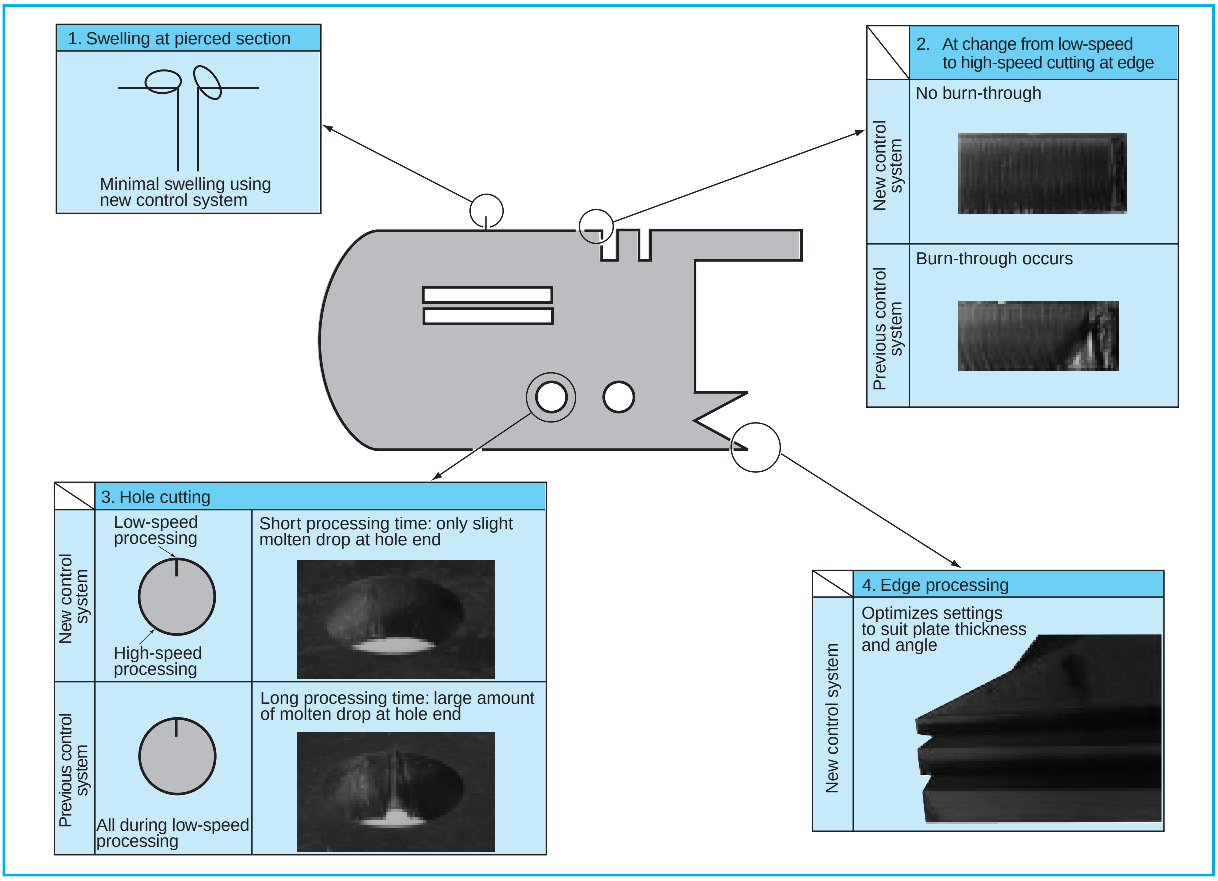

Fig. 4 Automatic control of processing conditions.

and improves beam pointing stability.

Finally, the oscillator uses an internal gas flow action to prevent oil mist and dust from adhering to the oscillator optics and degrading performance.

Cutting Speed and Accuracy

When CO_2 lasers were first applied to specialty metal fabrication, the maximum processing speeds were about 3m/min for cutting outlines in 1.2mm mild steel sheet and 1.5m/min for a 10mm dia. hole true to within 50µm. Mitsubishi Electric has achieved a fivefold increase in processing speed with improved cutting accuracy through developing lighter, more rigid moving parts and improved control technologies.

Fig. 3 illustrates this progress, showing cutting speed *vs.* accuracy curves for successively developed laser processing machines from 1989 to 1995. The 1.5m/min for 50µm circle cutting accuracy in 1989 has been increased to 8m/min, while at lower speeds accuracy has been boosted to 20µm for high-precision applications.

Control of Processing Conditions for Cutting Thick Steel Plate

Burn-through is a vigorous oxidation reaction caused by excessive local heating and insufficient assist gas flow at the kurf. Burn-through typically occurs in cutting steel plate thicker than 12mm at edges, corners, or locations where cutting speed changes.

Fig. 4 shows the benefits of an improved control system for processing conditions introduced for thick plate cutting. This system prevents excessive heating of burn-through-prone workpieces by turning off the laser beam, applying assist gas for cooling and then resuming processing, initially at low speed. This approach has increased quality and reduced processing time by about 15%.

Eight years of refinements to laser and positioning control technologies have brought substantial productivity improvements to laser processing machines, leading to a wider market for this equipment in quantity manufacturing applications. ❑

A Short-Pulse CO_2 Laser Processor for PCB Manufacturing

*by Masanori Mizuno and Tsukasa Fukushima**

Mitsubishi Electric has developed a commercial CO_2 laser processor for rapid drilling of small-diameter holes in high-density, multilayer printed-circuit boards (PCBs). The processor consists of a Mitsubishi-developed three-axis cross flow silent-discharge excited laser resonator with high peak power and short pulse duration, a high-speed laser positioning mechanism and an optical image-transfer system.

Background

Size and weight reductions in handheld computers, mobile phones and other modern information equipment demand densely mounted multilayer PCB technology. In pursuit of additional space savings, PCB designers are using via holes of 300µm and smaller. Mechanically drilling these holes suffers disadvantages of low productivity and drill bit wear and breakage problems.

Laser processing offers a viable alternative. Mitsubishi Electric currently offers the ML605GTX CO_2 laser processor for PCB drilling and similar processing applications. This system drills holes smaller than 300µm at a rate of 500 per second.

Overall Design

Fig. 1 shows the basic design of the ML605GTX. The rotating Galvano mirrors and f_θ lens scan the beam at high speed for drilling over a 50 x 50mm scanning area. When all the holes in the scanning area are completed, the XY table moves the next section of the PCB into the scanning area. Hole diameters between 50 and 300µm can be selected by changing the mask in the optical image-transfer system. A vision sensor uses image processing technology to recognize registration marks on the PCB, and this information is used to compensate for XY table positioning errors. Each unit is controlled by MELDAS Magic, a personal-computer-based numeric controller (NC).

Fig. 2 shows a photo of the system. The system features a space-saving design with all equipment contained in a single, fully enclosed unit that offers high safety and has an excellent dust precipitator for use in clean environments.

CO_2 Laser

Previous CO_2 lasers lacked a sufficient peak power level to vaporize glass, and consequently were unsuitable for drilling via holes in glass-

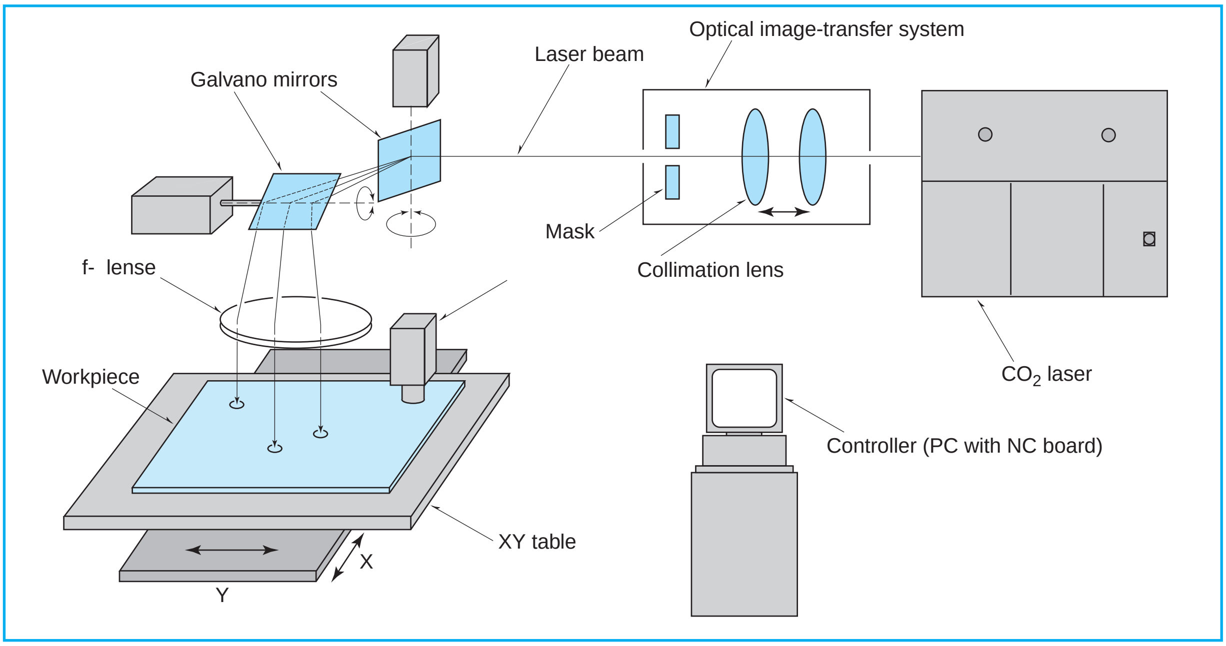

Fig. 1 Basic design.

**Masanori Mizuno and Tsukasa Fukushima are with the Nagoya Works.*

Fig. 2 The ML605GTX CO_2 laser processing machine.

epoxy PCBs since they left rough edges that interferred with the subsequent copper plating process.

The corporation has developed a CO_2 laser resonator employing a three-axis cross flow silent-discharge excitation system that produces smooth-walled holes by delivering short pulses at a power level sufficient to vaporize both glass and polymers.

Positioning Technology

A single high-density PCB may contain thousands or tens of thousands of via holes. Mass production of PCBs therefore requires some type of high-speed processing. We developed an original beam-positioning system for the ML605GTX employing a Galvano scanner that supports processing speeds of up to 500 points per second and an image processing system that compensates for positioning errors, yielding an accuracy of 20µm. This gives the laser processor a maximum rate of 500 holes per second in the scanning area. This system is combined with a high-speed extremely rigid XY table that can shift scanning areas in 0.3s.

Controller

We employ a personal computer with an add-in NC board to control all aspects of the laser processor's operation: the Galvano scanning system, drilling data conversion and positioning error compensation. In addition to excellent performance, the controller offers the advantages of a graphical user interface, easy operation and a wide array of networking and communication options.

Processing Quality

Fig. 3 shows a cross section of copper-plated 150µm blind via holes in a 100µm-thick FR4 glass-epoxy board. The laser removes the PCB material and processing stops when the laser reaches the reflective copper layer below. The glass and resin are vaporized almost simultaneously, yielding smooth-walled holes that plate well.

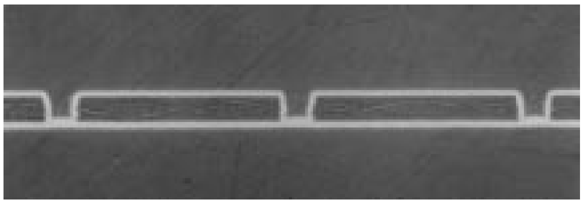

Fig. 3 Blind via hole processing of a glass-epoxy PCB.

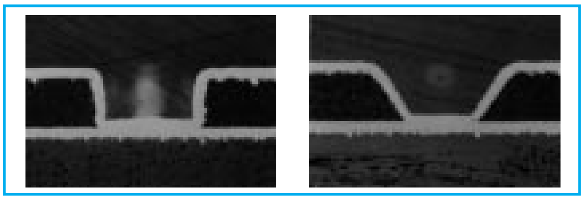

Fig. 4 Taper drilling of epoxy resin PCB.

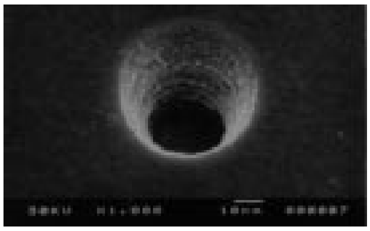

Fig. 5 A 50µm blind via hole in an epoxy-resin PCB.

PCB Quality

The via hole walls require a slight taper for plating fluid circulation to enhance plating effectiveness. Laser systems that achieve this taper by defocusing the beam are unsatisfactory because hole roundness suffers.

We developed a new taper function that uses beam modes to simultaneously control the drilling progress in the thickness and diameter directions without defocusing. The beam is focused on the board surface so that the maximum focal depth is available to absorb the effects of thickness and positioning irregularities.

Fig. 4 shows 150µm blind via holes with tapers of 15 and 30° in 70µm-thick epoxy resin. Fig. 5 shows a 50µm blind via hole in a 50µm epoxy film. The high-quality laser beam yields a perfectly round hole.

Advanced laser and beam-positioning technologies give this laser PCB processor the capability to accurately drill hundreds of holes in minimal time, thus improving PCB quality and reducing production time. ❑

A High-Brightness Nd:YAG Laser Processing Machine

*by Akihiro Otani**

Mitsubishi Electric is developing commercial solid-state neodymium yttrium-aluminum-garnet (Nd:YAG) lasers superior to CO_2 lasers for many welding and cutting applications. This report describes original technology for increasing the brightness of Nd:YAG rod lasers and introduces the Mitsubishi product line.

High-Brightness Technology

Substantial increases in Nd:YAG laser output have benefited processing applications; however, laser outputs of 200W and more cause thermal distortion of the YAG rod, which disturbs the laser light wavefront and degrades the beam mode quality. As a result, convergence is poorer than in CO_2 lasers operating at ten times the wavelength.

Pulsed operation can be used to minimize these effects, allowing greater penetration depth in laser welding applications. To support continuous-wave applications, Mitsubishi Electric has studied how thermal distortion of rod lasers affects brightness, and developed a new high-brightness laser oscillator that we call a high-power polarization-dependent-erased resonator (HIPER). This design provides for uniform pumping of the crystalline rod and eliminates thermal lens aberration caused by the polarization components.

One of the chief advantages of rod lasers is that the beam can be easily delivered through optical fiber. A new beam-delivery system using graded-index (GI) fiber has been developed to handle the enhanced power of Mitsubishi rod lasers.

Commercial YAG Laser Products

We will now introduce the Mitsubishi Electric YAG lasers incorporating these technologies. In July 1995, the corporation introduced the ML0202SC with a high-brightness continuous-wave output of 250W. In April 1996, ML0606SC-K, with a high-brightness continuous-wave output of 500W, and ML0606SC-S, with a continuous-wave output of 600W, were introduced. In May 1997, ML1005SP, a 500W general-purpose pulsed-wave laser, was released. Fig. 1 shows an SC Series continuous-wave laser and Fig. 2 the ML1005SP pulsed laser. Table 1 lists the specifications of these lasers.

Fig. 1 An SC Series continuous-wave laser processing machine.

Fig. 2 The ML1005SP pulsed laser processing machine.

The beam quality index (M2) is M2 ≤30 for ML0202SC and M2 ≤60 for ML0606SC-K. ML1005SP delivers 100J per pulse with a peak pulse output of 10kW.

The excellent beam convergence of the

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Table 1 Laser Specifications

Laser type	ML0202SC (high brightness)	ML0606SC-K (high brightness)	ML0606SC-S (high power)	ML1005SP (high power)
Oscillation type	Continuous wave			Pulsed
Wavelength (µm)	1.06			
Operation mode	Continuous wave and pulse modulated			Pulse
Rated power (W)	250	500	600	500
Peak power (kW)	0.4	1	1	10
Pulse energy (J/pulse)	—	—	—	100
Beam quality (M2)	≤30	≤60	—	—
Power input (kVA)	25	35		28
Dimensions (W x D x H)(mm)	1,350 x 700 x 1,455			2,000 x 750 x 1,590
Construction	Single unit containing laser oscillator, power supply and pure-water circulation unit			
Weight (kg)	600	700		1,050

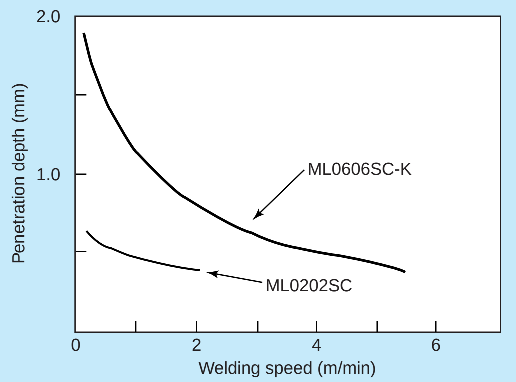
continuous-wave lasers (ML0202SC and ML0606SC-K) supports high-quality cutting and high-speed, high-quality seam welding. ML0606SC-S is suitable for low-aspect ratio welding and surface-treatment applications. The pulsed-wave ML1005SP offers excellent general-purpose performance for spot welding, low-heat welding, welding of highly reflective materials and many other welding applications.

Processing Performance

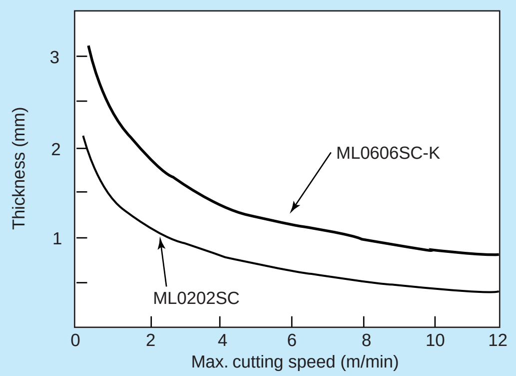
We next explain the processing performance and typical applications of high-brightness continuous-wave lasers.

WELDING. Welding is the single largest application of YAG lasers. Continuous-wave lasers are superior to pulsed lasers in continuous welding capability and quieter operation. They offer high-reliability welding at high welding speeds with fewer cracks and less spatter than pulsed lasers.

Fig. 3a shows the welding speeds and penetration depths of ML0202SC and ML0606SC-K for bead-on-plate welding of SUS304 stainless steel. ML0202SC welds at 2m/min to a depth of 0.4mm, while ML0606SC-K welds at 3m/ min to 0.6mm. Fig. 4 shows bead width and penetration depth for bead-on-plate welding of SUS304. This continuous-wave laser yields a sharp bead cross section with a 1.0~1.6 aspect ratio.



a) Welding characteristics for SU304 bead on plate



b) Cutting characteristics for SPC mild steel plate

Fig. 3 SC Series processing characteristics.

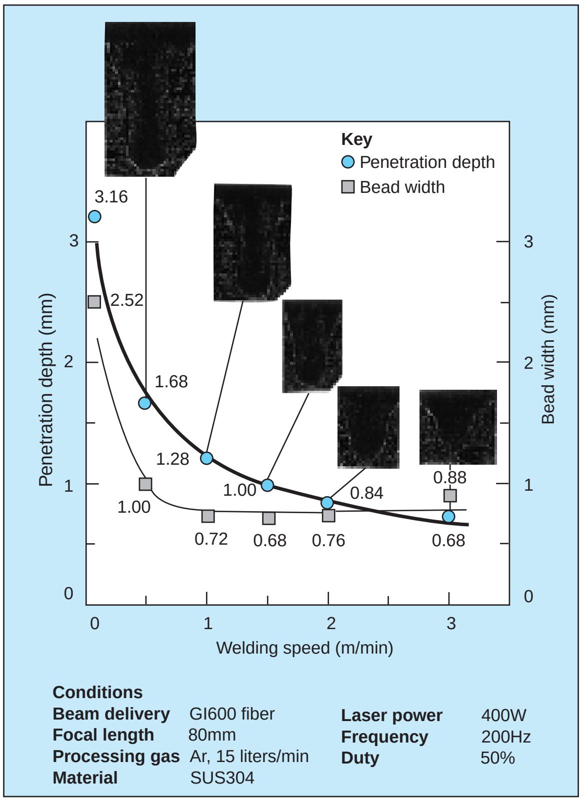


Fig. 4 Welding characteristics of the ML0606SC-K.

CUTTING. The speed and quality of cutting by previous YAG lasers were inferior to that of CO_2 lasers for plate thicker than 1mm due to the poorer convergence of YAG lasers. YAG lasers with the high-brightness laser oscillator and the high-brightness beam-delivery system offer superior performance for welding and thin steel plate cutting applications.

Fig. 3b shows the cutting speed and thickness relationships for models ML0202SC and ML0606SC-K. ML0606SC-K cuts 3.2mm mild steel plate at 1m/min, making it suitable for cutting sheet metal for most stamping applications.

By addressing the largest weakness of YAG rod lasers—thermal distortion of the YAG rod—Mitsubishi Electric has developed products superior to CO_2 lasers for many welding and cutting applications. ❑

An Electron-Beam Processing Machine for Micro-Scale Welding and Joining Applications

by Kyuzo Arakawa and Masao Kikuchi*

Mitsubishi Electric has developed a commercial electron-beam processing machine that realizes operating cycle times under 1s through the use of a high-performance beam-deflection system, cassettes carrying multiple workpieces and a continuous-duty vacuum exhaust system. The machine can seal ceramic packages rapidly with a much smaller thermal input than conventional soldering and welding technologies.

Beam Deflection System

Fig. 1 shows the configuration of the beam deflection system. The system can sweep the beam at rates exceeding 10,000m/min and modulation rates nearing 100kHz for small amplitudes. The beam diameter is 110μm±15% over a swept area of 60 x 60mm.

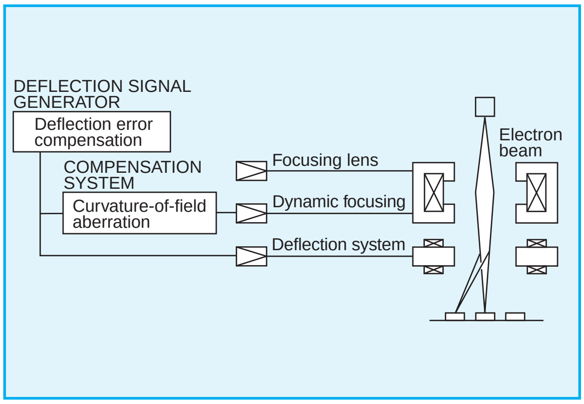


Fig. 1 The deflection system.

The beam speed can be changed instantaneously from several meters per minute for welding to 10,000m/min for traversing to the next weld point. Beam switching is unnecessary because at this high speed the thermal input to the workpiece is negligible (about 1/10,000 of the energy used for welding). Fast and accurate beam deflection enables the system to process multiple workpieces in a cassette in a single pass for outstanding throughput (Fig. 2).

Curvature-of-field aberrations, which increase at high deflection angles, are reduced by the combined effects of compensation in the deflection signal generator and dynamic focusing of an auxiliary lens. In addition, high-resistance materials used in the vicinity of the deflection system eliminate the distorting effects of eddy currents otherwise induced by high-frequency deflection signals.

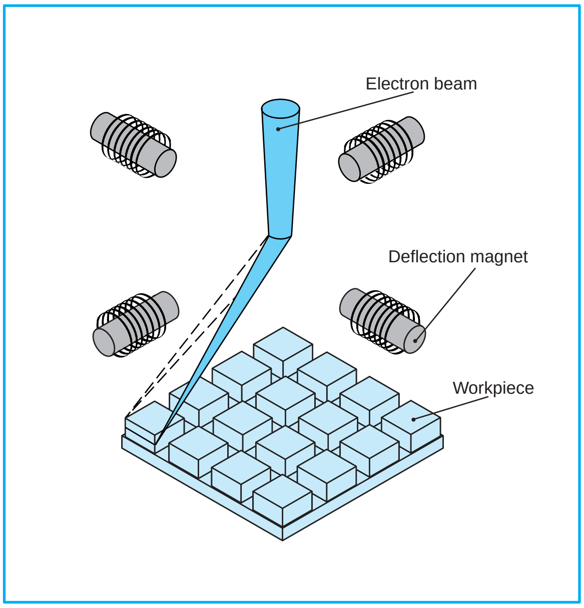


Fig. 2 High-throughput processing using beam deflection.

Continuous-Duty Exhaust System and Cassette Transport Mechanism

The system transports cassettes at the same time that the vacuum system exhausts the chambers, permitting operating cycle times of 13s in even high-vacuum applications. Fig. 3 shows the electron-beam processing machine's cassette transport mechanism. The exhaust unit has a pipe-shaped cassette transfer tube with several vacuum chambers and multiple cylindrical cassettes. The cassettes are transported sequentially from the loader to a vacuum antechamber to the processing chamber. O-rings on the cassettes prevent the introduction of air to the processing chamber. This reduces the load on the exhaust system, allowing the use of small-capacity vacuum pumps and enhancing reliability.

*Kyuzo Arakawa is with the Transmission & Distribution, Transportation Systems Center and Masao Kikuchi with the Manufacturing Engineering Center.

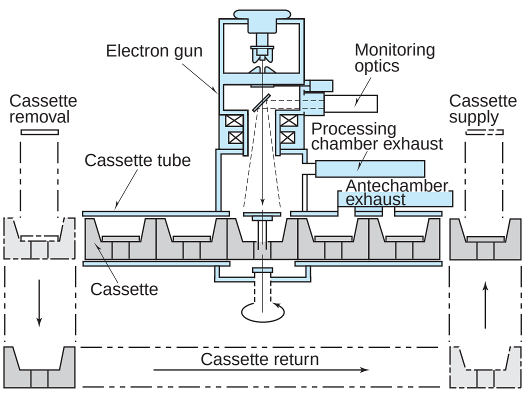


Fig. 3 Equipment configuration.

Component Packaging Applications

Sealed ceramic packages are used for ICs requiring reliability and long operating life. Ceramic packages are sealed by a metal cap attached by a seam weld, solder or low-melting glass under a nitrogen atmosphere or vacuum. The heat associated with these conventional processes can damage the IC and reduce yields, leading manufacturers to search for a low-power sealing process suitable for mass production.

Electron-beam processing offers a nearly ideal solution. The cassette transport and high-speed beam deflection control realize short operating cycle times. The welded joint resists moisture penetration and corrosion. Furthermore, heating is highly localized, reducing thermal stresses on the semiconductor device. The ceramic package under the die reaches a peak temperature of 110°C (383K) 0.5 seconds after sealing with the electron-beam processor and returns to near ambient temperature after 10s.

Table 1 Temperatures of Ceramic Package Sealing Processes

Electron-beam joining	110°C (383K) at substrate under die
Seam welding (Au joint)	250°C (523K) at substrate under die
Au-Su brazing	Melts at 280°C (553K)
Solder	Melts at 300°C (573K)

By using an electron beam to supply energy, ceramic packages can be sealed with minimal thermal effects on the die and higher yields as a result. The electron-beam processing machine described here performs this operation at throughput levels suitable for mass production. ❑

Excimer Laser Processing System Using Holographic Optical Elements

*by Yasushi Minamitani and Tomohiro Sasagawa**

Mitsubishi Electric has developed a commercial excimer laser processing system using holographic optical elements (HOEs). The holographic elements are used to convert a single beam into separate beams of uniform energy and specific shape. The holographic method makes it possible to form a processing hole pattern with one mask with much less wastage than a conventional blocking-type mask. This higher efficiency lowers laser equipment power requirements and running costs, and improves productivity.

Issues in Excimer Laser Processing Machines

Previous excimer laser processing machines optically reduced and transferred a mask pattern to a workpiece, allowing processing in a single step. However poor light utilization presented a significant problem. A $1cm^2$ mask for forming 100, 100μm holes transmits only 0.8% of the incident light. When the losses of a beam homogenizer and transfer lens are added, the efficiency falls to 0.6%. This corresponds to usage of less than 1W of a 100W laser's output. This huge waste is especially significant because excimer lasers have high running costs that increase disproportionately with output power. The costs are high because laser gas must be resupplied to the laser's discharge pumping system and the laser light output window must be maintained regularly due to the corrosive effects of F_2 and HCl discharge gas.

Better light utilization lowers laser capacity requirements and makes lasers more economical for manufacturing applications. A fivefold increase in light utilization would allow a 100W laser to be replaced by a 20W unit, reducing initial investment and running costs. This logic led us to pursue technologies for highly efficient optical processing and development of the current holographic laser system.

Principles of the Holographic System

In previous optical transfer systems, the loss of light associated with the mask area was large. If the task at hand was to form a single hole, the beam could be focused through a convergent lens and 100% of the available light used. Now assume that the converging rays could be separated and directed individually. This would eliminate the need for a mask entirely.

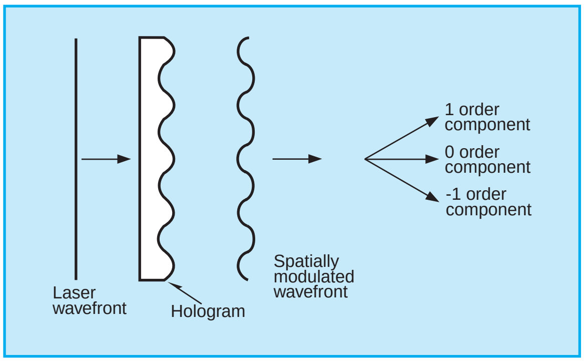


Fig. 1 Principle of a holographic optical element.

One way to control the beam would be through introducing numerous prisms. A similar effect can be achieved through using diffraction gratings. A diffraction grating can be used to modulate the laser wavefront forming a spatial frequency distribution that produces the desired beam directions. A HOE, a type of diffraction grating that creates periodic differences in light paths, can be used to provide the required spatial modulation function. Fig. 2 shows how an HOE would be used with a lens in an optical transfer system. The system includes a simple aperture mask, transfer lens, HOE transfer mask and the workpiece. The presence of the hologram distributes the laser light, creating overlapping images at the points where processing is required. If the HOE is omitted, the light is focused into a single point on the workpiece surface.

A Processing Application

We will describe a typical application of the holo

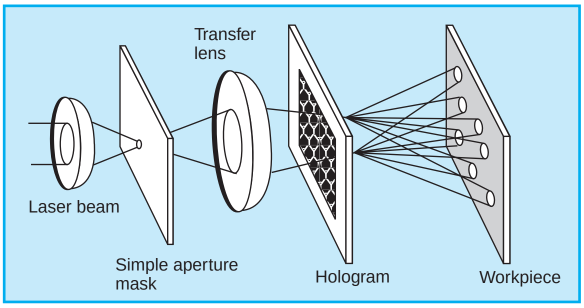


Fig. 2 A hologram-based multiple imaging optical system.

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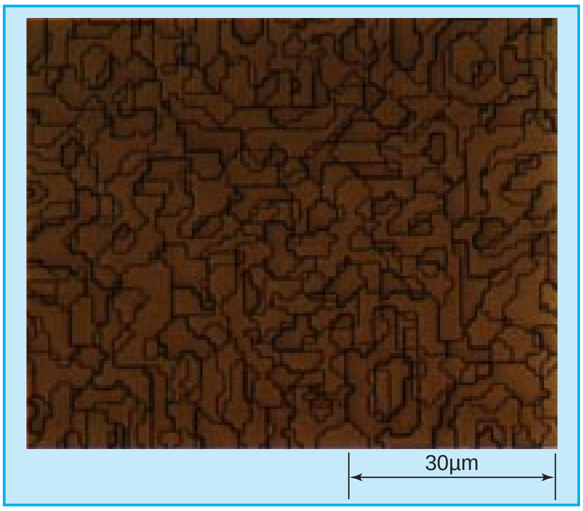

Fig. 3 Micrograph showing the surface of the holographic element.

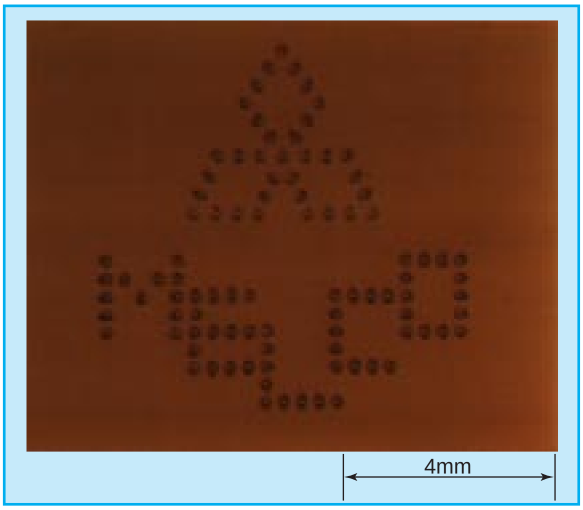

Fig. 4 Result of machining by the holographic imaging system.

graphic optical system to the processing of a 20µm polyimide film. The hologram pattern, designed to form 95 holes, employs a pattern of 1,024 × 1,024 pixels of $1\mu m^2$ each and four phase levels. The transmission efficiency of the grating was calculated at 72% with a maximum variation of 1%. Fig. 3 shows a micrograph of the hologram, and Fig. 4 the processed film with a $1cm^2$ pattern of 95, 100µm holes. Pulses from a laser with an energy of 20mJ are attenuated to 3.9mJ at the workpiece, an energy density of $514mJ/cm^2$ at an

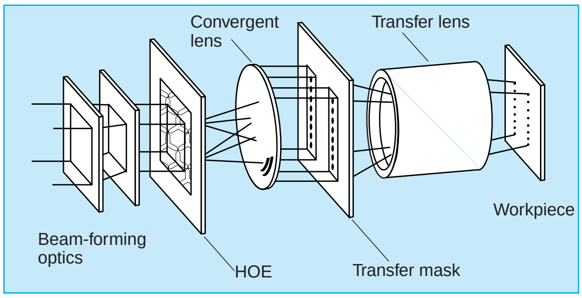

Fig. 5 A processing system with a homogenizer function.

outstanding 19.4% efficiency. Energy utilization efficiency is 20 times better than conventional equipment since the pattern transmission ratio is less than 1%.

Using a Hologram as a Homogenizer

Another application of holograms is as homogenizers. The optical intensity distribution of an excimer laser generally has a top-hat distribution in the axis defined by the length of the discharge gap and a Gaussian distribution in the direction of the discharge. Beam uniformity requirements tighten for processing scales of less than 100µm. Fig. 5 shows the design of a system exploiting the ability of a hologram to separate and superimpose, achieving a region of uniform beam-energy distribution over the aperture of a transfer mask. This processing system is effective when the openings are concentrated in several local areas. Since the homogenized beam illuminates only the transfer mask aperture, the optical efficiency is five times better than previous laser processing systems.

Use of holograms to control the transmission of laser light has brought about a dramatic increase in efficiency because the hologram eliminates the need for masks that block a large portion of the beam's usable light. ❑

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