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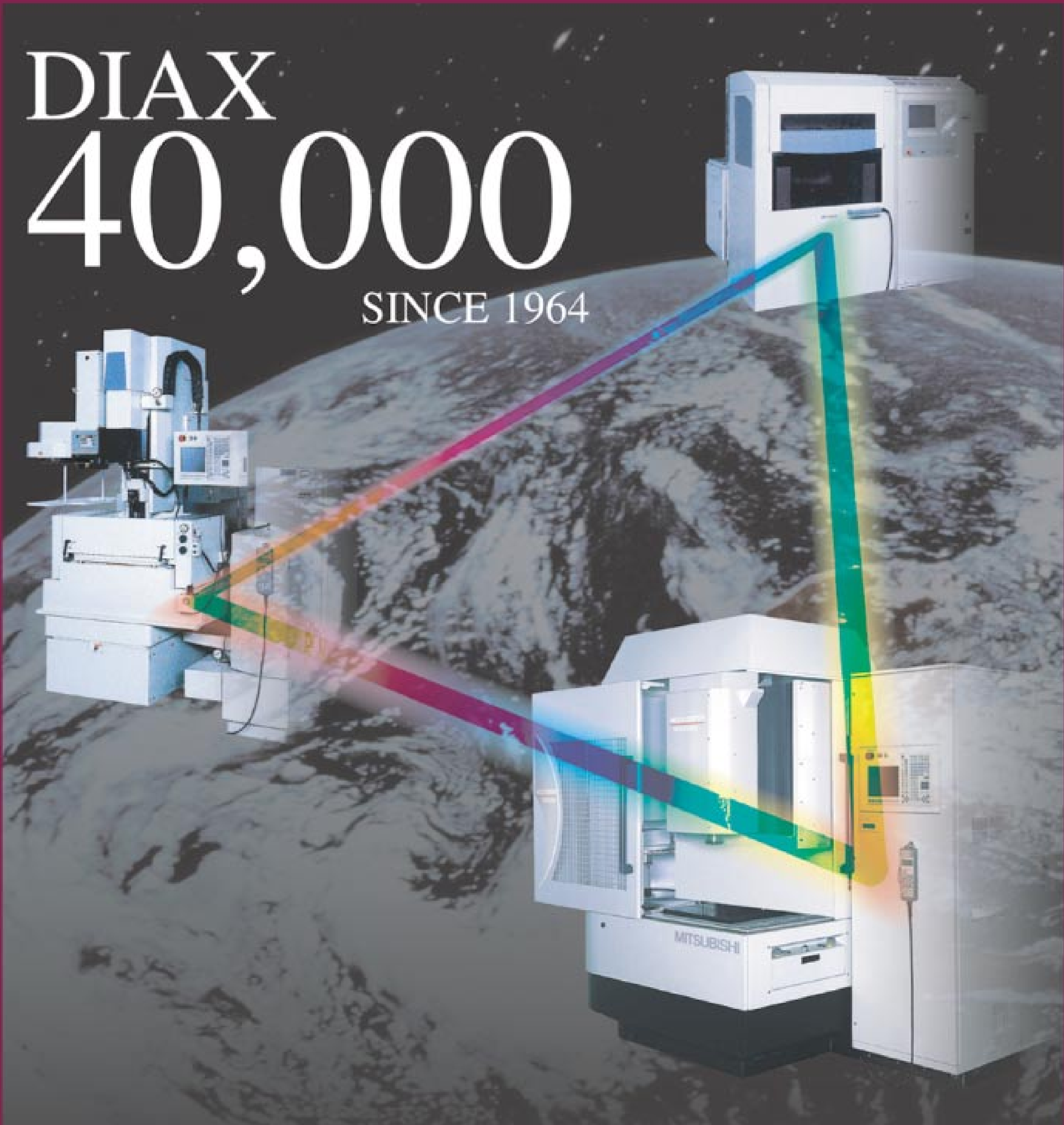
Super-Precise Electrical Discharge Machines Edition



MITSUBISHI ELECTRIC
Changes for the Better

A Quarterly Survey of New Products, Systems, and Technology
●Vol. 98/June 2002 Mitsubishi Electric **ADVANCE**

Super-Precise Electrical Discharge Machines Edition

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Cover Story
This issue of Advance explains the super-precise triangle concept for electrical discharge machines (EDMs) and gives practical examples illustrating its very great importance for ultrahigh-precision machining at the start of the 21st century, a time when manufacturing industry is undergoing sweeping changes. Specific examples include the MA2000 super-precise die-sinking EDM, the PX05 super-precise wire-cut EDM and the VH10 super-precise micro-hole EDM, each of which offers specifications providing precision in the ±0.002mm class. Consideration is also given to the basic configurations needed to achieve ultrahigh-precision die machining in the future.

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Overview

A Vision for the Future of Electrical Discharge Machining

*by Fumitada Shimana**

The business environment has entered a period of intense competition, calling for corporate strategies that consistently develop new products creating new added value, and that help to maintain the leadership role Mitsubishi Electric Corporation has already established.

Die making is representative of value-added manufacturing, whether by EDM or milling, and leads the high-precision manufacturing industry in its efficient use of CAD/CAM technology, and is being extensively adopted over a very wide range of component-processing fields. For example, the factory workshop is undergoing great changes as the skills and knowhow previously dependent upon human resources for supporting the entire die-making process are being replaced by information technology (IT) integrated with CAD/CAM systems. This applies to wire-cut EDM, the milling of electrodes, rough cutting of die blanks, die-sinking EDM and finishing, and CMM measurements of the machined shapes.

From now on, high-level product planning and design will center increasingly around three-dimensional CAD/CAM systems, and the information generated at this design stage will be transferred seamlessly in its entirety to the manufacturing process, where it will play a crucial role in reducing lead times and increasing overall efficiency. This is the environment within which EDM must be integrated into the supply chain, in synergy with information systems, and with aggressive reforms implementing networks for remote supervision and maintenance, etc.

However, there are problems affecting manufacturing processes that depend upon knowhow for their resolution, and cannot be resolved merely by linking high-precision technology with information technology. There is no doubt that personal skills will retain their importance alongside sophisticated engineering technology.

Several areas of development hold great promise for the future of EDMs. These include: high-quality mirror finishing, ultrahigh-precision die-making processes for full net shapes, systems for ultrafine machining holes corresponding to the latest μBGA, high-speed processing of new materials, the development of power supplies that will consume less energy, network-based automatic systems (including IT), and ultrahigh-precision die making for optical components.

EDM is well placed to meet the unending needs of the workshop for more sophisticated processing, and has enormous potential for growth as a viable business. ❑

**Fumitada Shimana is a Director and General Manager of Factory Automation Systems Group.*

Recent Engineering Trends in EDMs, and Areas for Future Development

*by Naokazu Tomimoto and Masaru Shinkai**

Mitsubishi Electric Corporation began production of electrical discharge machines (EDMs) in 1964, and our shipments over the years have topped 40,000 units. For over three decades we have been the leader of the EDM industry, and have continuously developed the most advanced technology and pursued added value in our EDM products.

In the area of sinker EDMs, we have announced the EA series lineup of sinker EDMs adopting the new "Dynamic Technology" concept for a quantum leap in machining performance, as well as products such as the ultra-fine hole-forming unit VH10 for use in fine and ultra-precise machining; through these and other products we have responded to changes in market demands.

On the other hand, among our wire-cut EDM products are the FA series of wire-cut EDMs, which offer a wide range of features and a new machining control system through the amalgamation of 64-bit CNC technology and power-supply control engineering. These products have won high praise from customers. In the area of high-precision machining, we commercialized the industry's first ultra-high precision wire-cut EDM product, the PX05, capable of guaranteed machining precision to within ±0.002 mm. It is in wide use as a mother machine for precision die machining, primarily in semiconductor manufacturing.

We expect ever-mounting demands for higher precision and machining to finer detail levels in die-related areas, as well as increasing demands for enhanced productivity in machining component parts. This article describes the background to development of new products which are in step with such changing market demand, and also highlights the latest engineering trends in EDMs.

Engineering Trends in Sinker EDMs

THE DYNATECH SYSTEM OF INTEGRATED MACHINING CONTROL. Discharge machining is a method in which contact-free machining is performed while maintaining a minute distance from the workpiece; it is quite distinct from machining methods in which contact is made with the workpiece. A particularly important difference is the fact that the electrode (master) is finished to the same dimensions as the final product. Consequently, it is not a method in which simple path data and a cutting tool are combined to machine the piece, as in cutting; instead, expertise is especially important to the progress of the machining process. This is because it is not easy to determine the optimum machining process for a given shape; the machining characteristics can change markedly depending on powder and sludge distributed around the machining gap. Hence, work to improve the performance of sinker EDMs concentrated mainly on the evacuation of sludge and on avoiding short-circuits which may accompany the accumulation of sludge.

In order to conduct a thorough reevaluation of the basic machining characteristics of discharge machines, in our current development project we introduced the new concept of sludge control, and developed a system for integrated control of all engineering aspects of the machining process, making use of high-speed 64-bit CNC technology. We have dubbed this "DynaTech", a contraction of "dynamic technology) (see Fig. 1). As a result, compared with conventional EDMs, a striking improvement in performance was achieved, together with enhanced precision.

One key technology incorporated into the DynaTech system is an oscillation function; by exercising control so as to maintain effectively the same discharge load, without remaining static in a fixed position, machining time can be shortened and the gap and surface roughness rendered more uniform. A similar approach was also taken to improvement of "Fuzzy Pro," which optimally controls the jump condition during machining.

By adopting this technology in a cell phone mold as shown in Fig. 2, machining time can be dramatically shortened, and at the same time the bottom and side surface roughness is rendered uniform, and less electrode is consumed. Substantial savings in machining time are also achieved when forming ribs with a high aspect ratio, which are very difficult to machine using

**Naokazu Tomimoto and Masaru Shinkai are with Nagoya Works.*

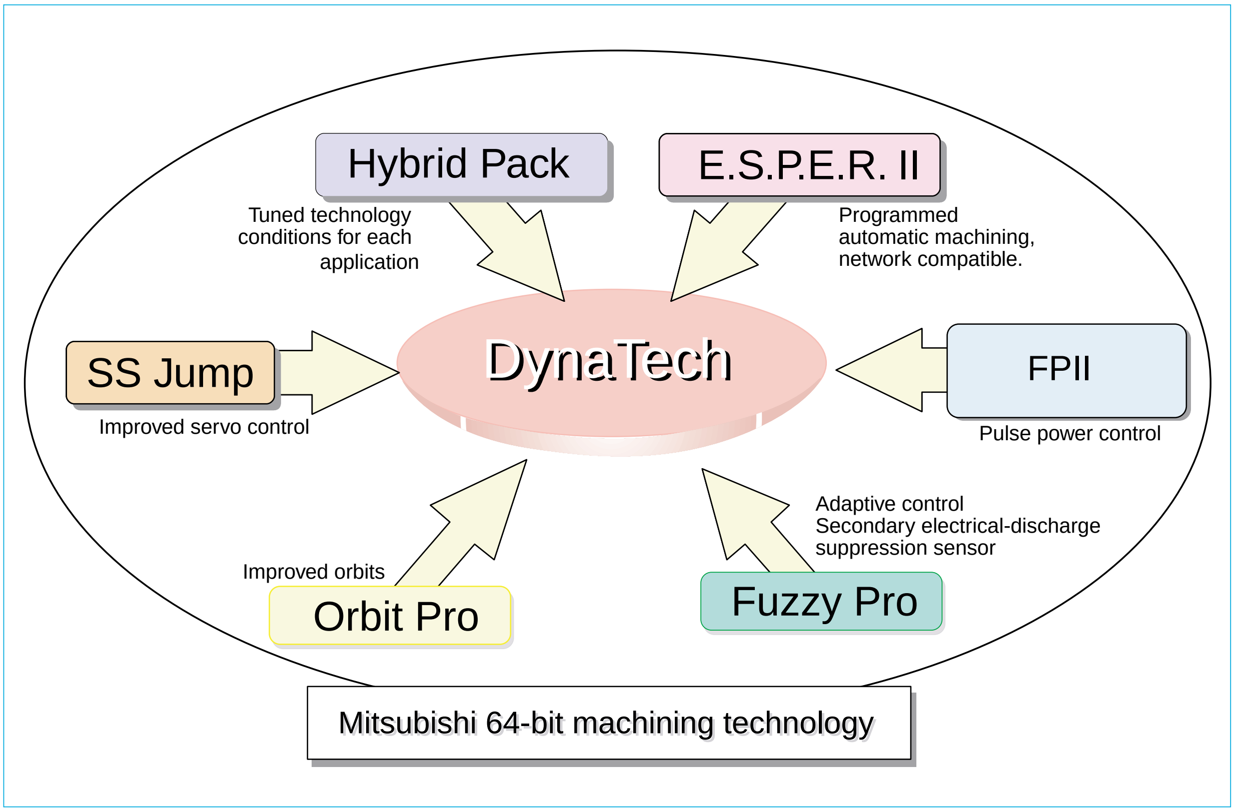


Fig. 1 "Dyna Tech" advanced machining technology

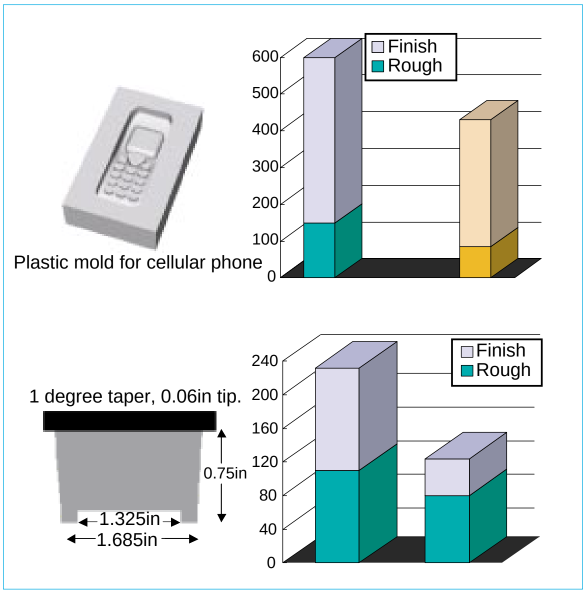


Fig. 2 Comparison of machining times and surface roughness for plastic molds and rib machining

conventional techniques. Fig. 3 shows the external appearance of the EA12, the latest 64-bit

Fig. 3 External appearance of a new 64bit CNC and the product concepts behind it

CNC sinker EDM adopting the DynaTech system.

RECENT TECHNOLOGY FOR FINE-HOLE MACHINING. As demands for higher component densities in semiconductors, electronic devices and optical communications become ever more exacting, it has become necessary to continuously open from several thousands to more than 10,000 holes, each of diameter 0.1mm and with a pitch precision of 5µm or less, as for instance in µBGA. In response to such demands, we have also developed the high-precision VH10 hole-opening EDM, which supports automated machining with high precision and to small diameters. Features of the VH10 include an NC central guide, prevention of vibrations of the small-diameter electrode by controlling the optimal position according to the position of the main axis, and the ability to use long electrodes. Consequently, automated high-precision machining over long periods of time was realized. By adopting a guide with a special construction, it became possible, for the first time in the industry, to automatically replace 50µm rod electrodes.

Trends in Wire EDMs

HIGH-SPEED WIRE MACHINING TECHNOLOGY AND ITS LONG-TERM POTENTIAL. Wire-cut EDMs have lately attracted renewed interest as a means of energy-efficient machining which produces extremely few machining chips (scraps).

The most advanced wire-cut EDMs adopting 64-bit CNC technology are equipped with newly-developed corner control, which, combined with high-speed digital oscillator control of the power supply, reduces speeds in corner areas. And through improvements to the machining power supply, the industry's highest-speed machining, 30in^2/hour (325mm^2/min), is achieved, in addition to adopting "AutoMaster" (AM) adaptive control which takes advantage of such high-speed performance (see Fig. 4). AM is an "integrated adaptive control technology" which incorporates "Power Master" (PM), "Corner Master" (CM), and "Technology Master" (TM) subunits (Fig. 5). The features of these are described below.

1. Automated machining is possible which flexibly combines processes optimized to a variety of machining patterns, including machining

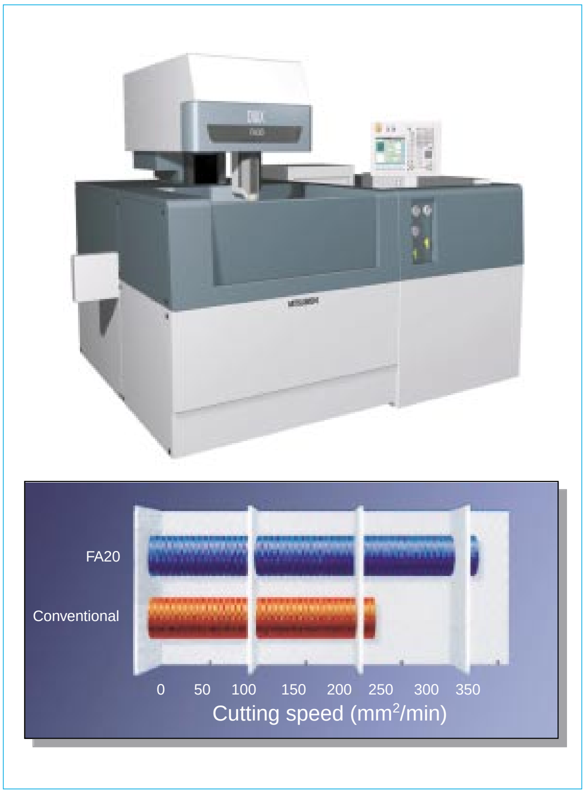


Fig. 4 External appearance of the FA20 EDM and a comparison of cutting speeds.

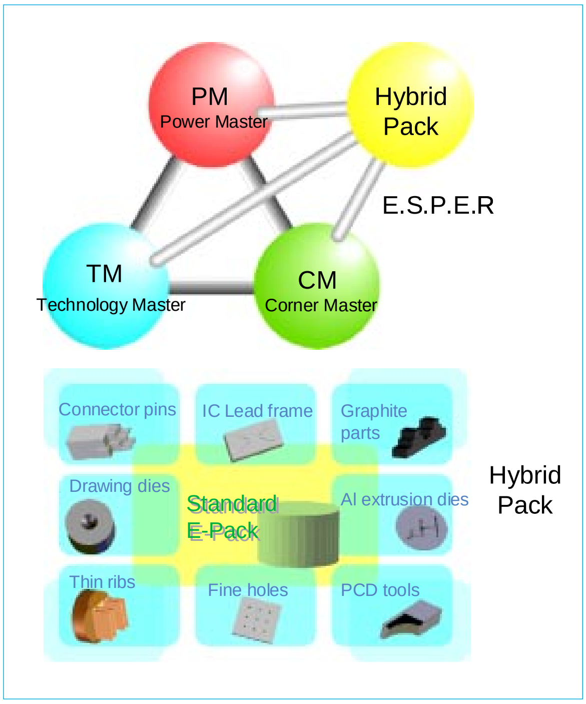


Fig. 5 Major elements of electrical discharge machine systems and their applications

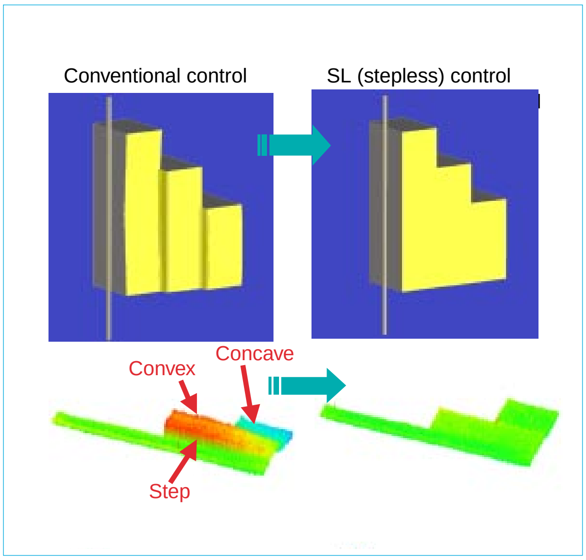


Fig. 6 Stepless control for the high-precision fully automatic machining of complicated form finishing

of workpieces to complex shapes, nozzle part-off, and corner machining.

2. High-speed processes and high-precision processes can be optimized.
3. Productivity and reproducibility are greatly improved.

Through AM functions, it has become possible to easily create processes that are optimal to the type of machining to be performed, whether plastic, molds, parts machining, or some other type of operation. In addition, high-precision finishing machining control (stepless, or SL, control) has been developed which enables a marked improvement in the planar precision of surrounding planes in finishing of complex shapes other than plates. Thus, it is now readily possible to perform high-speed, highly precise machining (see Fig. 6).

This enhancement of basic performance, taking into consideration the balance between speed of operation, precision, and automation, will become a key technology in the development of many classes of mechanical equipment for widespread use. In future, it is anticipated that still higher operating speeds will open the door to applications in still other areas of parts machining.

ULTRA-HIGH PRECISION WIRE ELECTRICAL DISCHARGE MACHINING. The expansion of semiconductor-related industries in the 1990s was accompanied by the development of ultra-precise wire-cut EDMs for use in fabricating the dies for lead frames, and wire-cut electric discharge machining came to be widely applied to fine high-precision machining tasks. In such ultra-precise wire-cut electrical-discharge scan machining, a full-cabinet construction incorporating a thermal disturbance shield mechanism and machine cooling system is employed to achieve, for the first time in the industry, a guaranteed precision of 2µm, and a best surface roughness of 0.3µmRy. Lead frames are conventionally manufactured by grinding using a split mold; in recent years, however, integral machining using extremely fine wire electrodes has become possible, and at present, they are manufactured as lead frame dies, with the inner pitch of the QFP216P at 148µm. In future also, pitches will become finer still, and fine machining techniques using wire EDMs will become even more important.

Electrical-discharge machining is entering a new phase as a consequence of improvements in machining speed, precision and automation. Hereafter, Mitsubishi Electric will continue with development of leading-edge technology enabling us to anticipate and target new and expanding markets. ❑

The Super-Precise Triangle Concept Comes to EDM

*by Yozo Sakai and Toshio Moro**

As the globalization of the manufacturing industry continues to gain momentum in this, the 21st century, we are approaching a "broad-band era," properly so called; one requiring the seamless upload and downloading of data, and the creation of seamless manufacturing processes. Responding to these market needs requires a new concept that transcends conventional electrical discharge machine (EDM) and wire-cut EDM processes. They will adopt a new concept, the "super-precise triangle." This article provides specific examples to explain the critical role that will be played by the super-precise triangle concept in precision machining as the manufacturing industry undergoes a host of transitions at the dawn of the new century.

The Super-Precise Triangle Concept

The super-precise tools used in the manufacture of semiconductors and optical ferrules cannot be fabricated using only a single type of machine tool; rather, their production requires a variety of high-precision processes. For example, the fabrication of electrodes for high-precision EDMs requires super-precise wire-cut EDMs. The fabrication of the very small start holes required also naturally calls for a high-precision hole-fabrication process. The high-precision hole-fabrication process is also extremely important in the finishing processes for wire-cut EDM, and if the machining amount in remain against the wire electrode is not uniform, this can have a major impact on the precision of circularities and linearities. In this way, super-precise dies are only possible when the machines used possess an excellent balance of roles and capabilities, as shown in Fig. 1. This is what we call the "super-precise triangle" concept, comprising the MA2000 super-precise die-sinking EDM, the PX05 super-precise wire-cut EDM, and the VH10 super-precise/microhole EDM, each of which can produce guaranteed precisions of the order of ±0.002mm. We take this to be the fundamental structure for producing future super-precise dies in the future.

Fig. 1 Machine group for the super-precise triangle concept

The MA2000 Super Precise Die-Sinking EDM and Product Specifications.

Fig. 2 is a general view of the equipment, and Fig. 3 is an example of the cell configuration with a robot system. The entire unit is enclosed in a cabinet, which greatly reduces the variability of the ambient temperature. The structure is able to maintain thermal stability over extended machining processes, containing the heavy equipment itself (at 4.5 tons) and providing synchronized control using the working fluid to eliminate ambient temperature differences. As a result, the MA2000 is the first in the indus-

Fig. 2 The super-precise MA2000 die-sinking EDM

Yozo Sakai and Toshio Moro are with the Nagoya Works.

Fig. 3 The MA2000 robot system

try to provide machine specifications and functionality guaranteeing machining precision of ±0.002 mm.

THE SUPERHIGH-SPEED SERVO SYSTEM WITH SUPER "DYNATECH." Die-sinking EDMs have three-dimensional electrodes, and their machining characteristics are strongly shape dependent. Experience is required to know the processing conditions and the sequence of operations, and this need for experience currently hinders the optimization of EDM processes and the enhancement of performance. The DynaTech integrated machining control system, based on a new sludge-control concept, has already been incorporated into products as a way to completely eliminate this problem. This DynaTech integrated machining control system is provided as standard equipment in the MA2000, being incorporated into "Super DynaTech," which is specific to the MA2000, to provide even higher levels of performance.

Fig. 4 shows a comparison of the jump patterns resulting from differing machine specifications, where the wasted time in the jumps is

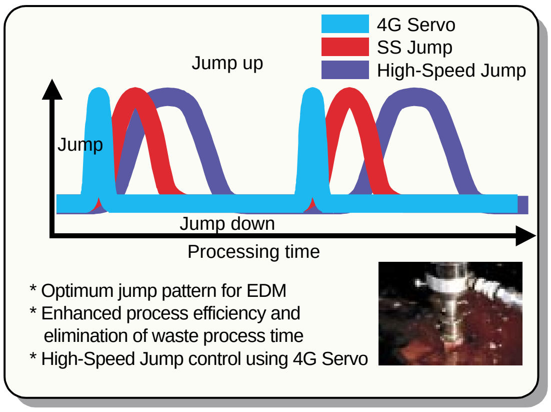


Fig. 4 High-speed jumping pattern in the Z-axis direction

less for the 4G super-gain servo than for the SS jump pattern, which itself is still less than the wasted time in the conventional high-speed jump pattern. Through the application to the super high-speed jump pattern of Fuzzy Pro, which automatically adjusts the height of the jump according to the machining depth, it becomes possible to increase the effective machining time significantly, thereby improving the duty factor. In the MA2000, this jump pattern has produced a maximum movement speed of 60m/min and a maximum acceleration of 4G.

Machining Samples Using the MA2000.

THE NP CIRCUIT FOR SUPER-PRECISE FINISHING MACHINE POWER SUPPLIES. As evident in the super-precise triangle concept, responding to future market needs will require machining surface qualities providing ever-increasing levels of miniaturization and precision. Specifically, as is shown in Fig. 5, the new NP circuit for finish-machining power supples is able to provide a

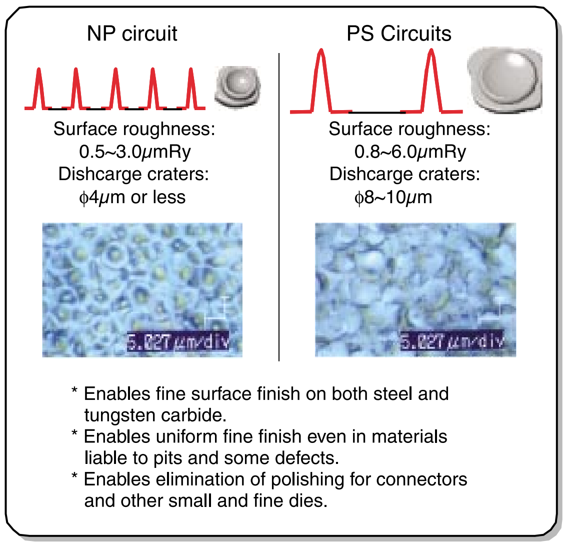


Fig. 5 The super-finish NP circuit

surface roughness up to 0.5μmRy, subject to some size constraints on the shape being machined. This NP circuit, as is clear from the figure, not only greatly improves the surface roughness by reducing discharge craters to about half their former size but also substantially improves the speed of machining by providing higher discharge pulse frequencies. In practice, when this quality of surface is obtainable, the final die-polishing process can be dispensed with.

Fig. 6 is an example of machining a fine-pitch connector, with a finish that has an extremely small in-corner radius and extremely small di-

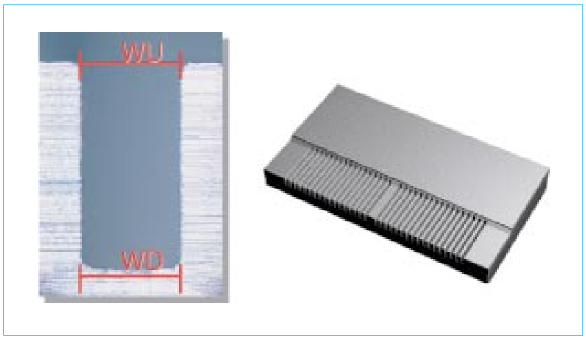


Fig 6 Test-cut sample of connector using NP circuit

mensional deviation across the openings and across the width of the bottom. With this type of die, it is virtually impossible to perform polishing. Thanks to this power supply, the die is usable with just the finishing provided by EDM, greatly reducing the number of die-machining processes and eliminating manual operations such as polishing, making it easier to maintain high levels of precision.

GATE-PIN MACHINING. Fig. 7 shows an example of machining a gate-pin hole. For a 3mm hole with a side slope of 1° processed to a depth of 50mm, the system can machine it in seven hours if there is no pre-machining hole, and in only five hours with a pre-machining hole. Here, the 4G super-gain servo of the MA2000 has a major effect even in cases where the pre-machining hole itself involves a problematically high aspect ratio. Because this gives greater freedom to modify the design of die structures, it then becomes possible to reduce the number of parts,

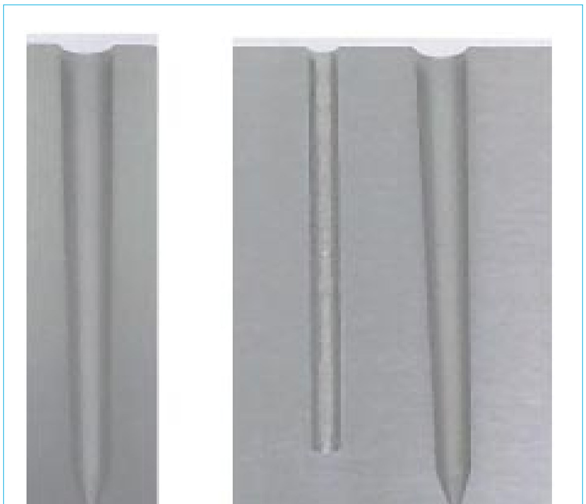


Fig. 7 High-speed test-cut sample for sub-gate pin holes

with consequent significant further reductions in manufacturing costs.

The PX05 Super-Precise Wire-Cut EDM

BENEFITS OF THE PX05. Fig. 8 shows the thermally insulating full-cabin structure and the Z-axis base cooling of the PX05 (which won a

Fig. 8 Super-precise PX05 wire-cut EDM

technical award for excellence from the Japan Society of Mechanical Engineers in 1998). The equipment itself has the benefit of a full cabin cover in a thermally insulating structure: its interior surface is coated with an insulator. Providing an external cover for the entire casting structure eliminates, for instance, the thermal disturbances caused by air currents and exposure to direct sunlight. Even in the setup work before machining starts, the inside cover protects the casting structure parts from air currents when the front cover is opened. Additionally, as a means of dissipating the thermal energy generated within the covered area, the heat of machining is absorbed by the working fluid and circulated to the working fluid tank, and thus goes outside of the cover. In addition, the use of circulating working fluid to control the machine unit to temperatures matching those of the machines structural elements (the z-axis base and the base arm) reduces relative movement in the vertical direction and makes the structure itself less susceptible to thermal effects.

Fig. 9 shows the change in thermal time constant due to the thermal disruption control structure. When a 3°C temperature change was applied for 12 hours, the thermal deformation

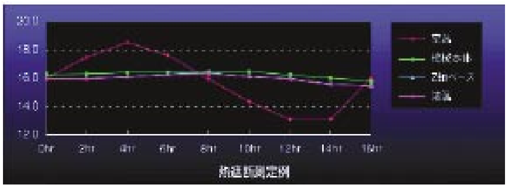


Fig. 9 Controlling effect for thermal deformation due to room temperature equalization

insulation full-cabin structure buffered the temperature change, delaying by one to three hours the time at which the temperature reached its peak. Furthermore, the magnitude of the temperature change was held to between 0.2 and 0.5°C, as can be seen in the Figure.

INDEPENDENT X AND Y AXIS STRUCTURES. In conventional cross-tables the axis of movement in one direction is on the axis of movement for another direction, causing the central movement of the structural elements for the upper axis of movement to be affected by the precision of the angle of the lower axis of movement, if only slightly. Fig. 10 shows the mechanical structure

Fig. 10 The PX05 (with independent X and Y axes)

for the PX05, where the positioning accuracy is improved by the use of a head structure of hardened steel, and where the X and Y axes are mutually independent. The result is that each axis is virtually unaffected by the other, making it possible to provide high-precision positioning across the entire stroke range (see Fig. 11).

HG2 + CORNER EXPERT. Conventionally, the smaller the processing shape, the more difficult

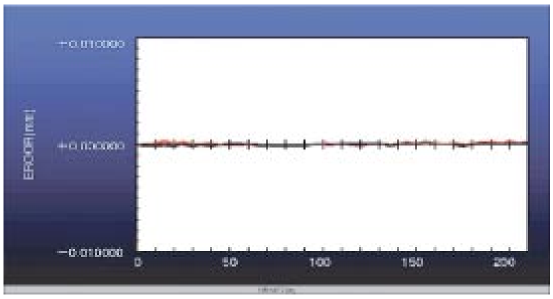


Fig. 11 Laser measurement of typical X axis pitch error

it is to set the processing conditions in order to provide a high precision finish, and specialized know-how was required for adjustments to compensate for errors. The purpose of the high precision gap control or (HG2) control system is to prevent arc discharges in corners while improving the precision of the corner geometries, and the newly developed electrical discharge gap-control technology has greatly improved the control responsiveness and stability in micro-machining geometries. The result is substantial improvements in the precision of geometries in parts where there are sudden changes in the amount of material with machining conditions that are easier to set.

Fig. 12 is an example where an outside shaped edge was machined in 10mm-thick die steel using a wire with a 0.1mm diameter. In con-

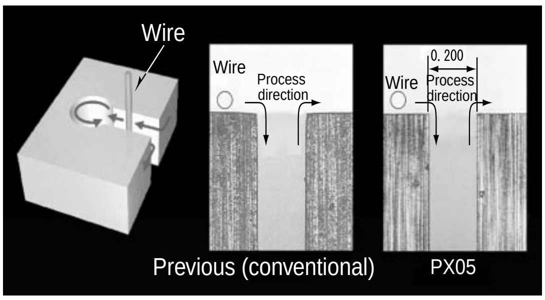
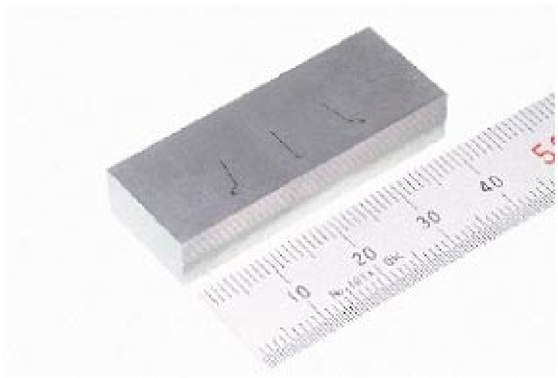


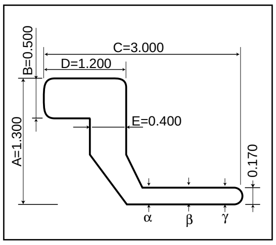
Fig. 12 High-precision performance in corner machining with HG2+ Corner Expert

trast to a conventional example wherein there would be two to three microns of edge wear, with this technology the edge wear was improved to less than 1μm.

MACHINING AND IC LEAD-FRAME DIES. Fig. 13 shows a sample that models an IC lead-frame die. The data sheet shown is the result of benchmark testing evaluating the machining performance on the lead-frame shapes performed by



Process shape



Process conditions

Wire diam.:	ϕ 0.1
Material:	Hardened, 10mm
Corner R:	0.080 x 10
Circuit length:	Expanded process = 16.4mm Shape = 8.0mm

Comparison between PX05 and DWC90PA processing efficiency

PX05

Processing tolerance (in microns)

Y-direction	A:0	B:1	
X-direction	C:+3	D:+3	E:+2
Slit	α:0	β:0	γ:0

Processing time 28m 44s (7 processes)

DWC90PA

Processing tolerance (in microns)

Y-direction	A:–2	B:2	
X-direction	C:–3	D:–3	E:0
Slit	α:–3	β:–3	γ:–4

Processing time 45m 28s (9 processes)

Fig. 13 Benchmark test-cut result for IC lead-frame die using PX05

Mitsubishi Electric Corporation. When compared to a conventional super-precise WEDM (the DWC90PA), not only does the PX05 provide an improvement in machining precision, but, as evident from the figure, it also provides a dramatic improvement in the total machining time. This improvement is due to an improvement in both the rough machining speed (shown in the magnified view in the table below), and a reduction in the number of passes in the finish machining, where the improvement in the rough machining speed is the result of the new power supply that supplies electrodischarge pulses optimized for fine wire-cut machining. Additionally, the high-performance servo HG2 and the Corner Expert function combine to improve the shaping-error correction capability in the finishing process, making it possible to perform super-precise machining with fewer finishing passes than previously possible.

EXTREMELY FINE-WIRE MACHINING. Even in cases other than the machining of IC lead-frame dies, there has been remarkable miniaturization of products in a host of fields including the electronics industry, which requires the application of wire-cut EDM to smaller and more precise application in die fabrication factories. An example of machining that meets these needs follows. Fig. 14 shows a 1.2mm steel plate that was finished with a single cut using a 0.020mm-diameter tungsten wire to machine a super-precise slit. In order to create this narrow slit, the FS3 finishing power-supply circuit was used, and the machining was done in a single process with an extremely low energy level, making possible machining that simultaneously provides extremely precise linearity and extremely favorable surface finishing.

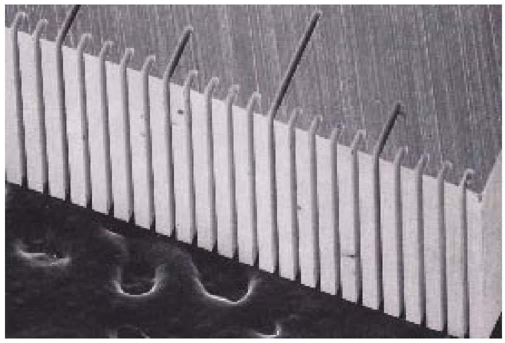


Fig. 14 Narrow-slit machining applications using fine electrodes with 0.02mm diam.

The VH10 Super Precise Microhole EDM

FEATURES OF THE VH10. Fig. 15 shows the VH10, which has the following advantages. Based on

Fig. 15 The VH10 super-precise micro-hole EDM

recent high-precision multi-hole continuous machining processes, the VH10 has succeeded in substantially improving microhole machining process efficiency in, primarily, fabricating dies, through widely implemented automation and high-precision hole-machining processes.

* Succeeded in automatically changing 0.050mm-diameter electrodes.
* Succeeded in machining microholes 0.070mm in diameter, without electrode forming by EDM (electrode dressing).
* Reduced the processing time of the high-precision microholes.
* Succeeded in creating a high-precision multihole-machining process.
* Selection of working fluid specifications depending on the machining application (Both dielectric working fluid and deionized working fluid are available.)

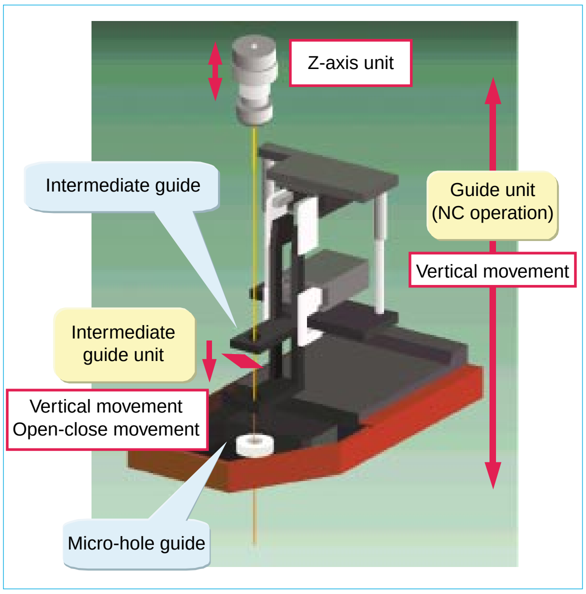


Fig. 16 The structure of the intermediate guide

Process Automation and the Elimination of Electrode Dressing

When using conventional electrodes with diameters less than 0.10mm, it has usually been necessary to use ultrafine electrodes fabricated on the machine itself using a reverse discharge method and a block electrode or using wire electrical discharge grinding (WEDG)[1], with correspondingly extremely low processing efficiency. This was because there was no reliable technology for inserting the superfine electrodes into their guides, and none for changing electrodes automatically. The VH10 machine tool developed by the corporation has a newly developed microhole guide arm and an intermediate guide, with the great advantage of making it possible to perform machining directly using rod electrodes in the market place. The electrode dressing process that has generally been used conventionally is now unnecessary, greatly reducing the total processing time.

The guide arm and intermediate guide mechanism are shown in Fig. 16. The mechanism comprises a microhole guide (which can be moved up and down by an NC drive) and an intermediate guide (similarly controlled by the NC drive), which can be opened and closed and which can also be driven up and down. This type of intermediate guide approach is generally applied to electrodes with diameters of at least 0.100mm. With diameters less than 0.090mm, exchange is performed automatically using a special electrode holder, as shown in Fig. 17. Although this figure shows the approach used for a rod electrode with a diameter of 0.050mm, it is also readily able to handle rod electrodes with extremely small diameters, previously very difficult to handle. Machining is stable because a mechanical pencil-feed is used until the rod electrodes stored within the holder have been used up; because the amount of rod electrode that extends beyond the tip part is small, there is the additional benefit of little difference between the diameters of the entrance and exit holes.

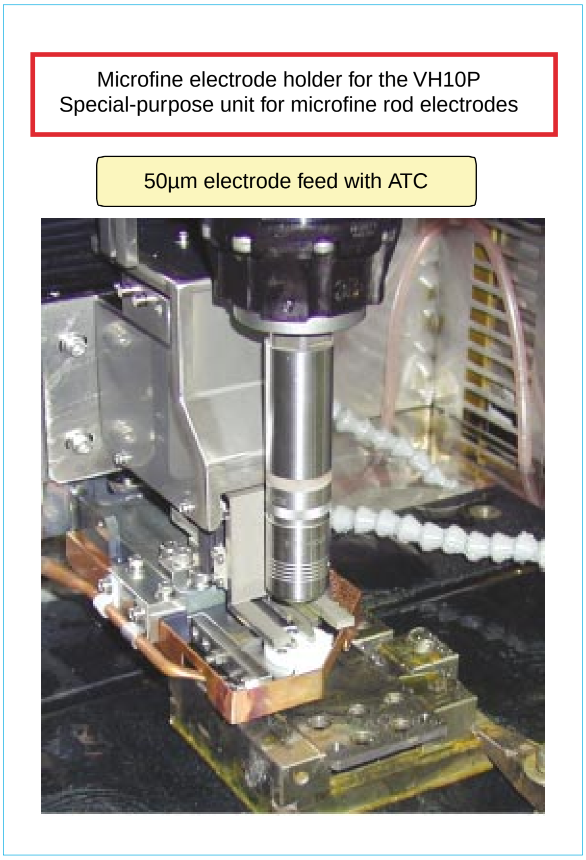


Fig. 17 Microfine electrode holder for the VH10P

MACHINING 0.050MM ROD ELECTRODES. Fig. 18 shows an example of machining continuously undergoing changes using 0.050 mm-diameter tungsten rod electrodes. Here, the electrodes experienced 0.2mm of wear per hole in a 0.5mm steel plate (SKD11), the electrodes were changed automatically after each ten holes, and the entrance hole is between 0.069 and 0.073mm in diameter. Adequate precision was obtained to produce green sheet with extremely small hole variability, and for precision dies for, for example μBGA use. Furthermore, pitch error was excellent, within 0.002 to 0.003mm.

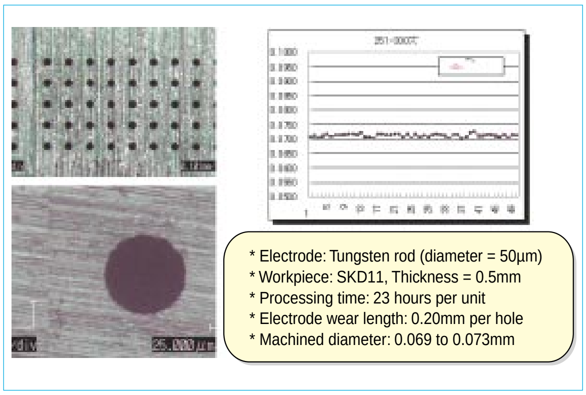


Fig. 18 Multi-stage machining test-cut sample using fine electrodes

As noted in the foregoing article, we anticipate continually increasing demand for super-precise dies. This alone will make it necessary to increase the overall performance of the various super-precise machining tool groups currently proposed, and also to perform systematic research over a broad range of disciplines in the future. ❑

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Technology in the Ingersoll EDM System

*by Jurgen Schmitz and Georg Zander**

The "golden age" of EDM sinker technology in the 1980s is over, and the fight for larger market share has become increasingly difficult, since high-speed cutting technology has taken over the simple die and parts fields of EDM application. In the last decade of the 20th century, EDM fell far behind high-speed cutting (HSC) technology, and no new technological directions pointed to new die-sinking EDMs. Some well-known EDM producers have disappeared and the survivors are working hard to maintain their leadership. The need is to develop new technology for highly efficient EDM machining. Ingersoll and Mitsubishi Electric have remained powerful partners in generating new, advanced technology.

Today's Ingersoll EDM products range from the compact C400 to the Gantry 2000 (see Fig. 1). Machines for large-scale EDM applications are used mostly in the automotive industry. From mid-2001, the newly developed Gantry 2000, with its 3,200 x 2,000mm work tank became the high-end Ingersoll die-sinker EDM. The worldwide partnership of these two advanced corporations forms the basis for ongoing success both at present and in the future.

Fig. 1 The large, top-of-the-line Gantry 2000.

History

Ingersoll is one of the largest privately-owned machine-tool manufacturers in the world. It started the die-sinker EDM business in the US in 1955. Ingersoll Germany was founded in 1962 in Burbach, and took over the die-sinker business from its US parent company in 1968.

Since then, Ingersoll has continuously developed the die-sinker business and specialized in big-machine EDM applications (see Fig. 2).

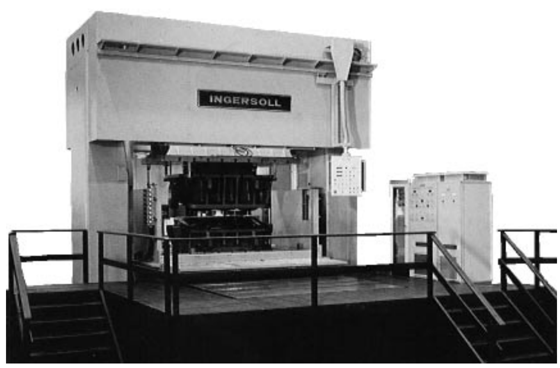

Fig. 2 A large, portal-type die sinker for draw dies.

Ingersoll was also a leader in developing new EDM technologies for small machines, such as ATC, full-screen, CNC and orbiting strategies (see Fig. 3). In 1992, Ingersoll took over the die-sinker business of Maho Hansen, which was the market leader for small die sinkers in Germany.

Cooperation with Mitsubishi Electric

In 1994, Ingersoll Funkenerosionstechnik and Mitsubishi Electric Corporation entered a strategic alliance with cooperation in marketing for the German market using the same agents for both Ingersoll die-sinker and Mitsubishi wire-cut EDMs.

In 1995, marketing cooperation was extended to technical cooperation, with Mitsubishi Electric supplying generators, CNC functions and drives for Ingersoll die-sinker EDMs. The first machine to result, the Gantry 500, was intro-

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Fig. 3 The Ingersoll IC 110

Fig. 4 The Gantry 500

duced in 1996 (see Fig. 4). As with all Ingersoll die-sinker EDMs, it uses the most advanced technologies, such as raising and lowering the work tank, a gantry design for optimum precision and stability, and provides ATC and C-axis operation as standard. Until the advent of the Gantry 2000, the top-of-the-line Ingersoll EDM product was the Gantry 1300 (see Fig. 5).

Automation

In today's EDM market, interest is increasingly concentrated on automated systems. Ingersoll has therefore concentrated in recent years on

Fig. 5 The Gantry 1300

the development of hardware and software solutions for automated EDM processes.

Center 4000, which Ingersoll presented at EMO 1999 in Paris, is an EDM center equipped with an integrated electrode- and workpiece-handling system. The machine is based on the concepts behind the Center 400, developed jointly with Mitsubishi Electric the previous year (see Fig. 6). The same concepts also form the basis of future joint developments between the two companies. The cooperation entered its next phase

Fig. 6 The Center 4000 (a Center 400 with robot)

at the end of 2000. Ingersoll is now completing the die-sinker EDM Model EA8 (see Fig. 7) with Ingersoll components like the C-axis function (see Fig. 8) and safety-related parts meeting CE regulations. The EA-8 is sold under the

Fig. 7 The Mitsubishi EA8

Fig. 8 An Ingersoll C-axis unit

Mitsubishi brand name in the European market. The combination of advanced Ingersoll mchanics with powerful Mitsubishi Electric electronics has created the most succssful die-sinker EDM on the European market, (see Fig. 9).

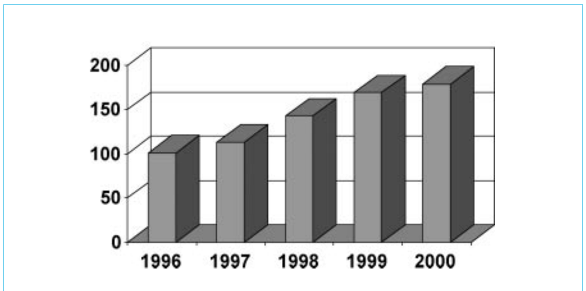

Fig. 9 Sales of Ingersoll die-sinker EDMs

The worldwide partnership and the powerful resources of these two world leaders is the basis for further successes in the future. ❑

Applying Virtual Engineering to EDM

by Masao Akiyoshi and Akihiko Imagi

Mitsubishi Electric Corporation has applied virtual engineering to electrical discharge machines (EDMs), optimizing the waveform of the electrical current by performing thermal analysis for electrical discharge coating. Thermal analysis is able to predict the temperature distribution and the size of the vaporization and melt regions in electrical discharges on an electrode and a workpiece. In depositing a hardened layer of TiC using electrical discharges, this use of thermal analysis in developing the electrical discharge waveforms to optimize control of the temperature of the layer being deposited has yielded greater layer hardness.

Single-Discharge Electrical Discharge Thermal Analysis Model[1]

Fig. 1 shows the analysis model. An arc column is generated between the electrode and the workpiece. The size of the arc column is affected by the discharge current and its duration. In order to estimate changes in the radius of the arc column, the discharge energy consumed to increase the size of the arc column is calculated by Eq. 1, assuming that the energy spent on this arc-column expansion balances the total energy transmitted to the dielectric fluid plus the energy to change the state of electrical discharge beside the arc column.

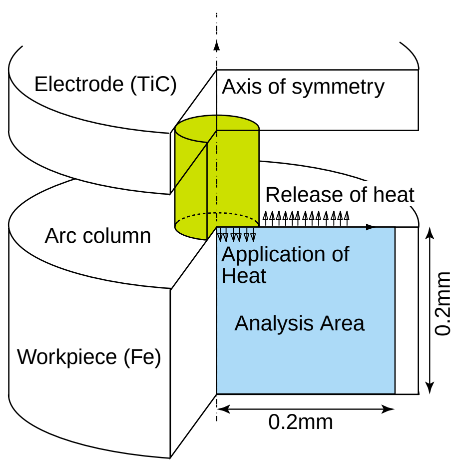

Fig. 1 The analysis model

$$\eta i v dt = 2\pi R l h \Delta T dt + 2\pi R l E dR \quad \text{.................. Eq. 1}$$

Here i is the discharge current, v is the discharge voltage, R is the arc column radius, l is the gap between the electrodes, h is the heat-transfer coefficient of the arc column surface, ΔT is the difference in temperature between the arc column surface and the dielectric fluid, E is the energy required to cause the arc discharge, t is the duration of the discharge, and η is the proportion of the electrical discharge energy consumed to increase the size of the arc column. Dividing both sides by dt and then rearranging the terms gives Eq. 2:

$$R\frac{dR}{dt} = C_1 i - C_2 R,\quad C_1 = \frac{\eta v}{2\pi l E},\quad C_2 = \frac{h\Delta T}{E} \quad \text{..... Eq.2}$$

The following assumptions were made: h=2.1x10^5 W/m^2K, ΔT=5,000K[2], E=3.5x10^8 J/m^3, v=20V, and l=5 x10^{-5}m. In C_1, η is the solution if C_1 is a parameter, and is calculated after determining C_1 to match the arc column radius that is inferred from the crater made by the single-discharge electrical discharge. η was calculated assuming it to be dependent on the discharge current i. The values for C_1 and C_2 substituted in Eq. 2 and the arc-column radius R are calculated using the *Runge-Kutta* method.

The region of the workpiece in contact with the bottom surface of the arc column, calculated using Eq. 2, is heated by the heat flux $q=\alpha iv/\pi R^2$. Here α is the proportion[3] of the electrode discharge energy transmitted to the workpiece; this depends on the materials of both the electrode and the workpiece. In the case where Fe is used as the workpiece and semi-sintered TiC is used as the electrode, when α is about 20%, the crater depth predicted by themal calculation matches the experimental result from a single electrical discharge. Additionally, it is assumed that the temperature of the dielectric fluid is 293K and the heat-transfer coefficient on the surface of the workpiece is 2.5 x 10^5 W/m^2K.

The analysis model has two-dimensional symmetry, and the analysis region is a 0.2 x 0.2mm square on the side of the workpiece with the TiC. The analysis region is divided into 400 units

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both front to back and side to side. The two-dimensional heat conduction equation in Eq. 3 was used to calculate the temperature. However, in consideration of the latent heat of fusion and the latent heat of evaporation of the Fe in the workpiece, the change in enthalpy was calculated and the temperature was redefined.

$$\frac{\partial T}{\partial t} = k\left(\frac{1}{r}\left(\frac{\partial}{\partial r} r \frac{\partial T}{\partial r}\right) + \frac{\partial^2 T}{\partial z^2}\right) \quad \text{Eq.3}$$

Here, k is the thermal diffusivity, T is the absolute temperature, and r is the distance from the center of analysis.

Results of the Single-Discharge Electrical Discharge Thermal Analysis

The larger the diameters of the crystallites on the surface of the workpiece, the greater its hardness. In order to lengthen the period of crystallite growth, a supplemental heating pulse is added after the main pulse. Fig. 2 shows the new electrical discharge waveform that resulted. After a current of eight amps was caused to flow for 8ms, a one-amp current was caused to flow for 20ms.

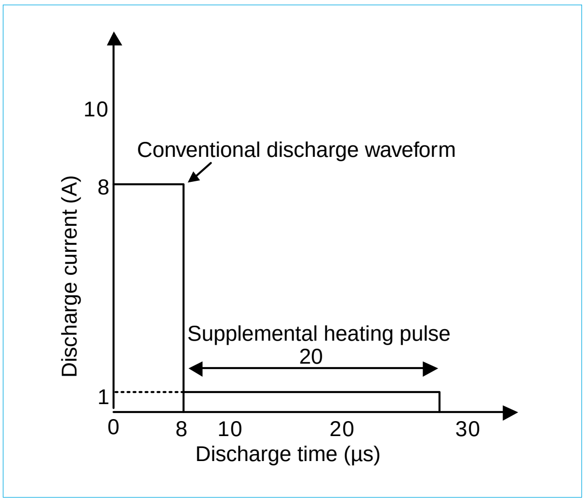


Fig. 2 Electrical discharge waveform

Fig. 3 shows the relationship between the discharge time and the temperature on the surface of the discharge crater as it changes over time at a position that is r=5μm from the surface of the workpiece (z=0). The horizontal axis shows the passage of time from the start of the discharge.

In conventional discharges, the surface temperature increases to 3,200K for a 2μs interval, and for the following 6μs the temperature remains above 3,000K with little change. Because

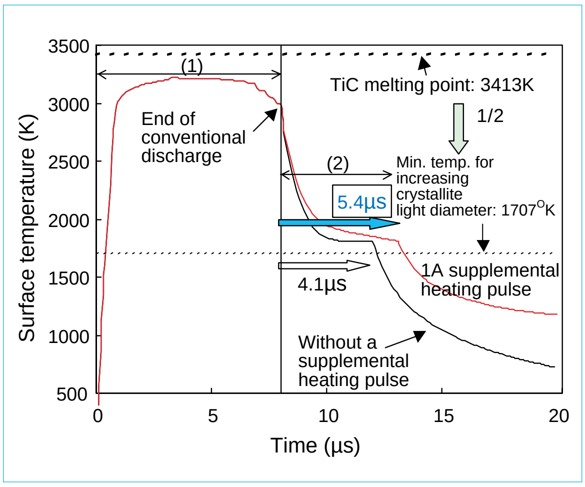


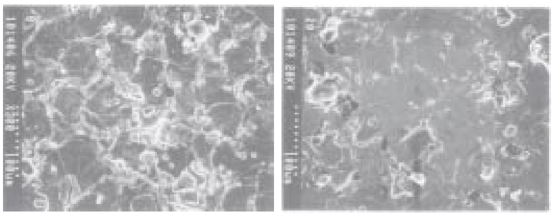
Fig. 3 Temperature variation on a workpiece surface

the TiC melting point is 3,413K, the TiC that moves from the electrode begins to solidify after arriving on the workpiece; however, because the TiC continues to be supplied to the workpiece from the electrode during the discharge ((1) in the figure), the process by which the TiC crystallite diameters grow is thought to take place after the discharge is complete ((2) in the figure).

The growth of crystallite diameters is generally affected by processes that take place at temperatures from the melting point down to those about half of this; in this case it was taken as the time to reach a temperature of 1,707K. When there was no supplemental heating pulse, the time taken to reach that temperature was 4.1μs; however, when the supplemental pulse was added, this time expanded 1.3 times to 5.4μs. We found that it is possible to extend the period of crystallite growth by adding the supplemental heat pulse, and to increase the crystallite diameters.

Experimental Results

Using a 5 x 5mm TiC semi-sintered electrode, a TiC layer was layed down by performing a five-minute process. Fig. 4 shows the results of surface observations of the TiC layer using a scanning electron microscope (SEM). Fig. 4 (a) is without the supplemental heating pulse and (b) is with it. The white striations indicate roughness. The circular shape surrounded by the white striations is the electrical discharge mark within which a melted region formed by the single-discharge electrical discharge has resolidified. In Fig. 4 (a), the boundaries of each individual discharge crater can be seen clearly in the texture of the TiC layer surface. Because the temperature of the discharge crater surface falls rapidly, there will be some roughness in the surface of the crater due to the influence of thermal stresses, etc., that occur during solidification. In Fig. 4 (b), there is almost none of this white striation showing the boundaries of the discharge craters. This indicates that the surface of the workpiece is rendered smooth by the supplemental heating pulses that extend the period of time over which heat is injected into the coating layer.



(a) Without a supplemental heating pulse

(b) With the supplemental heating pulse

Fig. 4 Surface conditions of the TiC layer

Table 1 shows the crystallite diameters calculated by X-ray diffraction measurements of the TiC layer surface, along with measurements of the TiC cutting hardness (in microvickers with a load of 10gf). Crystallite size can be inferred from the increase in the half width of the diffraction peak. The calculation made use of the *Scherrer* formula. While the size was 100 angstroms in the absence of a supplemental heating pulse, the addition of such a pulse made it possible to increase the TiC coated layer crystallite diameter about 2.5 times. When TiC layer hardness was compared, an additional 20μs-long one-amp supplemental heating pulse increased the hardness to 1500HV, an improvement of approximately 15% over the 1,289HV hardness achieved using the conventional electrical discharge waveform.

Table 1 Results of X-ray Diffraction Analysis and Vickers Hardness Tests

	Without heating pulse	With heating pulse	Unprocessed workpiece
Crystallite diam.		100A	250S
Vickers hardness	1289HV	1500HV	253HV

The application of virtual engineering made it possible to predict localized transient temperature changes that have, in the past, been quantitatively unknown. Increased understanding of these temperature changes has already paid off in significant improvements in surface hardness using electrical discharge machines. ❑

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Adaptive Control Technology for Wire-Cut EDM

*by Tatsushi Sato and Atsushi Morita**

In wire-cut electrical discharge machines (EDMs), the use of the maximum power that can be applied without breaking the wire electrode is critical in optimizing the speed of machining. At Mitsubishi Electric Corp., an adaptive machining control method has been developed to optimize this power when the optimal power may depend on a variety of factors such as the thickness of the workpiece and the flow of dielectric fluid. This type of control has increased machining speeds as much as three fold.

In wire-cut electrical discharge machining, increasing the number of discharge pulses generated per unit time accelerates the machining process. However, if the pulse frequency is too high, the wire electrode will break, causing instead an abrupt drop in the machining speed. If the wire-cut EDM machining speed is to be optimized, the pulse frequency must be maintained at as high a value as possible without exceeding the maximum limit that would cause the wire electrode to break.

Of the factors that influence this maximum electrical discharge pulse frequency, those with particularly critical effects are the state of flow of the dielectric fluid (which is determined by the relationship between the dielectric fluid nozzle and the workpiece) and the thickness of the work piece being processed. This not just because both factors have a high impact on the limiting pulse frequency but also becasue they may change during the machining process, requiring adaptive control of machining power control to match the speed of machining to any such changes.

For example, as in Fig. 1, we can consider workpieces to which the dielectric fluid nozzles cannot be close, or the case where a workpiece with a hollow part is being processed. In conventional wire-cut EDMs, the machining power is not controlled in this way, and thus it becomes necessary to process all parts of a component at a power low enough not to break the wire electrode at points where this is most likely. As a result, the limiting electrical discharge pulse frequency is substantially lowered even at places where there is an excellent flow of dielectric fluid,which is extremely inefficient. The corporation has developed a function that controls automatically the machining parameters depending on variations in these two factors, and has succeeded in increasing the machining speed by a factor of 2.9.

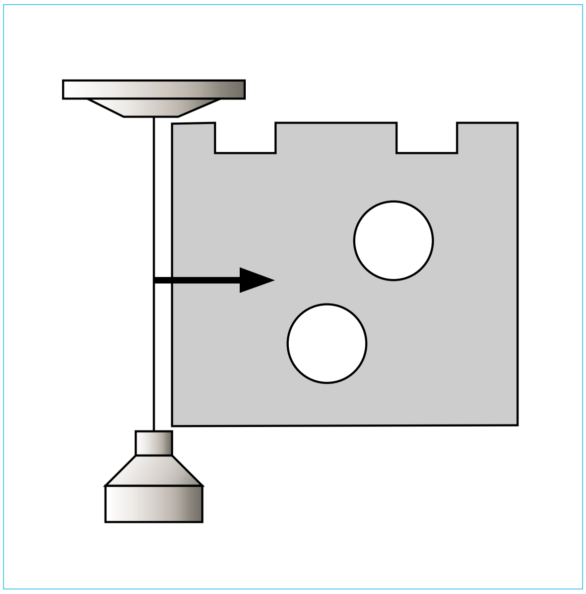

Fig. 1 A variety of flushing conditions

Detecting the Thickness of the Work Piece

Generally, the wire electrode is least likely to break in wire-cut EDMs when workpiece thickness is between two and three inches, but for other thicknesses the limiting pulse frequency must be lowered. In particular, if the workpiece is too thin, then the limiting frequency must be reduced substantially. As a result, machining-power control must reflect the thickness of the workpiece throughout the machining process if the maching speed is to be increased, making it important to be able to sense workpiece thickness.

Workpiece thickness T_k can be obtained from the following formula where the volumetric speed of machining is defined as V_m, the width of the machining is W_g and the feed speed is V_x.

$$T_k = \frac{V_m}{W_g V_x} \quad \text{Eq. 1}$$

The volumetric speed of processing V_m is nearly proportional to the electrical power E_m required for machining, and thus if the constant of pro-

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portionality between them is defined as K_m, then the volumetric speed of processing V_m is given by the following equation;

$$V_m = K_m E_m \quad \text{...... Eq. 2}$$

Consequently, if a new constant of proportionality $K = K_m/W_g$ is introduced, then the workpiece thickness T_k can be expressed as;

$$T_k = K(E_m/V_x) \quad \text{...... Eq. 3}$$

In other words, the thickness of the workpiece T_k can be calculated from the machining power E_m (which is calculated from the electrical discharge pulse coefficient results), and the speed of movement V_x along the processing path, which is stored in the NC control equipment.

Controlling the Machining Power Depending on the State of the Dielectric Fluid

Even given workpieces of the same thickness, if the dielectric fluid can flow easily into the working gap (for instance, when the dielectric fluid nozzle is close to the workpiece), the wire electrode is less likely to break than if the nozzle is away from the workpiece. This makes it important to control the machining power according to the state of flow of the dielectric fluid.

Normally, the machining power is controlled by the time interval during which no voltage is applied between the wire electrode and the workpiece (i.e., the pause time). Given this, we investigated the relationship between the pause time and the pulse frequency in three situations: when both the top and bottom dielectric fluid nozzles are close to the workpiece; when either a top nozzle or a bottom nozzle is close to the workpiece; and when both the top and the bottom nozzles are away from the workpiece. The results are as shown by the solid line in the schematic diagram of Fig. 2. Note that in this figure the x marks are the positions at which the wire electrode broke at the various nozzle settings.

When both of the dielectric fluid nozzles were close, the limiting pulse frequency was higher than when one of them was away, which was in turn higher than when both were away. This indicates that the poorer the flow of dielectric fluid, the lower the limiting pulse frequency will be, as would be expected. Note, however, that in all cases the slopes of the solid lines for all nozzle settings leveled off before the electrode broke. In other words, we discovered that near the limit, the pulse frequency did not increase much even with shorter pause times.

From this, it is possible to establish a threshold curve such as shown by the dotted line in Fig. 2, where the machining can be performed at optimal power by controlling so that the point on the graph (the operating point) for the pause time that has been set and the electrical discharge pulse frequency that has been measured is near the threshold curve.

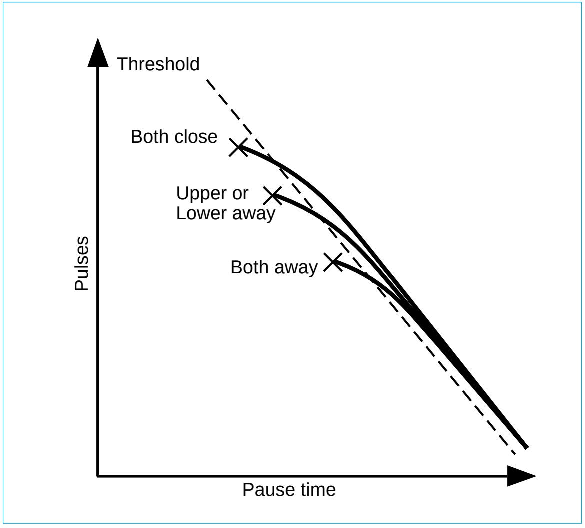


Fig. 2 Pause time vs. discharge frequency

In other words, the control should be such that the pause time is lengthened if the operating point is below the threshold curve, and shortened if it is above the threshold curve. Of course, a threshold curve that depends on the thickness of the workpiece that is detected must be used because the threshold curve will be different for each workpiece thickness.

Results of the Experiments

Fig. 3 shows the shapes of the samples from the machining tests when the plate thicknesses and

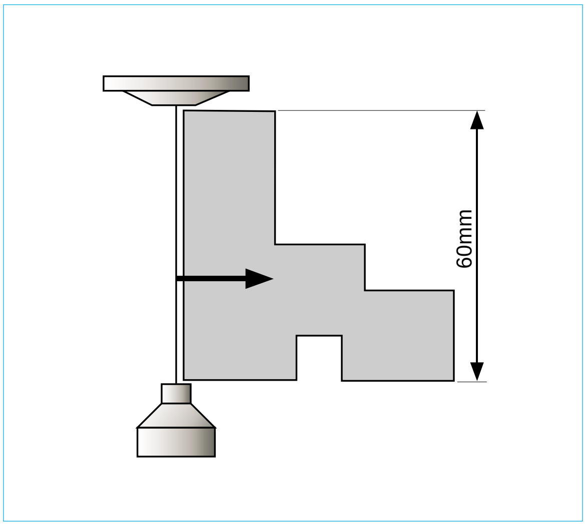


Fig. 3 Shape of the test cut

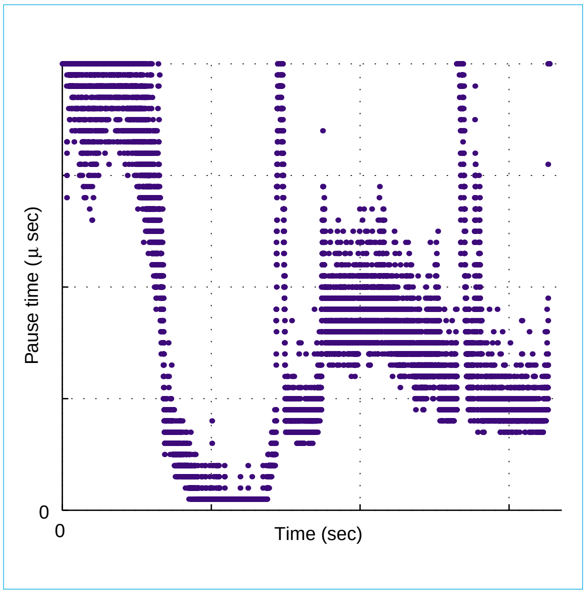


Fig. 4 Results of controlling pause time

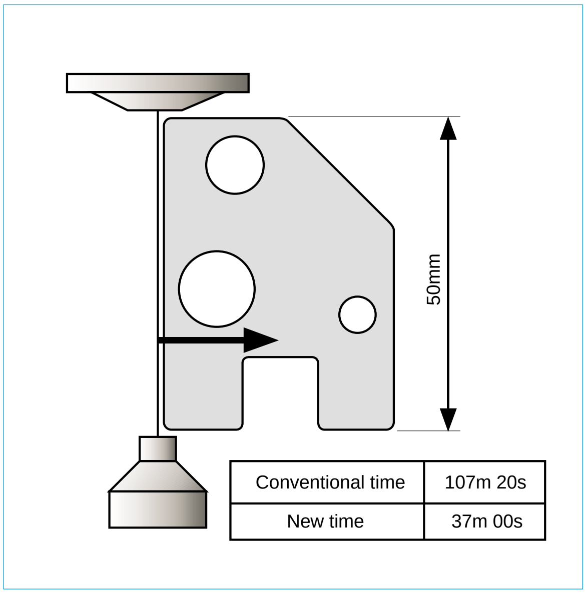


Fig. 5 Test-piece shape and the result of the sprayed test cut

nozzle setups were varied, and Fig. 4 shows the control results for pause times. It is evident that the pause time was controlled appropriately following the changes in the workpiece thickness and the changes in the status of the working fluid flow.

Note that the pause time immediately after the start of machining was controlled at a very large value. This was due to the insufficient supply of the dielectric fluid to the machining gap when the fluid tended to flow off the edge of the work piece because a part of the opening of the dielectric fluid nozzle was not close to the edge of the workpiece. After the machining had progressed to where the entire opening of the fluid nozzle was facing the workpiece, the pause time was shortened because adequate amounts of the dielectric fluid flowed into the machining gap.

In a conventional wire-cut EDM, the wire must be prevented from breaking by using approach machining conditions for the first 5 to 10mm with lower power than in normal machining, which is one of the reasons for low machining speeds. However, by using our control method, the machining power is adjusted automatically so that it will be no more than required and adequate for the start of the machining process, and thus no such special considerations need be made.

Fig. 5 shows the results of machining under conditions where the dielectric fluid was sprayed and where the machining sample shape was particularly susceptible to broken electrodes. Wires have usually tended to break on hollow (undercut) parts, making very low machining powers inevitable. By using this control method, however, the machining power is controlled as appropriate for each individual piece being machined, resulting in a 2.9-fold increase in machining speed.

Mitsubishi Electric's adaptive machining power control function greatly improves the machining efficiency on workpieces with shapes for which it is difficult to secure dielectric fluid flow (shapes for which the workpiece thickness changes or hollow shapes, etc.), significantly expanding the range of processes for which wire-cut EDMs can be used, and freeing them from use primarily on flat workpieces. ❑

FA/FA-P Series Wire-Cut EDMs

*by Takuji Magara and Toshio Suzuki**

Requirements for short-term delivery, enhanced precision, and cost reduction in dies have increased in severity and, in addition to the machining performance itself, improvement in the productivity to include even maintenance time and long-term stability in continuous automatic operation are being sought in wire-cut electrical-discharge machines (EDMs) the "mother machine."

In order to respond to these market requirements, 64-bit CNC wire-cut FA series and FA-P series EDMs, which are high-precision machines, were developed by integrating the new technologies with the three keywords "Fast," "Easy" and "Reliable."

The FA/FA-P series consists of high-performance wire-cut EDMs that cover a wide range of applications from die cutting to the machining of parts. The three models in the FA series (FA10, FA20 and FA2) and the two in the FA-P series (FA10P and FA20P) correspond with the size of the intended workpieces. Fig. 1 is a photograph of the FA20. This article concentrates on introducing the new technologies featured in the FA/FA-P series.

Fig. 1 Photograph of FA20

New Technologies Featured in the FA/FA-P Series

HIGH-SPEED "AT" AUTOMATIC THREADER. The AT is a key device that is indispensable in automating wire-cut EDMs. The FA/FA-P series have been provided, as standard, with the AT connection function developed by redesigning the conventional device. It achieves an insertion time of ten seconds. High speed and reliable insertion were achieved by an optical sensor system that provides high-speed detection of the wire electrode load and large-diameter feed roller under load. An original vacuum system was adopted to collect broken wires; many wires can be collected even when the broken sections are longer than 2m. This enhances reliability even in long, continuous operation.

INTEGRATIVE "AUTOMAGIC" ADAPTIVE CONTROL. This integrates three adaptive controls. The first of these is Power Master (PM—an adaptive control that maximizes the machining efficiency while recovering from wire breakage by automatically detecting the plate thickness of the workpiece and changes in the plate thickness, then optimizing the machining conditions, see Fig. 2). The second is Corner Master (CM—a function that improves the accuracy in corner machining, see Fig. 3). And the third is Technology Master (TM—a function for automatically generating the machining conditions when there is a deviation from the conditions provided by the manufacturer, such as being unable to bring the nozzle into close contact, etc., see Fig. 4).

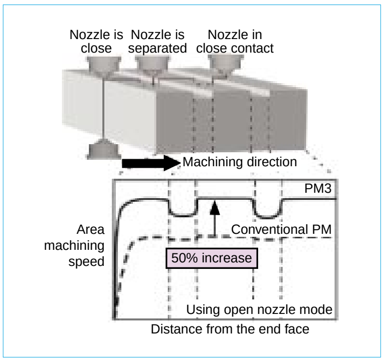


Fig. 2 Conceptual diagram of Power Master

AutoMagic provides functions for optimizing the processes for machining workpieces such as model dies, press dies, part machining, etc. Complex shapes (those involving corner machining, for example) and high-speed, high-precision machining are possible without requiring specific know-how.

Power Supplies for Machining.

HIGH-SPEED "AE3-HS" POWER SUPPLY FOR MACHINING. This, provided in the FA series, achieves high-speed machining of 325mm^2/min by using a wire electrode for high-speed machining (55% faster than conventional modes). Even if a brass wire electrode is used, the machining speed still increases by 20% or more and significantly improves productivity.

THE "HL" POWER-SUPPLY CIRCUIT FOR ROUGH FINISHING. This power-supply circuit noticeably improves rough finish. A machining example is shown

**Takuji Magara and Toshio Suzuki are with Nagoya Works.*

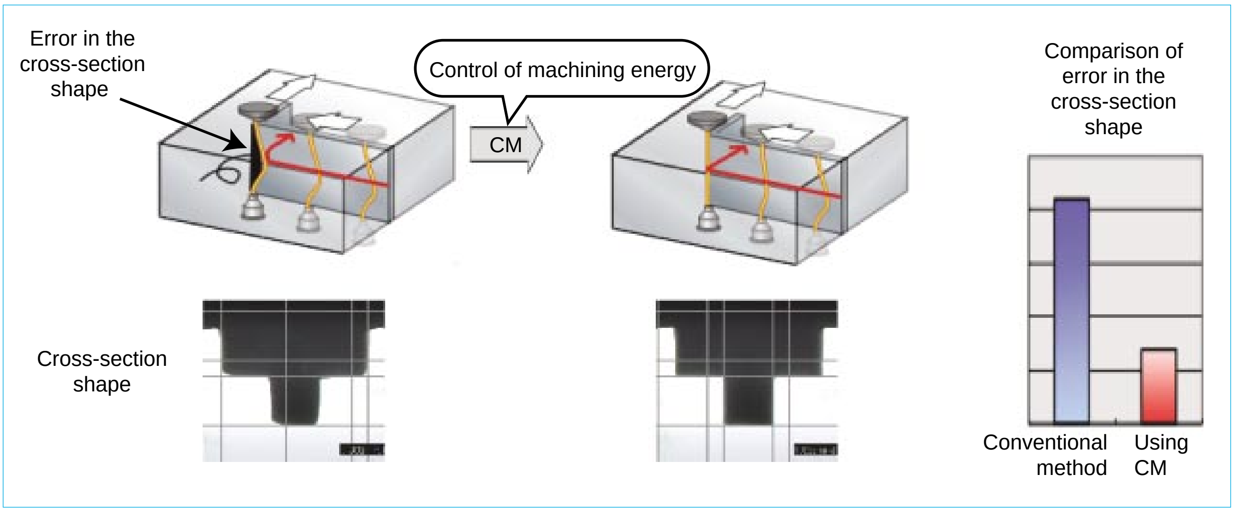


Fig. 3 Conceptual diagram of Corner Master

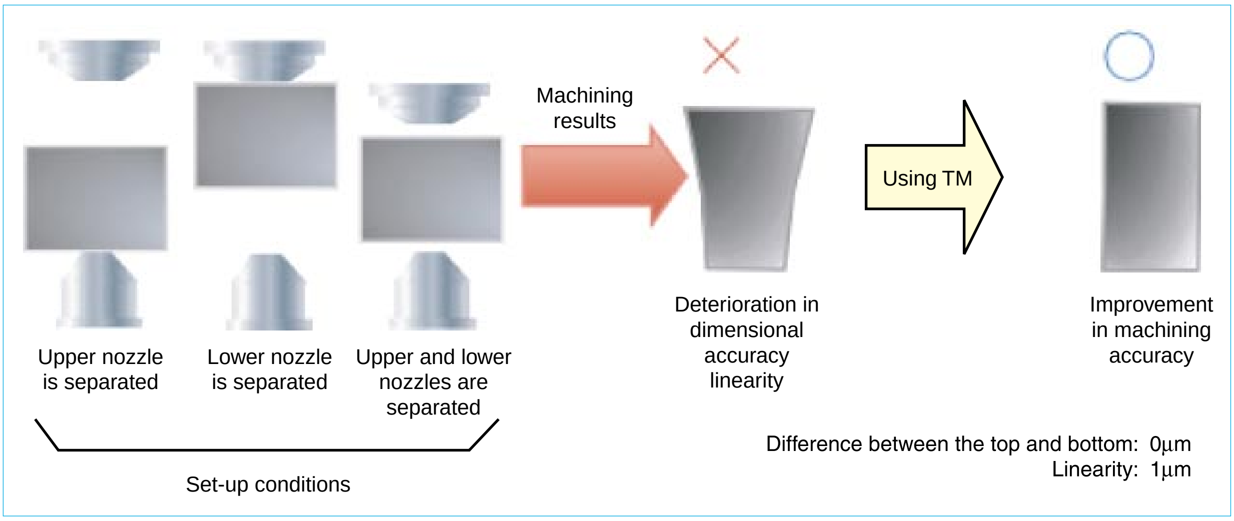
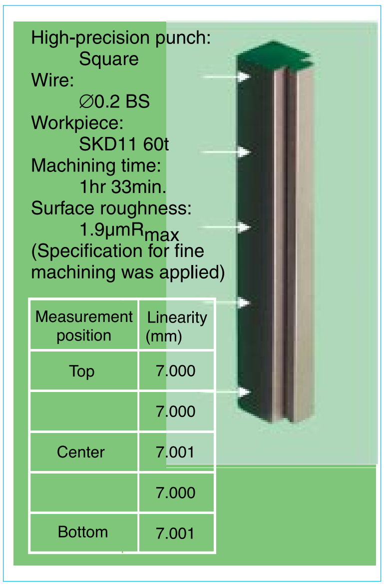


Fig. 4 Conceptual diagram of Technology Master

in Fig. 5. This circuit is also suitable for machining graphite, diamond compacts, etc.

THE "PF" POWER SUPPLY FOR FINISH MACHINING (FA-P SERIES). This is a power supply that ensures best surface smoothness of 0.6µmRy when the workpiece is placed directly on the surface plate (Fig. 6). By placing it directly on the surface plate, a favorable surface finish can be obtained without reducing the speed for rough machining.

AUTOMATION IN MACHINING COMPLEX SHAPES (FA-P SERIES). Stepless (SL) technology mounted in the FA-P series and machining of complex shapes described below can be performed automatically.



Measurement position	Linearity (mm)
Top	7.000
	7.000
Center	7.001
	7.000
Bottom	7.001

Fig. 5 Example of machining with HL circuit

Decrease in Level Difference of Machining Surfaces

With stepless (SL) control, the

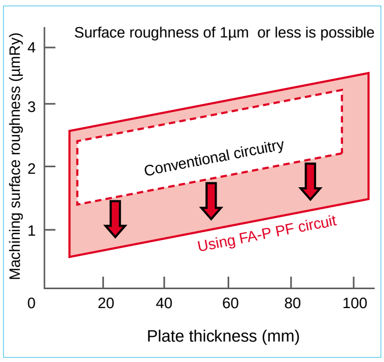
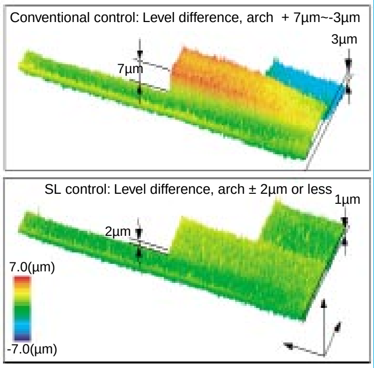


Fig. 6 Capabilities of PF circuit showing the surface roughness achieved by FA-P Series EDMs

level differences of machining surface finishes can be decreased in workpieces undergoing plate-thickness changes and the linearity can be improved greatly. An example of machined surfaces with level differences is shown in Fig. 7. Conventionally, there were big level differences in workpieces that underwent thickness changes. However, with SL control, most of these level differences have been eliminated.



Machining example

Wire	∅ 0.2 brass
Workpiece	80 → 40 → t steel
Machining conditions	High precision

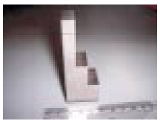
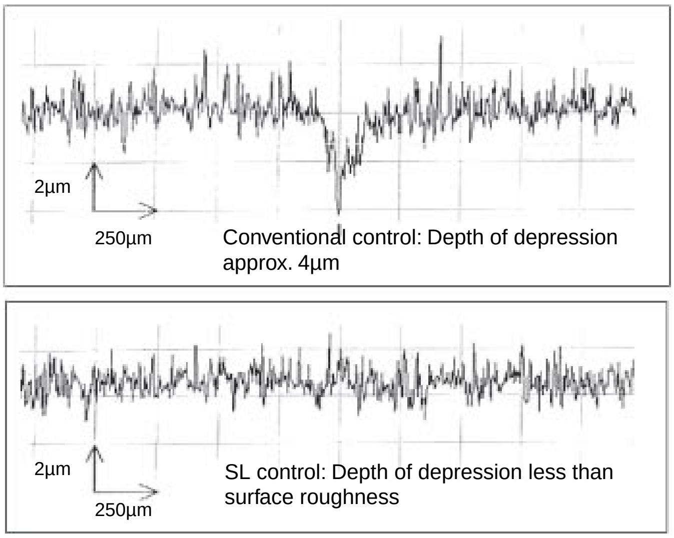
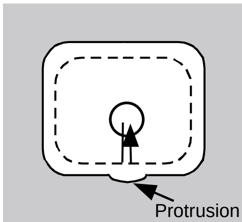


Fig. 7 Decrease in level difference with SL control

IMPROVEMENT IN THE SHAPE OF THE APPROACH PART. This eliminates the generation of protrusions. Fine depressions created in the approach part are eliminated and high-precision machining can be achieved with SL control (see Fig. 8). Also, the approach part can be shaped into a protruding shape and the polishing cost can be greatly reduced.

IMPROVEMENT IN THE ACCURACY OF SHARP EDGES IN CENTRAL SECTIONS OF THICK PLATE. The shape of the outward corner sharp edges of a thick plate is greatly improved with SL control (see Fig. 9) and high-precision machining of edges is enabled over the middle 60mm section of plates that is difficult using conventional methods.

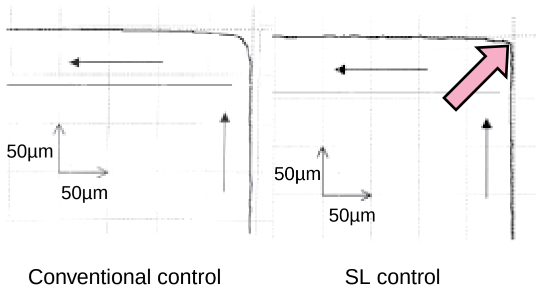


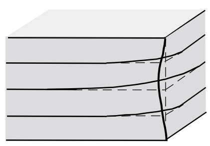


Example of die machining

Wire	∅ 0.2 brass
Workpiece	60t steel
Conditions	High precision
Surface roughness	3.6µmR_{max}

Fig. 8 Improvement in the shape at the approach part with SL control





Machining example

Wire	∅ 0.2 brass
Workpiece	60t steel
Conditions	High precision

Fig. 9 Improvement in the precision of sharp edges with SL control

The FA/FA-P series wire-cut EDMs and the new technologies introduced here go a very long way to satisfy the unending quest for wire-cut EDMs with higher machining speed and ultrahigh precision, etc. We are committed to developing technologies that not only respond to current market needs but also open up whole new markets. ❑

EA Series Sinker EDMs with "DynaTech"

*by Kenji Iwasaki and Hajime Ogawa**

A new integrated machining system that we have called "DynaTech" was developed using 64-bit CNC technology. The DynaTech system is provided as a standard in EA series sinker EDMs, enabling optimized machining control by means of a condition database appropriate for the type of machining process used. The article focuses on examples of high precision and highly efficient machining made possible by DynaTech.

Features of EA Series Sinker EDMs

Fig. 1 is a photograph of the EA series Model EA12E and Table 1 lists the specifications of the EA12E sinker EDM.

Fig. 1 A photograph of EA Series model EA12E

INTEGRATED MACHINING CONTROL. DynaTech provides complex and sophisticated control instructions (high-gain modes, etc.) to the servo mechanism with the adoption of 64-bit CNC. Also, the development of DynaTech enables dramatically improved machining speeds and precision by executing integrated control of FPII power supplies, FuzzyPro, etc.

MACHINING-CONDITION DATABASES. The optimum machining characteristics are implemented over a wide range of machining processes by adopting the conventional EXPERT database for general-purpose machining and the HybridPack database for advanced machining.

COMPATIBILITY WITH AUTOMATION TECHNOLOGY. Recently, there has been an increase in the introduction not only of LANs in manufacturing plants but also of automation systems in the die-manufacturing workplace with the aim of improving operating times. The EA series is compatible with networks and a wide range of peripheral equipment is available. It can therefore respond flexibly to the manufacturing needs of next-generation products.

Main Functions

We developed the sinker EDMs by incorporating an adaptive control technology, including "Fuzzy" control, so that our customers would be able to handle machining processes of greater difficulty. DynaTech incorporates various items of machining know-how as control functions, and implements integrated machining control that fully utilizes the merits of 64-bit CNC (see Fig. 2). The provision of more complex and sophisticated control instructions to the servo mechanism employs 64-bit CNC, and machining speeds and precision improve immensely. The main functions are described below.

FPII POWER SUPPLY. In EDM, the discharge waveform of the pulses greatly influences the machining characteristics. With the FPII power supply, it is possible to supply the pulses appropriate for various materials such as steel products, Cu alloys, Al alloys, hard materials, etc. Also, surface roughness of better than 1μmRy is optionally possible with NP circuits.

Table 1 Specifications of the EA12E

Work tank inner dimensions (X x Y x Zmm)	850 x 600 x 350
Maximum workpiece dimensions (X x Y x Zmm)	800 x 500 x 250
Each axis movement amount (X x Y x Zmm)	400 x 300 x 300
Minimum drive unit	0.05μm for each of XYZ
Minimum command value	0.10μm for each of XYZ
Maximum electrode mass	50kg
Machine main body dimensions (mm)	1740 x 1960 x 2265
Maximum average machining current	60A (FP60)
Primary options	SP circuit for machining hard materials FP100B booster power supply Micro-voltage power supply NP circuit (EA8, 12[1]) Tool exchanger ATC High performance spindle C axis

Note 1: 8, 12, 22, and 30 were prepared for members of the EA series according to size.

Kenji Iwasaki and Hajime Ogawa are with Nagoya works.

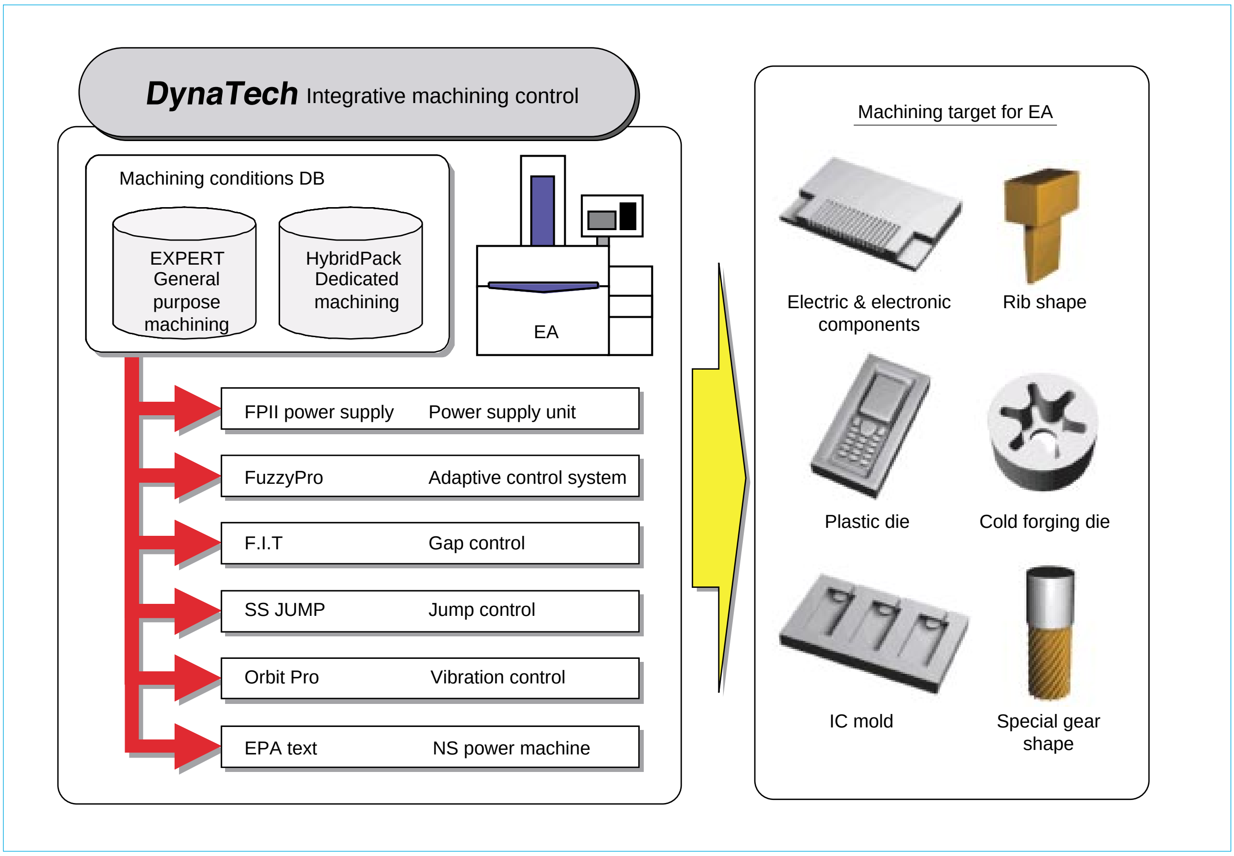


Fig. 2 Integrative machining control DynaTech

FUZZYPRO ADAPTIVE CONTROL. This is a function that accurately grasps the moment-to-moment changes in machining states. The inference engine automatically adjusts to satisfy the correct machining conditions in accordance with the particular machining state (see Fig. 3). The operator therefore no longer needs to constantly monitor the machining state. In the EA series, a high-speed lead-in function enhances discharge stability at the start of machining and an optimum jump function cuts wasted machining time in half. These were additions to the conventional FuzzyPro functions.

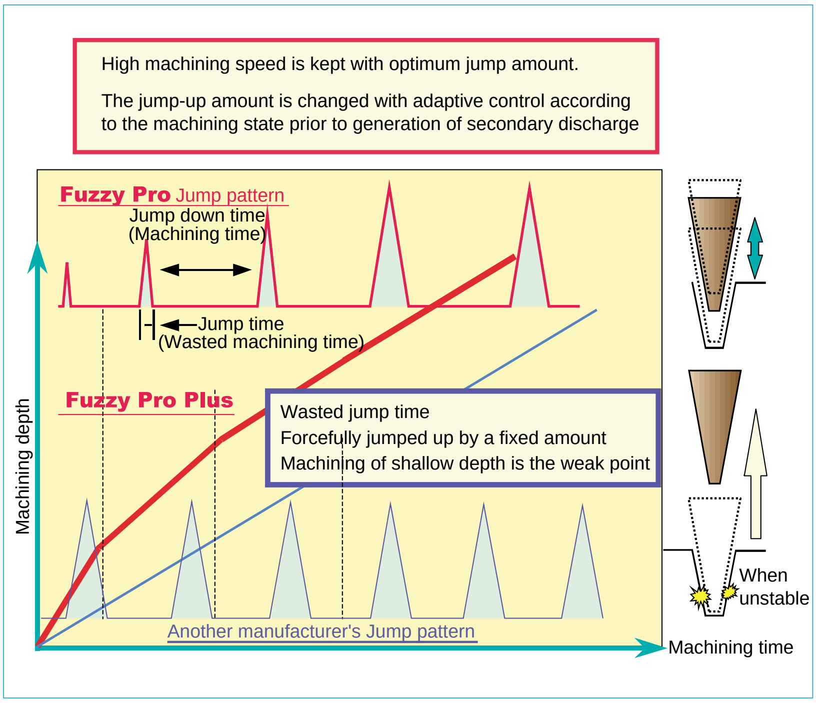


Fig. 3 Optimum setting of machining conditions with FuzzyPro

F.I.T CONTROL. In EDM, the discharge gap between the electrode and the workpiece determines the machining precision. The discharge gap readily changes according to the shape being machined and the efficiency with which sludge is discharged. This leads to a variance of a few microns from exact machining dimensions. With F.I.T control, it is possible to keep the discharge gap uniform by monitoring the state of the electrical discharge and only then determining the final machining position. The result is a significant enhancement in the precision of machining, particularly in continuous multi-step machining.

SS JUMP AND ORBIT PRO. Discharging the sludge and maintaining stable machining are critically important factors in EDM. Optimum sludge discharge efficiency independent of the machining depth and the electrode shape is achieved by SS JUMP. With OrbitPro, a stable discharge state is constantly maintained by oscillating control without applying the machining load so that electrodes of complex three-dimensional shape can be formed with high efficiency.

HYBRIDPACK. This is a new machining-condition retrieval system. With our EDMs, general-purpose machining conditions can be generated automatically just by inputting the machining depth, surface roughness, reduction value, etc. (the E.S.P.E.R function). On the other hand, superior machining conditions can be implemented by restriction to a particular machining process. The HybridPack system comprises the most frequently used specialist machining knowhow previously provided to individual users, and enables it to be retrieved for specific machining processes (see Fig. 4). The system can also incorporate the user's know-how.

EPA POWDER MACHINING UNIT. In the EA series, NS powder was prepared by improving on conventional powder. With NS powder, two types of powder machining methods can be selected according to the purpose of the machining, namely, high-speed satin finish machining NS1 that places the importance on ease of polishing, and glossy-finish machining NS2.

Machining Examples

High precision and enhanced quality are achieve with DynaTech particularly in machining of so-called small- and medium-size articles (up to 10,000mm^2). Below, actual machining examples are described.

SPOOL-GATE MACHINING. Gate-hole machining for sealing resin is generally known as a particularly difficult part of plastic die machining. Also, with more rib parts and thinner components, the difficulties of high-aspect machining in milling operations call for enhanced performance. The typical results of improved spool-gate machining are shown in Fig. 5. A considerable reduction in machining time is achieved by the adoption of the DynaTech system based on FuzzyPro. An ideal machining state is maintained with very little wasted machining time.

HIGH-PRECISION MACHINING OF SMALL ITEMS. The majority of plastic die machining for small items is done using multiple continuous machining with a single electrode, and this requires enhanced precision. An example of high-precision continuous machining with DynaTech is shown in Fig. 6. A great improvement in machining precision is enabled by controlling the inter-pole discharge distance.

HIGH-PRECISION MACHINING OF PLASTIC DIES. Plastic die manufacturers have the major share of the domestic die manufacturing market but this market is also suitable for EDM. In recent years, dies for portable telephones are representative of plastic dies, but this is a field where even milling shops are aware of competition from EDM. The current "mainstream" manufacturing process is to make a rough cut of the shape with milling machines and execute the rough machining and finish machining with EDMs. Recently, the domain of high-speed milling machining has

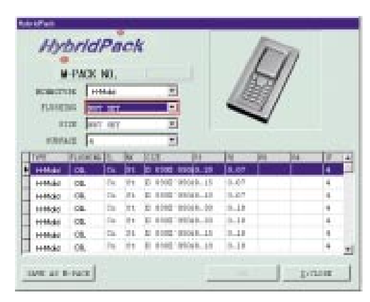
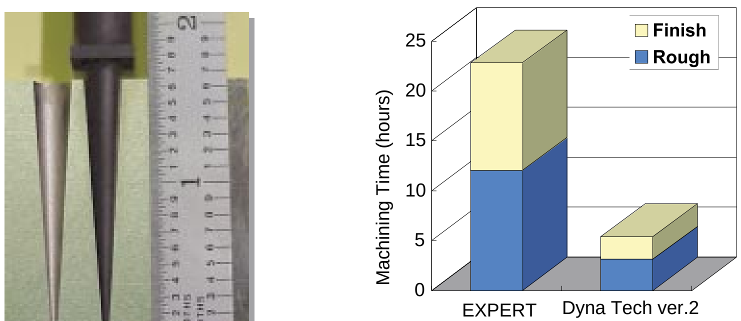


Fig. 4 HybridPack system



Gr-Steel
Tip: 0.02 inch, taper angle: 3.5¡
Machining depth: 1.65in
Non-jet
Machine: EA12

	Conventional EXPERT	Dyna Tech Ver.2
Machining time	22hrs 42min	5hrs 28min
Surface roughness	10µmRmax	10µmRmax
Speed enhancement ratio		76% enhancement

Fig. 5 Machining of spool gate

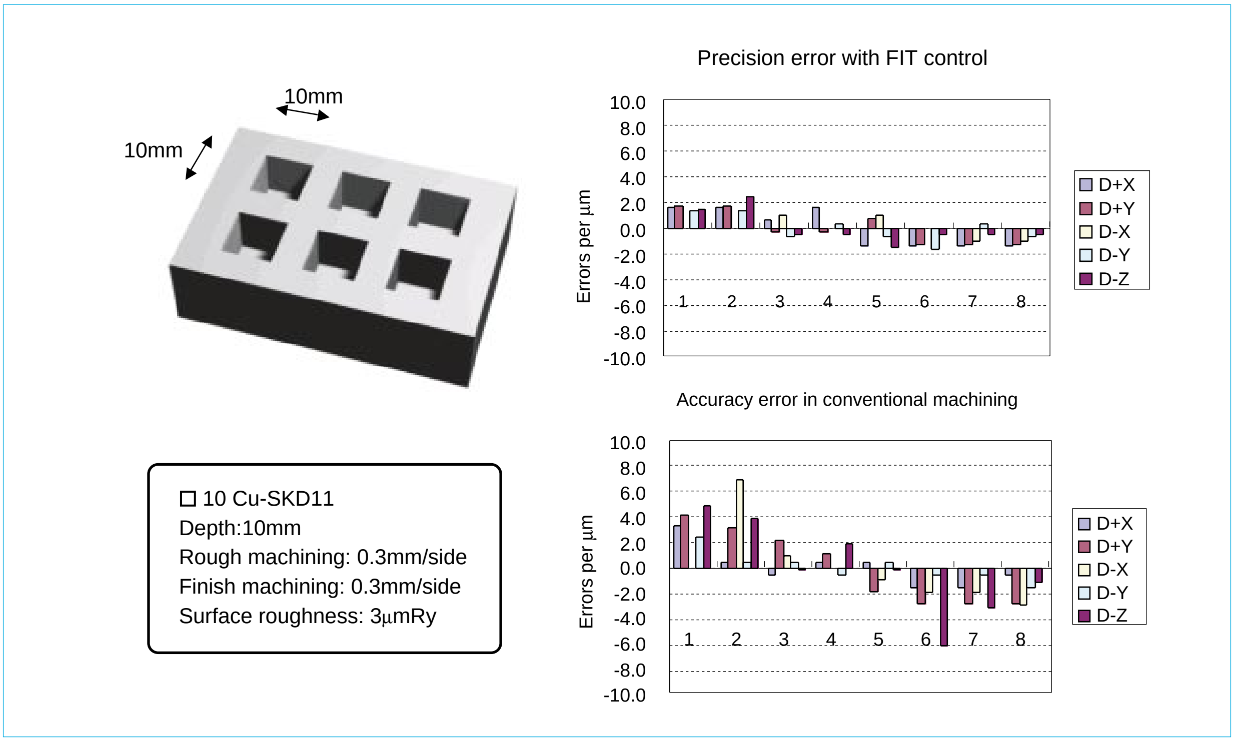


Fig. 6 High-precision continuous machining of small items

been expanding for shallow articles. Hence, the general practice is to do the rough machining with milling machines then apply high shape transference and high-precision machining using EDM for the finish machining. The machined shape and the machining results are shown in Fig. 7.

In EDM, the lead-in to the machining surface after milling is very important. If the machining shape is pre-formed to some extent, the area to which the discharge is applied is smaller than the target, and machining becomes very unstable. With FuzzyPro, the machining is executed very stably with a high-speed lead-in function. Also, even electrodes of complex three-dimensional shapes can be transferred with high precision using OrbitPro. If the separate roles for milling machines and EDMs are clarified, lead time can be reduced significantly while reducing the cost of producing electrodes. The effects are particularly beneficial in fields such as portable telephone dies where the product cycle is very short.

Basic EDM performance in the EA series was maximized by implementing DynaTech integrated machining control based on 64-bit CNC. With the latter, more complex control is possible, with correspondingly greater enhancement in the basic performance to be expected. We plan to further enhance the machining performance achieved with DynaTech and continue to develop it in the next-generation models. In the future, we intend to concentrate our efforts into developing a comprehensive solution for die manufacture centering on EDM and in developing functions that respond to the needs for higher precision and higher quality machining. ❑

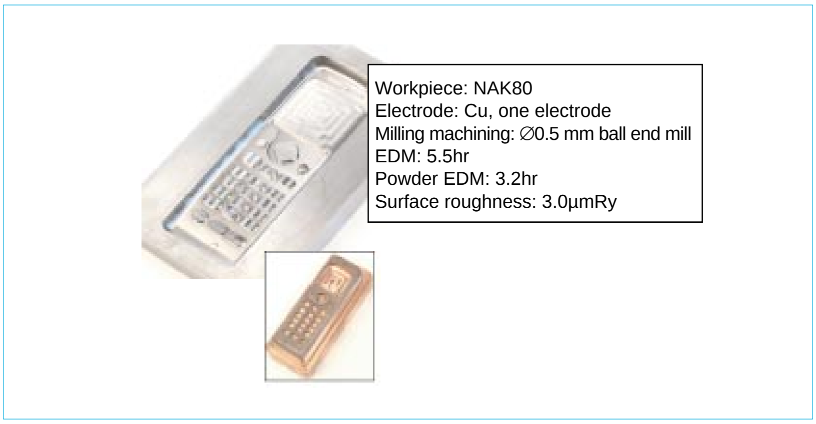


Fig. 7 High-precision machining of plastic dies

Introducing Information Technology to the EDM Workplace

Some 80% of establishments in the die-making industry are small to medium businesses with under ten employees. In the past, the world-renowned dies that supported Japanese industry were produced by craftsmen with superb technical skills using superior equipment. However, in order to adapt and survive in the changed environment of the die-making industry-short-term delivery, cost reductions, and globalization-it is necessary to scientifically analyze the technical skills required, create systematic procedural manuals, and convert technical skills into technical information. In other words, information technology must be applied. This article introduces concrete measures to support the application of information technology at workplaces with electrical discharge machines (EDMs).

EDM Information Service

As a business information site specializing in EDM and die machining, http://www.diax-net.com was opened in October 2000. For general users, the website consists mainly of product guides and topics and was prepared in cooperation with the sales division. There are also pages for which access is restricted to users of Mitsubishi Electric EDMs. These were prepared to provide information for 100% utilization of these machines.

By providing the constantly advancing machining technology in real time, it becomes possible to ensure that the machines are operating under the latest and best conditions known. The machining know-how was compiled for users based on what had been used in the corporation so as to transfer the technology. Documenting know-how is the major aim of implementing information technology.

EDM Network System

EDMs connected to a network enable remote EDM operation if the network is provided with remote monitor functions, emergency notification functions, file-transfer functions and process-control terminal functions. Servers can regularly collect information such as the operating status of each machine, any alarm conditions, etc., and transmit and receive data via the worldwide web according to requests from the respective divisions.

On the client side (at the workplace, in the design division, and for management), data can be optionally accessed without special software simply by preparing a personal computer with normal browser functions. Machine monitoring functions include blanket monitoring and individual monitoring. With the former, the operating status of the EDMs and other machines within a plant can be checked at a glance on a personal computer.

Previously, the time-wasting work of checking each machine by making the rounds of the plant was essential, whereas the new system enables machines to be checked from a personal computer located anywhere in the plant. This facilitates smooth operation of the machines. Also, if an abnormal condition arises, detailed status of the machine (what kind of alarm went off and what caused the interruption) can be checked by selecting the machine affected and switching to the individual monitoring function. This enables appropriate instruction for handling the situation to be given quickly. It is possible to notify the status of an alarm, interruption, etc. arising in a machine via E-mail and i-mode phones. Abnormal conditions can therefore be detected immediately without the need for constant monitoring, recovery can be initiated quickly, and each machine's duty factor improved.

Remote Diagnostic System

Full, twenty-four-hour operation is essential at EDM workplaces. Therefore, machine down-time is critical, with great pressure to reduce the time needed to restore machines to operation. If an alarm is generated in a machine that is being supervised and controlled, this is notified via E-mail to the operator over a preset mobile telephone at the same time as the service center is notified. This alarm notification facilitates rapid recovery by enabling the service center to schedule repairs.

In order to identify the malfunction from the nature of the alarm, the service center requests information from the machine side, the condition of the machine is determined, and a firm diagnosis made. Formerly, such diagnoses were made on the basis of information provided over the telephone by an operator at the workplace. However, this has the disadvantage of inaccurate or incomplete verbal exchange of information. This often resulted in the serviceman needing to visit the site after all. In such cases, more time was lost making arrangements to obtain replacement parts, etc. The new function enables accurate diagnoses to be made based on accurate information, with resulting improvements in the quality of service. ❑

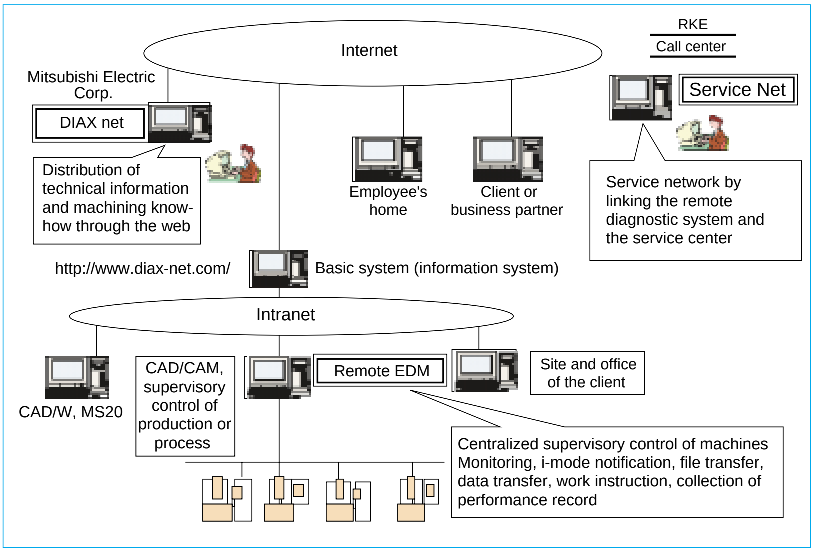


Fig. 1 The concepts of network utilization

Latest CAD/CAM Systems in EDM

CAD/CAM is an important tool not just for drafting and creating machining programs but also as a tool for enhancing machining performance and productivity through digitalization of know-how, machining simulations, etc. As the starting point for the manufacturing process, CAD/CAM also has an important role in applying information technology to the manufacturing process, seamlessly streaming the design data from the design stage to its applications at the workplace and maximizing the utilization of information.

CAD/CAM systems for EDM include "CamMagic," a three-dimensional system for dies that gives comprehensive support to die makers in milling and EDM. Then there is MEDIAPT CAD/W for wire-cut EDM, which supports all the processes from initial drafts to final machining. Thirdly, there is E.S.P.E.R PRO for comprehensive support of sinker EDM see Fig. 1. The special features of these systems are introduced below.

CamMagic for Dies

CamMagic is a CAD/CAM for dies that handles two-dimensional and three-dimensional data and die design through to machining so that they can be executed in a consistent flow. Die-design functions include taper functions, shelling functions, parting line automatic computing functions and strip layout functions.

In milling machining, compatibility with high-speed milling machines, high quality finish with automatic selection of optimal paths, etc., are realized. In electrode design for EDM, there is a special feature for readily creating a model electrode shape using Boolean operators based on the product shape. Also, the machining characteristics of the electrode milling machines and the materials (copper, graphite, etc.) for electrodes were researched and the resulting know-how incorporated.

In wire-cut EDM, a curved surface based on the path of NC data can be created on a three-dimensional surface and the power of this system is exhibited in four-axis machining of complex shapes.

In sinker EDM, this system shows its effectiveness by improving the duty factor through rationalized machining, specifying and utilizing the measurement position on an electrode model when centering electrodes.

MEDIAPT CAD/W for Wire-Cut EDM

This is a CAD/CAM for wire-cut EDM that supports the processes from drafting to final machining and fully utilizes the capabilities of wire-cut EDM.

Wire-cut EDM, from general purpose to high precision, can be accommodated by making the most of the special features of each EDM. This system incorporates the machining conditions and diagrams of the machining tables from the old model series up to the latest series as standard and has been configured so that the flow from preliminary setup to final machining can all be verified with CAD/W.

Functions for monitoring the status of the machines (operating conditions such as alarms, etc., and maintenance information such as the wire remaining time and operation from remote sites are provided in network functions in addition to the basic function of simply transmitting the NC program.

E.S.P.E.R PRO for Sinker EDMs

E.S.P.E.R PRO has the functions to create machining programs for sinker EDM, e.g., electrode/workpiece measurement programs, to access machining conditions, among others. Programming and operation can therefore be separated and efficiency achieved with external setup. Also, by networking a number of sinker EDMs, data for machining programs and machining conditions created with E.S.P.E.R PRO can be transferred to each of the machines via the network. ❑

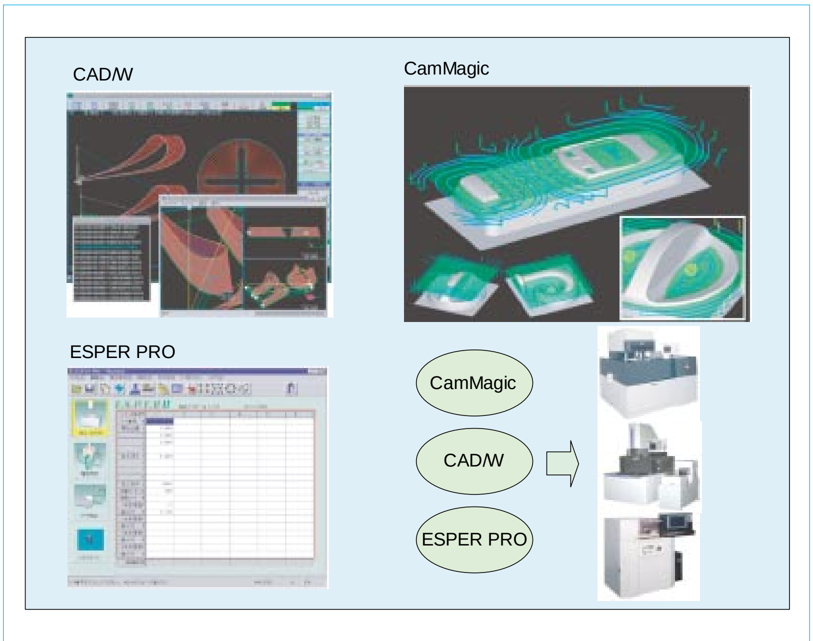


Fig. 1 CAD/CAM Systems for EDM