1991

An Analysis of the Electrical Discharge Machining (EDM) Process and Its Projected Impact on the Manufacturing Industry

Roger L. Woock
University of Northern Iowa

An Analysis of the Electrical Discharge Machining (EDM) Process and Its Projected Impact on the Manufacturing Industry

Abstract

A fifty year old technology giant is alive and well. Electrical discharge machining (EDM), the process of removing electrical conductive material with an electrical impulse has opened its eyes and stretched its possibilities. Technical advancements in EDM power sources, electrode materials, and automatic wire rethreading have been contributing factors in changing the course of manufacturing practices.

AN ANALYSIS OF THE ELECTRICAL DISCHARGE MACHINING (EDM) PROCESS AND ITS PROJECTED IMPACT ON THE MANUFACTURING INDUSTRY

by

Roger L. Woock

Departmental Research Paper
Submitted In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Approved:

____
Dr. Douglas Pine, Advisor

____
Dr. Gary Hoppes, Faculty Reader

University of Northern Iowa

April 1991

TABLE OF CONTENTS

Introduction

A fifty year old technology giant is alive and well. Electrical discharge machining (EDM), the process of removing electrical conductive material with an electrical impulse has opened its eyes and stretched its possibilities. Technical advancements in EDM power sources, electrode materials, and automatic wire rethreading have been contributing factors in changing the course of manufacturing practices.

The concept of electrically transferring metal from one location to another is not new. It was first discovered during World War II by a team of Russian technicians while working on automotive point systems. Shortly afterwards the same process was discovered by the Americans (Eade, 1987, p. 28).

During the early years the theories of EDM were proven and the principles established. During the mid-1950's electrical discharge technology found its way into toolrooms and mold shops. The technology was first used as a ram or sinking process for removing broken taps from workpieces and the like. Because the process was time consuming, it was used as a last resort (Eade, 1987, p.28).

As with any technology, progress continued slowly until the early 1970s. The introduction of computer technology brought about rapid gains in EDM possibilities. The mid-1970s brought about the use of using a thin wire as the electrode. The process was slow at first, but its potentials were phenomenal. Today, with better power supplies, CNC, CAD/CAM, improved electrodes, and tooling specifically designed for EDM, the technology has moved from an option to a primary production technology (Milton, 1989, p. 53).

Outwardly, it may appear that this technology is nearing its peak. Just the opposite is true. EDM is still in its infancy with surprising possibilities. The machine tool industries are meeting the demands of their customers. Manufacturers are discovering the potentials of EDM for production. Skilled craft occupations are recognizing the effects of EDM on their trades.

As a global manufacturing industry, companies must meet the challenges of the future to survive. Changing the methods of producing parts affects the labor market. Meeting those challenges are often frightening and sometimes met with apprehension. Fear of the unknown is a great restrictor. Having an understanding of electrical discharge machining, its component parts and their functions helps break down the barrier of fear. With knowledge comes understanding and then change.

Change is a characteristic of industrialism. Changes in the skills and competencies of the workforce require training and retraining at all levels. As technologies surface, it requires the workforce to have a wide variety of high-level skills. It also requires a disciplined and adaptable work force with a positive attitude toward these changes and the levels of technical knowledge (DeVore, 1980, p. 78).

Electrical Discharge Machining

The principle of electrical discharge machining is based on erosion of metal by spark discharge (Kalpakjian, 1990, p. 796). Four items must be present in the EDM process -- an electronic power source, an electrical conductive electrode, an electrical conductive workpiece, and a dielectric fluid.

One terminal of the DC power source is connected to the electrode and the other terminal is connected to the workpiece. There is no direct contact between the workpiece and the electrode. They are held in close proximity by the machine's control, yet they are separated by a small gap ("About The EDM," 1989, p. 54). This gap is filled with a dielectric fluid.

When the DC voltage from the power source is turned ON, no current flows between the electrode and the workpiece because of the dielectric fluid. However, an electric field begins to build up across the gap. When the power of the electric field ionizes the dielectric fluid, a channel of positive and negative particles is formed. As these particles build up and migrate to the opposing poles, an electrical current begins to flow, generating high temperatures and pressures ("About the EDM," 1989, p. 54). Because the spark is much hotter than the melting temperature of the workpiece, the concentrated area heats and melts the workpiece surface (Shobert II, 1983, p 3). The power source is turned off at this point, so no spark is generated. While the spark is OFF, the dielectric fluid which surrounds the electrode and workpiece flushes the vaporized chip away.

The discharge is repeated at rates of between 50 kHz and 500 kHz, with voltages ranging between 50 V and 300 V and currents from 0.1 A to 500 A (Kalpakjian, 1990, p. 796). The time aspect for power ON, power OFF occurs in microseconds. When the power source is set for high energy output, a spark may occur every 2000 microsecond. For very low energy output, a spark may occur every one microsecond. A microsecond is one millionth (.000001) of a second. It is the time unit used in EDM when measuring the ON and OFF time of the power source (Jameson, 1983, p. 49).

There are two EDM processes, ram (or sinking) and traveling wire. The terms <u>ram</u> and <u>wire</u> will be used throughout this paper to designate the two processes.

Ram EDM is the older of the technologies. Wire EDM techniques have been around since the mid-1970s. Both have made steady and beneficial contributions to the success of EDM.

Ram/Sinking EDM

Ram EDM was the first of the two EDM processes and acquired its name because the electrode is plunged into the workpiece. It was first used in toolrooms to remove broken taps, etc., and in the mold making industry. When ram was introduced, it was slow and messy. However, it did have some advantages, it could machine tool steel and carbides which were impervious to standard cutting tools. Even though it was slow, it could be left untended for long periods of time (Milton, 1989, p. 52).

In mold making, cavity contours are rough machined to size and shape using conventional methods. A carbon electrode is machined to within a few thousands of the finished dimensions. Using the ram EDM machine, the carbon electrode was lowered into the rough cavity. The carbon electrode and the workpiece never come into contact with each other. As the electrode comes into close contact with the workpiece, electric sparks are generated over sections that are close to each other. "As each spark impinges on the workpiece surface, it removes a minuscule amount of material that is flushed away with the flowing fluid. Sparking frequencies may reach as high as 300,000 cps" (Milton, 1989, p. 53).

A one-cavity mold might take 200-300 hours of machining the conventional way. With the use of EDM, the same mold can be done in approximately 38 hours (Eade, 1987). One mid-West supplier of molds used to fabricate automotive front-end structural supports found that the advanced, CNC ram-type C462 EDM from Ingersoll GmbH, Inc. is making significant improvements in direct labor expended, mold quality, electrode wear, which has helped cut two weeks from delivery schedules for the mold (Eade, 1987, p. 29).

Ram electrode materials. When ram EDM was first introduced, it was slow and messy. Machining the graphite electrodes caused a dust problem. But ram EDM had the capabilities of cutting hardened tool steels and carbides. Even though the EDM process took a long time, it could be left unattended for long periods of time (Milton, 1989, p. 52). Graphite was the first material used for ram electrodes.

The first graphites had satisfactory metal removal characteristics and were inexpensive. These were offset by negative aspects such as grain size, high wear rate, poor surface finish (requiring hours of hand work to polish), and low accuracy. The poor performance of these roughing graphites added to the total cost of the process. Many jobs required multiple electrodes to compensate for their high wear (Bardin, 1987, p. 76).

Finishing graphites were developed which provided better surface finishes and had better wear capabilities, but they were expensive. Additional drawbacks of these finishing graphites were low metal removal rates and limited size availability. Because of the drawbacks, ultrafine-grain graphites found limited use (Bardin, 1987, p. 76).

As EDM machine technology progresses, ram electrode materials also improved. The graphites used today are available in numerous grades for a wide variety of applications. The isostatically pressed material is now dense, fine grained, and highly controlled to ensure consistent quality (Bardin, 1987, p. 76). Synthetic graphites are now available in a variety of grades. The seven graphites on the market are categorized into three areas: roughing, universal, and finishing. The universal grade graphites are usually used from roughing to finishing (Bardin, 1987, p. 77).

Improvements in the EDM process and its machines are a driving force in graphite improvement. As the EDM processes are integrated into the production phase of manufacturing, the incorporation of ram and wire EDM seems feasible. The development of orbiting capabilities, increased use of CNC EDMs with tool changers and adaptive controls, improved power supplies, and improved flushing techniques are contributors to ram EDM usage. Improved surface finishes, ultrafine graphites, improved metal-removal rates without electrode erosion, and a decline in graphite cost are positive indicators for ram EDM (Bardin, 1987, p. 76).

Copper electrodes are coming into use more frequently. Copper does not create the dust problems as graphites do and has good machinability characteristics. With copper size, availability is not a problem as with graphite.

Ram EDM drilling has increased over the past few years, especially since the introduction of electrode rotating. The introduction of small brass or copper tubular electrodes in a wide range of sizes and cross sections in straight and spiraled configurations has helped in ram drilling operations (Wijers, 1991, p. 59).

Traveling Wire EDM

The early 1970s brought about another technological break-through in EDM. A small wire about ten one thousands diameter (0.010 in. dia.) was used as the electrode. Wire EDM operates on the same principles as that of ram EDM. That is, an electrical discharge occurs between the electrically conductive wire and the workpiece. The wire is held in place by top and bottom guides and continually moves through the workpiece, similar to a band saw (Sikora, 1988, p. 50). The wire is fed from a supply spool through the guides to a takeup spool. During the cutting phase, the wire never touches the workpiece. The spark causes minute erosions in the wire, as a result the wire is used only once.

Wire EDM Electrodes. When wire EDM was introduced in the early 1970s, copper wire was used. Copper, because of its excellent conductibility, was the most logical choice, and it was readily available on spools from copper-cable manufacturers. However, copper wears rapidly and has poor tensioning abilities in thicker workpieces, which results in wire breakage (Dudas, 1987, p. 74).

Materials used as wire electrodes have kept pace with the technical advancements of wire EDM machines. The first wire EDM machines were relatively slow cutting. The cutting performance of wire depends on a combination of electrical and mechanical characteristics. Surface finish and tolerance control are directly related to the quality of the wire. Wire with low melting temperatures and low vapor pressure are desirable in wire. These aid in a quicker ionization time in the electrical discharge (Dudas, 1987, p. 74).

Brass wire soon replaced copper wire. Brass offered higher performance and the tensile strength needed to meet the demands. The introduction of automatic wire rethreading also introduced the need for a hard straight wire. Straightness for the automatic wire rethreading and hardness for higher tensioning for lower wire drag in fast cutting and less workpiece bow in thicker pieces (Dudas, 1987, p. 74).

Zinc-coated brass or copper wire was introduced in the early 1980s. Zinc has a low melting temperature and vapor pressure allows faster ionization. As a result, a faster cutting speed was obtained. Some of the early zinc-coated wire was dipped which resulted in uneven deposits. Today, electroplating is used which gives an even coating. Since the early 1980s, a low-tensile zinc-coated brass wire has been available. The annealed surface has a rough oxidized surface, which aids in flushing, provides faster cutting speed, and keeps guide wear low. A harder wire with a smooth shiny coating is available for machines with auto-wire rethreaders. However, it has a tendency to inhibit flushing, has a lower cutting speed, and causes more guide wear.

A zinc-coated copper wire was also introduced in 1985. It has a grainy, oxidized surface which provides faster cutting speeds. Because of its excellent conductivity, which allows excellent current flow, a 50%

increase in cutting speeds has been reported (Dudas, 1987, p. 74).

The need for accuracy and cutting speed promotes continued research. A copper-magnesium-core wire with a very grainy, rough zinc coating was developed. It provided high cutting speeds, but the accuracy was not obtained (Dudas, 1987, p. 74). For some roughing cuts this may be suitable.

Molybdenum wire has been used in fine detailed applications where multiple skim cuts are needed to hold tight tolerances. Molybdenum wire has a slower cutting rate but is used in applications for very fine radius. Because molybdenum wire can be used without coating, it is applicable where no zinc contaminations are permissible (Dudas, 1987, p. 74).

Coated and multicoated wires all have their advantages. These coatings can assist in raising cutting speeds drastically. Carl Meyer, president of Progressive Tool Co. states, "On some of our older machines, we can increase speed by 50% in the initial cut just by changing wire. Of course, you use more wire than in the past, but the expense may be easy to justify by the time you can save" (Schreiber, 1990, p. 41).

In searching for the best for all conditions, a double-coated steel wire has been developed called GoldSabre. The center steel core for strength, a middle copper coating for conductivity, and an outer coating of brass for flushability. The three component wire will cut faster than brass or zinc-coated brass wire, and it is equal to the cutting speed of zinc-coated copper wire. Because of the steel core, the GoldSabre is said to be stronger, especially under extreme heat conditions ("Double Coated," 1989, p. 17). Dan Tomalin, president of Composite Concepts, Twinsburg, Ohio, says of wire EDM materials, "... when you maximize tensile strength, you tend to minimize flushability" ("Double Coated," 1989, p. 17).

Dielectric Fluids

Flushability is a very important part of the EDM process. Flushing the debris from the spark gap eliminates the possibilities of spark short circuiting and wire breakage. The spark gap is the distance between the electrode and the workpiece when discharges are occurring. Flushing is accomplished by the use of dielectric fluids. These fluids serve a two-fold purpose. The EDM Digest Volume 1 defines dielectric fluid as, "A light oil or water in which the work zone is immersed. It fills the gap between the electrode and workpiece and acts as an insulator until specific gap and voltage are achieved. It then ionizes and becomes an electrical conductor, allowing the current (spark) to flow through it (ionized path) to the workpiece. It also serves to cool the work and to flush away the particles" ("About the EDM," 1989, p. 54).

Light oil, or a kerosene derivative, is the most common dielectric fluid used in ram EDM. Deionized water is used for wirecut EDM. Deionized water is used for several reasons--fast material removal, rapid cooling, and total lack of fire potential. The narrow cutting gap used in wire cutting requires low-viscosity to ensure adequate flushing (Wirecut EDM, 1989). Dielectric fluids must meet three requirements:

1. The dielectric fluid must act as an insulator until sufficient voltage is applied across the spark gap to break the dielectric strength.
2. Dielectric fluid must cool the workpiece, electrode, and the melted particles.
3. The fluid must act as a flushing agent.

When current is applied to the electrode, the voltage begins to build up. The dielectric fluid must act as an insulator until sufficient voltage is applied across the spark gap to break the dielectric strength. When the voltage strength is strong enough, the dielectric must ionize and become an electrical conductor and allow the current (spark) to flow through to the workpiece. This buildup and release is measured in microseconds, so it occurs very rapidly. The second requirement is the dielectrics ability to cool the vaporized particle so it resolidifies. This process is referred to as thermal transfer. Without this ability the melted particle would re-adhere itself to the workpiece and nothing would be gained. It is also necessary for the dielectric fluid to act as a cooling agent for the electrode and workpiece. The third requirement of dielectric fluids is flushing. Flushing conditions affect unattended machining efficiency (Vollaro, 1978, p. 83).

Dan Nierste, Charmilles Technology, says, "We recommend submerged cutting to aid flushing and provide better thermal stability especially in tapered cuts or stacked parts that may have air space. One benefit of nonsubmerged cutting, however, is that you can cut large parts that hang over the table" (Noaker, 1991, p. 55).

The closer the flushing heads are to the part, the better. EDM machines are now available with programable flushing options. Elox's Americut system provides programable flushing with separate control of upper and lower nozzles (Noaker, 1991, p. 55). Deionized water dielectric systems normally recycle the water to reduce operating cost. Recycling consists of filtering used water through a 5-micron disposable paper filter or a diatomaceous earth filter. After filteration, the resistivity of the water is adjusted by passing it through a deionizer cartridge ("Wirecut EDM," 1989, p. 55).

EDM and The Machine Tool Industry

Machine tool industries are those companies which build or supply machines for industry. There are a number of companies within the United States, Japan, and European countries. Some of the companies are suppliers for foreign manufactured machines. The following is a partial list of machine tool companies:

*Agie USA Ltd. Addison, Illinois	*LeBond Machine Tool Co. Mason, Ohio
*Hitachi America Ltd. Arlington Heights, Illinois	*Mitsubishi International Corp EDM Division Bensenville, Illinois
*Raycon Corporation Ann Arbor, Michigan	*Elox Corporation Davidson, North Carolina

*Charmilles Technologies
Mount Prospect, Illinois

*Japax Division
Japax Division
M M T S Inc.
Schaumburg, IL 60173

Machine tool companies listen to the demands of the industry when designing and building machines. EDM technology has made major advancements in several of its component units. One major area is in the power source.

Power Supply

The power supply is the part of the EDM system that supplies the current that causes the spark or discharge between the electrode and the workpiece (Jameson, 1983, p. 227). Power supply technology has evolved from the vacuum tube to sophisticated pulse generators. The first power supplies used vacuum tubes for switching the spark ON and OFF (Jameson, 1983, p. 229). There was little control and the machine was at the mercy of the tube. The capacitor replaced the vacuum tube, which was an improvement in the right direction. The capacitor is an electrical component that stores an electrical charge. The current for the spark comes directly from the capacitor when it is discharged (Jameson, 1983, p. 225). The transistor provided even greater control of the ON/OFF pulse time needed for EDM. The transistor has the capabilities of opening and closing millions of times a second (Jameson, 1983, p. 228).

The modern power supplies produce a pulsed direct current. The pulse is a discharge of quantity of electrical energy having a preset voltage and amperage and is extended over a preset time. Pulses for EDM are measured in microseconds. A microsecond is one millionth (.000001) of a second. This is the unit of time measured on the ON and OFF time of the pulse (Jameson, 1983, p. 227).

"Sophisticated pulse generators provide close process control," says John Shanahan, EDM specialist, LeBlond Makino Machine Tool Co., "with each spark turned on for a specific time, followed by off time before subsequent spark may discharge. This pulse aids wire cooling and chip removal via the pressurized flushing water" (Noaker, 1991, p. 54). With today's power supplies and electrodes, it is possible to obtain accuracies of $^{+}/_{-}$ .0001 inch with wire and $^{+}/_{-}$ .0002 inch with ram EDM. However, to obtain these, there is a price to pay. The customer who wants or needs them realizes this and is willing to pay the price (Milton, 1989, p. 54).

Cutting Speeds and Feeds

Improved power supplies have also had positive effects on cutting speeds and surface finishes for both ram and wire EDM. Cutting speeds have increased primarily because of improved power supplies and wire technology. Randall Bormann, Agie USA Ltd. (Addison, Ill.) states, "Five years ago I thought we were close to topping out at wire cutting speeds, but I was wrong. Today, people are talking about cutting rates of 20 to 30 in^2 per hour, and we hear of rates as high as 35 to 40 in^2 per hour in the R & D labs" (Schreiber, 1990, p. 39).

With the usage of a five axis wire EDM machine from Elox Corp., Americut can contour cut at up to 30 in^2 per hour in 2.00 inch thick D-2 tool steel using .013 inch diameter coated wire (Noaker, 1991, p. 53). This is slow compared with conventional machining methods. However, the payoff for EDM comes when machining problematic materials as magnesium alloys, ceramics, etc. (Noaker, 1991, p. 53).

Bill Fricke of Spectrum Manufacturing believes that EDM cutting rates will continue to improve because cutting rate accuracy will not be sacrificed. This is because of improved spark parameters, finer servo systems, efficient flushing, improved wire types, and better guide systems ("Faster Cutting," 1989, p. 17).

J.L.C. Wijers, a Research Engineer in Eindhoven, The Netherlands, writes, ". . . . EDM is now being used on a production basis for drilling deep and narrow holes at linear rates as high as two inches per minute, with length-to-diameter ratios as high as 100 to 1. Such holes range from .0012 inch to .120 inch diameter. They may be square or triangular as well as round" (Wijers, 1991, p. 56).

Accuracy

Many of the parts cut by EDM, whether ram or wire, are very accurate. Carl Meyer, president of Progressive Tool Co., says, "Wire machines can cut thick and they can cut accurate. As far as the stepping motors and controllers go, all wire EDM machines have about the same movement accuracy" (Schreiber, 1990, p. 39). Most new machines have the capability of cutting within the range of $^{+}/_{-}$ .00010 inch with multiple cuts (Schreiber, 1990, p. 39).

Auer Precision of Mesa Arizona, had one job which consisted of cutting 16 pieces from a piece of 304 stainless steel. The tolerances had to be held to +/- .0002. After the parts were cut all measured well within the specified tolerance (Automated EDM, 1990, p. 138).

Surface Finish

"Five or six years ago, you were lucky to get a 30-60 rms finish with wire EDM," says Carl Meyer. "Now, with new power generators and some trim cutting, you can do much better than that. This level of finishing saves moldmakers hours of polishing time" (Schreiber, 1990, p. 40).

Surface finish of material plays an important part in industry. If the designated surface happens to be a cutting edge of a die, the smoothness is important. If the designated surface has no functional purpose, then the smoothness is unimportant.

When Meyers made reference to a 30-60 rms, he was referring to the degree of smoothness of the surface. RMS refers to the root-mean-square. In layman's terms, it means an average deviation from the mean surface. The "mean surface" is the perfect surface that would be formed if all the roughness peaks were cut off and used to fill the valleys below the surface. A 30-60 rms finish would be comparable to a milled surface.

Today's machines are capable of producing finishes of 4 to 6 rms. Many of the newer wire EDM machines have fine-finish circuitry options available. To produce a finish of 4 rms, it is necessary to make a series of cuts. Begin with a roughing cut followed by a semi-rough cut. The final cut will be cut at a slower rate than the previous two. The amperage and voltage settings will be lower on the final cut. As a result, the surface finish will be considerably smoother (Bormann, 1991, p. 57).

Automatic Wire Rethreading

Untended production, having no operator waiting for an operation to finish, would be the ultimate in production. The introduction of automatic wire rethreading has been a major breakthrough for the untended production process.

"Ten years ago, saying you could run a machine untended overnight was a big benefit. But overnight operation depended on how long a cut you had in the machine. It applied to that one cut only" (Schreiber, 1990, p. 40). Automatic wire rethreading is accomplished with the use of a tube of water fired through a waterjet guide (Noaker, 1991).

Model EE3 from LeBlond Makino Machine Tool Co. follows a prescribed set of maneuvers to think its way through a problem. If the machine does not rethread on the first try, it keeps trying a specified number of times, then assumes the wire tip is bent. It moves out of the work area, cuts the wire at a fresh section, and returns to the start hole and rethreads. When the rethreading function is not effective, the EE3 stops machining at that position and skips to the next. The system remembers all positions skipped (Schreiber, 1990, p. 40).

When Intricate Wirecut, Inc., Patterson, New Jersey employed the use of a wirecut EDM machine with automatic wire rethreading, the results met the expectations. In the first year of operation, the machine ran 4000 hours, frequently untended for over 100 consecutive hours ("Automatic Wire," 1991, p. 72).

EDM and Manufacturing

How much has EDM technologies affected manufacturing? Will manufacturers look toward EDM job shops for guidance in this area, or will they try it on their own? The following examples are just a few of the many successful production stories available. Naturally, there has to be a few situations in which wire EDM did not prove successful. It appears there are more successes than failures in wire EDM production. The more successes, the more companies are willing to view it as a possibility for their jobs.

Applying EDM technology to their manufacturing, the Zellweger Group of Switzerland reduced production time by 85% and manufacturing costs by 25% in one year ("Cutting Edge," 1990, p. 70). The use of EDM technology is cutting away at old production practices. Cutting speed, surface finishes, and accuracy have allowed manufacturers these luxuries.

EDM is helping production job shops in becoming more competitive in job bidding on the global market. When ARC Industries was faced with overseas competition, they turned to EDM capabilities for help. ARC used the capabilities of a Robofil CNC wire EDM from Charmilles Technologies Corporation to produce a telephone housing mold. A total of 600 hours of wire EDM work was required. Over 400 of these hours were untended. Automatic wire threading, thermo-stable submerged EDMing, and CNC EDM software were the key contributors to the Robofil's operator free production ("CNC Wire," 1989, p. 132).

EDM technologies are affecting industries worldwide. Companies throughout the United States are discovering the benefits of EDM. When Harmony Industrial Corporation of Ashville, New York, received a large order of clevises, they turned to CNC EDM. The clevises were made of 4340 alloy steel heat treated to RC 45. Traditional methods of milling and grinding were not feasible. The close tolerances and deep slot width ruled out milling and grinding. After careful consideration EDM seemed to be an ideal solution even though it was slow. Using a Hitachi American Ltd. H-Cut 304S wire EDM, they were able to produce the clevises. Even though the EDM was slower, they were able to produce them in half the time while holding better tolerances ("CNC EDM," 1989, p. 97).

Another company, Schaeffer Magnetics of Chatsworth, California, needed to produce several titanium actuator housings. Their current EDM machine was not large enough to handle the material size. Milling with conventional means was not a viable solution. Titanium tends to harden so a series of stress-relieving steps would have to be done. Doing the machining by conventional methods would have taken 40 hours per part.

Shaeffer solved the problem by using a Sodick A280L wire EDM machine. It was estimated the production time was reduced by more than 50%, with setup requiring only two hours ("Production EDM," 1991, p. 64).

There are many examples of EDM specialty shops doing production specialty job with both ram and wire EDM. Some of the special jobs are for just a few parts while others include hundreds or thousands. How should production be defined? Harry Kerns, president of AGIE USA, states production EDM as, "Doing more than one part at a time and thereby lowering cost-per-part" (Mason, 1990, p. 44).

Once the EDM market catches on, the whole dollar value will double. Kerns believes that the cost-per-part is the key to production EDM. Multi-lead ram EDMs, multi wire EDMs, standard models of multi-spindle EDM drilling machines will lead the way into a new and challenging frontier (Mason, 1990, p.45).

Another definition of production EDM is offered by David Carlson, Vice-President of Adron Tool Company. He says, "The advent of high speed wire EDM machines six years ago was the turning point in making wire EDM a production alternative. We feel production pertains to any multiple workpiece that becomes a component part and not tooling" (Mason, 1990, p. 45).

Wire EDM is proving itself as a valuable alternative in short run, stamping-type production. When tolerances are tight and good finishes are required, wire EDM is the choice. Building a die for short stamping production runs is expensive. By the time the die steel is worked up, stripper plates made, and labor cost figured, the cost exceeds that of EDMing the job. The time factor is another important variable. EDM allows for turn around time in just a few days.

For many short run production jobs, the material is stacked and one cut produces many parts. Sometimes several parts are made from one stack of steel. Cutting parts in this manner produces a lot of inexpensive parts. Adron Tool cuts jewelry blanks of .025 in. thick titanium stacked 65 inches high. Nesting helps keep the cost down. The thin stem, tough material, and burr-free requirements all pointed to production wire EDM as the process of choice (Mason, 1990, p. 46).

Spectrum Manufacturing (Wheeling, Ill.) has modified some of its older wire EDMs to run high volume production jobs. Spectrum makes one-million/year plus of an automotive electrical conductor. The part is round in shape, with windows, and it would have been very difficult to stamp it without burrs. Made of beryllium copper it has a tolerance of .001 inch. The cycle time is 300 pieces per hour (Mason, 1990, p. 47).

The use of multi-head wire machines is rare to date. A few have been built, but their acceptance has not caught on. The idea behind the multi-wire machines is to lower the cost of production. There is much controversy among wire users about the benefits. Multi-head wire machines are slow when compared with single-head machines. Another disadvantage is that the multi-head machines can not use automatic wire rethreading. Despite these reasons, milti-jead machine research and development is continuing (Mason, 1990, p. 48).

Other advantages to production wire is the quick turn around time on some jobs. This meets today's just-in-time manufacturing requirements. Even though EDM takes longer to cut, the cost is proving to be less in the total scheme of things. The medical field is turning to production shops for wire cutting replacement knee joints. The cobalt chrome material is difficult to machine. However, using wire EDM the close tolerances and difficult contours can be machined in one cut. This keeps the part cost down, which makes it affordable to the customer (Mason, 1990, p. 51).

The capabilities of wire EDM to handle parts production is ever expanding. Machine size, speed, surface finish, control technology, and wire development are meeting the needs. Wire EDM is proving itself reliable, just-in-time, and with excellent quality. Most of the production is done by EDM job shops. These shops are willing to take the risk and put the machines to the test and are making it happen. A few manufacturing companies have caught on to production wire and are discovering the benefits (Mason, 1990, p.52).

Implications of EDM For Skilled Crafts

Wire EDM is being used more everyday by tool and die shops. Mold shops continue their use of ram EDM. Wire EDM is finding its way into more mold shops in recent years. As a result, ram and wire EDM technologies are affecting the future of the skilled occupations of the tool and die maker and the mold maker. The review of the literature and personal experience indicated that die building procedures are changing. Will EDM eliminate these skilled occupations totally? It seems unlikely, but it will alter the required skills level.

Tool and Die Makers

As the average age of the tool and die maker and the mold maker increases, managers are becoming concerned over replacing these individuals. Training programs are being rebuilt, but this is a slow process. As a result, managers are turning to the machine tool companies to provide hardware with some of those skills built in (Mason, 1991, p. 48).

The tool and die maker of today faces more complex designs, a demand for higher accuracy, and an increasing need for quality ("EDM Impacts," 1989, p. 142). To meet the challenges created by industrial demands, many job shops are looking at EDM technologies for the answer. The old traditional methods of die building are changing. For example, a large lamination die was machined using the wire EDM machine. It required a 475 inch length of cut consisting of 245 lines and 330 arcs. The job took approximately 60 to 70 hours to machine. Even at that, it was 10 to 15 times quicker than by conventional tool and die making procedures ("EDM Expands," 1989, p. 99).

The following is the normal procedure for building a simple blank and pierce die which consists of one hole and a slot. The bottom inserts would have to be squared. The notch was milled in the side to the required size, less .020 for grinding. Matting blocks had to be matched to make up the fourth side of the slot. The round hole was jig bored in location to dimensions from two sides. The mounting holes and dowel holes were selectively located and put in the inserts.

The top punch for the slot was machined from a block of tool steel. Mounting holes, dowel holes were drilled and reamed. The round punch holder was made from a block of cold roll steel. The round punch was purchased from one of the many suppliers. All the tool steel inserts were heat treated to a hardness of RC 58-60. After heat treat, the inserts were ground to size. Care was taken so as not to take too much material from the slotted insert.

The tool steel was positioned on a die shoe and the mounting holes were transferred. The die shoe was drilled for the corresponding holes. The bottom inserts were securely fastened and doweled. The top punches had to be located in their appropriate holes and shimmed for proper clearance. The mounting holes transferred and then the top die set drilled, etc. The top punches were then fastened and clearance between punches and die steel was checked for proper clearance. This is just a brief explanation of what a tool maker would do to build a simple die. The procedure may vary depending on the builder.

With the introduction of wire EDM, the bottom die insert could have been made from a solid block. Starting holes for the wire would be drilled and the mounting holes put in. The dowel holes could be EDM wired along with the slot and round hole. The block was then heat treated, then sent to the wire EDM machine. The top slot punch in this example would be made similar to that of the traditional method. The savings in these examples would be in the time it would take to make and fit the segmented bottom inserts.

There is still a need for the skills of the tool and die maker. EDM technologies can be used to the advantage of the tool and die maker.

Moldmaker

By increasing their ratio of EDM to milling, a builder of plastic injection molds has reduced machining time, man-hours, and lead time. When two mold builders compared identical mold built times, there was a significant difference. One of the builders used the old conventional methods, milling/EDM/polishing. The total was 910 hours, or 57 days at two shifts per day. The other builder used an Ingersoll CNC ram type EDM. The Ingersoll uses a much higher EDM-to-milling ratio. The total time was 634 hours or 40 days at two shifts. That represents a 30% reduction in time.

The key to extended EDM machining of complex molds is the electrode longevity provided by planetary or orbiting motion. Improved accuracy and enhanced control of form geometry are assisting moldmakers in doing a better job. However, like the tool and die makers, there are skills that the moldmakers have that EDM as of yet cannot replace ("EDM Saves," 1988, p. 88).

Future Trends In EDM

What does the future hold for EDM and the manufacturing industry? One projected growth area is the development of EDM machines with fuzzy logic. Fuzzy logic means that the control unit does not follow strict rules to reach conclusions or arrive at decision, but weighs options according to desired results. This approach is appropriate when there may be more than one correct answer. The correctness of the situation is determined by the user. Fuzzy logic is such a promising development for EDM because it encourages strategic planning while enhancing automatic operation (Albert, 1991, p. 72).

Fanuc's Series 16 control is based on 32-bit computer processing. The controller queries the user about the workpiece material, thickness, and wire diameter. The user is asked to indicate the desired cutting speed, surface finish, and accuracy (in order of priority). The user must also indicate the number of cutting passes desired. The control unit responds by presenting a series of results based on the priorities of the user. The user can then look over the list and make a judgement (Albert, 1991, p. 72).

Mitsubishi's fuzzy logic is based on 32-bit technology, and is similar to Fanuc's logic. Mitsubishi's emphasis is how the fuzzy logic is used to monitor and adjust cutting conditions in a closed-loop feedback system (Albert, 1991, p. 72). Fuzzy logic holds some promises for EDM, but it is unclear just how well it will be accepted.

Submerged wire cutting has been available for some time, but until recently, acceptance has been minimal. Most of the Japanese EDM machines are now equipped with submerged wire cutting capabilities. Submerged cutting enhances accuracy, cutting speed, surface finish, and flushing. Submerged cutting has proven to be beneficial where flushing is especially difficult. Hollow pieces, tubes or stacks of workpieces with recesses or steps are ideal candidates for submerged cutting (Albert, 1991, p. 73).

Automatic slug handling is another feature that is available on some models. This is an area of concern for companies doing extended untended production jobs. However, slug handling is not limited to production jobs. The advantage of slug handling is allowing continual untended cutting of thicker material.

Slug handling and removal systems are designed to hold the slug as it comes free when the wire cut is complete. Japanese builders tend to favor the use of robotics with a magnetic arm. The magnet is positioned over the slug by programmable servo-drives. When the slug is free, the arm lifts it out and moves it out of the way (Albert, 1991, p. 75).

Work shuttles and pallet shuttles are beginning to appear on wire and ram EDM units. The interest in these systems comes from two perspectives. One is extended operation in the untended mode; the other is setup away from the machine. In either way, the goal is to increase machine utilization without additional manpower. The technical issue behind work shuttles is in positioning accuracy. Locating the workpiece precisely in the work-zone is extremely important. Mitsubishi's DWC110Z wire machine has workchanger features. Seibu's APC-3A wire machine also has pallet shuttle capabilities (Albert, 1991, p. 76).

"Utilization is everything, if a machine sits idle, we don't make money," states Ron Leone of Intricate Wirecut, Inc. The company goal is to have a palletized system which is loaded robotically and operated untended for five, six, or more days at a time. Leone thinks the goal is nearly within reach (Schreiber, 1990, p. 42)

Ram EDM also has some promising new features. A "smokeless" EDM is exhibited on Makino's EDNC-156 machine. Rather than pumping the dielectric fluid through the holes in the electrode, this machine sucks the fluid and gases through the electrode and into special filtering and cooling units (Albert, 1991, p. 77).

Hitachi has inverted the workpiece and electrode. The idea is to obtain better flushing by having the workpiece on top. This process requires unusually strong, rigid construction. The machine can also be operated with the electrode mounted on top (Albert, 1991, p. 78).

The use of EDM processes for production work is a priority topic in EDM circles. Customer demands for higher quality and reliability, shorter delivery times, without cost increases is intense (Albert, 1991, p. 78).

Faced with labor crunches, mold and die shops have to concentrate on streamlining mold and die processing. Not only must these processes be as efficient as possible, but they must magnify the productivity of the process that goes before and after (Albert, 1991, p. 79).

Conclusion

The review of literature gives clear indication that EDM technologies have made an impact on manufacturing. Technical advancements in power sources, electrode materials, and automatic wire rethreading have made major contributions. These contributions are not singular in scope. Improved power sources have allowed enhanced spark control, better surface finishes, and faster cutting speeds. Improved electrode materials for ram and wire have contributed to better surface finishes, faster cutting speeds, greater accuracy, and improved flushability. Automatic wire rethreading has been a major feature in untended operations. The ability to leave a machine run untended for days appealed to manufacturing production. Combined with palletization, work can be loaded away from a machine, then automatically transferred into the machine.

Machine tool manufacturers are listening to the advice of their customers. The goal is to increase cutting speed with accuracy, improve flushability, and develop palletization. Improvements in CNC programing and software interfacing have also contributed to the success of EDM.

Experience has shown that EDM production is cost effective. Industries involved in product manufacturing are realizing the benefits of EDM. EDM specialty shops are doing both specialty jobs and the production jobs from manufacturers. Specialty shops are willing to experiment with wire possibilities and are having remarkable success. The skilled occupations of tool and die makers and moldmakers are being affected as well. Die making procedures of the past are no longer cost effective. EDM capabilities have allowed tool and die makers to construct dies with closer tolerances, better punch and die accuracy, and less hand fitting. Tool steels are now being used because they can be machined with EDM. As a result, dies have less maintenance and longer operating life.

Moldmakers are also being affected by EDM technologies. Improvements in ram electrode materials are contributing to greater speed and accuracy. Better surface finishes are being achieved, thereby eliminating the need of hours of hand polishing.

Molds are now being built using the technologies of wire EDM, a concept that was not practical in the past. Multi-axes features of wire EDM have been a contributing factor. EDM technologies have opened doors that have previously been closed. However, the literature suggests the skills of tool and die makers and moldmakers will be valued and needed in the future.

Recommendations For Further Studies

The purpose of the paper was to review EDM technologies and its affect on production manufacturing. The review of literature indicates that there will continue to be a shift to more EDM usage in manufacturing. While much has been written about the EDM process, a review of the literature did not indicate how a shift in manufacturing production methods will affect the labor force. New technologies will continue to have an effect on manufacturing, and this will effect labor.

It is recommended that a study be done on how labor will be affected by these technologies. To what degree will labor be affected in the next ten years? Will the labor force need to be more technical, and to what degree? How will the technical training be administrated to the labor force?

The skilled occupations of tool and die makers and moldmakers are already being affected by EDM. It is recommended that training for these skilled people be reviewed and updated to keep current with the technologies of EDM. A study should be done to reflect the current training program curriculum for these skilled occupations. It should also reflect future trends in EDM processes and how they will affect these occupations.

References

About Rhe EDM Process. (1989, January). Tooling & Production, pp. 54-56.

Albert, M. (1991, February). EDM In Japan. Modern Machine Shop, pp. 70-81.

Automated EDM Cuts Tool-and Die Man Hours. (1990, September). Tooling & Production, p.161.

Automatic Wire Threading Speeds EDM Production. (1991, March). American Machinist, pp. 71-72.

Bardin, L., & Kwiatkowski, E. (1987, December). Choosing The Best EDM Graphite. American Machinist & Automated Manufacturing, p.76.

Bormann, R. (1991, February). Getting those better EDM'd Surfaces. Modern Machine Shop, pp. 56-66.

CNC EDM Increases Productivity. (1989, September). American Machinist, p.97.

Cutting-Edge EDM. (1990, April). Manufacturing Engineering, pp. 70-72.

CNC Wire EDM helps U.S. Job Shop Win Job From Singapore. (1989, August). Modern Machine Shop, pp. 132-134.

DeVore, P. W. (1980). Technology An Introduction. Massachusetts: Davis.

Double-Coated-Steel EDM Wire. (1989, December). American Machinist, p.17.

Dudas, M. (1987, August). Trends in EDM Wire. American Machinist, p.74.

Eade, R. (1987, November). EDM: Riding a Crest of Success. Manufacturing Engineering, p. 28.

EDM Expands Company's Market Base. (1989, September). American Machinist, pp. 97-99.

EDM Impacts Tool and Die Make. (1989, April). Modern Machine Shop, pp. 142-144.

EDM Saves Mold Making Time. (1988, February). Tooling & Production, p. 88.

Faster Cutting With Wire EDM. (1989, December). American Machinist, p. 17.

Jameson, E. C. (1982, May). Hole Edge Condition Using Electrical Discharge Machining (EDM). Electrical Discharge Machining, pp. 42-53.

Kalpakjian, S. (1990). Manufacturing Engineering and Technology. Massachusetts: Addison-Wesley.

Mason, F. (1991, July). Intelligent NC Runs Wire EDM. American Machinist, p.48.

Mason, F. (1990, September). Wire EDM Is For Your Parts. American Machinist, pp. 43-52.

Milton, R. (1989, April). Contact Shop Expands EDM's Role. Modern Machine Shop, pp. 52-62.

Noaker, P. M. (1991, June). Kill The Arc, Tame The Spark. Manufacturing Engineering, p. 55.

Production EDM Trilogy. (1991, June). Manufacturing Engineering, p.64.

Schreiber, R. R. (1990, June). Hot Off The Wire. Manufacturing Engineering, pp. 39-44.

Shobert II, E. I., (1976, July). What Happens In EDM. Electrical Discharge Machining, pp. 3-4.

Sikora, E. (1988, April). TW/EDM Is Changing Mold Making. Modern Machine Shop, p.50.

Vollaro, C., (1978, March). Specifications of EDM Dielectric Fluids. Electrical Discharge Machining, p. 83.

Wijers, J. L. C. (1991, June). EDM Drilling Picks Up Speed. Modern Machine Shop, pp. 56-66.

Wirecut EDM--How Many Axes. (1989, January). Tooling & Production, p. 54.