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A Review on Electric Discharge Machine

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Abstract: *The beginning of Electric Discharge Machine, EDM came during the Second World War, when two Russian physicists B.R. and N.I. Lazarenko published their study on The Inversion of the Electric Discharge Wear Effect. which related to the application to manufacturing technology of the capacity of electrical discharges, under controlled distribution, to remove metal.EDM was being used at that time to remove broken taps and drills. The early "Tap-Busters" disintegrated taps with hand fed electrodes, burning a hole in the center of the tap or drill, leaving the remaining fragments that could be picked out. This saved work pieces and very expensive parts from being scrapped and having to be made over again.This process opened the birth of Vertical EDM, also called: Sinker, Conventional, RAM, Plunge or Diesinker EDM's. These machines were, and still are primarily used to make precision cavities in metal primarily for the mold industry.*
Keywords: *Electric discharge wear effect, EDM, Tap busters.*

I. Introduction

WIRE EDM MACHINE

It was introduced in the late 1960's, and has revolutionized the tool and die, mold, and metal working industries. It is probably the most exciting and diversified machine tooldeveloped for this industry in the last fifty years, and has numerous advantages to offer.

It can be machine anything that is electrically conductive regardless of the hardness,from relatively common materials such as tool steel, aluminum, copper, and graphite, to exotic space-age alloys including hastaloy, waspaloy, inconel, titanium, carbide,polycrystalline diamond compacts and conductive ceramics. The wire does not touch theworkpiece, so there is no physical pressure imparted on the workpiece compared to grindingwheels and milling cutters. The amount of clamping pressure required to hold small, thin andfragile parts is minimal, preventing damage or distortion to the workpiece.The accuracy, surface finish and time required to complete a job is extremelypredictable, making it much easier to quote, EDM leaves a totally random pattern on thesurface as compared to tooling marks left by milling cutters and grinding wheels. The EDM process leaves no residual burrs on the workpiece, which reduces or eliminates the need forsubsequent finishing operations.

Wire EDM also gives designers more latitude in designing dies, and managementmore control of manufacturing, since the machining is completed automatically. Parts thathave complex geometry and tolerances don't require you to rely on different skill levels ormultiple equipment. Substantial increases in productivity is achieved since the machining isuntended, allowing operators to do work in other areas. Most machines run overnight in a"lights-out" environment. Long jobs are cut overnight, or over the weekend, while shorter jobs are scheduled during the day. Most workpieces come off the machine as a finished part,without the need for secondary operations. It's a one-step process.

II. Literature Review

C.Sarvananan et.al. has studied the existing methods of manufacturing of Metal Matrix Composites. These are classified basically into liquid state and solid state methods[1]

Liquid state manufacturing of MMC:-

1. Stir Casting: - In this matrix material is heated to liquid state so it will melt. Then this melt is cooled to semi solid state, at this stage preheated particles are added and the slurry is again heated to liquid state and mixed by stirring
2. Composite Casting: - Composite casting is a liquid state process in which reinforced particles are added in semisolid state melt and it will agitated. This will result in better distribution of particles.

3. Squeeze Casting: - In this technique reinforced material is forced into molten metal by movable mould part (ram) which forces the molten metal to penetrate into a preformed dispersed phase, placed in the lower mould part.
4. Spray Deposition: - This technique typically consists of winding fibers onto a foil-coated drum and spraying molten metal onto them to form a mono tape. The source of molten metal may be powder or wire feedstock which is melted in a flame, arc or plasma torch.
5. In-situ Fabrication of Metal Matrix Composites: - In-situ synthesis process the reinforcements are formed in the matrix by controlled metallurgical reactions. During the process one of the reacting elements is usually a constituent of molten matrix alloy and other reacting element may be either externally added fine powder of gaseous phases. For better coherent property and homogeneous distribution this method is preferred.
6. Ultrasonic assisted casting: - This process combines solidification processes with ultrasonic cavitations based dispersion of nano-particles in metal melts. It can produce hotspots of transient micro size having temperatures of about 5000 degree celcius.This strong impact coupling with such high temperatures potentially break the nanoparticle clusters and clean the surface.

Solid state fabrication of Metal Matrix composites:-

1. Powder metallurgy:- Powder metallurgy is a process of blending fine powdered materials. Pressing them into desired shape. and then heating the compressed material in a controlled atmosphere to bond the material(sintering). It consists of four steps (1)powder manufacture (2).mixing and blending (3).compacting(At room temperature) (4).sintering (At atmospheric pressure.)
2. Diffusion bonding:- It is a common solid state processing technique for joining similar or dissimilar metals. In this process bonding is achieved by inter diffusion of atoms between two clean metallic surfaces at an elevated temperature. This principle enables the process to be carried out on variety of metal matrices and control of fiber orientation and volume fraction
3. Friction Stir Process:- It is used to get fine-grained microstructure which uses same principle as friction stir welding(FSW). Friction stir process has been basically advanced as a grain refinement technique, It is a very attractive process for also fabricating surface composites.

B C Kandpal et.al. work has added some other MMC manufacturing processes such as [2]

1) Infiltration:-It is a liquid state method of composite materials fabrication, in which a preformed dispersed phase(ceramic particle) is soaked in ala molten matrix metal, which fills the space between the dispersed phase inclusion. The motive force in this process maybe capillary force or the dispersed phase or an external force applied to the liquid matrix phase.
2) Chemical Vapor Deposition Technique (CVD):-This involves coating individual fibers in a tow with the matrix material needed to form the composites followed by diffusion bonding to form a consolidated or structural shape. It is a vaporized component decomposes or reacts with another vaporized chemical on the substrate. The processing is generally carried out at elevated temperatures.

Z.Fan et al. Studied various manufacturing processes of MMC's and find out they exhibits extremely low ductility and the processes used are non economical for producing engineering components. To overcome thisproblems to a certain extent he suggested a novel rheo-process. They carried out this experiment on Al alloy and SiC reinforcement.They discovered that the rheo-process is based on intensive shearing of liquid metal containing particulate clusters. Novel rheo-process is successfully carried out to fabricate metal matrix composites with uniform microstructures and without formation of particulate agglomerates.[3]

Peter Tatarko et al. has performed Spark Plasma Sintering for joining CVD-SiC coated and uncoated fiber reinforced ceramic matrix with pre-sintered Ti_3SiC_2 .joining parameters were carefully selected to avoid the decomposition of Ti_3SiC_2 and the reaction between the joining filler and the CVD-SiC coating. He discovered while that diffusion bonding occurred during joining of the observed coated composites, a combination of both solid state reaction and diffusion bonding was observed for the uncoated C_f/SiC composites, no reaction between the Ti_3SiC_2 and CVD-SiC was observed. The infiltration of the joining filler into the surface cracks in the CVD β-SiC coating allowed the filler to be more uniformly integrated with the matrix material all along the interface.[4]

Xinchen Xiong et al. has performed ultrasonic vibration treatment for improvement of particles distribution of in-situ 5 vol% TiB_2 particulates reinforced Al-4.5Cu alloy matrix composites. And discovered that TiB_2 particles are uniformly distributed throughout the bulk melt after treated by ultrasonic vibration of 240s.The tiny agglomerations formed by TiB_2 particles smaller than 100nm are also broken by ultrasonic vibration. By this experiment the ultrasonic vibration treatments are successfully introduced into composites fabrication .Large agglomerations in the melt are eliminated at the very early stage of ultrasonic vibration treatment. after this process yield strength of composites is improved by 114% and 61% comparing with base metal and untreated composite, respectively.

Mikhail Tashkinov. Performed statistical approach on micro-scale modeling of phase-level elastic fields of SiC reinforced metal matrix multiphase composites. He worked on developing a instrument on statistical mechanics as well as their application in studying micro structural behavior of MMC. He did study od multiphase TiC+SiC and Al+SiC MMC. He varied the microstructural parameters for obtaining the variations in the stress and strain fields. By this experiment he investigated that the possible variations of the mechanical and geometrical properties of the microstructure allows to asses their influence on stress strain field. This property of microstructure to influence the stress strain field can be used in optimizing MMCs.[6]

S. Kumar et al. have done a grey relational analysis of aluminium based composites machined by wire electrical discharge machining. In their work analysis has made to optimize parameters such as peak current, pulse on time, wire feed rate and weight percentage of reinforcement that affect the responses like kerf width and surface roughness. They have found that the inclusion of reinforcement particles in the composite increases the surface roughness of the machined area. An increase in the pulse duration also increases the surface roughness.[8] Lal et al. have conducted experiments in the Al7075/Al_2O_3/SiC hybrid composite through Wire-EDM to determine the effect of the process parameters, and found that the pulse on time is the major contributing factor.[7]

G. Ugrasen et al. studied Wire EDM the machining performance on metal matrix composites for accuracy, surface roughness and volumetric material removal rate. The analysis was done by Taguchi's technique. Their results based on ANOVA methods show that the most effective parameter on surface roughness, volumetric material removal rate and accuracy is current.[8]

Study on titanium carbide reinforced steel metal matrix composite was done by **Probir Saha et al.** They have used a Neuro-Generic technique to evaluate the results. Their results show that the process parameters namely pulse on-time and average gap voltage have great influence on the cutting speed and the kerf width. The optimization results show that it may be possible to achieve significant improvement in the cutting speed value for the same kerf width which was obtained through experiments.[9]

M. Nataraj et al. have done analysis of Al6061 based hybrid metal matrix composite for Wire EDM machining. They have considered current pulse on time and pulse off time as inputs and measured the metal removal rate, tool wear rate and surface roughness with respect to it. The results show that pulse off time has less effect on MRR and surface roughness. The optimum parameters they came across are 1.40 Amps of current, 30µs pulse on time and pulse off 7µs for maximizing the metal removal rate and minimizing the surface roughness.[10]

S. Gopalakannan et al. performed analysis of varience to investigate the influence of process paraeters and their interactions viz. pulse current, gap voltage, pulse on time and pulse off time on material removal rate, electrode wear rate and surface roughness. The analysis was done on Al 7075-B_4C MMC using response surface methodology. The results show that two main significant factors that affect the MRR are pulse current, pulse on time. The MRR first increases with an increase in pulse on time and then decreases if further increase in pulse on time is done.[11]

H. K. Kansal et al. have studied the Powder Mixed electrical discharge machining to determine the inter relation between pulse on time, pulse off time, duty cycle, peak current and concentration of dielectric fluid. MRR increases with the concentration of dielectric, however more improvement in surface roughness is still expected at higher concentration level in dielectric.[12]

B. Mohan et al. have done the study on controlling the electrical process parameters, and empirical relationships between process parameters and optimization of process parameters in EDM process. The study found that peak current and pulse duration are dominating the performance measures EDM process.[13]

III. Machine

Wire EDM's are manufactured in various sizes and styles of flush or submerged typemachines to fit the needs of the consumer. Large scale EDM's can handle workpiece weighing over ten thousand pounds and can cut over twenty inches thick. Automatic WireThreaders (AWT) are usually standard equipment on most models. In addition to the X-Ytable travels, wire EDM's have U / V travels for providing the movement to cut tapers. Mostmachines can cut tapers of 20-30 degrees depending on workpiece thickness.The wire EDM in figure 1 represents current technology. The system consists of aCNC control, power supply with anti-electrolysis circuitry, automatic wire threading, handheld pendant, programmable Z- axis, water chiller and filtration system.

Fig . Wire electric discharge machine

IV. Principle of Wire Electrical Discharge Machining

The Spark Theory on a wire EDM is basically the same as that of the vertical EDMprocess. In wire EDM, the conductive materials are machined with a series of electricaldischarges (sparks) that are produced between an accurately positioned moving wire (theelectrode) and the workpiece. High frequency pulses of alternating or direct current isdischarged from the wire to the workpiece with a very small spark gap through an insulateddielectric fluid (water).

Many sparks can be observed at one time. This is because actual discharges can occurmore than one hundred thousand times per second, with discharge sparks lasting in the rangeof 1/1,000,000 of a second or less. The volume of metal removed during this short period ofspark discharge depends on the desired cutting speed and the surface finish required.

The heat of each electrical spark, estimated at around 15,000° to 21,000° Fahrenheit,erodes away a tiny bit of material that is vaporized and melted from the workpiece.(Some of the wire material is also eroded away) These particles (chips) are flushed awayfrom the cut with a stream of de-ionized water through the top and bottom flushing nozzles.

The water also prevents heat build-up in the workpiece. Without this cooling, thermalexpansion of the part would affect size and positional accuracy. Keep in mind that it is theON and OFF time of the spark that is repeated over and over that removes material, not justthe flow of electric current.

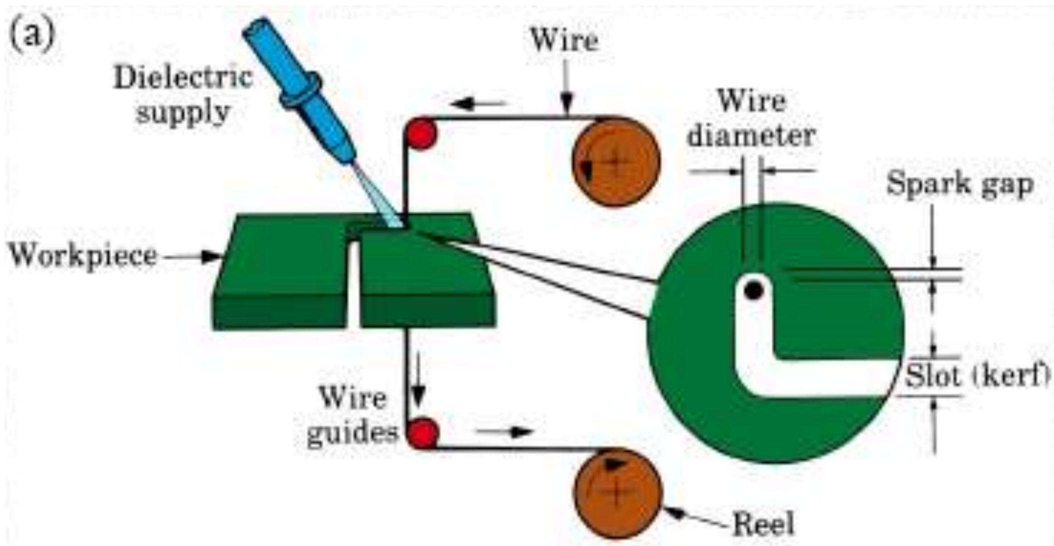

Fig. Principle of WEDM

V. Computer Numerical Control (Cnc)

Today's numerical control is produced with the needs of the operator in mind.Programs, machine coordinates, cutting speeds, graphics and relevant information isdisplayed on a color monitor, with easy to use menu's.The control unit displays menu's that are designed to give top priority to operability.Characters and commands are input using the keyboard. The system is very easy to use,allowing the operator to quickly become familiar with it, resulting in his/her learning curvebeing drastically reduced.

Besides executing NC data for positioning movement of the axes, the control amendsthese movements when using offsets, tapering, scaling, rotation, mirror images, or axisexchange. The control also compensates for any pitch error compensation or backlash errorin the axes drives, to ensure high accuracy positioning. The machine has multiple coordinatesystems, and jobs can be programmed in absolute or incremental modes saving valuableprogramming time. For example, multiple jobs can be set-up on the worktable, while storingthe separate reference points or locations of these jobs in specific coordinate registers.

The numerical control offers the capabilities of scaling, mirror imaging, rotation, axisexchange and assist programs. This enables an operator to produce an entire family of partsfrom a single program without the need to edit the program. Mirror imaging is great for leftand right handed parts. Scaling is useful when working with "shrink factors" for plasticcavities or extrusion dies. Assist programs find the edge of parts, vertically align the wire,and perform centering routines that are very useful to the operator when setting up jobs.

Other features include technology to aid in the prevention of wire breaks, backgroundediting and graphic display of programs while the machine is running.

Fig. CNC pannel

VI. Power Supply

When wire EDM machines were first introduced in the United States, they wereequipped with power supplies that could achieve less than one square inch per hour.

Today, most machines are rated to cut over twenty square inches per hour and faster.

Faster or slower speeds are obtained depending on the workpiece material, part thickness,wire diameter, type of wire, nozzle position, flushing condition and required part accuracy. .

Adaptive Control is yet another improvement where high speed circuitry hasimproved the spark gap sensitivity, reaction time of the servo motors, and changes to thepower. With these improved capabilities, wire breakage is reduced to a minimum, makingtoday's machines far more "forgiving" than in the past.Another feature is the anti-electrolysis circuitry that prevents the risk of electrolysiswhile cutting workpieces that are in the machine for extended periods. This AC circuit alsoeliminates the blue discoloration that appears when cutting titanium alloys with DC circuitsand is a beneficial feature when cutting aluminum.

Surface finishes on steel parts today are around sixty RMS for the roughingoperations and surface finishes better than 0.5 μ R max can achieved with multiple skimpasses. In many cases, this eliminates or minimizes "benching", hand polishing, or lapping ofparts that have fine finish requirements.

VII. Mechanical Section

a)Table movement

Machine movement is accomplished with precision lead screws with recirculating ball bearings on all axes that are driven by AC motors. Before shipping, the machine's position is checked and any errors or backlash are corrected by pitch error compensation that is permanently stored in the computers memory.

Fig. WEDM work table

b) WIRE PATH

When wire EDM was first introduced, copper wire was used on the machines because it conducted electricity the best. But as speeds increased, its limitations were soon discovered. The low tensile strength of copper wire made it subject to wire breaks when too much tension was applied. Poor flushability was another problem, due to coppers high thermal conductivity. A good portion of the heat from the EDM spark was transferred to the wire and carried away from the workzone instead of using that heat to melt and vaporize the workpiece. There is a vast array of wires to choose from with brass wire normally being used however, molybdenum, graphitized, and thick and thin layered composite wires are available for different applications.

Needs for various wires include: optimizing for maximum cutting speeds, (coated or layered wire) cutting large tapers, (soft brass) or cutting thick workpieces (high tensile strength with good flushability).

Wire diameters range from .004" through .014" with .010" being the most commonly used. The wire originates from a supply spool, then passes through a tension device (different diameter wires require different amounts of tension to keep it straight). It then comes in contact with power feed contacts where the electric current is applied. The wire then passes through a set of precision, round diamond guides, and is then transported into a waste bin. The wire can only be used once, due to it being eroded from the EDM process. (The used brass wire is sold to the scrap dealer for recycling)

VIII. Dielectric System

Wire EDM uses deionized water as the dielectric compared to Vertical EDM's that use oil. The dielectric system includes the water reservoir, filtration system, deionization system, and water chiller unit. During cutting, the dirty water is drained into the unfiltered side of the dielectric reservoir where the water is then pumped and filtered through a paper filter, and returned to the clean side of the dielectric tank.

Following filtration, the clean water is measured for conductivity, and if required passes through a vessel that contains a mixed bed of anion and cation beads. This mixed bed resin (the ion exchange unit) controls the resistivity of the water to set values automatically.

The clean water fills the clean side of the dielectric reservoir and proceeds to the cutting area. Used water is drained and returned to the unfiltered side of the dielectric reservoir to complete the cycle. A water chiller is provided as standard equipment to keep the dielectric, workpiece, worktable, control arms, and fixtures thermally stable.

During the cutting process the chips from the material that is being eroded, gradually changes the water conductivity level. Resistivity levels of the water are set according to the cutting requirements of the workpiece material being machined.

IX. Controlling Parameter

- Pulse on time
- Pulse off time
- Wire feed
- Wire tension
- Peak current
- Servo voltage

X. Response Surface Methods

Rutherford notes that there are a few different types of experimental designs for computeranalysis. The first type is the sampling approach. Monte Carlo methods, Latin Hypercube andimportance sampling all fall into this category. These methods involve sampling parametersfrom distributions and then running computational analysis (or physical experiments) to findoutput features. He notes that these may involve many simulations, especially when the event ofinterest is one that is low probability. Response surface methods make up the second category,these include classical response surface methods (the focus of this thesis), reliability methods,and spatial methods. Advantages of response surface methods are that they all tend to reduce thenumber of computational/physical experiments necessary to explore the response space.Because the basis of the formulation of the metamodels in this research is provided by thestatistical techniques of response surface analysis, a brief review of the philosophies andterminologies is provided below. For a more extensive explanation, the reader is referred to themany publications in existence on this topic. This review relies primarily on *Response SurfaceMethodology* by Myers and Montgomery and the *Design-Expert* Software Users Manual byAs stated in the introduction the primary utility of using design of experiments or responsesurface methods (RSM) is that it provides a way of rigorously choosing a few points in a designspace to efficiently represent all possible points. Many different types of designs have beenproposed in the literature, all are different with respect to which points are chosen forrepresentation of the full factorial set (the set of outputs that correspond to the combination of allinput parameters set at all possible levels). It is important to note that no design, unless itincludes every possible point of interest (full factorial), will ever provide a perfect fit.

Alldesigns will impose certain constraints on the form of the model that can be fitted. In the case ofpolynomials, more points added to the model means that a higher order model may be fitted.One of the biggest limitations of response surface metamodels is "aliasing" or a mixing of higherorder effects. Designs with only a few points may be used to fit higher order surfaces, but greatcare must be taken, because the higher order effects will be mixed, or aliased, with other effects,resulting in an inability to distinguish what the "true" effect is. Because the focus of this thesis isnot to discuss the mechanics of response surface design, the reader is referred to Meyers andLet us first consider the form which a response surface model takes. A response surface is afunctional mapping of several input parameters to a single output feature. In our case, it is of apolynomial form

$z = Ax+By+Cxy+Dx2 \ldots +£$

where in this case, *z* is the output feature of interest and *x* and *y* are input parameters, and € is the error term. *A*, *B*, *C*, *D*,… are regression coefficients, determined by the method of least squares.

The number of input parameters may be unlimited; here only two are considered becausevisualization is easier. Order of the model is determined by the number of points used to "train"it. Typically model properties of interest are those that characterize model fit quality,contribution of an individual variable to total model variance, parameter aliasing properties (howmuch one parameter gets "mixed up" with other parameters), and model resolution. Whenperforming response surface anlysis, it is customary to use normalized or "coded" inputparameter values. Also, if power transformations of the model output feature result in a betterfit, they are commonly employed.Commonly used models are always some fraction of the full factorial design space and aretherefore called "fractional-factorial models". When building models the number of levels ofinput parameters must be considered. The more levels incorporated into a design, the larger thedesign will be for the same resolution of a design with fewer input parameter levels. Followingis a brief summary of each of the models used in this work.

2k factorial design – This design is for any number of model inputs considered at two levels.

These types of designs are useful in doing input parameter screening or determining how mucheach individual parameter contributes to the total model variance. Those that do not contributemuch can be discarded. Larger "fractions" of the full factorial design will result in higherresolution designs with more design points.*Plackett Burman Design* – A two level fractional factorial design (each input parameter set attwo different levels). Because this design has a complex aliasing structure, it is commonly usedfor parameter screening purposes, or designs in which main effects (first order terms) are thoughtover shadow any higher order effects.*Central Composite Design* – A design for input parameters with three to five levels. Often usedto fit second order response surfaces. Runs consists of a center point, and then the corners of asquare (or cube or higher order equivalent) and axial points.

XI. Specimen Details

MATERIAL:-

Aluminum/Copper Metal Matrix Composite Al77.9/SiC17.8/Cu 3.3/Mg 1.2/Mn 0.4

MECHANICAL PROPERTIES:-

- Density (g cm-3) 2.85
- Elongation at gbreak (%) 6
- Tensile modulus (GPa) 100
- Tensile strength - longitudinal (MPa) 610
- Volume fraction of SiC (%) 17
- Yield strength (MPa) 400

SPECIMEN DIMENTIONS:

- Diameter-15mm
- Length-100mm
- Cost of specimen – 21000rs

XII. Conclusion

Wire EDM process gives best results for cost and material removal. The parameters determined above show variation in characteristic surface properties if changed. Investigations are done on various materials with changing every other parameter that can be controlled by operator. The various combinations give drastic change in results which are material removal rate, electrode wear rate and average surface finish of the surface.

Mathematical techniques like response surface methodology, Taguchi analysis or ANOVA suits better for result evaluation. There are a lot many variables present in an analysis thus such method can predict nearly most effective machining parameter.

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