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Investigation of Wire-EDM Process

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Abstract: Electrical Discharge Machining (EDM), also known as spark machining, spark eroding, die sinking, wire burning or wire erosion, is a metal fabrication process whereby a desired shape is obtained by using electrical discharges (sparks). [1] Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the tool or electrode, while the other is called the workpiece-electrode, or work piece. The process depends upon the tool and work piece not making physical contact.

When the voltage between the two electrodes is increased, the intensity of the electric field in the volume between the electrodes becomes greater, causing dielectric break down of the liquid, and produces an electric arc. As a result, material is removed from the electrodes. Once the current stops (or is stopped, depending on the type of generator), new liquid dielectric is conveyed into the inter-electrode volume, enabling the solid particles (debris) to be carried away and the insulating properties of the dielectric to be restored. Adding new liquid dielectric in the inter-electrode volume is commonly referred to as flushing. After a current flow, the voltage between the electrodes is restored to what it was before the breakdown, so that a new liquid dielectric breakdown can occur to repeat the cycle.

Keywords: Titanium alloy, Material removal rate, approach, Wire-EDM.

I. INTRODUCTION

Wire-cut EDM

The wire-cut type of machine arose in the 1960s for making tools (dies) from hardened steel. The tool electrode in wire EDM is simply a wire. To avoid the erosion of the wire causing it to break, the wire is wound between two spools so that the active part of the wire is constantly changing. The earliest Numerical Controlled (NC) machines were conversions of punched-tape vertical milling machines. The first commercially available NC machine built as a wire-cut EDM machine was manufactured in the USSR in 1967. Machines that could optically follow lines on a master drawing were developed by David H. Dulebohn's group in the 1960s at Andrew Engineering Company [5] for milling and grinding machines. Master drawings were later produced by Computer Numerical Controlled (CNC) plotters for greater accuracy. A wire-cut EDM machine using the CNC drawing plotter and optical line follower techniques was produced in 1974. Dulebohn later used the same plotter CNC program to directly control the EDM machine, and the first CNC EDM machine was produced in 1976.[6]

Commercial wire EDM capability and use has advanced substantially during recent decades.[7] Feed rates have increased [7] and surface finish can be finely controlled.[7]

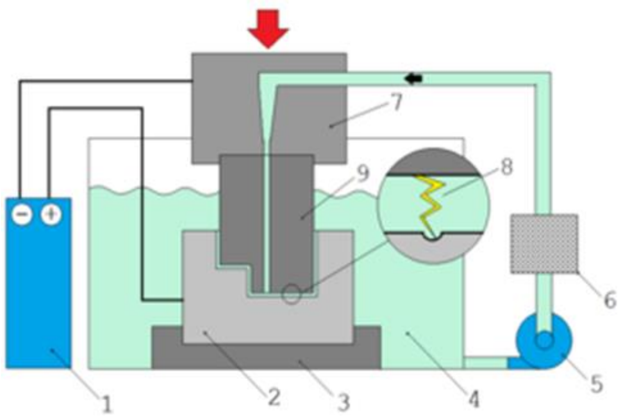

Fig. 1 Wire-cut EDM Principle

1 Pulse generator (DC). 2 Workpiece. 3 Fixture. 4 dielectric fluid. 5 Pump. 6 Filter. 7 Tool holder. 8 Spark. 9 Tool.

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Electrical discharge machining is a machining method primarily used for hard metals or those that would be very difficult to machine with traditional techniques. EDM typically works with materials that are electrically conductive, although methods have also been proposed for using EDM to machine insulating ceramics [8][9]. EDM can cut intricate contours or cavities in pre-hardened steel without the need for heat treatment to soften and re-harden them. This method can be used with any other metal or metal alloy such as titanium, hastelloy, kovar, and inconel. Also, applications of this process to shape polycrystalline diamond tools have been reported.[10]

EDM is often included in the "non-traditional" or "non-conventional" group of machining methods together with processes such as Electrochemical Machining (ECM), water jet cutting (WJ, AWJ), laser cutting and opposite to the "conventional" group (turning, milling, grinding, drilling and any other process whose material removal mechanism is essentially based on mechanical forces).[11]

Ideally, EDM can be seen as a series of breakdown and restoration of the liquid dielectric in-between the electrodes. However, caution should be exerted in considering such a statement because it is an idealized model of the process, introduced to describe the fundamental ideas underlying the process. Yet, any practical application involves many aspects that may also need to be considered. For instance, the removal of the debris from the inter-electrode volume is likely to be always partial. Thus, the electrical properties of the dielectric in the inter-electrodes volume can be different from their nominal values and can even vary with time. The inter-electrode distance, often also referred to as spark-gap, is the end result of the control algorithms of the specific machine used. The control of such a distance appears logically to be central to this process. Also, not all of the current between the dielectric is of the ideal type described above: the spark-gap can be short-circuited by the debris. The control system of the electrode may fail to react quickly enough to prevent the two electrodes (tool and workpiece) from coming into contact, with a consequent short circuit. This is unwanted because a short circuit contributes to material removal differently from the ideal case. The flushing action can be inadequate to restore the insulating properties of the dielectric so that the current always happens in the point of the inter-electrode volume (this is referred to as arcing), with a consequent unwanted change of shape (damage) of the tool-electrode and workpiece. Ultimately, a description of this process in a suitable way for the specific purpose at hand is what makes the EDM area such a rich field for further investigation and research.[12]

To obtain a specific geometry, the EDM tool is guided along the desired path very close to the work; ideally it should not touch the workpiece, although in reality this may happen due to the performance of the specific motion control in use. In this way, a large number of current discharges (colloquially also called sparks) happen, each contributing to the removal of material from both tool and workpiece, where small craters are formed. The size of the craters is a function of the technological parameters set for the specific job at hand. They can be with typical dimensions ranging from the nanoscale (in micro-EDM operations) to some hundreds of micrometers in roughing conditions.

The presence of these small craters on the tool results in the gradual erosion of the electrode. This erosion of the tool-electrode is also referred to as wear. Strategies are needed to counteract the detrimental effect of the wear on the geometry of the workpiece. One possibility is that of continuously replacing the tool-electrode during a machining operation. This is what happens if a continuously replaced wire is used as electrode. In this case, the correspondent EDM process is also called wire EDM. The tool-electrode can also be used in such a way that only a small portion of it is actually engaged in the machining process and this portion is changed on a regular basis. This is, for instance, the case when using a rotating disk as a tool-electrode. The corresponding process is often also referred to as EDM grinding.[13]

A further strategy consists in using a set of electrodes with different sizes and shapes during the same EDM operation. This is often referred to as multiple electrode strategy, and is most common when the tool electrode replicates in negative the wanted shape and is advanced towards the blank along a single direction, usually the vertical direction (i.e. z-axis). This resembles the sink of the tool into the dielectric liquid in which the workpiece is immersed, so, not surprisingly, it is often referred to as die-sinking EDM (also called conventional EDM and ram EDM). The corresponding machines are often called sinker EDM. Usually, the electrodes of this type have quite complex forms. If the final geometry is obtained using a usually simple-shaped electrode which is moved along several directions and is possibly also subject to rotations, often the term EDM milling is used.[14]

In any case, the severity of the wear is strictly dependent on the technological parameters used in the operation (for instance: polarity, maximum current, open circuit voltage). For example, in micro-EDM, also known as μ-EDM, these parameters are usually set at values which generates severe wear. Therefore, wear is a major problem in that area.

The problem of wear to graphite electrodes is being addressed. In one approach, a digital generator, controllable within milliseconds, reverses polarity as electro-erosion takes place. That produces an effect similar to electroplating that continuously deposits the eroded graphite back on the electrode. In another method, a so-called "Zero Wear" circuit reduces how often the discharge starts and stops, keeping it on for as long a time as possible.[15]

Definition of the technological parameters

Difficulties have been encountered in the definition of the technological parameters that drive the process.

Two broad categories of generators, also known as power supplies, are in use on EDM machines commercially available: the group based on RC circuits and the group based on transistor-controlled pulses.

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In the both categories, the primary parameters at setup are the current and frequency delivered. In RC circuits, however, little control is expected over the time duration of the discharge, which is likely to depend on the actual spark-gap conditions (size and pollution) at the moment of the discharge.[16] Also, the open circuit voltage (i.e. the voltage between the electrodes when the dielectric is not yet broken) can be identified as steady state voltage of the RC circuit.
In generators based on transistor control, the user is usually able to deliver a train of pulses of voltage to the electrodes. Each pulse can be controlled in shape, for instance, quasi-rectangular. In particular, the time between two consecutive pulses and the duration of each pulse can be set. The amplitude of each pulse constitutes the open circuit voltage. Thus, the maximum duration of discharge is equal to the duration of a pulse of voltage in the train. Two pulses of current are then expected not to occur for a duration equal or larger than the time interval between two consecutive pulses of voltage. The maximum current during a discharge that the generator delivers can also be controlled. Because other sorts of generators may also be used by different machine builders, the parameters that may actually be set on a particular machine will depend on the generator manufacturer. The details of the generators and control systems on their machines are not always easily available to their user. This is a barrier to describing unequivocally the technological parameters of the EDM process. Moreover, the parameters affecting the phenomena occurring between tool and electrode are also related to the controller of the motion of the electrodes.
A framework to define and measure the electrical parameters during an EDM operation directly on inter-electrode volume with an oscilloscope external to the machine has been recently proposed by Ferri et al.[17] These authors conducted their research in the field of μ-EDM, but the same approach can be used in any EDM operation. This would enable the user to estimate directly the electrical parameters that affect their operations without relying upon machine manufacturer's claims. When machining different materials in the same setup conditions, the actual electrical parameters of the process are significantly different.[17]

Material removal mechanism

The first serious attempt of providing a physical explanation of the material removal during electric discharge machining is perhaps that of Van Dijck.[18] Van Dijck presented a thermal model together with a computational simulation to explain the phenomena between the electrodes during electric discharge machining. However, as Van Dijck himself admitted in his study, the number of assumptions made to overcome the lack of experimental data at that time was quite significant.
Further models of what occurs during electric discharge machining in terms of heat transfer were developed in the late eighties and early nineties, including an investigation at Texas A&M University with the support of AGIE, now Agiecharmilles. It resulted in three scholarly papers: the first presenting a thermal model of material removal on the cathode,[19] the second presenting a thermal model for the erosion occurring on the anode[20] and the third introducing a model describing the plasma channel formed during the passage of the discharge current through the dielectric liquid.[21] Validation of these models is supported by experimental data provided by AGIE.
These models give the most authoritative support for the claim that EDM is a thermal process, removing material from the two electrodes because of melting or vaporization, along with pressure dynamics established in the spark-gap by the collapsing of the plasma channel. However, for small discharge energies the models are inadequate to explain the experimental data. All these models hinge on a number of assumptions from such disparate research areas as submarine explosions, discharges in gases, and failure of transformers, so it is not surprising that alternative models have been proposed more recently in the literature trying to explain the EDM process.
Among these, the model from Singh and Ghosh [22] reconnects the removal of material from the electrode to the presence of an electrical force on the surface of the electrode that could mechanically remove material and create the craters. This would be possible because the material on the surface has altered mechanical properties due to an increased temperature caused by the passage of electric current. The authors' simulations showed how they might explain EDM better than a thermal model (melting or evaporation), especially for small discharge energies, which are typically used in μ-EDM and in finishing operations.
Given the many available models, it appears that the material removal mechanism in EDM is not yet well understood and that further investigation is necessary to clarify it,[17] especially considering the lack of experimental scientific evidence to build and validate the current EDM models.[17] This explains an increased current research effort in related experimental techniques.[12]
In this conclusion, there are following major factors are achieved during machining operations:

- Resulting foremost conclusions can be stated from review of work in this area that EDM performance is generally evaluated on the basis of TWR, MRR, Ra and hardness.
- In material removal rate (MRR) from all selected parameters, spark current (I) is the most significant input factor affecting the machining of workpiece.
- The performance is affected by discharge current, pulse on time, pulse off time, duty cycle, voltage for EDM.
- For tool wear rate (TWR) from the all selected parameters, spark current (I) is the most significant input factor affecting the machining of workpiece followed by spark time and voltage.

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- Innovative technology in the EDM is unceasingly progressing to make this procedure further appropriate for the Machining. In the field of manufacturing additional attention is on the optimization of the method by dropping the number of Electrode.

Fig. 2 Wire EDM

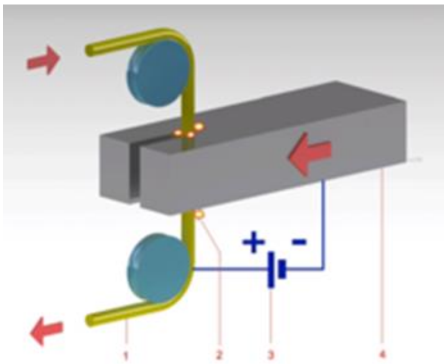

Fig. 3 CNC Wire-cut EDM machine

1 Wire. 2 Electrical discharge erosion (Electric arc). 3 Electrical potential. 4 Workpiece.

In wire electrical discharge machining (WEDM), also known as wire-cut EDM and wire cutting,[27] a thin single-strand metal wire, usually brass, is fed through the workpiece, submerged in a tank of dielectric fluid, typically deionized water.[25] Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods. The wire, which is constantly fed from a spool, is held between upper and lower diamond guides which is centered in a water nozzle head. The Charmilles Robofill 300 uses carbide guides. The guides, usually CNC-controlled, move in the x–y plane. On most machines, the upper guide can also move independently in the z–u–v axis, giving rise to the ability to cut tapered and transitioning shapes (circle on the bottom, square at the top for example). The upper guide can control axis movements in the GCode standard, x–y–u–v–i–j–k–l–. This allows the wire-cut EDM to be programmed to cut very intricate and delicate shapes. The upper and lower diamond guides are usually accurate to 0.004 mm (0.16 mils), and can have a cutting path or kerf as small as 0.021 mm (0.83 mils) using Ø 0.02 mm (0.79 mils) wire, though the average cutting kerf that achieves the best economic cost and machining time is 0.335 mm (13.2 mils) using Ø 0.25 mm (9.8 mils) brass wire. The reason that the cutting width is greater than the width of the wire is because sparking occurs from the sides of the wire to the work piece, causing erosion.[25] This "overcut" is necessary, for many applications it is adequately predictable and therefore can be compensated for (for instance in micro-EDM this is not often the case). Spools of wire are long — an 8 kg spool of 0.25 mm wire is just over 19 kilometers in length. Wire diameter can be as small as 20 µm (0.79 mils) and the geometry precision is not far from ± 1 µm (0.039 mils). The wire-cut process uses water as its dielectric fluid, controlling its resistivity and other electrical properties with filters and PID controlled de-ionizer units. The water flushes the cut debris away from the cutting zone. Flushing is an important factor in determining the maximum feed rate for a given material thickness. Along with tighter tolerances, multi axis EDM wire-cutting machining centers have added features such as

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multi heads for cutting two parts at the same time, controls for preventing wire breakage, automatic self-threading features in case of wire breakage, and programmable machining strategies to optimize the operation. Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process. The work piece may undergo a significant thermal cycle, its severity depending on the technological parameters used. Such thermal cycles may cause formation of a recast layer on the part and residual tensile stresses on the work piece. If machining takes place after heat treatment, dimensional accuracy will not be affected by heat treat distortion.

II. PRINCIPLE OF WIRE ELECTRICAL DISCHARGE MACHINING

The Spark Theory on a wire EDM is basically the same as that of the vertical EDM process. In wire EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an accurately positioned moving wire (the electrode) and the workpiece. High frequency pulses of alternating or direct current is discharged from the wire to the workpiece with a very small spark gap through an insulated dielectric fluid (water).
Many sparks can be observed at one time. This is because actual discharges can occur more than one hundred thousand times per second, with discharge sparks lasting in the range of 1/1,000,000 of a second or less. The volume of metal removed during this short period of spark 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 away from 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, thermal expansion of the part would affect size and positional accuracy. Keep in mind that it is the ON and OFF time of the spark that is repeated over and over that removes material, not just the flow of electric current.

1. Introduction
WEDM is a method to cut conductive materials with a thin electrode that follows a defined path. It is necessary to drill a hole for machining the workpiece or start from the edge. Machining is always through the entire workpiece. On the machining area, each discharge creates a crater in the workpiece and an impact on the wire electrode. If at some point the amount of stock removed from the electrode becomes greater than the amount being removed from the workpiece, the wire electrode breaks and the discharge is stopped. The dielectric fluid acts as an insulator and cooling agent. Since no cutting forces are present, WEDM is ideal for delicate parts. It is possible to make parts with taper or with different profiles at the top and bottom as the wire can be inclined. There is never any mechanical contact between the wire and workpiece [13]. Fig. 1 [12] shows the schematic representation of WEDM process.

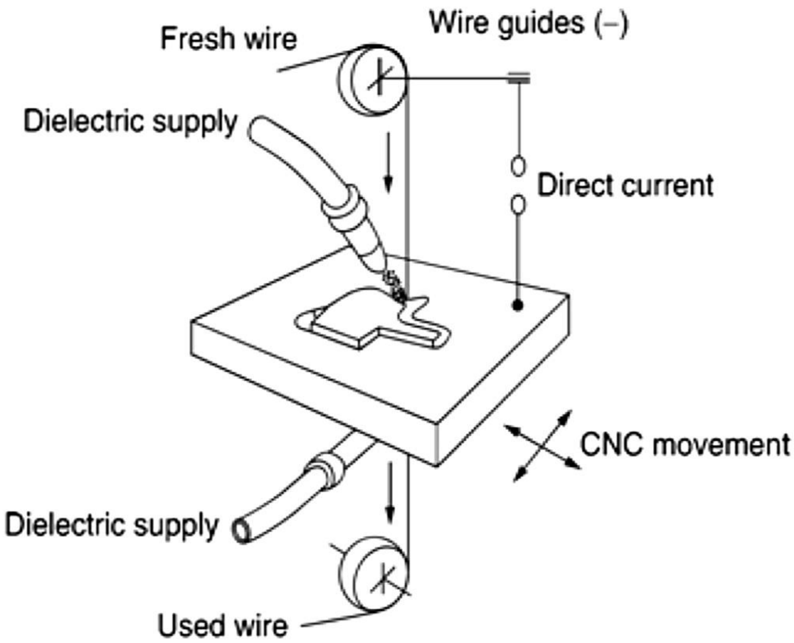

Fig. 4 Schematic representation of WEDM process

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III. CONCLUSION

The data thus obtained (utility data) is subsequently analyzed by the appropriate statistical techniques for the optimal setting. The effect of various input process parameters viz. pulse-off time, pulse-on time, spark gap set voltage, peak current, wire feed and wire tension on response variables (MRR and SR).

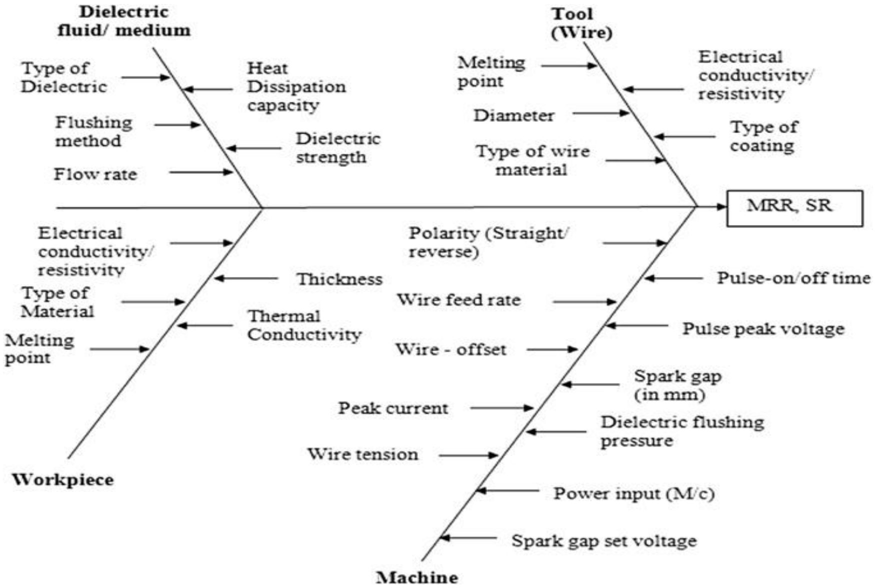

Fig. 5. Cause and effect diagram for MRR and SR in WEDM.

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