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A Review on Current Research Trends in Wire Electrical Discharge Machining (WEDM)

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***Abstract*: A Wire-EDM or Electrical-discharge wire cutting is basically a variation of an EDM process in which a slowly moving wire travels along a prescribed path, cutting the work piece, by discharge sparks which occurs in a small gap between wire & work piece and removes unwanted material from parent metal by melting & vaporization. The wire should have sufficient tensile strength and fracture toughness, as well as high electrical conductivity. Creation of extrusion dies, blanking punches and metal & tool fabrication are performed by WEDM. The paper reviews of the research work carried out in different fields related to WEDM such as modeling and simulation, ultrasonic vibrations, dry machining, composite materials & other key studies including the effects, investigations, improvements & developments carried out on the field of WEDM.**

***Keywords*: Dry Machining, Modelling and Simulation, Optimization, Ultrasonic Vibration, Process Parameters, Literature Review, Wire-EDM**

1. Introduction

A. Introduction to EDM

Electrical Discharge Machining is known as a non-conventional machining method and used to remove the material by a number of the repetitive electrical discharges of a small duration and high current density between the work piece and tool. EDM is an important and cost-effective method of machining extremely tough and the brittle electrically conductive materials. In EDM, since there is no direct contact between the work piece and the electrode, hence there are no mechanical forces existing between them. Any type of conductive material can be machined using EDM irrespective of the hardness or toughness of the material.

1) Principle of EDM

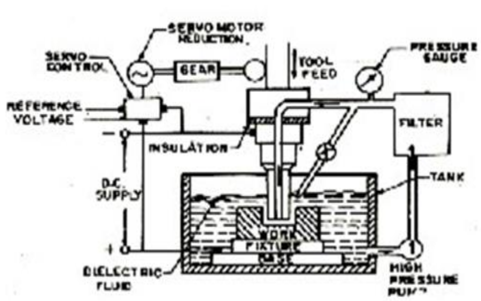

Fig. 1. Schematic diagram of EDM

The principle of Electrical Discharge Machining (EDM), also called electro discharge or sparks erosion machining, is based on the erosion of metals by spark discharges. As we know when two conducting wires will be allowed to touch with each other than arc is produced. A closely look at the point of contact between two wires show that that a small amount of metal gets eroded away, leaving a small crater.

2) Types of EDM

EDM process have two types: Die-sinking EDM and Wire-cut EDM.

- *Die-sinking EDM*

Die-sinking EDM is also known as cavity type EDM process consists of an electrode and the work piece which is submerged in the insulating fluid such as the dielectric fluids.

- *Wire-cut EDM*

Wire- cut EDM is also known as the Spark EDM process and mostly used low residual stresses are required, because it does not needs high cutting forces for the removal of the materials. In this type of EDM a fine diameter wire is used for cutting [1].

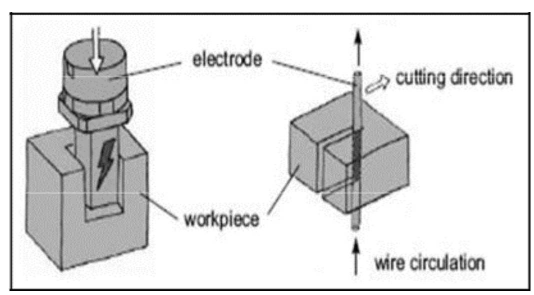

Fig. 2. Die Sinking and Wire Cut EDM Process

B. Introduction in the wire–cut EDM process

In wire EDM process, the conductive of materials is machined with series of electrical discharges that are produced between accurately the positioning moving wire and work piece.

High frequency of pulses of alternating and direct current is discharged from wire to the work piece with very small spark gap through an insulated dielectric fluid and sparks can be observed at one time. This is because actual discharges can occur more than one hundred thousand times per second.

The volume of the metal removed during this short period of the spark discharge depends on desired cutting speed and surface finish required. The heat of each electrical spark, estimated at around 21,000° Fahrenheit, erodes away the tiny bit of material that is vaporized and melted from the work piece. These particles are flushed away from cut with a stream of de-ionized water through the top and bottom of the flushing nozzles.

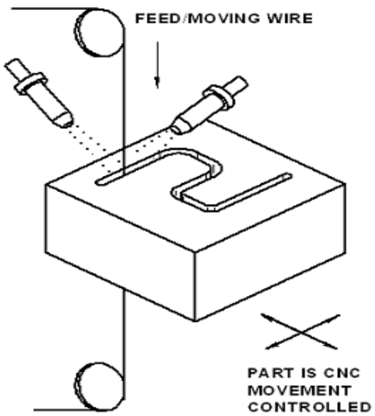

Fig. 3. Wire EDM setup

The water also prevents heat build-up on the work piece. Without this cooling, the thermal expansion of the part would effect of the size and positional accuracy. The wire is usually made of the brass, copper and multi coated wires are used. The wire diameter is typically about 0.30 mm for roughing cuts and 0.20 mm for finishing cuts.

The wire travels with a constant velocity in the range of 9 m/min and a constant gap is maintained during the cut. Typically on the early 70's these machines are typically slow, the cutting about 2 sq. inches an hour. Speeds went up to 6 sq. inches per hour in early 80's. Today the machines are equipped with the automatic wire threading and can be cut around 20 times faster than the initial machines.

The numerically controlled machines are conversions of the punched-tape the vertical milling machines. The first NC machine built as a wire-cut EDM machine are manufactured in USSR 1967. Only towards the mid of the 1970s, when computer numerical control drawing plotter and the optical line follow techniques were produced. Dulebohn later on the used the same plotter of the CNC program to directly control the EDM machines and The first CNC wire-EDM machine is developed 1976 and brought about a major evolution of the machining processes. As a result, the broad capabilities of the WEDM process were extensively exploited for through-hole machining owing to the wire, which has to pass through the part to be machined. The review presented in this paper is based upon the major and current research trends carried out by the different researchers of the world who utilized different fields related to the Wire-EDM technology and many ideas were obtained regarding the improvements of the process.

C. Principal of wire-cut EDM

In wire EDM, the conductive materials are machined with a series of electric sparks that are produced between the tool (cathode) and work material (anode). High frequency of current is discharged from the wire to the work piece with a very small spark gap through an insulated dielectric fluid.

Heat generated due to sparking results in the melting of work piece and wire material and a constant gap between tool and work piece is maintained with help of a computer controlled, positioning system. This system used to cut through complicated contours especially in difficult to machine materials.

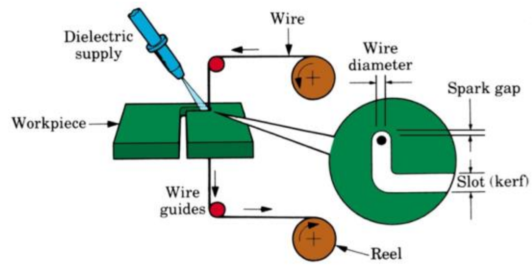

Fig. 4. Basic principal of wire EDM

D. Process of wire-cut EDM

Wire EDM machining is an electro–thermal production process in which a thin metal wire in conjunction with deionized water allows the wire to cut the metal by the use of heat from electrical sparks. Complex parts and precision components out of hard conductive materials can be easily make by using wire EDM.

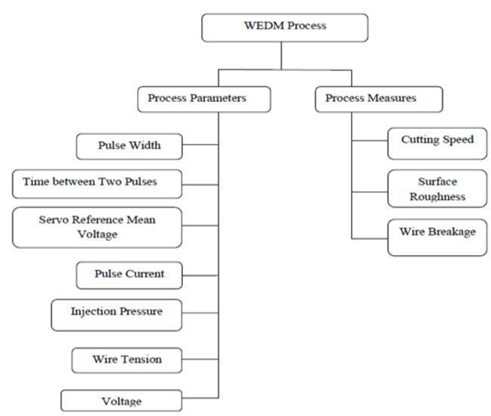

Fig. 5. WEDM process

Wire EDM machine works by creating an electrical discharge between wire or electrode and the workpiece. As the spark jumps across the gap, material is removed from both the workpiece and the electrode.

E. Process parameters

1) Pulse duration

Pulse duration is also called as pulse on time and expressed in micro seconds. During the pulse on the time, the voltage are applied in the gap between workpiece and electrode, producing discharge. Higher the pulse time, higher will be the energy applied there by generating more amount of heat energy during this period. Material removal rate depends upon the amount of energy applied during the pulse on time [3].

2) Pulse interval

Pulse interval is also called as Pulse off time .The time between discharges and the off Time has no effect on discharge energy. Off Time is pause between the discharges that allows the debris to solidify and is flushed by the dielectric prior to the next discharge. The reducing Off Time can dramatically increase in the cutting speed by allowing more productive discharges per unit time. However the reducing off time, it can overload the wire and then causes wire breakage or instability, the cut is not allowing the enough time to evacuate the debris before the next discharge.

3) Servo voltage

Servo voltage acts as the reference voltage to control the wire advances and retracts. Mean machining voltage is higher than the set servo voltage level, the wire advances, and it is lower, the wire retracts. When a small value is set, the mean gap become narrow, which leads to an increase in the number of electric sparks, resulting in higher machining rate. However the state of machining at the gap become unstable then causing wire breakage.

4) Peak Current

Peak current is amount of power used in the discharge machine .The current increases until it reaches a preset value during each pulse on time, which is known as peak current. The Peak current is governed by surface area of the cut. Higher the peak current is applied during the roughing operation and details with the large surface area.

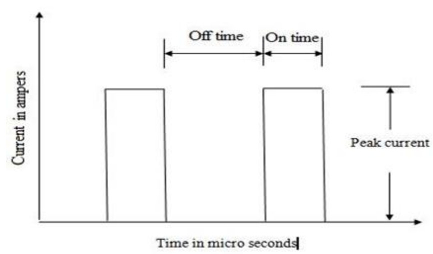

Fig. 6. Shows peak current, pulse-off time and on time

5) Wire feed

Wire feed is a rate at which the wire-electrode travels along the wire guided path and it is fed continuously for the sparking. The wire feed range are available on the present WEDM machine is 1m/min. It is always desirable to set wire feed to maximum and the result on less wire is breakages, better the machining stability and slightly the more cutting speed.

6) Wire tension

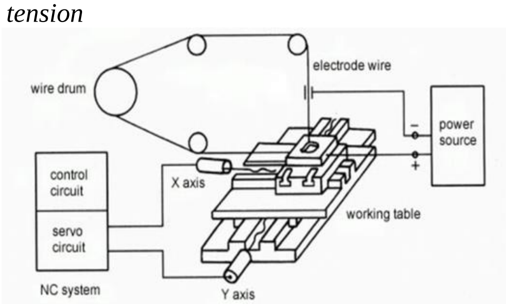

Fig. 7. Wire-cut EDM process

The wire is to be stretched between the upper and the lower wire guides. This is a gram-equivalent load with which the continuously fed the wire is kept under tension so that it remains straight between wire guides. The wire tension range available on machine is 15 units.

F. Process measures

1) Cutting speed

For WEDM, cutting rate is a desirable characteristic and it should be as high as possible to give least machine cycle time leading to increased productivity. In the present study cutting rate is a measure of job cutting which is digitally displayed on the screen of the machine and is given quantitatively in mm/min.

2) Gap current

In WEDM machining the specimen is mounted on the machine and during the process of cutting a small amount of gap is maintained between the job and the electrode wire. To initiate the cutting a pulse of current is given by the pulse generator and the current passes through the material being cut which is measured and named as gap current. The gap current is read on an ammeter, which is an integral part of the machine, in amperes.

2. Conclusion

From all the literature review, Wire cut EDM has resulted as the most efficient and accuracy machining process. The Wire cut EDM machining process can machine any material irrespective of their hardness and they can produce any intricate shape. The modeling and optimization of various machining parameters of Wire cut EDM improved in precision machining of work materials. The wire cut EDM worked with metals, alloys, composites and ceramics.

we can hereby conclude that Latent heat of fusion and vaporization influences the simulation results, high pulse on time, low pulse off time and low servo voltage gives optimal value of cutting rate, surface roughness is influenced by pulse on time and ultrasonic vibrations (which were found to be more significant in roughing conditions and probability of rapture wire was reduced because of its introduction), Wet wire-EDM gives better surface integrity as compared to dry Wire-EDM, open circuit voltage and pulse duration were found to be the most effective parameters on WWR, MRR will decrease with increasing pulse off time and peak current, however increase in servo voltage decreases MRR, high melting efficiencies can be achieved with high relative speeds. However, many other conclusions were made related to the different fields in wire-EDM including modeling, dry machining, composite materials, optimization, ultrasonic vibrations and other investigations, effects, improvements & developments suggested were also mentioned.

Table 1
Literature review

S. No.	Name of author	Years	Methods	Methodology used/ Parameter analysis	Results and discussion
1	E. Weingartner, F. Kuster and K.Wegener	2012	Modeling and Simulation	Studied the influence of heat source on modeling single discharges as well as influence of temperature dependent material properties and latent heat of fusion and vaporization on simulation results.	Latent heat of fusion and vaporization showed to have significant influence on simulation results.
2	Amit Kumar Gupta and Dr. Sanjeev Kumar	2013	Modeling and Simulation	Conducted experiments on high carbon chromium Steel with a wire of diameter 0.2 mm and obtained data was analyzed using response surface methodology.	The results of ANOVA indicated that proposed a mathematical model can adequately describe the performance within limit of factors being studied and founded that high pulse on time, low pulse of time and low gives optimal value of cutting rate.
3	Ravindranath Bobbili, V. Madhu and P. K. Gogia	2015	Modeling and Simulation	Attempted to establish the relation between parameters by employing Buckingham Pi theorem to model the input variables and Thermo physical characteristics of Wire EDM.	Founded that the results predicted by the model regarding material removal rate and surface roughness work well matching with experiment results.
4	Mu-Tian Yan, Chi Cheng Fang	2008	Modeling and Simulation	Proposed a genetic algorithm-based fuzzy logic controller t o investigate the dynamic performance of the closed-loop wire tension control system.	The proposed genetic algorithm-based fuzzy logic controller can obtain faster transient response and smaller steady-state error than a PI controller.
5	Y.S. Liao, J.T. Huang and H.C.	2004	Optimization	Proposed an effective and precise way of determining the appropriate machining parameters based on Taguchi design method and ANOVA which was time effective and cost saving as well.	Larger table feed and a smaller Ton will result in higher value of surface roughness.
6	Kapil and Sanjay Agarwal	2012	Optimization	Applied Multi-objective genetic algorithm NSGA-II to optimize the multiple objectives of MRR and surface roughness on machining high speed steel (M2, SKH9).	Results also indicate that the surface quality decreases as the MRR increases and they vary almost linearly.
7	Shivkant Tilekar, Sankha Shurva Das, P.K. Patowari	2014	Optimization	Included effect on kerf width along with surface roughness of Aluminum and mild steel using single objective Taguchi method.	Both kerf width and surface roughness were minimized successfully and process parameters word stated ANOVA showed that in case of kerf width wire feed rate and Spark on times have significant effect on Aluminum and mild steel respectively
8	Pujari Srinivasa Rao, Koonu Ramji and Beelasatyanarayana	2014	Optimization	besides presenting optimal combination of parameters for surface roughness and material removal rate for Aluminum 2014 T6 alloy also developed mathematical models which predicted the SR and MRR with high Regression coefficient value with the help of Optimization of performance measures by hybrid genetic algorithm	Its results clearly showed that a sacrifice in cutting efficiency is essential for production of Quality Surfaces and vice versa. White layer thickness measurements were made for suggested the combination of parameters whose magnitude or value is relatively high when compared to heavy and other light metals
9	Chaiya Praneetpongrung, Yasush Fakuzawa, Shigeru Nagasawa and Ken Yamashita	2010	Ultrasonic Vibrations	studied the effects on combined ultrasonic vibrations on machining properties of Si_3N_4.	They found that ultrasonic vibrations should be applied after transition time is passed however large amplitude values do not always contribute to large MRR. However surface roughness was increased after introduction of ultrasonic vibration.
10	Guo et al.	2014	Ultrasonic Vibrations	Studied the machining mechanism of wire EDM along with ultrasonic vibration.	High frequency vibration of wire improves the discharge concentration and reduces the probability of rapture wire.
11	Mohammadi, A. F. Tehrani, A. Abdullah	2013	Ultrasonic Vibrations	Proposed a new method of vibration transfer to wire in ultrasonic assisted wire electrical discharge turning.	In roughing condition ultrasonic vibration effect was found to be more significant.

Table 1 (Contd.)
Literature review

12	Nihat Tosun and Can Cogun	2002	Machining Investigations	Investigated the outcomes on wire wear ratio due to the variations of machining parameters both experimentally and statistically in wire EDM.	The most effective parameters on WWR found to be open circuit voltage and Pulse duration.
13	J. F. Liu, L. Li. U. B. Guo	2014	Machining Investigations	Investigated the process capability of wire EDM in machining Nitinol Ni50.8 Ti49.2 by one main cut (MC) followed by four trim cuts (TC).	Significant softening occurred in heat affected zone in MC due to thermal degradation can be minimized by the TC at relatively low discharge energy.

3. Future scope

- Unique cutting in manufacturing industries.
- Submersible cutting.
- Tapered holes may be produced.
- Can be used environmentally friendly dielectic may add some new dimension to the WEDM research.

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