

Review Study and Importance of Micro Electric Discharge

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Abstract
Micro EDM process is one of the micro- machining processes. It can be used to machine micro features and makes a micro parts. There is a huge demand in the production of microstructures by a non-traditional method which known as Micro-EDM. Micro-EDM process is based on the thermoelectric energy between the work-piece and an electrode. Micro-EDM is a newly developed method to produce micro-parts which in the range of 50 µm -100 µm. Micro-EDM is an efficient machining process for the fabrication of a micro-metal hole with various advantages resulting from its characteristics of non-contact and thermal process. A pulse discharges occur in a small gap between the work piece and the electrode and at the same time removes the unwanted material from the parent metal through the process of melting and vaporization. This paper describes the importance, parameters, principle, difference between Macro and micro EDM, applications and advantages of µ-EDM and discuss about the literature reviews based on performance measure in micro- EDMP process.
Keywords: Micro EDM, MRR, TWR, SR

1-INTRODUCTIONS

The miniaturization of devices is today demanding the manufacture of mechanical components with manufactured features in the range of a few to a few hundred microns in fields that contain optics, electronics, medicine, biotechnology, communications, and avionics, to name a few. Specific applications consist of micro-scale fuel cells, fluidic micro-chemical reactors requiring micro-scale pumps, valves and mixing devices, micro-fluidic systems, micro-holes for fiber optics, micro-nozzles for high-temperature jets, micro-molds, deep X-ray lithography masks, and a lot of more. Various types of needs and reasons during micro manufacturing, micro machining and miniaturization of the products such as:

- Minimizing spend energy level
- Minimizing materials use in manufacturing
- Reduction of power budge
- Faster devices
- Increased selectivity and sensitivity
- Improved precision and reliability
- Cost/ performance advantages
- Integration with electronics, simplifying systems

2-MICRO-EDM

Micro-EDM is a process based on the thermoelectric energy between the work-piece and a tool electrode. Micro-EDM is a newly developed method to produce micro parts which in the range of 50 µm -100 µm. Micro-EDM is an efficient machining process for the fabrication of a micro-metal hole with various advantages resulting from its characteristics of non-contact and thermal process. EDM is a known and widely used non-traditional machining process for hard to cut materials because of its ability to function Independently of the hardness, brittleness or toughness of the work-piece. Using low energies, it has been successfully applied in micro- and precision machining, for example, in the mould making industry.

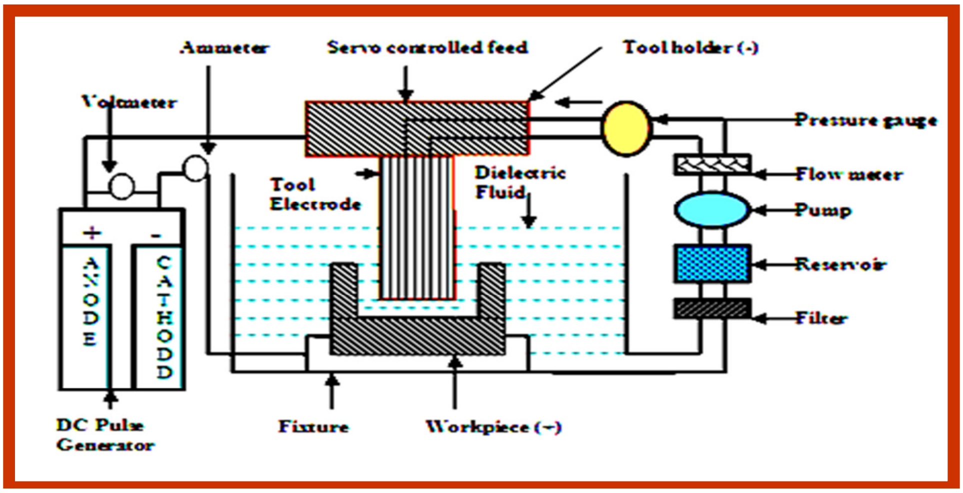

Figure: 2 Diagram of EDM [Choudhary & Jadoun (2014)]

3-PARAMETERS OF MICRO-EDM

EDM Parameters mainly classified into two categories:

3.1 Process Parameters
3.2 Performance Parameters

3.1 PROCESS PARAMETERS: The process parameters in micro-EDM are used to manage the performance measures of the micro-EDM machining process. Process parameters are commonly controllable machining input factors that decide the condition in which machining is carried out.

1. **Pulse on time:** The pulse on time represents the duration of discharge and is the time during which the electrode material is heated by the high temperature plasma channel.
2. **Pulse off time:** The pulse off time represents the duration when no discharge exists and the dielectric is allowed to demonize and recover its insulating properties.
3. **Arc Gap:** The Arc gap is distance between the electrode and work piece during the process of EDM. It may be called as spark gap.
4. **Duty cycle:** Duty factor is a percentage of the pulse duration relative to the total cycle time (Pulse-on time +.pulse-off time)
5. **Discharge Current:** It is a measure of the amount of electrical charges flowing between the tool and work-piece electrode. Discharge current is directly proportional to the MRR.
6. **Gap Voltage:** This can be measured as two different values during one complete cycle. The voltage, which can be read across the tool electrode / workpiece gap before the spark current start to flow is called the open gap voltage.
7. **Electrode polarity:** Polarity refers to an electrical condition determining the direction of the current flow relative to the electrode.
   Straight polarity: Electrode (-) & work-piece (+)
   Reverse polarity: Electrode (+) & work-piece (-)

3.2 PERFORMANCE PARAMETERS: These parameters measure the different performances of micro-EDM results. Performance parameters classified into following types.

1. **Material Removal Rate (MRR):** Erosion rate of the work-piece, it is expressed as the weight of material removed from work-piece over a period of machining time in minutes.
2. **Tool wear Rate (TWR):** Erosion rate of the tool electrode, TWR is calculated by using the weight loss from the tool divided by the time of machining.
3. **Surface Roughness (SR):** To investigate the surface quality, we choose to analyze the mean roughness, or the arithmetical roughness Ra, which is shown as:

$$Ra = \frac{1}{L} \int_0^L |h(x)dx|$$

   $h\ (x)$ =Value of the roughness profile
   L = Evaluation length
4. **The heat-affected zone (HAZ):** HAZ is situated just below the recast layer. HAZ refers to the region of a work-piece that did not melt during electrical discharge but has experienced a phase transformation.
5. **Recast layer Thickness (RLT):** The recast layer refers to the region of re-solidified molten material

occurring as the top most layer of the machined surface. The RLT is usually located above the HAZ.

6. **Over-Cut (OC):** The difference between the size of the electrode and the size of the cavity (or hole) is called the overcut. The electrode is always smaller than the width of the final cavity to allow for the spark gap.

Table-1 Difference between Macro and Micro EDM

Points of distinction	Macro- EDM	Micro- EDM
Pulse generator	Transistor Based circuit	RC based circuit
Dielectric	Mineral oil and deionized water	deionized water
Flushing	External & internal	Internals
Electrode material	Copper, graphite	Tungsten
Current	0.5- 400 Amp	0.1- 10 m Amp
Voltage	40- 400 V	60-120 A
Electrode wear ratio	1 – 5%	1.5 – 100%
Pulse duration	0.5 µs- 8 ms	60 ns->0.5ms
Surface roughness	0.8-3.1 µm	0.07-1µm
Energy	>25µJ	<25µJ
Applications	Automotive, defense, aerospace, prototype production, coinage die making	Fabrication of micro nozzles, ink jet and micro punches & hole

4. PRINCIPLE OF MICRO EDM

The electro discharge machining process is based on ablation of material through melting and evaporation. Fig. 2 shows the process principle. The electrical discharges take place between the tool electrode and the work-piece in a dielectric medium that separates the two. A voltage is applied to both electrodes and, when the breakdown voltage of the medium is reached, a plasma channel allowing for a current flow is established and a discharge takes place. At the base of the plasma channel, the temperature can reach $T \geq 10{,}000$ °K, melting and evaporating the electrode material. When the energy input is stopped the discharge ends, leading to a collapse of the plasma channel and the surrounding gas bubble. The reflow of the dielectric medium flushes liquid material away and cools the electrode surface. Repeating the process, a voltage is attached to the electrodes again and the setup is prepared for the next discharge. Naturally, the discharge will take place where the breakdown barrier is lowest, that is when the distance between the electrodes is the smallest – in an ideal dielectric – or, in a real dielectric liquid, when the conductivity of the gap between the electrodes is the highest, e.g. when particles or gas bubbles reduce the breakdown voltage of the medium. By constant repetition of the process, the tool electrode surface is re-assembled in the workpiece and, by feeding the tool, a transfer of the geometry takes place. Because of the process nature, the surface is an assembly of single discharges and shows a crater-like topology. The geometrical accuracy and the surface roughness depend on the size and shape of these craters and therefore on the volume that is ablated with each discharge. A minimization of discharge energy is the key to precision and optimal surface characteristics.

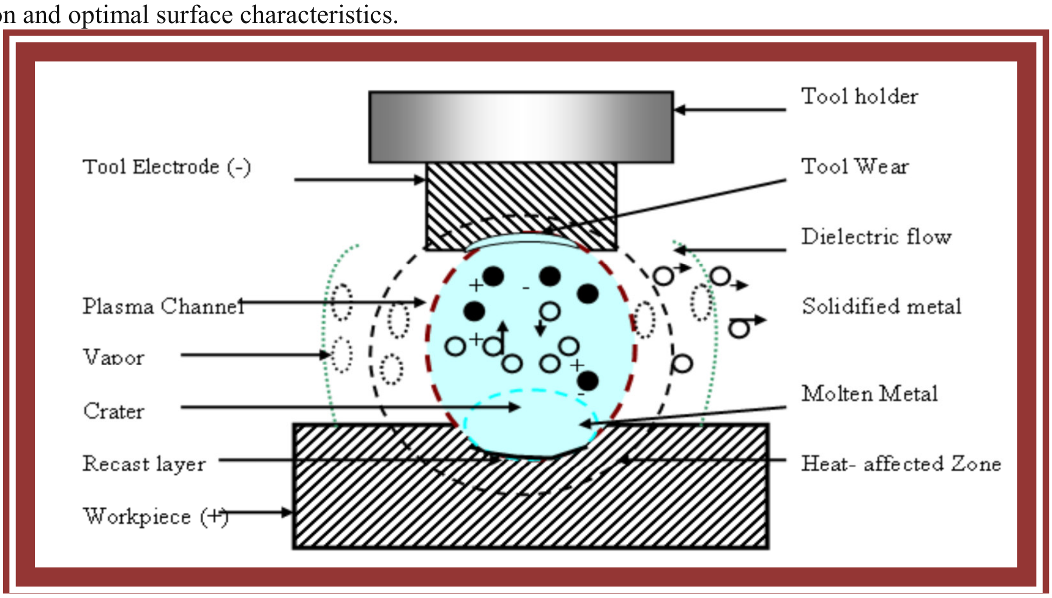

Figure: 2 Principle of Micro EDM

5. APPLICATIONS OF MICRO EDM

1) Drilling of micro hole
2) Helical profile milling
3) Produce Thread cutting & narrow slots
4) Curved hole drilling
5) Deep small diameter hole using tungsten wire
6) Creation of holes in fuel injectors & turbine blades
7) Removal of damaged drill bits
8) Create vent holes, cutting equipment coolant holes, and punch ejector holes.
9) Creation of coolant holes in hard machine tool bits such as drills, end mills, and taps

6. ADVANTAGES OF MICRO-EDM

1) Compared with conventional milling processes, the walls of micro EDM drilled holes have less or no burrs. Burr-free EDM drilling process is especially suited for machining difficult holes (an example would be drilling holes in turbine blades). When machining speed and discharge energy of EDM machines are controlled, small holes can be drilled in work pieces with high levels of accuracy.
2) EDM machines have long needles as the tool electrode, which are used for drilling deep holes in work pieces. For instance, the aspect ratio of EDM drilled structures can be as high as 10:1 (hole depth versus hole diameter). Conventional machining processes are not ideal for drilling deep micro holes.
3) EDM drilling machines can be used to drill materials such as soft copper and aluminum that produce gummy chips when machined.
4) Micro EDM drilling is a non-contact micromachining process. Therefore, work piece surfaces and discharge electrodes are free from any mechanical pressure during machining. This property is also advantageous in machining curved and jangled structures or ultra thin surfaces.
5) EDM machining process is best suited for drilling holes in hard semi conductive or conductive materials (ferroelectric materials and silicon are examples of ultra hard materials). Materials such as hardened tool steel and carbide are difficult to drill through conventional methods.
6) While drilling holes in angled or curved surfaces, drill bits of conventional drilling machines tend to break if torque conditions are not carefully controlled. In EDM drilling, there is no need for torque control since discharge electrodes never contact with work pieces.
7) The non-contact EDM drilling process is suited for drilling deep straight holes in work pieces, as opposed to conventional methods in which the drill bits tend to drift during deep hole drilling.
8) EDM micro drilling operations can be precisely controlled to drill accurate holes with diameters ranging from 5 µm to 300 µm.

7-FEATURES OF MICRO- EDM

1. Forming electrode adapted to product shape is not required.
2. Any electrically conductive material can be machined irrespective of its hardness & strength.
3. EDM machine can be operated unattended for long time at high operating rate.
4. Electrode wear is negligible.
5. Machined surfaces are smooth.
6. Geometrical & dimensional tolerances are tight.
7. Relative tolerance between punch & die is extremely high & die life is extended.
8. Straight holes can be produced to close tolerances.
9. Machining is done without requiring any skills.
10. EDM allows the shaping of complex structures with high machining accuracy in the order of several µ-meters and achievable surface roughness Rz=0.µm.
11. It proves to be a competitive method for ceramic processing because of the abilities to provide accurate, cost- effective and flexible products.

8. LITERATURE REVIEW BASED ON PERFORMANCE MEASURES IN MICRO-EDM

The observation of various machine-setting parameters such as MRR, TWR, SR, circularity error, overcut, micro-cracks and HAZ in micro-EDM process is reviewed in this section.

Sundaram et al. (2007) investigated ultrasonic assisted micro-electro discharge machining. They found that introducing ultrasonic vibration of workpiece is significant for higher MRR. **Jahan et al. (2010),** investigated the feasibility of machining deep micro-hole in two difficult-to-cut materials, cemented carbide (WC-Co) and austenitic stainless steel (SUS 304), using micro-EDM drilling. The results showed that WC-Co exhibits better MRR than SUS 304. They observed that higher hardness and melting point of WC-Co is a good condition for EDM, in preference to SUS 304. **Put et al. (2001)** investigated MRR by altering electrode polarity on a zirconia-based composite and concluded that negative polarity gives the most stable machining conditions with a noticeably lower risk of arcing. Carbide and nitride give higher MRR with positive polarity, whereas boride gives faster machining with negative polarity. However, to minimize the chance of thermal shock and consequence cracking mostly negative polarity is preferred. **Beri et al. (2008)** investigated the influences of electrodes made through powder metallurgy in comparison with conventional copper electrode during electric discharge machining. It was found that Cu electrode shows higher material removal rate than Cu-W which is made by powder metallurgy. **Sanchez et al. (2001)** studied the performance of various electrodes on ceramic material. It was found that maximum MRR can be achieved using copper (Cu) as electrode and worst results were found with graphite electrode (Gr). **Wang et al. (2011)** investigated the influence of adhesion composed of heat-resolved carbon and graphite during the machining of poly crystalline diamond by micro-EDM. The results revealed that an appropriate volume of adhesion on the tool electrode increases MRR and reduces TWR by protecting the electrode. **Lim et al. (2003)** investigated the machining performance of high-aspect ratio micro-structures using micro-EDM and it is observed that more material is removed as capacitance value increases. **Gupta et al. (2010)** studied the performance analysis of micro-EDM process using paralytics carbon. ANOVA was performed to identify the effect of process parameters on the process responses. The results revealed that MRR increases with the increase of gap voltage and a smoother surface is obtained at 110V gap voltage and low capacitance. **Zahiruddin et al. (2012)** studied the comparison of energy and removal efficiencies between micro and macro-EDM. The main difference identified is the ratio of energy consumed for material removal with regard to energy distributed into the work-piece and the ratio of total removal volume per pulse with respect to the molten area volume. It was also found that the power density in micro-EDM is approximately 30 times greater and consequently energy efficiency and removal efficiency were significantly greater than macro-EDM. **Yu et al. (2004)** proposed a recently developed uniform wear method integrated with CAD/CAM software to generate 3D micro cavities. They found that the uniform wear method compensates the tool wear and helps in regaining the tool shape during machining. The compensation for wear maintains the desired inter electrode gap.**Yoshida and Kunieda (1999)** studied the mechanism for minute tool electrode wear in dry EDM. The tool electrode wear is almost negligible for any pulse duration because the attached molten workpiece material protects the tool electrode surface against wear. However, this is subjected to polarity adapted in micro-EDM. Also, attachment/transfer of molten work-piece material to the electrode changes its status by way of release of electrode and related gap condition. **Uhlmann and Roehner (2008)** investigated on the reduction of tool electrode wear in micro-EDM using novel electrode materials. The investigation results revealed that to minimize the wear of tool electrode, novel materials such as electrically conductive boron doped CVD diamond (B-CVD) and polycrystalline diamond (PCD) can be used. However, one has to look for the stability of the diamond wits spark erosion environment**. Yu et al. (2003)** developed a simulation model for uniform wear method. The proposed method was based on one-dimensional wear model and predicted the longitudinal tool wear length**. Bigot et al. (2005)** investigated the suitability of electrode wear compensation methods, during the micro-EDM process. Electrode shape deformation and random variation of the volumetric wear were studied as the main factors and as an indicator for the achievable accuracy with the micro-EDM process. The measured wear ratio does not appear to be constant, which does not allow for the use of compensation method. Usage of suitable sensor for gap measurement, with necessary adaptive control technique can ensure sustained machining. **Wang et al. (2009)** experimentally investigated a wear-resistant electrode for micro-EDM. The results proved that Cu-ZrB2 composite (copper-zirconium di boride) coated electrodes have better wear resistance than pure copper electrodes. They also found that it is feasible to use the wear compensation method on the basis of the difference between the wear ratio of matrix and that of coating material to maintain electrode shape precision. **Aligiri et al. (2010)** developed a new micro-EDM drilling method, in which the material removal volume is estimated as machining progresses. A real-time, material removal volume estimator is developed based on the theoretical electro-thermal model, number of discharge pulse and pulse discrimination system. The result showed that the proposed method is more reliable as compared to the uniform wear method. In drilling micro-holes of 900m depth error can be reduced to 4% using the proposed method. **Tsai and Masuzawa (2004)** evaluated the wear resistance of the electrode in micro-EDM. They found that the volumetric wear ratio of the electrode becomes small for the electrode material with high boiling point, high melting point, and high thermal conductivity. The result also showed W and Cu are good candidates for electrode. **Yan and Lin (2011)** presented a novel multi-cut process planning method and a new electrode wear compensation method based on a machine vision system for three-dimensional (3D) micro-EDM. Experimental results indicated that the proposed multi-cut process planning and electrode wear compensation methods can improve machining time. **Uhlmann et al. (2010)** investigated the influence of grain size of the boron-doped CVD diamond coating on the wear behavior in micro-sinking EDM. Experimental investigations showed that nanocrystalline coatings exhibit smaller discharge craters compared to those for microcrystalline diamond coatings. The microcrystalline coating also shows melted material around the discharge crater. However, it is subjected to further investigations. In sum, the literature on TWR in micro-EDM emphasizes the need for wear compensation and associated adaptive control strategy.

Zhang et al. (2005) studied the roughness of the finished surface of AISI 1045 steel using copper as the electrode. The result revealed that surface roughness increases with an increase in the discharge voltage, discharge current and pulse duration. **Ogun et al. (2004)** investigated the various machining parameters, which influence the surface profile of 2080 tool steel. It is found that surface roughness increases with increase in discharge current, pulse duration and dielectric flushing pressure. While studying the molecular dynamics simulation of the material removal mechanism in micro-EDM. **Yang et al. (2011)** observed that the existence of micro pores in the workpiece material increases the depth of the discharge crater and melted area, which results in the increase of machining surface roughness. In micro-EDM, the machined surface is covered with many craters, micro-cracks and heat affected zones (HAZ) that are generated by sparks. The machined surface is covered by a multitude of overlapping craters whose geometry depends on the process parameters used, the physical properties of the electrodes, and the type of dielectric medium. **Nakaoku et al. (2007)** experimented with the micro-EDM of sintered diamond (SD) and found that the surface roughness of SDs is sufficiently good for only minimum amount of retained austenite phase and the intensity of micro cracks are identified in the white layer of the plastic mould steel than with kerosene as dielectric. It is possible that pickup of carbon can induce brittleness /cracking, sulphur in kerosene can also cause damage in HAZ. **Kahng and Rajurkar (1977)** analyzed the texture of eroded surface and reported that the application of higher discharge energy results in deeper HAZ and subsequently deeper cracks. **Thao and Joshi (2008)** identified the area of HAZ around the micro-electrical discharge machined holes and thereby reduced the micro-hardness of the bulk material around the hole. However, presence of HAZ needs not bring down hardness, unless there is any depletion of chemistry. **Liu et al. (2005)** studied the micro-EDMed high nickel alloy micro-holes and reported that the overcut is identified around the micro-holes. It may be due to side erosion / inadequate electrode stiffness. It is seen that during micro-EDM process, there is a possibility to attain varying size / geometry of holes varying HAZ characteristics and varied response to MRR and texture depending on the types of electrode used and associated machining conditions. **Paul et al. (2012)** also observed that smaller overcut dimensions of crater could be identified with low energy discharge with a decrease in MRR, during the micro-EDM process of -titanium aluminide alloy using steel rod as electrode.

9. CONCLUSIONS

Micro-EDM processes enable us to improve process capabilities in terms of the surface roughness, material removal rate, reduce tool wear rate and geometrical accuracy. To fabricate complex micro-parts on hard-to-machine and multi-materials, a micro-EDN process can be extremely beneficial to obtain higher machining efficiency. However, relying on a proper comprehension of the process-material interaction, process parameters should be opted in an appropriate approach. Otherwise, undesirable consequences such as deteriorated surface finish, micro-cracks, etc. can be obtained. The authors believe micro-machining processes have great potential for fabricating 3D complex micro-components with high accuracy and surface quality.

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