

Review on Micro Electrical Discharge Machining

A. P. Tiwary¹, Abhishek Sinha², B. B. Pradhan³ & B. Bhattacharyya⁴

^{1,2&3}Department of Mechanical Engineering, Sikkim Manipal Institute of Technology, Sikkim-737136

⁴Department of Production Engineering, Jadavpur University, Kolkata-32

E-mail : aptiwary@gmail.com¹, abhishekbaban@gmail.com², bbpradhan@rediffmail.com³, bb13@rediffmail.com⁴

Abstract - Recent trend in reducing the size of products has given Micro Electrical Discharge Machining (MEDM) a significant amount of research attention. Due to the high precision, low tolerance and good surface quality that it can deliver, MEDM is potentially an important process for fabrication of micro-tools, micro-components and parts with micro-features. This paper briefs and highlights the various advancements in MEDM process, useful for the purpose of further research and development and can be used as a reference to the various developments that have taken place in this field over the years.

Keyword - Micro electrical discharge machining, EDM, MEDM Process parameters and New strategies.

I. INTRODUCTION

Micro Electrical Discharge Machining (MEDM) process is suitably used for machining intricate shaped structures with values of tolerances in micrometers. The working principle of MEDM is similar to that of the Electrical Discharge Machining (EDM). So, to understand MEDM it is important to understand the EDM process.

A. EDM

EDM is one of the earliest forms of non-traditional machining processes and is an all-around accepted machining option for manufacturing geometrically intricate or hard material parts that are extremely difficult-to-machine by conventional machining processes. EDM process is based on thermoelectric energy between the work piece and an electrode. In order to generate the spark, the electrode and the work piece must be electrically conductive. A temperature range within 8000°C to 12000°C [1] is achieved by the plasma generated between the electrodes which provides with the necessary thermal energy. When the pulsating direct current supply occurring at the rate of approximately 20,000–30,000 Hz. [2] is turned off, the plasma channel breaks down which causes a sudden

reduction in the temperature allowing the circulating dielectric fluid to break the plasma channel and flush away the molten microscopic debris. Thus, the unwanted material from the parent metal is removed through melting and vaporizing by a pulse discharge which occurs in a small gap between the work piece and the electrode, maintained by a servomechanism preventing contact between the electrode and the workpiece.

There are various types of products which can be produced using EDM with high precision and good surface quality, such as dies and moulds, parts for aerospace and automotive industry and surgical components [3].

B. MEDM

The term micro-machining defines the processes that manufacture products in the range of 1 to 999 micrometers [4]. The MEDM process is essentially similar to that of the conventional EDM process with the main difference being in the size of the tool used, the power supply of current and voltage supply and the resolution of the X, Y and Z axes movement. The system has a servo system with highest sensitivity and positional accuracy of 0.5 micrometers [5]. It permits setting of a minimized discharge gap width of 1micrometer [6]. Therefore, the system is helpful for conventional precision engineering purposes as well as for micro-components fabrication like micro-molds, micro inserts, and in general micro structures. It is especially used for drilling micro holes with high accuracy and aspect ratio in materials. In recent years, numerous developments in MEDM have focused on the production of micro features. This has become possible due to the availability of the new Computer Numerical Control (CNC) systems and advanced spark generators that have helped to improve machined surface quality. Current MEDM technology used for manufacturing

micro features can be categorized into four different types:

- (i) Micro wire EDM, where a wire of diameter down to 0.02 mm is used to cut through a conductive workpiece.
- (ii) Die-sinking MEDM, where an electrode with micro features is employed to produce its mirror image on the workpiece.
- (iii) MEDM drilling, where micro electrodes of diameters down to 5–10 micrometers are used to drill micro holes in the workpiece.
- (iv) MEDM milling, where micro-electrodes of diameters down to 5–10 micrometers are employed to produce 3D cavities by adopting a movement strategy similar to that in conventional milling [7].

II. PROCESS PARAMETERS AND THEIR IMPACTS

A. Effect of Voltage on MRR

In experiments conducted by T. Jesudas and RM Arunachalam [8], it was established that the voltage is an important parameter. To study the effect of voltage, the spark gap and capacitance were kept constant. It was observed that, with increase in voltage, the Material Removal Rate (MRR) increases. This is because, the energy discharge from the electrode increases with increase in voltage. Due to increase in discharge energy, higher temperatures are generated between the electrodes resulting in higher MRR.

B. Effect of capacitance on MRR

Continuing referring to the mentioned research paper [8], we learn that the capacitance is a more influencing parameter in MEDM especially when using remote controlled circuit. To study the effect in capacitance, other two parameters such as voltage and spark gap were kept constant. It is observed that, with increase of capacitance the MRR also increases. This is caused as the energy discharged from the capacitor increases. Hence, higher energy results in higher MRR.

C. Effect of Spark Gap on MRR

The spark gap also known as discharge gap is the gap between the tool and workpiece, which must be maintained constant throughout the machining process. As mentioned above, to find the influence of the spark gap on MRR, capacitance and voltage were kept constant. With the increase in spark gap, the MRR decreases. This is because, when the distance between electrodes increases, the discharge energy (thermal)

concentration towards the workpiece is less, resulting in lower MRR [8].

D. Peak Current

Peak current is known as the amount of power used in discharge machining which is measured in amperage and an important parameter in MEDM machining. In roughing operations or cavities in large surface areas higher amperage is used. Using higher currents will definitely improve MRR but it will give an impact on the surface finish and tool wear. Despite the machined cavity is a replica of tool electrode, excessive wear will hamper the accuracy of machining [9].

E. Pulse Duration and Pulse Interval

It is expressed in units of micro-seconds, the cycle has an on-time and off-time. On the on-time all the work is produced and the duration of these pulses and the number of cycles per second is important. Material removal is directly proportional to the amount of energy applied during the on-time (Singh et. al., 2005). The energy applied during the on-time controls the peak amperage and the length of the on-time. Pulse duration and pulse off-time is called pulse interval. If the pulse duration is longer, then more work piece material will be melted away. It will have a broader and deeper hole than using shorter pulse duration. Whereas, if the optimum pulse duration for each electrode and work material combination is exceeded, the material removal rate will start to decrease. The pulse interval also affects the speed and the stability of the cut. In theory, the shorter the interval the faster the machining operation will be. At the same time, pulse interval must be greater than the de-ionization time to prevent continued sparking at one point (Fuller, 1996). In ideal conditions, each pulse creates a spark. However, it has been observed practically that many pulses fail if duration and interval are not properly set, causing loss of the machining accuracy and those pulses are called open pulses (Sanjeev Kumar, Rupinder Singh) [9].

F. Pulse Waveform

The normal pulse waveform that we always observe are rectangles, but now new shapes have been developed, such as- pulse wave is a non-sinusoidal waveform that is similar to square wave, by using trapezoidal wave generators the relative tool wear can be reduced to a very low value. Other types of generators introduce an initial pulse of high voltage but low current and a few microseconds duration, before the main pulse, which facilitates ignition (Sanjeev Kumar, Rupinder Singh) [9].

G. Polarity

Polarity can either be positive or negative. New practices of reversing the polarities are being carried out to prevent arcing between the electrodes.

H. Dielectric flushing

The dielectric fluid used, have characteristics of high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability, good degree of fluidity and easy availability. Tool Wear Rate (TWR) and MRR are affected by the type of dielectric and the method of its flushing [10]. The different types of flushing are injection flushing, suction flushing, side flushing and flushing by dielectric pumping [11]. In flushing, most dielectric fluids are hydrocarbon compounds or water. The dielectric fluid is flushed through the spark gap to remove gaseous and solid debris during machining and to maintain the dielectric temperature by acting as coolant also.

I. Rotating the work piece

In addition to the flushing of the dielectric, the techniques of applying rotational motion to the sparking process also affect the machining performance. Guu and Hocheng [12] provided a workpiece rotary motion to improve the circulation of the dielectric fluid in the spark gap and temperature distribution of the workpiece yielding improved MRR and Surface Roughness (SR). On the other hand, Kunieda and Masuzawa [13] proposed a horizontal EDM (HEDM) process in which the main machining axis is horizontal instead of the conventional vertical axis. The change in the basic construction in addition to the rotary motion of the workpiece offered an accessible evacuation of debris improving the erosion efficiency and accuracy of the sparking process. HEDM has also been experimented in the micro-machining of small parts [14], [15].

J. Rotating the electrode

The performance measures of the MEDM process improves by the introduction of the rotary motion to the electrode. It serves as an effective gap flushing technique, which significantly improves the MRR and SR [16], [17]. An alloying effect of migrating material elements from the work piece and tool is also observed, in relation to the morphology, chemical composition and size distribution of debris, when using rotating electrodes [18]. The rotary motion of electrode yields comparable effects as the vibratory motion of the electrode improving the MRR, enhancing the surface quality of work piece and increasing the stability of machining process.

III. NEW STRATEGIES IN USE

Utilizing the various MEDM process parameters and their impacts to yield satisfactory results new strategies have been developed in the recent past which are being used during the micro-machining process.

A. Use of abrasives in the dielectric

Fine abrasive powder is mixed into the dielectric fluid. The hybrid material removal process is called powder mixed EDM (PMEDM) where it works steadily at low pulse energy [19] and it significantly affects the performance of the process. Electrically conductive powder reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and the work piece. It makes the process more stable and improves machining efficiency, MRR and Surface Quality (SQ).

The general trend observed in the various papers on the use of abrasives can be represented graphically as in Fig.1.

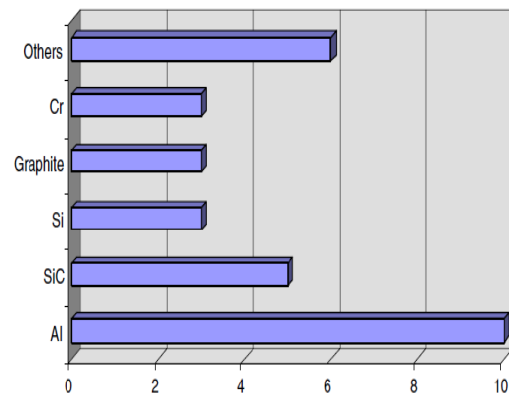


Fig.1 : Number of Papers vs Abrasives Used [20].

(i) SiC Powder in water as dielectric:

Micro machining finds extensive application in fields of micro electrical mechanical systems (MEMS). The demand for highly precise products such as micro-pumps, micro-engines, and micro-bots is huge. For the machining in these cases, MEDM is used extensively. Chow et al. [21] have developed a micro-slit machining using electro-discharge machining with a revised rotary disk electrode. They observed that most die-sinking EDM processes use kerosene as the EDM dielectric fluid. However, kerosene's relevant properties degrade during long-term machining. It also decomposes at higher temperatures and causes carbon depositions on the electrode surface. Pure water has high thermal conductivity, low viscosity coefficient, and a high flow rate. Also, pure water temperature is not affected by long working time, hence higher MRR is sustained. Pure

water added to SiC powder has good post-process treatment without environmental pollution.

(ii) *Powder added dielectrics:*

With various powdered material, MRR is influenced. With copper, aluminum, iron and graphite powder, it has been reported that the machining rate generally is proportional to the concentration of the powder, although the machining becomes unstable at higher concentrations. Another study using graphite powder presents an increase of as much as 60 % in MRR and reduced tool wear of 15% [22]. A study by F. Klocke et al. [23] suggests that Al powder leads the highest MRR. The plasma channel expands in contrast to the standard dielectric, so the discharge energy is distributed on a bigger workpiece surface.

(iii) *Use of additives to kerosene as dielectric*

The addition of both SiC and aluminum powder to the kerosene permits an extension of the gap between the electrode and the workpiece. The extended gap increases the debris removal rate and the material removal depth. Furthermore, a bridging effect is created by the added powder drifting within the kerosene and, in doing so, facilitates the dispersion of the discharge into several increments. Thus, several discharging trajectories are formed within a single input impulse and several discharging spots are created within a discharging impulse also [24]. The experiments done by Biing-Hwa Yan, et al. concluded that kerosene with either Al or SiC powder added in EDM can extend the gap between the electrode and the workpiece. The added powder disperses the discharging energy to obtain superior surface roughness. In case of SiC powder, the carbon might adhere to the workpiece and hence pose a problem, even though higher depth and MRR is achieved using SiC powder than Al. But on the overall, Al powder with kerosene appears to be the best amongst the three different dielectric fluids, namely plain kerosene, kerosene and Al powder and kerosene and SiC powder [24].

B. *Use of Urea Solution in Water as dielectric*

Referring to the research paper by Biing Hwa Yan, Hsien Chung Tsai & Fuang Yuan Huang [25], it has been observed that while machining of Ti alloys, use of kerosene as dielectric leads to the formation of TiC layer and the use of pure water leads to the formation of TiO layer upon the surface. Machining in Urea solution causes nitrogen to be transferred onto the Ti surface. Using urea solution in water as dielectric has marginal differences in MRR and Electrode Wear Rate (EWR). The difference that has been observed is in the surface quality, with the urea solution being better than only

water dielectric. The urea solution depicts an increase in MRR with increasing peak current and a steady decrease in MRR with increase in the pulse durations. Also EWR decreases with increase in pulse duration and surface roughness increases with increase in the peak current [26].

C. *Use of Deionized Water as dielectric*

Detailed research has led to the establishment of the fact that pure dielectrics and additive-mixed dielectrics have different effects on the MEDM performance measures such as MRR, TWR, overcut, etc. Based on research conducted by G. Kibria, B.R Sarkar, B.B. Pradhan & B. Bhattacharya [27], it has been observed that material removal rate is high in deionized water dielectric as compared to pure kerosene. Mixing of B₄C to deionized water improves the MRR manifolds. DI Water doesn't decompose at the temperatures at which kerosene decomposes. TWR is more in case of DI water mixed with B₄C, than pure kerosene. Moreover, pure deionized water results in excellent machining efficiency as compared to kerosene as well as B₄C mixed dielectrics. Also the addition of B₄C abrasive in dielectrics results in increased machining time in comparison to pure dielectrics.

D. *Use of Kerosene as dielectric*

Kerosene is one of the most commonly used dielectric fluids. The main objective of a dielectric fluid is to form the plasma carrying medium, and so that the electro-discharge takes place locally and does not spread, carry away the heat from the workpiece and flush away the debris from the cavity. Kerosene is readily and easily available at very cheap rates. However, it is inflammable and poses fire hazards. Also, at higher temperatures, it tends to disintegrate and carbon deposits form and adhere to the electrode. Referring to the work by S.L. Chen et al. [28], it has been observed that distilled water is favored over kerosene keeping MRR and relative electrode wear rate in consideration since, carbides are also formed on the workpiece in kerosene. Crack propagation does not occur in case of kerosene and it also has smaller debris size when compared to distilled water.

E. *MEDM in Water*

Water is used as dielectric due to the health concerns and the easy availability as compared to the hydrocarbon oils. Water does not have any harmful gaseous release such as CO or CH₄. The use of water can be subdivided into:

(i) *Pure Water:*

In a study conducted by researchers, machining in distilled water resulted in a higher MRR and a lower

wear ratio than in kerosene when a high pulse energy range was used. With distilled water, the machining accuracy was poor but the surface finish was better [29]. Best machining rates have been achieved when using tap water as dielectric with copper electrodes in negative polarities.

(ii) Water with additives

Koenig and Joerres [30] reported that a highly concentrated aqueous glycerin solution has an advantage as compared to hydrocarbon dielectrics when working with long pulse durations and high pulse duty factors and discharge currents, i.e. in the roughing range with high open-circuit voltages and positive polarity tool electrode.

F. Powder Mixed EDM (PMEDM)

Powder mixed electric discharge machining (PMEDM) is one of the recent innovations for the enhancement of capabilities of EDM and MEDM process. In PMEDM, electrically conductive powder such as Al, Cu, Cr powder etc. are mixed in the dielectric of EDM, which reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and workpiece [31]. As a result, the process becomes more stable, thereby, improving the material removal rate (MRR) and surface finish. Moreover, the surface develops high resistance to corrosion and abrasion [32].

G. Rotary electrical discharge machining in magnetic polarity reversal

Rotary electrical discharge machining is a new technique of machining where the work table can be rotated at the desired angles and at the desired speed. Research done by K. D. Chattopadhyay, P. S. Satsangi, S. Verma & P. C. Sharma [33] has established that rotary electrical discharge machining with a polarity reversal magnetic field delivers better machining output than machining in a non-magnetic field. It benefits the MEDM process by reducing the machining costs and by producing better geometrical trueness on work pieces, as MRR is increased and EWR is decreased better geometrical accuracy and closer dimensional tolerances are attained. Generation of non-homogeneous magnetic lines at the workpiece aids in transporting of the debris out of the spark zone and reduces sparking chances and spark zone contamination.

H. Workpiece Vibration

A new method for micro ultrasonic machining has been developed by Egashira and Masuzawa [34]. The work piece was vibrated during machining and they have succeeded in machining micro-holes as small as 5 micrometers in diameter in quartz glass and silicon. Gao

and Liu [35] found that the efficiency of the ultrasonic MEDM is eight times greater than MEDM when the workpiece as stainless steel and tungsten as the electrode. The studies of Gunawan Setia Prihandana, M. Hamdi, Y.S. Wong & Kimiyuki Mitsui [36] have shown that when the vibration was introduced on the workpiece the flushing effect increased. High amplitude combined with high frequency increased the MRR, which can be attributed to the fact that there is more number of sparks taking place while the vibration of the workpiece is done. Larger feed and better surface finish can also be obtained through this method [37].

I. Use of Pulse Generators

An RC pulse generator can easily generate a pulse on-time as short as a several dozen nanoseconds, but its discharge frequency is low due to the time needed to charge the capacitor, which strongly effects the pulse generator's working efficiency negatively. For benchmarking and comparison a transistor-type pulse train generator and a transistor-type iso-pulse generator for MEDM were developed and it was found that transistor-type pulse train generator is unsuitable for MEDM, due to its low machining speed. Whereas, transistor-type iso-pulse generator can provide two to three times higher machining speed than that of the conventional RC pulse generator, as established in a research by Fuzhu Han, Li Chen, Dingwen Yu & Xiaoguang Zhou [38].

J. Ultrasonic vibration

Ultrasonic machining, as stated by L. Kops [39], is defined as an impact-abrasive method of material removal, in which the machining process is carried out by means of the abrasive powder being driven by the striking tool-bit oscillating at ultrasonic frequencies, it follows that the most essential machining factor, acting as the actual tool in this process, are the abrasive grains. Phenomenon such as cavitation caused by ultrasonic vibration, directly removes the material. Extremely high stresses associated with the formation and collapse of cavitation bubbles cause material removal by fracture [40]. This process can be used to remove material from both brittle and ductile materials. Simultaneously, material is also removed by melting and evaporation due to electric discharges caused by MEDM. The higher efficiency gained by the employment of ultrasonic vibration is mainly attributed to the improvement in dielectric circulation which facilitates the debris removal and the creation of a large pressure change between the electrode and the work piece, as an enhancement of molten metal ejection from the surface of the work piece [41].

The following inferences could also be made through the research published by H Huang, H Zhang, L Zhou and H Y Zheng [42]:

- (i) A greater UV amplitude results in a higher efficiency and a smaller electrode wear.
- (ii) A higher applied voltage leads to a higher efficiency, as well as a larger electrode wear.
- (iii) The larger pre-set sparking gap helps the flushing in the gap, and thus results in a higher machining efficiency. However, the electrode wear is also larger.
- (iv) A larger electrode has a higher machining efficiency, but has little effect on the tool wear.

K. Ultrasonic Vibration in gas

Q.H. Zhang, R. Du, J.H. Zhang & Q. Zhang [43] studied the ultrasonic EDM in gas. The gas is applied through the internal hole of a thin walled pipe electrode. The result showed that the MRR increased with respect to the increase of open voltage, pulse duration, amplitude of ultrasonic actuation, discharge current and the decrease of the wall thickness of electrode pipe while the surface roughness increased with respect to the increase of open voltage, pulse duration and the discharge current.

L. Reverse Simulation of Die-Sinking EDM

A research by Masanori Kunieda, Wataru Kowaguchi & Takashi Takita [44] aimed to develop a simulation method for die-sinking EDM to solve the inverse problem of obtaining the appropriate tool electrode shape for achieving the desired final workpiece shape. In this the workpiece is fed towards the tool electrode in the direction opposite to forward simulation.

M. Dry machining

In dry MEDM, tool electrode is formed of a thin walled pipe. High pressure gas or air is supplied through the pipe. The role of the gas is to remove the flow of debris from the gap and to cool the inter electrode gap. The technique was developed to decrease the pollution caused by the use of liquid dielectric which leads to production of vapour during machining and the cost to manage the waste [43].

N. Power Supply

(i) RC Type

RC-generator can produce micro-holes with good surface quality with rim free of burr-like recast layer, lower spark gap, good circularity and dimensional accuracy. The performance can be controlled more

easily by controlling the discharge energy as it is resolved by voltage and capacitance only. Energy can be reduced easily in RC-type using very low capacitance [45].

(ii) MOSFET Type

One of the most important parts of the EDM is the MOSFET (Metal Oxide Semiconductor Field Effect Transistor). It completes the circuit of the EDM when it is in the ON state. This transistor is given a clock pulse input in the range of a few kHz so that it acts as a continuous toggle switch to the EDM circuit. A MOSFET transistor is used since it turns ON very quickly [46].

IV. CONCLUSION

Considering a range of different approaches, this paper shares the objectives of study on achieving more efficient material removal rate coupled with a reduction in tool wear rate along with an improved surface quality. It may be noted that at various places EDM processes are referred to draw conclusion for MEDM processes, this is because they share a common working principle and also a similar domain of process parameters, as discussed in the beginning. At present, MEDM processes demand strong research and development and prompt machine tool manufacturers to improve the machining characteristics. This paper can be used as a reference to the various developments that have taken place in the micro electrical discharge machining process over the years and prove to be useful for the purpose of further research and development. So that MEDM processes continue to remain competitive as a micro-manufacturing technology.

V. REFERENCES

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