A Review on Current Research Trends in Micro-EDM

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***Abstract*: Rapid advancement in manufacturing industries has given rise to miniature and lightweight products with increasing high engineering applications. Micro-EDM is mostly used machining processes without chip to fabricate desired product to be produced. In recent years, many types of research have been directed to enhance the performance of micro-EDM. A review on the research activities carried out in the micro-EDM process, is provided by this paper. The effects of dielectric fluids, pulse characteristics and ultrasonic vibration, which play a vital role in the machining performance of micro-EDM, are highlighted in this paper. Also, attempts made by various researchers to fabricate a high aspect ratio microstructure using micro-EDM are discussed. Hence, a consolidated review of this research work will enable a better understanding of the various contributions to effective implementation/application. The focuses of the review also on the optimisation of various parameters using different methods viz., Taguchi, ANN, grey relational analysis and fuzzy logic control system.**

***Keywords:* micro-EDM; dielectric; pulse-duration; ultrasonic vibration; MRR; tool wear Taguchi method; fuzzy logic control system.**

I. INTRODUCTION

Electrical discharge machining (EDM) is one of the most wildly used non-conventional material removal processes. EDM process removes metal by discharging electric current from a pulsating DC power supply across a thin interelectrode gap between the tool and the workpiece. A dielectric fluid filled the gap between electrode and workpiece becomes locally ionized at the point where the inter-electrode gap is the narrowest. This will facilitate favoring an avalanche of an electron in the electrode gap resulting in high movement of collision and causing vaporization. When more electrons are collected in the gap, the resistance drops and generates a high-energy spark. The sudden energy produced causes vapourizations of the workpiece. Of late for precision machining of parts, it is essential to maintain the least order of mechanical/thermal distortion. This call for resisting the spark intensity (in terms of current density, frequency, and related feature) leading to micro-EDM.

Micro-EDM is similar to the principle of macro-EDM, where the processing mechanism is based on an electro-thermal process that relies on a discharge through a dielectric in order to supply heat to the surface of the workpiece. The plasma channel radius or diameter significantly differentiate between micro and macro-EDM. The plasma size in macro-EDM is larger by several orders of magnitude than the plasma channel radius. Constant current and gap voltage throughout the discharge in macro-EDM, however, in micro-EDM the current and gap voltage varies. Pulse generators such as RC type single pulse discharge are used in micro-EDM and RC relaxation type is used in macro-EDM

The advantages of micro-EDM are that the workpiece is not subjected to mechanical deformation, as there is no physical contact between the tool and workpiece, thus eliminating chatter and problems by vibration and allowing very small or thin components to be machined without mechanical force. It has the ability to manufacture intricate shapes with high accuracy and machine any conductive material regardless of hardness. It has become one of the most important methods for manufacturing micro parts with high accuracy and large design freedom at low set-up cost. The current micro-EDM technology used for manufacturing micro-features can be categorized into four different types:

1. Micro-wire EDM, where a wire diameter down to 0.02mm is used to cut through a conductive workpiece.
2. Die-sinking micro-EDM, where an electrode with micro-features is employed to produce its mirror images in the workpiece.
3. Micro-EDM drilling, where micro-electrodes (of diameters down to 5–10m) are used to ‘drill’ micro-holes in the workpiece.
4. Micro-EDM milling, where micro-electrodes (of diameters down to 5–10 m) is employed to produce 3D cavities by adopting a movement strategy similar to that in conventional milling.

Despite the number of experiments results extolling the improved capabilities of these processes, they are still not widely used. The available machine tools and process characteristics are still not sufficiently reliable due to the fact they are not in used widely. The main problems restricting or limitations in application of micro-EDM and presents some specific solutions describe by this papers.

Figure 1 shows the schematic diagram of laboratory developed a micro-EDM system used by Kim et al. (2006). The machining system consists mainly of a micro-feed mechanism by servo control, an X-Y work stage, a work tank and ultrasonic vibrator. To minimise the influence of vibration on the workpiece and feeding stages, the work tank had polymer supports. A work tank with the workpiece is placed on X-Y stage for desired feed travels and the main shaft (mandrel type) was installed on the V-groove of the Z-stage. Kerosene was used as the dielectric fluid and RC circuit was used as the electric source.

In EDM, the efficiency of the machining in the system depends on conditions prevailing over the inter-electrode gap such as gap voltage, beam current, spark frequency and related features. These are controlled by the condition of dielectric and the nature of inter-electrode space (presence/absence of debris). In this context, the review on the literature on micro-EDM widens the knowledge with regards to processing characteristics, the significance of process parameters on performance, application of novelties such as superimposition of ultrasonic vibration, type of dielectric including water-based ones and also new electrode materials such as coated and doped ones. However, certain uncertainties crop up due to possible corrosion, embrittlement due to the usage of water; also the significance of frequency and amplitude of vibration for desired performance and effectiveness of magnetic field in the electrode gap are not explicit.

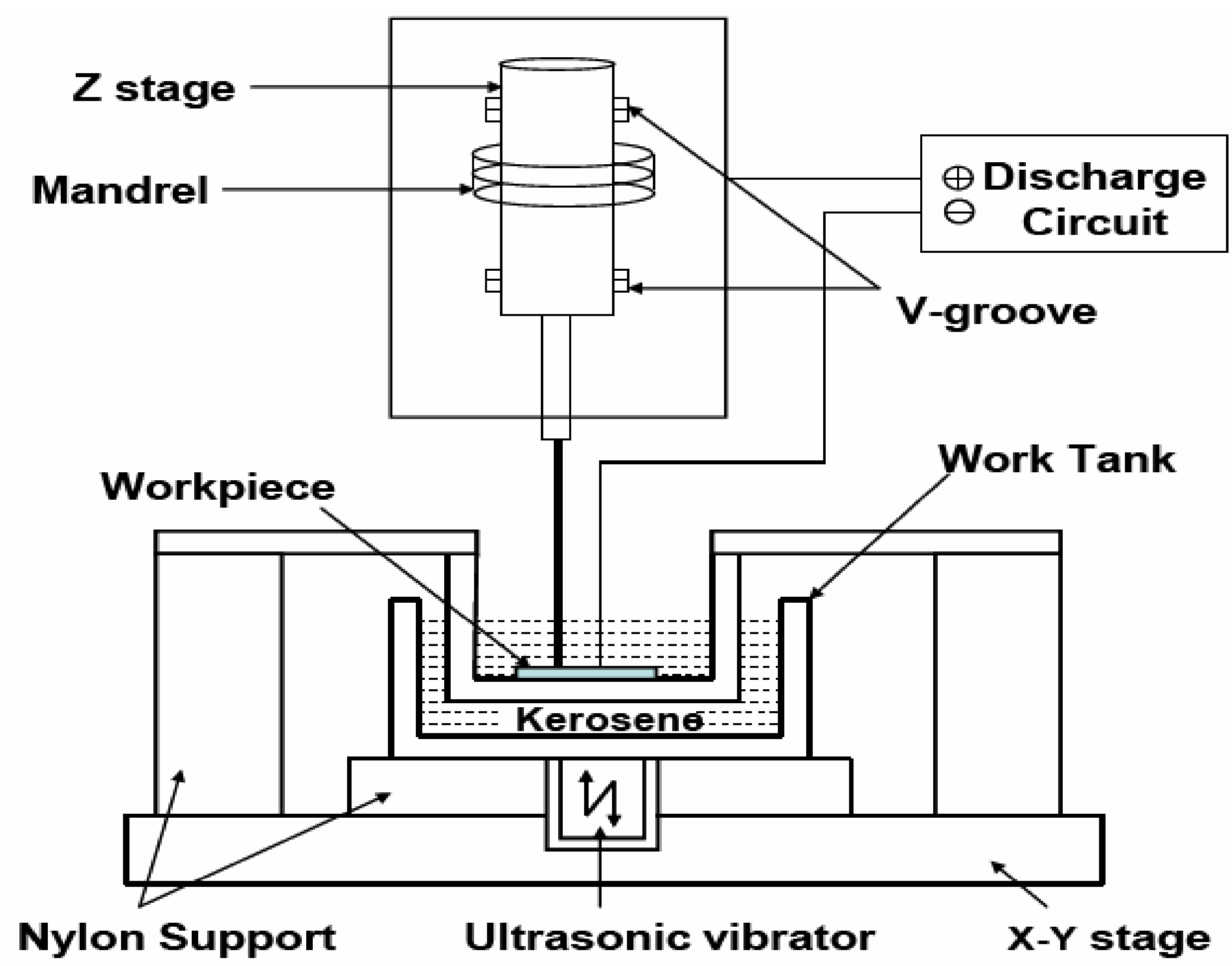

Figure 1 A schematic diagram of hybrid micromachining system [1]

Accordingly, the review presented in the paper focuses on the influence of dielectric fluids, pulse characteristics and induced ultrasonic vibration of the electrode on machining performance in terms of material removal rate (MRR), tool wear and surface integrity. The illustration also includes fabrication of high aspect ratio, monitoring, and control system and various output parameters like MRR, tool wear, and surface roughness. It also focuses on various optimisation techniques such as Taguchi method, grey relational analysis, artificial neural network (ANN) and fuzzy logic control (FLC) on performance. Applications and future trends of micro-EDM are also highlighted. Details are presented in the following section

1.1 Different Issues in Micro-Edm

Figure 2 shows the fish-bone diagram of the selected parameters that influence the machining performance of micro-EDM. In this study, various researches related to these parameters to achieve high MRR, low TWR and good surface finish is highlighted.

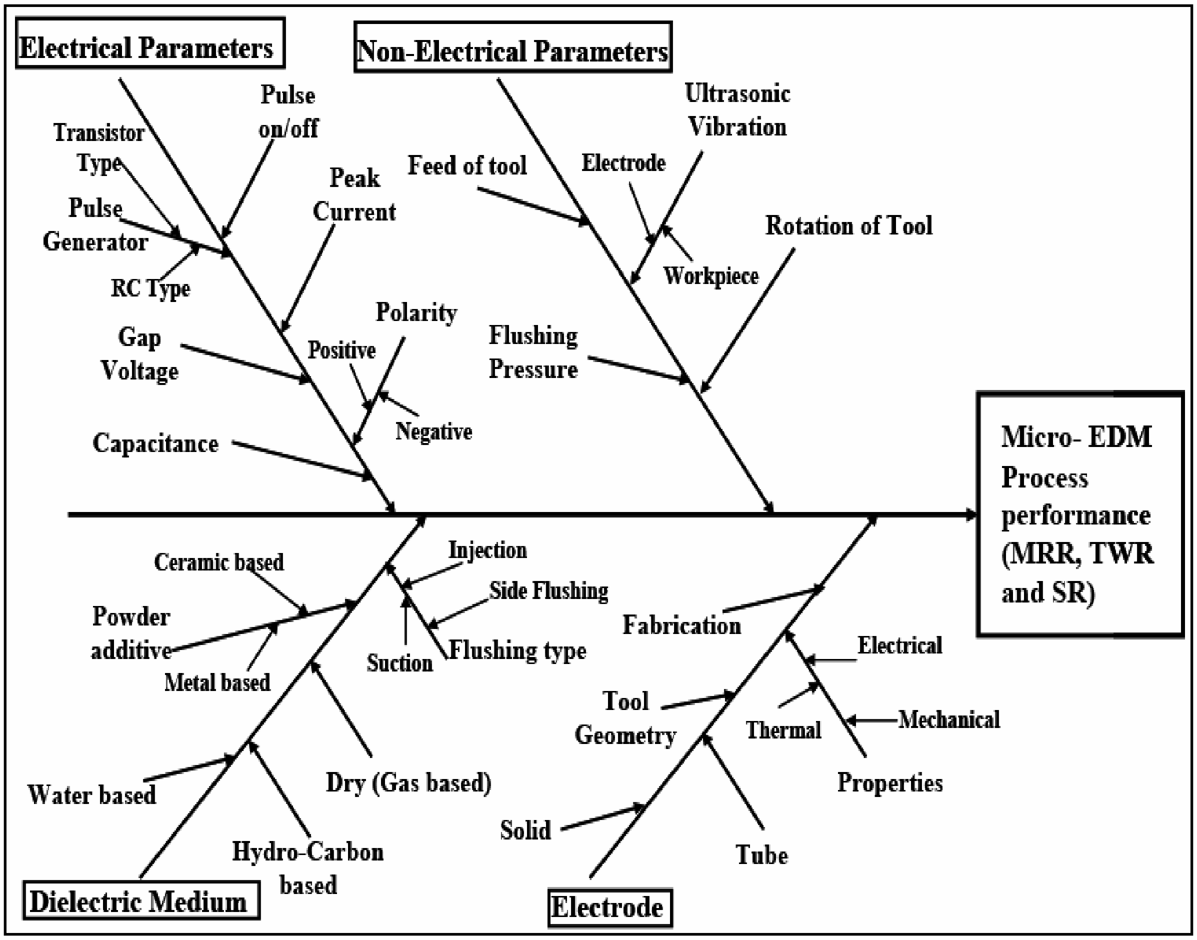

Figure 2 A fishbone diagram of selected parameters of micro-EDM [6]

1.2 Applications:

Micro-EDM is proved to be one of the widely used machining processes because of its extensive applications in various areas. As the demand for micro-EDM is high, many types of research are required to overcome the parameters and new techniques should also be implemented to use it more effectively

The modern industries are facing challenges from advanced materials such as superalloys, composites, and ceramics that are hard and difficult to machine, with high precision, a surface quality associated with higher machining cost. These problems can be overcome by the micro-EDM process. The major area of applications of micro-EDM are to make inkjet nozzles, high aspect ratio holes and slots, gasoline injector spray nozzles, dies for extrusion, liquids, and gas micro fields, needles for the medical field and semiconductor industries such as electrolysis needles (spiral electrodes). Micro-EDM has also made its presence felt in the new fields such as MEMS, medical and surgical instruments. It has also become popular with its potential applications in pharmaceutical industry, orifices for biomedical devices, microfluidic channels, cooling vents for gas turbine, turbine blades of jet engines, military affairs, aerospace industries and automobile industries, heat exchangers, micro gears, micro-robot, micro robotic arm and micro stage can be realised and spinneret holes, etc. The micro-EDM process has to be constantly reviewed in order to compete and satisfy the future crucial machining requirements.

- In recent years, a new technique is introduced to use micro-EDM with the electrically non-conductive material. One material such as SiN4 is proved to be good. However, research is necessary to use the non-conductive materials in the micro-EDM process.
- Researchers recently discovered that the functions of the dielectric liquid can also be achieved with different gases.

II. LITERATURE REVIEW

Following papers have been reviewed to understand current research trends in micro-EDM.

SN	Author	Process review	Output parameter	Benefits/conclusion
1	N. B. Gurule, S. A. Pansare	Potentials of Micro-EDM	1.Material Removal of Micro-EDM 2.2D and 3D Machining by micro-EDM 3.Tool Electrode Manufacturing and Wear in Micro-EDM 4. Basics of Micro-EDM process 5. application of Micro-EDM	This paper is helpful to fabricate the micro-EDM setup for the purpose of experimental research work. It is observed that micro-holes are the most simple and widely used micro products that can be successfully manufactured by using micro-EDM.
2	D.T. Pham∗ S.S. Dimov, S.Bigot, A.Ivanov, K. Popov	Recent developments and research issues	1. Handling of electrodes and parts 2.Electrode and workpiece preparation 3. EDM process & measurement 4. Sources of errors I. Machine errors II. Jigs and fixtures III. Electrode dressing IV. Electrode wear	This paper has given an overview of the main issues affecting the performance and limiting the application of micro-EDM Tolerance, Efficiency Techniques
3	Norliana Mohd Abbas, DariusG. Solomon, Md. Fuad Bahari	A review on current research trends in electrical discharge machining (EDM)	1.Ultrasonic vibration, dry EDM machining, 2.EDM with powder additives and 3.EDM in water 4.Modeling techniques	The ultrasonic vibration method is suitable for micromachining, dry machining is cost-effective, EDM in water is introduced for safe and conducive working environment, EDM, with powder additives is concerning more on increasing SQ, MRR and tool wear using dielectric oil and EDM modeling is introduced to predict the output parameters which leads towards the development of precise and accurate EDM performance.
4	K.takahata, N.shibaike H.guckel	High aspect ratio WC-Co Microstructure produced by the combination of LIGA and Micro EDM	Fabrication of microstructure by LIGA (**Li**thographie, **G**alvanoformung, **A**bformung) and Micro EDM	A new microfabrication process which combines with LIGA and micro EDM has been developed. We can fabricate microstructure by using suitable bulk materials and various purposes.
5	Qingyu Liu, Qinhe Zhang, Min Zhang, Jianhua Zhang	Review on size effects in micro electrical discharge machining	Careful research and precise attention must be given to size effects in micro EDM. Size effect information especially benefits the machining speed and machining precision of micro EDM.	The performances of micro EDM differs significantly from that of macro EDM due to side effects. This paper is the first to comprehensively define the size effects in micro EDM and to further establish three categories of side effects as related to material microstructure, processing parameter, and thermal conduction
6	S.Mahendran D.Ramasamy	Micro-EDM overview and recent developments	Principles, recent developments, parameters for Material removal rate and the tool wear rate	The paper focuses on the principal of micro-EDM, the types of EDM processes, dielectric fluid, electrodes, fuzzy logic, piezo-actuated tool feed control, material removal rate(MRR) and the tool wear ratio(TWR). This paper is essential if or the new development in the research for the micro-EDM machine.
7	M.P. Jahan M.Rahman Y.S.Wong	A review on the conventional and micro-electro-discharge machining of tungsten carbide	Developments in electro-discharge machining of tungsten carbide are grouped broadly into conventional EDM of tungsten carbide, micro-EDM of tungsten carbide and current research trends in EDM and micro-EDM of tungsten carbide	Future advancement in the area of EDM and micro-EDM of tungsten carbide will continue towards understanding the fundamental science and engineering of the process as well as broadening the application of the process for the industries.
8	Mehdi Hourmand Ahmed A. D. Sarhan Mohd Sayuti	Micro-electrode fabrication processes for micro-EDM drilling and milling: a state-of-the-art review	This paper extensively describes and compares various smicro-electrode and micro-tool fabrication processes in order to produce precise micro-products	This paper extensively reviews micro-EDM process as well as various micro-electrode and workpiece materials, dielectrics, and micro-electrode fabrication and measurement processes that have been used by previous researchers. Moreover, the advantages and disadvantages of various micro-electrode fabrication processes are discussed
9	A. Kadirvel*, P. Hariharan, and S. Gowri	A review on various research trends in micro-EDM	Focuses on the optimization of Various parameters using different methods viz., Taguchi, ANN, grey relational analysis and fuzzy logic control system.	The review focuses on recent research trends to improve the output parameters such as MRR, TWR and surface analysis to obtain precise and accurate micro-EDM performance
10	Sinan Filiz, Caroline M. Conley, Matthew B. Wasserman, O. Burak Ozdoganlar	An experimental investigation of micro-machinability of copper 101 using tungsten carbide micro-endmills	The experiments were conducted on an ultra-precision miniature machine tool. Tungsten carbide micro-endmills with 254 mm diameter were used to create full-immersion cuts (slots). The effect of increased wear on the cutting forces, surface roughness, and burr formation was also analyzed	This paper presented an experimental investigation of micro-machinability of OFHC pure copper (101) in terms of tool wear, cutting forces, surface roughness, and burr formation.

III. CONCLUSIONS

The review focuses on recent research trends to improve the output parameters such as MRR, TWR and surface analysis to obtain precise and accurate micro-EDM performance. Thus, there is a number of issues remains to be solved in order to successfully implement micro-EDM in industries. These include the influence of dielectric fluids, pulse characteristics and ultrasonic vibration on machining parameter.

1) Many researchers proved that the water-based dielectric is more suitable, however further research is required to overcome hydrogen embrittlement, explosion, and corrosion in the material.
2) Also, an incremental variation of the spark intensity with the depth of drilling can be a solution for producing defect constrained high aspect ratio structure/hole.
3) The shorter pulse-on duration is preferable to make accurate machining with higher removal rate and lower TWR, though; pulse-off duration will be a key factor in sustaining the process.
4) RC type pulse generator proves to be better in producing a smoother surface, especially for high aspect ratio structure. Electrode rotation can assist better surface texture in micro-EDM.
5) The uses of diamond either as a coating or as polycrystalline status have been cited. However, the stability aspect is not illustrated.
6) Application of magnetic field needs further study from the point of sustaining (undisturbed) plasma channel in the dielectric.
7) When assigning process tolerances for micro-EDM all aspects of the process, such as the type of electrode grinding, type of positioning and duration of the operation, should be considered. All these activities will accumulate errors, which should be taken into account.
8) Grain size can not only influence the minimum machinable size of the microrod, but also the machining speed and surface roughness. Both the thermal conductivity and melting point of the grain boundary are lower than those of the grain, due to high solute concentration, therefore, the micro EDM performances change with grain size (volume fraction of grain boundary,) and the variation tendency depends on the material.
9) The tool electrodes used in micro EDM and wire EDM are small in diameter, and thus susceptible to process force and residual stress during spark discharge. Vibration and deflection of electrodes impair machining precision and limits the minimum machinable size.
10) The MRR and TWR of the workpiece show monotonous rising trends as voltage and peak current increase during conventional EDM process, however, during micro EDM with low voltage and/or current, the MRR, and TWR show abnormal trends dependent on the other processing parameters.

IV. FUTURE SCOPE IN MICRO-EDM

The following are the future research areas to be concentrated in order to make the micro-EDM process a more effective one.

1. Micro-EDM of different composite materials/ ceramics materials which is difficult to machine
2. Micro-EDM of material doped with non-conductive materials, for example, metal matrix composite (MMC)
3. Geometry prediction and simulation of micro-EDM
4. Integration of CAD/CAM with micro-EDM
5. Development of new electrode materials that can be used in micro-EDM
6. Experimental investigation and optimization of micro-EDM parameters.
7. Mathematical modelling of various parameter influenced in micro-EDM.

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