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Potentials of Micro-EDM

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ABSTRACT: *Presently manufacturing industries are facing challenges from difficult-to-machine materials viz. Super alloys, ceramics and composites which require high precision and surface quality thereby increase machining cost. In addition to this rapidly developing technology aims to develop products in miniaturized compact volumes with more functions are embedded in the products. This requires advancement of micro manufacturing; hence industrial research on micro-machining has become considerably important and widespread. To meet these challenges, non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy, with less tool wear. In this context, micro-EDM is one of the topics towards developing micro manufacturing. Micro-EDM is a newly developed method to produce micro-parts in the range of 50 -100 μm. It is an efficient machining process for the fabrication of a micro-hole. Micro-EDM process is based on the thermoelectric energy between the workpiece and electrode. There are many electrical and technological parameters of micro-EDM process which are decisive in the machining characteristics and affect geometrical shape and surface quality of the machined parts. This paper describes the potentials of micro-EDM process, the micro-machining principles, characteristics, process parameters and recent developments.*

Keywords: *Micro-machining, EDM, Micro-EDM, Material Removal Rate, Tool Wear*

I. INTRODUCTION

Electrical Discharge Machining (EDM) is a process used to remove metal through the action of an electrical discharge of short duration and high current density between the tool or electrode and the workpiece. EDM has proved valuable and effective in machining of super tough, hard, high strength and temperature resistance of conductive material. It plays an excellent role in the development of least cost products with more reliable quality assurance. There are various developments in field of EDM like wire EDM, micro EDM, dry EDM, rotating disk electrode EDM, powder mixed EDM, ultrasonic assisted EDM, etc. Micro-EDM is a derived form of EDM, which is generally used to manufacture micro and miniature parts and components by using the conventional electrical discharge machining principles. Similar to conventional EDM, material is removed by a series of rapidly recurring electric spark discharges between the tool electrode and the workpiece in micro-EDM. The basic physical characteristics of the micro-EDM process is essentially similar to that of the conventional EDM process with the main difference being in the size of the electrode used, the power supply (current and voltage), and the resolution of the X-, Y- and Z- axes movement. Micro EDM is a process based on thermoelectric energy between workpiece and electrode. In micro-EDM; pulse generator produces very small pulses within pulse duration of a few micro seconds or nano seconds. Because of this reason, micro-EDM utilizes low discharge energies (~joules) to remove small volumes (~μm) of material. Micro EDM in particular is an important micro manufacturing process because it is unconstrained by the hardness or material strength of the material being machined. One major reason for its wide implementation is that there is no direct contact of the electrode and machined component; hence no contact forces are induced during machining process. Therefore, it is highly suitable for machining of all types of conductive metals, ceramics and semi-conductors. In drilling hard, tough, high strength and temperature resistance material, micro Electro discharge machining is one of the best ways in terms of getting micro-hole. Growing popularity of micro EDM depends on the its advantages including low set-up cost, high aspect ratio (depth/diameter ratio) of the holes, enhanced precision and large design freedom. The theory underlying the micro EDM process is the same as that underpinning the conventional EDM technique. Both techniques rely upon the use of a dielectric fluid situated between the electrode and the work piece. Hence, one important distinction between the two techniques lies in the intensity of the discharge energy. The micro EDM process deliberately employs lower discharge energy in order to improve the machining precision. Micro-hole drilling has found widespread applications in the fabrication of micro nozzles, ink jet and micro punches etc.

Table 1 Difference between macro EDM and micro EDM

Points of distinction	Macro EDM	Micro EDM
Equipment Specifications		
Pulse Generator	Switch circuit	RC circuit
Dielectric	Mineral oil, De ionized water	Mineral oil
Flushing	External and Internal	Internal flushing
Electrode Material	Copper / Graphite	Tungsten
Process Parameters		
Current	0.5 – 400A	0.1 – 10mA
Voltage	40 – 400V	60 – 120V
Pulse Duration	0.5μs – 8ms	ns – μs
Electrode Wear Ratio	1 – 5%	1.5 – 100%
Surface Roughness	0.8 – 3.1μm	0.07 – 1μm
Applications	automotive, defense, aerospace, prototype production, coinage die making	fabrication of micro nozzles, ink jet and micro punches

II. BASICS of Micro-EDM PROCESS

The most important factor which makes micro-EDM very important in micromachining is its machining ability on any type of conductive and semi-conductive materials with high surface accuracy irrespective of material hardness. It is preferred especially for the machining of difficult-to-cut material due to its high efficiency and precision. Small volumetric material removal of micro-EDM provides substantial opportunities for manufacturing of micro-dies and micro-structure such as micro holes, micro slot, and micro gears etc. The use of micro-EDM has many advantages in micro-parts, the main advantage is that it can machine complex shapes into any conductive material with very low forces. The forces are very small because the tool and the workpiece do not come into contact during the machining process. This property provides advantages to both the tool and the workpiece. The other advantages of micro-EDM include low set-up cost, high aspect ratio, enhanced precision and large design freedom. In addition, EDM does not make direct contact between the tool electrode and workpiece material, hence eliminating mechanical stress, chatter and vibration problems during machining. Therefore, relying on the above advantages, micro-EDM is very effective to machine any kind of holes such as small diameter holes down to 10 μm and blind holes with aspect ratio 20. Although micro-EDM is a very efficient process in micro-hole machining and having many advantages, it has also some disadvantages. One of them is that it is a rather slow machining process; the other is that while the workpiece electrode is being machined, the tool electrode also wears at a rather significant rate. This tool-wear leads to shape inaccuracies. Another drawback is the formation of a heat affected layer on the machined surface. Since it is impossible to remove all the molten part of the workpiece, a thin layer of molten material remains on the workpiece surface, which re-solidifies during cooling. Micro-EDM can be used as variant machining processes; they are micro-ED drilling, micro-ED milling, micro-ED die sinking, micro-ED contouring, micro-ED dressing, and micro wire electrical discharge grinding (micro-WEDG). All of these processes are integrated in a today’s sophisticated micro-EDM machines.

III. LITERATURE SURVEY

Most of the published papers on micro-EDM are about the applications with micro-EDM to meet the needs for industrial applications. Many of them generally mention about technology, significant machining parameters such as voltage, current, etc., affecting the machining qualities, its machining ability on different type materials, material removal rate of workpiece and wear ratios of tool electrode and so on. Advantages and disadvantages of micro-EDM as a micromachining technique are also generally reported in several papers. Literature review of micro-EDM is presented in various sub-sections and arranged according to past to present.

3.1 Material Removal of Micro-EDM

Material removal mechanism in micro-EDM is similar to the conventional EDM. The scientists have continually tried to get more efficient material removal mechanism in EDM systems, mostly researchers have worked on the type of circuit used for pulse generation, and they have used different circuit mechanism to obtain efficient material removal in micro-EDM. Wong et al. (2003) investigated the micro-EDM material removal characteristics using single RC-pulse discharges. It was reported that estimated erosion efficiency of material removal at low-energy discharges is found to be seven to eight times higher than that at higher-energy discharges. They observed that the volume and size of the micro-craters are more consistent at lower energy discharge than at higher energy discharges [1]. Klocke et al. (2004) investigated the influence of powder particles in micro-sinking-EDM on thermal spread in dielectric and on the influenced zone. They reported that physical properties of powder play an important role in changing the recast layer composition and morphology. Their two important conclusions: 1) Al powder leads to thinnest rim-zone and highest MRR. 2) Si powder produces a grey zone beneath the actual white zone [2]. Liu et al. (2005) reported that MRR for micro-hole machining over high nickel alloys is increasing sharply with increasing discharge current and reached a maximum at a discharge current of 500 mA when pulse duration is fixed at 4 μs. This report reveals that a significant portion of the total energy is used to vaporize the material at lower current result in reducing in MRR, however, when the discharge current is too large (e.g. 2A) the explosive energy density is huge, and the discharge spark is drastic [3]. Han et al. (2006) have developed a new transistor-type iso-pulse generator for micro-EDM. Their experiments showed the machining characteristics proved that the transistor type iso-pulse generator is suitable for micro-EDM. Their experimental results reveal that the transistor-type pulse train generator is unsuitable for micro-EDM due to its low removal rate. The removal rate of the transistor-type isop-ulse generator is two or three times higher than that of the traditional RC pulse generator [4]. Kim et al. (2006) has studied the characteristic of micro EDM process and application on micro holes machining. They have built PWM circuit into RC circuit to control pulse width of 200 ns per each step [5]. Allen and Chen (2007) investigated the material removal for micro-EDM on molybdenum using a MATLAB-based thermo-numerical model, which simulated single spark discharge process. Depending on the proposed model, they reported the percentage of tool wear decreases with an increase in the pulse duration and much higher for molybdenum than steel at the same machining conditions. Son et al. (2007) investigated the influences of EDM machining conditions on micro-EDM characteristics. The pulse condition is particularly focused on the pulse duration and the ratio of off-time to on-time, and the machining properties are reported on tool wear, material removal rate, and machining accuracy. Their experimental results show that the voltage and current of the pulse exert strongly to the machining properties and the shorter EDM pulses is more efficient to make a precision part with a higher material removal rate [6].

3.2 Tool Electrode Manufacturing and Wear in Micro-EDM

Micro-tool electrode manufacturing is going to be more important for micro parts and holes machining in micro-EDM. Because of the developments in very small size tool manufacturing technology micro-EDM can be use for micro-hole drilling. The most powerful technique for manufacturing micro-tool is WEDG (Wire Electro-Discharge Grinding). It is an important step of the improving technology in micro-EDM.

Takahata et al. (1999) developed a novel micro-EDM method using electrodes fabricated by the LIGA [7].

Fleischer et al. (2004) developed a way to produce milling tools in tungsten carbide with CNC- EDM. Their research has shown the potential of machining of micro-cutting tools with a diameter smaller than 100 μm [8].

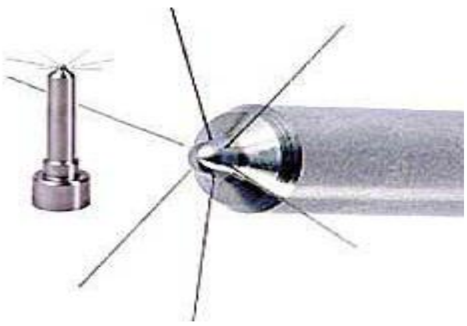
Tsai and Masuzawa (2004) investigated the relationship between the tool wear ratio and the thermal properties of tool and workpiece made of a variety of materials. And they proposed a repetitive machining method which uses reground tools until a required profile is obtained [9].
Zhao et al. (2004) have used online measurement of electrode wear to compensate the electrode wear and maintain the machining accuracy [10].

3.3 2D and 3D Machining by micro-EDM

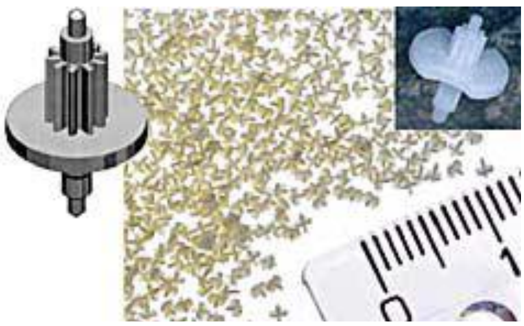
EDM process is a mostly favored machining technique to produce microstructures and micro mold with 3D and high aspect ratios. Feasibility of micro tool electrode by WEDG unit in micro EDM systems also gains advantages in 3D micro parts manufacturing. This type of EDM generally called as electrical discharge milling process, because tool electrode has a movement through the defined tool path like in milling operation. Rajurkar and Yu proposed (2000) an approach to integrate CAD/CAM systems with micro-EDM while accounting for tool wear using recently developed uniform wear method. Using this proposed approach, some complex 3D micro shapes were machined successfully [11]. Lim et al. (2003) have studied the machining of high aspect ratio micro-structures using micro-EDM [12]. (Murali and Yeo, 2004) were investigated the paremeters affecting the micro-EDM and micro-structure has been successively fabricated. They realized that the machining dept is inversely proportional to the feed rate [13]. A micro slit die easily manufactured using a micro electrical discharge machining (micro-EDM) is proposed for micro heat sink fabrication (Wang et al. 2005) . Tseng et al. (2005) reported the integration of LIGA and micro-EDM to fabricate the micro mold for the ink jet printer nozzle plates. With this method, the positioning an alignment accuracy of the micro pins and holes have improved significantly [14]. Cao et al. (2007) reported fabrication of micro-scale mold by using micro-EDM. Surface morphology of these molds are characterized by SEM, X-ray photoelectron spectroscopy and transmission electron microscopy [15].

IV. APPLICATIONS OF Micro-EDM

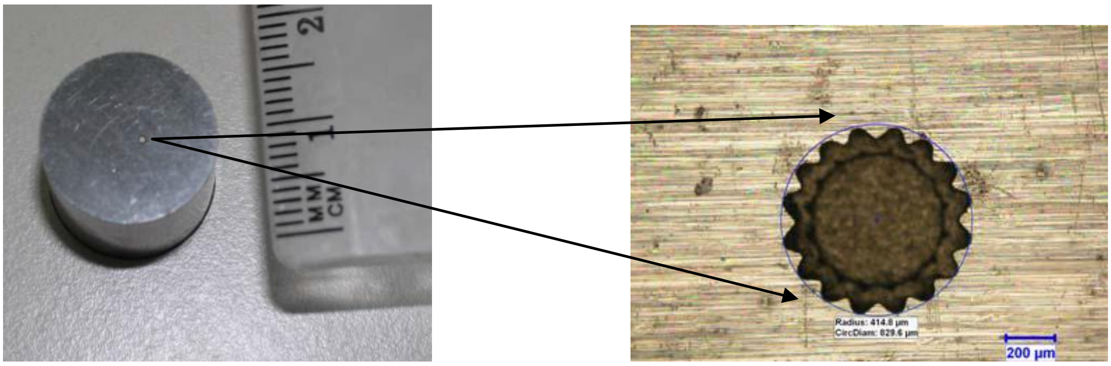
Machining capability of micro-EDM, in conductive materials with high precision regardless of material hardness, create a wide range of application area with the increasing demand for miniaturized parts and components such as holes, nozzles, and gears. Produced micro parts by micro-EDM are widely used in micro-electro-mechanical systems (MEMS), biomedical applications, automotive industry, and defence industry. Although the main research is going on micro-hole manufacturing, different shape of three-dimensional (3D) and two-dimensional (2D) cavities are also machined to demonstrate the machining capability of micro-EDM. A CAD/CAM system is used to generate tool paths of 3D and 2D micro-parts. Fig. 1 (a-f) shows photographs of samples of micro-EDM products [16].



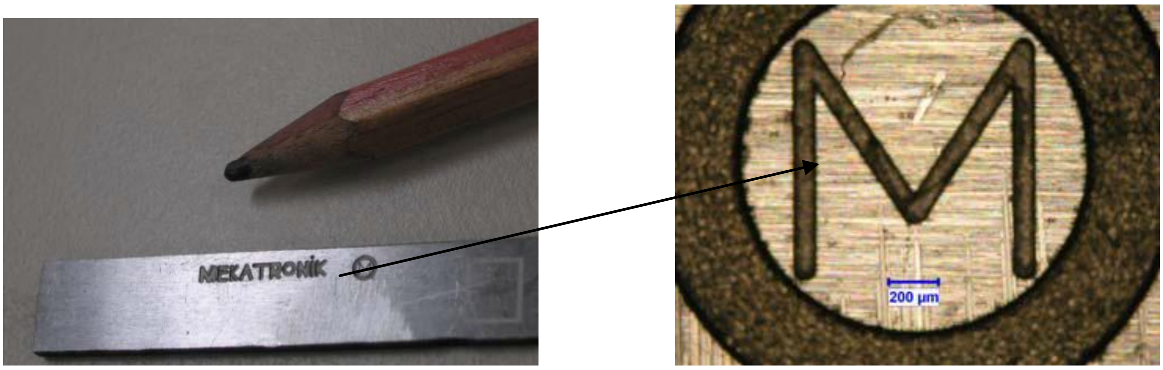
(a) Nozzle for diesel injectors
(http://www.sarix.com/)



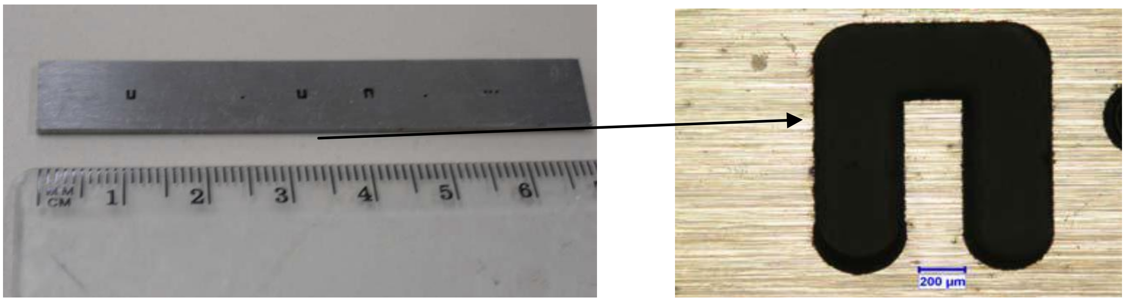
(b) Plastic gear for watches
(http://www.sarix.com/)



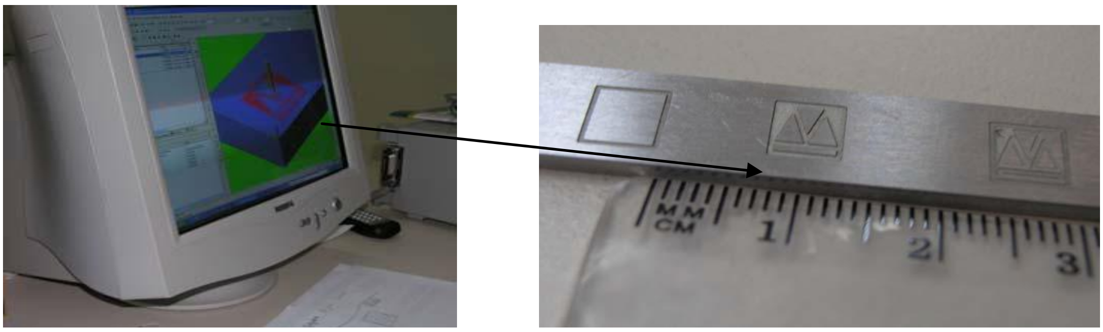
(c) Micro-gear die with outer diameter around 600 µm and depth of 100 µm.



(d) A letter of ‘mekatronik’ and ‘M’ shape are machined by contouring process.



e) Micro-channels with a depth of 1mm by using 400 µm-diameter circular electrode.



(f) Department of Mechatronics Engineering Logo machined on a metal plate with a depth of 100 µm.
Fig.1 [a-f]. Sample of micro-EDM products

V. CONCLUSION

This paper is helpful to fabricate the micro-EDM setup for the purpose of experimental research work. Potentials of micro-EDM technique are discussed extensively in the literature review based on previous and recent research on micro-EDM. From the available literature it is noticed that micro-EDM process could be successfully used as a micro fabrication technique to produce micro-parts and components needed in the micro-mechatronic systems and industrial applications. It is observed that micro-holes with a diameter less than 50 µm is the most simple and widely used micro products that can be successfully manufactured by using micro-EDM.

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