# Micro-channel fabrication using electrical discharge machining process and optimization of parameters

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**Abstract**

In this paper investigation of micro-channels fabrication using electrode sheets in die-sinking electrical discharge machining (EDM) process has been done. The micro-channels were fabricated on AISI D3 die steel using sheets of copper as electrode material. Parametric optimization for process parameters of EDM has been done using Taguchi Method. The control parameters taken were current, pulse-on time, pulse-off time, and voltage. Surface roughness was taken as response parameter.

## 1. Introduction

In the last few decades, owing to the rapid developments in micro-electronics and biotechnologies, the applied research in micro-coolers, micro-biochips, micro-reactors, and micro-fuel cells has been expanding at a tremendous pace. Among these micro-fluidic systems, micro channels have been identified to be one of the essential elements to transport fluid within a miniature area. In addition to connecting different chemical chambers, micro channels are also used for reactant delivery, physical particle separation, fluidic control, chemical mixing, and computer chips cooling (Jyh-tong Teng et al, 2012).

Micro channels are primarily used in biomedical devices and micro fluidic applications. Fabrication of micro channels has always been a tough task using conventional manufacturing technologies. Various types of materials are in use for fabricating micro channels in different types of applications including metals, polymers and ceramics. A number of methods are in use for fabricating different types of micro channels. These processes include both conventional and nonconventional fabrication techniques (Prakash Shashi, and Subrata Kumar, 2015). Some of the most established techniques include Micro-machining, lithography, Stereo lithography, Diffusion Bonding Chemical Etching, LIGA, embossing processes, and laser ablation processing, etc. In this paper fabrication of micro channels by electro-discharge machining process using copper sheet as electrode has been reported. Electro-discharge machining or EDM is a machining method primarily used for hard metals or those that would be impossible to machine with traditional techniques. So, electro discharge machining (EDM) is one of the most important non-traditional machining processes, which is used for machining difficult to machine materials like composites and inter-metallic materials (Trupti G. Raut and M.Y. Shinde, 2015).

In electro discharge machining the erosive action of an electrical discharge between conductive tool and work-piece is used to remove material. Electro-thermal erosion (material melting and evaporation for every spark) creates small craters both in the piece and in the tool during machining progress, then tool shape is copied in the work piece with a no contact system. With this technique it is possible to machine not only difficult to cut metals (like hardened steels) or carbides but also semiconductors and conductive ceramics. The discharge results from the application of an electrical voltage between electrodes (tool and work piece) with a dielectric flushed fluid interposed (Gentili, E, 2005).

We also used Taguchi method for optimization of EDM process parameters for surface roughness in the machined micro channels. The main disadvantage of this method is that the results obtained are only relative in nature and do not exactly indicate which parameter has the highest effect on the performance characteristic value. Hence, ANOVA is used for finding the most significant parameters. The schematic of the work piece and electrode sheet is shown in Figure 1. This is a fast process for cutting micro channels using electrode sheets as the complete micro channel is made using only the vertical movement of the electrode.

## 2. Experiments

### 2.1Materials & Measurements

The experimental studies were performed on EDM Die Sink ECOCUT by Electronica shown in Figure 2. Different settings of Current (Ip), Pulse-on Time (Ton), Pulse-off Time (Toff), and Voltage (Vg) used in the experiments are shown in Table 1. All other factors were kept constant during the experiments. Rectangular micro-channels of size 0.5mm X 0.9mm X 25mm were cut on the

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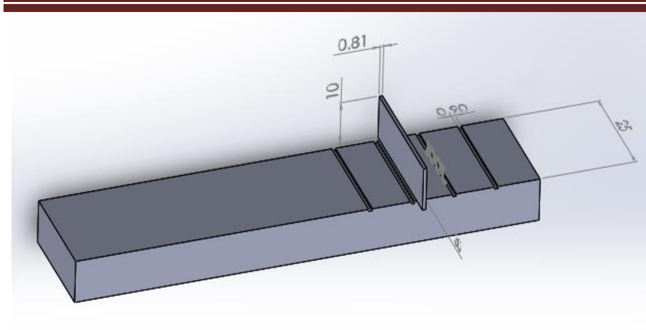


**Fig. 1**: Schematic of workpiece and electrode sheet

work piece of AISI D3 Die steel with 25mm × 200mm × 10mm size. AISI D3 die steel is one of the most extensively used materials in mould and die-manufacturing industry. The electrode used was copper sheet. Although doped copper may be used as electrode material in EDM because it has very high wear resistance. But for experimental purpose, as to save time and energy, copper sheets were used for better investigation of tool wear rates.


**Fig. 2**: EDM Set-up

The surface roughness for each micro-channel was measured using Surftest SV-2100 manufactured by MITUTOYO Pvt. Ltd. The Surftest is a high precision, high performance surface roughness tester with dedicated control unit mounted on a heavy-duty granite base with a choice of manual or power drum. The measured values of surface roughness are given in Table 2.

**Table 1**: Levels of machining parameters as used in experiments

| S. No | Machining Parameter | Symbol | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|---|---|
| 1 | Current (A) | Ip | 5 | 7 | 9 | 11 |
| 2 | Pulse-on Time (μs) | Ton | 10 | 20 | 30 | 40 |
| 3 | Pulse-off Time (μs) | Toff | 5 | 10 | 15 | 20 |
| 4 | Voltage (V) | Vg | 30 | 40 | 50 | 60 |

**Table 2** Surface Roughness (Ra) Values

| **S. No.** | **Surface Roughness ( in micro-meters)** |
|---|---|
| 1 | 4.370 |
| 2 | 3.716 |
| 3 | 3.326 |
| 4 | 2.963 |
| 5 | 4.035 |
| 6 | 4.026 |
| 7 | 3.406 |
| 8 | 4.477 |
| 9 | 3.969 |
| 10 | 3.984 |
| 11 | 3.874 |
| 12 | 3.237 |
| 13 | 4.454 |
| 14 | 4.036 |
| 15 | 3.795 |
| 16 | 2.771 |

### 2.2 Design of experiments based on Taguchi Method

The experiment was designed using Taguchi's design of experiments (Ross PJ, 1998), (Antony J and Antony FJ, 2001). L16 orthogonal array was chosen. Taguchi method is one of the simple and effective solutions for parameter design and experimental planning (Ross PJ, 1998). Taguchi method is a powerful technique for the design of a high quality system. It provides not only, an efficient, but also a systematic approach to optimize designs for performance and quality (Shahul Backer, 2014), (Siddiquee et al, 2014).

Any man-made system is viewed by Taguchi methods as an engineered system that comprises four main components as illustrated in Figure 3. It is designed to employ energy transformation in converting input signal into specific, intended function requested by customers by applying the laws of physics (Yih-fong Tzeng and Fu-chen Chen, 2007).

Taguchi methods advocate that appropriate design of the control factors makes the system transform energy very efficiently. Unintended effects due to noise factors that are the hardly controllable variables can be minimized. In theory, when all the applied energy is transformed into creating its intended function without any noise effects, a system reaches its ideal function (Yih-fong Tzeng and Fu-chen Chen, 2007) (Khan, Z.A et al, 2014).

The experiments were conducted with four control factors with four levels. Sixteen experimental runs based on the orthogonal array L16 were carried. Table 1 shows the four controlled factors, i.e., current (A (Ampere)), pulse ON time (B (μs)), pulse OFF time (C (μs)), and voltage (D (volts)) with four levels for each factor. Figure 4 shows working of EDM. Table 3 shows the experimental trials according to the selected orthogonal table. After that the quality objective of the work-pieces was chosen, including the surface roughness Ra (µm). The values of all the parameters namely Current, Pulse ON, Pulse OFF and Voltage were kept at four levels as shown in Table 1.

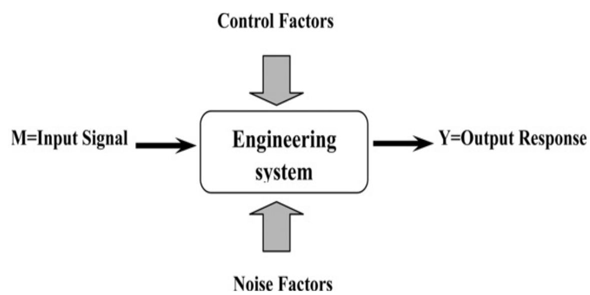


**Fig.3**: Schematic of an engineering system
Source: (Yih-fong Tzeng and Fu-chen Chen, 2007)

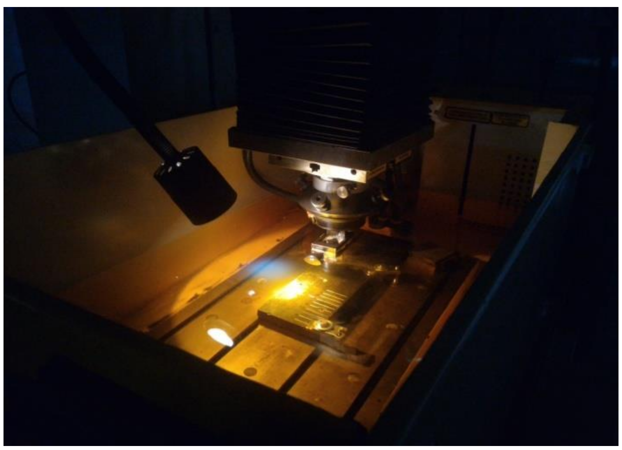

**Fig 4**: Working of EDM

**Table 3** Experimental design using Taguchi L16 Orthogonal Array

| S.No. | Current(Ip) | Pulse-on Time(T-on) | Pulse-off Time (T-off) | Voltage(Vg) |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 1 | 4 | 4 | 4 |
| 5 | 2 | 1 | 2 | 3 |
| 6 | 2 | 2 | 1 | 4 |
| 7 | 2 | 3 | 4 | 1 |
| 8 | 2 | 4 | 3 | 2 |
| 9 | 3 | 1 | 3 | 4 |
| 10 | 3 | 2 | 4 | 3 |
| 11 | 3 | 3 | 1 | 2 |
| 12 | 3 | 4 | 2 | 1 |
| 13 | 4 | 1 | 4 | 2 |
| 14 | 4 | 2 | 3 | 1 |
| 15 | 4 | 3 | 2 | 4 |
| 16 | 4 | 4 | 1 | 3 |

## 3. Results

### 3.1 Analysis of experiments

The experiments were conducted based on varying the process parameters, which affect the machining process to obtain the required quality characteristics. Quality characteristics are the response values or the output values expected out of the experiments. As the objective is to obtain best surface finish, we are concerned with obtaining smaller value of surface roughness. Hence, the required quality characteristic for Surface Roughness is smaller the better, which states that the output must be as low as possible. Table 4 shows the signal to noise ratios for the experiments.

ANOVA (Analysis of variance) was performed and the effects of individual parameters are shown in Table 5. And the Main Effect plot is shown in Figure 5.

Where DOF = Degree of Freedom
SS = Sum of Square
MS = Mean of Square

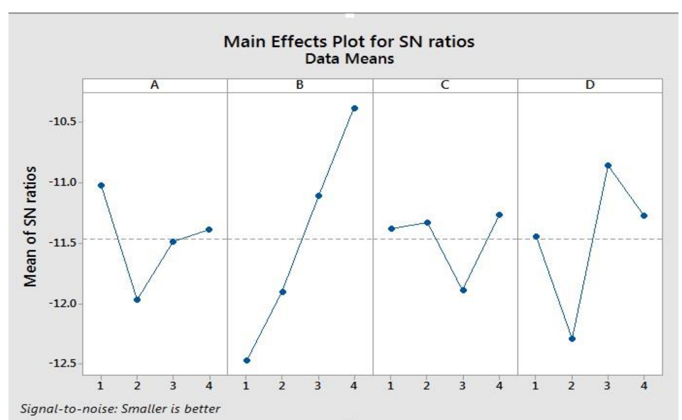


**Fig 5**: Main Effect Plot

**Table 4**: S/N Ratios

| S.No. | A | B | C | D | Surface Roughness | S/N Ratio |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 4.37 | -12.8096 |
| 2 | 1 | 2 | 2 | 2 | 3.716 | -11.4015 |
| 3 | 1 | 3 | 3 | 3 | 3.326 | -10.438 |
| 4 | 1 | 4 | 4 | 4 | 2.963 | -9.4346 |
| 5 | 2 | 1 | 2 | 3 | 4.035 | -12.1168 |
| 6 | 2 | 2 | 1 | 4 | 4.026 | -12.0974 |
| 7 | 2 | 3 | 4 | 1 | 3.406 | -10.645 |
| 8 | 2 | 4 | 3 | 2 | 4.477 | -13.0197 |
| 9 | 3 | 1 | 3 | 4 | 3.969 | -11.9736 |
| 10 | 3 | 2 | 4 | 3 | 3.984 | -12.0063 |
| 11 | 3 | 3 | 1 | 2 | 3.874 | -11.7631 |
| 12 | 3 | 4 | 2 | 1 | 3.237 | -10.2028 |
| 13 | 4 | 1 | 4 | 2 | 4.454 | -12.975 |
| 14 | 4 | 2 | 3 | 1 | 4.036 | -12.119 |
| 15 | 4 | 3 | 2 | 4 | 3.795 | -11.5842 |
| 16 | 4 | 4 | 1 | 3 | 2.771 | -8.8527 |

**Table 5**: ANOVA table for Surface roughness

| **Symbol** | **Process Parameter** | **DOF** | **Sum of Squares** | **Mean Squares** | **%Contribution** |
|---|---|---|---|---|---|
| A | Current | 3 | 1.8206 | 0.6069 | 8.026 |
| B | Pulse-on | 3 | 9.0916 | 3.0305 | 40.087 |
| C | Pulse-off | 3 | 0.9626 | 0.3209 | 4.24 |
| D | Voltage | 3 | 4.0269 | 1.3423 | 17.75 |
| Error | | 3 | 5.7902 | 1.9301 | |
| Total | | 15 | 22.6833 | | |

## 4. Conclusions

Micro-channels were fabricated on AISI D3 Die-steel using copper electrodes in the form of sheets. The effects of current, pulse on time, pulse off time, and voltage were experimentally investigated using Taguchi method and ANOVA. The combination of machining parameters $A_1B_4C_4D_3$ i.e. current at 5 A, pulse on time at 40 µs, pulse off time at 20 µs and voltage at 50 V was found to be optimum for minimum surface roughness. In addition, it was also found that pulse on time was the most dominant factor for surface roughness, its percentage contribution is maximum i.e. 40.087%. The level of importance of current, pulse off time and voltage, indicated by percentage contribution, on the surface roughness was observed to be 8.026%, 4.24%, and 17.75% respectively. This paper also demonstrates the effectiveness of the Taguchi approach to optimize machining parameters with minimum number of experiments.

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