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EXPERIMENTAL AND INVESTIGATION OF MICRO ELECTRIC DISCHARGE MACHINING PROCESS OF AISI 1040

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ABSTRACT

There is an increasing demand for industrial products, not only with the increased number of functions and also there will be a requirement of product in reduced size. Hence, it is essential to develop a product with maximum functions and minimum size. Micromachining technology gives the best solution to develop the product with maximum number of functions and also the size of the product will be in micrometers range. Micromachining technology uses various machining techniques to launch miniaturized products more efficiently and well ahead of their competitors in the market. One of the machining techniques involved in micromachining is Micro Electrical discharge machining (Micro – EDM). Micro – EDM uses the same working principle as EDM which produces repetitive discharges of electrical sparks between the gap of tool (electrode) and the work piece.

AISI 1040 steel is a high carbon steel which provides high yield strength and also it is employed in making spring materials, cutting saws, blades and in micro level applications it is used in manufacture of micro grippers, micro actuators. The wear rate is also less compared to the copper and graphite electrodes employed previously in EDM machining.

In this present work, optimization of micro electrical discharge machining parameters using Taguchi's approach is proposed for AISI 1040 steel because of its higher hardness and also economically feasible to produce dies at cheaper cost. Experimentation was planned as per Taguchi's L_9 orthogonal array. Each experiment was performed under different machining conditions of gap voltage, capacitance, feed, and threshold.

Two responses namely material removal rate and surface roughness were considered for each experiment. The optimum machining parameter combination is obtained by using the analysis of signal to noise (S/N) ratio. The level of importance of the machining parameters on the material removal rate and surface roughness is determined by using analysis of variance (ANOVA).The highly effective parameters on both the MRR and surface roughness are found as gap voltage and capacitance. The variation of the MRR and surface roughness with machining parameters is optimized by using taguchi technique and gray relational analysis technique with the experimental values.

Keywords: Micro-EDM, machining, micro hole, AISI 1040, anova, taguchi method.

INTRODUCTION

Electrical discharge machining (EDM) is a non-traditional concept of machining which has been widely used to produce dies and molds. It is also used for finishing parts for aerospace and automotive industry and surgical components [1]. This technique has been developed in the late 1940s [2]. The EDM process is based on the thermoelectric energy created between a work piece and an electrode submerged in a dielectric fluid. When the work piece and the electrode are separated by a specific small gap, the so-called 'spark gap', a pulsed discharge occurs which removes material from the work piece through melting and evaporation. In recent years, numerous developments in EDM have focused on the production of micro-features. This has become possible due to the availability of new CNC systems and advanced spark generators that have helped to improve machined surface quality. Also, the very small process forces and good repeatability of the process results have made micro-EDM the best means for achieving high-aspect-ratio micro-features [3].

Electrical discharge machining (EDM) enables to machine extremely hard materials and complex shapes can be produced with high precision. Therefore, EDM is a potential and attractive technology for the machining of ceramics, providing that these materials have a sufficiently high electrical conductivity. A maximum electrical resistivity of 100 Ω cm is seen as a limit [4]. EDM does not make direct contact between the electrode and the work piece eliminating mechanical stresses, chatter and vibration problems during machining. Today, an electrode as small as 0.1 mm can be used to 'drill' holes into curved surfaces at steep angles without drill 'wander' [5].

The basis of EDM can be traced as far back as 1770, when English chemist Joseph Priestly discovered the erosive effect of electrical discharges or sparks [6]. However, it was only in 1943 at the Moscow University where Lazarenko and Lazarenko [7] exploited the destructive properties of electrical discharges for constructive use. They developed a controlled process of machining difficult-to-machine metals by vapourising material from the surface of metal. The Lazarenko EDM system used resistance–capacitance type of power supply, which was widely used at the EDM machine in the 1950s and later served as the model for successive development in EDM [8].

It has also been seen in recent years, rapid developments in the defense industry, communication systems and micro-electro-mechanical systems (MEMS) have led to significant amounts of research in the field of magnetic interference of MEMS and system with micro-structures including micro-shafts, micro-holes, specially shaped micro-holes and micro-slots. Micro-manufacturing technique has increasingly attracted research interest. Currently micro-holes are formed by differ chemical machining (ECM) and micro-ultrasonic machining (MUSM). Due to the different working mechanisms, these methods yield different results. Among them manufacturing methods including micro-EDM, electron beam machining (EBM), and laser machining, etching, and electric. Among them, micro-EDM provides advantages such as low-cost apparatus, high aspect ratio of parts, and the capability of fabricating complex 3D shapes. It is therefore potentially suitable for manufacturing micro-holes and micro-parts in miniature devices [9-20].

EXPERIMENTAL DETAILS

Machine details

DT - 110 integrated multi process micro machine tool developed by Mikro tools Pvt Ltd., was used for conducting the experiments and the machine tool is shown in the Figure-1. It is a 3– axis automatic multi – process integrated machining system for micro – machining of a variety of materials, metallic and non – metallic to a very high order of precision. However, with technology moving rapidly towards the development of micro devices in the millimeter to sub – millimeter range, demand for more complex miniaturized and high – precision parts is accelerating. DT – 110, with the capability of multiple machining processes and high machine accuracy (+/- 1 micron) is leading the way. The maximum travel range of machine is 200mm (X-axis), 100mm (Y-axis), 100mm (Z-axis) and the resolution is 1µm. In this experiment the micro-EDM setup shown in Figure-2 is used for performing the experiments. [21].

Figure-1. DT-110 multi process Micro machine tool.

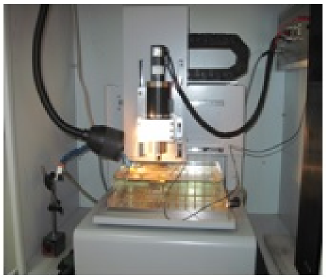


Figure-2. Micro–EDM setup.

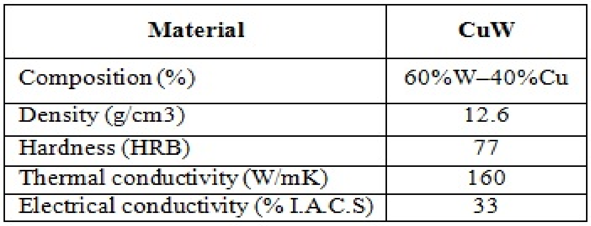
Work piece, lectrode and dielectric fluid

The work piece material used in this study was AISI 1040 steel. The standard (ASME) composition of AISI 1040 steel is given in the Table-1. The electrode material used in this study was copper tungsten of diameter 300µm with a length of 70mm. The dielectric fluid used in this study was commercially available "Total EDM 3 oil". The properties of the electrode and dielectric material are listed in Tables-2, 3, respectively.

Table-1. Composition of AISI 1040 steel (% by weight).

C	Mn	Si	S	P
0.37-0.44	0.60-0.90	0.04	0.05	0.37-0.44

Table-2. Properties of electrode material.

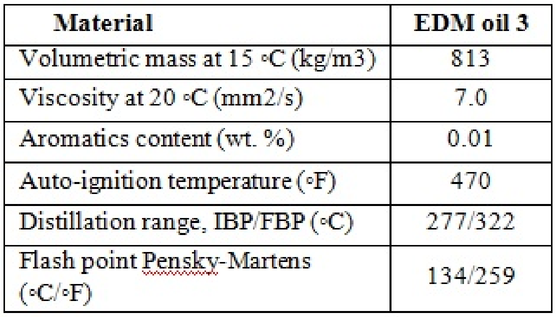


Material	CuW
Composition (%)	60%W–40%Cu
Density (g/cm3)	12.6
Hardness (HRB)	77
Thermal conductivity (W/mK)	160
Electrical conductivity (% I.A.C.S)	33

Experimental design

Experiments were carried out by DOE approach using L_9 OA. The input machining parameters such as gap voltage, capacitance, feed and threshold at three levels were considered and they were allocated in L_9 OA (Table-4).

Table-3. Properties of dielectric fluid.



Material	EDM oil 3
Volumetric mass at 15 ◦C (kg/m3)	813
Viscosity at 20 ◦C (mm2/s)	7.0
Aromatics content (wt. %)	0.01
Auto-ignition temperature (◦F)	470
Distillation range, IBP/FBP (◦C)	277/322
Flash point Pensky-Martens (◦C/◦F)	134/259

Electrical discharge machining (EDM) enables to machine extremely hard materials and complex shapes can be produced with high precision. Therefore, EDM is a potential and attractive technology for the machining of ceramics, providing that these materials have a sufficiently high electrical conductivity. A maximum electrical resistivity of 100 Ω cm is seen as a limit [4]. EDM does not make direct contact between the electrode and the work piece eliminating mechanical stresses, chatter and vibration problems during machining.

Table-4. Machining parameters and their levels.

S. No	Control Factor	Unit	Level 1	Level 2	Level 3
1	Gap voltage	V	80	100	120
2	Capacitance	pF	10	100	1000
3	Feed	μm/s	4	6	8
4	Threshold	-	20	40	60

Equipments used for measurement

Video measuring system (VMS)

Video Measuring System is a photoelectric measuring system of high precision and efficiency. It is composed of a series of components, such as CCD color camera of high resolution, continuous zoom lens, color monitor, video crosshairs generator, precise linear scale, multi-functional Digit Readout (DRO), 2D measuring software and high precision work table. In this study the diameter of the micro hole drilled by using micro-EDM was measured by using Video measuring system. The picture of video measuring system is shown in Figure-3.

Figure-3.

Talysurf CCI non contact 3D Profiler

The Talysurf CCI Lite is an advanced type of measurement interferometer. It uses an innovative, patented correlation algorithm to find the coherence peak and phase position of an interference pattern produced by our precision optical scanning unit. All material types are measurable including glass, liquid inks, photo resist, metal, polymer and pastes. Versatility is one key benefit of the Talysurf CCI. Polished or rough, curved, flat or stepped surfaces with reflectivity between 0.3% and 100% can all be measured using one single algorithm, with no need to change mode for different surfaces and no concerns about the wrong mode being used. In this study, Talysurf CCI non contact profiler was used to find out the surface roughness of the micro hole surface. The Talysurf CCI non contact 3D profiler is shown in Figure-4 and the optical scanning unit is shown in Figure-5.

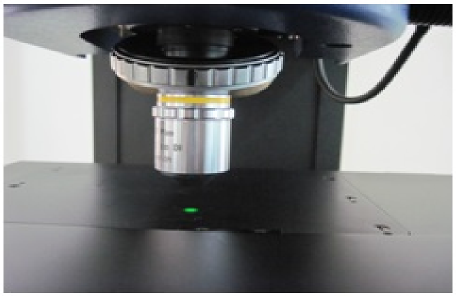


Figure-4. Talysurf CCI non contact 3D profiler.

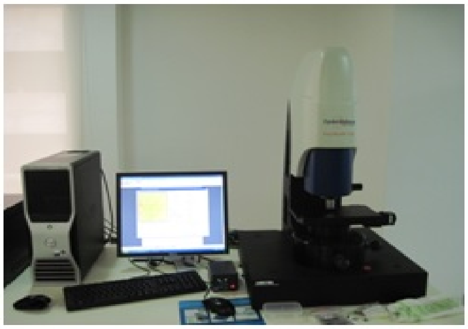


Figure-5. Optical scanning unit.

RESULTS AND DISCUSSION

Diameter of micro hole

The diameter of micro hole was measured by using video measuring system. The image of the micro hole obtained in VMS is shown in Figure-6.From the obtained diameter, the MRR was calculated by using the formula

$$\text{MRR} = \frac{\text{Volume of the material removed from the work piece}}{\text{Time of machining}}$$

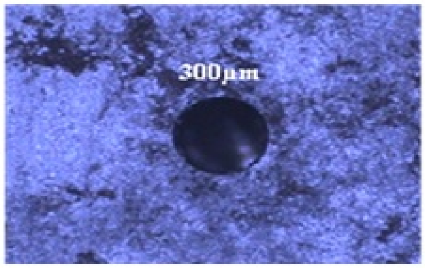


Figure-6. Blind micro hole.

Surface roughness of micro hole

The surface roughness of the micro hole was measured by using Talysurf CCI non contact 3D profiler. The surface image of the section of a micro hole is shown in Figure-7. From the obtained image the non contact profiler uses the Talymap surface analysis software provide the value of surface roughness for respective section of micro hole.

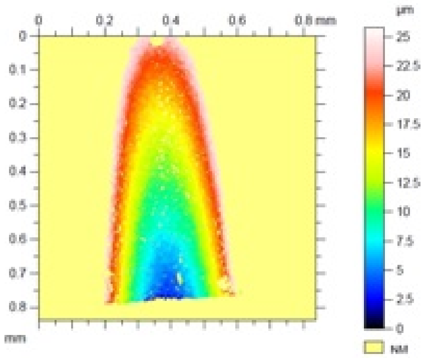


Figure-7. Surface image of micro hole.

Values of MRR and surface roughness

The results of the values of the MRR and surface roughness are given in the Table-5. In this study, two output parameters MRR and surface roughness was considered to determine the performance of micro-EDM of AISI 1040 steel. Therefore it is necessary to determine the optimal combination of the parameters to be used. The single optimal combination for multiple output parameters can be obtained by applying the Taguchi Method.

Table-5. L9 orthogonal array, machining parameters and observed values.

Ex. No.	Gap Voltage (V)	Capacitance (pF)	Feed (µm/s)	Threshold	MRR (10^{-4} mm^3/min)	SR R_a (µm)
1	80	10	4	20	4.42	0.5262
2	80	100	6	40	4.77	0.4965
3	80	1000	8	60	5.12	0.3423
4	100	10	6	60	5.60	0.6135
5	100	100	8	20	4.77	0.9132
6	100	1000	4	40	5.47	0.2440
7	120	10	8	40	6.09	0.3312
8	120	100	4	60	6.79	0.1762
9	120	1000	6	20	5.12	0.4150

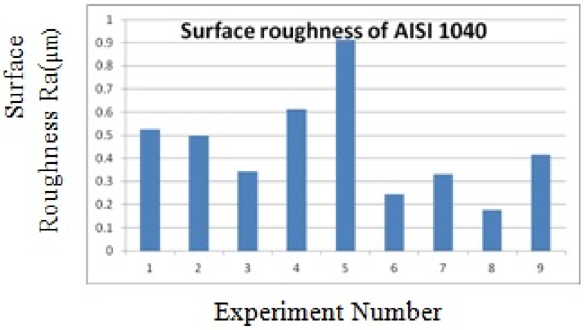


Figure-8. Variation of MRR between experiments.

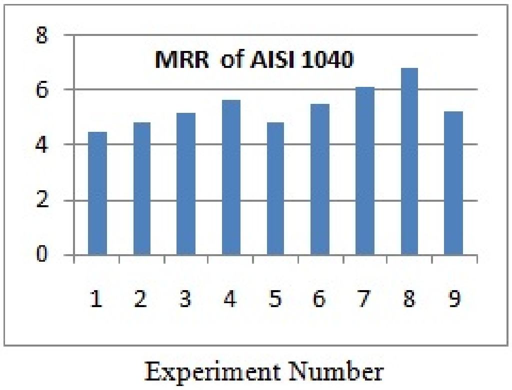


Figure-9. Variation of surface roughness between experiments.

Taguchi method

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on “ORTHOGONAL ARRAY” experiments which gives much reduced “variance” for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

Calculation on S/N ratio for MRR

The objective of this study is to maximize the material removal rate, therefore the S/N ratio for larger the better was selected and it is given by

$$\eta = - 10 \log_{10} (1/y_i^2)$$

Where, η - S/N ratio;

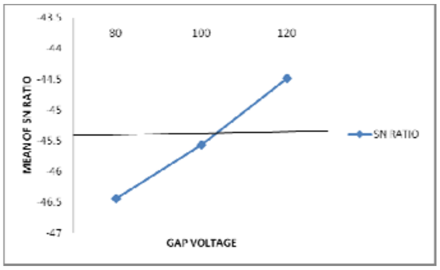
Y_i – measured value of output parameter

The values obtained by Taguchi method (S/N ratio with respect to MRR) are given in Table-6

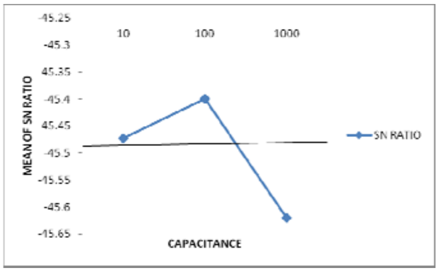
The values obtained by Taguchi method (S/N ratio with respect to Surface roughness) are given in Table-7.

Table-6. S/N ratio with respect to MRR.

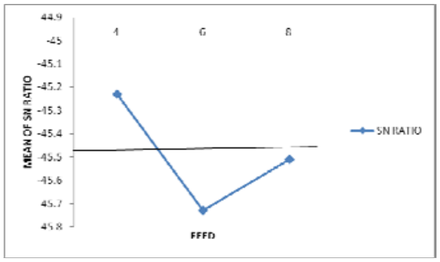
Exp. No.	MRR	S/N ratio (dB) $\eta = -10 \log_{10} (1/y_i^2)$
1	4.20	-47.09
2	4.98	-46.42
3	4.71	-45.81
4	5.27	-45.03
5	5.19	-46.42
6	5.14	-45.24
7	5.52	-44.30
8	6.54	-43.36
9	5.44	-45.81



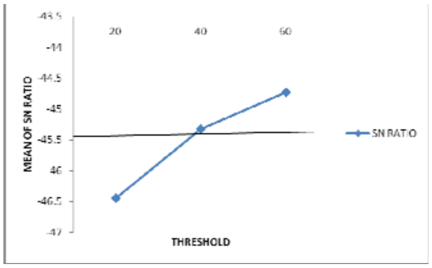
a) At Gap voltage level



b) At capacitance level



c) At Feed level

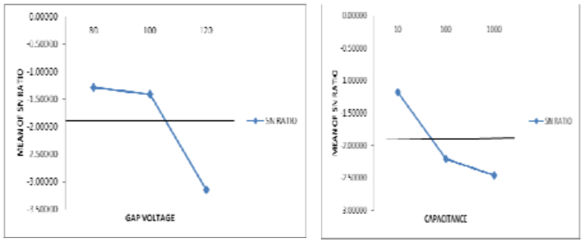


d) At Threshold level

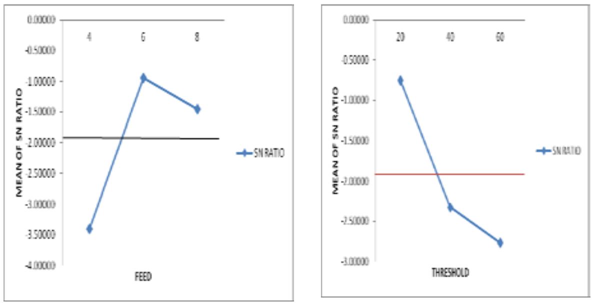
Figure-10. Main effects plot for means of S/N ratio for MRR.

Table-7.

Exp. No.	Surface Roughness R_a(μm)	S/N ratio (dB) $\eta = -10 \log_{10} (y_i^2)$
1	4.20	-0.7777
2	4.98	-0.924
3	4.71	-2.167
4	5,27	-0.450
5	5.19	-0.015
6	5.14	-3.752
7	5.52	-2.303
8	6.54	-5.685
9	5.44	-1.458



a) At Gap voltage level b) At capacitance level



c) At Feed level d) At Threshold level

Figure-11. Main effects plot for means of S/N ratio for Surface roughness.

ANOVA method

One of the most powerful statistical methods for data analysis is the method of analysis of variance (ANOVA). It is a statistically based decision tool for detecting any differences in average performance of the group of items tested.

In this study, ANOVA is used to determine the percentage contribution of the process parameters that affecting the MRR and Surface roughness. From the means of gray relational grades at different levels for the corresponding factors the ANOVA table was given in Table

Table-8. ANOVA table for AISI 1040.

Factors	Degrees of Freedom	Sum of Squares	Mean sum of Squares	F- ratio	% contribution
Gap Voltage	2	0.8440	0.422	7.482	22.408
Capacitance	2	1.1239	0.56195	9.9636	29.843
Feed	2	0.9408	0.4704	8.3404	24.973
Threshold	2	0.8560	0.428	7.5886	22.721
Error	2	0.1129	0.0564		
Total	10	3.3306			100

From the ANOVA table it was observed that the feed has 26.793% contribution which is followed by 26.748% of capacitance, 23.412% of gap voltage and 23.082% of threshold. The percentage contribution of the process parameters obtained through ANOVA is shown in the Figure-13.

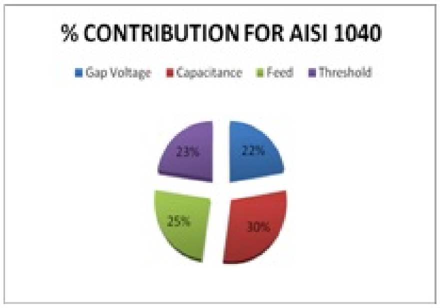


Figure-12. Percentage contribution of machining parameters.

CONCLUSIONS

In this study, an attempt has been made to find the optimal combination of process parameters to obtain maximum material removal rate and minimum surface roughness using Taguchi technique as well as Gray relational analysis technique and the percentage contribution of process parameters and its influence on the output parameters were investigated using ANOVA. It is shown that the output parameters namely material removal rate (MRR) and surface roughness are improved in the optimal combination obtained by Taguchi technique and Gray relational analysis technique. The results were discussed in detail and from the results, the following conclusions are drawn:

The optimal combination of process parameters for obtaining maximum MRR through Taguchi technique for machining AISI 1040 steel using Micro-EDM is given below:

1. Gap voltage – 80V
2. Capacitance – 10nF
3. Feed – 8μm/s
4. Threshold – 20

The optimal combination of process parameters for obtaining minimum surface roughness through Taguchi technique for machining AISI 1040 steel using Micro-EDM is given below:

1. Gap voltage – 80V
2. Capacitance – 1000nF
3. Feed – 4μm/s
4. Threshold – 20

The optimal combination of process parameters to obtain maximum material removal rate and minimum surface roughness through Gray relational analysis technique for machining AISI 1040 steel using Micro-EDM is A2B3C4D1. i.e.

1. Gap voltage – 120V
2. Capacitance – 100nF
3. Feed – 8μm/s
4. Threshold – 60

The percentage contribution and the influence of process parameters on MRR and surface roughness were determined by using ANOVA, which gives the following results:

1. Gap voltage – 23.412%
2. Capacitance – 26.748%
3. Feed – 26.793%
4. Threshold – 23.082%

Finally, it was concluded that the feed has more influence on the surface roughness and material removal rate, which is followed by capacitance, gap voltage and threshold

Suggestions for further study

- Mathematical models are to be constructed for generating the results that matches with the practical experiments.
- Optimization of process parameters using different electrode materials like CuW, AgW and the performance of the electrode materials are to be studied.

Other than material removal rate and surface roughness, some other performance characteristics like cylindricity of micro hole, roundness of micro hole are to be identified and the optimal combination is to be determined.

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