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Optimization of Process Parameters in Electrochemical Discharge Machining (ECDM)

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Abstract—*Electrochemical discharge machining (ECDM) is an effective micromachining process for high strength non conducting materials such as glass, ceramics etc. The objective of this present work is to investigate the effects of various ECDM process parameters on the machining quality and to obtain the optimal sets of process parameters to get better result of material removal rate (MRR).For conducting the experimental work a functional setup of ECDM is designed and fabricated in house. In the present work, Taguchi method based L9 (3^3) orthogonal array has been used to plan the experiments. The signal to noise(S/N) ratio and analysis of variance (ANOVA) analysis were used to determine the contribution of machining parameters such as voltage, tool work piece gap and tool rotation on MRR. The copper as tool material and KOH at 30% concentration as an electrolyte used for drilling of holes in a borosilicate glass. Experimental result showed that applied voltage was most influencing parameter on MRR.*

Keywords*: ECDM,MRR, Taguchi Method Optimization, S/N ratio, ANOVA*

1. INTRODUCTION

Electrochemical discharge machining (ECDM) is a novel hybrid micro machining process that combines the features of electro chemical machining (ECM) and electro discharge machining (EDM). It involves high-temperature melting and accelerated chemical etching under the high electrical energy discharged on the electrode tip during electrolysis that enables the ECDM process to machine very hard and non conducting materials such as borosilicate glass, quartz, ceramics etc. efficiently and economically. Such simple procedure involved endows ECDM with great potential in micro-machining of non-conductive hard brittle materials.

Much of the work in ECDM has been concentrated on glass which has useful properties such as its chemical resistance or biocompatibility. The importance of glass is also growing in the field of Micro Electro Mechanical Systems. Some promising applications of glass in the MEMS field are micro accelerometers, micro reactors, micro pumps, and medical devices such as flow sensors or drug delivery devices. All these applications give birth to the need of effective and economical machining of glass. To meet this need and industrial requirement of machining of brittle non-conducting materials, studies are needed to improve the quality characteristics of ECDM process.

Machining with ECDM is a complex process affected by various process parameters. Up till now it is not clear that which parameter controls mainly the machining so there is need to optimize these control parameters to improve the performance of ECDM process.

The various researchers have carried out study on parametric optimization of electrochemical discharge machining process. Cheng-Kuang Yang et al.[1] Investigated the effect of surface roughness of different tool electrode materials on gas film formation and hence the machining characteristics. This study shows that selection of proper tool material is very important in case of micro machining. C. S. Jawalkar et al. [2] have concluded from the experimental result, applied voltage was the most influencing parameter in both MRR and TWR studies. Xuan Doan Cao et al. [3] studied the effect of various ECDM parameters in order to improve the machining of 3D microstructures of Pyrex glass. Obtained result shows that smaller size of hole obtained in KOH 30 wt%. M. L. Harugade et al. [4] discussed the effect of different electrolyte solution on MRR in ECDM. The obtained results evidence that applied voltage was found to be most influencing parameter for MRR and KOH shows the better removal rate than other proposed electrolyte solutions used in an experiment. Mohammad Reza Razfar et al. [5] investigated the effects of tool longitudinal oscillations on the drilling speed of glass. They have observed that vibration has considerable effect on the electrolyte circulation in the bottom of the hole which can remove the plateau faster and make the higher material removal rate. From the experiment carried out by Baoyang jiang et al. [6] it is seen that there is problem of tool wear associated with use of tapered tool electrode. Sumit K. Jui et al. [7] investigated and explored the feasibility of machining high aspect ratio micro holes in glass. The results obtained from test were rotation of the tool electrode improves the circularity of machined hole along with high aspect ratio and lower surface roughness. Srinivas Athereya et al. [8] present the optimization procedure used in Taguchi method. Krishankant et. al. [9] discussed the application of Taguchi method for optimizing turning process by the effects of machining parameters. From the optimization results author predicted Taguchi method is a good method for optimization of various machining parameters as it reduces the number of experiments.

Thus parametric study is to be carried out based on Taguchi method to optimize the ECDM process parameters. The experiments were conducted using Taguchi L_9 orthogonal array on borosilicate glass. The effect of process parameters such as applied voltage, tool rotation and tool work piece gap on material removal rate was studied. ANOVA was used to study the significant machining parameters affecting on output characteristics.

2. WORKING PRINCIPLE.

Electro chemical discharge machining makes use of electrochemical and physical phenomena to machine glass. The following simple experiment clearly describes electrochemical discharge phenomena as shown in Fig. 1.

The work piece is dipped in an appropriate electrolytic solution usually NaOH or KOH. A constant DC voltage is applied between the tool-electrode (cathode) and the counter-electrode (anode). The tool-electrode is dipped a few mm in the electrolytic solution. Generally the tool- electrode surface must be always significantly smaller than the counter-electrode surface. The tool-electrode is generally polarized as a cathode, but the opposite polarization is also possible.

When D.C. voltage is applied, electrolysis happens and Hydrogen gas bubbles are formed at the tool-electrode (cathode) and oxygen bubbles at the counter electrode (anode). When the voltage is increased, the current density increases too and more and more bubbles grow forming a bubble layer around the electrodes. When the voltage is increased above the critical voltage, bubbles coalesce into a gas film around the tool-electrode. Sparking phenomena is observed in the film where electrical discharges happen between the tool-electrode and the surrounding electrolyte which results in removal of material from the work piece.

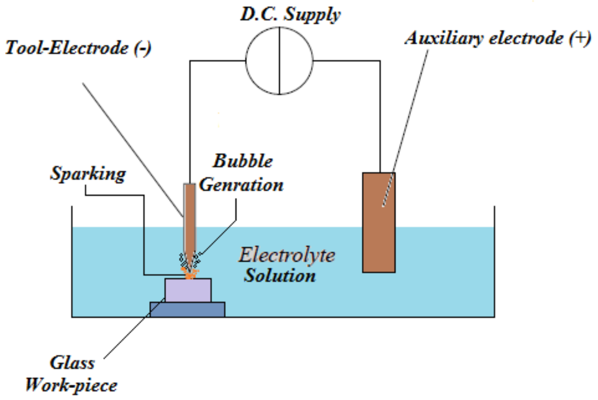

Fig. 1: Principle of ECDM process [5]

3. FABRICATION OF EXPERIMENTAL SETUP.

A functional set up of ECDM is designed and fabricated in house by selecting proper components. ECDM setup consists of various sub systems including: machining chamber , tool holding, rotating and feeding unit, work piece fixture, inter electrode gap control arrangement pulsed DC power supply etc as shown in Fig. 2.

The machining chamber is actually a box type container which is made up of glass having length 200 mm, width 130 mm and height 40 mm and thickness of glass is 4mm. At the machining chamber, there is a provision of keeping the work piece and adding the electrolyte in it. To maintain the work-piece material at its original position the glass fixture is made in such a way that to load and unload the work-piece one side of fixture is kept open while other three sides are permanently fixed to the machining chamber.

Tool feed unit is nothing but micrometers with I sectioned strip and it is placed on top of the glass chamber. U shaped slot is produced at the centre of strip and hole of 12 mm diameter is drilled at 85 mm apart from the centre of it for installation of stepper and geared motor respectively. A screw gauge micrometer is used to dip the tool in electrolyte with controlled depth in microns. With the help of micrometer tool can be moved in positive X (downward) and negative X (upward) direction.

A tool holder was used to hold the tool electrode in a desired position. A stepper motor is designed to rotate the tool electrode at different speeds by using microcontroller and it is mounted at U slot on horizontal steel strip. Motor shaft and tool holder are coupled together in order to rotate the tool. Auxiliary electrode (anode) which is made up of copper is also mounted at the top of glass chamber with the help of L sectioned steel frame. There is provision made to change the distance between tool electrode and Auxiliary electrode from 30mm to 50mm as per the requirement.

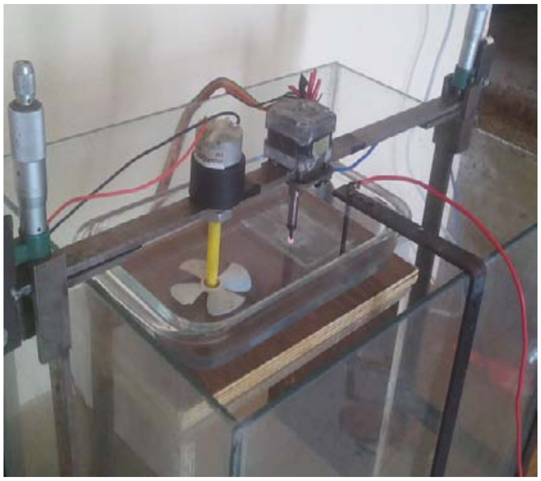

Fig. 2: ECDM Setup

The stirrer is used to maintain the uniformity of electrolyte solution in the region of sparking. This stirrer is rotated with help of geared motor of 12V D.C power supply and designed to rotate at 10 rpm.

As ECDM demands lower DC voltage a step down transformer with AC to DC converter is used as a power supply and dimmer is used for control the voltage effectively. Thus experimental setup of ECDM is fabricated.

4. EXPERIMENTAL PLANNING AND SELECTION OF PROCESS PARAMETERS

In this study, experiments were performed on 25X25 mm and 3mm thick borosilicate glass whose chemical composition is presented in table1. KOH at 30% conc. is used as an electrolyte. The control of electrolyte level also affects the spark reaction so the level of electrolyte used was 2 mm above the work piece. Copper as material used for both tool and auxiliary electrode. Conical shaped tool was used because it gives more consistent spark and it can be molded more accurately. Inter electrode gap is taken as 50 mm. The machining rate of glass is slow because of its hard and brittle in nature so machining time used for the experimentation was 30 min.

Table 1: Composition of borosilicate glass.

Composition	SiO2	Al2O3	Fe2O	B2O	Na2O
Wt%	80.90	2.30	0.03	12.70	4.03

For the present investigation three process parameters such as voltage, tool rotation, tool work piece gap at three different levels was selected to predict the effect on the quality characteristics of ECDM process such as material removal rate (MRR). The selection of process parameters with their levels are shown in table 2

Table 2: Machining parameters and their levels.

Symbol	Parameter	Level 1	Level 2	Level 3
A	D.C Voltage (V)	40	50	60
B	Tool work piece gap (μm)	20	40	60
C	Tool rotation (rpm)	50	100	150

5. MEASUREMENT OF PERFORMANCE.

The purpose of this experimental investigation is to find out the Material removal rate of borosilicate glass. The amount of material removed (MR) is measured by taking difference in weight of the specimen before machining (W1) and weight of the specimen after machining (W2).The MRR can be calculated by dividing the difference in weight by machining time [5]. It is expressed as

$$\mathrm{MRR} = \frac{(\mathrm{W1} - \mathrm{W2})}{\mathrm{T}} \tag{1}$$

Where,

T = Machining time.

W1 = Weight before machining

W2 = Weight after machining

The objective of this research work is to maximize the material removal rate so the objective function used here for maximize the material removal rate is Larger the better:

S/N Ratio for this function is

$$SN = -10 \log\left(\frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{1}{\mathrm{Yi}^2}\right) \tag{2}$$

6. TAGUCHI METHOD BASED DOE

In the present analysis, taguchi method based optimization technique was used to investigate the optimum parametric condition for obtaining optimum parametric effect during machining of borosilicate glass. In this study, Taguchi standard L9 (33) orthogonal array as shown in table 3 has been used for experimental investigation. Analyses of S/N ratio and ANOVA were carried to study the importance of selected machining parameters of ECDM process on MRR of borosilicate glass. With the help of result obtained from S/N ratio and ANOVA optimal setting of machining parameters for MRR was obtained.

Table 3: Standard L9 (3^3) Orthogonal Array.

Experiment No.	Factors		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

7. EXPERIMENTAL PROCEDURE

Firstly clean the machining chamber properly with the help of pure distilled water and dried so that there should not be present any impurities in it. Prepare the work piece and electrolyte for a particular concentration by mixing KOH salt with distilled water of known amount. The weight of job was measured with the help of electronic weighing machine having least count of 0.001gm.Then work piece is clamped on the fixture so that the work piece cannot be moved due to tool vibration. A care must be taken so that the gap between top surface of the job and tool electrode must be in a specified microns. Electrolyte is poured in to the machining chamber from reservoir of electrolyte. Upper level of the electrolyte must be controlled in such a way that 2 mm above the work piece.

The main power supply of 230 volt AC is supplied to the specially designed step down transformer which produces DC voltage in the range of 0V-100V. As per the experimental plan constant DC voltage is supplied to the tool electrode (cathode) and auxiliary electrode (anode) dipped in machining chamber with the help of regulator. A microcontroller is used to control rotary motion of tool electrode. From microcontroller stepper motor is turned on by operating switches for getting different speeds of tool electrode. After setting of tool work piece gap and speed of tool electrode slowly increase the voltage up to a value as per Taguchi's method of design experimental plan.

During machining spark takes place between tool work piece gap and erosion of work material starts. At the same time a small amount of electrolyte is supplied to electrolyte chamber with drop by drop to make up the volume of electrolyte changed due to heating and vaporization of electrolyte. The machining operation was performed for predefined time and it was noted with the help of stop watch. After completing the defined time firstly decrease the voltage and then stopped the stepper motor for stopping the tool rotation. Finally all the power supplies were switched off. Then work piece was removed from the machining chamber and it was cleaned and dried properly before measuring the weight of it.

Now the weight of the job was measured again. Material removal rate is obtained by dividing the difference in final weight and initial weight by machining time. Above experimental procedure is repeated for different set of planned experiments and MRR is calculated for these set of experiments. The obtained readings of MRR are recorded for further analysis.

8. RESULTS AND DISCUSSIONS.

By using above mentioned Taguchi's L9 (3^3) orthogonal array design experiments were conducted and obtained results has been tabulated in table 4.

Table 4: Experimental results

Run order	Voltage (V)	Tool work piece gap µm)	Tool rotation	MRR	S/N ratio
1	40	20	50	1.366	2.713
2	40	40	100	0.733	2.694
3	40	60	150	0.400	7.958
4	50	20	100	0.700	3.098
5	50	40	150	0.733	2.694
6	50	60	50	1.266	2.053
7	60	20	150	1.533	3.712
8	60	40	50	1.266	7.107
9	60	60	100	1.500	3.521

9. ANOVA FOR MATERIAL REMOVAL RATE

The experimental results of ANOVA with percentage of contribution of each machining parameter on MRR are presented in Table 5. The obtained value of F from table is used to measure relative parameter effects. As the value of F is larger controlling this factor is more important.

From the below table it was observed that among the influencing parameters on MRR voltage and tool rotation are two significant parameters which contributes 60.54% and 36.91 % respectively and tool work piece gap contributes only 2.17 %.

Table 5: ANOVA for MRR

Source	DF	Adj. SS	F ratio	P value	% contribution
Voltage	2	1.6266	168.99	0.006	60.54
Tool work gap	2	0.0585	6.08	0.141	2.17
Tool rotation	2	0.9919	103.05	0.010	36.91
Error	2	0.0096			0.35
Total	8	2.6867			
S = 0.0693 R-Sq=99.64% R-Sq(adj) = 98.57%					

10. INFLUENCE OF VARIOUS MACHINING PARAMETERS ON MRR

1) Influence of voltage on MRR: Applied voltage is the most significant parameter that affects the value of MRR. The MRR increases with increase in voltage from 40V to 50 V almost linearly but after supply of 50 V MRR increases significantly as shown in Fig. 3.

2) Influence of Tool work piece gap on MRR: Tool work piece gap has very little effect on MRR. As the gap between tool and work piece increases there is reduction in MRR considerably is shown in Fig. 3.

3) Influence of Tool rotation on MRR: Tool rotation is the second most influencing factor which decides the value of MRR. As the speed of tool electrode increases MRR decreases. This can be shown in Fig. 3.

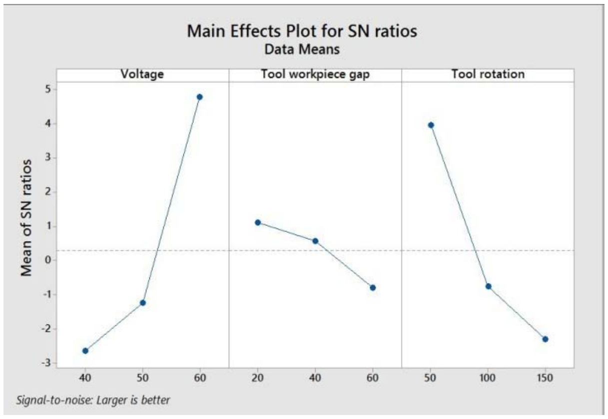

Fig. 3: Main effect plot for MRR

The regression analysis for MRR using Minitab 17 software is shown in eq. (3)

$$MRR= – O.278 + 0.0467A – 0.00361B – 0.00745C \qquad (3)$$

Where,

A = voltage (V)

B = tool work piece gap (μm)

C = tool rotation (rpm)

Above equation (2) shows that voltage is dominant factor affecting MRR.

11. CONCLUSION

For optimization of machining parameters of ECDM process for drilling of hole on glass Taguchi method is used. On the basis of experimental results, S/N ratio and ANOVA analysis, the following conclusions are drawn.

1) The machining parameters of ECDM process such as applied voltage and tool rotation significantly affects MRR of this process.

2) The applied voltage and tool rotation are the most influencing parameters on MRR with 60% and 36.91 % contribution. Tool work piece gap has little effect on MRR which contributes only 2.17 %.

3) For achieving maximum MRR, optimal setting of parametric conditions are A3,B1,C1 i.e. material removal rate is maximum at 60 volts DC voltage, 20μm tool work piece gap and 50 rpm speed of tool electrode.

REFERENCES

[1] Cheng-Kuang Yang, Chih-Ping Cheng, Chao-Chuang Mai, A. Cheng Wang, Jung-Chou Hung, Biing-Hwa Yan, (2010) Effect of surface roughness of tool electrode materials in ECDM performance, International Journal of Machine Tools & Manufacture (50), 1088–1096.

[2] C.S. Jawalkar, Apurbba Kumar Sharma, Pradeep Kumar, (2012) Micromachining with ECDM: Research Potentials and Experimental Investigations, World Academy of Science, Engineering and Technology (61), 90-95.

[3] Xuan Doan Cao, Bo Hyun Kim, Chong Nam Chu, (2009) Micro-structuring of glass with features less than 100um by electrochemical discharge machining, Precision Engineering (33), 459–465.

[4] M. L. Harugade, M.V. Kavade, N.V. Hargude, An Experimental Investigation Of Effect Of Electrolyte Solution On Material Removal Rate In ECDM, International Journal of Engineering Research & Technology (IJERT), 2(1), 1-8.

[5] Mohammad Reza Razfar, Ali Behroozfara, Jun Nib, (2014) Study of the effects of tool longitudinal oscillation on the machining speed of electrochemical discharge drilling of glass, Precision Engineering, (38), 885–892.

[6] Baoyang Jiang, Shuhuai Lan, Jun Ni, Zhaoyang Zhang, (2014) Experimental investigation of spark generation in electrochemical discharge machining of non-conducting materials, Journal of Materials Processing Technology (214), 892– 898.

[7] Sumit K. Jui, Abishek B, Kamaraj, Murali M. Sundaram, (2013) High aspect ratio micromachining of glass by electrochemical discharge machining (ECDM), Journal of Manufacturing Processes (15), 460–466.

[8] Srinivas Athreya and Y.D. Venkatesh, (2012) Application Of Taguchi Method For Optimization Of Process Parameters In Improving The Surface Roughness Of Lathe Facing Operation, International Refereed Journal of Engineering and Science (IRJES), 1(3), 13-15.

[9] Krishankant, Jatin Taneja, Mohit Bector, Rajesh Kumar, (2012) Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters, International Journal of Engineering and Advanced Technology (IJEAT) , 2 (1), 263-274.