National Journal of Multidisciplinary Research and Development
ISSN: 2455-9040
Impact Factor: RJIF 5.22
www.nationaljournals.com
Volume 3; Issue 3; September 2018; Page No. 56-60

Modeling and Optimization for different quality characteristics on electric discharge drilling by Taguchi methodology

Ankit Jain[1], Rohit Kumar[2], Surendra Kumar[3]
[1-3] Mechanical Engineering Department, Modern Institute of Technology & Research Centre, Alwar, Rajasthan, India

Abstract
Among the different advanced machining processes, the electrical discharge drilling may be applied with certain advantages over other processes. But electrical discharge drilling has certain defects or disadvantage at the drill specimen due to sparking such as hole circularity at entry and exit. These may be optimized by selecting the optimum process parameter levels. This study, the experiments have been conducted by well-planned orthogonal array L_{27} in the electrical discharge drilling of mild steel sheet. For the experimentation, discharge current, pulse on time, pulse off time and dielectric pressure have been selected as input process parameters and hole circularity at entry and exit as output parameters. The multi regression models for hole circularity (entry and exit) have been developed by using the experimental data. The statistical analysis for the developed models shows that the models are reliable and adequate and may be used for predicting these quality characteristics satisfactorily. These quality characteristics have been optimized simultaneously by using the taguchi orthogonal array.

Keywords: electrical discharge drilling, hole circularity entry, hole circularity exit, taguchi method, anova

1. Introduction

Electric Discharge Machining (EDM) process originated around 1770 when an English Scientist Joseph Priestly discovered the erosive effect of the electric discharges (sparks). In 1930, first attempts were made to machine metals and diamonds using electric discharges, and the process was referred to as “arc machining or spark machining” [1] In the 1980s the introduction of Computer Numerical Control (CNC) in EDM, brought tremendous advancement in improvising the efficiency of the machining process. Modern EDM machines are so stable these days that these can be operated round the clock under adaptive control system monitoring [2]. The material removal mechanism primarily uses the electrical energy and transforms it into thermal energy through a series of discontinuous electrical discharges occurring between the tool and the work piece, submerged in the dielectric fluid [3]. The thermal energy generates a virtual plasma channel between the two electrodes [4] at a temperature in the range of 8000-12000·C [5], this temperature can go as high as 20000·C [6]. This temperature range causes the material of any hardness to melt at the surface of each pole. When the pulsed DC power supply of around 20,000-30,000 Hz [7] is turned off, the plasma channel breaks down. This causes an abrupt reduction in temperature at the tool-work piece interface, which allows the circulating dielectric to flush away the molten material from the melt cavity, in the form of microscopic debris. Electric Discharge Machining (EDM) is a manufacturing process where thermal energy is mainly responsible for material removal [8, 9]. However, not only the material removal process takes place but also rim zone properties change due to heat flux into the work piece. The prediction of these work piece properties in the rim zone after a manufacturing process is important for the resulting part functionality and is one of the main aims of the collaborative research center SFB/TRR 136. For this purpose it is necessary to identify the relation between the material loadings and the resulting material modifications. [10, 11]. The idea of Process Signatures is that each manufacturing processes is characterized by a specific combination of different energy flows. These energies are expressed by i. e. forces or heat flow and cause material loads like strains and temperature gradients. During the last two decades, the inclination of the industries towards the use of advanced ceramic materials has increased. The ceramics are employed in the machine tool, aerospace, automotive, electrical and electronics sectors [12, 13].They are widely used as ballistic armors, ceramic composite automotive brakes, diesel particulate filters, prosthetic products, piezoceramic sensors and next generation computer memory products [14, 15]. To address the issue of shaping advanced ceramics, both traditional as well advanced machining processes are developed. One of the principle requirements of ceramic materials machining is the generation of fine shapes without micro-cracks, which is very difficult to be addressed by traditional mechanical machining methods. Advanced machining processes can suitably overcome the dis-advantages offered by the traditional machining methods due to difference in material removal mechanisms. Mechanisms such as thermal material removal (electrical discharge machining (EDM)), mechanical material removal (abrasive jet, abrasive water jet, ultra-sonic machining), chemical (chemical machining), ionic dissolution (electro-chemical machining), etc. can be used individually or in hybrid form to shape hard to cut brittle materials. Among different advanced machining processes, which are available, EDM is the process, whose application is presented in this paper for the machining of insulating ceramics. EDM is a non-contact thermal machining process, which produces controlled and spatially discrete high frequency electric discharges to remove material from the work piece leaving craters. The electric discharges take place between the tool electrode and the work piece electrode in a dielectric fluid at the point of minimum distance between the two, creating a channel of plasma that facilitates the migration of ions and electrons between the electrodes. The electrons move towards the anode and strike the anode, removing material from its surface. Similar process occurs at the cathode with material removal taking place due to ions. The temperature of the plasma may be as high as 20000◦C [16]. Another advantage of the EDM process is the multi furious avenues it can offer by changing the basic configuration of the machining setup. Kumar [17] presented favorable machining conditions for the surface alloying to take place during the machining process. Chi *et al.* [18] fabricated micro-spiral structure using the electric discharge deposition process in air. Many studies have been conducted to analyze the process details and find optimal conditions in this machining process Electrical charge of high-frequency current through the electrode to the work piece. This removes (erodes) very tiny pieces of metal from the work piece at a controlled rate. Localized regions of very high temperatures are formed. Work piece material in this localized zone melts and vaporizes [19]. Most of the molten and vaporized material is carried away from the inter-electrode gap by the dielectric flowing, in the form of debris particles. Drilling is a process used to produce holes inside solid parts. The tool is rotated and also moved in the axial direction. Drilling is used to create tiny round holes in different advanced materials such as super alloys, ceramics and composites.

In the present research work, L_{27} orthogonal array is used for electrical discharge drilling of mild steel sheet by using brass electrode. Discharge current, pulse on time, pulse off time and dielectric pressure have been selected as machining parameters and hole circularity at Entry and Exit as output parameters.

2. Experimental procedure

2.1 Experimental setup and machining parameter selection

This experimental work was carried out on EDM, model innovative Automation Product (IAP) 3X-spark DRO (EDM-Drill) with a DC stepper motor which continuously maintaining the constant gap voltage between electrode and work material. Hole were made in a 2mm thick plate of mild steel using single hole brass tubular electrode of diameter of 1mm and length 400 mm tool was used for experiments and the chemical compositions of mild steel and brass are shown in Table 1 and Table 2. The mild steel plate after drilling is shown in Fig.4.Deionized water was used as dielectric fluid. The machine tool has four process parameters viz. pulse on time, pulse off time, discharge current and distilled water pressure in table 3 [20] and a series of pilot experiments were performed to determine their feasible range in which a desired through hole can be achieved. In the present study (with four machining parameters each at three levels), choice of L_9 and L_{27} orthogonal arrays (OAs), both were possible but for the sake of higher resolution factor L_{27} OA was considered for experimentation.

Table 1: Chemical composition of mild steel

C	Si	Mn	S	P	Fe
0.16-0.18%	0.40%max	0.70%-0.90%	0.040%	0.040%	Remaining

Table 2: Chemical composition of brass electrode

Chemical Composition	Percentage
Copper	56.7
Aluminum	0.03
Tin	0.02
Phosphorous	0.02
Lead	3
Iron	0.1
Zinc	39.85
Nickel	0.08

Table 3: Control factors and their levels

Symbol	Parameter	Unit	Levels		
			1	2	3
X_1	Pulse on time(T_{on})	(μs)	2	4	6
X_2	Pulse off ime(T_{off})	(μs)	1	3	5
X_3	Dist. Pressure(P_d)	(kg/cm^2)	70	80	90
X_4	Current(I)	(Amp)	3	6	9

Evaluation of response variable

$$C_{ent} = \frac{(d_{min.})entrance}{(d_{max.})entrance} \quad (1)$$

The d_{min} and d_{max} are the values of minimum and maximum diameters, respectively, out of the four readings (i.e., d_1 to d_4) for each hole.

The mathematical value of C_{ent} has been calculated using equations (3) as follows:

$$C_{exit} = \frac{(d_{min.})exit}{(d_{max.})exit} \quad (2)$$

Weren't' is the sheet thickness and d_{ent} is the diameter of hole at entrance. The d_{min} and d_{max} are the values of minimum and maximum diameters respectively, out of the four readings (i.e., d_1 to d_4) for each hole.

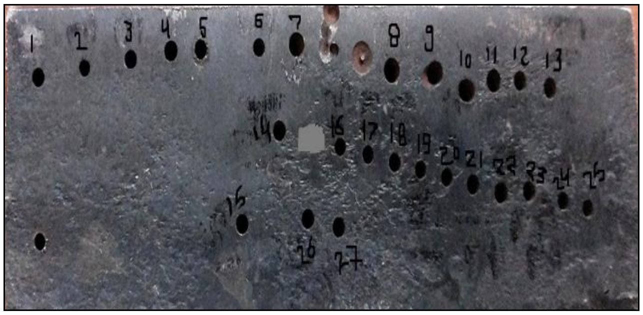

Fig 1: Specimen after EDM drilling

Table 4: Analysis of variance (ANOVA) for C_{entry}

Source	DF	Seq SS	AdJ MS	F	P
Pulse on time	2	0.067049	0.033525	3.49	0.052
Pulse off time	2	0.000203	0.000102	0.01	0.989
Distilled water	2	0.006788	0.003394	0.35	0.707
Discharge current	2	0.108727	0.054363	5.66	0.012
ERROR	18	0.172789	0.009599		
Total	26	0.355556			

Table 5: Analysis of variance (ANOVA) for C_{exit}

Source	DF	Seq SS	AdJ MS	F	P
Pulse on time	2	0.000720	0.000360	0.11	0.895
Pulse off time	2	0.006348	0.003174	0.99	0.392
Distilled water	2	0.001800	0.000900	0.28	0.759
Discharge current	2	0.010884	0.005442	1.69	0.212
ERROR	18	0.057826	0.003213		
Total	26	0.077579			

Results of analysis of variance (From Table 4 & 5) indicate that distilled water is the most significant machining parameter for affecting the multiple performance characteristics.

The response table was given in Table 6 &7. It was exhibited that the large value is the stronger effect of factor from the both table, A2B1C3D3 (4µs, 1µs, 90 kg/cm^2, 9A) and A1B3C2D2 (2µs, 5µs, 80 kg/cm^2, 6A) were found the optimum level. When the difference between the factors A, B, C and D were compared, it is observed that the D's was bigger than for C_{entry} and C_{exit} than other factors. Fig. 2 & Fig. 3 show the Main effects plot graph for C_{entry} and C_{exit} [23]. And the dash line indicated in Fig. 2 & Fig. 3 is the value of the total mean of Main effects plot. Table 6&Table 7 show the Response table for C_{entry} & C_{exit}. It's indicated that discharge currenthas greatest contribution for C_{entry} and C_{exit}.

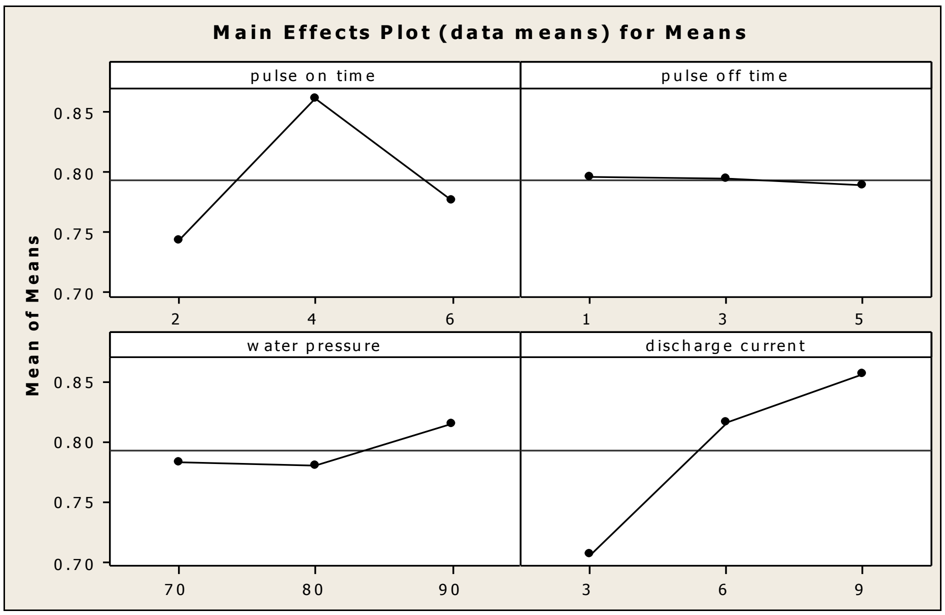

Fig 2: Main effects plot for means (GRG)

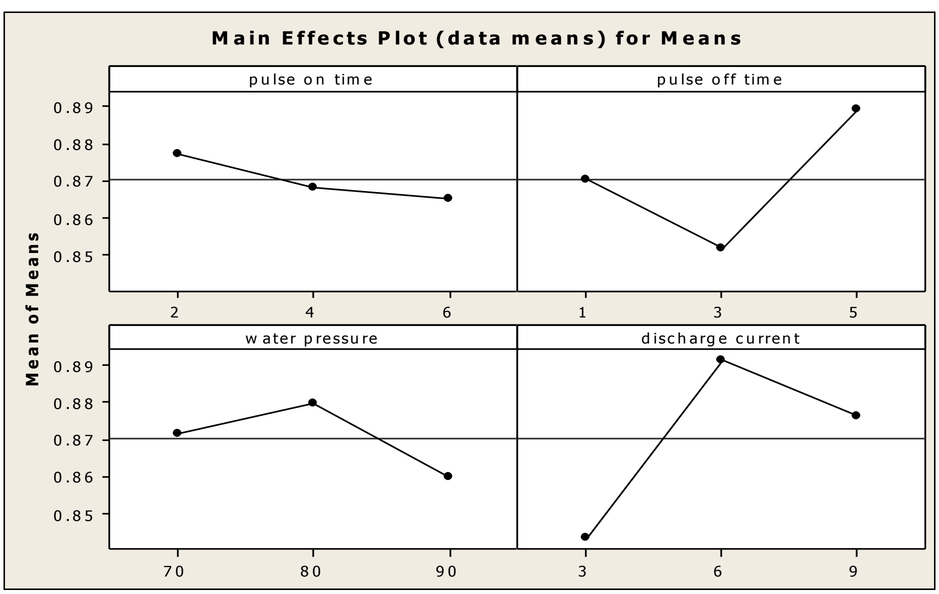

Fig 2: Main effects plot for C_{exit}

Table 6: Response table for C_{entry}

EDM drilling parameter	Average grey relational grade by factor level			Max–min
	Level 1	Level 2	Level 3	
1	0.7420	0.8604	0.7757	0.1184
2	0.7952	0.7940	0.7889	0.0063
3	0.7822	0.7808	0.8151	0.0343
4	0.7060	0.8160	0.8561	0.1501

Table 7: Response table for C_{exit}

EDM drilling parameter	Average grey relational grade by factor level			Max–min
	Level 1	Level 2	Level 3	
1	0.8773	0.8681	0.8652	0.0121
2	0.8700	0.8516	0.8891	0.0376
3	0.8714	0.8796	0.8597	0.0199
4	0.8432	0.8913	0.8761	0.0481

3. Regression Modelling

Usually, regression analysis method is used to obtain the relation between machining parameters and performances. In this study, linear regression analysis was used to establish a mathematical model between the experimentally obtained hole circularity at entry and exit values and micro drilling parameters. The regression equation of can be calculated as follows.

The regression equation is

$C_{entry} = 0.65 + 0.236 X_1 - 0.171 X_2 - 0.0081 X_3 + 0.0771 X_4 - 0.0212 X_1*X_1 - 0.00540 X_2*X_2 + 0.000008 X_3*X_3 - 0.00918 X_4*X_4 + 0.0113 X_1*X_2- 0.000627 X_1*X_3 - 0.00683 X_1*X_4 + 0.00170 X_2*X_3 + 0.00212 X_2*X_4 + 0.000962 X_3*X_4$

The regression equation is

$C_{exit} = 1.40 - 0.0330 X1 - 0.0887 X2 - 0.0110 X3 + 0.0804 X4 - 0.0121 X1*X1+ 0.00292X2*X2 + 0.000067 X3*X3 - 0.00222 X4*X4 + 0.00750 X1*X2 + 0.000633 X1*X3 + 0.00493X1*X4+0.000756X2*X3-0.00289X2*X4- 0.000778 X3*X4$

4. Model Validation

To validate the developed models, the S-values and coefficients of determination (R2and adjusted- R^2 values) have been calculated for each model. These values for all three responses are mentioned in Table 8.

Table 8: Regression parameters of reduce models

Response	Regression parameters		
	S value	$R^{2\,(\%)}$	Adjusted-R^2 (%)
C_{entry}	0.0387285	93.5%	86.0%
C_{exit}	0.0288611	91.3%	81.1%

5. Conclusions

In this study, the effects of EDD parameters such as pulse on time, pulse off time, distilled water pressure and discharge current on machining characteristics of Mild Steel was investigated. Summarizing the main features of the results, the following conclusions may be drawn:

1. According to the response table for C_{entry} & C_{exit}, The discharge current has greater effect on multi performance characteristics than other parameters.
2. The optimal parameters combination was determined as A1B3C2D2 for C_{entry} i.e. Pulse on time at 2μs, pulse off at time 5μs, distilled water pressure at 80kg/cm^2 and discharge current at 6Amp and A2B1C3D3 for C_{exit} i.e. Pulse on time at 4μs, pulse off at time 1μs, distilled water pressure at 90kg/cm^2 and discharge current at 9Amp.
3. Response table for C_{entry} & C_{exit} indicated that Discharge current has greatest contribution for HT and HD.

6. References

1. KH Ho, ST Newman. "State of the Art Electrical Discharge Machining (EDM)", International Journal of Machine Tool and Manufacture. 2003; 43:1287-1300.
2. S Kumar, R Singh, TP Singh, BL Sethi. "Surface Modification by Electrical Discharge Machining: A review", Journal of Materials Processing Technology. 2009; 209:3675-3687.
3. HC Tsai, BH Yan, FY Huang. "EDM Performance of Cr/Cu-based Composite Electrodes", International Journal of Machine Tools Manufacture. 2003; 43:245-252.
4. EI Shobert. "What Happens in EDM: E.C. Jameson (Ed.), Electrical Discharge Machining: Tooling, Methods and Applications" Society of Manufacturing Engineers, Dearbern, Michigan, 1983, pp.3-4.
5. G Boothroyd, AK Winston. "Non-conventional Machining Processes", Fundamentals of Machining and Machine Tools, Marcel Dekker, Inc., New York, 1989, pp.491.
6. JA McGeough. "Electro Discharge Machining: Advanced Methods of Machining", Chapman & Hall, London, 1988, pp.130.
7. SF Krar, AF Check. "Electrical Discharge Machining: Technology of Machine Tools", Glencoe/McGraw-Hill, New York, 1997, pp.800.
8. F Klocke, W Koenig. Fertigungsverfahren 3 - Abtragen, GenerierenLasermaterialbearbeitung. Auflage, 2007, 4.
9. BM Schumacher. After 60 years of EDM the discharge process remains still disputed. Journal of Materials Processing Technology. 2004; 149:376-381.
10. E Brinksmeier, F Klocke, D Lucca, J Sölter, D Meyer. Process Signatures A New Approach to Solve the Inverse Surface Integrity Problem in Machining Processes. Procedia CIRP. 2014; 13:429-434.
11. E Brinksmeier, R Gläbe, F Klocke. "Process Signatures an Alternative Approach to Predicting Functional Work piece Properties," Procedia Engineering. 2011; 19:44-52.
12. B Bhattacharya, BN Doloi, SK Sorkhel. "Experimental investigations into electro chemical discharge machining (ECDM) of non-conductive ceramic materials," J Mater Process Technology. 1999; 95:145-54.
13. MM. Schwartz, Engineering applications of ceramic materials, Source book. Ohio, American Society for Metals Metals Park, 1985.
14. YH Liu, XP Li, RJ Ji, LL Yu, HF Zhang, QY Li. "Effect of technological parameteron the process performance for electric discharge milling of insulating Al2O3 ceramic." J Mater Process Technology. 2008; 208:245-50.

15. Anon. USA advanced ceramics demand, Mater Technology. 2005; 20:168-175.
16. Y Fukuzawa, N Mohri, H Gotoh, T Tani. “Three-dimensional machining ofinsulating ceramics materials with electrical discharge machining,” Trans Non-ferrous Met Soc China. 2009; 19:150-160.
17. S Kumar. “An experimental study of the phenomenon of surface alloying by EDM process using Inconel tool electrode,” ASME, 2013, International Manufacturing Science and Engineering Conference Collocated with the 41st North American Manufacturing Research Conference, 1. V001T01A040, 1-8.10.1115/MSEC2013-1014.
18. G Chi, Z Wang, K Xiao, K Cui, B Jin. “The fabrication of a micro-spiral structure using EDM deposition in the air, “J MicromechMicroeng. 2008; 18:1-9.
19. AK Pandey, AK Dubey. Multiple quality optimization in laser cutting of difficult-to-laser-cut material using grey–fuzzy methodology, International journal of advanced manufacturing technology. 2013; 65:421-431.
20. AK Pandey, AK Dubey. Taguchi based fuzzy logic optimization of multiple quality characteristics in laser cutting of Duralumin Sheet, Optics and lasers in engineering. 2012; 50:328-335.
21. Lin JL, Lin CL. The use of the orthogonal array with grey relational analysis to optimize the electrical discharge machining process with multiple performance characteristics, International Journal of Machine Tools & Manufacture. 2004; 44:237-244.
22. JL Deng. Basic methods of Grey system, Journal of Grey System. 1987; 1:1-24.
23. Ng David, KW Grey. System and grey relational model, ACM SIGICE Bulletin. 1994; 20:1-9.
24. CK Chang, HS Lu. Design optimization of cutting parameters for side milling operations with multiple performance characteristics, International Journal of Advanced Manufacturing Technology. 2007; 32:18-2
25. LK Pan, CC Wang, SL Wei, HF Sher. Optimizing multiple quality characteristics via Taguchi method-based grey analysis, Journal of Material Processing Technology. 2007; 182:107-116.