INVESTIGATION ON THE EFFECT OF PROCESS PARAMETERS IN ELECTRICAL DISCHARGE MACHINING

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Abstract: ***Electrical discharge machining (EDM) is a non-conventional metal removal process as well as one of the best manufacturing processes suitable for producing jigs, fixtures, and dies. Among others, the advance EDM machine is able to cut a workpiece having oblique and taper form. The objective of this paper is to optimize the input parameters of EDM machine, such as discharge current, pulse on-time, pulse off-time, dielectric level and flushing pressure for machining AISI H13 tool steel.***

The Taguchi design of experiments, the signal-to noise ratio, and analysis of variance are employed to analyze the effects of the input parameters by adopting L27 Taguchi orthogonal array (OA) to conduct experiments. In order to achieve the minimum surface roughness (SR), five controllable factors, i.e., the parameters of each at three levels are applied for determining the optimal combination of factors and levels. The results reveal that the SR is greatly influenced by the discharge current. Experimental results affirm the effectiveness of the method, and also prove that the Taguchi method is suitable to solving the stated problem within minimum number of experiments as compared to that of a full factorial design.

Index Terms: Electrical Discharge Machining, Surface roughness, Taguchi method.

I. INTRODUCTION

Machining processes are indispensable in the manufacturing industries. In addition, the advance material technology attests that more and more products can hardly be manufactured using conventional machining processes. Therefore, non-conventional machining processes have been developed to overcome the shortcoming of conventional machining processes. Non-conventional machining processes have some advantages, such as accuracy, precision, quality, ability to cut high-strength materials, and the ability to perform complex cutting motions on workpiece having complex shapes.

However, the processes also have a weakness in terms of lower productivity in comparison to that of conventional machining processes. Electrical discharge machining (EDM) is a non-conventional machining process for performing material reduction which is accomplished by the virtue of erosion caused by the electric spark discharge process. EDM has become today's most popular non-conventional production process. EDM can be categorized into three processes, i.e., sinking EDM, cutting EDM, and grinding EDM processes. The sinking EDM includes drilling EDM, deep sinking EDM, planetary EDM, and contouring EDM processes. Currently there are various types of cutting EDM machines including disc-, ribbon-, or wire-shaped tools (Wire EDM) cutting processes [1, 2]. EDM is a non-conventional process by which material is eroded by electric discharge occurring in a small gap between the tool (cathode) and the workpiece (anode).

EDM is frequently employed to produce dies and molds. Unfortunately the availability of machining data with regard to the precise input parameters to obtain optimum results is very limited.

A number of researches have been conducted to optimize the turning machining parameters affecting the surface roughness (SR), cutting force, and tool lifetime by using Taguchi method alongside with response surface methodology and Grey relational method [1-4]. Taguchi method has also been applied in optimization of drilling machining parameters effecting the surface finish and dimensional accuracy [3-9]. Many researchers have also adopted Taguchi method to examine the effects of end mill, flank mill, and pocket milling processes on the optimum SR and product dimensions.

They also complemented Taguchi method with Grey relational method, response surface methodology, and fuzzy logic [10-15]. As is also the case with EDM machining process, many researches implemented Taguchi method to optimize EDM machining parameters for sinking EDM, rotary EDM, and for machining certain types of metal and composite materials [16-20].

This research aims to examine the correlation between EDM input parameters and SR, and to optimize the application of Taguchi method in determining the input parameter values resulting in optimum SR. To achieve the aims, the research activities are focused on and narrowed down to the followings:

- The EDM input parameters in the optimization considered are the discharge current (Ip), pulse on-time (Ton), pulse off-time (Toff), dielectric level (DL) and flushing pressure (FP).
- The machining process optimized response functions
- Considered SR
- AISI H13 tool steel was employed for the experiments

II. APPLICATION OF EDM

1. The EDM process is most widely used by the mould-making tool and die industries, but is becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries in which production quantities are relatively low.
2. It is used to machine extremely hard materials that are difficult to machine like alloys, tool steels, tungsten carbides etc.
3. It is used for forging, extrusion, wire drawing, thread cutting.
4. It is used for drilling of curved holes.
5. It is used for internal thread cutting and helical gear cutting.
6. It is used for machining sharp edges and corners that cannot be machined effectively by other machining processes.
7. Higher Tolerance limits can be obtained in EDM machining. Hence areas that require higher surface accuracy use the EDM machining process.
8. Ceramic materials that are difficult to machine can be machined by the EDM machining process.
9. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D areas.
10. It is a promising technique to meet increasing demands for smaller components usually highly complicated, multi-functional parts used in the field of micro-electronics.

III. EXPERIMENTAL WORK

3.1 The Equipment

The EDM used in this research is model ELECTRONICA- ELECTRAPULS PS 50ZNC with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. The maximum allowable dimension of workpiece on the machine is 200 mm x 150 mm x 250 mm.

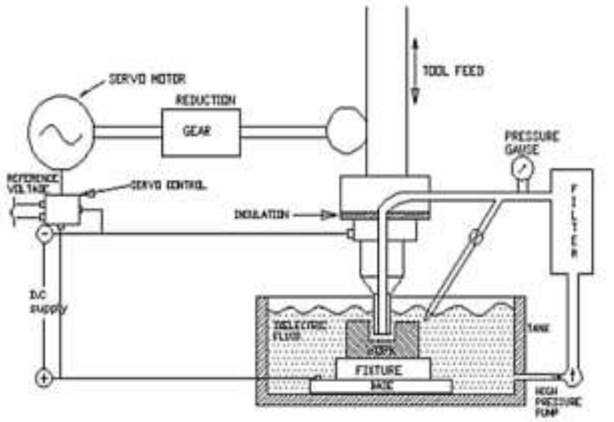

Fig. 1 EDM Process

EDM is a non-conventional machining process capable of cutting very hard and strong materials. EDM can be performed only on conductive workpiece materials because EDMs working principle is based on electrical discharge of sparks between the electrode and the workpiece. Schematically, EDM working principle is shown in Fig. 1.

In EDM process, the workpiece is clamped on the worktable and is cut using electrical discharges produced by the electrode. Electrical Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.

The components of EDM process are as follows:

- **The workpiece**

The workpiece hardness is not a significant factor in EDM process. The main requirement for the workpiece material is that of a conductor.

- **The dielectric fluid**

The dielectric fluid functions as the tool, the workpiece coolant, and the insulating agent in the gap between the tool and the workpiece. When the fluid is ionized, it enables the electrical discharges and it pushes off chips from the gap. The dielectric fluid used in the process is commercial grade EDM oil (specific gravity= 0.763, freezing point= 94°C).

3.2 Machining parameters

Machining parameters can affect SR. EDM process parameters consist of

(a) **Spark On-time (pulse time or Ton):** The duration of time (μs) the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time.

(b) **Spark Off-time (pause time or Toff):** The duration of time (μs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable.

(c) **Arc gap (or gap):** The Arc gap is distance between the electrode and workpiece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system (fig 1).

(d) **Discharge current (current Ip):** Current is measured in amp Allowed to per cycle. Discharge current is directly proportional to the Material removal rate.

(e) **Duty cycle (τ):** It is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time pulse off time).

(f) **Voltage (V):** It is a potential that can be measure by volt it is also effect to the material removal rate and allowed to per cycle. Voltage is given by in this experiment is 50 V.

(g) **Electrode size:** The electrode used in the research is a cupper of 8 mm x 3.78 mm in size.

(h) **Over cut –** It is a clearance per side between the electrode and the workpiece after the marching operation.

(i) **Dielectric level** - Dielectric level is measured in mm.

(j) **Flushing Pressure -** The dielectric fluid functions as the tool, the workpiece coolant, and the insulating agent in the gap between the tool and the workpiece. The experimental studies were conducted under varying dielectric flushing pressure.

3.3 The Work piece and the Electrode Materials

The material selected as the workpiece is H13 tool steel having the composition of 0.39 C, 1 Si, 0.4 Mn, 5.2 Cr, 1.4 Mo, 0.9 V and 0.04 S in percent of weight. The material is commonly used for producing punch holders, die holders, guide plates, jigs, fixtures, and simple bending dies. The shape of the workpiece is a slab of 110 mm x 40 mm x 14 mm in dimension. The electrode used in the research is a cupper of 8 mm x 3.78 mm in size.

IV. DESIGN OF EXPERIMENTS

Traditional design of experiments procedures are too complicated and difficult of a task to be executed where a huge number of experimental works need to be carried out in accordance with the combinatorial array of the input parameters. Moreover, the traditional experiment conducts a very cumbersome one-factor-at-a-time experiments in which each and every one of the variables shall be varied while holding the others constant [21].

The major limitation of this method is that it fails to recognize the possibility of interactions among the parameters. To resolve this problem the Taguchi method arranges a special design of orthogonal arrays (OAs) to study the entire input parameters in much less number of experiments. Taguchi's philosophy which was originated by Dr. Taguchi [21] is an efficient tool for designing high-quality manufacturing systems. The method is based on OA experiments requiring much reduced combinatorial arrangement of the experiment; nevertheless it is capable of resulting in optimal setting of process control parameters. In addition, OA dictates fewer experimental runs and provides the Taguchi's signal-to-noise (S/N) ratios.

In turns, Taguchi method has gained its recognition for undertaking engineering analysis. The method consists of hatching a plan of experiments which objective is to acquiring data in a controlled manner, i.e., to obtain information regarding the behavior of a given process. The most pronounced benefits of the method are in reducing the required number of experiments, the time of carrying out the experiments, and the cost of executing the experiments. Finally, Taguchi method is also capable of quickly concluding the significant factors determining the process.

The parameter design is a systematic approach to improve the product quality and to reduce the production cost by minimizing the sensitivity to noise factors. The mean and the variance of a response are formulated into a single performance measure known as the S/N ratio. Taguchi classifies parameter design problems into different categories depending on the goal of the researcher. The standard S/N ratios generally used are as follows:

- Nominal the best characteristic
  $$S/N = 10\ log \frac{\bar{y}}{s_y^2} \qquad (1)$$
- Larger the better characteristic
  $$S/N = -10\ log \frac{1}{n}\left(\sum \frac{1}{y^2}\right) \qquad (2)$$
- Smaller the better characteristic
  $$S/N = -10\ log \frac{1}{n}\left(\sum y^2\right) \qquad (3)$$

Where $\bar{y}$ is the average of observed data, y is the observed data, s_y^2 is the variance of data and n is number of observation. In addition to the *S/N* ration, statistical analysis of variance (ANOVA) can be employed to indicate the effect of input parameter on the response function.

The steps in the Taguchi experimental design are:

1. to select the output function response to be optimized,
2. to identify the factors affecting output functions and to choose the levels of these factors,
3. to select the appropriate OA,
4. to assign factors and interactions to the columns or the array,
5. to perform experiments,
6. to analyze the result using *S/N* ratio analysis and ANOVA
7. to determine the optimal input parameters, and
8. to perform confirmatory experiments.

The range of input parameter and the number of levels of the design are given in the Table 1. The present experimental design adopts Taguchi's L27 of OA with each design parameter having three levels. The experimental arrangement of this study is shown in Table 2.

Table 1 Selected Parameters and their Levels

Control Factors	Levels 1	2	3	Unit
Ip	4	6	8	Amp
Ton	28	38	48	µs
Toff	7	8	9	µs
DL	20	40	60	mm
FP	0.3	0.5	0.7	Kg/cm2

Table 2 Selected Parameters and their Levels

Experimental Number	Control factors Ip	Ton	Toff	DL	FP	SR Ra (µm)	*S/N* ratio
1	4	28	7	20	0.3	2.633	-8.409
2	4	28	7	20	0.5	2.057	-6.2647
3	4	28	7	20	0.7	2.695	-8.6112
4	4	38	8	40	0.3	1.836	-5.2775
5	4	38	8	40	0.5	2.197	-6.8366
6	4	38	8	40	0.7	1.536	-3.7278
7	4	48	9	60	0.3	1.561	-3.8681
8	4	48	9	60	0.5	1.551	-3.8122
9	4	48	9	60	0.7	1.481	-3.4111
10	6	28	8	60	0.3	2.842	-9.0725
11	6	28	8	60	0.5	2.813	-8.9834
12	6	28	8	60	0.7	2.593	-8.2761
13	6	38	9	20	0.3	2.425	-7.6942
14	6	38	9	20	0.5	1.925	-5.6886
15	6	38	9	20	0.7	2.129	-6.5635
16	6	48	7	40	0.3	2.542	-8.1035
17	6	48	7	40	0.5	2.209	-6.8839
18	6	48	7	40	0.7	2.437	-7.7371
19	8	28	9	40	0.3	3.313	-10.4044
20	8	28	9	40	0.5	2.957	-9.417
21	8	28	9	40	0.7	3.424	-10.6907
22	8	38	7	60	0.3	3.042	-9.6632
23	8	38	7	60	0.5	3.21	-10.1301
24	8	38	7	60	0.7	3.176	-10.0376
25	8	48	8	20	0.3	3.051	-9.6888
26	8	48	8	20	0.5	2.325	-7.3285
27	8	48	8	20	0.7	2.65	-8.4649

Table 3 Analysis of Variance for *S/N* Ratios

Control factors	DOF	Sum of Squares	Mean Square	F	P	Factor Effect (%)
Ip	2	1.27	0.635	61.64	0	44.19
Ton	2	0.537	0.269	26.07	0	18.69
Toff	2	0.398	0.199	19.32	0.03	13.85
DL	2	0.283	0.142	13.74	0	9.85
FP	2	0.386	0.193	18.73	0	13.43
Error	16	0.305	0.01			
Total	26	2.874				

V. EXPERIMENTAL RESULTS AND ANALYSIS (OPTIMAL COMBINATION OF INPUT PARAMETERS)

This research aims to optimize SR. Therefore, constituting 'the smaller-the-better' principle of the S/N ratio for the SR. SR is measured using Mitutoyo SURFTEST SJ-210 surface roughness measuring apparatus. The results of experiment for SR are shown in Table 2 and the corresponding S/N ratios calculated according to Eqs. 3 are shown in Table 2.

The optimum setting is the parameter combination which has the highest S/N ratio. The S/N ratio for each parameter at different levels for SR is plotted in Figure 2. Figure 2 shows that the smallest SR can be achieved by setting the following control factors: Ip = 4 Amp, Ton = 48 µs, Toff = 9 µs, DL = 20 mm and FP = 0.5 kg/cm2.

Applying ANOVA, the effect of each input parameter on SR can be determined. Tables 3 illustrate the results of the ANOVA correspond to the SR of machining H13 tool steel. Based on the calculation resumed in Table 3 it is clear that Ip is the parameter most significantly affects SR at 44.19 % of factor effect, followed by Ton, Toff, FP and then DL at 18.69%, 13.85 %, 13.43 % and 9.85 % factor effect respectively.

In addition, statistical box-plots of the relations found in ANOVA analysis are shown in Fig. 2 to study their relations.

Figure 2 shows that higher values of Ip produce lower SR values although a higher dispersion of the values is also produced.

5.1 Confirmation Experiments

Validation of the machining process optimization is produced by carrying out confirmation experiments implementing the assigned input parameters. The confirmation experiment results show an SR of 1.499 µm, which is very close to the predicted result (1.21 % difference). It is obvious that the optimum parameters were close to the confirmation experiments.

VI. CONCLUSIONS

The result inquires the optimum EDM process employing Taguchi method. The application of Taguchi method in the analysis of experimental result yields the following conclusion.

The surface roughness increases with the increase in discharge current. The surface roughness decreases with the increase of pulse on-time and pulse off-time. Taguchi’s robust Orthogonal Array design method is suitable to analyze the surface roughness problem as described in this research work.

It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the cutting parameter.

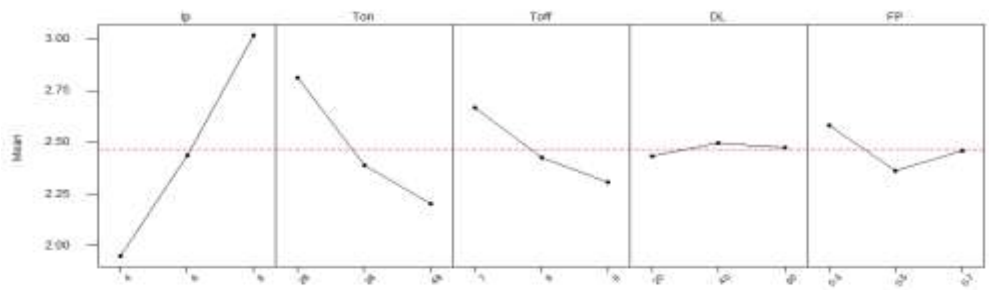

Figure 2. Mean S/N Ratio Graph for SR

Analysis of variance indicates that P-values are less than 0.05, as shown in table these factors have a statistically significant effect at the 95.0% confidence level.

To obtain the smaller SR, the following parameter are recommended Ip = 4 Amp, Ton = 48 µs, Toff = 9 µs, DL = 20 mm and FP = 0.5 kg/cm2.

With a factor effect value of 44.19%, Ip parameter proves to be most significant for SR followed by Ton, Toff, FP and then DL at 18.69%, 13.85 %, 13.43 % and 9.85 % factor effect respectively.

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REFERENCES

[1] S. Kalpakjian, S.R. Schmid, Manufacturing Engineering and Technology, 5th edn. (Prentice Hall, Singapore City, 2006)

[2] A. Bhattacharyya, New Technology (The Institution of Engineers (India), Calcutta, 1977)

[3] El-Taweel, T.A., 2009. Multi-response optimization of EDM with Al-Cu-Si-tic P/M composite electrode. International Journal of Advanced Manufacturing Technology, 44(1-2), 100-113.

[4] Lin, y., Cheng, C., Su, B and Hwang, L, 2006. Machining characteristics and optimization of machining parameters of SKH 57 high-speed steel using electrical-discharge machining based on Taguchi method. Materials and Manufacturing Processes, 21(8), 922-929.

[5] Jagadish, Ray A., 2014, Optimization of process parameters of green electrical discharge machining using principal component analysis (PCA), Int J Adv Manuf Technol, 1-13

[6] Jagadish, Ray A., 2014, Optimization of Green Electrical Discharge Machining Using an Integrated Approach, Proceedings of the 2014 IEEE IEEM

[7] Lee, S.H. and Li, X.P., 2001. Study of the effect of machining parameters on the machining characteristics in electrical discharge machining of tungsten carbide. Journal of Materials Processing Technology, 115(3), 344-358.

[8] Puertas, I. And Luis, C.J., 2004. A study of optimization of machining parameters for electrical discharge machining of boron carbide. Materials and Manufacturing Processes, 19(6), 1041-1070.

[9] Tsai, H.C., Yan, B.H. and Huang, F.Y., 2003. EDM performance of Cr/Cu-based composite electrodes. International Journal of Machine Tools and Manufacture, 43(3), 245-252.

[10] Habib, S. S. (2009). Study of the parameters in electrical discharge machining through response surface methodology approach. Applied Mathematical Modelling, 33(12), 4397-4407.

[11] Balasubramanian, P., Senthilvelan, T., 2014. Optimization of Machining Parameters in EDM process using Cast and Sintered Copper Electrodes. 3rd International Conference on Materials Processing and Characterisation (ICMPC 2014), 1292 – 1302

[12] Sohani, M.S., Gaitonde, V.N., Siddeswarappa, B. And Deshpande, A.S., 2009. Investigations into the effect of tool shapes with size factor consideration in sink electrical discharge machining (EDM) process. International Journal of Advanced Manufacturing Technology, , 1-15.

[13] Izquierdo, B., Sánchez, J.A., Plaza, S., Pombo, I. And Ortega, N., 2009. A numerical model of the EDM process considering the effect of multiple discharges. International Journal of Machine Tools and Manufacture, 49(3-4), 220-229.

[14] Wei; Bin, and Lee; Martin Kin-fei April 16, 2002. Apparatus and method for electrical discharge machining multiple holes United States Patent 6,373,018, et al.

[15] Kung, K.-., Horng, J.-. and Chiang, K.-., 2009. Material removal rate and electrode wear ratio study on the powder mixed electrical discharge machining of cobalt-bonded tungsten carbide. International Journal of Advanced Manufacturing Technology, 40(1-2), 95-104.

[16] Ding, S. and Jiang, R., 2004. Tool path generation for 4-axis contour EDM rough machining. International Journal of Machine Tools and Manufacture, 44(14), 1493-1502

[17] Chorng-Jyh Tzeng, Rui-Yang Chen, 2013, Optimization of Electric Discharge Machining Process Using the Response Surface Methodology and Genetic Algorithm Approach. International Journal of Precision Engineering and Manufacturing 14(5), 709-717

[18] Chang, Y.-. and Chiu, Z. 2004. Electrode wear-compensation of electric discharge scanning process using a robust gap-control. Mechatronics, 14(10), 1121-1139.

[19] Singh, S. and Maheshwari, S. Anf Pandey, P. (2004). Some investigations into the electric discharge machining of hardened tool steel using different electrode materials. Journal of Materials Processing Technology, 149(1-3):272–277.

[20] Hascalık, A., Caydas, U., "Optimization of turning parameters for surface roughness and tool life based on the Taguchi method", Int J Adv Manuf Technol, 2008, pp. 896–903.

[21] Nalbant, M., Gokkaya H., Sur G., "Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning", Materials and Design, 2007, No. 28, pp. 1379–1385.