Electrical Discharge Machining of AISI P-20 tool Steel using Taguchi Technique

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Abstract— The present work is aimed to optimize the Electric Discharge Machine input parameters like current (Ip), Pulse-on-time (Ton) and electrode diameter (D) on output parameters like overcut. The experiments are carried out on AISI P-20 tool steel work-piece. Eighteen (18) experiments have been conducted with these input parameters in three different levels & measured for each of the experiments run. Effects of These parameters have been optimized by Taguchi technique. It is observed that for optimal results, it has been found that current (Ip) 5Amp, pulse-on-time (Ton) 1000μs and electrode diameter (D) 6mm, which are the best combination of this analysis. ANOVA find the significant parameters of the experiments.

keywords — EDM, Taguchi technique, overcut, ANOVA, S/N ratio

1. Introduction

Electrical Discharge Machining is a capable of machining geometrically complex or hard material components, that are precise and difficult to machine such as heat treated tool steels, composites, supper alloy, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics ad nuclear industries [1]. It is the discharge by which the machined hole in the work piece exceeds the tool size and is determined by both the initiating voltage and the discharge energy [2]. During the process of machining EDM cavity produced are always larger than the tool this deference (size of tool and cavity) is called Over Cut (OC). It becomes important when close tolerance components are required to be produced for space application and also in tools, dies and moulds for press work. Khan [3] investigated tool wear and material removal rate during Electric Discharge Machining of aluminium and mild steel using different types of (copper and Brass) electrodes and concluded that tool wear is more during machining along their cross section than along its length. Copper electrode wear less as compare to brass electrode because the thermal conductivity of copper is higher than brass. Malhotra et. al. [4] investigated the control parameters for surface roughness inside flushing from a die sink EDM and concluded that experimental investigation on the effect of current, pulse on time, spark Gap, voltage, duty cycle and flushing pressure on surface roughness wear rate when using EDM on EN-31 Die Steel using copper as electrode, and find current and pulse on time have maximum influence on surface roughness. Cydus and Hascalik [5] developed a model electrode wear (EW) and recast layer (WLT) through response surface methodology in a die sinking EDM process. For this purpose a central composite rotatable design (CCRD) involving three variables with five levels employed to establish a mathematical model between input parameters and responses (EW & WLT) and conclude that Pulse current was found the most important factor effecting the both EW and WLT, while pulse off-time has no significant effect on both responses. Bao et al. [6] Material removal and surface damage of Ti3SiC2 ceramic during electrical discharge machining (EDM) were investigated. As increasing in the discharge current, working voltage, but increased declaratively with pulse duration. Micro cracks in the surface and loose grains in the subsurface resulted from thermal shock were confirmed, and the surface damage in Ti3SiC2 ceramic led to a degradation of both strength and reliability. Lau et al [7] stated the feasibility of using Electrical Discharge Machining (EDM) as a means of machining CFRP materials. Machining was performed at various currents, pulse durations and with different tool materials and polarities and they concluded that it is entirely feasible machine carbon fiber composite materials by EDM process. Copper electrodes prove to be better than graphite electrodes in terms of tool wear rate and surface finish. On the basis of above study to optimize the Electric Discharge Machine input parameters like current (Ip), Pulse-on-time (Ton) and electrode diameter (D) on output parameters like overcut. Effects of these parameters have been optimized by Taguchi technique.

2. Experimentation

2.1 Material and Setup

The material used for the work-piece is a pre hardened high tensile tool steel (AISI P-20 tool steel). The chemical composition of AISI P-20 steel shown in Table 1. The electrode used in electrolytic copper (99.97% pure) of 8930 kgm^3 density with melting point of 1083^{0}C. These electrodes are U-shape with different diameters of 4mm and 6mm used in the experimentation. The machine used is ELECTRONICA- ELECTRA PULS PS 50ZNC (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. The dielectric fluid used for the EDM was an EDM oil 40 grade.

2.2 Design of Experiment (Taguchi Technique)

Taguchi's method is a power full design of experiments tool, which provides a simple, effective and systematic technique to determine optimal machining parameters. In this technique reduce drastically the number of experiments that are required to model response function. Traditional experimentation involved one factor at a time experiments, where in on e variable is changed while the rest are held constant [8]. It is also impossible to study all factors and determine the main effects in a signal experiment. The main effect is the average value of the response function at particular level of a parameter. The effect of a factor level is the deviation it causes from the overall mean response. Taguchi technique is devised for process optimization and identification of optimal combinations factors for given responses the steps involved are:

Step-1: Identify the main function, side effects, and failure made.
Step-2: Identify the noise factors, testing conditions, and quality characteristics.
Step-3: Identify the objective function to be optimized.
Step-4: Identify the control factors and their levels.
Step-5: Select the orthogonal array matrix experiment.
Step-6: Conducted the matrix experiment.
Step-7: Analyze the data; predict the optimal level and performance.
Step-8: Perform the verification experiment and plan the future action.

According to Taguchi technique, the characteristic that the large value represents better machining performance, such as Overcut, is called the-smaller-the-better type of problem. The S/N Ratio, i.e. η, can be calculated as shown below:

$$S/N \text{ ratio} = \eta = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_{Overcut}^{2}\right) \quad (1)$$

Where $y_{overcut,}$ denote the response for overcut, and n denotes the number of trials in each experiment.

The different setting of control factors chosen for the experiments are pulse-on-time (Ton), current (Ip) and Electrode diameter (D) while the response characteristics are overcut. According to capavality of the commercial EDM machine available and general recommendations of machining conditions for AISI P-20 tool steel the range and the number of the levels of the parameters are selected as given in Table 2.

Table-2 Setting of levels for control factors

Machining parameter	Symbol	Level			Unit
		I	II	III	
Pulse on time	T_{ON}	50	500	1000	μs
Electrode diameter	D	4	6	-	mm
Discharge current	I_P	1	3	5	A

2.3 Measurements

During the process of machining EDM cavity produced are always larger than the electrode this deference (size of electrode and cavity) is called Over Cut (OC). OC is expressed as half the difference of diameter of the hole produced to the tool diameter that is shown in these equations

$$oc = \frac{D_{jt} - D_t}{2}\ mm \quad (2)$$

Where D_{jt} = diameter of hole produced in the work-piece
D_t = Diameter of tool

2.4 Analysis of Variance (ANOVA)

ANOVA is a statically based, objective decision making tool for detecting any differences in average performance of groups of items tested [18]. An ANOVA table consists of sum of squares, corresponding degree of freedom, the F-ratio corresponding to the ratios of two mean squares, and the contribution proportions from each of the control factors. These contribution proportions can be used to assess the importance of each factor for interested multiple performance characteristics (MPCs). The total sum of squares, SS_T, in the ANOVA is:

$$S_T = \sum_{I=1}^{N}(Y_I - \bar{Y})^2 \quad (3)$$

This can be reduced to the following forms:

$$S_T = \sum_{I=1}^{N}\left(Y_I^2 - \frac{T^2}{N}\right) \quad (4)$$

Following a similar approach, the variation caused by an individual parameters, say A, is obtained an expression called the parameters sum of square as

$$S_A = \frac{A_1^2}{N_{A1}} + \frac{A_2^2}{N_{A2}} + \frac{A_3^2}{N_{A3}} - C.F \quad (5)$$

Where C.F. is the correction parameters ($= \frac{T^2}{N}$), N_{A1} the total number of experiments in which level 1 of parameters A is present, and A_1 the total results Y_1 that parameters A_1.

The total and parameters sum of square are the basic calculation needed for ANOVA table. Three another quantities calculated as parts of ANOVA table information are all derived from the original Sum of squares for factor A, they are follows:

$$\text{Mean Square (or Variance) } \mathbf{V_A} = \frac{S_A}{f_A} \quad (6)$$

$$\text{F - Ratio } \mathbf{F_A} = \frac{V_A}{V_e} \quad (7)$$

$$\text{Percentage Influence} = \frac{\text{Sum of squares of A}}{\text{Total Sum of squares}} \quad (8)$$

The total degrees of freedom needs to be computed an appropriate orthogonal array for the experiments. The degrees of freedom are defined, as the number of comparisons that needs to be made to determine which level is better.

3 Result and Discussion

Experiments are performed, randomly, according to the L_{18} orthogonal array, on an AISI P 20 tool steel. Each experiment a separate electrode used. The experimental results for over cut based on L_{18} orthogonal array is shown in Table 3. Analysis of the result, in fig. 1, this graphs are represent the diameter of tool is increase then over cut decrease. Increasing in the discharge current from 1 to 3 A the overcut is decreasing, with increase in discharge current from 3A to 5A the OC decreasing slightly. Coloum effect method some data associated with first level, second level and third level is noted that and difference of largest and smallest of three levels represents “Delta”. According this method priority level of significance factors, for the performance characteristics overcut, are follows, discharge current, electrode diameter and pulse on time shown in Table 4. Based on analysis of S/N ratio, the optimal machining performance for over cut was obtained as Electrode Diameter (Level 3), Ip (Level 3) and Ton (Level 3) gives minimization of over cut.

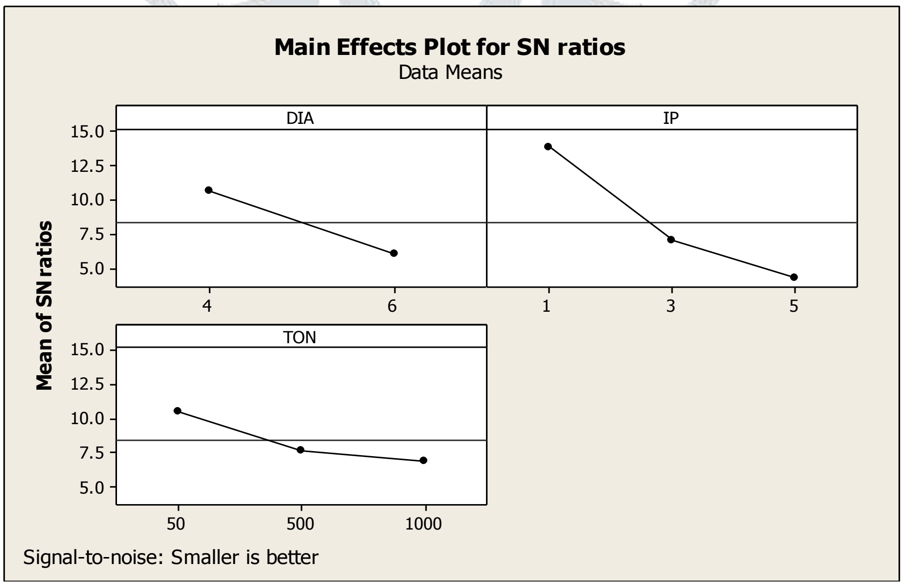

Fig.1 Main effect plot for S/N ratio Overcut

Table 3 Experimental results of overcut

Run order	D (mm)	Ip (A)	Ton (µs)	OC (mm)	S/N ratio (db)
1.	4	1	50	0.0710	22.974
2.	4	1	500	0.0895	20.963
3.	4	1	1000	0.1435	16.862
4.	4	3	50	0.3650	8.7541
5.	4	3	500	0.3720	8.5891
6.	4	3	1000	0.3790	8.4272
7.	4	5	50	0.6590	3.6222
8.	4	5	500	0.7940	2.0035
9.	4	5	1000	0.6140	4.2366
10.	6	1	50	0.1670	15.545
11.	6	1	500	0.5965	4.4877
12.	6	1	1000	0.7620	2.3609
13.	6	3	50	0.4225	7.4834
14.	6	3	500	0.5715	4.8596
15.	6	3	1000	0.6410	3.8628
16.	6	5	50	0.5770	4.7764
17.	6	5	500	0.5465	5.2481
18.	6	5	1000	0.5200	5.6799

Table 4 S/N ratio response table for OC

Level	D	Ip	Ton
1	10.714	13.866	10.526
2	6.034	6.996	7.692
3	-	4.260	6.904
Delta	4.680	9.606	1.622
Rank	**2**	**1**	**3**

Table 5 Analysis of Variance for Mean data for OC

Parameters	DF	SS	Adj SS	Variance	F-ratio	P
D	1	98.57	98.57	98.572	24.26	**(Significant) 0.008**
Ip	2	293.91	293.91	146.955	36.16	**(Significant) 0.003**
Ton	2	43.55	43.55	21.774	5.36	0.074
D × Ip	2	168.23	168.23	84.113	20.70	**(Significant) 0.008**
D × Ton	2	10.58	10.58	5.291	1.30	0.367
Ip × Ton	4	59.34	59.34	14.834	3.65	0.119
Residual Error	4	16.26	16.26	4.064		
Total	17	690.43				

For overcut the calculated F-ratios are shown in Table 5. According to the above stated concept, factors D and Ip are significant factor. Ton are insignificant factors and remaining factors (columns) are estimates of error variance.

4. CONFIRMATION EXPERIMENT

A confirmation experiment is performed by conducting a test using a specific combination of the factors and levels previously evaluated. The sample size of confirmation experiment is larger than the sample size of any specific trial in the previous factorial experiment. The key task to conduct the confirmation experiment is the determination of the preferred combination of the levels of the factors indicated to be significantly by the analytical methods. The purpose of the confirmation test is to be validating the conclusions drawn during the analysis phase.

The final step of the Taguchi's parameter design after selecting the optimal parameters is to be predicted any verifying the improvement of the performance characteristics with the selected optimal machining parameters in Table 6.

Table 6 Confirmation experiment result for OC

Optimal machining parameters				Over cut (mm)	
Parameters	D	Ip	Ton	Experimental Value	Predicted Value
Value	6	5	1000	0.5000	0.5200
				Error (%)	3.846

5. Model Analysis of OC

The coefficients of model S/N ratios for over cut shown in Table 7 and parameter result are standard deviation of error S=2.016, amount of variation R^2= 96.6% and R^2 (adj.) = 90.0%. And comparing the P value is less than or equal to 0.05 it can be concluded that the effect is significant, otherwise not significant [9].

Table 7 Estimated Model Coefficients for SN ratios (OC)

Term	Coef	SE Coef	T	P
Constant	8.3740	0.4752	17.624	**(Significant) 0.000**
DIA 4	2.3401	0.4792	4.925	**(Significant) 0.008**
I_P 1	5.4919	0.6752	8.173	**(Significant) 0.001**
I_P 3	-1.3779	0.6752	-2.051	0.110
T_{ON} 50	2.1521	0.6752	3.203	**(Significant) 0.033**
T_{ON} 500	-0.6820	0.6752	-1.015	0.368
DIA*I_P 4 1	4.0610	0.6752	6.043	**(Significant) 0.004**
DIA*I_P 4 3	-0.7460	0.6752	-1.110	0.329
DIA*T_{ON} 4 50	-1.0825	0.6752	-1.611	0.182
DIA*T_{ON} 4 500	0.4866	0.6752	0.724	0.509
I_P*T_{ON} 1 50	3.2422	0.9503	3.412	**(Significant) 0.027**
I_P*T_{ON} 1 500	-0.4583	0.9503	-0.482	0.655
I_P*T_{ON} 3 50	-1.0294	0.9503	-1.083	0.340
I_P*T_{ON} 3 500	0.4104	0.9503	0.432	0.688
S=2.016	R-Sq=96.6%		R-Sq(adj)=90.0%	

6. Conclusion

In the present study, the effect of EDM process parameters on terms of overcut of AISI P-20 tool steel have been studied using Taguchi technique (L_{18} orthogonal Array). The optimal sets of process parameters were obtained. The Conclusions are as follows:

- Electrode diameter and discharge current are the significant parameters for overcut.
- The confirmation experiments shows that the errors associated with overcut are 3.846%.

- The optimal solution for the value of electrode diameter, discharge current and pulse on time are 6mm, 5A and 1000 µs for overcut.
- It is also concluded from the analysis of variance that the model is significant and reproducibility of the results are good with the value of R^2 96.6 %.

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