Optimizations of EDM process parameters for surface roughness machining die steel using copper tungsten electrode by adopting Taguchi array design

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Abstract

In this paper, machining of hard material High Carbon High Chromium (HCHCr) die steel using Electrical Discharge Machining (EDM) with a Copper-tungsten electrode by using Tagughi methodology has been reported. The Taguchi method is used to formulate the experiment format, to analyze the effect of each control factors on machining characteristics, and predicts the optimal EDM control factor such as Servo voltage, pulse current, pulse duration and interval time. It is found that these control factors have a significant influence on machining characteristics such as material removal rate, electrode wear and Surface roughness. In order to see the impact of control factors on quality characteristic, number of experiments were conducted and. results were analyzed by Taguchi methodology and analysis of variance (standard analysis). The effect of control factors were examined for obtaining optimum surface roughness. The analysis of Taguchi method reveals that, peak current, servo voltage and pulse duration have significantly affected the surface roughness.

Keywords: Electrical discharge machining, Taguchi method, Die steel, Surface roughness, Electrode.

1. Introduction

The Electrical Discharge Machining (EDM) is one of the most useful processes for the production of complicated shapes and tiny apertures of high quality with greater accuracy. During EDM, the tool and the work piece are submerged in dielectric fluid and operated by a small gap. The discharge energy produces very high temperature on the surface of the work piece on the point of spark. This causes local melting and vaporization of molten metal, which is washed away by circulating dielectric fluid. During EDM process the surface of the work piece gets affected heavily because of variation in processing variables which depend on material to material and because of this some adverse affects in terms of properties are observed. These properties can vary to different levels with the variation in the main processing parameters. If the process parameters for machining are optimized, the EDM can be easily used as routine valuable tool. As the process parameters increases the numbers of experiments also increases and consequently increase in the cost of experiments. In order to solve this complexity, Taguchi approach is better to understand the effect of these variables by performing only few experiments (Hwa-Tang Lee *et al.,* 2004; Payal *et al*., 2003). Taguchi approach is being used as powerful tool for improving productivity during research and development. Various researchers to optimize the process parameters have implemented this design and the results are in expected lines (Ranjit K Roy, 1999; Park, 1996; Yan *et al.,* 2000; Hwa-Tang Lee *et al*., 2004; Amorim & Weingaertner, 2004).

Considering the above fact the Taguchi L9 Method is adopted to analyze the effect each control factors on the quality characteristics (QC) such as MRR and surface roughness (SR). The MRR and SR are two main objective of the designer to achieve while electrode wear is the secondary objective. In order to achieve optimum quality characteristics, dependant and independent variables are selected and accordingly the problem is formulated. A brief description of the formulation of the problem followed by experimental plan is presented below.

2. Taguchi method, design of experiment, and experiment details

2.1 Taguchi method

Taguchi defines the quality of a product, in term of the loss imparted by the product to the society from the time the product is shipped to the customer (Ranjit K Roy, 1999). Some of those losses are due to deviation of the product's functional characteristic from its targets value, and these are called losses due to functional variation. The uncontrollable factors, which cause the functional characteristic of a product to deviate from their target values, are called noise factors which can be classified as external factors (e.g. temperature, human errors), manufacturing imperfections (e.g. unit to unit variation in product parameters) and product deterioration. Over all aim of quality engineering is to make products that are robust with respect to all noise factors (errors).

Taguchi has empirically found that the two stage optimization procedure involving S/N ratios, indeed gives the parameter level combinations, where the standard deviation is minimum while keeping the mean on the target, (Phadke, 1988; Mohd Amri lajis *et al.,* 2009). This implies that engineering system behaves in such a way that the manipulated production factors that can be divided into three categories: 1. Control factors, which affect process variability as measured by the S/N ratio. 2. Signal factors, which do not influence the S/N ratio or process mean. 3. Factors, which do not affect the S/N ratio or process mean.

In practice, the target mean value may change during the process development application in which the concept of S/N ratio is useful are the improvement of the quality through variability reduction and improvement in measurement. The S/N ratio characteristics can be divided in to three categories of quality characteristics lower-the-better, larger-the-better and the nominal is better. The each level of process parameter is computed based on larger-the-better corresponds to better quality characteristics for materials removal rate. A smaller-the-better response is required for surface roughness. Therefore, the optimal level of process parameter is the level of highest delta value. The optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental condition. To solve this complexity, the Taguchi method uses a special design of orthogonal array to study the entire process parameter with a small number of experiments only. Furthermore, impact of control factor on quality characteristic is performed to see which process parameter is statistically significant.

Table 1. *Factors and level used in experiment*

Factors	Levels		
	1	2	3
A-Voltage (Volts)	40	50	60
B-Current (Ampere)	5	10	20
C-Pulse duration (µs)	1.6	12.5	100
D-Interval time (µs)	3.2	100	500

2.2 Experimental details

The experiments were carried out with four factors at three levels each as shown in the Table 1. The fractional factorial design used is a standard L9 (3^4) orthogonal array. This orthogonal array is chosen due to its capability to check interaction among the factors. Results reported in are mean values of five repetitions at each set of experimental condition for each control factors. The machining trials were carried out on the EDM machine Electronica ePules-50. The H11 grade Die steel work material having chemical composition 1.72%C, 0.8%Si, 0.36%Mn, 12.65% Cr. hardened to 52 HRc and annealed to remove any residual stresses prior to the machining. Copper-Tungsten tool electrode is used. The sample machined for 20 minutes each. Commercial grade dielectric fluid with side flushing was used. The machining parameters were Servo Voltage, Peak current, Pulse duration, and Interval time were selected. Details of machining parameters are shown in Table 1.

Each experimental trial was performed with 5 repetitions at each set of value. The average surface roughness (R_a) was measured on Roughness Meter SJ901P which is a compact independent roughness measuring instrument.

The observed value optimize by comparing by analysis of variance which was based on Taguchi method. Statistical software used is used to determine the effect of control factors to perform ANOVA and to establish the optimum condition.

3. Result and discussions

3.1 Signal to noise ratio

The main objective of the experiment is to optimize the EDM process parameters (Voltage, Current, Pulse duration and Interval time). Table 2 shows the actual data of surface roughness along with its computed S/N ratio values. Whereas S/N ratios at each level of the surface roughness are calculated signal-to-noise, ration using smaller the better characteristics.

$$S/N - 10 \log \frac{1}{n} (\Sigma y^2) \quad (1)$$

In the standard L9 (3^4) orthogonal array factors A,B,C,D are arranged as shown in Table 3. The results reported in are mean values of five repetitions at each set of experimental condition for each process parameter variables.

3.2 Analysis of variance for S/N ratio

Taguchi is recommended to analyze data using the S/N ratio that will offer two advantage; it provides a guidance for selection the optimum level based on least variation around on the average value, which closet to the target, and also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target (Phadke, 1988). The experimental results are analyzed to investigate the main effects and difference between the main effects of level 1, 2 and 3 on the variable. Average S/N ratio for each level of experiment is calculated on the value of table 1 and is shown in Table 2.

Table 2. *Average observed value and S/N ratio for surface roughness*

Exp.	Parameters				Surface Roughness Ra (µm)	S/N ratio for Surfaces Roughness
	Voltage (V)	Current (A)	Pulse on Time (µs)	Pulse off time (µs)		
1	40	5	1.6	3.2	4.61	-13.28
2	40	10	12.5	100	5.69	-15.11
3	40	20	100	500	9.36	-19.47
4	50	5	12.5	500	4.84	-13.73
5	50	10	100	3.2	6.71	-16.56
6	50	20	1.6	100	8.07	-18.15
7	60	5	100	100	4.99	-13.97
8	60	10	1.6	500	9.13	-19.55
9	60	20	100	3.2	10.75	-20.67

The different values of the S/N maximum and minimum (Δ) are shown in Table 3. The current, Voltage and interval time are three factors with highest difference in value of 5.77, 2.11 and 1.84 respectively. Based on Taguchi prediction that the bigger difference in value of S/N ratio shows a more effect on surface roughness or more significant. Therefore, it can be concluded that, change in the current increase or decrease the surface roughness significantly. Furthermore, the voltage and interval time changes mainly increase or decrease the surface roughness significantly.

The result of S/N ratio analysis for the surface roughness value which was calculated using Taguchi method is shown in Table 3. Then the analysis of variance is shown in Table 4 which consist of DF degree of freedom, S sum of square, V variance, F variance ratio and P significant factor (Phadke, 1988; Mohd Amri Lajis *et al*., 2009). In the most engineering cases, the significant value selected was 5% (α=0.05). Table 4 shows that significant value of current (P) is 0.000. It means that the current influence significantly on the surface roughness value at significant value of 0.05. In addition to P value for the pulse duration are insignificant. From the result it can be concluded that the current is more significant factor and give most contribution on the surface roughness. The significant factors, which affects the surface roughness of die steel is the current therefore the quality of surface roughness can be controlled by a suitable current value. Previous researchers suggest similar result. They claim that the surface roughness well strongly depends on the current followed by voltage and Interval time.

Table 3. *Average for S/N ratio and main effect of surface roughness*

Factors	Levels			Δ	Rank
	1	2	3		
A-Voltage	-15.95	-16.15	-18.06	2.11	2
B-Current	-13.66	-17.07	-19.43	5.77	1
C-Pulse Duration	-16.99	-16.50	-16.67	0.49	4
D-Interval Time	-16.84	-15.74	-17.58	1.84	3

Table 4. *ANOVA analysis for S/N ratio for Surface Roughness*

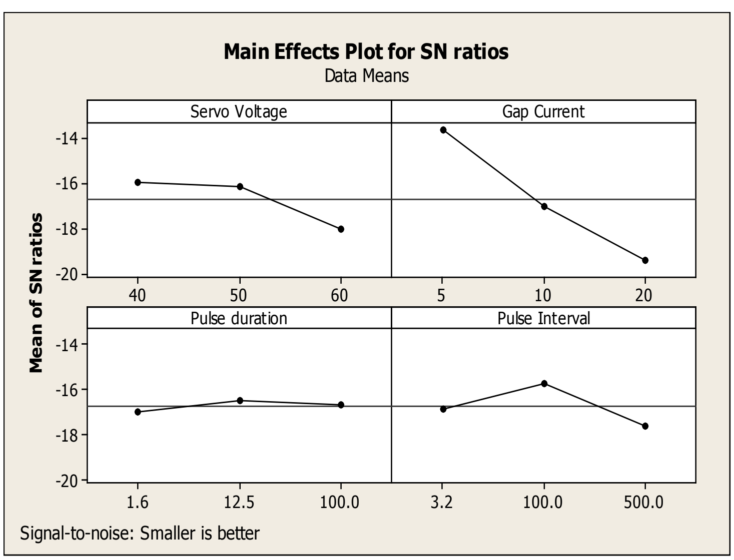
No.	Variable factors	Designation	DF	Seq. SS	Adj. SS	Variance	F	P
1	Voltage	A	2	18.233	16.833	8.418	5.50	0.014
2	Current	B	2	94.425	91.106	45.553	29.74	0.000
3	Pulse Duration	C	2	1.349	1.136	0.568	0.37	0.695
4	Interval time	D	2	10.976	10.976	5.488	3.58	0.049
	Error		18	27.568	27.568	1.532		
	Total		26	152.551				

Table 5. *Optimum condition and performance surface roughness*

	Factors	Level value	Level	Level contribution
1	Voltage	40	1	0.729
2	Current	5	1	3.018
3	Pulse Duration	12.5	2	0.187
4	Interval Time	100	2	0.292
Total contribution from all Factors				4.862
Current Grand average				-16.664
Expected result at optimum condition				-11.801

Table 5 shows level of contribution each parameter on the surface roughness value for estimating optimum condition. The biggest contribution is from current at 3.018 and moderate contributions are from 0.729 and 0.292 voltage and interval time respectively. The optimum condition in EDM Die steel material which produces low surface roughness is at current level 1, Voltage level 1, pulse 4duration level 2 and interval time level 2. The main effects for each level of control factors on surface roughness are shown in Fig. 1. The best choice for machining die steel is based on S/N ratio is followed at current. It means that the current effects significant changes on surface roughness, and the same trend can also be observed on the plot.

Fig.1. *Main effect plot for the control factors verse S/N ratio of surface roughness*



4. Conclusion

This paper has discussed the machining of die steel by EDM with Copper-Tungsten electrode. Taguchi method has been used to determine the main effects, significant factors and optimum surface roughness. Based on result presented herein it is concluded that current mainly affects the surface roughness with the contribution of 3.018. The optimum condition for control factors to achieve best surface roughness resulted at current 5A, Voltage at 40V, Interval time at 100 µsec and Pulse duration at 12.5 µsec.

5. References

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