International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 03 | June-2015 www.irjet.net p-ISSN: 2395-0072

Experimental Investigation of Wire EDM to Optimize Dimensional Deviation of EN8 Steel through **Taguchi's Technique**

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Abstract - *In this research paper, different parameters of wire EDM are studied. Workpiece material for which parameters are to be optimized is EN 8 steel. In these days it is very important to find best operating conditions for any manufacturing technique. Specially in case of non-conventional machining such as electro discharge machining, abrasive jet machining, electro chemical machining etc., because in these processes operating cost is higher than the conventional machining. Output parameter which is to be optimized is dimensional deviation and input parameters are wire feed, pulse off time and servo voltage. Taguchi method was used to optimize the* ***parameter. 'L18' orthogonal array was used for*** *statistical analysis. MINITAB-17 software was used to get optimum values for the test and a confirmation experiment was done for validating the results.*

Key Words: Wire EDM, EN 8 steel, Taguchi Method, Dimensional Deviation

1. INTRODUCTION

The wire-cut EDM is a discharge machine that uses CNC movement to produce the desired contour or shape. It uses a continuous-traveling vertical wire under tension as the electrode. The electrode in wire-cut EDM is about as thick as a small diameter needle whose path is controlled by the machine computer to produce the shape required.

Wire electrical discharge machining (WEDM) technology has gain popularity since it was first applied more than 4 decades ago. In 1974, D.H. Dulebohn applied the optical-line follower system to automatically control the shape of the components to be machined by the WEDM process. By 1975, its popularity rapidly increased, as the process and its capabilities were better understood by the industry. It was only towards the end of the 1970s, when computer numerical control (CNC) system was initiated into WEDM, which brought about a major evolution of the machining process [1]. So using CNC has made the wire EDM process very precise and accurate. This process is being used in various application fields such as automobile, electronic industries, aerospace and tool and die making process etc. Now in case of WEDM dimensional deviation is a measure of work quality because final product should be in the dimensional limits which are to be obtained. In this paper dimensional deviation is optimized by applying Taguchi method.

1. WORKING PRINCIPLE

The wire-cut EDM machining can only performed on the materials which conduct the electricity. Materials are cut by the WEDM process by electro-thermal mechanism. Material removal takes place by series of discrete discharge between wire electrode and workpiece in the presence of a dielectric fluid.

The dielectric fluid gets ionized in the gap between wire electrode and workpiece. Thus electric spark is generated and this area is heated to very high temperatures. Because of this heat generation surface of workpiece material melts and removed away. Now dielectric fluid flushes away the cut particles (debris). Thus material removal process occurs in wire EDM process. Figure 1 shows the schematic diagram of wire EDM machining.

1. LITERATURE REVIEW

Huang et al. investigated experimentally the effect of various machining parameters on the gap width, SR and the depth of white layer on the machined workpiece (SKD11alloy steel) surface. They adopted the feasible-direction non-linear programming method for determination of the optimal process settings [3].

Miller et al. investigated the effect of spark on-time duration and spark on-time ratio on the material removal rate (MRR) and surface integrity of four types of advanced material; porous metal foams, metal bond diamond grinding wheels, sintered Nd-Fe-B magnets and carbon–carbon bipolar plates. Regression analysis was applied to model the wire EDM MRR. Scanning electron microscopy (SEM) analysis was used to investigate effect of important EDM process parameters on surface finish [4].

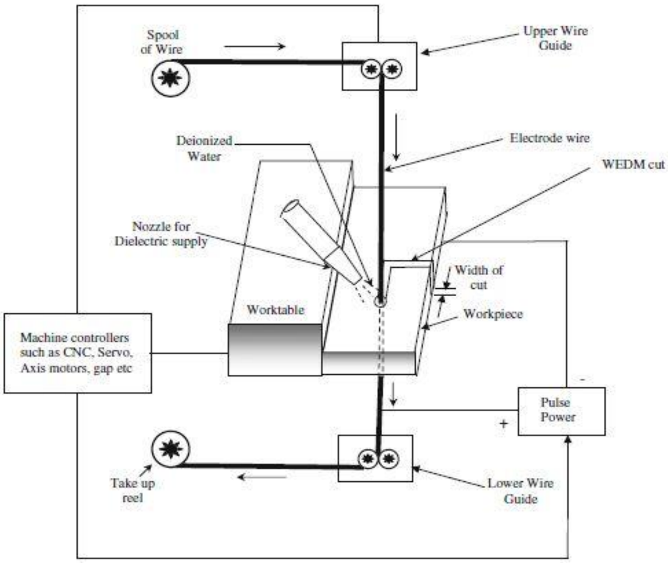

Fig.-1: Schematic diagram of WEDM [2]

Sarkar et al. performed experimental investigation on single pass cutting of wire electrical discharge machining of γ-TiAl alloy. The process was successfully modelled using additive model. Both surface roughness as well as dimensional deviation was independent of the pulse off time. The process was optimized using constrained optimization and pareto optimization algorithm [5].
S. Sivakiran et al. studied the influence of various machining parameters Pulse on, Pulse off, Bed speed and Current on metal removal Rate (MRR). The relationship between control parameters and Output parameter (MRR) was developed by means of linear regression. Taguchi's L16 (4*4) Orthogonal Array (OA) designs had been used on EN-31 tool steel to achieve maximum metal removal rate [6].
Lokeswara Rao T. et al. found optimum cutting parameters for Titanium Grade5 (Ti-6Al-4V) using Wire-cut Electrical Machining Process (WEDM). The response of Volume Material Removal Rate (MRR) and Surface Roughness (Ra) are considered for improving the machining efficiency. A brass wire of 0.25mm diameter was applied as tool electrode to cut the specimen. The Experimentation has been done by using Taguchi's L25 orthogonal array (OA) under different conditions like pulse on, pulse off, peak current, wire tension, servo voltage and servo feed settings. Regression equation is developed for the VMRR and Ra. The optimum parameters are obtained by using Taguchi method [7].
Rajkamal Singh Banga et al. studied on AISI M2 and AISI H13 materials and molybdenum wire electrode diameter (0.18mm); experiment is conducted according to Taguchi's L16 OA, with input parameters as Peak current, Pulse on, Pulse off their response on MRR, Surface Roughness, Kerf width & Spark Gap is analysed to check the significance of each using ANOVA. Process parameter optimization is done by Analytic Hierarchy Process with the criteria Maximum MRR, minimum kerf and surface roughness [8].

2. EXPERIMENTAL SETUP

Fig.-2: Workpiece mounted on EUROCUT MARK II machine

The experiment was carried out on EUROCUT MARK II machine (Figure 2). The electrode wire material was brass-copper (90:10). Diameter of wire was 0.25 mm. Dielectric fluid used was low conductivity water. Electrode can be used once only because of dimensional deviation, so wire was continuously feed through the feeding mechanism. Workpiece was a block of EN8 Steel with Dimension 200×100×21 (all in mm). From the workpiece of above given dimensions, small pieces were cut. Dimensions of each piece were 5×5×21 as shown in the figure 3 while measuring the dimensions.

Table -1: Experimental Setup Followed by the experiment

Workpiece Material	EN8 Steel
Dimensions of Workpiece	200×100×21(in mm)
EDM used	EUROCUT MARK II
Tool material	Brass-Copper
Measuring instrument	Micrometer
Dielectric fluid	Water

2.1 Measurement of Dimensional Deviation

Dimensional Deviation is the measure of the deviation of actual dimension after machining from required dimension. It is an important parameter because dimensional accuracy is of great importance. Dimensional deviation is given by following formula:

$$\text{Dimentional Deviation} = \frac{\text{Observed value} \sim \text{Actual value}}{\text{Actual Value}} \times 100$$

Fig-3: Measuring the dimensions with micrometer

Table -2: Levels of Input parameters

Factors	EDM Machining parameters	Symbols	Levels		
			L1	L2	L3
A	Wire Feed (m/min)	-	5	10	
B	Pulse Off Time (machine unit)	Toff	40	50	60
C	Servo Voltage (volt)	-	5	10	15

Table 1 shows experimental detail setup and experiments were carried out on the basis of Taguchi technique. In table 2 levels of the three machining parameters wire feed, pulse off time and servo voltage is shown. On the basis of available orthogonal arrays L18 was selected.

3. RESULTS

Table 3 shows response value i.e. dimensional deviation obtained after experiments. Dimensional deviation is taken as percentage of the required dimension.

Table -3: Experimental value of response

Exp. No.	Wire Feed	Toff	Servo Voltage	Dimensional Deviation(%)
1	L1	L1	L1	1.2
2	L1	L1	L2	1
3	L1	L1	L3	0.8
4	L1	L2	L1	1.6
5	L1	L2	L2	1.4
6	L1	L2	L3	1
7	L1	L3	L1	1.4
8	L1	L3	L2	1.4
9	L1	L3	L3	1.2
10	L2	L1	L1	1
11	L2	L1	L2	0.8
12	L2	L1	L3	0.8
13	L2	L2	L1	1.4
14	L2	L2	L2	1.4
15	L2	L2	L3	1
16	L2	L3	L1	1
17	L2	L3	L2	0.8
18	L2	L3	L3	0.6

Table -4: Analysis of variance for S/N Ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Wire feed	1	18.98	18.98	18.984	10.85	0.006
Toff	2	25.49	25.49	12.746	7.28	0.009
Servo Voltage	2	28.42	28.42	14.211	8.12	0.006
Error	12	21.01	21.01	1.750		
Total	17	93.90				

Table -5: Response for S/N Ratio

Level	Wire Feed	Toff	Servo Voltage
1	-1.5643	0.7052	-1.9185
2	0.4896	-2.1417	-0.8152
3		-0.1756	1.1216
Delta	2.0540	2.8468	3.0401
Rank	3	2	1

By using MINITAB-17 software ANOVA was carried and results are shown in table 4. All the parameters have significance at 95 % confidence level.

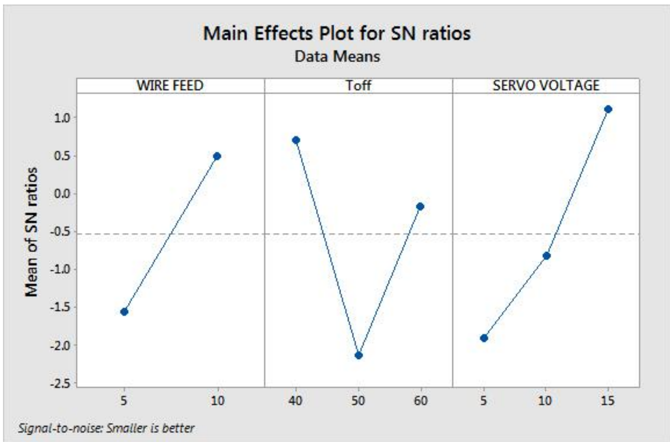

Fig.-4: S/N ratio plot for dimensional deviation

Figure 4 shows the S/N ratio plots for the dimensional deviation. As dimensional deviation is the "lower the better" type quality characteristic, from Figure 3, It can be seen that the second level of wire feed (A2), first level of pulse off time (B1) and third level of servo (C3) provide minimum value of dimensional deviation.
The ranks and the delta values for various parameters show that servo voltage has the greatest effect on dimensional deviation and is followed by pulse off time, and wire feed in that order.

4. VALIDATION

The optimum value of dimensional deviation is predicted at the optimal levels of significant variables which have already been selected as wire feed (A2), pulse off time (B1) and servo voltage (C3). The estimated mean of the response characteristic (DD) can be determined [9]:

$$\mu_{DD} = \overline{A_2} + \overline{B_3} + \overline{C_3} - 2 \times \overline{T}$$

Where,
$\overline{T}$= overall mean of DD = 1.1% Table 3
$\overline{A_2}$= average value of DD at the second level of wire = 0.97778 % Table 3
$\overline{B_1}$ = average value of DD at the third level of pulse off time = 0.93333 % Table 3
$\overline{C_3}$ = average value of DD at the third level of servo voltage = 0.9 % Table 3
Substituting the values of various terms in the above equation,

μ_{DD} = 0.977778 + 0.93333 + 0.9 – 2(1.1) = 0.6111

The 95 % confidence intervals of confirmation experiments (CI_{CE}) and Population (CI_{POP}) are calculated by using the following equations [9], [10]:-

$$CI_{CE} = \sqrt{F_\alpha(1, f_e)V_e \left[\frac{1}{\eta_{eff}} + \frac{1}{R}\right]}$$ and

$$CI_{POP} = \sqrt{\frac{F_\alpha(1, f_e)V_e}{\eta_{eff}}}$$

Where,
$F\alpha(1, fe)$ = The F ratio at the confidence level of (1-α) against DOF 1 and error degree of freedom (fe).

$$\eta_{eff} = \frac{N}{1+[\text{responsemean of estimatethein associated DOF}]}$$
= 18/(1+5)
= 3

N = Total number of results = 18
R = Sample size for confirmation experiments = 3
Ve = Error variance = 0.02370
fe = error DOF = 12 Table 4
$F_{0.05}(1,12)$ = 4.75 (Tabulated F value)

So, CI_{CE} = ± 0.2739, and
CI_{POP} = ± 0.1937

Therefore, the predicted confidence interval for confirmation experiments is:
Mean μ_{DD} – CI_{CE} < Improved DD < Mean μ_{DD} + CI_{CE}
0.3372 < Improved DD < 0.885

The 95% confidence interval of the population is:
Mean μ_{DD} – CI_{POP} < Improved DD< Mean μ_{DD} + CI_{POP}
0.4174< Improved DD < 0.8048

The optimal values of process variables at their selected levels are as follows:
Second level of wire feed (A2) : 10 mm/meter
First level of pulse off time (B1) : 40 machine units
Third level of servo voltage (C3) : 15 volts

5. CONFIRMATION EXPERIMENT

In order to validate the result obtained, three experiments were done at the optimum parameters setting. At value of wire feed 10 m/min, pulse off time 40 machine units and servo voltage 15 volt. Average experimental value of dimensional deviation was found 0.6 %, which was within the confidence interval as calculated.

6. CONCLUSIONS

Following conclusions can be drawn on the basis of optimization as discussed above:

- Increasing the wire feed rate decreases the dimensional deviation.
- Increasing the pulse off time initially dimensional deviation increases and further it decreases.
- Increasing servo voltage decreases dimensional deviation.
- Among the three parameters, servo voltage has the greatest effect on dimensional deviation and is followed by pulse off time, and wire feed in that order.

ACKNOWLEDGEMENT

I am very much thankful to Dr. Arun Kumar Chaudhary, Assistant Professor, I.P.E.D., G. B. P. U. A. & T. Pantnagar for supervising during the present research work. I also my co-authors Mr. Tirath Singh and Mr. Amit Kumar Rana for their contribution and support.

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