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Statistical Investigation into Effects of Wire EDM Parameters on EN8: Parametric Analysis and Optimization

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Abstract—*The industry demand now a days is high material removal rate & machining of complex shapes, conventional machines are unable to achieve the desired results. Wire EDM is one of the non conventional machining processes which are used to achieve the desired results. This paper deals with the maximization of material removal rate while machining of EN 8 material as work piece on wire electric discharge machining using zinc coated wire. Taguchi single response optimization technique is used for this study & L_9 orthogonal array is used for the design of experiments. The chosen input parameters are Peak Current, Pulse on Time, Pulse off Time & Servo Voltage. For each experiment material removal rate is determined. Analysis of Variance is also conducted to check the significant factors. The observed results are also validated by conducting confirmation experiments.*

Keywords*: WEDM, Process Parameters, ANOVA (Analysis of Variance), Peak Current (I_P) Pulse on time, Pulse off Time, Servo Voltage (SV)*

1. INTRODUCTION

The world's first WEDM was produced by the SWISS FIRM "AGIE" in 1969. The first WEDM machine worked simply without any complication and wire choices were limited to copper and brass only. Several researches were done on early WEDM to modify its cutting speed and overall capabilities. In recent decades, many attempts were done on Wire EDM technology in order to satisfy various manufacturing requirements, especially in the precision mould and die industry. Wire EDM efficiency and productivity have been improved through progress in different aspects of WEDM such as quality, accuracy, precision and operation. A schematic of a WEDM process is shown in Figure, where the wire and the work piece are immersed in a dielectric fluid. Wire EDM uses electro-thermal mechanisms to cut electrically conductive materials. The material removal mechanism in WEDM is based on the melting and vaporization of material. The applied voltage creates a channel of plasma in the working gap between work piece and wire that are immersed in de-ionized water. There is a small gap between wire and work pieces and wire that are immersed in de-ionized water.

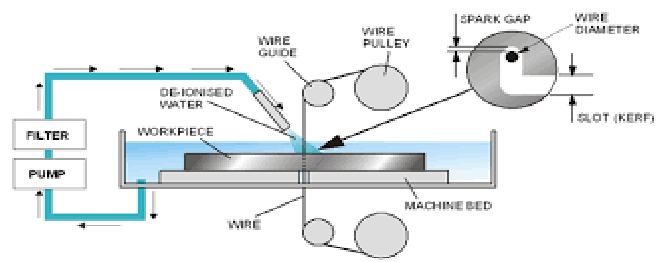


Fig. 1: Schematic diagram of WEDM

EN8 tool steel is used in this study. It is a high quality alloy steel having good ductility and resistance to shock. It also happens to be wear resistant. It is generally used to make die steel and tools for other machining processes. It was tested to have a hardness of 62-63 HRC before being used for machining. The following steps were involved before machining the materials, starting from first step shaper was used for shaping the scrap into rectangular block of symmetrical features then parting on surface grinding was done to create 9 pieces, sizing on surface grinding heat treatment for hardening and at last final grinding on surface grinder & Burr removal. The composition of EN 8 tool steel is as shown by Table 1.

Table 1: Elements and Composition of EN8

ELEMENTS	C	Si	P	Mn	S	Fe
COMPOSITION %	0.36-0.44	0.10-0.40	0.50 max	0.61-1.00	0.05 max	Balance

The wire used to perform the experiment was a zinc coated brass wire of 0.25mm diameter. Coated wires were found to have a higher productivity due to its faster MRR and also less wire breakage while experimentation. The zinc coating gets evaporated after the machining is over and just the inner core of brass is received at the end of machining of each workpiece. The 9 runs were conducted on SPRINTCUT WEDM at Dimensions, Sector 10, Noida.

2. EXPERIMENTAL DESIGN

Taguchi recommends orthogonal array (OA) for lying out of experiments. Wei Chung Wang et al suggested that OAs are widely used & reduces the number of experiments as compared to full factorial design. The chosen process parameters and their levels are shown in table 2. A total of 9 workpiece were prepared of 15mm*15mm*4mm as length, breadth and thickness respectively. The machining was done for 5 minutes for each run and the initial weight and final weight were noted in order to calculate the MRR (gm/min) using the following formula-

$$MRR = \frac{\text{Initial weight - Final weight}}{\text{Time Taken}}$$

Table 2: Process Parameters and their Levels

Factors	Symbol Used	SI Units	Level 1	Level 2	Level 3
Pulse on Time	A	µs	115	120	125
Pulse off Time	B	µs	40	45	50
Peak Current	C	A(amp.)	210	220	230
Servo Voltage	D	V(volts)	10	15	20

3. OPTIMIZATION METHODOLOGY

Taguchi methodology (TM) is a widely used accepted method of design of experiments. This methodology is not only used in India but successfully applied in many countries like US, Japan and many European manufacturing firms (Phadke et al. 1989).

d.f= [{(number of levels-1) for each factor} x{(no of levels-1)×(number of levels-1) for each interaction}]+1

The S/N ratio represents the quality characteristics for the observed data in the Taguchi DOE and mathematically it can be computed. (Phadke, *et al.1988*)

$$SNR = -10 \log (MSD) \qquad (1)$$

Where MSD is the mean square deviation and also known as quality loss function, the quality loss function are classified into three types: lower the better, larger the better and nominal the best type. In case of MRR, Length of cut higher the better and in case of surface roughness lower the better is desirable.

$$\text{For larger the better: } MSD = [\frac{1}{n}\sum^{n}_{i=1} 1/Yi^2] \qquad (2)$$

The orthogonal array as obtained after experimentation is shown by table 4.

Table 3: Response table for MRR

Level	Ton	Toff	IP	SV
1	-33.38	-32.21	-32.74	-30.78
2	-31.64	-28.77	-29.62	-29.93
3	-28.16	-32.20	-30.83	-32.48
Delta	5.21	3.45	3.12	2.55
Rank	1	2	3	4

The response for signal to noise ratio as per different combinations of levels is thus calculated as per the **'larger is better'** approach & a response table is obtained as shown by table 3. Here Pulse on Time shows maximum value at third level, similarly pulse off time, peak current and Servo Voltage at second level respectively. Main effect plots are now obtained using MINITAB software and it is shown by Fig. 2.

Table 4: Response table (Material Removal Rate)

Run No	A	B	C	D	Peak Current (amp)	Ton (µs)	Toff (µs)	Servo Voltage (V)	Initial weight (gm)	Final weight (gm)	MRR (gm/min)
1	1	1	1	1	210	115	40	10	6.98	6.90	0.016
2	1	2	2	2	210	120	45	15	7.73	7.57	0.032
3	1	3	3	3	210	125	50	20	7.74	7.62	0.024
4	2	1	2	3	220	115	45	20	7.76	7.62	0.028
5	2	2	3	1	220	120	50	10	7.77	7.63	0.028
6	2	3	1	2	220	125	40	15	7.74	7.51	0.046
7	3	1	3	2	230	115	50	15	7.77	7.66	0.022
8	3	2	1	3	230	120	40	20	7.75	7.65	0.020
9	3	3	2	1	230	125	45	10	7.78	7.51	0.054

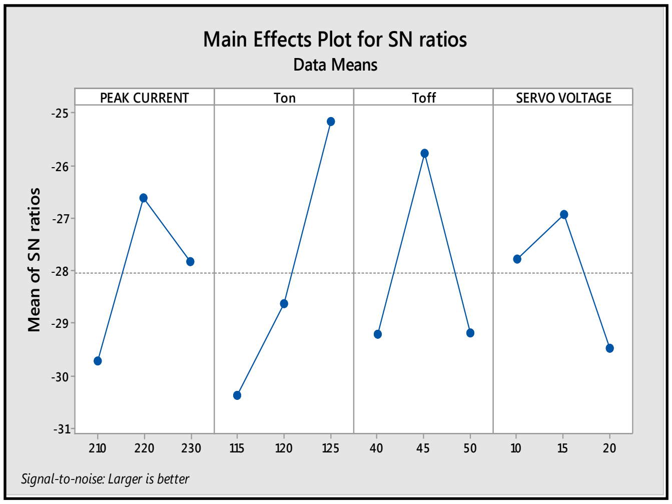


Fig. 2: Optimum conditions for MRR (A2B3C2D2)

From the Fig. 2 we get the optimized condition of material removal rate is A2B3C2D2 i.e. peak current at 220A, pulse on time 125µs, pulse off time 45 µs and servo voltage at 15V.

4. ANALYSIS OF VARIANCE

A better feel for the relative effect of the different parameters/factors can be obtained by the decomposition of the variance, which is commonly called ANOVA. It is a statistical method to estimate the quantitatively the relative contribution that each factor of parameter makes an overall measured response. F ratio represents a relative significance of factors or percentage contribution. Greater the F ratio more significant will be the parameter. The most favorable condition (optimal settings) of process parameters in terms of main response characteristics are established by analyzing response curve and the ANOVA table. The analysis of response data is done by well-known software MINITAB 17.

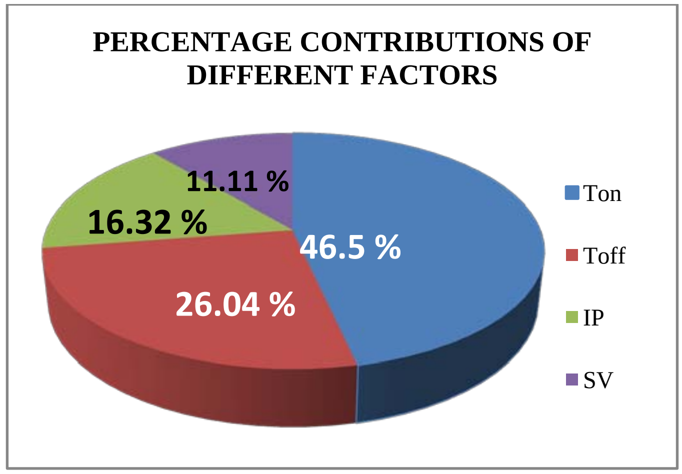
Table 5: ANOVA table for Material Removal Rate

Source	Df	Adj SS/Seq SS	Adj MS	F	%
Ton	2	42.2630	21.1315	2.11315	46.5
Toff	2	23.6539	11.8269	1.18269	26.04
IP	2	14.8218	7.4109	0.74109	16.32
SV	2	10.0924	5.0462	0.50462	11.11
Total	8	90.8310			100

5. RESULTS AND DISCUSSIONS

The result shows that the pulse on time and servo voltage has significant for MRR. The contribution of factors in increasing order for MRR is Servo Voltage (SV), pulse on time (Ton), peak current and pulse off time i.e A2B3C2D2.

Optimal value of material removal rate (MRR) = 0.49 gm/min



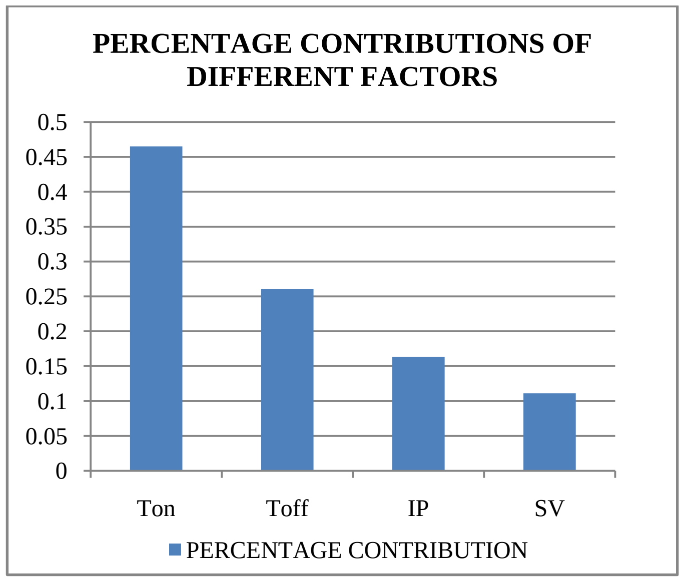


Fig. 3: Percentage contribution of different factors in pie chart and bar graph.

6. CONFIRMATION EXPERIMENTS

In order to validate the above result, Confirmation experiment is conducted that verifies the above results; a specimen is cut by keeping the value of Parameters as obtained by Taguchi Technique. The confirmation table shows that the MRR obtained after cutting is 0.51 gm/min which is close to the result & has small error. Thus this confirmation experiment validates the result.

7. CONCLUSIONS

Experimental investigation of EN 8 is done on Wire EDM using Zinc Coated wire having diameter of 0.25mm. The conclusions drawn are described below:

- Based on Taguchi single Response Optimization Technique, input Parameter Peak Current is set to a level of 220 A, Pulse on time is set to a level of 125 µs, Pulse off Time is set at 45 µs & Servo Voltage is set at 15 V to obtain maximum material removal rate.
- MRR is most affected by Pulse on Time.
- The Response Parameter Material Removal Rate (MRR) is optimised and the same is validated by confirmation Experiments.

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