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Parametric Optimization of WEDM parameters on EN 31 steel for lower surface roughness using taguchi method

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Abstract: *Wire electrical discharge machining (WEDM) is widely used in machining of conductive materials when precision is of primary significance. Wire-cut electric discharge machining of EN31 steel has been considered in the present work. Experimentation has been completed by using Taguchi's L9orthogonal array with different levels of input parameters. Optimal combination of parameters was obtained by this technique. Experimental results make obvious that the machining model is proper and the Taguchi's method satisfies the practical requirements. The results obtained are analyzed for the selection of an optimal combination of WEDM parameters for proper machining of AISI D3 tool steel to achieve better surface finish.*
Keywords: *Anova, DOE, Taguchi, Surface roughness, WEDM*

I. Introduction

WEDM process is one of the most widely used nontraditional machining processes in current manufacturing . It involves the removal of metal by discharging an electrical current from a pulsating DC power supply across a thin inter-electrode gap between the tool and the work piece. It is most commonly used for machining hard and difficult to machine materials with very close tolerances. Generally, WEDM is perceived to be an extremely actuate process and there are various reasons for this perception. Firstly, in WEDM, no direct contact takes place between the cutting tool (electrode) and the work piece; as a result, the adverse effects such as mechanical stresses, chatter, and vibration normally present in traditional machining are eliminated. To maintain machine and part accuracy, the dielectric fluid flows through a chiller to keep the liquid at a constant temperature. A DC or AC servo system maintains a gap from .002 to .003" (.051 to .076 mm) between the wire electrode and the workpiece. The servo mechanism prevents the wire electrode from shorting out against the workpiece and advances the machine as it cuts the desired shape. Because the wire never touches the workpiece, wire EDM is a stress-free cutting operation. The wire electrode is usually a spool of brass, or brass and zinc wire from .001 to .014" (.025 to .357 mm) thick. Sometimes molybdenum or tungsten wire is used. New wire is constantly fed into the gap; these accounts for the extreme accuracy and repeatability of wire EDM.

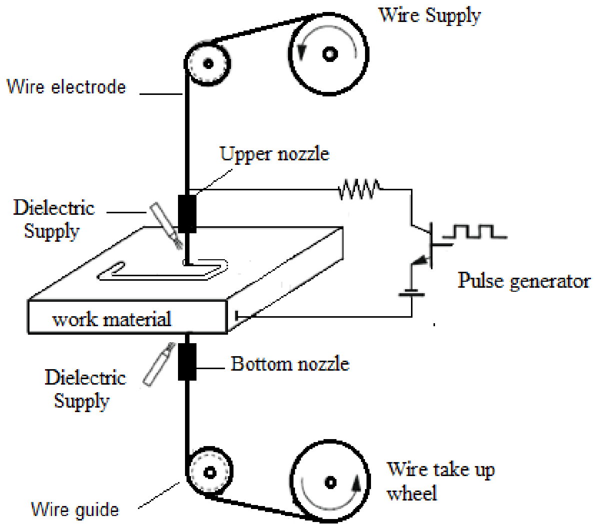

Fig 1: WEDM Machine

Brajesh Kumar Lodhi , Sanjay Agarwal have experimented wedm on material of AISI D3 Steel using parameters pulse on time ,pulse off time, peak current and wire feed. Using Taguchi optimization they concluded that peak current has most influence on surface roughness taking only surface roughness as the only output parameter during the machining process.

Taking the parameters like pulse on time , pulse off time and wire feed G. Lakshmikanth , Nirmal Murali ,G. Arunkumar , S. Santhanakrishnan had the wedm process on Cemented tungsten carbide .They found that pulse on time influences both material removal rate and surface roughness taking both material removal rate and surface roughness as two different output parameter using Taguchi optimization method.

Using wedm input parameters like applied voltage ,pulse width and pulse interval speed Jaganathan P , Naveen kumar T, Dr. R.Sivasubramanian experimented that at a particular combination of these optimized parameters they combinely affect the material removal rate and surface roughness using metal EN31 steel for high value of material removal rate and lower value of surface roughness.

Vikas , Apurba Kumar Roy, Kaushik Kumar optimize the input wedm parameters like pulse on time ,pulse off time, peak voltage and discharge current using the material EN31 steel and using Taguchi method concluded that out that the input parameters discharge current had a larger impact over the surface roughness parameter. The effect of the other parameters was significantly less and can be ignored.

S Sivakiran , C. Bhaskar Reddy, C. Eswara reddy had conducted the wedm process on EN31steel using the input parameters like pulse on time, pulse off time , bed speed and peak current and optimized the parameters using Taguchi method and found that peak current has most influence on the material removal rate .

H.Singh et al analyze the effects of various input process parameters like pulse on time, pulse off time, gap voltage, peak current , wire feed and wire tension have been investigated and impact on MRR is obtained. Finally they reported MRR increase with increase in pulse on time and peak current. MRR decrease with increase in pulse off time and servo voltage. Wire feed and wire tension has no effect on MRR.

In this present paper, for the optimal selection of process parameters, the Taguchi method has been extensively adopted in manufacturing to improve processes with single performance characteristic to achieve lower surface roughness (Ra).

II. Materials And Methodology

2.1. EN 31

EN31 is a quality high carbon alloy steel which offers a high degree of hardness with compressive strength and abrasion resistance. Typical applications for EN31 steel include taps, gauges, swaging dies, ejector pins, ball and roller bearings. It is a good quality steel for wear resisting machine parts and for press tools which do not merit a more complex quality.

Composition of EN 31:
Carbon 0.90-1.20%
Chromium 1.00-1.60%
Sulphur 0.050% max
Silicon 0.10-0.35%
Silicon 0.10-0.35%
Manganese 0.30-0.75%
Phosphorous 0.050% max

Fig 2: EN 31 steel (Material size-30*20*12mm)

2.2. Experiment

The experimental studies were performed on a ECO CUT WEDM machine. Zinc coated brass wire with 0.25 mm diameter (900 N/mm^2 tensile strength) was used in the experiments. The parameters, selected for different settings of pulse on time, pulse off time, gap voltage and wire feed were used in the experiments (Table 1). The photographic view of the machine and machining zone has been shown in fig.3 (a) and (b) respectively. The other details of the experimentation have been shown in Table 2. The surface roughness was measured by profilometer TR200 model.

Table 1(machining settings used in the experiment)

PARAMETER	UNIT	LEVEL1	LEVEL2	LEVEL3
Gap voltage	v	40	45	50
Wire feed	mm/min	2	4	6
Pulse on time	μs	4	6	8
Pulse off time	μs	4	6	8

Table 2(fixed parameters)

Wire	Zinc coated brass wire of diameter 0.25mm.
Shape and size of work piece	Rectangular piece of 50*30*12mm
Dielectric fluid	Deionised water
Conductivity of dielectric fluid	20mho

Fig 3(a)

Fig 3(b)

2.3. Design of Experiment Based On Taguchi Method

To evaluate the effects of cutting parameters of Wire EDM process in terms of cutting performance characteristics such as Surface Roughness a Taguchi method used here to model the Wire EDM process. In this study, Taguchi method, a powerful tool for parameter design of performance characteristics, for the purpose of designing and improving the product quality.

In the Taguchi method, process parameters which influence the products are separated into two main groups: control factors and noise factors. The control factors are used to select the best conditions for stability in design or manufacturing process, whereas the noise factors denote all factors that cause variation.

In Taguchi a loss function is used to calculate the deviation between the experimental value and the desired value. This loss function is known as signal to noise ratio(s/n ratio). There are several s/n ratios are available such as lower is better, nominal is best, higher is better.

In WEDM higher MRR and lower surface roughness are the indication of better performance. Therefore 'higher is better' for MRR and 'lower is better' for surface roughness is used.

The loss function L for machining performance results Yi of n number repeated are

$$L_{HB} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2}$$

$$L_{LB} = \frac{1}{n}\sum_{i=1}^{n} yi^2$$

The S/N ratio N_{ij} for the i^{th} performance characteristics in the j^{th} experiment can be expressed as:

$$N_{ij} = -10 \log (L_{ij})$$

2.4. Surface roughness

Profilometer TR200 is used for measurement for SR.

- Roughness parameters-Ra,Rz,Ry,Rq(RMS)
- Assessed profiles-primary profile , roughness profile
- Measuring mode- Metric(µm), English (µ inch)
- Range- Ra,Rq: 0.01-40µm ;Rz, Ry-0.02-160µm
- Stylus-standard model ts100 inductive; diamond tip with a 5µm radius.

Fig 4: Profilometer TR 200

Table 3: Effect of WEDM parameters on surface roughness

Job	Gap Voltage	Wire Feed	Pulse On Time	Pulse Off Time	Surface Roughness	Snra1
1	40	2	4	4	1.4	-2.92256
2	40	4	6	6	1.311	-2.35205
3	40	6	8	8	1.675	-4.4803
4	45	2	6	8	1.928	-5.70214
5	45	4	8	4	2.2584	-7.07602
6	45	6	4	6	1.422	-3.05799
7	50	2	8	6	2.13	-6.56759
8	50	4	4	8	1.55	-3.80663
9	50	6	6	4	2.023	-6.11992

III. Results And Discussion

The experimental results are collected for surface roughness and 9 experiments were conducted using Taguchi (L9) experimental design methodology and there are two replicates for each experiment to obtain S/N values. In the present study all the designs, plots and analysis have been carried out using Minitab statistical software. Lower amount of surface roughness show the high productivity of Wire EDM. Therefore, high the better and small the better are applied to calculate the S/N ratio of MRR and surface roughness respectively.

3.1 Analysis of surface roughness

The purpose of the analysis of SR is to determine the factors and their interactions that have strong effects on the machining performance.

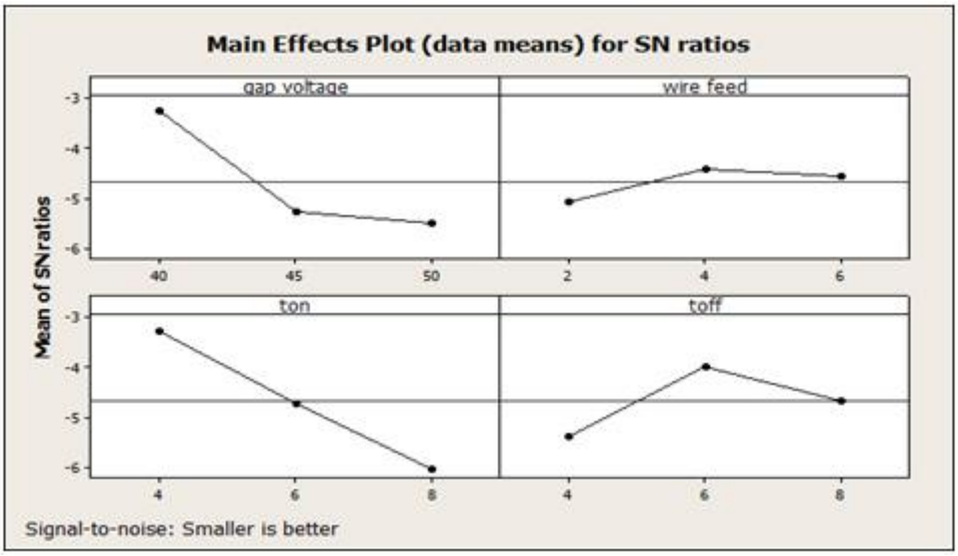

Fig 5: Factors affecting S/N ratio for SR

Table 4: Input parameters according to levels

LEVEL	VOLTAGE	WIRE FEED	PULSE ON TIME	PULSE OFF TIME
1	-3.252	-5.064	-3.262	-5.373
2	-5.279	-4.412	-4.725	-3.993
3	-5.498	-4.553	-6.041	-4.663
Delta	2.246	0.653	2.779	1.380
Rank	2	4	1	3

Table 5: Optimized Value For SR

PARAMETER	RANK	LEVEL	VALUE
Pulse On Time	1	1	4µs
Gap Voltage	2	1	40V
Pulse Off Time	3	2	6µs
Wire Feed	4	2	4mm/min

The optimal machining performance for SR was obtained as 4µs pulse-on time (Level 1), 6 µs pulse-off time (Level 2), 40v gap voltage (Level 1) and 4 mm/min wire feed (Level 2) settings that give the minimum SR. Fig. 5 shows the effect of machining parameters on the SR. That SR increases with the increase of pulse on time and increases with increase in gap voltage, wire feed and gap voltage has mixed effect on SR. The discharge energy increases with the pulse on time and larger discharge energy produces a larger crater, causing a larger surface roughness value on the work piece.

3.2 ANOVA ANALYSIS

The analysis of variance was used to establish statistically significant machining parameters and percent contribution of these parameters on the SR. A better feel for the relative effect of the different machining parameters on the SR was obtained by decomposition of variances, which is called analysis of variance. The relative importance of the machining parameters with respect to the SR was investigated to determine more accurately the optimum combinations of the machining parameters by using ANOVA. The results of ANOVA for the machining outputs are presented. Statistically, F-test provides a decision at some confidence level as to whether these estimates are significantly different. Larger F-value indicates that the variation of the process parameter makes a big change on the performance characteristics. F-values of the machining parameters are compared with the appropriate confidence.

Table 6: ANOVA for SR

Process Parameter	DOF	SS	V	F-value	P-value	% contribution
Gap Voltage	2	0.3597	0.1799	1.75	0.252	36.81
Wire Feed	2	0.02543	0.01272	0.08	0.924	2.60
Pulse On Time	2	0.4772	0.23862	2.86	0.134	48.84
Pulse Off Time	2	0.1148	0.05739	0.40	0.687	11.75
Total						100
At least 95% confidence.						

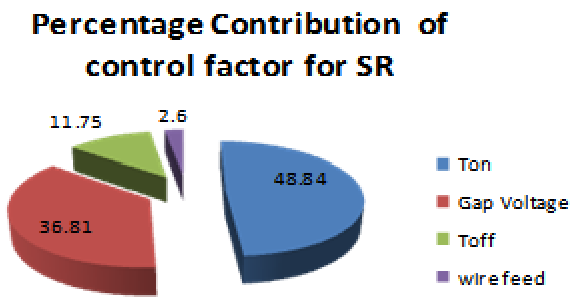

Fig 6: Percentage contribution of control factor for MRR

According to F-test analysis, the significant parameters on the SR are pulse-on time and Gap Voltage. The percent contributions of the machining parameters on the SR are shown. Pulse On Time is found to be the major factor affecting the SR (48.84%). The percent contribution of pulse-off time, gap voltage and wire feed on the SR are 36.81%, 11.75% and 2.6% respectively.

3.3 Conformation experiment

The confirmation experiment is performed by conducting a test using a specific combination of the factors and levels previously evaluated. The final step of the Taguchi's parameter design after selecting the optimal parameters is to be predicted any verify the improvement of the performance characteristics with the selected optimal machining parameters. The predicted S/N ratio using the optimal levels of the machining parameters can be calculated with the help of following prediction equation:

The results of experimental confirmation using optimal machining parameters are shown in the table below.

	Prediction Value	Experiment Value	%Error
Surface Roughness	1.01433	1.461	11.50

From the above observations, it can be interpreted that the obtained SR have reasonable accuracy for esulting model because an error of 11.50% for SR are measured.

IV. Conclusion

This project describes the optimization of the WEDM process using parametric design of Taguchi methodology. It was observed that the Taguchi's parameter design is a simple, systematic, reliable, and more efficient tool for optimization of the machining parameters. The effect of various machining parameter such as pulse-on time, pulse off time, gap voltage and wire feed has been studied though machining of EN31 steel. it was identified that the pulse on time and gap voltage have influenced more than the other parameters for SR considered in this project. The confirmation experiment has been conducted. Result shows that the errors associated with SR are only 11.50 %. The selection of optimum values is essential for the process automation and implementation of a computer integrated manufacturing system. Thus the optimized condition, not only makes the WEDM a more commercially viable process for industrial applications, but also turns a spotlight on WEDM process as a promising field for further advancements.

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