International Journal of Industrial and Manufacturing Systems Engineering
2016; 1(3): 69-72
http://www.sciencepublishinggroup.com/j/ijimse
doi: 10.11648/j.ijimse.20160103.15

Communication

Optimum WEDM Process Parameters of SS304 Using Taguchi Method

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To cite this article:

P. Bharathi, Tummalapenta Gouri Lalitha Priyanka, G. Srinivasa Rao, Boggarapu Nageswara Rao. Optimum WEDM Process Parameters of SS304 Using Taguchi Method. *International Journal of Industrial and Manufacturing Systems Engineering.* Vol. 1, No. 3, 2016, pp. 69-72. doi: 10.11648/j.ijimse.20160103.15

Received: October 15, 2016; **Accepted**: December 12, 2016; **Published**: January 10, 2017

Abstract: Studies are made on the WEDM process performance parameters such as material removal rate, kerf and surface roughness of SS304 following the Taguchi's design of experiments. ANOVA is performed to trace the statistically significance of input parameter (viz. voltage, pulse-on-time, pulse-off-time and wire feed) on the output response parameters. A multi-objective optimization method is adopted here to trace the optimum WEDM process parameters for achieving sufficiently high material removal rate, and low surface finish as well as the kerf width.

Keywords: ANOVA, Kerf, Material Removal Rate, Surface Roughness, SS304, WEDM

1. Introduction

Wire electrical discharge machining (WEDM) technology is being employed for machining parts of hard materials with complex shapes in aerospace and automobile industries. Taguchi's design of experiments is one of the promising techniques to select optimum WEDM process parameters for achieving high material removal rate and low surface roughness with less number of experiments.

Singh et al. [1] have performed ANOVA (Analysis of Variance) by obtaining signal-to-noise ratio (S/N ratio with lower is better) from the value of surface roughness for each test run. They have set the optimum input parameters to obtain minimum surface roughness on AISI H13 and identified wire-type and pulse-on-time as significant parameters. Mahapatra and Patnaik [2] have used a multi-objective optimization based on genetic algorithm for maximization of both metal removal rate (MRR) and surface finish (SF) simultaneously. Mahapatra and Patnaik [3] have studied factors like discharge current, pulse duration, pulse frequency, wire speed, wire tension and dielectric flow rate and few selected interactions both for maximization of MRR and minimization of surface roughness (SR) in WEDM process using Taguchi method. Mahapatra and Patnaik [4] have employed genetic algorithm to optimize WEDM process with multiple objectives and adjusted the process parameters to achieve better MRR, SF and cutting width simultaneously. By varying the machine feed rate with constant current, Alias et al. [5] have performed experiments on Ti-6Al-4V alloy using brass wire in the WEDM process and obtained fine surface at high level machine feed rate. Tosun et al. [6] have followed a multi-objective optimization approach to set optimum machining parameters to obtain maximum possible MRR and low kerf on AISI 4140. Lodhi and Agarwal [7] have optimized the WEDM process parameters for AISI D3. Pulse-on-time and peak current are influencing more on the surface roughness when compared to pulse-off-time and wire feed. Lingadurai et al. [8] have conducted WEDM experiments on SS304. Pulse-on-time, wire feed, and input voltage are significantly influencing the kerf width, SR and MRR. The optimal machining conditions to achieve high MRR and low

SR are found to be different. It is preferable to have a set of optimum machining parameters to achieve high MRR and low SR adopting a reliable multi-objective optimization technique. Nourbaksh et al. [9] have performed experiments to study the influence of zinc coated brass wire in the WEDM process of Titanium alloy. Cutting speed is increased with peak current and pulse interval. Surface roughness increases with pulse width and pulse interval. Dhiman et al. [10] have optimized the process parameters for S7 steel. Cutting rate is increased with pulse-on-time, pulse duration and peak current. It is decreased with servo gap voltage. From the experiments of Sharma et al. [11] on SS100 it is noted that MRR and SR increase with increasing pulse-on-time and peak current.

It should be noted that Taguchi has introduced the signal-to-noise (S/N) ratio transformation and consolidated several repetitions into a single value to reflect the amount of variation in the output responses. But, many of the above researchers have applied the transformation on a single value of each test run output response and carried out additional computation. Adopting the Taguchi's design of experiments, performing ANOVA and utilizing a multi-objective optimization approach, studies are made on SS304 to identify the optimum WEDM process parameters to achieve sufficiently high material removal rate and low surface roughness as well as the kerf width.

2. Taguchi's Design of Experiments and Analysis of Variance

Large number parameters in many processes influence the final outcome. It is possible through design of experiments to identify their individual contributions and their intricate relationship. Defining a set of orthogonal arrays, Taguchi provided a standard approach to evaluate several factors and acquire much information with minimum of experiments [12-15].

In the present study, SS304 is considered as the work piece material. Thickness of the work piece is 5mm. Brass wire is used as the tool electrode material having of 0.25mm diameter. De-ionized water is used as the dielectric fluid. The properties of SS304 are [8]: Elastic modulus or Young's modulus=193 GPa; Elongation=40%; Hardness=88HRB; Poisson's ratio=0.3; Reduction in area=50%; Tensile strength=515 MPa; Coefficient of thermal expansion=17.2 x10^{-6}/K; Thermal conductivity=16.2W/m-K; Specific heat=500 J/Kg-K; and Electric resistivity=720x 10^{-9}/Ω-m.

Table 1 gives the assignment levels of process parameters (viz., machining voltage, pulse-on-time, pulse-off-time and wire feed rate). The output responses (viz., MRR, SR and kerf) for the assigned process parameters as per L_{18} orthogonal array [8] are presented in Table 2. Following Refs.12-14 analysis of variance (ANOVA) is performed to trace the optimum process parameters for achieving possible high MRR and low SR as well as the kerf width.

Table 1. *Assignment levels of process parameters.*

Control Factors (Input parameters)	Designated Factor	Level-1	Level-2	Level-3
Voltage (V)	A	50	60	-
Pulse- on-time (µs)	B	2	4	6
Pulse-off-time (µs)	C	4	6	8
Wire feed (m/min)	D	3	5	7

It is noted from the ANOVA results of Table 3 that pulse-on-time has an immense effect on MRR with 42.1% contribution and other parameters like voltage, pulse-off-time and wire feed rate on the MRR are 21, 29.3 and 7.4% respectively. High pulse-on-time leads to faster erosion of the material and high spark energy discharge causing enhancement in the MRR. Wire feed rate has 69.4% contribution on SR and other parameters like voltage, pulse-on-time, pulse-off-time and wire feed rate on the SR are 1, 29.1 and 0.5% respectively. High wire feed rate results rougher surface. Pulse-on-time has 76.3% contribution on kerf and other parameters like voltage, pulse-off-time and wire feed rate on the kerf are 0.4, 3.7 and 19.6% respectively. High pulse-on-time leads to faster destruction of the material and high spark energy discharge causing enhancement in kerf width. Denoting the subscripts as the level of the process parameters, one can find the maximum MRR for the set of parameters: $A_1B_3C_1D_2$, whereas $A_2B_3C_2D_1$ for minimum surface roughness (SR) and $A_2B_2C_3D_1$ for the minimum kerf width. Conformation experiments are necessary to find output responses for the optimum process parameters.

Table 2. *Performance output responses (viz., MRR, SR and kerf) for the assigned process parameters as per L_{18} orthogonal array.*

Test Run	Levels of input parameters				Output responses [8]			ζ Eq. (2)
	A	B	C	D	MRR (g/min)	SR (µm)	Kerf (mm)	
1	1	1	1	1	0.043776	3.7	0.342	0.57975
2	1	1	2	2	0.042108	3.9	0.363	0.62552
3	1	1	3	3	0.037500	4.7	0.375	0.73342
4	1	2	1	1	0.049680	3.3	0.345	0.51224
5	1	2	2	2	0.043956	2.9	0.333	0.52242
6	1	2	3	3	0.041280	4.3	0.344	0.64043
7	1	3	1	2	0.051120	5.6	0.355	0.64801
8	1	3	2	3	0.049000	5.3	0.350	0.64025
9	1	3	3	1	0.045012	2.7	0.341	0.50843
10	2	1	1	3	0.036712	5.4	0.353	0.76514
11	2	1	2	1	0.033600	3.9	0.350	0.71623

Test Run	Levels of input parameters				Output responses [8]			ζ Eq. (2)
	A	B	C	D	MRR (g/min)	SR (μm)	Kerf (mm)	
12	2	1	3	2	0.029568	5.6	0.343	0.88008
13	2	2	1	2	0.042408	1.5	0.342	0.46129
14	2	2	2	3	0.037968	5.5	0.339	0.74343
15	2	2	3	1	0.037024	4.4	0.356	0.70443
16	2	3	1	3	0.047736	3.8	0.351	0.56125
17	2	3	2	1	0.046080	2.2	0.360	0.48692
18	2	3	3	2	0.039904	2.4	0.344	0.54167

Table 3. *Analysis of variance (ANOVA) for the material removal rate (MRR), surface roughness (SR) and kerf width.*

Parameters	1-Mean	2-Mean	3-Mean	Sum of squares	% contribution
Material removal rate, MRR (g/min)					
A	0.044825	0.039	-	0.0001	21.0
B	0.037211	0.042053	0.046475	0.0002	42.1
C	0.045238	0.042118	0.038381	0.00014	29.5
D	0.042528	0.041511	0.041699	0.0000035	7.4
Surface roughness, SR (μm)					
A	4.044	3.855	-	0.105	1.5
B	4.533	3.65	3.667	3.058	29.1
C	3.883	3.95	4.016	0.053	0.5
D	3.366	3.65	4.833	7.264	69.4
Kerf width (mm)					
A	0.3497	0.3486	-	0.000002	0.4
B	0.3543	0.343	0.350	0.00039	76.3
C	0.348	0.349	0.3505	0.000019	3.7
D	0.349	0.346	0.352	0.0001	19.6

3. Prediction Methodology and Multi-objective Approach

By means of additive law [15], one can estimate the optimal output response ($\hat{\eta}$):

$$\hat{\eta} = \sum_{i=1}^{n_p} \eta_i - \left(n_p - 1\right)\eta_{mean} \tag{1}$$

Here η_{mean} is the overall mean of η with 18 test runs; η_i is the mean of η at the optimal level for the process parameters (i); and n_p is the number of process parameters. The estimated output responses are in good agreement with test results.

The optimum values of MRR, SR and Kerf for the identified process parameters obtained from the equation (1) are: 0.052161 g/min, 2.9 μm and 0.340 mm respectively. The optimum process parameters to achieve the above optimum output responses are found to be different. Hence it is essential to specify a set of optimal process parameters to achieve maximum MRR, minimum SR and Kerf width. For this purpose a non-dimensional parameter ζ is introduced as

$$\zeta = \omega_1\left(\frac{(MRR)_{\max}}{MRR} - 1\right) + \omega_2 \frac{SR}{(SR)_{\max}} + \omega_3 \frac{Kerf}{(Kerf)_{\max}} \tag{2}$$

Here ω_1, ω_2 and ω_3 are weighing factors, whose sum is unity. To have common optimum process conditions, equal weight are given (i.e., $\omega_1=\omega_2=\omega_3=1/3$). The process parameters in Test run-13 indicate the optimum for the three output responses, MRR, SR and kerf width as per the data in the Taguchi's design of experiments. The maximum values estimated for the output responses are: $(MRR)_{max}=0.053161$ g/min; $(SR)_{max}=3.09$ μm and $(Kerf)_{max}=0.352$ mm. The ζ values for all the 18 test runs of Table 2 are generated and ANOVA is performed on ζ and obtained the optimum process parameters to achieve minimum ζ. The selected process parameters are voltage (A_2), pulse-on-time (B_2) pulse-off-time (C_1) and wire feed rate (D_2). Table 4 gives the summarization of the optimum process parameters and the corresponding output responses.

Table 4. *Optimum process parameters and the corresponding output responses.*

For the optimal parameters of	Optimum levels A, B, C, D	Expected Values (Present Study)			Test Results [8]		
		MRR (g/min)	SR (μm)	Kerf (mm)	MRR (g/min)	SR (μm)	Kerf (mm)
MRR	1, 3, 1, 2	0.052161	3.3	0.35	0.051120	5.6	0.355
SR	2, 3, 2, 1	0.044261	2.9	0.33	0.046080	2.2	0.360
Kerf	2, 2, 3, 1	0.036061	3.0	0.34	0.037024	4.4	0.356
ζ	2, 2, 1, 2	0.042063	3.1	0.33	0.042408	1.5	0.342

4. Concluding Remarks

This paper deals with WEDM process performance parameters such as material removal rate (MRR), surface roughness (SR) and kerf width of SS304 adopting the Taguchi's Design of Experiments. ANOVA is performed to identify the significance of the input parameters, viz. voltage, pulse-on-time, pulse-off-time and wire feed rate on the output response parameters (viz., MRR, SR and Kerf). The maximum MRR of 0.052161 g/min can be achieved for 50V voltage, 6 µs pulse-on-time, 4 µs pulse-off-time and 5m/min wire feed rate. The minimum surface roughness, SR of 2.9 µm can be achieved for 60V voltage, 6 µs pulse-on-time, 6 µs pulse-off-time and 3m/min wire feed rate. The minimum kerf of 0.34 mm can be achieved for 60V voltage, 6 µs pulse-on-time, 8 µs pulse-off-time and 3m/min wire feed rate. Since the optimum process parameters are found to be different for the output response parameters (viz., MRR, SR and Kerf), a simple multi-objective-optimization approach is suggested and specified a set of optimum input parameters as 60V voltage, 4µs pulse-on-time, 4 µs pulse-off-time and 5m/min wire feed rate. For these parameters, the output response parameters obtained from equation (1) are: MRR=0.053161 g/min, SR=2.89 µm and kerf width=0.345 mm. The prediction methodology and the multi-objective optimization approach adopted in this paper are quite simple and useful in the Taguchi's design of experiments.

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