IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 3 Ver. I (May- Jun. 2016), PP 46-50
www.iosrjournals.org

Optimization of WEDM Process Parameters of EN47 Spring Steel Based On Roughness Using Taguchi Method

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Abstract : *The present paper deals with the experimental study of roughness (R_a) characteristics of EN 47 spring steel in WEDM and optimization of the machining process parameters based on L_{27} orthogonal design. Experiments are carried out by utilizing the combination of four process parameters namely, pulse on time (T_{on}), pulse off time (T_{off}), wire feed (WF) and gap voltage (V).The optimum combination of process parameters for minimum roughness is obtained as $T_{on}3T_{off}3WF1V1$ i.e., highest levels of pulse on time and pulse off time along with lower level of wire feed and gap voltage. Furthermore, a statistical analysis of variance (ANOVA) is performed to find the significance of machining parameters and their interactions. It is observed that pulse on time together with wire feed play a vital role in controlling the roughness characteristics of EN 47 spring steel. A reduction of around 26% is observed in roughness at the optimal condition compared to the initial condition. The composition of specimen material is studied with the help of chemical test.*

Keywords :*WEDM, EN47 spring steel, surface roughness, optimization, Taguchi method.*

I. Introduction

Nowadays manufacturing sectors are emphasized on non-traditional machining processes due to increasing demands of high surface finish and machining of complex shape geometries [1,2]. Wire Electrical Discharge machining (WEDM) is an indispensable thermal machining process capable of accurately machining parts of hard materials with intricate shapes. WEDM has grown as a simple means of making tools and dies to the best alternative of producing micro-scale parts with the highest degree of dimensional accuracy [3,4]. The metal removal mechanism is due to melting and vaporization caused by the sufficiently high gap voltage and electric spark, which increase the temperature about 10000˚C (that leads to melting and removing of surface material). By this way the metal is removed from the work piece [5-7]. The WEDM processes are having several performance characteristics like Metal Removal Rate, Surface roughness, Kerf width; Dimensional error etc. Generally electrode material of WEDM is made of copper, brass, tungsten, molybdenum etc. with diameter of range 0.05-0.30 mm [8,9]. A number of researchers focused on surface roughness of WDEM and the pulse on time and wire feed rate are significantly affected on surface roughness [10-13].

In this present work 27 experiments are conducted based on the L_{27} Orthogonal array considering pulse on time, pulse off time, wire feed and gap voltages as control factors and the response measured is surface roughness (R_a). Here EN 47 spring steel is used as the work piece. It is 1% chromium-vanadium type spring steel, which is widely used in aerospace industries (smaller aircraft's landing gear), motor vehicle industries (material of leaf spring and coil spring), crank pin of heavy machineries, steering knuckles and disc springs for heavily bolted sections [14]. The objective of the present study is to evaluate the roughness characteristic of EN47 spring steel and optimization of WEDM process parameter for minimum surface roughness based on Taguchi methodology.

II. Taguchi Method

In this present study, Taguchi method [15,16] is used to optimize the WEDM process parameters for minimum roughness based on L_{27} orthogonal array that reduces the number of experiments. Thus, the cost and time of experimentation is decreased. To measure the quality characteristics, Taguchi suggests the use of loss function whichis statistically converted into Signal to noise ratio. Depending on the criteria of experiment, S/N ratio is categorized as lower the better (LB), higher the better (HB) and Nominal the best (NB). For the present study of roughness, lower the better criterion is used. Furthermore, a statistical analysis of variance (ANOVA) is done to find the most significant parameters [17]. With the use of both S/N ratio and ANOVA analysis, the optimal combination of process parameters can be predicted.

III. Details of Experiment

3.1 Work piece material

EN47 spring steel is selected for this study. It is high carbon alloy steel with good harden ability. The average microhardness value is 550 HV_1. It is a tough oil quenching spring steel which when heat treated, offers good wear resistance. The material composition is obtained by chemical test and It is shown in Table 1

Table 1 Chemical composition of EN 47 spring steel

Chemical composition	Carbon (C)	Chromium (Cr)	Manganese (Mn)	Silicon (Si)	Sulphur (S)	Phosphorus (P)	Vanadium (V)
Desired	0.45-0.55	0.80-1.20	0.50-0.80	0.50 (Max.)	0.050 (Max.)	0.050 (Max.)	0.15 (Min.)
Obtained	0.42	0.91	0.81	0.23	0.030	0.027	0.17

3.2 Design of experiment

A scientific approach to plan the experiment is necessary for efficient conduct of experiments. While design factors are applied to study the roughness behavior of the cutting material using WEDM. In present study, design factors and their levels are shown in Table 2. It is a four-factor three-level experiment, so the total degree of freedom (DOF) considering the individual factors and their interaction is 20. Here, L_{27} OA is selected as it satisfies all the DOF conditions. The selected array requires the execution of 27 experiments. The factors (T_{on}, T_{off}, WF and V) and their interactions ($T_{on} \times T_{off}$, $T_{on} \times$WF and $T_{off} \times$WF) are assigned to their respective positions in the OA. Here roughness of EN47 spring steel is taken as the response variable.

Table 2 Design parameters and their levels

Design factors	Unit	Levels		
		1	2	3
Pulse on (T_{on})	µs	4	6	8
Pulse off (T_{off})	µs	8	10	12
Wire feed (WF)	mm/min	6	8	10
Gap voltage (V)	V	50	55	60

3.3 Machining operation

The experimental studies are performed on CNC controlled WEDM machine (JOEMARS WT355). The pictorial view the WEDM is shown in Fig. 1 and the parameters which are kept constant during machining are shown in Table 3.

Fig. 1 Pictorial view of WEDM

Table 3 Constant parameter of WEDM during machining

Parameter	**Value**
Wire	Copper wire, Ø 0.25mm
Shape cut	10×7 mm^2
Thickness/ height of the work piece	13mm
Location of the work piece on work table	At the center of table
Angle of cut	Vertical
Drive system	AC Servo Motor
Dielectric	De-ionized water

3.4 Roughness measurement

Surface roughness describes the morphological features on a real surface. Any real surface is not planar but covered with microscopic hills, valleys, and even scratches. Surface roughness is a bulk measure of the average size of the hills and valleys. A stylus type profilometer, Talysurf (MITUTOYO SJ210) is used to measure the roughness (R_a) of the machining surface of EN47 spring steel. Roughness (R_a) measurement on the machining surface is repeated five times and the average of the measurements is taken as the response for the actual experiment.

IV. Results And Discussion

4.1 Signal to noise ratio analysis

Taguchi method utilizes the S/N ratio approach instead of the average value to convert the experimental results into a value for the evaluation characteristic in the optimum parameter analysis. In the present work, S/N ratio analysis is done with R_a as the performance index. Surface roughness is to be minimized with the help of lower the better criterion. Table 4 shows the R_a values and corresponding S/N ratio values. The average of S/N ratio of each level of the factors of T_{on}, T_{off}, WF and V is given in Table 5 and total average value of S/N ratio of all the 27 experiments is also listed in this Table. It is found that process parameter T_{on} has the highest delta value (rank 1). Hence, pulse on time has the maximum influence on roughness of EN47 spring steel. Parameter WF and T_{off} also have some influence on the roughness. But parameter T_{off} has the least influence on the roughness of EN47 spring steel. The optimal process parameter combination is the one that yields maximum mean S/N ratio which is found to beT_{on}3T_{off}3WF1V1.

Table 4: Experimental values of SR and their corresponding S/N ratio

Exp. No.	Surface roughness (µm)	S/N Ratio	Exp. No.	Surface roughness (µm)	S/N Ratio	Exp. No.	Surface roughness (µm)	S/N Ratio
1	2.185	-6.789	10	2.164	-6.7052	19	2.736	-8.7423
2	2.878	-9.1818	11	2.582	-8.2391	20	2.501	-7.9623
3	2.262	-7.0899	12	2.029	-6.1456	21	2.45	-7.7833
4	2.584	-8.2459	13	2.51	-7.9935	22	2.092	-6.4112
5	2.52	-8.028	14	2.071	-6.3236	23	2.551	-8.1342
6	3.037	-9.6489	15	2.105	-6.465	24	1.86	-5.3903
7	2.262	-7.0899	16	2.421	-7.6799	25	1.938	-5.7471
8	2.187	-6.797	17	2.707	-8.6498	26	2.02	-6.107
9	2.198	-6.8406	18	2.779	-8.8778	27	2.55	-8.1308

Table 5 Response table for mean S/N ratio

Level	T_{on}	T_{off}	WF	V
1	-7.746	-7.627	-7.267	-7.321
2	-7.453	-7.405	-7.714	-7.528
3	-7.157	-7.324	-7.375	-7.506
Rank	1	3	2	4
Delta	0.589	0.302	0.447	0.207

Total mean S/N ratio = 7.452 dB

The main effect and interaction plots between the process parameters are shown in Fig. 2 and Fig. 3 respectively. In the main effects plot if the line for particular parameter has the highest inclination will have the most significant effect. It is very much clear from the main effects plot that parameter T_{on} and WF are the most significant parameters for controlling the roughness of EN47 spring steel. In case of interaction, parallel lines indicate the absence of interaction between the factors, while non-parallel lines indicate the presence of interaction between the factors. And if the lines intersect strong interaction is said to exist between those two factors. Fig. 3 shows that there are strong interactions between T_{on} and T_{off} and T_{off} and WF.

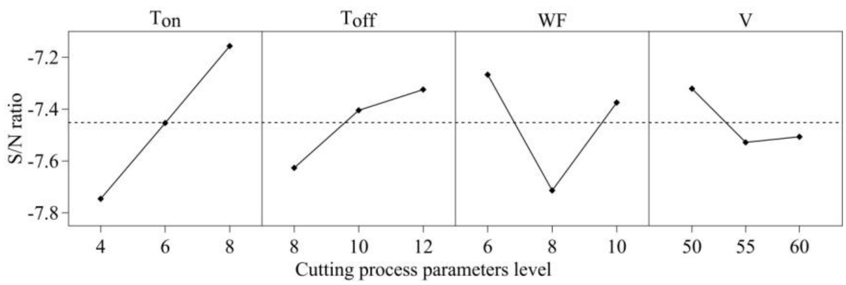

Fig. 2 Main effect plot for signal-to-noise ratio

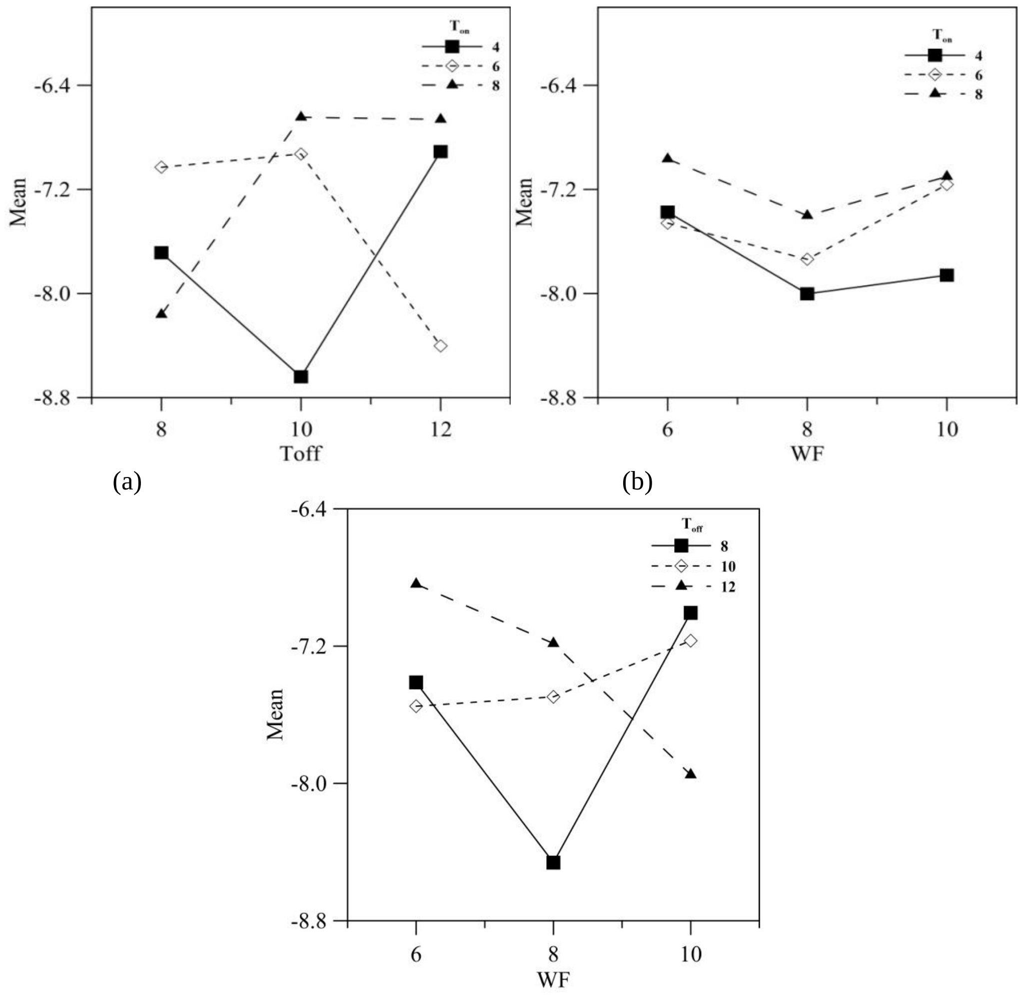

Fig. 3 Interaction plots for mean S/N ratio (a) T_{on}vs T_{off}, (b) T_{on}vs *WF* and (c) T_{off} vs *WF*

4.2 Analysis of variance (ANOVA)

To conduct an analysis of the relative importance of each factor more systematically, an analysis of variance (ANOVA) is applied to the data. Analysis of variance finds out the significance of process parameters and also the percentage contributions of the factors and the interactions in affecting the response. From table 6 it is observed that parameter T_{on} i.e. pulse on time has got the maximum contribution in controlling the roughness characteristics of EN47 spring steel. It is also seen that parameter WF i.e. wire feed has moderate contribution in controlling the surface roughness of EN47 spring steel. Among the interactions, $T_{on}*T_{off}$ gives the highest contribution (39.39%) in controlling the surface roughness of EN47 spring steel while T_{off}*WF has reasonable contribution to influence the roughness of EN47 spring steel within the experimental range in the study.

Table 6 Results of ANOVA for surface roughness

Source	Degree of freedom	Sum of square	Mean square	F-ratio	% Contribution
T_{on}	2	1.562	0.781	0.42	4.844
T_{off}	2	0.441	0.22	0.12	1.37
WF	2	0.978	0.489	0.26	3.033
V	2	0.233	0.117	0.06	0.723
$T_{on}*T_{off}$	4	12.699	3.175	1.69	39.39
T_{on}*WF	4	0.463	0.116	0.06	1.44
T_{off}*WF	4	4.599	1.15	0.61	14.265
Error	6	11.265	1.878		34.941
Total	26	32.24			100

4.3 Confirmation test

Once the optimal level of the process parameters is achieved, it is necessary to carry out the confirmation test to evaluate the accuracy of the analysis and validate the experimental results. Table 7 shows the comparison of the estimated S/N ratio with the experimental S/N ratio using the optimal parameters. The mid-level combination of machining parameters i.e. $T_{on}2T_{off}2WF2V2$, is considered as the initial condition for the present case. The increase of the S/N ratio from the initial condition to the optimal condition is found to be about 1.8364dB. This implies that surface roughness is reduced around 26% from initial to optimal condition and it is a significant improvement.

Table 7 Results of validation test

	Initial condition	Optimal condition	
		Prediction	Experimentation
Level	$T_{on}2T_{off}2WF2V2$	$T_{on}3T_{off}3WF1V1$	$T_{on}3T_{off}3WF1V1$
R_a (µm)	2.2905		1.854
S/N ratio (dB)	-7.1986	-6.84401	-5.3622

Improvement of S/N ratio = 1.8364 dB

V. Conclusion

Taguchi orthogonal array is employed to optimize the WEDM process parameters with respect to surface roughness of EN47 spring steel. It is seen that pulse on time and wire feed rate have the most significant influence in controlling roughness characteristics of the material. The interaction of pulse on time and pulse off time and pulse on time and wire feed have adequate contribution to control the roughness behaviour. The optimal parameter combination for minimum surface roughness is obtained as $T_{on}3T_{off}3WF1V1$ i.e., highest levels of pulse on time and pulse off time along with lower level of wire feed and gap voltage. The surface roughness is reduced by about 26 % from initial to optimal.

Acknowledgements

The authors gratefully acknowledge the research support provided by the Jalpaiguri Govt. Engineering College, MSME Tool Room Kolkata and Narula Institute of Technology, India.

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