Experimental Investigation of WEDM Variables on Surface Roughness of AISI H13

Harvinder Singh, Khushdeep Goyal*, Parlad Kumar

¹Department of Mechanical Engineering, Punjabi University, Patiala, 147001, Punjab, India

*Corresponding Author: khushgoyal@yahoo.com

Copyright © 2013 Horizon Research Publishing All rights reserved.

Abstract The objective of this paper is to experimentally investigate the effects of various Wire Electrical Discharge Machining variables on Surface Roughness of AISI H13 using ANOVA method. The effect of all the input parameters on the output responses have been analyzed using analysis of variance (ANOVA). Plots of S/N ratio have been used to determine the best relationship between the responses and the input parameters. The optimum set of input parameters for minimum surface roughness has been determined. It has been found that wire type and pulse on time are most significant factors for surface roughness

Keywords WEDM, ANOVA, Surface Roughness, S/N Ratio, Process Parameters

1. Introduction

The AISI H13 has been used as workpiece material, which is the most popular and most versatile, hot work tool steel, providing a good balance of toughness, heat check resistance and high temperature strength in addition to moderate wear resistance. Taguchi's L27 Orthogonal Array is used to conduct experiments, which correspond to randomly chosen different combination of process parameters: wire type, pulse on time, pulse off time, peak current, servo voltage, wire tension, wire feed rate, servo feed rate, flushing pressure each to be varied in three different levels.

2. Literature Survey

Hascalyk et al., [1] conducted experiment to study wire electric discharge machining of AISI D5 tool steel. Experimentally it was found that the micro-hardness distribution below the surface with increased dielectric fluid pressure was not changed but the hardness of surface increased slightly. Wire speed do not had any effect on micro-hardness distribution of specimen. The cutting surface of all specimens shows red hardness than the bulk material because of white layer, while the heat affected zone was

softer in quenched and tempered specimen because of over tempered martensite. The models for co-relating the inter-relationships of various WEDM machining parameters of Inconel 601 material was established using Response Surface Methodology [2]. Results showed that the volumetric material removal rate generally increases with the increase of the peak current value and flushing pressure. Wear ratio increases with increase of peak current. Surface Roughness increases with the increase of peak current and decreases with increase of duty factor and wire tension. Yuan et al., [3] used a predictive approach based on Gaussian Process Regression in order to develop a reliable multi-objective optimization to optimize the HS-WEDM process. The authors used mean current, on time and off time as process parameters and MRR and SR were chosen as machining performance parameters. The experiments were conducted on DK-7732C2 WEDM-HS machine. The maximum MRR was 20 mm²/min and SR was less than 2.5 μ m. Singh and Garg [4] carried out Wire Electric Discharge Machining of H-11 hot die tool steel material on Electronica Sprintcut WEDM machine. They investigated the effect of pulse on time, pulse off time, gap voltage, peak current, wire feed, wire tension on material removal rate of hot die steel (H-11) using one variable at a time approach. The optimum parameters were predicted to maximize the material removal rate. Rao et al., [5] studied the effect of WEDM conditions on surface roughness for a parametric optimization using Taguchi Method. The minimum SR was obtained at low peak current (10A) and low pulse on time (105 μ s). The minimum SR was obtained at high wire tension (10 kg-f) and low spark gap voltage (8V). The proposed regression model (with high correlation co-efficient) successfully predicted the parametric values in the machining of Aluminium BIS-24345 alloy. Alias et al., [6] investigated the influence of feed rate on the performance of WEDM on Titanium Ti-Al-4V. It was found that smoother surface which can be obtained at high machine feed rate. When wire tension is increased, it reduces the vibration and improved the machined surface quality. The authors found that low machine feed rate gives bigger crater as compared to high feed rate and vice versa.

The optimal set of parameters has also been predicted to

maximize the material removal rate by authors [7]. Results showed that the better parameter setting was pulse on time 24 μ s, pulse off time 6 μ s, bed speed 35 μ m/s and current 5 Ampere to obtain maximum material removal rate. The strength order of parameter are found from response table is current, pulse on time, bed speed and pulse off time. Muthuraman et al., [8] studied the influence of Process Variable during WEDM of O1 Steel. It was found that surface Roughness decreases with increase in Pulse on time. Pulse on time does not affect the dimensional deviation largely. Wear ratio increases with the increase in Pulse on time. MRR initially decreases and then increases significantly. Surface Roughness increases with increase in Pulse off time. The effect of Pulse off time on dimensional deviation was negligible. The ANOVA was carried out to study the effect of process parameters on process performance and it was shown that pulse-on time, pulse-off time and peak current were most significant parameters [9]. An optimum parametric combination for the maximum material removal rate was obtained by using signal-to-noise ratio.

3. Objectives

The following objectives have been decided for this research work:-

- To find out the effect of different process parameters on surface roughness of the machined specimen.
- To work out the optimum set of input parameters for minimum surface roughness by using ANOVA method.
- To check the validity by conducting confirmation experiments.

4. Experimentation

The experiments were carried out on a WEDM machine, model: ELEKTRA SPRINTCUT 734 of Electronica Machine Tools Ltd., Installed at Central Tool Room, Ludhiana, Punjab, India.

The aisi H13 hot work tool steel specimens of 50 mm length, 27 mm width and 15 mm thickness have been used as workpiece material for the present investigation. The Photographic view of workpiece specimen is shown in Figure 1.

Figure 1. A Photographic views of a workpiece specimen.

4.1. Input Factors and Their Parameters

In this study the factors which mainly affect the response parameters (surface roughness and material removal rate) with their levels were taken. Some of the factors like number of passes, thickness of workpiece, angle of cut were kept constant during the experimental study. The various parameters which were taken for experimental study were type of wire, pulse on time, pulse off time, peak current, servo voltage, wire tension, wire feed rate, servo feed rate, flushing pressure. Three levels of each parameter were taken for the experimental operation. Table 1 shows various levels of input factors.

Table 1. Input factors and their levels

S.No.	Paramater	Symbol	Level 1	Level 2	Level 3	Units
1.	Wire Type	-----	Brass	Diffused	Coated	
2.	Pulse On Time	TON	117	122	127	μ s
3.	Pulse Off Time	TOFF	50	52	54	μ s
4.	Peak Current	PC	210	220	230	Ampere
5.	Servo Voltage	SV	20	25	30	Volts
6.	Wire Tension	WT	6	7	8	Kg-f
7.	Wire Feed Rate	WF	4	5	6	m/min
8.	Servo Feed setting	SF	2100	2110	2120	mm/min
9.	Flushing Pressure	FP	10	12	14	Kg/cm ²

The experiment was designed with L27 orthogonal array, 27 workpieces were machined to complete 27 experimental runs. For each experiment the level of input factors were adjusted on the machine according to their values in the orthogonal array.

5. Results and Discussion

5.1 Analysis of S/N Ratio for Surface Roughness

The results observed for the surface roughness are shown in Table 2. In this table, value of surface roughness is given for each work and also the calculate value of S/N ratio in last column for all 27 treatment conditions. In this design situation, surface roughness is find out with lower is better, which is a logarithmic function based on mean square deviation. The experimental results for surface roughness were analyzed using ANOVA calculations and are given in table 3.

Table 2. Result for Surface Roughness (Ra)

Exp. No.	WIRE TYPE	TON (μ s)	TOFF (μ s)	PC (A)	SV (V)	WT (Kg-f)	WF (m/min)	SF (mm/min)	FP (Kg/cm ²)	SR (μ m)	S/N Ratio(dB)
1.	Brass	117	50	210	20	6	4	2100	10	3.41	-10.655
2.	Brass	117	50	210	25	7	5	2110	12	3.56	-11.029
3.	Brass	117	50	210	30	8	6	2120	14	3.87	-11.754
4.	Brass	122	52	220	20	6	4	2110	12	4.16	-12.381
5.	Brass	122	52	220	25	7	5	2120	14	3.62	-11.174
6.	Brass	122	52	220	30	8	6	2100	10	3.71	-11.387
7.	Brass	127	54	230	20	6	4	2120	14	3.54	-10.980
8.	Brass	127	54	230	25	7	5	2100	10	3.81	-11.618
9.	Brass	127	54	230	30	8	6	2110	12	3.39	-10.603
10.	Diffused	117	52	230	20	7	6	2100	12	3.15	-9.966
11.	Diffused	117	52	230	25	8	4	2110	14	2.28	-7.158
12.	Diffused	117	52	230	30	6	5	2120	10	2.73	-8.723
13.	Diffused	122	54	210	20	7	6	2110	14	2.97	-9.455
14.	Diffused	122	54	210	25	8	4	2120	10	3.91	-11.843
15.	Diffused	122	54	210	30	6	5	2100	12	3.04	-9.657
16.	Diffused	127	50	220	20	7	6	2120	10	3.43	-10.705
17.	Diffused	127	50	220	25	8	4	2100	12	3.57	-11.053
18.	Diffused	127	50	220	30	6	5	2110	14	3.50	-10.881
19.	Coated	117	54	220	20	8	5	2100	14	3.62	-11.174
20.	Coated	117	54	220	25	6	6	2110	10	3.28	-10.317
21.	Coated	117	54	220	30	7	4	2120	12	2.71	-8.659
22.	Coated	122	50	230	20	8	5	2110	10	4.01	-12.062
23.	Coated	122	50	230	25	6	6	2120	12	3.26	-10.264
24.	Coated	122	50	230	30	7	4	2100	14	3.34	-10.474
25.	Coated	127	52	210	20	8	5	2120	12	4.25	-12.567
26.	Coated	127	52	210	25	6	6	2100	14	3.84	-11.686
27.	Coated	127	52	210	30	7	4	2110	10	3.48	-10.831

Table 3. Analysis of Variance for S/N ratio for Surface Roughness (Ra)

S. No.	Source	Sum of Squares	Degree of Freedom	Mean Square	F- ratio	Status	Percentage Contribution
1.	WIRE TYPE	8.658	2	4.329	3.790	Insignificant	22.86%
2.	PULSE ON TIME	8.249	2	4.124	3.611	Insignificant	21.78%
3.	PULSE OF TIME	1.198	2	0.599	0.524	Insignificant	3.16%
4.	PEAK CURRENT	3.549	2	1.774	1.553	Insignificant	9.37%
5.	SERVO VOLTAGE	2.710	2	1.355	1.186	Insignificant	7.15%
6.	WIRE TENSION	1.907	2	0.953	0.834	Insignificant	5.03%
7.	WIRE FEED RATE	1.314	2	0.657	0.575	Insignificant	3.46%
8.	SERVO FEED RATE	0.499	2	0.249	0.218	Insignificant	1.31%
9.	FLUSHING PRESSURE	0.647	2	0.323	0.282	Insignificant	1.71%
	ERROR	9.143	8	1.142			24.14%
	TOTAL	37.874	26				100%

The F-values given in the table suggests the significance of the factors on the desired characteristic. The principle of F test is that larger the F value more is the significance of factor. In these experiments the $F_{0.05,2,8}$ table value, determines significance of a factor at 95% confidence level, if it is greater than 4.46. Since $F_{0.05,2,8} = 4.46$, none of the effects are significant. Using the pooling rule, owing to lower values the SS Servo Feed Rate, SS Flushing Pressure can be pooled into the error term leaving the seven effects in the pooled ANOVA as shown in Table 4.

Table 4. Pooled Analysis of Variance for S/N ratio for Surface Roughness

S. No.	Source	Sum of Squares	Degree of Freedom	Mean Square	F- ratio	Status	Percentage Contribution
1.	WIRE TYPE	8.658	2	4.329	5.051	Significant	22.86%
2.	PULSE ON TIME	8.249	2	4.124	4.812	Significant	21.78%
3.	PULSE OF TIME	1.198	2	0.599	0.698	Insignificant	3.16%
4.	PEAK CURRENT	3.549	2	1.774	2.070	Insignificant	9.37%
5.	SERVO VOLTAGE	2.710	2	1.355	1.581	Insignificant	7.15%
6.	WIRE TENSION	1.907	2	0.953	1.112	Insignificant	5.03%
7.	WIRE FEED RATE	1.314	2	0.657	0.766	Insignificant	3.46%
	ERROR	10.289	12	0.857		Insignificant	27.16%
	TOTAL	37.874	26				100%

Table 5. Response Table for Signal-To-Noise ratio for Surface Roughness

LEVEL	WIRE TYPE	TON	TOFF	PC	SV	WT	WF	SF	FP
1	-11.286	-9.937*	-10.986	-11.053	-11.105	-10.616	-10.448*	-10.852	-10.904
2	-9.937*	-10.966	-10.652	-10.859	-10.682	-10.434*	-10.987	-10.524*	-10.686
3	-10.892	-11.213	-10.478*	-10.205*	-10.329*	-11.066	-10.681	-10.741	-10.526*
DELTA	1.349	1.276	0.508	0.848	0.776	0.632	0.539	0.328	0.378
RANK	1	2	7	3	4	5	6	9	8

*Larger S/N ratios are better to minimize loss function.

With pooled error variance, again, only the input factor 'wire type' and 'pulse-on time' shows significance at 5% level of significance. The response table for signal-to-noise ratio for all the variables is given in Table 5. In the last row of Table 5 ranks have been given to various factors. Higher is the rank, higher is the significance. In the Table 5 wire type has the highest rank 1 and this is the most significant factor followed by pulse-on time with rank 2. However, the other factors have less effect.

5.2. Effect of Different Wire Electrodes

The effect of different wire electrode's materials on surface roughness is shown in Figure 2. It shows that the value of surface roughness decreases when wire is changed from plain brass wire to diffused wire and it increases, when the wire is changed from diffused wire to coated zinc wire. Minimum surface roughness was observed with diffused wire and maximum with plain brass wire.

Figure 2. Effect of Wire Type on Surface Roughness

Figure 3. Effect of Pulse-On Time on Surface Roughness

5.3. Effect of Pulse-On Time

The effect of varying pulse on time on surface roughness is shown in Figure 3. It shows that the surface roughness increases with increase in value of pulse-on time. It may be due to increase in pulse current produces stronger spark and higher temperatures. This causes more melting of the material and eroding the workpiece and consequent increase in surface roughness. The results are inline with Muthuraman et al. [8], who conducted experiments to investigate the influences of process variables during Wire Electric Discharge Machining of O1 steel and found that the surface roughness increases with increase in value of pulse on time.

5.4. Effect of Pulse-Off Time

The effect of varying pulse off time on surface roughness is shown in Figure 4. It shows that with increased value of pulse off time, the surface roughness decreases. This may be because of higher the value of pulse off time, lesser is the number of discharges in a given time, resulting in non uniform sparking and lesser number of particles dislodged near surface of work materials. This causes more hills and valleys rather than uniform rounded surfaces. Similar results have been shown by Subramanyam et al. [9] who conducted experiments for Evaluation of optimal parameters for machining with Wire-Cut EDM using Grey-Taguchi method.

Figure 4. Effect of Pulse Off Time on Surface Roughness

5.5. Effect of Peak Current

The effect of varying peak current on surface roughness is shown in Figure 5. It shows that the surface roughness decreases with increase in value of peak current. The results are inline with Subramanyam et al.[9], who conducted

experiments for Evaluation of optimal parameters for machining with Wire-Cut EDM using Grey-Taguchi method and found that the surface roughness decreases with increase in value of peak current.

Figure 5. Effect of Peak Current on Surface Roughness

Figure 6. Effect of Servo Voltage on Surface Roughness

5.6. Effect of Servo Voltage

The effect of varying servo voltage on surface roughness is shown in Figure 6. It shows that with increase in value of servo voltage, surface roughness decreases. The reason for this may be that when the value for servo voltage is higher; the gap between the workpiece and the electrode becomes

wider. Higher value for servo voltage decreases the number of electric sparks, stabilizing electric discharge, although the machining rate is slowed down. When a smaller value is set for servo voltage, the mean gap becomes narrower, which leads to an increase in number of electric sparks. It can speed up the machining rate; however, resulting in poor surface and wire breakage. Similar results have been reported by Muthuraman et al. [8], Rao et al. [5].

5.7. Effect of Wire Tension

The effect of varying wire tension on surface roughness is shown in Figure 7. It shows with increase in wire tension, surface roughness first decreases and then increases with more increase in wire tension. Surface roughness did not have much of a variation with the increase in wire tension, though wire tension reduces a vibration and improves the surface quality of the machined part. On the other hand wear ratio has increased linearly with an increase in wire tension. Therefore, with more increased wire tension, the surface roughness has been reduced. Subramanyam et al. [9] conducted a study on evaluation of optimal parameters for machining with Wire-Cut EDM using Grey-Taguchi method and similar results were found.

Figure 7. Effect of Wire Tension on Surface Roughness

5.8. Effect of Wire Feed Rate

The effect of varying wire feed rate on surface roughness is shown in Figure 8. It shows with increase in wire feed, that surface roughness first increases and then decreases. Wire feed did not play a vital role on surface roughness of the workpiece. On the other hand as the wire feed increased the wear ratio decreased drastically. This is because the spark erosion on the travelling wire electrode becomes thin and brittle with increased feeds. When wire feed is at maximum,

fresh wire is introduced and the spark generation was also greater. This results in lesser usage of wire electrode. The results are inline with Rao et al. [5], Muthuraman et al. [8] and Subramanyam et al. [9].

Figure 8. Effect of Wire Feed Rate on Surface Roughness

5.9. Effect of Servo Feed Rate

The effect of varying servo feed rate on surface roughness is shown in Figure 9. It shows that with increase in servo feed rate, surface roughness values initially decreases and then increases with further increase in value of servo feed rate. Alias et al. [6] conducted a study on WEDM: Influence of machine feed rate in machining Titanium Ti-6Al-4V using brass wire and constant current (4A) and similar results were found.

Figure 9. Effect of Servo Feed Rate on Surface Roughness

5.10. Effect of Flushing Pressure

The effect of varying flushing pressure on surface roughness is shown in Figure 10. It shows that increase in value of flushing pressure decreases the surface roughness. This may be due to the cooling effect of dielectric flow rate on the workpiece surface. The other reason could be that increased flow on the workpiece may prevent debris adhering to the surface. Sufficient flushing pressure is needed for proper functioning.

Figure 10. Effect of Flushing Pressure on Surface Roughness

6. Conclusions

The wire type, pulse-on time found to be most significant factors for surface roughness, while less effect has been shown by peak current, servo voltage, pulse off time, wire tension, wire feed rate, servo feed rate, flushing pressure on surface roughness. The conclusions of this research work are:

- The surface roughness was found to be minimum with diffused wire and maximum with plain brass wire.
- The surface roughness increases with increase in pulse on time.
- The surface roughness decreases with increase in pulse off time, peak current, servo voltage, and flushing pressure.
- As the wire tension increases, the surface roughness first decreases and then increases with further increase in wire tension.
- As the wire feed rate increases, the surface roughness first increases and then decreases.
- As the servo feed rate increases, the surface roughness initially decreases and then increases with more increase in servo feed rate.

REFERENCES

- [1] Hascalyk, A., and Caydas, U. Experimental study of wire electric discharge machining of AISI D5 tool steel, *Journal of Material Processing Technology*, Vol. 148, 362-67, 2004.
- [2] Ramakrishnan, R., and Karunamoorthy, L. Modelling and multi-response optimization of Inconel-718 on machining of CNC Wire Electric Discharge Machining process, *Journal of Material Processing Technology*, Vol. 207, 343-349, 2008.
- [3] Yuan, J., Wang, K., Yu, T., and Fang, M. Reliable multi-objective optimization of high speed WEDM process based on Gaussian process regression, *International Journal of Machine Tools and Manufacture*, Vol. 48, 47-60, 2007.
- [4] Singh, H., and Garg, R. Effects of process parameters on material removal rate in Wire Electric Discharge Machining, *Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 32, No. 1, 70-74, 2009.
- [5] Rao, P.S., Ramji, K., and Satyanarayana, B. Effect of WEDM conditions on Surface Roughness: A parametric optimization using Taguchi method, *International Journal of Advanced Engineering Sciences and Technologies*, Vol. 6, No. 6, 1041-048, 2011.
- [6] Alias, A., Abdullah, B., and Abbas, N.M. WEDM: Influence of machine feed rate in machining Titanium Ti-6Al-4v using Brass wire and constant current(4A), *Procedia Engineering*, Vol. 41, 1812-1817, 2012.
- [7] Sivakiran, S., Reddy, C. B., and Reddy, C. E. Effect of process parameters on material removal rate in Wire Electric Discharge Machining of EN-31 steel, *International Journal of Engineering Research and Applications*, Vol. 2, No. 6, 1221-1226, 2012.
- [8] Muthuraman, V., Ramakrishnan, R., Karthikeyan, L., and Praveen, C. Influences of process variables during Wire Electric Discharge Machining of O1 steel, *European Journal of Scientific Research*, Vol. 79, No. 3, 2371-77, 2012.
- [9] Subrahmanyam, S.V., Sarcar, M.M.M. Evaluation of Optimal Parameters for machining with Wire-Cut EDM using Grey-Taguchi method, *International Journal of Scientific and Research Publications*, Vol. 3, No. 3, 1-9, 2013.