Multi-Quality Characteristics Optimization of WEDM for IN-625 by Applying Taguchi DEAR Technique

S. Sonawane[1] and M. Kulkarni[2]

[1]Research Scholar, Walchand Institute of Technology, Solapur, India
[2]Professor, Rajarshi Shahu School of Engineering and Research, Narhe, Pune, India
{sonawanesachin09@gmail.com}

Abstract: To manufacture quality products at lowest cost in industries, optimization is an effective technique which can be applied to find out the best manufacturing conditions. The objective of this research work is to examine the effect of control factors and to choose the correct settings of these factors to maximize MRR and minimize surface roughness and overcut while WEDM of Inconel-625. The control factors chosen for the study are pulse on time, pulse off time, servo voltage, peak current, wire feed rate and wire tension. Experiments were planned as per Taguchi's L27 orthogonal design under diverse cutting conditions of control factors. Data envelopment analysis based ranking technique (DEAR) was employed for multi-quality characteristic optimization. The optimal values of control factors was found as pulse on time 118 µs, pulse of time 41µs, servo voltage 30 volts, peak current 230 Amp, wire feed rate 1 m/min and wire tension 5 Gram. From the outcomes of the ANOVA, Pulse-on time was found to be the major significant factor affecting the quality characteristics.

Keywords: ***WEDM, Taguchi method, Inconel-625, DEAR, multi-quality characteristic optimization, ANOVA***

1 Introduction

Nickel based alloys finds wide applications in different parts of gas turbines of aircraft, steam turbine power plants, reciprocating engines, tool & die industry, medical field, heat treatment equipments, nuclear power plants, chemical industries, pollution control apparatus and in coal gasification and liquefaction systems. As nickel based super alloys possesses high hardness, high strength at elevated temperature, low thermal diffusivity and high chemical reactivity with the tool materials, they are very difficult to machine conventionally. This leads to nick wear of the tool nose, abrasive wear of the tool, greater diffusion wear rate, fragmentation of the tool rake face, degradation of tool material by seizure and cratering, increase in the temperature of tool tip and uneven temperature distribution in the cutting tool. [1,2]. Wire electrical discharge machining (WEDM) is one of the significant non-conventional thermoelectric process for machining of materials with high hardness, chemically reactive and which are difficult to machine using conventional methods. In WEDM material removal takes place due to melting and evaporation by thermal energy produced due to continuous discrete sparks. It finds major applications in aerospace, nuclear and automotive industries to cut intricate shapes in electrically conductive materials. Liao and Chen [3] used DEAR method for multi-objective optimization and found that the proposed method eliminates uncertainty and complication associated with PCA and Taguchi method. Sahu et.al. [4] carried out experiments on AISI D2 steel with response surface methodology to find out the effect of machining parameters on MRR, TWR, surface roughness and circularity. Data envelopment analysis was applied to find out optimal responses. Chalisgaonkar and Kumar [5] applied utility concept approach to determine optimal combination of parameters while WEDM of pure titanium. Rajyalashmi and Ramaiah [6] used grey relational analysis to carry out multi-response optimization of WEDM parameters while machining Inconel-825. Reddy et. al. [7] applied Taguchi based DEAR method to optimize the process parameters of EDM.

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This paper reports multi-quality characteristic optimization of control factors while wire electrical discharge machining of Inconel-625 using Taguchi method integrated with data envelopment analysis based ranking method (DEAR).

Taguchi's L27 orthogonal array was applied for experimental design. ANOVA was performed to find out the major significant factor which affects the quality characteristics.

2 Experimental Work

Inconel-625 was selected as a work piece material for the present experimental investigation with dimensions 30 mm x 30 mm x 5 mm thickness. With the help of Brass wire of diameter 0.25 mm as a tool electrode, a block of 10 mm x 10 mm x 5 mm was cut from the work piece. Taguchi's L27 orthogonal design was used for experimental planning. Six control factors considered for study were pulse on time, pulse off time, servo voltage, peak current, wire feed rate and wire tension. Control factors along with their levels are shown in Table 1. The quality characteristics selected for this study were MRR, surface roughness and overcut. The "lower-the-better" quality characteristic has been used for calculating signal to noise ratio (S/N) of surface roughness and overcut, whereas "higher-the better" quality characteristic for MRR.

Eq. 1 and 2.

$$\zeta\ LB = -10 \log\left[\frac{1}{n}\sum_{1}^{n} Zij^2\right] \quad (1)$$

$$\zeta\ HB = -10 \log \left[\frac{1}{n}\sum_{1}^{n} 1/Zij^2\right] \quad (2)$$

where Zij is the response of the ith experiment at the jth test and n is the total number of repetitions.

Mitutoyo make surface roughness tester SJ-201 was used to measure surface finish in µm on the machined square block. MRR and overcut were calculated by using following equations:

$$MRR= \frac{Volumeofmaterialremoved}{Timetakeninmin} \quad (3)$$

$$Overcut = \frac{Widthofcut - D}{2} \quad (4)$$

Where, D = wire diameter in mm

Width of cut is the algebraic difference of dimensions of square on the work piece and square block. MRR was measured in mm3/min and overcut in mm. Statistical analysis was carried out using Minitab 16 software. Table 2 shows Taguchi's L27 orthogonal design along with the results obtained from the experiments and corresponding S/N ratios.

3 Data Envelopment Analysis based Ranking (DEAR) technique

In DEAR technique, a set of unique quality characteristics are converted into a ratio which is called as multi-quality characteristic index (MQCI). This MQCI value is used to determine optimal settings of control factors. The different steps in DEAR technique are as follows:

I. Compute the weight of each quality characteristic: The weight of each quality characteristic is the ratio of value of quality characteristic at any particular experiment to the summation of values of quality characteristic of all experiments. Weights are computed by applying the following equations:

$$\beta SR = \frac{(\frac{1}{SR})}{(\sum 1/SR)} \quad (5)$$

$$\beta OC = \frac{(\frac{1}{OC})}{(\sum 1/OC)} \quad (6)$$

$$\beta MRR = \frac{MRR}{(\sum MRR)} \quad (7)$$

Table 1 Control factors and their levels

Symbol	Control Factor	Unit	Level 1	Level 2	Level 3
A	Pulse on Time	µs	110	114	118
B	Pulse off Time	µs	41	46	51
C	Servo Voltage	Volts	20	30	40
D	Peak Current	Amp	170	200	230
E	Wire Feed Rate	m/min	1	3	5
F	Wire Tension	Gram	2	5	8

Table 2 Taguchi's L_{27} orthogonal design with quality characteristics and respective S/N ratios

Ex. No.	A	B	C	D	E	F	SR (µm)	S/N ratio	OC (mm)	S/N ratio	MRR (mm^3/min)	S/N ratio
1.	110	41	20	170	1	2	1.82	-5.2332	0.370	8.6212	33.30	29.9882
2.	110	41	20	170	3	5	1.68	-4.3511	0.230	12.749	27.60	28.2153
3.	110	41	20	170	5	8	1.60	-3.9551	0.265	11.523	26.60	27.712
4.	110	46	30	200	1	2	1.76	-4.7944	0.402	7.9133	31.16	29.3075
5.	110	46	30	200	3	5	1.70	-4.4375	0.224	13.007	28.43	28.6294
6.	110	46	30	200	5	8	1.61	-4.0827	0.300	10.419	26.64	27.7466
7.	110	51	40	230	1	2	1.79	-5.0095	0.340	9.3529	32.25	29.6556
8.	110	51	40	230	3	5	1.58	-3.8283	0.380	8.4023	25.67	27.6978
9.	110	51	40	230	5	8	1.52	-3.5025	0.168	15.492	24.53	27.6619
10.	114	41	30	230	1	5	2.32	-7.3475	0.320	9.8773	55.00	34.5062
11.	114	41	30	230	3	8	2.19	-6.9537	0.270	11.345	48.63	33.8563
12.	114	41	30	230	5	2	1.85	-5.3749	0.167	15.528	33.70	30.2365
13.	114	46	40	170	1	5	2.28	-7.1217	0.186	14.625	52.37	34.1899
14.	114	46	40	170	3	8	1.79	-5.1215	0.179	14.958	32.92	29.7878
15.	114	46	40	170	5	2	2.01	-6.0496	0.176	15.106	37.62	30.7563
16.	114	51	20	200	1	5	1.95	-5.6816	0.286	10.872	34.00	30.4922
17.	114	51	20	200	3	8	2.06	-6.3054	0.165	15.65	39.20	31.0776
18.	114	51	20	200	5	2	1.97	-5.772	0.159	15.972	36.60	30.5405
19.	118	41	40	200	1	8	2.51	-7.9132	0.352	9.0606	58.70	34.9792
20.	118	41	40	200	3	2	2.04	-6.2784	0.172	15.303	38.90	30.9849
21.	118	41	40	200	5	5	2.41	-7.5559	0.164	15.721	56.34	34.6794
22.	118	46	20	230	1	8	2.10	-6.568	0.404	7.8794	44.37	31.6185
23.	118	46	20	230	3	2	2.36	-7.4225	0.288	10.822	55.20	34.6204
24.	118	46	20	230	5	5	2.25	-6.9922	0.200	14.108	50.90	33.9312
25.	118	51	30	170	1	8	2.50	-7.7954	0.212	13.473	57.60	34.9689
26.	118	51	30	170	3	2	2.31	-7.3226	0.163	15.755	54.50	34.4202
27.	118	51	30	170	5	5	1.73	-4.592	0.180	14.892	29.20	29.0937

II. Transform each quality characteristic value into weighted values by multiplying each characteristic value with its own weight using the following equations:

$$s = SR \times \beta SR \quad (8)$$

$$oc = OC \times \beta OC \quad (9)$$

$$m = MRR \times \beta MRR \quad (10)$$

III. Divide the larger-the-better characteristic with smaller the better characteristic to get the MQCI value using the following equation

$$\text{MQCI} = \frac{m}{(s+oc)} \quad (11)$$

4 Results and Discussion

Fig. 1 to 3 depicts the effect of control factors on quality characteristics. From Fig. 1 & 2 it is found that as there is an increase in the value of pulse-on time and peak current, stronger sparks with greater amount of discharge energy is produced. These sparks strikes the work piece, resulting in melting of material and produces large and deep craters on the work piece surface. This results in significant increase in the values surface finish and MRR. With increase in pulse-off time, discharge energy produced per spark decreases resulting in decrease of MRR and surface finish. As servo voltage increases, there is delay in the discharge which results in the generation of less discharge energy. This leads to decrease in the value of surface roughness and MRR. At low values of wire feed rate, duration of contact between wire and work piece increases values of surface roughness and MRR increases. Wire tension has no significant effect on surface roughness and MRR.Fig. 3 shows that as pulse on time increases, overcut first decreases rapidly then increases very slightly. With increase in the value pulse off time, overcut first increases and then decreases. Values of overcut decreases, with the increment in peak current and servo voltage. Increase in wire tension value leads to higher overcut. Effect of wire feed rate is not very significant.

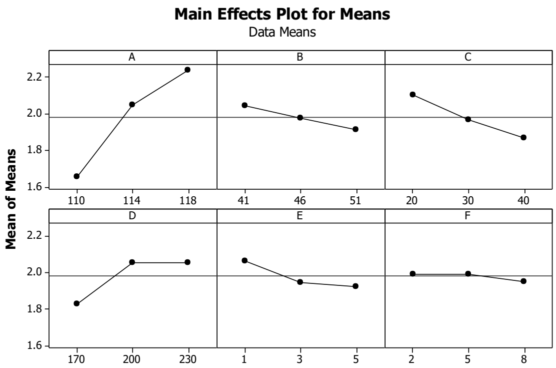

Fig. 1. Effect of control factors on surface roughness

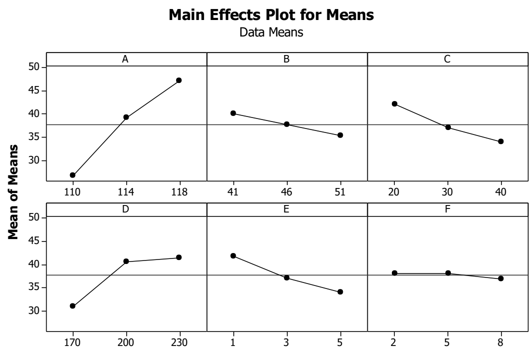

Fig. 2. Effect of control factors on MRR

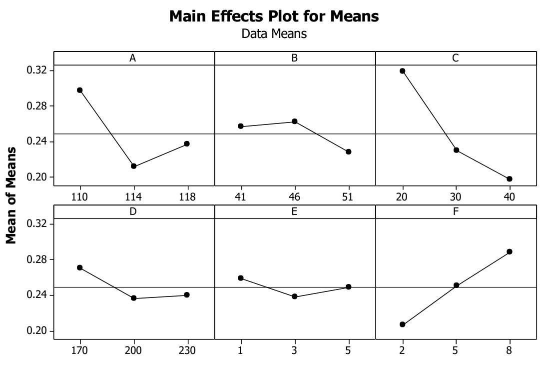

Fig. 3. Effect of control factors on overcut

Further, multi-quality characteristic optimization was carried out by applying Taguchi-DEAR technique. Weights of the quality characteristics and MQCI values are computed by using Eqs. (5) to (11). These values are represented in Table 3. Highest value of MQCI for a particular control factor represents optimal level for that factor. From Table 4 values of optimal control factors were found to be pulse on time 118 µs, pulse of time 41µs, servo voltage 30 volts, peak current 230 Amp, wire feed rate 1 m/min and wire tension 5 Gram. From the outcomes of ANOVA, it is found that pulse on time is the most noteworthy factor affecting the quality characteristics. Confirmation experiments were conducted at the optimal settings of control factors. Table 5 depicts the outcomes of confirmation experiments.

Table 3 Weights and MQCI values for all experiments

Exp. No.	Weights			MQCI
	Surface roughness β_{SR}	Overcut β_{OC}	MRR β_{MRR}	
1.	0.039573	0.022513	0.031065	12.87419
2.	0.042871	0.036217	0.025748	8.844019
3.	0.045015	0.031434	0.024815	8.214758
4.	0.040922	0.020721	0.029069	11.27266
5.	0.042367	0.037187	0.026522	9.383939
6.	0.044735	0.027766	0.024852	8.239482
7.	0.040237	0.024500	0.030086	12.07511
8.	0.045584	0.021921	0.023947	7.650384
9.	0.047384	0.049583	0.022884	6.985968
10.	0.031045	0.026031	0.051309	35.12019
11.	0.032887	0.030851	0.045367	27.45617
12.	0.038932	0.04988	0.031439	13.18534
13.	0.031589	0.044784	0.048856	31.84173
14.	0.040237	0.046536	0.030711	12.58204
15.	0.035833	0.047329	0.035096	16.43119
16.	0.036935	0.029125	0.031718	13.42114
17.	0.034963	0.050484	0.03657	17.84036
18.	0.03656	0.052389	0.034144	15.55227
19.	0.028695	0.023664	0.054761	40.00439
20.	0.035306	0.04843	0.03629	17.56834
21.	0.029885	0.050792	0.052559	36.85235
22.	0.034297	0.020619	0.041393	22.85653
23.	0.030518	0.028923	0.051496	35.37607
24.	0.03201	0.041649	0.047484	30.07925
25.	0.028809	0.039292	0.053735	38.51913
26.	0.031179	0.051104	0.050843	34.48454
27.	0.041632	0.046277	0.027241	9.899134

Table 4 Response table for MQCI

Level	A	B	C	D	E	F
1	9.505	**22.236**	18.340	19.299	**24.221**	18.758
2	20.381	19.785	**20.840**	18.904	19.021	**20.344**
3	**29.516**	17.381	20.221	**21.198**	16.160	20.300
Delta	20.011	4.855	2.5	2.294	8.061	1.586

Table 5 Outcomes of the confirmation experiments at the optimal settings of control factors

Sr. No.	Quality characteristic	Optimum value	
		Predicted value	Experimental value
1.	Surface roughness, µm	-	2.38
2.	Overcut, mm	-	0.341
3.	MRR, mm^3/min	-	59.36
4.	MQCI	40.00439	41.3517

Table 6 ANOVA for MQCI

Factors	DF	Seq SS	Adj MS	F	P
A	2	1806.54	903.269	12.2	0.001*
B	2	106.06	53.029	0.72	0.506
C	2	30.52	15.261	0.21	0.816
D	2	27.08	13.542	0.18	0.835
E	2	300.59	150.294	2.03	0.168
F	2	14.68	7.342	0.1	0.906
Residual Error	14	1036.86	74.061		
	26	3322.33			

* Significant at 95% confidence level

5 Conclusions

In this research work, Taguchi based DEAR technique is applied for multi-quality characteristic optimization while WEDM of Inconel-625. The optimal settings of control factors obtained are pulse on time 118 µs, pulse of time 41µs, servo voltage 30 volts, peak current 230 Amp, wire feed rate 1 m/min and wire tension 5 Gram. Outcomes of the ANOVA represent that pulse-on time is the major considerable factor affecting the quality characteristics.

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