OPEN ACCESS

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Parametric Optimization of WEDM Characteristics on Inconel 825 using Desirability Research

Pawan Kumar, Meenu Gupta, Vineet Kumar

***Abstract:** The present research focuses on the optimization of wire-cut electric discharge machining (WEDM) parameters. In this study, RSM based multi-response desirability method is used to optimize the WEDM characteristics for single and multiple responses. Input parameters of WEDM viz. pulse-on time, pulse-off time, spark gap voltage, wire tension, peak current, wire feed and performance was measured in terms of material removal rate (MRR) and surface roughness (SR). WEDM is a nontraditional method uses the spark erosion principle to produce the intricate shape and profiles of difficult-to-cut material. Inconel 825 is increasing in demand in the aerospace industry for more heat resistant and tough material. Because of its robust nature, it is difficult to be machined with conventional methods. WEDM is best alternate to overcome this problem. It has been observed that at Ton 111 MU, Toff 35 MU, SV 46V, IP 140A, WT 9 MU and WF 6 m/min, the values obtained for MRR and SR are 32.015mm2/min and 2.528 µm respectively.*

***Keywords:** Wire-cut electrical discharge machining; Material removal rate; Surface roughness; Inconel 825; Response surface methodology; Desirability*

I. INTRODUCTION

Now a day, in the field of manufacturing technologies superalloys increase in demands because of their high tensile strength and resistance to deterioration. Superalloys are currently being applied in technologically advanced industries such as marine, space, automobiles and other applications [1]. Nickel-based superalloys are the most multifaceted used alloy for the hottest parts and constitute over 50 % of the weight of advanced aircraft engines. Among nickel based superalloys, Inconel 825 has an austenitic structure that imparts high ductility and work hardening properties for this superbly resulting in a gummy machining behavior similar to that of steels. [2]. Because of this, the machining of this hard material with conventional method is very difficult [3]. WEDM is non-traditional machining technique in the machining of superalloys and by the use of WEDM, a revolutionary change has been found in tools. WEDM is the best alternative of making intricate shape and profile with better surface finish and accurate dimensions of hard and tough material like Inconel 825 [4].

The execution of WEDM is measured as material removal rate (MRR) and surface roughness (SR) which are subjective to numerous input characteristics such as pulse-on time (T_{on}), pulse-off time (T_{off}), peak current (IP), gap voltage (SV), wire tension (WT) and wire feed (WF). Many workers employed Taguchi's methodology to obtain the most excellent combination of parameters for desired machining performances [5, 6]. Goyal [7] investigated that the pulse on time, tool electrode and current intensity are the significant parameters that affects the MRR and SR during machining of Inconel 625. Kumar et al. [8] employed desirability based RSM approach to optimize the machining parameters for machining of Inconel 800 using Powder mixed EDM. Optimum conditions obtained was current 1A, pulse on-time 0.98 µs, pulse off-time 0.03 µs, tool material 0.31 and the powder (suspended particles) 0.64. Amongst the nickel based superalloy, many reports published on the WEDM cutting of Inconel 718 [9]. Moreover, surface integrity investigation is required to determine the final performance of the machined product. Surface roughness parameters included surface morphology, residual stress surface roughness, microstructure, and micro-hardness and formation of heat affected zone, micro-cracks, porosity was crucial in determining the final performance of the machined specimen [10]. After critically analyzing the literature, it is revealed that there is limited work done on the machining of Inconel 825 by WEDM process. This research mainly focuses on the standardization of WEDM parameters by measuring their effect on MRR and SR on Inconel 825 using RSM based desirability approach.

II. MATERIALS AND METHODS

A. *Work material and mechanism of WEDM*

Inconel 825 (150 mm x 150 mm x 10 mm) was used as work material for the present study. All experiments were performed on CNC WEDM machine tool (ELECTRA SPRINT CUT 734) in advanced manufacturing lab of Mechanical Engineering Department, N.I.T., Kurukshetra, India. The workpiece was mounted with the help of a fixture on the machine table. The electrode material used was a single-strand plain brass wire (0.25 mm diameter).

Revised Manuscript Received on 30 July 2019.
* Correspondence Author
Pawan Kumar, Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India.
Meenu Gupta, Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, India.
Vineet Kumar, Department of Mechanical Engineering, UIET, Maharishi Dayanand University, Rohtak, India.

The upper head supplied the fresh wire under tension through the workpiece and lower head received the used wire after machining. Control panel of the machine was used to display the cutting speed (mm/min) and time taken for machining is noted down for every run. The surface roughness (SR) of machined specimen was measured in micrometer (µm) using Accretech's surfcomflex instrument SJ-301. Least count of the instrument was 0.8 mm. A sampling length of 5 mm was selected for measurement.

B. Design of Experiments

Central composite design (CCD) at α value of ± 2 was employed using Design expert software (version 9.0.7, Statease) to optimize the levels of significant variables. Six parameters, i.e. pulse on time (Ton), pulse off time (Toff), peak current (IP), gap voltage (SV), wire tension (WT) and wire feed (WF) were chosen as input parameters as suggested from literature searches. The machining performance is measured in terms of material removal rate (MRR), and surface roughness (SR).

The regression equation is used to fill the data by multiple regression procedure. The developed empirical statistical model shows the relation between measured characteristics and input parameters of the experiment

$$y = \beta_0 + \sum_{i=1}^{k}\beta_i x_i + \sum_{i=1}^{k}\sum_{j=1,i<j}^{k}\beta_{ij}x_i x_j +$$
i=1kβiixi2 + ε (1)

where, y is the predicted response [MRR and SR], β_0 is the constant term, β_i the linear coefficients, β_{ii} the squared coefficients and β_{ij} is the interaction coefficients. Equation 1 is used to construct 3D plots.

The individual desirability index for each response is calculated. The desirability function approach is extensively used for single and multiple quality characteristic problems.

C. Prediction of optimum values for maximum MRR and minimum SR

After getting the model equation that explains the process, it was used for optimization of the input parameters using the numerical optimization option of the software. Criteria were set for each independent variable and the response (dependent variable). The independent variables were kept in the range used by the experimental set up. The response for MRR was set to maximum and for SR set to minimum. Response data was generated for multiple response optimizations.

D. Validation experiments

To ensure the validity of the chosen quadratic model, experiments were designed using the predicted optimum values of the parameters from equation 1. The responses are measured and compared with the predicted value. Experiments are conducted in triplicates and the data presented as mean ± SD.

III. RESULT AND DISCUSSION

In this study RSM was used to study the individual and the interactive effect of operating variables on output responses and optimization of parameters during cutting of Inconel 825. Two output parameters, i.e. material removal rate (MRR) and surface roughness (SR) were taken as output response. A total of 52 experiments are conducted as suggested by the software (Table 1) and results are fed and analyzed by ANOVA. Machining performance is optimized in such a way so that maximum material removal rate can be achieved with little damage to the material surface.

Table 1: Central composite design with actual responses

Run	T_{ON}	T_{OFF}	SV	IP	WT	WF	MRR	SR
1	111	38	50	130	10	4	21.27	2.618
2	111	38	50	130	10	6	20.44	2.306
3	109	35	54	140	11	7	18.59	2.453
4	113	35	54	120	11	7	27.79	2.967
5	113	41	54	120	9	7	20.63	2.766
6	113	35	54	120	9	5	27.69	2.867
7	113	41	46	140	9	7	20.06	2.711
8	111	38	50	130	10	6	21.97	2.673
9	109	41	46	120	9	7	17.01	2.783
10	109	35	54	140	9	5	21.34	2.844
11	109	41	46	140	11	5	31.81	2.793
12	109	41	54	140	9	7	16.17	2.716
13	109	41	46	140	9	5	20.23	2.732
14	113	35	46	120	9	7	27.63	2.678
15	111	38	50	130	10	6	21.89	2.911
16	111	38	50	130	10	6	20.41	2.875
17	109	35	46	140	9	7	28.94	2.442
18	115	38	50	130	10	6	31.25	3.32
19	113	35	46	140	11	7	34.72	2.84
20	111	32	50	130	10	6	30.87	2.613
21	111	44	50	130	10	6	17.19	2.667
22	113	35	54	140	11	5	31.42	3.271
23	109	41	54	140	11	5	18.55	2.514
24	111	38	50	130	10	6	35.93	2.963
25	113	41	46	120	11	7	28.95	3.299
26	109	35	46	120	9	5	25.79	2.721
27	109	35	54	120	11	5	19.92	2.489
28	111	38	50	130	8	6	24.09	2.767
29	111	38	50	150	10	6	27.08	2.684
30	109	35	54	120	9	7	20.21	2.681
31	113	41	54	140	11	7	27.68	2.742
32	111	38	50	130	12	6	26.05	2.792
33	111	38	50	130	10	6	24.59	3.074
34	109	35	46	140	11	5	25.47	2.622
35	111	38	50	130	10	6	23.94	2.461
36	111	38	42	130	10	6	25.57	2.594
37	113	41	54	140	9	5	33.28	2.892
38	109	41	46	140	11	7	20.52	2.415
39	109	41	54	120	9	5	16.7	2.521
40	113	41	54	120	11	5	24.46	2.263
41	109	41	54	120	11	7	16.71	2.318
42	109	35	46	120	11	7	23.14	2.485
43	111	38	58	130	10	6	19.61	2.734
44	113	41	46	120	9	5	28.39	2.805

45	113	35	46	120	11	5	34.56	2.827
46	107	38	50	130	10	6	14.7	2.844
47	111	38	50	130	10	8	25.77	2.94
48	113	35	46	140	9	5	36.14	2.833
49	113	35	54	140	9	7	36.13	2.842
50	111	38	50	130	10	6	29.48	2.853
51	109	41	46	120	11	5	23.67	2.64
52	111	38	50	110	10	6	28.08	2.748

A. Analysis of variance for MRR

A predictive two factor polynomial equation 2 was constructed by using multiple regression analysis to describe the correlation between MRR and the six process parameters.

$$MRR=25.30 + 3.73\times A-2.80 \times B-1.59 \times C + 0.40 \times D + 0.75 \times E - 0.29 \times F - 1.14 \times AB + 0.93 \times AC + 0.68 \times AD + 0.16 \times AE - 0.23 \times AF + 0.093 \times BC + 0.10 \times BD + 1.74 \times B \times E-0.24 \times BF + 0.13 \times CD - 1.26 \times CE + 0.39 \times CF + 0.084 \times DE + 0.41 \times D \times F + 0.024 \times EF \quad (2)$$

where, A, B, C, D, E and F are the coded values of T_{on}, T_{off}, SV, IP, WT and WF respectively. The F-value of 33.67 implies that the model is significant. The p-values <0.05 indicate that the linear (A, B, C, E) and interactive (AB, AC, AD, BE, CE) terms have a quite significant influence on the material removal rate. The percentage contribution of A, B, C, E, AB, AC, AD, BE, CE for MRR is 45.19, 25.38, 8.18, 1.84, 3.12, 2.07, 1.09, 7.26 and 3.81% respectively. The lack of fit was found to be not significant. The p-value for lack of fit was 0.9298, indicating that this model sufficiently fit into the data. The determination coefficient R^2 (0.9593) indicates that the predicted and experimental values have perfect coherence with each other. The value of adjusted R^2 (0.9308) suggests that the variation of 93.08% in the MRR is accredited to the independent variables and 6.92% of the total variation could not be explained by the model.

B. Effect of different input parameters on MRR

The interaction between two variables when the others are kept at its optimum value is presented in Figure 1 which is generated by the pair-wise combination of the two factors while keeping the other one at its optimum level. The three dimensional plot between T_{on} and T_{off} (AB), T_{on} and SV (AC), T_{on} and IP (AD) and T_{on} and WT (AE) on MRR are shown in Fig. 1 (a-d) respectively.

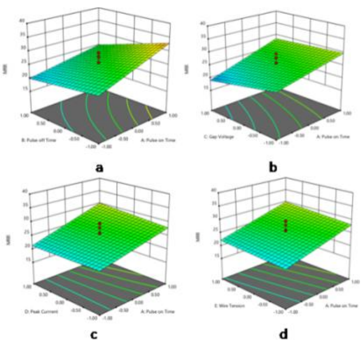

Figure 1. Three dimensional plots of combined effects of (a) T_{on} and T_{off} (b) T_{on} and SV (c) T_{on} and IP (d) T_{on} and WT on MRR

From the figure it was depicted that pulse on time had significant positive effect on MRR, as MRR increased from 19 mm^2/min to 33 mm^2/min approximately with an increase in value of T_{on} from 109 machine unit to 113 machine unit (Figure 1a) while T_{off} has negative effect on MRR, as MRR decreases with increases in value of T_{off} from 35 machine unit to 41 machine unit (Figure 1a). However, when applied in combination, the MRR value decreases. At high value of Ton, high discharge energy is produced leading to melting of more work material from the surface. High intense heat produced in plasma zone accelerates the erosion process which results in increase in the material removal rate [11]. Similarly, gap voltage is shown to have a negative effect on MRR (Figure 1b). The spark gap voltage is the theoretical voltage difference between wire electrode and workpiece during erosion. In combination T_{on} and SV reduced the MRR. MRR will be maximized at 113 machine unit T_{on} and low gap voltage, i.e. 46 V to 48 V (Figure 1b). The reason can be attributed to the fact that at high values of the SV, the gap between two successive sparks increases resulting in the production of less discharge energy which causes decreased MRR [12]. It is evident from Figure 1c that MRR rises with a rise in the value of T_{on} and IP which in turn improve MRR [13]. MRR is maximized (30 mm^2/min) at 113 machine unit T_{on} and 140 amp peak current. At higher value of IP the gap condition becomes unstable and to stable the gap condition it is necessary to reduce the value of peak current. Similarly, MRR is maximized (29 mm^2/min) at the interactive effect of the town (113 machine unit) WT (11 machine unit) (Figure 1d). Saini et al. [13] also concluded that wire tension has a reversible effect on MRR.

C. Analysis of variance for surface roughness (SR)

A predictive two factor polynomial equation 3 was constructed to describe the correlation between SR and the six process parameters.

$$SR=2.68 + 0.12 \times A - 7.032E - 003 \times B + 0.019 \times C + 0.012 \times D - 0.022 \times E - 8.676E - 003 \times F - 0.041 \times AB-1.219E - 003 \times AC + 0.022 \times AD + 0.053 \times AE + 0.039 \times AF - 0.078 \times BC + 6.781E - 003 \times BD-0.066 \times BE + 0.049 \times BF + 0.067CD - 0.053 \times CE + 0.011 \times CF + 0.028 \times DE - 0.078 \times DF + 0.014 \times EF \quad (3)$$

The F-value of 37.20 depicted the model is significant. In this case A, C, E, AB, AD, AE, AF, BC, BE, BF, CD, CE, DE, DF are important model conditions for SR with their contribution percentage of 36.87, 0.837, 0.346, 3.016, 0.893, 5.083, 2.681, 11.173, 7.821, 4.357, 7.821, 0.212, 1.396 and 10.614 % respectively. Lack-of fit value of 0.1642 depicted that it is not significant relative to pure error.

The determination coefficient for SR is found to be 0.9630 which shows that the factorial model can explain the variation in the surface roughness up to the extent of 96.30%. Therefore, the planned model is adequate in representing the process.
The other R^2 statistics, the Pred R^2 (0.8491), is in good agreement with the Adj R^2 (0.9371).

D. Effect of different input parameters on SR

The two variables interaction when the others were kept at its optimum value is for SR is presented in Figure 2. The interaction plot between T_{on} and T_{off} (AB), T_{on} and IP (AD), T_{on} and WT (AE) and T_{on} and WF (AF) are shown in figure (2a-d) respectively.

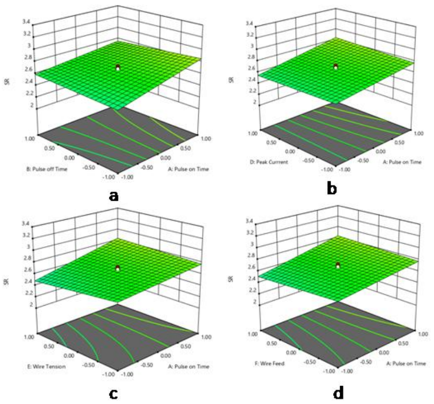

Figure 2 Three dimensional plots of combined effects of (a) T_{on} and T_{off} (b) T_{on} and IP (c) T_{on} and WT (d) T_{on} and WF on SR

From the Fig. 2a-b, it is observed that SR increases up to 2.756 µm at the combination of T_{on} and T_{off}. The reason can be attributed to the fact that T_{on} is the well-known factor to increase the discharge energy. Low value of the Ton decreases the time duration of current flowing while high value of Toff resulted in increases in the time interval between two sparks causing less discharge energy and less temperature generated between two electrodes which in turn improve the SR [13]. At high value of T_{on} (113 machine unit), surface roughness increases upto 2.838µm with an increase in the value of IP from 120 A to 140 A. As shown in Fig. 2b. Minimum surface roughness occur (2.569µm) at low value of pulse-on time, i.e. 111 to 109 machine unit and low value of IP 125 to 120 A (Figure 2b). At high value of IP, the pulse discharge energy increases resulted in increase the MRR as well as increase the SR [14]. Wire tension is a significant process parameter for surface roughness and affects the geometry of the specimen cut from the workpiece. Surface roughness decrease with increase of wire tension from 9 to 11 machine unit and when applied in combination with T_{on}, the SR increases upto 2.834µm as shown in Figure 2c. It has been observed that the increase in WT will reduce the wire vibrations and causes reduction in SR resulting in the improved superiority of the machined surface [14]. Wire feed has little effect on surface roughness. Increase in wire deed resulted in less increase in SR (Figure 2d). At higher WF with T_{on}, the SR increases upto 2.835µm because at higher wire feed, more wire moves on wire guides through the geometry of the workpiece resulting in large area of the wire get exposed to sparking zone forming large craters and pockmarks on the work surface which in turn increase the surface roughness [15].

E. Multi response optimization using desirability approach

After optimizing the each output responses individually, multi-response optimization was carried out for the responses MRR and SR. The desirability function approach is extensively used for single and multiple quality characteristics problems [18]. It is based on the fact that the "quality" of a product or process which is outside the desired limit is completely undesirable for multiple quality characteristics. The method results in operating conditions which provides the "most desirable" output response characteristics. Numerical optimization option of design expert software was used to carry out this. The values of six input variables were kept in range and the response factor MRR was set to maximum while SR was set to minimum. The lower and upper limit of each variable was taken individually and the weight of each variable and response was set to their default value of 1. Because the target of the present study is to increase the cutting rate while maintaining the minimum surface damage, the importance of MRR is taken as 4 and SR is taken as 3. Experiments were performed under predicted conditions as given by the software. It was observed that at 111machine unit T_{on}, 35machine unit T_{off}, 46V SV, 140A IP, 9 machine unit WT and 6 m/min WF, the values obtained for MRR and SR are 32.015 and 2.528 respectively which are near to the predicted values (Table 2) with an error of less than 5%. Thus, the model was successfully validated.

Table 2: Validation of predicted model

Type of Optimization	Objective	Optimization parameters						Response (Predicted)	Response (Experimental)	Desirability	% error
		Ton	Toff	SV	IP	WT	WF				
Single response	Maximize MRR	113	35	54	140	9	7	35.841	35.985	0.986	2.03
Single response	Minimize SR	109	35	46	140	9	7	2.072	2.2152	1.000	0.60

Retrieval Number: B1076078219/19©BEIESP
DOI: 10.35940/ijrte.B1076.078219
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Multi Response	Maximize MRR & Minimize SR	111	35	46	140	9	6	30.615, 2.383	32.015 2.528	0.807	2.86 3.87

IV. CONCLUSIONS

In this study, multi response optimization was done to study the effect of WEDM machining variables on machine outcome using desirability based RSM approach. It is concluded that pulse on time, gap voltage and peak current have significant positive effects on increasing MRR while an increase in pulse off time resulted in decreased SR. The developed method will result in improving productivity and reduced roughness of Inconel 825 in the aerospace industry. The optimum parametric combination obtained from the current study are advantageous for functioning on high strength, high thermal conductivity and low melting point materials like nickel alloys even at higher temperatures.

CONFLICT OF INTEREST

The author states that there is no conflict of interest

REFERENCES

1. R.K. Palakudtewar, S.V. Gaikwad, "Dry Machining of Superalloys: Difficulties and Remedies," Int. J. of Sci and Res, 2014, pp. 277-282.
2. P. Kumar, M. Meenu. Kumar, "Optimization of Process Parameters for WEDM of Inconel 825 Using Grey Relational Analysis," Dec. Sci. Letters, 2018, pp. 405-416.
3. A. Goswami, J. Kumar, "Investigation of surface integrity, material removal rate and wire wear ratio for WEDM of Nimonic 80A alloy using GRA and Taguchi method," Int. J. Engg. Sci. Technol, 2014, pp. 173-184.
4. G. Rajyalakshmi, P.A. Venkata, "Parametric optimization using Taguchi method: effect of WEDM parameters on surface roughness machining on Inconel 825," Elixir Int. J., 2012, pp. 6669-6674.
5. S.S. Mahapatra, A. Patnaik, "Optimization of wire electrical discharge machining (WEDM) process parameters using Taguchi method," Int. J. of Adv. Manuf. Technol, 2007, pp. 911-925.
6. U.A. Dabade, S.S. Karidkar, "Analysis of response variables in WEDM of Inconel 718 using Taguchi technique," Procedia CIRP, 2016, pp. 886 – 891.
7. A. Goyal, "Investigation of material removal rate and surface roughness during wire electrical discharge machining (WEDM) of Inconel 625 super alloy by cryogenic treated tool electrode," J King Saud Univ. Sci, 2017, pp. 528-535.
8. S. Kumar, A.K. Dhingra, S. Kumar, "Parametric optimization of powder mixed electrical discharge machining for nickel based superalloy inconel-800 using response surface methodology," Mech. of Adv. Mater. and Mod. Proces., 2017
9. B. Bijeta Nayak, S. Sankar Mahapatra, "Optimization of WEDM process parameters using deep cryo-treated Inconel 718 as work material," *Eng. Sci. and Technol., an Int. J.*, 2016, pp. 161–170.
10. P. Kumar, M. Gupta, V. Kumar, "Surface integrity analysis of WEDMed specimen of Inconel 825 superalloy," Int. J. of Data and Network Sci., 2018.pp.79-88.
11. M. Manjaiah, S. Narendranath, S. Basavarajappa, V.N. Gaitonde, "Wire electric discharge machining characteristics of titanium nickel shape memory alloy," Trans. Nonferrous Met. Soc. China, 2014, pp. 3201–3209.
12. S.P. Arikatla, M. K. Tamil, A. Krishnaiah, "Parametric Optimization in Wire Electrical Discharge Machining of Titanium Alloy Using Response Surface Methodology," *Materials Today: Proceedings*, 2017, 4, pp. 1434–1441.
13. P.K. Saini, M. Verma, Experimental "Investigation of Wire-EDM Process Parameters on MRR of Ti-6al-4v Alloy," *Int. J. of Innov .Technol. and Explor. Eng.*, 2014, 4, pp. 2278–3075.
14. R. Bobbili, V. Madhu, A.K. Gogia, Multi response optimization of wire-EDM process parameters of ballistic grade aluminium alloy, *Eng. Sci. and Technol., an Int. J.*, 2015, pp. 720-726.
15. Derringer, Suich, Myers, Montgomery and Anderson-Cook, *Response Surface Methodology*, 3rd edition, John Wiley and Sons, New York, 2009.