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A STUDY ON PARAMETRIC OPTIMIZATION OF WIRE ELECTRICAL DISCHARGE MACHINING USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Wire electrical discharge machining (WEDM) is extensively used in machining of exotic conductive materials when precision is of prime importance. Conventional machining in Beryllium copper alloy is difficult due to its hardness. WEDM is treated as a challenging one because improvement of more than one machining performance measures viz. material removal rate (MRR), surface finish (SF) are sought to obtain precision in work. An attempt to determine parameters setting is proposed. The Response Surface Methodology (RSM) and the Analysis of variance (ANOVA) are adopted to determine the significant factors that could affect the machining performance such as material removal rate, surface finish etc. In this study, pulse ON time, pulse OFF time, pulse duration and servo feed are considered as control parameters. It has been observed that a combination of factors for optimization of each performance measure is different. In this paper, the relationship between control factors and responses like MRR and SF are established by means of regression analysis, resulting in a valid mathematical model. The study also demonstrates that the WEDM process parameters are optimized to achieve better material removal rate and surface finish simultaneously.

Key words: Wire electrical discharge machining (WEDM), Response surface methodology (RSM), Analysis of variance (ANOVA), MRR, Surface finish.

INTRODUCTION

Wire electrical discharge machining is the most helpful non-traditional material removal process. This technique has been widely used in modern metal working industries for producing complex profile in dies and moulds in tool and die making and also other fields like aerospace, automotive, surgical component manufacturing industries etc. The process variables especially electrical variables are more significant parameters in deciding

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response values[1]. To attain the precise and accurate machining, it is necessary to predict response values of machining to decide the input parameters to be provided.

Optimum selection of process parameters is very much essential, as this is a costly process to increase production rate considerably by reducing machining time. Material removal rate (MRR) and surface roughness are most important output parameters, which decide the performance of machining[2]. In nature, material removal rate increased with decreasing of surface roughness and vice versa. In WEDM by a single pass of wire, the material from the work piece can be fully removed irrespective to rough cut and finished cut like conventional machining process[3]. Hence it brings interest to optimize the process input parameters at best in combination. Each parameter may have individual capacity to determine the output parameters.

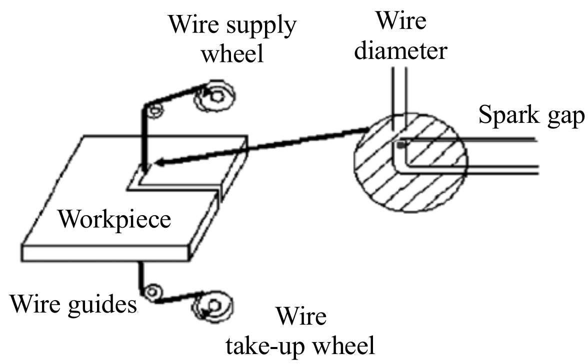

Fig. 1: Detail of WEDM cutting gap

EXPERIMENTAL

In the present study, MRR and surface roughness have been considered for evaluating the machining performance. MRR and surface roughness are correlated with input machining parameters such as pulse ON time (Ton), pulse OFF time (Toff), servo feed and pulse duration. The experiments were conducted on the Sodick AQ 300L CNC wire electrical discharge machine. A diffused brass wire of 0.25 mm diameter was used as cutting tool. Beryllium copper alloy used as the work piece in rectangular shape size of 50 x 50 x 16 mm^3. The deionised water is used as dielectric fluid.

Response surface methodology

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By design of experiments, the objective is to optimize a response (output variable), which is influenced by several independent variables (input variables)[7].

Table 1: Input parameters levels

Parameters	Level		
	Low	Medium	High
Pulse on time (µs)	8	10	14
Pulse off time (µs)	10	15	20
Pulse duration (µs)	250	300	350
Servo feed (mm/min)	30	75	120

RSM is often applied in the characterization and optimization processes. In RSM, it is possible to represent independent process parameters in quantitative form as:

$$Y = f\,(x1, x2, x3,\ldots\ldots\ldots\ldots\ldots\ldots\ldots..xn) \pm \varepsilon \qquad \ldots(1)$$

Where, Y is the response (yield), f is the response function, ε is the experimental error, and x1, x2, x3,…….., xn are independent parameters.

RESULTS AND DISCUSSION

The experiments are carried out on the Sodick WEDM, the input parameters to be chosen from a limited set of possible values. The values of input parameters, which are of interest in the rough cut with finishing phase, are recorded. The RSM, a tool for parameter design of the performance characteristics was used to determine optimal machining parameters for maximization of MRR, SF in WEDM.

Material removal rate

The volume of material removed during the cutting operation is calculated by the formula.

$$MRR = (Wb - Wa)/T \text{ (g/min)} \qquad \ldots(2)$$

Where, Wb – Weight before machining in gms,

Wa – Weight after machining in gms,

T – Machining time in min.

Table 2: Experiment results

S. No.	T ON (µs)	T OFF (µs)	MAO (µs)	Servo feed (mm/min)	MRR (g/min)	Ra (µm)
1	1	1	0	0	0.001	3.2
2	1	0	-1	0	0.00104	2.98
3	0	0	0	0	0.0007213	3.24
4	0	0	0	0	0.0007213	2.72
5	0	1	0	1	0.000733	3.02
6	0	0	-1	-1	0.0005323	2.87
7	0	-1	1	0	0.0008027	2.96
8	0	1	-1	0	0.000781	2.87
9	-1	0	-1	0	0.000496	2.78
10	1	0	0	1	0.00105	3.46
11	-1	0	1	0	0.000514	2.75
12	0	-1	-1	0	0.0006122	2.86
13	0	1	1	0	0.000733	3.06
14	1	0	0	-1	0.0005388	3.08
15	0	0	0	0	0.0007213	2.78
16	0	0	-1	1	0.000726	2.93
17	0	0	1	-1	0.0005587	3.03
18	0	0	0	0	0.0007	2.91
19	-1	0	0	-1	0.0005143	2.56
20	1	0	1	0	0.001073	3.1
21	0	0	0	0	0.0007	2.83
22	1	-1	0	0	0.001219	3.09
23	-1	1	0	0	0.0005191	2.71
24	0	1	0	-1	0.0005	3.36
25	-1	0	0	1	0.0005227	2.68
26	-1	-1	0	0	0.0005655	3.05

Cont…

S. No.	T ON (µs)	T OFF (µs)	MAO (µs)	Servo feed (mm/min)	MRR (g/min)	Ra (µm)
27	0	-1	0	-1	0.0003196	2.70
28	0	0	1	1	0.0005587	2.72
29	0	-1	0	1	0.0005454	3

The Effect of process parameters on MRR is shown in Fig. 1. MRR increases with increase in pulse ON time due to prolonged machining. If pulse OFF time increases MRR decreases. MRR increases with increase in pulse duration upto certain level and then it decreases. Here servo feed has the same effect like pulse duration on MRR (Fig. 3).

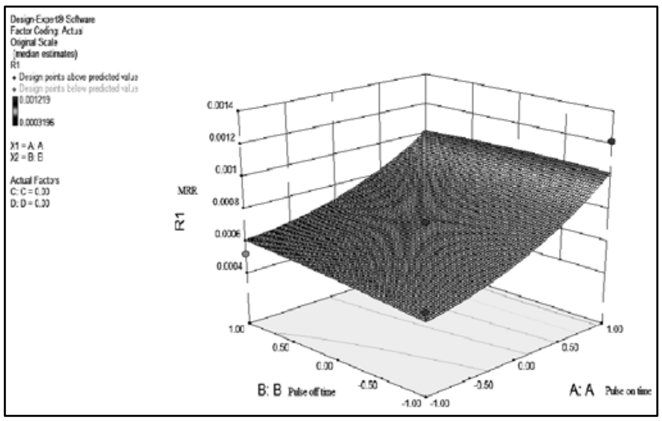

Fig. 2: Response (MRR) of pulse ON time Vs pulse OFF time

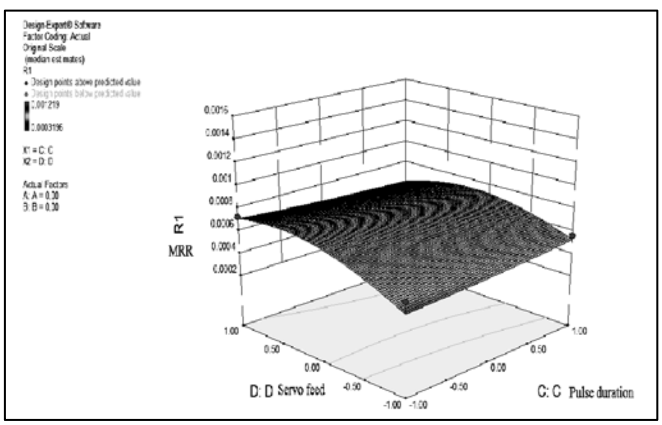

Fig. 3: Response (MRR) of pulse duration Vs servo feed

The increase in pulse OFF time has no considerable effect on MRR because it is period of deionization for dielectric. The combined increase pulse ON time and pulse OFF time causes increase in MRR[9].

Analysis of variance (ANOVA)

The purpose of the ANOVA is to investigate the design parameters that significantly affect the quality characteristic and to determine percentage of contribution on the process performance measures [2,7].

ANOVA table shows, pulse ON time has positive impact on MRR that means increase in value of pulse on time increase in MRR.

Table 3: Anova table for MRR

Factors	DOF	SS	Mean square	F value	Pp (%)
Pulse ON time	2	7.323 x 10-7	3.661×10^{-7}	81.5714	62.18
Pulse OFF time	2	9.0829 x 10-8	4.5414×10^{-8}	10.1174	7.71
Pulse duration	2	3.1749 x 10-8	1.5874×10^{-8}	3.5366	2.69
Servo feed	2	3.1383 x 10-7	1.5691×10^{-7}	34.9573	26.64
Error	20	1.2584 x 10-6	4.4887×10^{-9}	1	0.88

Surface finish

Surface finish may be defined as the irregularities on the surface controversy with imaginary profile. Graphically the roughness is in the form of short wave lengths[5]. Roughness gets more concern while mating and interference checking. A computer controlled contact type surface roughness tester is used to measure the surface roughness of machined pieces, which has equal length. Surface roughness tester has diamond tip robe, which moves over the piece on machined surface.

The surface finish will get decreased with increase in pulse ON time and vice versa (Fig. 4). The surface finish is moderately good when the pulse OFF time is less. The combined effect on surface finish by pulse ON time and pulse OFF time is not appreciable with the high values of pulse duration.

From Fig. 5, it is inferred that the servo feed and pulse duration are in same levels the surface finish is moderate. The surface finish is low when the two variables in opposite levels. The surface finish is good when the low servo feed combined with less pulse on time and irrespective to pulse of time.

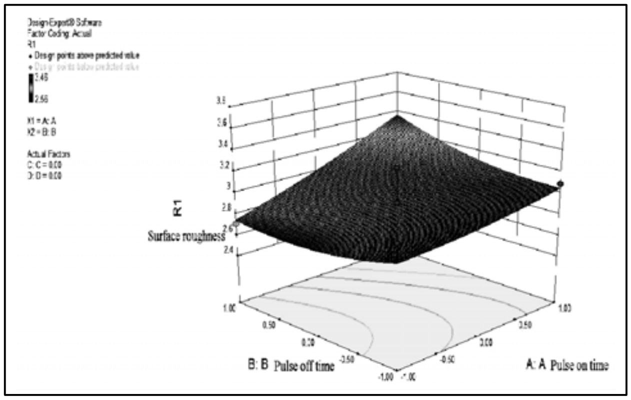

Fig. 4: Response of pulse on time Vs pulse off time

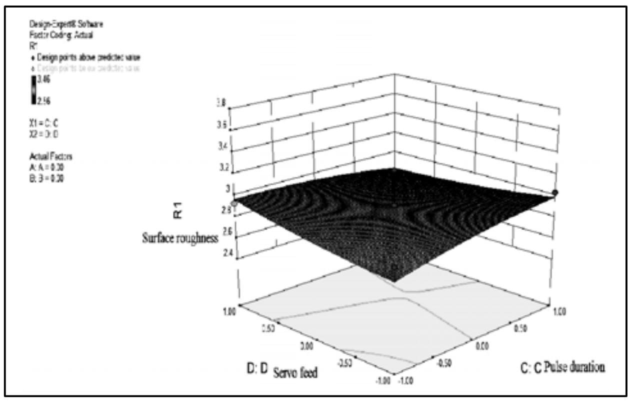

Fig. 5: Response of pulse duration Vs servo feed

Table 4: Anova table for R_A

Factors	DOF	SS	Mean square	F value	Pp (%)
Pulse ON time	2	0.475	0.2375	7.098	72.81
Pulse OFF time	2	0.074467	0.0372335	1.1128	11.416
Pulse duration	2	0.03037	0.015185	0.4538	4.65
Servo feed	2	0.005598	0.0027799	0.08308	0.85
Error	20	0.6692	0.03346	1	10.25

Mathematical model

The relationship between control factors and responses like material removal rate and surface roughness were established by means of non-linear regression analysis resulting in a valid mathematical model[4], Mathematical model are obtained with the help of Design Expert V8.0 software and the following relationships were obtained[4,11].

MRR = (4.17755E-3*Pulse ON time) + (4.88496E-4*Pulse OFF time) + (7.35913E-5*Pulse duration) + (1.95384E-3* Servo feed) + 0.025994 …(3)

SF = (0.19833*Pulse ON time) + (0.046667*Pulse OFF time) + (0.027500*Pulse duration) + (0.017500* Servo feed) + 2.94138 …(4)

CONCLUSION

(i) WEDM process has proved its adequacy to machine Beryllium copper alloy under acceptable material removal rate, which reached 0.000723 g/min and surface finish (Ra) of 2.56 μm.

(ii) The analysis of the response parameters using RSM technique has the advantage of explaining the effect of each working parameter on the value of the resultant response parameter.

(iii) The list of 29 parametric combinations will act as technical guideline for effective machining of the alloy.

(iv) ANOVA results show that pulse on time plays significant role on both MRR (62.8%) and surface finish (72.81%).

(v) Mathematical model for MRR and surface finish are obtained with the help of Design Expert V8.0 software and it can be used to find output parameters for different input combinations.

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