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Radial Over Cut Optimization of Titanium Alloy for Electric Discharge Machining using Advanced Optimization Technique – Jaya Algorithm

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***Abstract*: In this work, EDM parameter optimization is done to minimize radial overcut. Response surface methodology is used to develop a predictable mathematical model for radial over cut (ROC). The current, voltage, pulse on time and duty factor are selected as a process control parameters, radial over cut (ROC) is considered as quality measures. Central composite design (CCD) is used for the design of experiments. Total of thirty experiments were conducted as per the design of experiments (DOE). A mathematical model shows the relation between the machining parameter and ROC. This mathematical model used to optimize ROC using Jaya Algorithm an advanced optimization technique.**

***Keywords* : Electric Discharge Machining, EDM, response surface optimization, RSM, Advanced optimization, Jaya Algorithm, single objective optimization..**

I. INTRODUCTION

Electric discharge machining (EDM) is a very popular nonconventional machining. It can machine any shape and any material. EDM has the capability to machine difficult-to-cut material [1]. There are two electrodes (workpiece and tool) are separated by a certain distance and a potential difference is applied between electrodes [2]. As soon as breakdown voltage attain sudden current passes in the form of arc or spark. Sparking is concentrated to a very small area. Due to this sparking, a lot of heat energy is generated. This heat used melts and evaporates some material from both electrodes [3]. Ho and Newman review to improving performance measures of die-sinking EDM [4].

A model is required to predict and optimize any given problem. There are so many different techniques are available. Joshi and Pandey prepared thermo electric model using the finite element method for die-sinking EDM [5]. Pradhan and Biswas used response surface methodology (RSM) to develop a predictive model of surface roughness with four input parameter current, voltage, pulse on time and pulse off time [6]. Gopalakannan et al. carried experiments on MMC using the central composite design of response surface methodology [7]. Spedding et al. model Wire electrical discharge machining (WEDM) with through Response Surface Methodology and Artificial Neural Networks [8]. Nowadays intelligent modeling being popular. Joshi et al. used an intelligent modeling approach to model the EDM process [9]. Joshi et al. used an artificial neural network (ANN) and finite-element method (FEM) to model the EDM process [10]. Shrivastava and Dubey used a hybrid approach of the artificial neural network, genetic algorithm, and grey relational analysis for multi-objective optimization [11,12].

Optimization is defined as the finding of the solution of a given problem to which is minimized or maximized while the solution is feasible and fulfill the given constraints. Conventional optimization method is very difficult to solve if the number of control parameters increases or complexity of the problem increases. This limitation can be overcome by the use of advanced optimization techniques. Rao and Kalyankar reviewed of advanced optimization techniques in modern machining processes [13]. Dorigo and Thomas demonstrate Ant Colony Optimization (ACO) in optimization problem [14]. Donoso and Ramon states metaheuristics are high-level computer algorithm used to solve the optimization problem that converges towards optimal solution [15]. Rao developed an advanced optimization algorithm, Jaya Algorithm in 2016 [16, 17]. Jaya algorithm is a simple and powerful algorithm for solving unconstrained and constrained optimization problem. In Jaya algorithm solution moves toward the best solution and moves away from the worst solution simultaneously. Jaya algorithm is perfect for engineering optimization problem and became popular for single-objective optimization and multi-objective optimization as well.

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Radial over cut (ROC) is unavoidable in die-sinking EDM. Figure 1 show the radial over cut. ROC can overcome by suitable design of electrode. In this research paper Jaya algorithm is used to optimize (minimized) radial over cut (ROC) for parameter optimization of EDM machining. Muthukumar et al. applied response surface methodology to develop a predictable model of radial overcut for Incoloy 800 superalloy in die-sinking EDM [18]. Roy and Dutta work on parameter optimization for Stainless Steel SS 304 Grade for radial overcut [19].

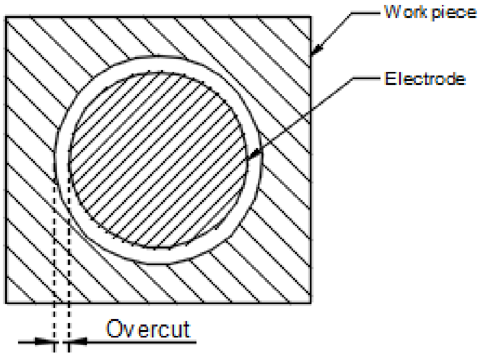

Figure 1: Radial overcut

II. EXPERIMENTAL SETUP

Titanium alloy is selected as workpiece and thirty machining operation on electric discharge machining conducted as per the design of experiments. Copper rod of 10 mm diameter is selected as a tool electrode. Each machining operations done for 30 minutes. After machining, cavity diameter is measured by light microscope with least count of 0.001 mm. Job is placed on a glass table which can be move by knob. Glass table is just below the eyepiece. A crossing line is inbuilt with the eyepiece. Initially, this line should be tangent to the round cavity of the machined hole. Initial reading as (Di). Then move glass table until crossing line made tangent to another end of diameter again this reading as (Do). The net diameter will be equal to (Do-Di). The net ROC will be equal to (Do-Di)/2. Control parameter and their ranges are shown in table 1. Here it is noted that the fourth parameter t (duty factor) range is between 8 to16. Where t=8 (equivalent to 25 % duty factor); t=12 (equivalent to 37.5 % duty factor); t=16 (equivalent to 50 % of duty factor).

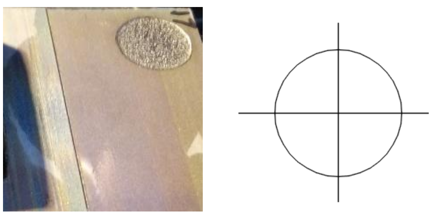

Figure 2: workpiece with a round cavity and cross hairs.

Table 1: Input parameter range

Parameter	Level 1	Level 2	Level 3
Ip (A)	4	6	8
V (Volt)	40	70	100
Ton (µs)	50	100	150
t (duty factor)	8	12	16

Table 2: Experimental observations of ROC

Exp.	Ip	V	Ton	t	ROC
1	8	40	150	16	0.110
2	8	40	50	8	0.232
3	4	40	50	8	0.050
4	8	40	50	16	0.280
5	6	70	100	12	0.122
6	6	70	100	12	0.146
7	6	70	100	12	0.117
8	4	40	50	16	0.220
9	4	40	150	16	0.059
10	4	100	150	8	0.080
11	4	40	150	8	0.054
12	4	100	50	16	0.275
13	4	100	50	8	0.052
14	8	100	50	16	0.235
15	6	70	100	12	0.167
16	8	100	150	16	0.105
17	8	100	150	8	0.107
18	8	40	150	8	0.144
19	4	100	150	16	0.091
20	8	100	50	8	0.201
21	6	70	50	12	0.118
22	6	40	100	12	0.185
23	6	100	100	12	0.103
24	6	70	100	16	0.135
25	6	70	100	8	0.002
26	6	70	100	12	0.123
27	6	70	150	12	0.063
28	8	70	100	12	0.265
29	6	70	100	12	0.129
30	4	70	100	12	0.237

III. MODELING USING RESPONSE SURFACE METHODOLOGY

RSM is a set of mathematical and statistical techniques used to develop a predictable model of ROC. A commercial software Minitab 18 used to prepare the design of experiment (DOE). Thirty experiments were carried out as per DOE and response (radial overcut) is recorded in table 2. A model is developed using response surface methodology as following equation number 1. The R2 value was found to be 95.1 %. Minitab 18 used to develop a predictive model.

$$ROC = -0.221 - 0.2738\ Ip + 0.001308\ V + 0.00503\ Ton + 0.1397\ t + 0.02927\ Ip*Ip - 0.000017\ Ton*Ton - 0.00412\ t*t - 0.000244\ Ip*V - 0.000107\ Ip*Ton - 0.002841\ Ip*t - 0.000155*Ton*t \quad \ldots \quad (1)$$

IV. OPTIMIZATION WITH JAYA ALGORITHM

Jaya algorithm is an advanced optimization technique used for engineering optimization to optimize. Radial over cut should be minimized to improve machining quality.

Step 1 : Generate Initial solution with in the given range as per table 1. Calculate objective function value for given equation (1)

Table 3: Initial population

Can.	Ip	Ton	t	V	ROC	
1	4.7832	149.2359	14.4181	65.4536	0.0722	Best
2	6.9155	57.3243	11.4589	85.8204	0.1757	Worst
3	5.9934	109.0991	13.9933	73.5292	0.1277	
4	7.236	141.0188	8.3135	51.0306	0.0931	
5	5.426	69.3766	15.5706	69.8769	0.1497	

Step 2: Now consider two random numbers r1=0.5178 and r2=0.9942. From table 3 it is observed candidate 1 has minimum objective function value hence selected as best candidate while candidate 2 has maximum objective function value (ROC) hence selected as worst solution.

Step 3: Now calculate new values of all four parameter as per equation (2)

X'j,k,i = Xj,k,i + r1,j,i (Xj,best,i - │Xj,k,i│)
- r2,j,i (Xj,worst,i - │Xj,k,i│) .... (2)

Ip1=4.7832+0.5178*(4.7832-|4.7832|)-0.9942*(6.9155-|4.7832|)= 2.6632 (=4 because minimum Ip=4)
Ip2=6.9155+0.5178*(4.7832-|6.9155|)-0.9942*(6.9155-|6.9155|)= 5.8113
Ip3=5.9934+0.5178*(4.7832-|5.9934|)-0.9942*(6.9155-|5.9934|)= 4.4500
Ip4=7.236+0.5178*(4.7832-|7.236|)-0.9942*(6.9155-|7.236|) = 6.2855
Ip5=5.426+0.5178*(4.7832-|5.426|)-0.9942*(6.9155-|5.426|) = 3.6122 (=4 because minimum Ip=4)

Ton1=149.2359+0.5178*(149.2359-|149.2359|)-0.9942*(57.3243-|149.2359|)=240.6144 (=150 because upper limit of Ton=150)
Ton2=57.3243+0.5178*(149.2359-|57.3243|)-0.9942*(57.3243-|57.3243|)=104.9161
Ton3=109.0991+0.5178*(149.2359-|109.0991|)-0.9942*(57.3243-|109.0991|)=181.3564 (=150 because upper limit of Ton=150)
Ton4=141.0188+0.5178*(149.2359-|141.0188|)-0.9942*(57.3243-|141.0188|)=228.4827 (=150 because upper limit of Ton=150)
Ton5=69.3766+0.5178*(149.2359-|69.3766|)-0.9942*(57.3243-|69.3766|)=122.7101

t1=14.4181+0.5178*(14.4181-|14.4181|)-0.9942*(11.4589-|14.4181|) =17.3601 (=16 because upper limit of t=150)
t2=11.4589+0.5178*(14.4181-|11.4589|)-0.9942*(11.4589-|11.4589|)=12.9911
t3=13.9933+0.5178*(14.4181-|13.9933|)-0.9942*(11.4589-|13.9933|) =16.7329 (=16 because upper limit of t=150)
t4=8.3135+0.5178*(14.4181-|8.3135|)-0.9942*(11.4589-|8.3135|)=8.3473
t5=15.5706+0.5178*(14.4181-|15.5706|)-0.9942*(11.4589-|15.5706|)=19.0169 (=16 because upper limit of t=150)

V1=65.4536+0.5178*(65.4536-|65.4536|)-0.9942*(85.8204-|65.4536|)=45.2041
V2=85.8204+0.5178*(65.4536-|85.8204|)-0.9942*(85.8204-|85.8204|)=75.2735
V3=73.5292+0.5178*(65.4536-|73.5292|)-0.9942*(85.8204-|73.5292|)=57.1269
V4=51.0306+0.5178*(65.4536-|51.0306|)-0.9942*(85.8204-|51.0306|)=23.91081 (=40 because minimum limit of V=40)
V5=69.8769+0.5178*(65.4536-|69.8769|)-0.9942*(85.8204-|69.8769|)=51.7346

If new calculated value of a variable falls below the lower limit then assign a lower range to the variable. If new value go beyond the upper limit then assign upper limit to that variable with reference to table 1.

Step 4: Now insert new calculated values of all parameter into table 4.

Table 4: New values of variables and the objective function value (first iteration).

Candidate	Ip	Ton	t	V	ROC
1	4*	150*	16	45.2041	0.1016
2	5.8113	104.9203	12.9911	75.2735	0.1372
3	4.45	150*	16	57.1269	0.0597
4	6.2845	150*	8.3473	40	0.0124
5	4*	122.7101	16	51.7346	0.1724

Step 5: Now compare table 3 and table 4. Candidate 1 from table 3 has better ROC value than table 4 hence select candidate 1 from table 3 and insert into table 5, as candidate 1. Candidate 2, 3 and 4 has better ROC value in table 4 as compare to table 3. Hence select candidate 2, 2 and 4 from table 4 and inserted into table 5 as candidate 2,3 and 4. Candidate 5 from table 3 has better ROC value than table 4 hence select candidate 5 from table 3 and insert into table 5 as candidate 5.

First Iteration is over now.

Table 5: Updated the values of variables and objective function value (first iteration).

Candidate	Ip	Ton	t	V	ROC
1	4.7832	149.2359	14.4181	65.4536	0.0722
2	5.8113	104.9203	12.9911	75.2735	0.1372
3	4.45	150*	16	57.1269	0.0597
4	6.2845	150*	8.3473	40	0.0124
5	5.426	69.3766	15.5706	69.8769	0.1497

Step 6: Now table 5 would be input to the second iteration and repeat same procedure (from step 2 to step 5). Consider random variable of r1=0.8549 and r2=0.9624.

Table 6: Input to the second iteration.

Can.	Ip	Ton	t	V	ROC	Remark
1	4.7832	149.2359	14.4181	65.4536	0.0722	
2	5.8113	104.9203	12.9911	75.2735	0.1372	
3	4.45	150	16	57.1269	0.0597	
4	6.2845	150	8.3473	40	0.0124	best
5	5.426	69.3766	15.5706	69.8769	0.1497	worst

Table 7: New values of variables and objective function value (second iteration)

Candidate	Ip	Ton	t	V	ROC
1	5.4479	150	8.1193	40	-0.012
2	6.5865	150	8	50.3136	0.0149
3	5.0788	150	9.8714	40	0.0423
4	7.1106	150	8	40	0.0591
5	6.1599	138.2976	9.3958	44.3366	0.0568

Table 8: Updated values of variables and objective function value (second iteration)

Candidate	Ip	Ton	t	V	ROC
1	5.4479	150	8.1193	40	-0.012
2	6.5865	150	8	50.3136	0.0149
3	5.0788	150	9.8714	40	0.0423
4	6.2845	150	8.3474	40	0.0124
5	6.1599	138.2976	9.3958	44.3366	0.0568

Step 7: Repeat the iteration for 100 iterations and report optimum solutions.

After calculation of 100 iterations of Jaya algorithm iteration wise best solution shown in table 9. Figure 3 shows the convergence diagram of ROC

Table 9: Iteration wise best solutions

Iteration	Ip	Ton	t	V	ROC (mm)
1	4.7832	149.2359	14.4181	65.4536	0.0722
2	6.2845	150	8.3473	40	0.0124
3	5.4479	150	8.1193	40	-0.012
4	6.1878	150.0000	8.0000	100.0000	- 0.0147
5	6.1878	150.0000	8.0000	100.0000	-0.0147
6	5.8814	150.0000	8.0368	100.0000	- 0.0185
7	5.7718	150.0000	8.0000	100.0000	-0.0202
8	5.7718	150.0000	8.0000	100.0000	- 0.0202
100	5.7718	150.0000	8.0000	100.0000	-0.0202

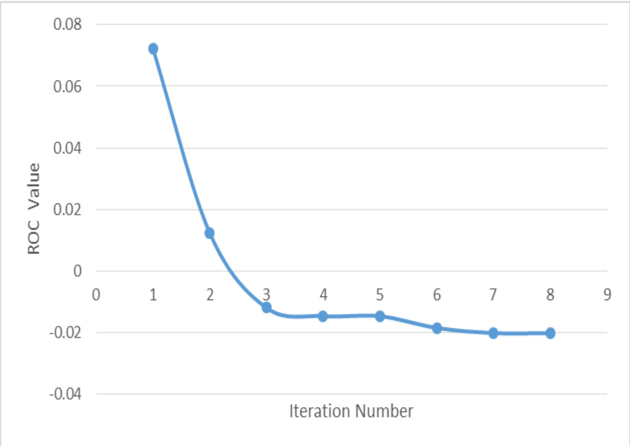

Figure 3: Convergence graph of ROC

V. RESULT AND DISCUSSION

Radial over cut (ROC) cannot be avoided in the case of EDM machining but it can be minimized to improved machining quality. Jaya algorithm is successfully applied to minimized radial over cut. Optimized parameter for minimum ROC as Ip=5.7718 A, Ton= 150 μs, duty factor t= 8 and V=100 v. Minimum radial over cut is -0.0202 mm (=0 mm).

VI. CONCLUSIONS

Jaya algorithm successfully applied for optimization problem. It took only eight iterations for ROC optimization. Jaya algorithm is efficient and suitable for engineering optimization problem.

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