# Optimization Of Surface Roughness Using Jaya Algorithm In EDM

**Neeraj Agarwal, Dr. Nitin Shrivastava, Dr. M. K. Pradhan**

**Abstract**: Electric discharge machining (EDM) is the most popular advanced machining process. EDM is able to cut any material. Titanium alloy has very good strength to weight ratio but It is very difficult to cut with conventional machining processes. Finishing process required an excellent surface finish. In this research paper surface roughness (Ra) is optimized. Four input parameter peak current (Ip), pulse on time (Ton), duty factor (t) and voltage (V) considered as a process control parameter. Response surface methodology is used to develop a predictable mathematical model to show the relation between surface roughness and four input parameter Ip, Ton, t, and V. This mathematical model is used to optimize surface roughness using advanced optimization technique – Jaya algorithm.

**Index Terms**: EDM, electric discharge machining, surface roughness, optimization, Jaya algorithm, advanced optimization, single objective optimization, RSM, Titanium alloy.

## 1. INTRODUCTION

ELECTRICAL discharge machining (EDM) is used to machine difficult to cut material. Two electrodes (workpiece and tool) is kept at a certain distance known as electrode gap. Both electrodes are submerged in dielectric fluid and voltage is applied between electrodes. As soon as breakdown voltage achieved sudden sparking takes place between electrodes [1]. Due to this sparking a very high local temperature is achieved at machining area and some material is melt and evaporated material from workpiece and tool [2]. A mathematical model shows the relation between input variables and quality measures (output). This model is used for optimization. Some time it is very difficult to optimize with convectional optimization techniques If numbers of input parameter increases or mathematical modeling are more complex. To overcome this limitation advanced optimization is more popular nowadays [3]. With the increasing use of computer population-based metaheuristic like evolutionary algorithm based optimization like a genetic algorithm (GA) [4], Evolutionary Programming (EP). Some optimization technique based on nature-inspired like particle swarm optimization (PSO), firefly algorithm. Particle swarm optimization requires some algorithm-specific parameter and this requires constant tuning of these parameters. A high-speed computer is required to solve this optimization problem [5]. To overcome this algorithm-specific parameter Rao introduce a new optimization technique known as Teaching–learning-based optimization (TLBO) [6]. TLBO does not require any algorithm-specific parameter. In 2016 new advanced optimization technique introduced by Rao is known as Jaya algorithm [7,8]. Jaya algorithm is efficient and powerful optimization technique and being more popular nowadays.


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Das et al. used an artificial bee colony to optimize surface roughness (Ra) [9]. Manjaiah et al. reviewed on machining of titanium alloy [10]. Agarwal et al. used Jaya algorithm to optimized EDM process parameter [11]. Shrivastava et al. used artificial neural network-based modeling followed by optimization with a genetic algorithm [12]. In this research paper response surface methodology used to develop a mathematical model which is followed by optimization using Jaya algorithm.

## 2 EXPERIMENTAL SETUP

Titanium alloy is selected as the workpiece. Workpiece size is 50X50X5 mm. 10 mm diameter copper rod is selected as the workpiece. Current (Ip), Voltage (V), pulse on time (Ton) and duty factor (t) is selected as a process parameter. Response surface methodology (RSM) is selected for the design of experiments (DOE). Three-level of the parameter is selected as per table 1. Thirty experiments were conducted as per DOE on electronica S50 CNC electric discharge machining. Each experiment were conducted for 30 minutes. After experiments surface roughness were measured using surface profilometer “TESA-rugosurf 10-G” make as shown in figure 1. Table 2 shows the experimental observation of Ra


***Fig. 1.*** *Surface Profilometer.*

**Table 1:** Process control parameters and 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 observation of Ra

| Exp. | Ip | V | Ton | t | Ra |
|---|---|---|---|---|---|
| 1 | 8 | 40 | 150 | 50.0 | 5.134 |
| 2 | 8 | 40 | 50 | 25.0 | 3.152 |
| 3 | 4 | 40 | 50 | 25.0 | 2.952 |
| 4 | 8 | 40 | 50 | 50.0 | 5.294 |
| 5 | 6 | 70 | 100 | 37.5 | 3.784 |
| 6 | 6 | 70 | 100 | 37.5 | 3.815 |
| 7 | 6 | 70 | 100 | 37.5 | 3.746 |
| 8 | 4 | 40 | 50 | 50.0 | 3.267 |
| 9 | 4 | 40 | 150 | 50.0 | 4.202 |
| 10 | 4 | 100 | 150 | 25.0 | 3.954 |
| 11 | 4 | 40 | 150 | 25.0 | 4.468 |
| 12 | 4 | 100 | 50 | 50.0 | 4.138 |
| 13 | 4 | 100 | 50 | 25.0 | 3.274 |
| 14 | 8 | 100 | 50 | 50.0 | 6.637 |
| 15 | 6 | 70 | 100 | 37.5 | 3.812 |
| 16 | 8 | 100 | 150 | 50.0 | 5.260 |
| 17 | 8 | 100 | 150 | 25.0 | 4.480 |
| 18 | 8 | 40 | 150 | 25.0 | 3.993 |
| 19 | 4 | 100 | 150 | 50.0 | 3.880 |
| 20 | 8 | 100 | 50 | 25.0 | 4.267 |
| 21 | 6 | 70 | 50 | 37.5 | 3.581 |
| 22 | 6 | 40 | 100 | 37.5 | 3.716 |
| 23 | 6 | 100 | 100 | 37.5 | 4.092 |
| 24 | 6 | 70 | 100 | 50.0 | 4.334 |
| 25 | 6 | 70 | 100 | 25.0 | 3.543 |
| 26 | 6 | 70 | 100 | 37.5 | 3.727 |
| 27 | 6 | 70 | 150 | 37.5 | 3.632 |
| 28 | 8 | 70 | 100 | 37.5 | 4.129 |
| 29 | 6 | 70 | 100 | 37.5 | 3.872 |
| 30 | 4 | 70 | 100 | 37.5 | 3.506 |

Modeling: A regression model is developed using commercial software Minitab 18 as following. Response surface methodology (RSM) methodology is used.

$$Ra=4.390 - 0.2707\,Ip - 0.0313\,V + 0.04200\,Ton - 0.1395\,t + 0.000268\,V*V + 0.001767\,t*t + 0.002826\,Ip*V - 0.002097\,Ip*Ton + 0.01398\,Ip*t - 0.000161\,V*Ton - 0.000411\,Ton*t \quad (1)$$

## 3 JAYA ALGORITHM

Jaya algorithm is an advanced optimization algorithm used in engineering optimization. Jaya algorithm works on iteration and with each iteration, it moves toward the best solution and moves away from worst solution simultaneously. Figure 2 shows flow diagram of Jaya Algorithm.

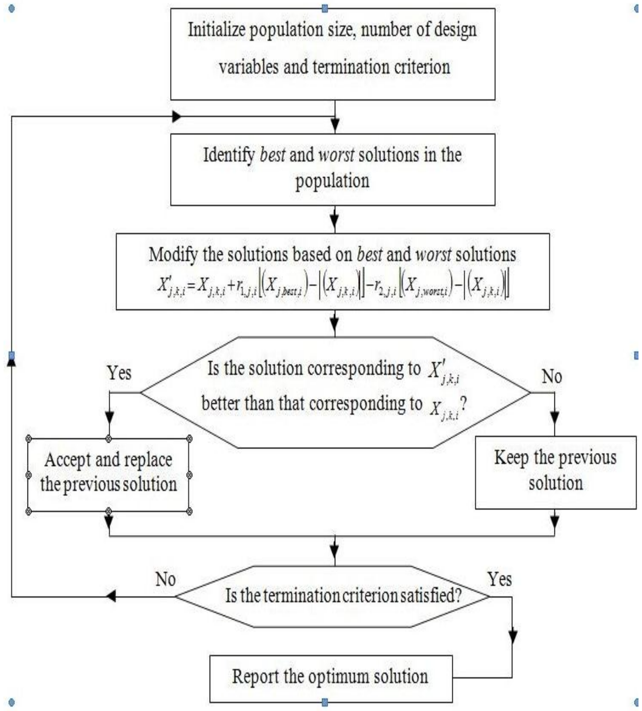


***Figure. 2:**. Jaya Algorithm flow diagram.*

New value of variable modified as per following equation

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}\,(X_{j,best,i} - |X_{j,k,i}|) - r_{2,j,i}\,(X_{j,worst,i} - |X_{j,k,i}|) \quad (2)$$

Where $X'_{j,k,i}$ is new value of variable, i=iteration number, $X_{j,k,i}$ is the value of the jth variable for the kth candidate during the I th iteration, r1 and r2 is random numbers within the range [0, 1]. $X_{j,best,i}$ is best candidate value and $X_{j,worst,i}$ worst candidate value.

## 4 ADVANCED OPTIMIZATION USING JAYA ALGORITHM

Jaya algorithm used to solve the optimization problem on surface roughness (Ra)

Step 1: Initial population: Initial population is random numbers of variables within the range of variables as specified in table 1.

**Table 3**: Initial solution /population

| Can. | Ip | Ton | t | V | Ra | Remark |
|---|---|---|---|---|---|---|
| 1 | 7.3244 | 142.8011 | 29.2371 | 93.0242 | 4.1155 | |
| 2 | 5.5515 | 124.1502 | 29.3529 | 91.2023 | 3.8467 | |
| 3 | 5.5303 | 94.7873 | 31.1149 | 63.8871 | 3.4561 | Best |
| 4 | 5.0858 | 120.9639 | 41.0232 | 46.9296 | 3.8137 | |
| 5 | 7.4715 | 144.4331 | 45.2153 | 44.8169 | 4.5541 | Worst |

Step 2: Objective function equation (1) is calculated for each candidate and written in table 3 under column Ra. The objective is to minimize surface roughness (Ra) hence the minimum value of surface roughness (Ra) is marked as best while the maximum value of Ra is marked as worst. In table 3

candidate 3 is marked as best and candidate 5 marked as worst. Under third candidate Ip_best=5.5303, Ton_best=94.7873, t_best=31.1149 and V_best=63.8871. Under fifth candidate Ip_worst=7.4715, Ton_worst=144.4331, t_worst=45.2153 and V_worst=44.8169. Consider two random numbers r1=0.3605 and r2=0.8289 within the range of 0 and 1.

Step 3: As per equation 2, new values of variables are calculated and inserted into table 4.

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i} (X_{j,best,i} - |X_{j,k,i}|) - r_{2,j,i} (X_{j,worst,i} - |X_{j,k,i}|) \quad (2)$$

Ip1= 7.3244+ 0.3605*(5.5303-|7.3244|)- 0.8289*(7.4715-|7.3244|) = 6.5556

Ip2= 5.5515+ 0.3605*(5.5303-|5.5515|)- 0.8289*(7.4715-|5.5515|) = 3.9523 (=4 because lower bound of Ip value is 4 as per table 1)

Ip3= 5.5303+ 0.3605*(5.5303-|5.5303|)- 0.8289*(7.4715-|5.5303|) = 3.9212 (=4 because lower bound of Ip value is 4 as per table 1)

Ip4= 5.0858+ 0.3605*(5.5303-|5.0858|)- 0.8289*(7.4715-|5.0858|) = 3.2685 (=4 because lower bound of Ip value is 4 as per table 1)

Ip5= 7.4715+ 0.3605*(5.5303-|7.4715|)- 0.8289*(7.4715-|7.4715|) = 6.7716

Ton1= 142.8011+0.3605*(94.7873-|142.8011|)-0.8289*(144.4331-142.8011|) = 124.1393603

Ton2= 124.1502+0.3605*(94.7873-|124.1502|)-0.8289*(144.4331-124.1502|)= 96.75237874

Ton3= 94.7873+ 0.3605*(94.7873-|94.7873|)-0.8289*(144.4331-|94.7873|)=53.63589638

Ton4= 120.9639+ 0.3605*(94.7873-|120.9639|)-0.8289*(144.4331-120.9639|)=92.07361582

Ton5= 144.4331+ 0.3605*(94.7873-|144.4331|)-0.8289*(144.4331-144.4331|)= 126.5357891

t1= 29.2371+ 0.3605*(31.1149-|29.2371|)- 0.8289*(45.2153-|29.2371|) =16.6697 (=25 because lower bound of “t” value is 25 as per table 1)

t2= 29.3529+ 0.3605*(31.1149-|29.3529|) -0.8289*(45.2153-|29.3529|) =16.8397 (=25 because lower bound of “t” value is 25 as per table 1)

t3= 31.1149+ 0.3605*(31.1149-|31.1149|) -0.8289*(45.2153-|31.1149|)= 19.4270 (=25 because lower bound of “t” value is 25 as per table 1)

t4= 41.0232+ 0.3605*(31.1149-|41.0232|) -0.8289*(45.2153-|41.0232|)=33.9764

t5= 45.2153+ 0.3605*(31.1149-|45.2153|) -0.8289*(45.2153-|45.2153|)= 40.1321

V1= 93.0242+ 0.3605*(63.8871-|93.0242|) -0.8289*(44.8169-|93.0242|)= 122.4793064 (=100 because upper bound of “V” value is 100 as per table 1)

V2= 91.2023+ 0.3605*(63.8871-|91.2023|) -0.8289*(44.8169-|91.2023|)= 119.8040285 (=100 because upper bound of “V” value is 100 as per table 1)

V3= 63.8871+ 0.3605*(63.8871-|63.8871|) -0.8289*(44.8169-|63.8871|)= 79.69438878

V4=46.9296+ 0.3605*(63.8871-|46.9296|) -0.8289*(44.8169-|46.9296|)= 54.79399578

V5= 44.8169+ 0.3605*(63.8871-|44.8169|) -0.8289*(44.8169-|44.8169|)= 51.6917071

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

| Candidate | Ip | Ton | t | V | Ra |
|---|---|---|---|---|---|
| 1 | 6.5558 | 124.1409 | 25 | 100 | 4.1592 |
| 2 | 4 | 96.7533 | 25 | 100 | 3.7027 |
| 3 | 4 | 53.6355 | 25 | 79.6945 | 2.9941 |
| 4 | 4 | 92.0743 | 33.9768 | 54.7935 | 3.213 |
| 5 | 6.7718 | 126.5374 | 40.1326 | 51.691 | 4.0685 |

Step 4: Now compare table 3 and table 4 for each candidate. Candidate 1 has a value of Ra in table 3 has 4.1155 while candidate 1 from table 4 has Ra value is 4.1592. The objective is to minimize Ra hence candidate 1 from table 3 has better value hence select candidate 1 from table 3 and insert into table 5. Similar candidate 2, 3, 4 and 5 of Table 4 has better value as compared to table 3 hence select candidate 2,3,4 and 5 from table 4 and insert into table 5.

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

| Can . | Ip | Ton | t | V | Ra | |
|---|---|---|---|---|---|---|
| 1 | 7.3244 | 142.8011 | 29.2371 | 93.0242 | 4.1155 | From table 3 |
| 2 | 4 | 96.7533 | 25 | 100 | 3.7027 | From table 4 |
| 3 | 4 | 53.6355 | 25 | 79.6945 | 2.9941 | From table 4 |
| 4 | 4 | 92.0743 | 33.9768 | 54.7935 | 3.213 | From table 4 |
| 5 | 6.7718 | 126.5374 | 40.1326 | 51.691 | 4.0685 | From table 4 |

Step 5: Iteration 1 is over. Table 5 would be input for the next iteration (same as table 3).

Step 6: Consider random numbers r1=0.2146 and r2=0.7910 for second iteration. Repeat the same procedure from step 1 to step 4.

**Table 6**: New values of variables and corresponding objective function (for the second iteration)

| Candidate | Ip | Ton | t | V | Ra |
|---|---|---|---|---|---|
| 1 | 6.611 | 123.6653 | 28.3278 | 90.1635 | 3.9704 |
| 2 | 4 | 51.0741 | 25 | 100 | 3.3721 |
| 3 | 4 | 50 | 25 | 69.1501 | 2.831 |
| 4 | 4 | 50 | 35.7995 | 40 | 2.8316 |
| 5 | 5.7397 | 98.0267 | 45.5037 | 40 | 4.0968 |

**Table 7:** Updated values of the variable for the second iteration

| Candidate | Ip | Ton | t | V | Ra |
|---|---|---|---|---|---|
| 1 | 6.611 | 123.6653 | 28.3278 | 90.1635 | 3.9704 |
| 2 | 4 | 51.0741 | 25 | 100 | 3.3721 |
| 3 | 4 | 50 | 25 | 69.1501 | 2.831 |
| 4 | 4 | 50 | 35.7995 | 40 | 2.8316 |
| 5 | 6.7718 | 126.5374 | 40.1326 | 51.691 | 4.0685 |

Step 7: Repeat the iteration to certain numbers of time like 100 or any numbers as per requirement.

**Table 8**: Best solution iteration wise.

| Iteration | Ip | Ton | t | V | Ra |
|---|---|---|---|---|---|
| 1 | 5.5303 | 94.7873 | 31.1149 | 63.8871 | 3.4561 |
| 2 | 4 | 53.6355 | 25 | 79.6945 | 2.9941 |
| 3 | 4 | 50 | 25 | 69.1501 | 2.831 |
| 4 | 4 | 50 | 28.6159 | 58.7785 | 2.7324 |
| 5 | 4 | 50 | 27.0659 | 53.378 | 2.7304 |
| 6 | 4 | 50 | 27.0659 | 53.378 | 2.7304 |
| 7 | 4 | 50 | 28.864 | 55.0363 | 2.7226 |
| 8 | 4 | 50 | 29.6703 | 49.6234 | 2.722 |
| 9 | 4 | 50 | 29.6703 | 49.6234 | 2.722 |
| 10 | 4 | 50 | 29.2314 | 51.475 | 2.7202 |
| 11 | 4 | 50 | 29.2314 | 51.475 | 2.7202 |
| 12 | 4 | 50 | 29.2314 | 51.475 | 2.7202 |
| 13 | 4 | 50 | 29.2314 | 51.475 | 2.7202 |
| 14 | 4 | 50 | 29.2314 | 51.475 | 2.7202 |
| 15 | 4 | 50 | 29.2314 | 51.475 | 2.7202 |
| 16 | 4 | 50 | 29.2314 | 51.475 | 2.7202 |
| 17 | 4 | 50 | 29.1503 | 51.9951 | 2.7202 |
| 18 | 4 | 50 | 29.1503 | 51.9951 | 2.7202 |
| 19 | 4 | 50 | 29.1503 | 51.9951 | 2.7202 |
| 20 | 4 | 50 | 29.1503 | 51.9951 | 2.7202 |
| 21 | 4 | 50 | 29.1682 | 52.1076 | 2.7201 |
| 22 | 4 | 50 | 29.1682 | 52.1076 | 2.7201 |
| 23 | 4 | 50 | 29.1682 | 52.1076 | 2.7201 |
| 24 | 4 | 50 | 29.169 | 52.1126 | 2.7201 |
| 25 | 4 | 50 | 29.2305 | 51.988 | 2.7201 |
| 26 | 4 | 50 | 29.2305 | 51.988 | 2.7201 |
| 27 | 4 | 50 | 29.2435 | 51.9637 | 2.7201 |
| 28 | 4 | 50 | 29.2272 | 52.1769 | 2.7201 |
| 29 | 4 | 50 | 29.2792 | 52.2615 | 2.72 |
| 30 | 4 | 50 | 29.3714 | 52.4118 | 2.72 |
| 31 | 4 | 50 | 29.3714 | 52.4118 | 2.72 |
| 32 | 4 | 50 | 29.4719 | 52.4989 | 2.72 |
| 33 | 4 | 50 | 29.4719 | 52.4989 | 2.72 |
| 34 | 4 | 50 | 29.4717 | 52.4545 | 2.72 |
| 35 | 4 | 50 | 29.5454 | 52.1212 | 2.7199 |
| 100 | 4 | 50 | 29.5454 | 52.1212 | 2.7199 |

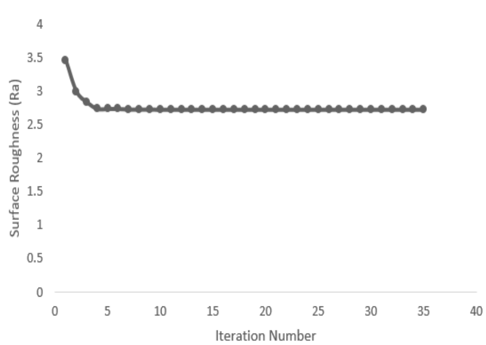


***Figure 3:*** *Convergence diagram of surface roughness (Ra).*

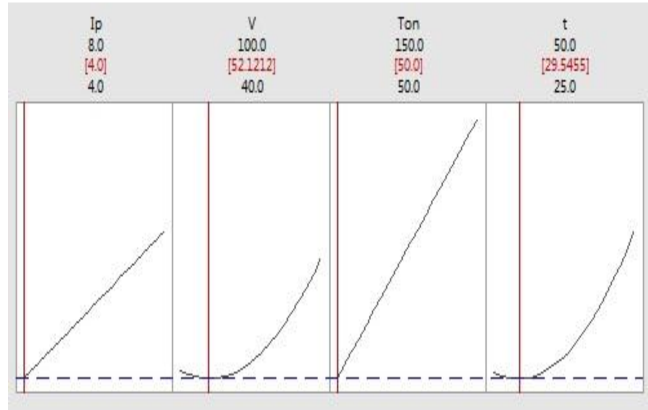


***Figure 4:*** *Optimization plot*

Table 8 shows iteration wise best result. Figure 3 shows the convergence graph of Ra and figure 4 shows the effect of various parameter on surface roughness.

## 5 CONCLUSIONS

Surface roughness (Ra) is successfully optimized using Jaya algorithm. To optimize surface roughness peak current (Ip) and pulse on time (Ton) should have minimum value where Ip=4 A, Ton= 50 µs. Duty factor (t) should be 29.5455 %, voltage (V) have 52.1212 and minimum surface roughness (Ra) achieved 2.7199 µm. Jaya algorithm took only 35 iterations to achieve the optimum solution. Jaya algorithm is suitable for an engineering optimization problem.

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