Optimization of Process Parameters of Dry Electric Discharge Machining using Taguchi and RSM Design of Experiments

Chandan Jadhav[1] Sultan Inamdar[2] Dr. Gaurang Shah[3]
[1]Assistant Manager [2]Production Engineer [3]PG Coordinator
[3]Department of Mechanical Engineering
[1]SKF Technologies India Ltd [2]Sandvik Asia Pvt. Ltd. [3]P.V.P.I.T. Bavdhan, Pune University

Abstract— Taguchi and Response Surface Method of Design of Experiments are utilized to optimize the process parameters of Electric Discharge Machining in order to get improved Material Removal Rate and Surface Finish. This paper explains the use of different Design of Experiments for optimizing input process parameters for any given process.

Key words: Taguchi & RSM Design, Dry Electric Discharge Machining

I. INTRODUCTION

Electric discharge machining (EDM) is one of the most popular non-traditional machining processes being used today. Use of mineral oil-based dielectric liquids is the major cause of environmental concerns associated with the EDM process. Dry EDM is an environment-friendly modification of the oil EDM process in which the liquid dielectric is replaced by a gaseous medium. Dielectric wastes generated during the oil EDM process are very toxic and cannot be recycled. Also, toxic fumes are generated during machining due to high temperature chemical breakdown of mineral oils. The use of oil as the dielectric fluid also makes it necessary to take extra precaution to prevent fire hazards. Replacing liquid dielectric by gases is an emerging field in the environment-friendly EDM technology. High velocity gas flowing through the tool electrode into the inter-electrode gap substitutes the liquid dielectric. The flow of high velocity gas into the gap facilitates removal of debris and prevents excessive heating of the tool and work-piece at the discharge spots [13].

A. Objective

Objective of this research work is to enhance the Material Removal Rate (MRR) and reduce the Surface Finish (Ra) by optimizing following process parameters:

- Gap Voltage
- Peak Current
- Pulse on time
- Pulse off time
- Wire feed
- Wire Tension
- Wire Velocity

B. Theory

In the scope of this project already established theory about impact of input process parameters in EDM on material removal rate & surface finish is included. This theory will be revalidated using experimental analysis. Current theory about various process parameters is given below:

1) Gap Voltage

It is the voltage applied between the tool and the work piece. The applied voltage determines the total energy of the spark. If the voltage is high, erosion rate increases and the higher machining rate is achieved. But at the same time, higher voltage will also contribute to poor surface finish. In order to achieve higher machining rate, higher voltage should be used, which results in higher tool wear. Therefore for EDM, a very moderate value of voltage needs to be used [11] [13].

2) Peak Current

This is another very important parameter that determines almost all the machining characteristics such as machining rate, surface finish. The term ‘peak current’ often used to indicate the highest current during machining. The higher the peak current setting is, the larger is the discharge energy. From experimental evidences of previous research work, it seems that sensitivity of peak current setting on the cutting performance is stronger than that of pulse on time. When the peak current is too high, it may lead to higher tool wear as well. Peak current is known as the amount of power used in discharge machining which this parameter is measured in amperage and above all this is the most important parameter in EDM machining. Using higher currents will definitely improve the material removal rate but it will deteriorate the tool wear and surface finish [9] [13].

3) Pulse on Time

This is the duration of the time the current is allowed to flow per cycle. Material removal rate is directly proportional to the amount of energy applied during this pulse on time. This energy is controlled by the peak current and the length of the pulse on time. The main EDM operation is effectively done during this pulse on time. With longer period of spark duration, the resulting cater will be broader and deeper, therefore the surface finish will be rougher. Shorter spark duration on the other hand helps to improve surface finish [11] [13].

4) Pulse off Time

This is the duration of time between two successive sparks when the discharge is turned off. Pulse off time is the duration of the rest or pause required for the re-ionization of the dielectric. This time allows the molten material to solidify and to be washed out of the spark gap. If the pulse off time is too short, it will cause spark to be unstable and then more short circuiting will occur. Although larger pulse off time slows down the process, it can provide stability required to successfully EDM a given application. When the pulse off time is insufficient as compared to on time, it will cause erratic cycling and retraction of the advancing servomotors, slowing down the operation [11] [13].

5) Wire Feed

Wire feed is another important parameter in EDM that shows the speed of the wire. As the wire feed increases the wire consumption and in result the cost of machining will increase. While low wire feed can cause to wire breakage in high cutting speed [12].

6) Wire tension (T_f)

As shown in the fig.1 wire tension strengthens the wire and ensures that it will not sag down during operation.

7) Wire velocity (V_w)

It is the velocity of the wire electrode in axial direction.

II. PROBLEM STATEMENT

Pictorial view and schematic diagram of dry EDM process are shown in fig.1 and fig.2 respectively [2] [4].

Fig. 1: EDM Process Set-up

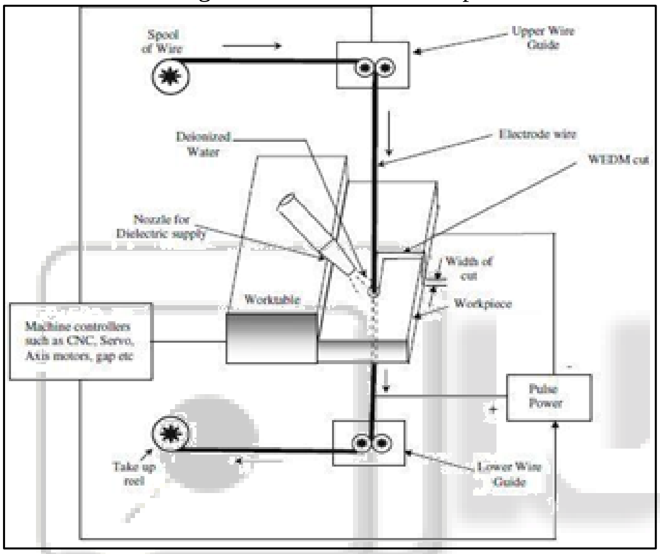

Fig. 2: Schematic diagram of EDM

Before - As is condition						
Process Parameters						
Gap Voltage	Peak Current	Pulse on time	Pulse off time	Wire feed	Wire Tension	Wire Velocity
V_g (V)	I_p (A)	T_{on} (µs)	T_{off} (µm)	W_f(m/min)	T_f (N)	Vw (m/s)
90	100	600	1500	4	18	0.5
Response						
Material Removal Rate					Surface Finish	
MRR (mm^3/min)					Ra (µm)	
1.74					1.60	

Table 1: Before Process Parameters and Process Performance

So as it is visible from the Table I obtained material removal rate is 1.74mm^3/min and surface finish is 1.60 µm. whereas, desired values are 3.0mm^3/min and 1.2 µm respectively. So the present response is very much deviated from the desired values.

III. RESEARCH METHODOLOGY

A. Identification of input process parameters

From the previous research work, for getting the best result for the performance of the EDM process following parameters needs to be optimized [3].

- Gap Voltage
- Peak Current
- Pulse on time
- Pulse off time
- Wire feed
- Wire Tension
- Wire Velocity

B. Base Line Data Collection

For any random setting, data regarding EDM performance i.e. Material Removal Rate (MRR) and Surface Finish (Ra) is collected. This forms the baseline for further experimentation.

- MRR = Volumetric material removal/Process time (mm^3/min)
- Ra = Surface finish (µm)

C. Designing or Formulating Design of Experiments

Defining levels or range of setting parameters, Selecting the DOE type (i.e. Taguchi / Factorial), and Generating orthogonal matrix containing different sets of setting parameters.

D. Experimentation

- Gathering data of EDM performance i.e. Material Removal Rate (MRR) and Surface Finish (Ra) for each set of parameters mentioned in matrix.
- Completing the matrix by consolidating results.

E. DOE Analysis

- Generating Interaction plot for all parameters and finding out S/N ratio (Larger is Better) for Material removal rate and (Smaller is Better) for Surface finish.
- S/N= -10 log ((1/n) (∑ (1/y^2)) ….. for Larger is Better. Where, y is value of response variables and n is number of observations in the experiments [14].
- S/N = -10 log (Σ (Y2)/n)) ….. for Smaller is Better. Where, y is value of response variables and n is number of observations in the experiments [14].
- Calculating the contribution of each parameter on the required response.
- Generating the Optimization plot.
- Finalizing the setting parameters.

F. Confirmation Run

- Putting up the finalized parameters on machine and taking confirmation regarding the performance.
- Standardizing the parameters and compiling the results:
- Standardizing the optimized parameters and compiling the results. Then in the end concluding the experimentation and preparing the report.

IV. EXPERIMENTAL SET-UP

The experiment was carried out on EUROCUT MARK II machine (Fig.3). The electrode wire material was brass-copper (90:10). Diameter of wire was 0.25 mm. Dielectric fluid used was compressed air. Electrode can be used once only because of dimensional deviation, so wire was continuously feed through the feeding mechanism. Work-piece was a block of K96 KENNAMETAL Grade Tungsten Carbide with Dimension 50×50×10 (all in mm). From the work-piece of above given dimensions, small pieces were cut and Volumetric material removal amount is measured while keeping process time constant as 30 sec. From Volumetric material removal and process time Material Removal Rate (MRR) is calculated. After taking cut surface finish of the cut is measured using portable surface finish tester manufactured by Mitutoyo Surftest SJ-210 series [1] [4].

Fig. 3: Experimental Set-up

Fig. 4: Work-piece mounted on Eurocut Mark II machine

Experimentation parameters and their specifications are given in following table [4].

Sr. No.	Parameter	Specification
1	Workpiece Material	K96 KENNAMETAL Grade Tungsten Carbide
2	Workpiece Dimension	50X50X10 (all in mm)
3	EDM used	EURO CUT MARK II
4	Tool Material	Brass-Copper alloy
5	Die Electric Fluid	Compressed air at 4.0 Bar
6	Instrument for measuring vibration amplitude	Piezo-electric vlocity pick-up
7	Measuring Instrument for Volumetric Material Removal	Digital Weighing scale is used to measure weight difference, then density of Tungsten Carbide is taken as 15630 Kg/m^3. To calculate the Volumetric material removal.
8	Measuring Instrument for Surface Finish	Portable surface finish tester manufactured by Mitutoyo Surftest SJ-210 series
9	Process Parameter Setting	Set on Human Machine Interface Mistubishi GOT 1000 series

Table 2: Experimentation Specification Table

V. EXPERIMENTATION

For first experimentation following parameters are taken

- Gap Voltage
- Peak Current
- Pulse on time
- Pulse off time
- Wire feed

Values of above parameters are taken at 3 different levels. Then available design of Taguchi Design Of Experiment is checked in MINITAB 17 software. From available DOE designs L27 design is chosen, i.e. in order to complete the experimentation 27 Nos of DOE runs need to be taken, each DOE run consists of specific combination of above input process parameters. Purpose of this experimentation is to obtain the Material Removal Rate (MRR) at different combinations of above input parameters. This is performed to understand the contribution and impact of input parameters on desired output from EDM process. So that in the end optimized values of input process parameters are obtained [6] [7].

Table 3 indicates the chosen DOE design, which is having 27 experimentation runs. Input process parameters given in each run are put on the machine using Human Machine Interface and response in terms of Material Removal Rate (MRR) is calculated [6] [7].

DOE Taguchi Design					
DOE Run No.	Gap Voltage	Peak Current	Pulse on time	Pulse off time	Wire feed
	V_g (V)	I_p (A)	T_{on} (µs)	T_{off} (µm)	W_f(m/min)
1	50	50	200	500	4
2	50	50	200	500	6
3	50	50	200	500	8
4	50	80	500	1500	4
5	50	80	500	1500	6
6	50	80	500	1500	8
7	50	110	800	2500	4
8	50	110	800	2500	6
9	50	110	800	2500	8
10	80	50	500	2500	4
11	80	50	500	2500	6
12	80	50	500	2500	8
13	80	80	800	500	4
14	80	80	800	500	6
15	80	80	800	500	8
16	80	110	200	1500	4
17	80	110	200	1500	6
18	80	110	200	1500	8
19	110	50	800	1500	4
20	110	50	800	1500	6
21	110	50	800	1500	8
22	110	80	200	2500	4
23	110	80	200	2500	6
24	110	80	200	2500	8
25	110	110	500	500	4
26	110	110	500	500	6
27	110	110	500	500	8

Table 3: L27 Structure of Taguchi DOE Design

Table 4 Shows the obtained response for each DOE run performed under this experimentation. Where first of all volumetric material removal is calculated using following formula.

VMR = Mass difference (Before cut – After cut) / Density of material under test…… (mm^3)

Where,

Density of Tungsten Carbide = 15630 Kg/m^3.

Mass difference is evaluated using weighing scale.

Then Material Removal Rate (MRR) is calculated using following formula.

MRR = VMR / Process Time (Tp)…… (mm^3/min).

DOE Run No.	Response		
	Volumetric Material Removal	Process Time	Material Removal Rate
	Vol (mm^3)	T_p (min)	MRR (mm^3/min)
1	0.54	0.50	1.08
2	0.60	0.50	1.20
3	0.53	0.50	1.06
4	0.58	0.50	1.16
5	0.62	0.50	1.24
6	0.69	0.50	1.38
7	1.10	0.50	2.20
8	0.93	0.50	1.86
9	0.88	0.50	1.76
10	0.76	0.50	1.52
11	0.79	0.50	1.58
12	0.77	0.50	1.54
13	1.11	0.50	2.22
14	1.03	0.50	2.06
15	1.08	0.50	2.16
16	1.48	0.50	2.96
17	1.55	0.50	3.10
18	1.53	0.50	3.06
19	1.15	0.50	2.30
20	1.16	0.50	2.32
21	1.24	0.50	2.48
22	1.52	0.50	3.04
23	1.44	0.50	2.88
24	1.46	0.50	2.92
25	1.89	0.50	3.78
26	1.96	0.50	3.92
27	1.93	0.50	3.86

Table 4: Response obtained for each DOE Run

For second experimentation following parameters are taken

- Wire Tension
- Wire Velocity

Values of above parameters are taken at 4 different levels. Then available design of Taguchi Design Of Experiment is checked in MINITAB 17 software. From available DOE designs L16 design is chosen, i.e. in order to complete the experimentation 16 Nos of DOE runs need to be taken, each DOE run consists of specific combination of above input process parameters. Purpose of this experimentation is to obtain the Surface Finish (Ra) at different combinations of above input parameters. This is performed to understand the contribution and impact of input parameters on desired output from EDM process. So that in the end optimized values of input process parameters are obtained [6] [7].

Table 5 indicates the chosen DOE design, which is having 16 experimentation runs. Input process parameters given in each run are put on the machine using Human Machine Interface and response in terms of Surface Finish (Ra) is recorded [6] [7].

DOE Taguchi Design			Response
DOE Run No.	Wire Tension	Wire Velocity	Surface Finish
	T_f (N)	V (m/s)	Ra (µm)
1	10.00	0.10	0.90
2	10.00	0.30	0.86
3	10.00	0.50	1.95
4	10.00	0.70	1.80
5	20.00	0.10	1.52
6	20.00	0.30	2.20
7	20.00	0.50	2.60
8	20.00	0.70	0.94
9	30.00	0.10	0.88
10	30.00	0.30	1.86
11	30.00	0.50	0.86
12	30.00	0.70	2.26
13	40.00	0.10	2.10
14	40.00	0.30	0.68
15	40.00	0.50	1.20
16	40.00	0.70	1.32

Table 5: Response obtained for each DOE Run

For third experimentation Response Surface Method is executed to fine tune the Gap voltage and Peak current, which are most critical input parameters in Dry Electric Discharge Machining.

DOE Run chart is given in Table

RSM DOE Design			
RunOrder	Input		Response
	Gap Voltage	Peak Current	MRR
1	150	150	5.12
2	130	130	4.76
3	130	130	4.74
4	150	110	4.02
5	130	130	4.78
6	110	110	3.91
7	110	150	4.98
8	130	130	4.73
9	130	130	4.72
10	130	130	4.8
11	130	158.28	5.22
12	101.72	130	4.85
13	130	101.72	4.13
14	158.28	130	4.45

Table 6: Response obtained for each DOE Run in RSM

VI. Analysis of Design of Experiments

Based on the response of each DOE run performed in first set of experiments, SN ration (larger is better) is obtained for Material Removal Rate (MRR). SN ratio is calculated for individual parameter using MINITAB 17 software. as shown in Fig.5 following values are optimized values for getting larger Material Removal Rate (MRR) [14] [6] [7].

- Gap Voltage = 110 V
- Peak Current = 110 A
- Pulse on time = 200 µsec
- Pulse off time = 500 µsec
- Wire feed = 4 m/min.

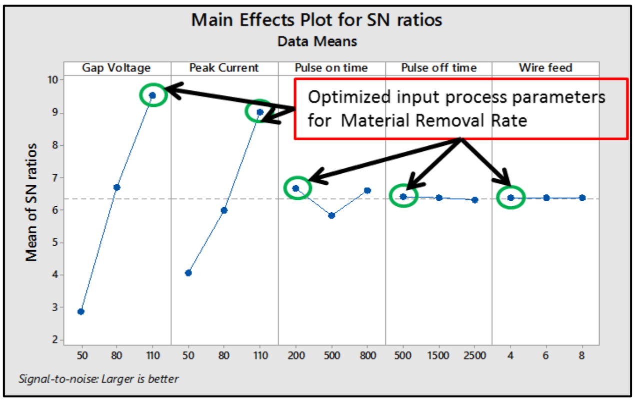

Fig. 5: Optimized Parameters for MRR

Ranking of contributing factors are obtained by generating response table. Following is the ranking order of influencing parameters starting from most to least [14].

- Gap Voltage
- Peak Current
- Pulse on time
- Pulse off time
- Wire feed
- TABLE VII

Response Table for Signal to Noise Ratios
Larger is better

Level	Gap Voltage	Peak Current	Pulse on time	Pulse off time	Wire feed
1	2.874	4.061	6.653	6.422	6.360
2	6.691	6.000	5.829	6.373	6.365
3	9.526	9.029	6.608	6.296	6.366
Delta	6.652	4.968	0.824	0.126	0.007
Rank	1	2	3	4	5

Table 7: Response Table for S/N Ration for MRR

Based on the response of each DOE run performed in second set of experiments, SN ration(smaller is better) for Surface Finish (Ra). SN ratio is calculated for individual parameter using MINITAB 17 software. as shown in Fig.7 following values are optimized values for getting smaller value of Surface Finish (Ra) [14] [6] [7].

- Wire Tension = 40 N
- Wire Velocity = 0.3 m/s

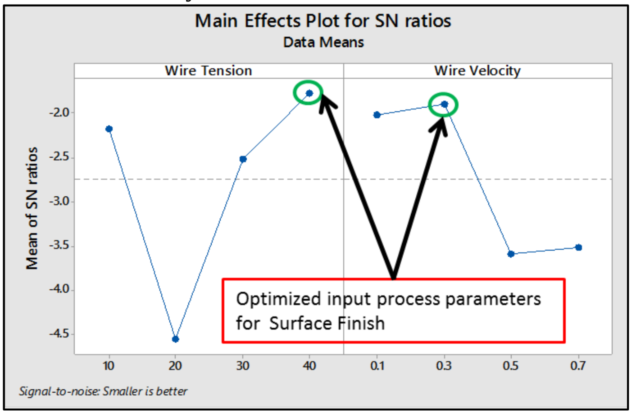

Fig. 7: Optimized Parameters for Surface Finish

Ranking of contributing factors are obtained by generating response table. Following is the ranking order of influencing parameters starting from most to least [14].

- Wire Tension
- Wire Velocity

Response Table for Signal to Noise Ratios
Smaller is better

Level	Wire Tension	Wire Velocity
1	-2.170	-2.014
2	-4.562	-1.895
3	-2.513	-3.593
4	-1.772	-3.515
Delta	2.789	1.699
Rank	1	2

Table 8: Response Table for S/N Ration for MRR

Analysis of Response Surface Method is given as follows:

Regression Equation obtained from Response Surface Method is:

MRR = -4.87 + 0.0549 Gape Voltage + 0.0719 Peak Current
0.000228 Gape Voltage*Gape Voltage-
0.000197 Peak Current*Peak Current
+ 0.000019 Gape Voltage*Peak Current

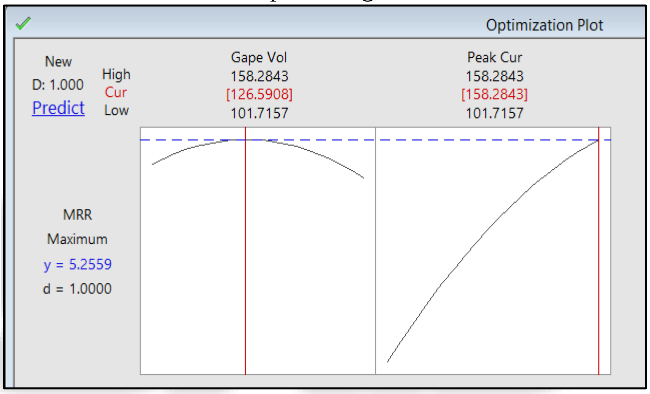

Fig. 6: Optimization Plot of RSM

From Response Surface Method analysis it is evident that as gap voltage increases material removal rate goes on increasing until it reaches to peak value at 126.6 gap voltage, then material removal rate goes on droping down.

Material removal rate goes on increasing as peak current increase and we get optimum material removal rate at peak current of 158.3 ampere. Optimization plot is given below which gives the graphical representation of relationship of material removal rate with gap viltage and peak current.

So the optimized values are

- Gap Voltage = 126.6 Volt
- Peak Current = 158.3 A

VII. RESULTS

After analysing the main effect plot and response table, values of optimized parameters are obtained; same are given in Table IX. Values of optimized parameters are quite different from the values of normal process parameters.

Optimized parameters were put on EDM machine and output response is recorded in terms of MRR and Ra, their values are also given in Table IX. In fig.7 comparison is made for before input parameter optimization and after input process parameter optimization condition of EDM process performance.

After - Optimized Parameters						
Process Parameters						
Gap Voltage	Peak Current	Pulse on time	Pulse off time	Wire feed	Wire Tension	Wire Velocity
V_g (V)	I_p (A)	T_{on} (µs)	T_{off} (µm)	W_f (m/min)	T_f (N)	Vw (m/s)
126.6	158.3	200	500	4	40	0.3
Response						
Material Removal Rate					Surface Finish	
MRR (mm^3/min)					Ra (µm)	
3.08					0.80	

Table 9: Optimized Process Parameters

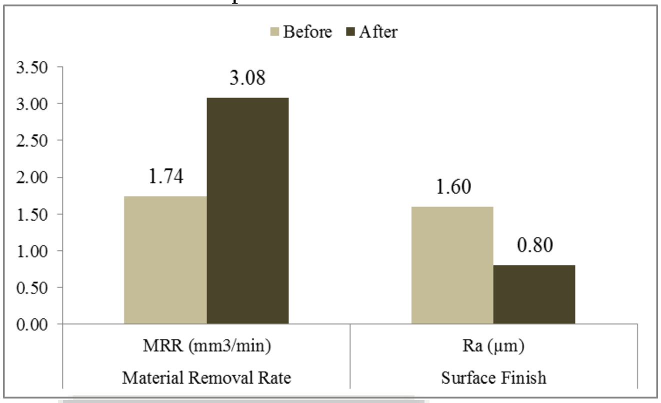

Fig. 7: EDM process performance comparison before v/s after

VIII. CONCLUSIONS

This paper describes the experimental analysis Dry EDM process for optimizing the input process parameters in order to obtain the desired values Material Removal Rate (MRR) and Surface Finish (Ra) on Tungsten Carbide work-piece. It also gives insight about process parameter optimization using Taguchi and RSM DOE.

First experimental analysis has been carried out using Taguchi design with 27 runs. Following are the finalized value of process parameters,

- Gap Voltage = 110 V
- Peak Current = 110 A
- Pulse on time = 200 µsec
- Pulse off time = 500 µsec
- Wire feed = 4 m/min.

Second experimental analysis has been carried out using Taguchi design with 16 runs to reduce the vibration in the wire and in turn improve the surface finish. Following are the finalized value of process parameters,

- Wire Tension = 40 N
- Wire Velocity = 0.3 m/s

Third experimental analysis has been carried out using RSM with 14 runs to fine tune the Gap Voltage and Peak Current. Following are the finalized value of process parameters,

- Gap Voltage = 126.6 Volt
- Peak Current = 158.3 A

By putting the above values of input process parameters obtained EDM process performance is as follows,

- Material Removal Rate (MRR) = 3.08 mm3/min.
- Surface Finish (Ra) = 0.8 µm.

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