IJSRD - International Journal for Scientific Research & Development| Vol. 4, Issue 10, 2016 | ISSN (online): 2321-0613

Optimization of Operating Parameters for EDM Process based on Taguchi - Grey Relational Analysis

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Abstract— The present work is aimed to optimize the input process parameters of (EDM) process by considering the effect of input parameters viz. Current, Voltage, Pulse On, Pulse Off. Experiments conducted with these parameters in three different levels data related to process responses viz. Metal removal rate, surface roughness (Ra), Dimensional Deviation (DD) measured for each of the experimental run. Predicted data utilized for identification of the parametric influence in the form of graphical representation for showing influence of the parameters on selected responses. Predicted data is given by the models (as per Taguchi's L27 OA and Grey Relational Analysis (GRA)) designs used in search of an optimal parametric combination to achieve desired yield of the process. Taguchi techniques used for optimization of minimizing the surface roughness and maximization MRR and Minimization of DD. Multi objective Grey relational analysis is used to find the optimal level of parameters for the output responses.

Key words: Dimensional Deviation, EDM, Grey Relational Analysis, Optimization of Parameters, Material Removal Rate, Surface Roughness, Taguchi

I. INTRODUCTION

Wire EDM Machining (also known as Spark EDM) is an electro thermal production process in which a thin single-strand metal wire (copper) in conjunction with kerosene and waste oil blended with kerosene (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods. WEDM is a thermo-electrical process in which material is removed by a series of sparks between work piece and wire electrode (tool). The part and wire are immersed in dielectric (electrically non-conducting) fluid, waste palm oil blended with kerosene and kerosene, which also acts as a coolant and flushes the debris away. The material which is to be cut must be electrically conductive. In WEDM, there is no direct contact between work piece and tool(wire) as in conventional machining process therefore materials of any hardness can be machined and minimum clamping pressure is required to hold the work piece. In this process, the material is eroded by a series of discrete electrical discharges between the work piece and tool. These discharges cause sparks and result in high temperatures instantaneously, up to about 10000º C.

II. SELECTION OF WORK PIECE

In the present experiment die steel (EN31) of size 10×10×10 mm plates were chosen for conducting the experiments. By its character this type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading.

Carbon	Manganese	Chromium	Sulphur	Silicon	Phosphorous
0.901.20%	0.300.75%	1.001.60%	0.050% max	0.100.35%	0.050% max

Table 1: Chemical composition of work piece Die steel (EN31)

III. DESCRIPTION OF OPTIMIZATION OF PARAMETERS

Dimensional Deviation as response is the perpendicular distance between the actual profile and the profile traced by the wire is equal to half of the width of the cut. Thus, the actual job produced is either undersized or oversized depending upon the job is punch or die. In the present study, the job has been considered as a square punch. The dimensional deviation of square punch is equal to half the width of the cut. The term "dimensional deviation" has been used as response parameter during the rough cutting operation with zero wire offset. The dimensional deviation was measured using a digimatic caliper (Mitutoyo) having least count 0.001 mm.

Surface roughness as response (Ra) is calculated as the Roughness Average of a surfaces measured microscopic peaks and valleys. This is most influenced by current and followed by other parameters and measured by Talysurf.

Material removal rate (mm^3/min) as response: Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. This is most influenced by Pulse off time and followed by other parameters. The calculation of material removal done by using electronic balance weight machine. This machine capacity is 1000 gram and accuracy is 0.001 gram.

IV. EXPERIMENTAL SET UP

For this experiment the whole work can be done by Electric Discharge Machine, mode l Electronica- Electrapuls PS 50ZNC (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Waste palm oil blended with kerosene and kerosene were used as dielectric fluids. Dielectric fluids were pumped towards the working area for the flushing. Experiments were conducted with positive polarity of electrode. The pulsed discharge current was applied in various steps in positive mode.

Technical Specifications	
Work tank internal dimensions	800 X 600 X 360 mm
Work table dimensions	660 X 360 mm
Transverse	300 , 200 , 250 mm
Maximum job weight	300 kg.
Maximum job height above the table	250 kg.
Feed motor/servo system for Z –axis	DC servo.
Position measuring system	Incremental linear scale.
Dielectric system	Integral with the machine tool.
Dielectric capacity	400 Ltr.
Filter element	10µ paper cartridge 2 no.
Power supply	3 phase 415 v, AC.

Table 2: Technical Specifications of EDM Machine

Dielectric Fluid Type	Density(gm/ml)	Visosity (at 4^0c)	Themalconductivity	Specifc heat (Kj/Kg.K)	Flash Point (C)	Dielectric Constant
Waste palmoil blendd with kerosene	0.92	9.55	0.20	1.67	171	2.86
Kerosene	0.80	2.71	0.15	2.01	81	4.7

Table 3: Properties of Dielectric fluids

V. EXPERIMENTAL PROCEDURE

Die steel (EN31) material particulate was using Copper tool with 16 mm diameter and the ELECTRONICA-ELECTRAPULS PS 50ZNC (die-sinking type) EDM machine were used. Waste palm oil blended with kerosene and kerosene were used as dielectric fluid. External flushing was used to flush away the eroded materials from the sparking zone. For a four factors are tackled with a total number of 27 experiments performed on die sinking EDM. The work piece and electrode were separated by a moving dielectric fluid such as waste palm oil blended with kerosene and kerosene. In the experiments waste palm oil blended with kerosene and kerosene used as the dielectric fluid to improve the machining performance and provide eco-friendly manufacturing. Machining experiments for determining the optimal machining parameters were carried out by setting.

S. No.	Parameter	Level-I	Level-II	Level-III
A	Current(A)	5	15	25
B	Voltage(V)	50	70	90
C	Pulse on time (µ sec)	120	170	220
D	Pulse off time (µ sec)	100	150	200

Table 4: for Process parameters and their levels for EDM process

VI. EXPERIMENTS BY TAGUCHI TECHNIQUE

S. No.	Current	Voltage	Pulse on (µ sec)	Pulse off (µ sec)	Surface finish ((µm)	DD%	MRR (mm^3/min)
1	5	50	120	100	1.4500	0.00957	13.250
2	5	50	120	100	1.2300	0.05720	15.792
3	5	50	120	100	1.2710	0.09700	24.871
4	5	70	170	150	2.3100	0.03150	32.764
5	5	70	170	150	2.5320	0.07230	36.972
6	5	70	170	150	2.9320	0.09530	41.231
7	5	90	220	200	2.9790	0.12100	48.354
8	5	90	220	200	3.3500	0.13500	45.172
9	5	90	220	200	3.0230	0.23100	51.762
10	15	50	170	200	2.4320	0.25700	57.897
11	15	50	170	200	2.4510	0.27700	66.754
12	15	50	170	200	2.3750	0.25900	72.753
13	15	70	220	100	1.4320	0.00790	77.123
14	15	70	220	100	1.1270	0.00853	82.310
15	15	70	220	100	0.9290	0.00999	89.546
16	15	90	120	150	1.2120	0.01230	93.121
17	15	90	120	150	1.7320	0.07540	97.452
18	15	90	120	150	1.9530	0.09730	103.765
19	25	50	220	150	1.2310	0.12000	109.972
20	25	50	220	150	1.0341	0.13500	117.754
21	25	50	220	150	1.3210	0.15200	115.234
22	25	70	120	200	1.9670	0.21300	119.543
23	25	70	120	200	2.1530	0.23700	121.792
24	25	70	120	200	2.2150	0.28500	124.987
25	25	90	170	100	0.7590	0.00798	120.346
26	25	90	170	100	0.9570	0.00910	123.789
27	25	90	170	100	1.2110	0.07950	121.573

Table 5: Response for waste palm oil blended with kerosene as dielectric fluid Larger is better

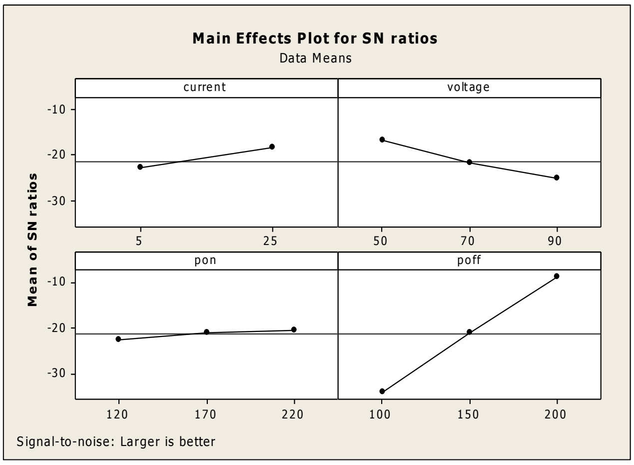

Fig. 1: Main effects plot for SN ratios

Level	Current	Voltage	Pon	Poff
1	22.794	-16.870	-22.510	-34.125
2	-18.454	-21.924	-21.134	-21.076
3		-25.250	-20.400	-8.842
Delta	4.340	8.380	2.110	25.283
Rank	3	2	4	1

Table 6: Response Table for Signal to Noise Ratios Larger is better

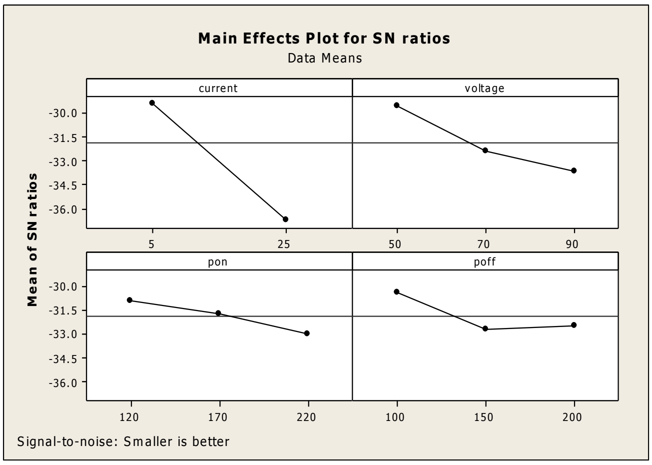

Fig. 2: Main effects plot for SN ratios

Level	Current	Voltage	Pon	Poff
1	-29.44	-29.57	-30.90	-30.41
2	-36.77	-32.41	-31.75	-32.71
3		-33.66	-32.99	-32.52
Delta	7.34	4.10	2.09	2.29
Rank	1	2	4	3

Table 7: Response Table for Signal to Noise Ratios

A. Conclusion from Taguchi for Waste Palm Oil Blended With Kerosene as Dielectric Fluid

MRR is most influenced by Pulse off time (level-1) and followed by voltage (level-3), current (level-2) and pulse on time (level-1). And Surface finish, Dimensional Deviation is most influenced by current followed by Voltage, Pulse off time and Pulse on time respectively by level-1 only.

S. No	current	voltage	Pulse on (μsec)	Pulse off (μsec)	surface finish (micro m)	DD%	MRR (mm^3/min)
1	5	50	120	100	0.975	0.0723	13.520
2	5	50	120	100	1.250	0.0790	13.975
3	5	50	120	100	0.795	0.0927	15.020
4	5	70	170	150	2.310	0.0315	23.791
5	5	70	170	150	2.765	0.0723	31.759
6	5	70	170	150	1.798	0.0271	36.973
7	5	90	220	200	2.979	0.0491	47.235
8	5	90	220	200	3.350	0.0992	52.770
9	5	90	220	200	3.023	0.0571	63.993
10	15	50	170	200	2.432	0.1100	67.235
11	15	50	170	200	2.451	0.1570	71.572
12	15	50	170	200	2.375	0.0875	75.397
13	15	70	220	100	1.532	0.1210	79.567
14	15	70	220	100	1.279	0.1520	85.532
15	15	70	220	100	1.979	0.0759	87.547
16	15	90	120	150	2.673	0.0235	89.236
17	15	90	120	150	2.591	0.0997	93.276
18	15	90	120	150	2.387	0.2350	95.975
19	25	50	220	150	1.231	0.5470	98.123
20	25	50	220	150	1.025	0.3750	101.543
21	25	50	220	150	1.311	0.0965	103.796
22	25	70	120	200	1.987	0.2750	107.237
23	25	70	120	200	2.027	0.7910	111.239
24	25	70	120	200	2.271	0.0110	115.756
25	25	90	170	100	1.267	0.0970	119.567
26	25	90	170	100	1.419	0.0754	121.571
27	25	90	170	100	1.256	0.0579	123.975

Table 8: Response for kerosene as dielectric fluid

1) Larger is better:

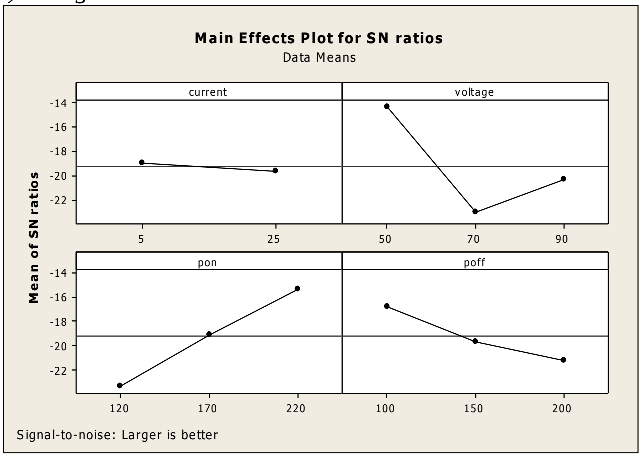

Fig. 3: Main effects plot for SN ratios

Level	Current	Voltage	Pon	Poff
1	22.794	-16.870	-22.510	-34.125
2	-18.454	-21.924	-21.134	-21.076
3		-25.250	-20.400	-8.842
Delta	4.340	8.380	2.110	25.283
Rank	3	2	4	1

Table 9: Response Table for Signal to Noise Ratios Larger is better

2) Smaller is better

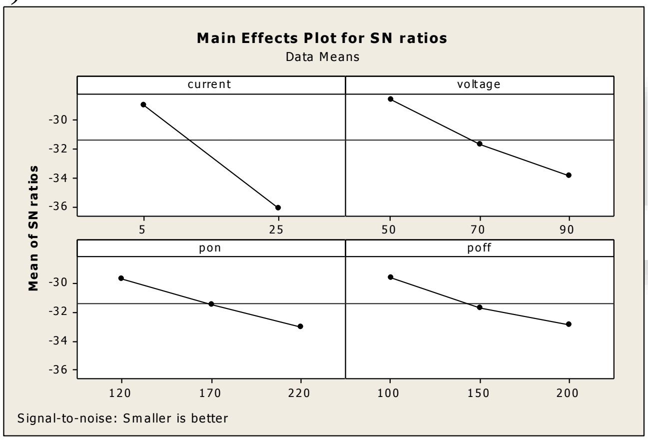

Fig. 4: Main effects plot for SN ratios

Level	Current	Voltage	Pon	Poff
1	-29.44	-29.57	-30.90	-30.41
2	-36.77	-32.41	-31.75	-32.71
3		-33.66	-32.99	-32.52
Delta	7.34	4.10	2.09	2.29
Rank	1	2	4	3

Table 10: Response Table for Signal to Noise Ratios Smaller is better

B. Conclusion from taguchi for kerosene as dielectric fluid

MRR is most influenced by Pulse off time(level-1) and followed by voltage(level-2), current(level-1) and pulse on time(level-3). And Surface finish and Dimensional deviation are most influenced by current and followed by voltage, pulse off time and pulse on time respectively by level-1 only.

VII. GREY RELATIONAL ANALYSIS:

Grey relational analysis is an impacting measurement method in grey system theory that analyzes uncertain relations between one main factor and all the other factors in a given system. Grey relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence. The comparability sequences to the reference sequence, then the grey relational grade for that comparability sequence and reference sequence will be higher than other grey relational grades.

S. No.	MRR grade	SR GRADE	DD Grade	AVG
1	1	0.739861	0.988090144	0.909317
2	0.96682	0.718227	0.737556561	0.807534
3	0.86438	0.722162	0.608609708	0.731717
4	0.79147	0.838604	0.854455751	0.828177
5	0.75741	0.868526	0.682680463	0.76954
6	0.7258	0.928201	0.613188759	0.75573
7	0.67845	0.935755	0.550566263	0.721589
8	0.69881	1	0.521550913	0.740122
9	0.65791	0.94294	0.383105212	0.661317
10	0.62391	0.854788	0.357410035	0.612035
11	0.58059	0.857364	0.339874893	0.59261
12	0.55451	0.847149	0.355575516	0.585746
13	0.53695	0.738042	1	0.758329
14	0.51749	0.708527	0.995473488	0.740496
15	0.49258	0.690598	0.985139363	0.722774
16	0.48114	0.716512	0.969220007	0.722292
17	0.46798	0.769574	0.672409609	0.636654
18	0.45003	0.794582	0.60780873	0.617472
19	0.43367	0.718322	0.552762817	0.568252
20	0.41477	0.7	0.521550913	0.545441
21	0.42071	0.72702	0.490182204	0.54597
22	0.41066	0.796221	0.403171832	0.536684
23	0.4056	0.818658	0.376852985	0.533703
24	0.39863	0.82642	0.333333333	0.51946
25	0.40884	0.675913	0.999422924	0.694725
26	0.40121	0.693078	0.991413238	0.695235
27	0.40609	0.716417	0.659290983	0.593932

Table 11: Grades of GRA Response Table for waste palm oil blended with kerosene as dielectric fluid

Rank	Exp. No	Grey Grade
1	1	0.909317
2	4	0.828177
3	2	0.807534
4	5	0.76954
5	13	0.758329
6	6	0.75573
7	14	0.740496
8	8	0.740122
9	3	0.731717
10	15	0.722774
11	16	0.722292
12	7	0.721589
13	26	0.695235
14	25	0.694725
15	9	0.661317
16	17	0.636654
17	18	0.617472
18	10	0.612035
19	27	0.593932
20	11	0.59261
21	12	0.585746
22	19	0.568252

23	21	0.54597
24	20	0.545441
25	22	0.536684
26	23	0.533703
27	24	0.51946

Table 12: GRA Rankings for waste palm oil

S. No.	MRR grade	SR GRADE	DD Grade	AVG
1	1	0.688887	0.864170175	0.851019
2	0.99387	0.71463	0.851528384	0.853344
3	0.98009	0.673018	0.826796693	0.826633
4	0.87786	0.834891	0.950060901	0.887605
5	0.80189	0.899895	0.864170175	0.855317
6	0.7589	0.772129	0.960354592	0.830463
7	0.68649	0.934102	0.911002102	0.843863
8	0.65288	1	0.815558344	0.822813
9	0.59393	0.941459	0.8942903	0.809894
10	0.57883	0.851381	0.797546012	0.742587
11	0.5598	0.854008	0.72761194	0.713806
12	0.54402	0.843596	0.836012862	0.74121
13	0.5278	0.743107	0.78	0.683636
14	0.50621	0.717458	0.734463277	0.652711
15	0.49931	0.793209	0.857331282	0.716618
16	0.49367	0.885948	0.968944099	0.782855
17	0.48069	0.873876	0.814706497	0.72309
18	0.47239	0.845224	0.635179153	0.650929
19	0.46598	0.71279	0.421166307	0.533312
20	0.45613	0.693428	0.517241379	0.555601
21	0.44987	0.720604	0.820189274	0.663555
22	0.44063	0.794167	0.596330275	0.610376
23	0.43035	0.798993	0.333333333	0.520893
24	0.41931	0.829754	1	0.749688
25	0.41043	0.716285	0.819327731	0.64868
26	0.4059	0.731428	0.858274648	0.665202
27	0.40061	0.715213	0.892652781	0.669492

Table 13: Response Table for GRA Grades kerosene as dielectric fluid

RANK	EXP.NO	Grey Grade
1	4	0.887605
2	5	0.855317
3	2	0.853344
4	1	0.851019
5	7	0.843863
6	6	0.830463
7	3	0.826633
8	8	0.822813
9	9	0.809894
10	16	0.782855
11	24	0.749688
12	10	0.742587
13	12	0.74121
14	17	0.72309
15	15	0.716618
16	11	0.713806
17	13	0.683636
18	27	0.669492
19	26	0.665202
20	21	0.663555
21	14	0.652711
22	18	0.650929
23	25	0.64868
24	22	0.610376
25	20	0.555601
26	19	0.533312
27	23	0.520893

Table 14: GRA ranking for kerosene

VIII. Results and Confirmation Tests

A. Conformation test for Taguchi - Grey relational analysis for waste oil as dielectric fluid

The conformation test for the optimal parameter setting with its selected levels was conducted to evaluate the equality characteristics for EDM of EN 31.First experiment run shows the highest grey relational grade indicating the optimal process parameter set of Pulse off time and pulse on time, current and voltage has the multiple performance characteristics among the 27 experiments, which can be compared with results of conformation experiment for validation of results. below table shows the comparison of the experimental results using the orthogonal array Poff-1 Pon-4 Current-3 Voltage-2 And grey theory design optimal (Poff-2 Pon-1 Current-2 Voltage-3)EDM parameters on EN31.The response values obtained from the conformation experiment are MRR=88.08mm^3/min, DD=0.0049%, RA=1.192 (micro m). The material removal rate shows increased value of 86.904 to 88.04. The Dimensional deviation decreased value of 0.00512 to 0.0049 and surface finish value decreased of 1.202 to 1.192 respectively.

Response characteristics	Response characteristics values	
	Prediction	Confirmation experiment
MRR	86.904	88.04
DD	0.00512	0.0049
RA	1.202	1.192

Table 15: Results of confirmation experiment for waste palm oil as dielectric fluid:

B. Confirmation test for Taguchi - Grey relational analysis for kerosene as dielectric fluid

Below table shows the comparison of the experimental results using the orthogonal array Poff-3 Pon-4 Current-1 Voltage-2. And grey theory design optimal (Poff-2 Pon-1 Current-2 Voltage-3) EDM parameters on EN31steel.The response values obtained from the conformation experiment are MRR = 85.231mm^3/min, DD=0.04123%, RA=1.279 (micro m). The material removal rate shows increased value of 83.032 to 85.231, the Dimensional deviation decreased value of 0.06164 to 0.04123 and surface finish value decreased of 1.6873 to 1.279 respectively.

Response characteristics	Response characteristics values	
	Prediction	Confirmation experiment
MRR	83.032	85.231
DD	0.06164	0.0412
RA	1.6873	1.279

Table 6: Results of confirmation experiment for kerosene as dielectric fluid

IX. CONCLUSIONS

This paper presents the multi objective optimization of the EDM process using parametric design of taguchi methodology by using waste palm oil blended with kerosene and kerosene as dielectric fluids. It was observed that the taguchi is simple and most efficient tool for optimization of machining parameters. The effect various parameters such as Current, Voltage, Pulse on, Pulse off has been studied through machining EN 31steel.It was identified that the Pulse off time and current have more influenced than the other parameters. From the confirmation test the multiple performance characteristics such as material removal rate increased, surface finish and dimensional deviation have decreased concurrently. Therefore a very beneficial multi objective optimization tool for manufacturing system especially for EDM operations has been proposed in this paper. From present analysis it is evident that the optimal parametric combination will be beneficial.

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