Influence of Electrode Geometry and Process Parameters on Surface Quality and MRR in Electrical Discharge Machining (EDM) of AISI H13

Kamlesh V. Dave*, D. S. Patel**
*(PG Student, Mechanical Engineering Department, Sankalchand Patel College of Engineering, Visnagar, North Gujrat)
** (Associate Professor, Mechanical Engineering Department, Sankalchand Patel College of Engineering, Visnagar, North Gujrat)

ABSTRACT
Electrical discharge machining (EDM) is a nontraditional process that uses the electrical spark discharge to machine electrically conducting materials such as tool and die steels, ceramics, etc., for geometrically complex shapes, which are difficult to machine using a more traditional approach. However due to the process nature there is still failure to accurately understand process parameter influence on the surface quality, material removal rate etc. On the other hand, designing and re-shaping of required electrodes for each feature are time consuming and the number of electrode stored is very high. Therefore to increase the productivity, quality and flexibility standardized simple electrode shapes, capable to machine different features, must be analyzed.

This study present experimental analysis based on taguchi design and found the contribution of Tool Geometry on the Surface Roughness and Material Removal Rate (MRR) with other processing parameter. The most significant parameter/s for both output parameters have been calculated.

Keywords **– Electrical Discharge Machining (EDM), Material Removal Rate (MRR), Surface Roughness (SR), Taguchi Design, Tool Geometry.**

1. INTRODUCTION & LITERATURE REVIEW.

Electrical discharge machining (EDM) is a non-traditional machining method commonly used to produce die cavities via the erosive effect of electrical discharges. The electrically conductive tool electrode,

Which has the male shape of the die cavity, is prepared to machine the die cavity. The method is especially effective in machining hard die steels, complex cavities and small work pieces. Die casting, injection molding, forging, extrusion, upset forging and power compaction dies are manufactured using EDM technology [1].

In EDM, a power supply delivers high-frequency electric pulses to the tool and the workpiece. The gap between the tool and workpiece is flushed with a stream of dielectric liquid. When an electric pulse is delivered from the power supply, the insulating property of the die electric fluid is momentarily broken down. This allows a small spark to jump the shortest distance between the tool and workpiece. A small pool of molten metal is formed on the work piece and the tool at the point of discharge. A gas bubble forms around the discharge and the molten pools. As the electric pulse ceases and the discharge disappears, the gas bubble collapses. The onrush of cool dielectric causes the molten metal to be ejected from the workpiece and the tool, leaving small craters. This action is repeated hundreds of thousands of times each second during EDM processing. This removes material from the work piece in a shape complementary to that of the tool. [2]

Yan et. al. studied that depending on the kind of material used and other requirements, positive or negative polarity can be applied. This is one of the most important parameters that have an effect on Electrode Wear Rate, Surface Roughness, MRR[3].Pradhan et al. & Y. Lin & Sundaram et al. studied that Process modeling is an important issue to cheapen manufacturing process because it facilitates the process basics understanding for optimizing the final process performance. However, the complex nature of the EDM process interaction between the electrode (tool) and the workpiece material does not facilitate this task. To solve this problem many authors have applied statistic methods such as analysis of variance (ANOVA) models and S/N ratios in order to analyze and optimize the process performance measures (process outputs) in comparison of the process parameters (process inputs). Taguchi method is very effective to deal with response influenced by multi-variables, which is clearly the case of EDM process The signal-to-noise ratio is a quality ratio that permits to evaluate the effect of changing a particular design parameter on the performance of the process[4][5][6].

M. Kiyak et al, Y Guu et al & M. Mahardika et al studied that EDM-workpiece material interaction is influenced by many process parameters and considered highly non-linear process. There are number of operational parameters which must be set during the process. These operation parameters are variable and can be adjusted in areas to optimize the desired quality of the machined features. However, there have been many studies aimed at systematically investigating the influence of process variables during EDM machining.[7][8][9].

Results obtained in this paper helps the user to select appropriate EDM parameters to design process plan based on product requirements such as geometrical features and surface roughness.

2. EXPERIMENTAL SETUP.

2.1 EDM Components

- Electric power supply
- Dielectric system (DEF-92 Fluid is used.)
- Work piece
- Electrode (Tool)
- Servo control

2.2 Specification

- Make: JOEMARS
- Made: Z 50 JM-322

2.2.1 Technical Specification

Table size : - 600 X 300 mm
X, Y, Z Travel :- 300/200/200 mm
Max. Electrode weight : 60 Kg
Max. Workpiece Weight: - 550 Kg
Tank size : - 830X500X300 mm
Weight of machine : - 1050 Kg.

Fig. 1 EDM Machine

2.3 Workpiece material

To conduct experiments the AISI H13 steel is used as workpiece material. AISI H13 is videly used in manufacturing of Extrusion tools, Forging Dies, Plastic moulds, Die casting Dies. Mandrels, Ejector pin.etc..

The Chemical composition of AISI H13 steel as per testing by DIVINE LABORATORY SERVICES, AHMEDABAD. is given in table 2.1.

Table1 Chemical composition of AISI H13 steel

Composition	C	Si	Mn	Cr	Mo	V
In %	0.40	0.97	0.45	5.30	1.35	0.80

2.4 Electrode material

Among the various metallic and non metallic electrode copper electrode was selected as tool. It is one of the oldest and commonly preferred as tool material. The characteristics of copper electrode is given below.

- Melting point at 1083°C
- Density = 8.9 g/cm3
- Electrical resistivity of 0.0167 ohm mm2/m
- Coefficient of expansion of 4.318 X 10-4 mm mm/°K

Copper is machinable but wheel loading in grinding seriously affect surface finish and accuracy. Copper is most often used when high surface finish in work material is required. The tool can be policed to about 0.25 micron Ra to provide best surface integrity in the work Material.

2.5 Electrode Geometry

Fig. 2 practically processed specimen.

Figure shows the processed specimen of Ø50 mm round bar of 6 mm thickness on which Four geometry of tool Electrode is grooved of 2 mm depth.

In the experiment work four different electrode geometry is taken into consideration they are

- Round(C) – Ø15mm
- Square(S) – 15 x 15
- Rectangle(R) – 15 x 19
- Triangle (T) – 15 x 15 x 15.

2.6. Surface Roughness

Surface topography or surface roughness, also known as surface texture are terms used to express the general quality of a machined surface, which is concerned with the geometric irregularities and the quality of a surface [9]. Surface Roughness measure as the arithmetic average, Ra (µm).

Fig. 3 Surface roughness tester.

The Ra value, also known as centre line average (CLA) and arithmetic average (AA) is obtained by averaging the height of the surface above and below the centre line. The Ra will be measured using a surface roughness tester from **Mitutoyo, Model: SJ 201P**. The Ra values of the WEDMed surface were obtained by averaging the surface roughness values of 5 mm measurement length.

2.7 Material Removal Rate

It is well-known and elucidated by many EDM researchers by Roethel that Material Removal Mechanism (MRM) is the process of transformation of material elements between the work-piece and electrode. The transformation are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction.

MRR is expressed as the ratio of the difference of weight of the workpiece before and after machining to the machining time and density of the material.

$$MRR = \frac{(W_{tb} - W_{ta})}{D \times t}$$

Where,

W_{tb}=weight before machining in gm.
W_{ta}=weight after machining in gm.
D=density of work piece material in gm/m3.
t=time consumed for machining in minute.

The weight of the work piece and tool is measured on precise weighing machine having least count of 0.001 gm.

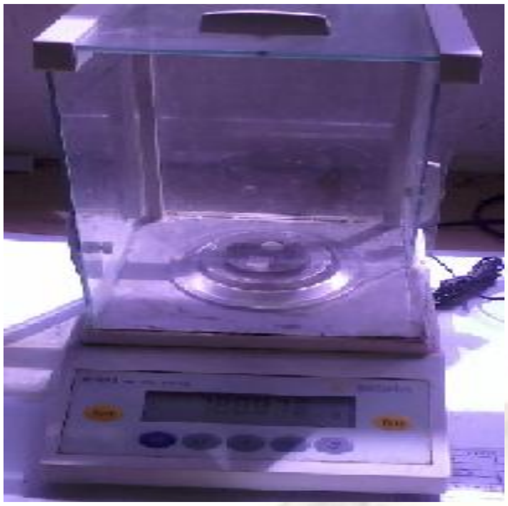


Fig. 4 precise weighing machine

3. DESIGN OF EXPERIMENTS.

To determine influential parameters for EDM groove machining, 24 experiments have been carried out based on Taguchi Orthogonal Array $OA_{16}(4^5)$ has been chosen in order to have representative data[10]

Gap Voltage, Current Intensity, Pulse on time, pulse off time are influential parameter to the common performance measures like MRR and Surface roughness [11].In addition, tool geometry is also considered to identify its influence on these process performance measures and especially on final accuracies. Table 2 presents the five different EDM process parameters chosen and their levels.

The rest of EDM parameters, presented in Table 3, must be kept constant during the experimentation to ensure a right comparison between the 24 test

Table 2 EDM process parameters and levels

Parameter	Level			
	L1	L2	L3	L4
Gap Voltage(V)	16	12	8	4
Current Intensity (A)	50	43	36	28
Pulse on time(µs)	22	42	52	62
Pulse off time(µs)	22	32	42	52
Tool Geometry.	ROUND	SQUARE	RECTANGLE	TRIANGLE

Table 3 Constant EDM Parameters

Parameter	Level
Polarity	+
Servo Sensitivity	7
Flushing Height	10
Working Time	10
Low Wear Factor	0

Table 4 Experimental results and respective S/N ratio of the 24 Experiment for Surface roughness.

V	A	Pon	Poff	Tool	SR	S/N (Ra)
16	50	22	22	C	8.561	-18.6505
16	43	42	32	S	6.047	-15.6308
16	36	52	42	R	3.014	-9.58286
16	28	62	52	T	2.335	-7.36574
12	50	42	42	T	8.304	-18.3857
12	43	22	52	R	3.105	-9.84123
12	36	62	22	S	2.325	-7.32846
12	28	52	32	C	9.14	-19.2189
8	50	52	52	S	7.921	-17.9756
8	43	62	42	C	5.513	-14.8278
8	36	22	32	T	2.63	-8.39911
8	28	42	22	R	2.223	-6.93879
4	50	62	32	R	8.507	-18.5955
4	43	52	22	T	6.503	-16.2623
4	36	42	52	C	5.648	-15.0379
4	28	22	42	S	3.688	-11.3358
8	50	42	22	R	8.726	-18.8163
12	43	62	42	C	6.981	-16.8784
4	36	52	32	S	6.595	-16.3843
16	50	62	22	T	10.531	-20.4494
8	36	52	32	C	6.261	-15.9329
12	28	62	52	R	3.75	-11.4806
4	28	52	52	S	2.84	-9.06637
16	28	22	22	R	3.208	-10.1247

The Taguchi method aims to find an optimal combination of parameters that have the smallest variance in performance. The signal-to-noise (S/N) ratio measures how the response varies relative to the nominal or target value under different noise conditions.

Larger is better - S/N = -10*log(S(1/Y2)/n)
Nominal is best - S/N = -10*log(s2)
Smaller is better- S/N = -10*log(S(Y2)/n))

Table 5 Experimental results and respective S/N ratio of the 24 Experiment for MRR.

V	A	P_{on}	P_{off}	Tool	MRR	S/N (MRR)
16	50	22	22	C	54.23	34.68479
16	43	42	32	S	36.54	31.25537
16	36	52	42	R	39.63	31.96048
16	28	62	52	T	35.35	30.96779
12	50	42	42	T	50.73	34.1053
12	43	22	52	R	44.48	32.9633
12	36	62	22	S	27.36	28.74232
12	28	52	32	C	26.46	28.4518
8	50	52	52	S	43.74	32.81758
8	43	62	42	C	45.64	33.18691
8	36	22	32	T	40.29	32.10395
8	28	42	22	R	38.38	31.6821
4	50	62	32	R	38.42	31.69115
4	43	52	22	T	35.65	31.04119
4	36	42	52	C	48.95	33.79505
4	28	22	42	S	25.61	28.16819
8	50	42	22	R	57.86	35.24757
12	43	62	42	C	48.62	33.7363
4	36	52	32	S	40.21	32.08668
16	50	62	22	T	53.93	34.63661
8	36	52	32	C	31.05	29.84123
12	28	62	52	R	35.63	31.03632
4	28	52	52	S	35.49	31.00212
16	28	22	22	R	15.48	23.79542

Table 4 presents the S/N ratio for surface roughness and Table 5 presents the S/N ratio for MRR.

The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the result of the experiments to determine the percentage contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which do not. Once the optimum condition is determined, it is usually good practice to run a confirmation experiments. Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating condition can be predicted.

Table 6 ANOVA for surface roughness.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	2.241	19.48	6.493	0.89	0.487
B	3	248.555	247.12	82.373	11.28	0.003
C	3	38.594	27.49	9.165	1.26	0.353
D	3	42.810	32.50	10.833	1.48	0.291
G	3	65.718	65.72	21.906	3.00	0.095
Residual Error	8	58.414	58.41	7.302		
Total	23	456.332				

Table 7 Response Table for Signal to Noise Ratios (Smaller is better)

	A	B	C	D	G
1	-14.45	-10.79	-11.67	-14.08	-16.76
2	-13.82	-12.11	-14.96	-15.69	-12.95
3	-13.86	-14.69	-14.92	-14.20	-12.20
4	-13.63	-18.81	-13.85	-11.79	-14.17
Delta	0.81	8.02	3.29	3.90	4.56
Rank	5	1	4	3	2

Table 8 ANOVA for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	6.114	1.867	0.6225	0.11	0.951
B	3	67.888	56.761	18.9204	3.39	0.074
C	3	9.929	8.994	2.9981	0.54	0.670
D	3	14.973	16.003	5.3345	0.95	0.459
G	3	5.944	5.944	1.9812	0.35	0.787
Residual Error	8	44.698	44.698	5.5872		
Total	23	149.546				

4 RESULT AND DISCUSSION.

All experiments is carried out by the process parameters shown in Table 2 and Table 3.

Table 4 and Table 5 shows the final results of five input variable viz., Gap voltage(V), Current Intensity (A), Pulse on time (µs), Pulse off time (µs) and Tool Geometry. S/N ratio is give for Surface roughness and MRR.

Table 6 presents the final results of ANOVA. From this Table we can see the p-value for B is 0.003 so this is most significant parameter that affects surface roughness. It is same for MRR that p-value for Table 9 Response Table for Signal to Noise Ratios (Larger is better)

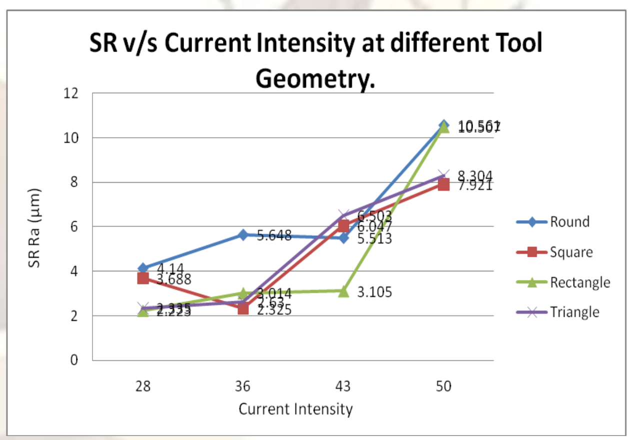
	A	B	C	D	G
1	31.30	29.30	30.34	31.40	32.28
2	32.48	31.42	33.22	30.91	30.68
3	31.51	32.44	31.03	32.23	31.20
4	31.22	33.86	32.00	32.10	32.57
Delta	1.26	4.56	2.87	1.33	1.89
Rank	5	1	2	4	3

B is less than others so it is the most significant factor and it is Current intensity. Table 7 and Table 9 presents the response table for S/N ratio for Surface roughness and MRR. From this, the rank is provided that which parameter affects the most to the least. For Surface roughness it is 1. Current intensity 2. Tool Geometry .3.Pulse off time 4. Pulse on time 5. Gap voltage. For MRR it is 1. Current Intensity 2. Pulse on time 3.Tool Geometry. 4. Pulse off time 5. Gap Voltage.

The result shows that Tool Geometry is also a significant factor for the Material Removal Rate and Surface Roughness.

Figure 4 shows that as current intensity increases the MRR increases and so the surface quality is detoriate. Both the graph shows a result whish agree with the fundamental physic rule. But for current intensity 36 the results are different and the MRR is good and Surface Quality also good for Triangle and Rectangle Geometry.

Fig. 5 shows that as the pulse on time and pulse off time difference increases the MRR and SR both give negative results that MRR decreases and SR increases. But as they come nearer to each other both the output parameter showing good results.



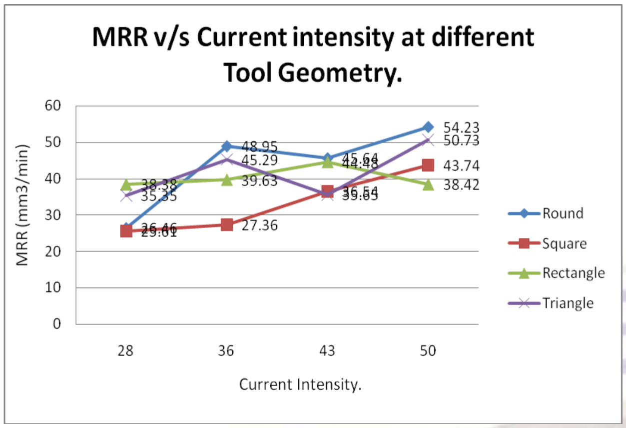


Fig. 4 Comparison of MRR and SR with current intensity at different tool geometry.

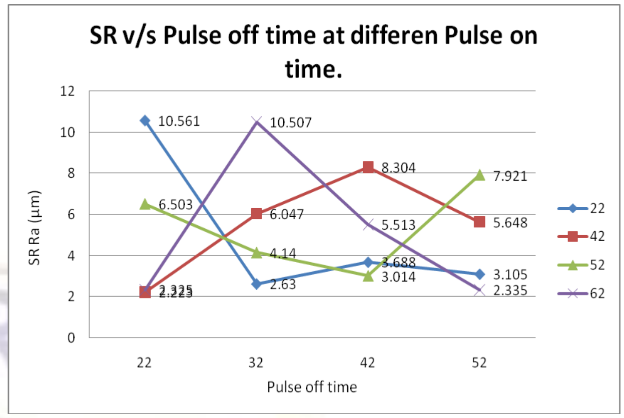
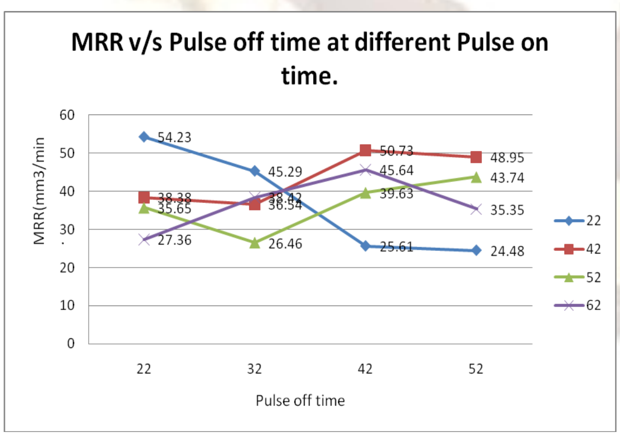


Fig. 5 Comparison of MRR and SR with pulse off time at different pulse on time.

5. CONCLUSION

Influence of process parameters (Gap voltage, Current intensity, Pulse on time, pulse off time, Tool Geometry) on MRR and Surface roughness has been analyzed for copper electrode and AISI H13 workpiece material on sinking EDM process using ANOVA.
Tool geometry is not the most significant factor that affects the performance measures the most but it is a significant factor that affects the performance measures.

As per the S/N ratio and ANOVA the percentage contribution of the tool Geometry is varies from 10% to 20%. This shows that the geometry change improve the MRR and surface quality up to certain extent. From Fig. 4 the Rectangle Geometry at 43 A



current give good results for both the performance measures.

Now, Pulse on time and Pulse off time range is also affects the MRR and SR. At P_{ON}=22 & P_{OFF} =22 hold good result but at P_{ON}=22 & P_{OFF}=62 the results are not favorable.

REFERENCES

Journal Papers:

[1] Bebedict GF (1987) Nontraditional machining processes. Dekker, New York.
[2] Ozgedik, A. (2006). An Experimental investigation on tool wears in electric discharge machining. *International Journal of Advanced Manufacturing Technology, 27, 488-496.*
[3] Yan, B. H., Huang, F. Y., Chow, H.M., & Tsai, J. Y. (1999). Micro-hole machining of carbide by electrical discharge machining. *Journal of Materials Processing Technology, 87(1-3), 139-145.*
[4] lin, Y., Cheng, C., Su B., & Hwang, L. (2006). Machining characteristics and optimization of machining parameters of SKH 57 high-speed steel using electrical-discharge machining based on Taguchi method. *Materials Manufacturing Processes, 21(8), 922-929.*
[5] Sundaram, M. M., Pavalarajan, G. B., & Rajurkar, K. P. (2008). A study on process parameters of ultrasonic assisted micro EDM based on Taguchi method. *Journal of materials Engineering perform, 17(2), 210-215.*

[6] Pradhan, B. B. Masanta, M., Sarkar, B. R., Bhattacharyya, B. (2008). Investigation of electro-discharge micro-machining of titanium super alloy. *International Journal advanced Manufacturing technologies 1-13.*

[7] Kiyak, M., & Cakir, O. (2007). Examination of machining parameters on surface roughness in EDM of tool steel. Journal of Materials Processing Technology, 191(1-3), 141-144.

[8] Guu Y. H., & Hou, M. T. (2007). Effect of machining parameters on surface textures in EDM of Fe-Mn-Al alloy. Materials Science Engineering, 466(1-2), 61-67.

[9] Mahardika, M., Tsujimoto, T., & Mitsui, K. (2008). A new approach on the determination of ease of machining by EDM processes. International Journal of Machine Tools and Manufacture,48, 746-760.

[10] Logothetis, N., & Wynn, H.P. (1989) Quality through design : Experimental design, off-line quality control and Taguchi's contributions. Oxford: Clarendon Press

Books:

[11] Salman, O., & Kayacan, M. C. (2008). Evolutionary programming method for the modeling the EDM parameters for roughness. Journal of Materials Processing Technology, 200 (1-3),347-355.