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M. Srinivasulu
Department of Mechanical Engineering, Chirala Engineering College, Chirala, Andhra Pradesh, India

Y. Venu Babu
Department of Mechanical Engineering, Chirala Engineering College, Chirala, Andhra Pradesh, India

Correspondence:
M. Srinivasulu
Department of Mechanical Engineering, Chirala Engineering College, Chirala, Andhra Pradesh, India

Experimental Investigation and optimization of Machining Time on EDM for Al-6061 Material using Taguchi Technique

M. Srinivasulu and Y. Venu Babu

Abstract
The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly in processes Related to Electrical Discharge Machining (EDM). It is a capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. The aluminum alloy 6061 T6 material is most widely for construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft. The Electric discharge machining process is finding out the effect of machining parameter such as discharge current, pulse on time, pulse off time 0and gap for aluminum alloy 6061 Using square shaped copper and graphite tool . A well- designed experimental scheme was used to reduce the total number of experiments. Parts of the experiment were conducted with the taguchi L9 orthogonal array based. Moreover, the signal-to-noise ratios associated with the observed values in the experiments were determined by which factor is most affected by the Responses of Total machining time (MRR).

Keywords: Optimization; EDM; Al-6061 Material; Taguchi Technique; Minimize Machining Time.

1. Introduction

Non-traditional manufacturing processes is defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use sharp cutting tools as it needs to be used for traditional manufacturing processes. Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non traditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below. Very hard fragile materials difficult to clamp for traditional machining When the workpiece is too flexible or slender When the shape of the part is too complex Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over non-traditional machining processes.

The history of EDM Machining techniques goes as far back as the 1770s when it was discovered by an English Scientist. However, Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes.

When it was originally observed by Joseph Priestly in 1770, EDM Machining was very imprecise and riddled with failures. Commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped shape the metalworking industry. In the mid 1980s, the EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes.

The EDM process can be compared with the conventional cutting process, except that in this case, a suitable shaped tool electrode, with a precision controlled feed movement is employed in place of cutting tool, and the cutting energy is provided by means of short duration electrical pulses EDM has found ready application in the machining of hard metals or alloys which cannot be machined easily by conventional methods. It thus plays a major role in the machining of dies, tools, etc, made of tungsten carbide, setllites or hard steels. Alloys used in aeronautics industry, for example, hast alloy, nimoic, etc, could also be machined conveniently by this process. This process has added advantage of being capable of machining complicated component.

The popularity of EDM process is due to the following advantages

1. The process can be readily applied to electrical conductive materials. Physical and metallurgical properties of the work material, such as strength, toughness, microstructure, etc. are no barrier to its application
2. During machining, the work piece is not subjected to mechanical deformation as there is physical contact between the tool and work.
3. Although the metal removal in this case is due to thermal effects, there is no heating in the bulk of the material.
4. Complicated die contours in hard materials can be produced to a high degree of accuracy and surface finish.
5. Overall production rate compares well with the conventional process because it can dispense with operations like grinding.
6. The surface produce by EDM consists of multitude of small crates. This may help in oil retention and better lubrication, especially for components where lubrication is a problem the random distribution of the craters does not result in an appreciable reduction in fatigue strength of the components machined by EDM
7. The process can be automated easily requiring very little attention from the operator

1.1 Working principle

The principle of spark erosion is simple. The workpiece and tool are placed in the working position in such a way that they do not touch each other. They are separated by a gap which is filled with an insulating fluid. The cutting process therefore takes place in a tank. The workpiece and tool are connected to a D.C. source via a cable. There is a switch in one lead. When this is closed, an electrical potential is applied between the workpiece and tool. At first no current flows because the dielectric between the workpiece and tool is an insulator.

However, if the gap is reduced then a spark jumps across it when it reaches a certain very small size. In this process, which is also known as a discharge, current is converted into heat. The surface of the material is very strongly heated in the area of the discharge channel. If the flow of current is interrupted the discharge channel collapses very quickly Consequently the molten metal on the surface of the material evaporates explosively and takes liquid material with it down to a certain depth. A small crater is formed. lf one discharge is followed by another, new craters are for med next to the previous ones and the workpiece surface is constantly eroded.

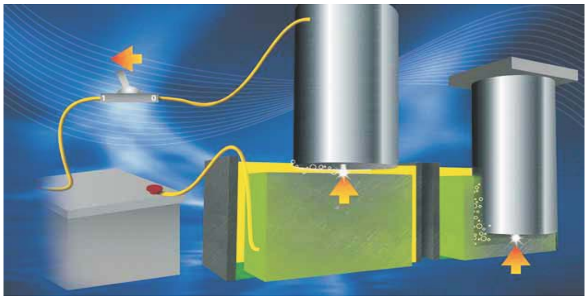

Fig1: Schematic of EDM process

1.2 Analysis Of The Pulses Used In The Edm Process

Performance measures such as MRR, tool wear, and surface finish for the same energy depend on the shape of the current pulses. Depending upon the situation in the gap which separates both electrodes, principally four different electrical pulses may be distinguished Open circuit or open voltage Effective discharges or real Sparks Arcs and

Short circuits They are usually defined on the basis of time evolution of discharge voltage and (or) discharge current Fig.2 .Their effect upon material removal and tool wear may differ quite significantly. Open voltages, occurring when the distance between both electrodes is too large, obviously do not contribute to any material removal or electrode wear.

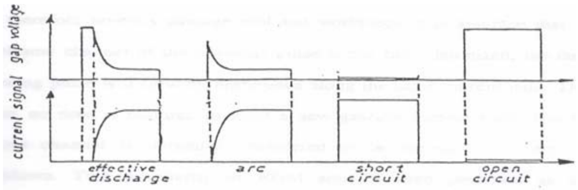

Fig 2: Schematic representation of different electrical pulses

When contact between tool and work piece takes place, a short circuit occurs which also does not contribute to material removal. The range of the electrode distances in between these two extreme cases can be considered to be a practical working gap yielding actual discharges, i.e., sparks and arcs. Both pulse types do show a characteristic voltage drop across the gap during a pulse. The difference between sparks and arcs is quite difficult to establish. It is believed that arcs occur in the same spot, or on the electrode surface and may therefore severely damage tool and work piece. It is assumed that arcs occur when the plasma channel of the previous pulse is not fully demonized; the current during the following pulse will flow by preference along the same current path. Therefore, in such a case, no time is required to form a new gaseous current path. The formation of the gaseous channel is normally considered to be necessary to initiate a new spark breakdown. This peculiarity of EDM arcs is often proposed as a discrimination characteristic with respect to effective discharges or real sparks. It is believed that only "sparks" really contribute to material removal in a desired mode. Until now it remains an open question how much arcs contribute in terms of material removal and tool wear.

Kamlesh V. Dave et.al reported that the tool electrode in EDM process is the means of providing electrical energy to the work piece. The contribution of Tool Geometry was found a significant factor on the Surface Roughness and Material Removal Rate (MRR). Copper was used as an electrode tool having different geometries such as Round, Square, Rectangle and Triangle. The work was carried out on AISI H13 Steel work piece.

Sohani *et al.* Presented about sink EDM process effect of tool shape and size factor are to be considered in technique using RSM process parameters like discharge current (Ip), pulse on- time (Ton), pulse off time (Tooff), and tool area. The RSM-based mathematical models of Metal Removing Rate (MRR) and Tool Wear Rate have been produced using the data got through central composite design (CCD). The analysis of variance is applied to check the lack of fit and adequacy of the developed models. The investigations showed that the best tool shape for higher MRR and lower TWR is circular, then triangular, then rectangular, and lastly square cross sections.

Rajesh *et al.* Concluded that the machining time (MT) mainly affected by wire tension (WT).voltage (V) has less effect on it. Voltage gap (Vg) and current (I) has a least effect on MT. The surface roughness (SR) is mainly influenced by wire tension (WT). The effect of voltage gap (Vg) and voltage (V) is less on SR and current (I) has least effect on it.

Nikil *et al.* From the results it is found that graphite electrode is more favourable than the copper electrode for the machining of steel work piece for MRR and TWR. It is also found that overall cost for machining of hard material with the use of graphite electrode is comparatively less than cop- per electrode

Santanu Dey Dr. D.C.Roy *et al.* At the initial stage MRR using graphite electrode is more as compare to copper electrode. Which implies that at low current, impulse duration and spark gap using graphite electrode is more economical. But as the value of the parameters increases, MRR with copper electrode increases more rapidly in respect of graphite electrode. He concluded that graphite electrodes are best suitable for lower values of parameters and mainly for finishing work as graphite electrode produces better surface finish due to lower MRR and copper electrodes are suitable for high metal removal process where finish requirements are not significance

2.0 Methodology

This Paper will emphasize on the quality machining of EDM die-sinker machine. This project required to study about EDM die-sinker machine operations. From the study, there are 3 parameters that will be concerned as variables factor. The EDM die-sinker will be machined on aluminium alloy 6061.current (1A, 3A 5A), GAP (0.15, 0.20, 0.25), Pulse on- ime parameter (5ìs, 7ìs and 9ìs) Pulse off- time parameter (2ìs, 4ìs and 6ìs) will be used in this experiment with 1 mm deep of the cavity. As an assessment on the quality, the total machining time will be measured. The total machining time will be calculated using a stop watch. The design of the related machining is shown in a design format in the below figure

2.1 Design of machining on graphite electrode

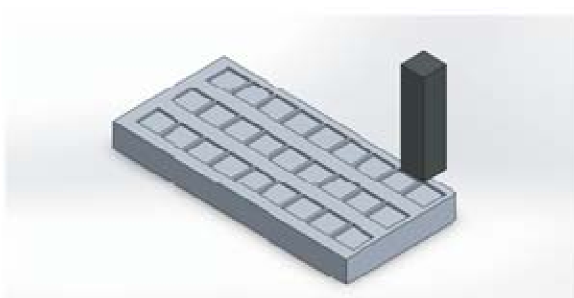

Fig 3:

2.2 Design of machining on copper electrode

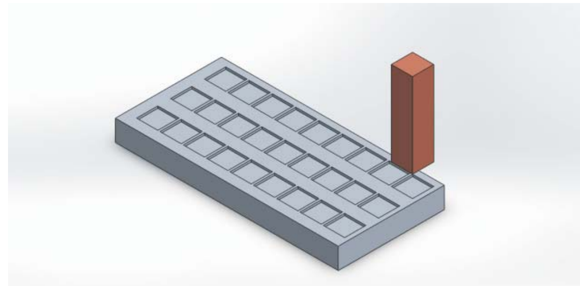

Fig 4:

The present work has done on EDM Altec 35A using edm oil has the dielectric

Fig 5:

2.3 Characteristics of EDM

EDM specification by mechanism of process, metal removal rate and other function that shown in this table no.1

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electric spark
Spark gap	0.010- 0.500 mm
Spark frequency	200 – 500 kHz
Peak voltage across the gap	30- 250 V
Specific power consumption	2-10 W/mm 3/min
Dielectric fluid	EDM oil, Kerosene liquid paraffin, deionized water etc.
Tool material	Copper, Brass, graphite, Ag-W alloys, Cu-W alloys
MR R/TWR	0.1-10
Materials that can be machined	Materials that can be machined
Shapes	Microholes, narrow slot s, blind cavities
Limitations	High specific energy consumption, noncom ducting materials can’t be machined.

Dielectric fluid

In this experiment using the Commercial grade EDM oil supplied by IPOL with (specific gravity= 0.763, freezing point= 94°C) was used as dielectric fluid

3.0 Taguchi Method

Taguchi design experiments in MINITAB

MINITAB provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB calculates response tables and generates main effects and interaction plots for: Signal-to-noise ratios (S/N ratios) vs. the control factors. Means (static design) vs. the control factors.

A Taguchi design or an orthogonal array the method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a three factor mixed level setup is chosen with a total of 9 numbers of experiments to be conducted and hence the OA L9 was chosen. it was decided to utilize the L9 setup, which in turn would reduce the number of experiments at the later stage. In addition, the comparison of the results would be simpler.

The levels of experiment parameters include Current (A), gap (g), spark on time (Ton), and spark off time (Toff) as shown in Table and the design matrix is depicted in the table

3.1 Design of experiment

Table 2:

Machining parameter	Symbol	Unit	Level		
Current	A	Amps	1	3	5
Gap	G	Mm	0.15	0.20	0.25
Sapark on time	T on	ìs	5	7	9
Spark off time	T off	ìs	2	4	6

Experiment with Copper

Fig 6:

Experment With Graphite

Experimental results for copper

Table 3:

S.no	current	Gap	Ton	Toff	Total Machinig Time				s/n ratios
					Exp 1	Exp 2	Exp 3	Avg	
1	1	0.15	5	2	14.54	15.42	15.55	15.17	-23.6197
2	1	0.20	7	4	13.02	14.56	15.08	14.22	-23.058
3	1	0.25	9	6	12.09	12.55	12.71	12.45	-21.9034
4	3	0.15	7	6	10.06	10.55	11.07	10.56	-20.4733
5	3	0.20	9	2	9.45	10.33	11.06	10.28	-20.2399
6	3	0.25	5	4	8.35	9.43	11.26	9.68	-19.7175
7	5	0.15	9	4	12.53	13.55	13.58	13.22	-22.4246
8	5	0.20	5	6	11.22	10.21	12.08	11.17	-20.9611
9	5	0.25	7	2	9.58	10.12	11.2	10.3	-20.2567

The following table gives the MRR values after conversion of time for copper electrode

Table 4:

Exp no.	Parameters level				MRR in g/min		
	A	**B**	**C**	D	**1**	**2**	**3**
1	1	1	1	1	6.877579	6.485084	6.430868
2	1	2	2	2	7.680492	6.868132	6.6313
3	1	3	3	3	8.271299	7.968127	7.867821
4	2	1	2	3	9.940358	9.478673	9.033424
5	2	2	3	1	10.58201	9.680542	9.041591
6	2	3	1	2	11.97605	10.60445	8.880995
7	3	1	3	2	7.980846	7.380074	7.36377
8	3	2	1	3	8.912656	9.794319	8.278146
9	3	3	2	1	10.43841	9.881423	8.928571

Main effects plot for SN ratios for copper electrode

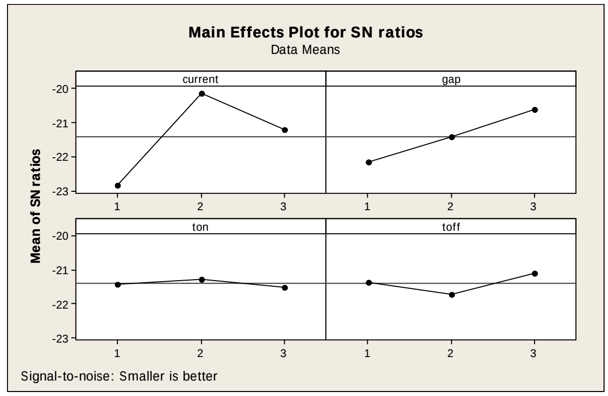

Fig 8:

Anova Test for Copper

Table 5:

Source of variation	Sum of squares	Degrees of freedom	Mean square			C (%)	Rank
Current	21.85042	2	10.92521	60.69561	5.14	71.49721	1
Gap	7.085156	2	3.542578	19.68099	5.14	23.18349	2
T on	0.182822	2	0.091411	0.507839	5.14	0.598216	4
T off	1.442822	2	0.721411	4.007839	5.14	4.721088	3
Error	1.40	6	0.233333			3.53389	
Total	30.56122	8	3.820153				

Experimental results for graphite

Table 6:

S.no	Current	GAP	TON	TOF F	TOTAL MACHINIG TIME				S/N Ratios
					EXP 1	EXP 2	EXP 3	AVG	
1	1	0.15	5	2	10.32	9.46	11.57	10.45	-20.3823
2	1	0.20	7	4	11.3	10.55	12.41	11.42	-21.1533
3	1	0.25	9	6	12.05	11.5	11.1	11.55	-21.2516
4	3	0.15	7	6	13.11	13.05	14.19	13.45	-22.5744
5	3	0.20	9	2	9.45	10.11	10.59	10.05	-20.0433
6	3	0.25	5	4	12.54	11.49	13.17	12.4	-21.8684
7	5	0.15	9	4	12.33	14.02	13.25	13.2	-22.4115
8	5	0.20	5	6	13.56	14.22	16.02	14.6	-23.2871
9	5	0.25	7	2	14.43	15.03	16.14	15.2	-23.6369

Table 7:

Exp no.	Parameters level				MRR in g/min		
	A	**B**	**C**	D	**1**	**2**	**3**
1	1	1	1	1	9.689922	10.57082	8.643042
2	1	2	2	2	8.849558	9.478673	8.058018
3	1	3	3	3	8.298755	8.695652	9.009009
4	2	1	2	3	7.627765	7.662835	7.047216
5	2	2	3	1	10.58201	9.891197	9.442871
6	2	3	1	2	7.974482	8.70322	7.593014
7	3	1	3	2	8.1103	7.132668	7.54717
8	3	2	1	3	7.374631	7.032349	6.242197
9	3	3	2	1	6.930007	6.65336	6.195787

Main effects plot for SN ratios for graphite electrode

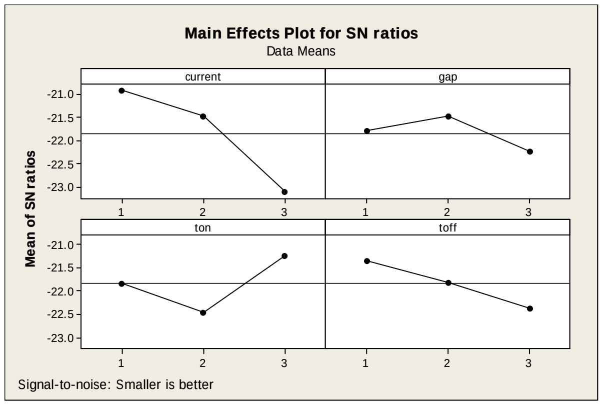

Fig 9:

Anova Test for Graphite

Table 8:

Source of variation	Sum of squares	Degrees of freedom	Mean square			C (%)	Rank
Current	16.48187	2	8.240935	19.69945	5.14	53.93067	1
Gap	7.085156	2	0.819434	1.958805	5.14	23.18349	2
T on	0.182822	2	2.314434	5.53251	5.14	0.598216	4
T off	1.442822	2	1.3116	3.135299	5.14	4.721088	3
Error	2.51	6	0.418333			8.213023	
Total	30.56122	8	3.1716				

4.0 Conclusions

After the Taguchi analysis we give a smaller is better for the Signal to noise ratio form equation n = -10

Log10 [mean of sum of squares of measured data] and we get result current is the more significant factor for total machining time and This may be noted on graph and analysis result to first rank. Taguchi designs traditionally focus on main effects, but it is important to test suspected interactions. The graphite electrode gives the most material removal rate and gives the better than surface roughness but it gives high electrode wear ratio

From the analysis of graph- it can be identified that at the initial stage MRR using graphite electrode is more as compare to copper electrode .Which implies that at low current, impulse duration and spark gap using graphite electrode is more economical. But as the value of the parameters increases, MRR with copper electrode increases more rapidly in respect of graphite electrode.

Finally, it can be concluded that graphite electrodes are best suitable for lower values of parameters and mainly for finishing work as graphite electrode produces better surface finish due to lower MRR and copper electrodes are suitable for high metal removal process where finish requirements are not significant.

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