Optimization of Process Parameters for Die Sinking Electrical Discharge Machining (EDM) of SS-316L

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Abstract

The objective of the current work is to investigate the Optimal Process Parameters of EDM. Stainless steel-316L is selected as a work piece material with Copper (99.9 %) purity as a Tool (Electrode) Material. The Input Parameters such as Current (A), Voltage (V), Pulse on Time (T_{ON}) & Pulse off Time (T_{OFF}) are selected for the experimental work. Effects of these Input Parameters on Output Response as Material Removal Rate (MRR) is studied. Analysis is carried out using Taguchi Technique and an attempt has been made to estimate the optimum machining conditions to get the best possible response within the experimental constraints. It was found that Pulse On-time was the most significant factor followed by Current, Pulse Off-time and Voltage.

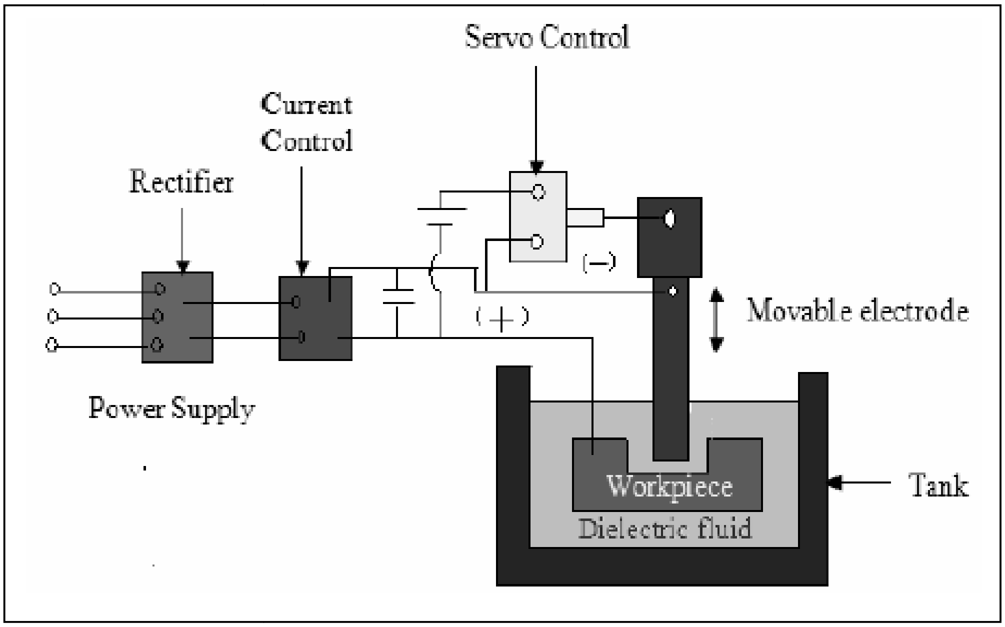
Keywords: Die Sinking EDM, Optimization, Stainless steel 316L, Taguchi Technique.

1. Introduction

Electrical Discharge Machining, also known as Spark Erosion, Electro-erosion or Spark Machining is a process of metal removal based on the principle of erosion of metals by an interrupted electric spark discharge between the electrode Tool and the work piece separated by a dielectric fluid medium [2]. The EDM process is best suited for making intricate cavities and contours which would be difficult to produce with normal machines like grinders, end-mills or other cutting tools [2]. Metals such as hardened tool-steels, hard carbides, titanium, Inconel kovar, Refractory metals and Exotic materials are easily machined through EDM.

A British Scientist-Joseph Priestly first discovered the erosive effects of electrical discharges in the year 1770. After that in 1943, B. Lazarenko and N. Lazarenko both soviet scientists had exploited the destructive effect of an electrical discharge and developed a controlled process for machining materials that are conductors of electricity.

Figure 1 illustrates the schematic layout of the electric discharge machining system. The main components are the work piece and the tool, the dielectric medium, the electric power supply and a servo control. The work piece and the tool are connected to electric power supply. Here both work piece and the tool should be conductors of electricity. In this process, work piece and tool are submerged into a non-conducting dielectric fluid which is forced through a gap, known as 'Spark Gap' between them to cause the spark discharge [3].This gap is varied to match the machining conditions such as Material Removal Rate (MRR) etc. [3]. Generally EDM oil, Kerosene orDeionized water are used as the dielectric medium.



As soon as the voltage gradient is set up between the tool and the work piece is sufficient enough to breakdown the dielectric medium, a conducting electrical path is developed for spark discharge and thereby causes the current to flow [3]. The metal is thus removed in this way from the work piece. Here, the tool shape or profile will be reproduced on the work piece.

2. Literature Review

Chandramouli S et.al. reported that, the Proper selection of input parameters will play a significant role in Electrical Discharge Machining. Here input parameters considered are current, pulse on time and pulse off time and their effect on material removal rate, tool wear rate and surface roughness are observed. [1]

Safian Sharif et.al. investigated the influence of EDM input parameters in characteristics of EDM Process. A combination of SS-316L as a work piece and Copper impregnated graphite as an electrode are used for experimentations. Results shows that the peak current was the most significant factor to all variable responses. [5]

M.A. Razak et.al. observed pulse on-time was the most significant parameter affecting surface roughness. Here Biodegradable AZ31 Magnesium alloy is used as a work piece along with copper as an electrode. [6]

P. Prasanna et.al. observed the performance of conventionally used copper electrode using kerosene as die-electric fluid for machining of AA7075 SiC Metal Matrix. Current as most significant factor was observed. [7]

It is revealed from the literature that most of the studies on EDM machining are carried on the hardened tool-steels, but very limited literature is available on the stainless steel as work piece. So in the present work an attempt is made in order to find out optimum values of process parameters for SS 316L material which is widely used due to its corrosion resistance property.

3.EDM Process Parameters and Performance Characteristic

Process Parameters are those which can affect the quality of machining i.e. cutting, drilling, grinding etc. There are different types of Electrical Discharge Machines. Every type of machine has certain effects of process parameters during or after machining. Hence selection of process parameters is important criteria. The process parameters and MRR as a performance characteristic which are mainly considered in the present work are described below:

a. Pulse on-time (T_{ON}):

It is the period of sparking time usually measured in microseconds (μs). During this duration, the current is allowed to flow through the electrode towards the work piece. An increase in the Pulse on-time causes an increase in the Material Removal Rate (MRR).

b. Pulse off-time (T_{OFF}):

It is the period of time expressed in μs between the two pulse on-time. This time permits the melted particle to coagulate on the work piece and to be washed away by flushing method from the gap.

c. Voltage (V):

Discharge voltage is associated with spark gap and the breakdown strength of the dielectric fluid. Once the flow of the current starts, the voltage drops and stabilizes at the working gap level. Hence the higher value setting of the voltage causes increase in the spark gap which improves the flushing conditions and stabilizes the cut.

d. Current (A):

Current is measured in the amp allowed to per cycle. It is directly proportional to the Material Removal Rate (MRR).

e. Material Removal Rate (MRR):

This is one of the performance measures. Material Removal Rate of the work piece is the volume of the material removed per minute. It is usually measured in the unit as mm^3/min. Maximum of MRR is an important indicator of the efficiency and the cost effectiveness of the EDM process. Other performance measures are Tool Wear Rate (TWR), Surface Roughness (SR) etc. Mathematically the MRR can be calculated as below [1]:

$$MRR\ (mm^3/min) = \frac{Volume\ Loss}{Time} \quad (1)$$

$$Volume\ loss = \frac{(Wi - Wf)}{\rho} \quad (2)$$

Where,

W_i = Initial weight of the work piece (gm)
W_f = Final weight of the work piece (gm)
ρ = Density of the work piece (g/mm^3) =0.008 g/mm^3 for SS-316L w/p

4. Experimental Details

In the present study, experiments are conducted on Die Sinking Electrical Discharge Machine S-20-4035 as shown in the following figure 2. The machine has current settings from 5 A to 20 A, Voltage settings from 30 to 60 V, 1 to 8 µs settings of pulse on-time and 1 to 8 µs settings of pulse off-time.

Figure 2. EDM

The experiments are conducted on Stainless Steel-316L work piece having dimensions as 130 mm × 40 mm × 12 mm (l×b×t) & Density-0.008 g/mm^3 as shown in figure 3.

Figure 3. SS-316L as a Work piece material-130 mm×40 mm×12 mm

Copper having Stability Property [7], and 99.9 % purity is selected for Tool (Electrode) material in circular shape, having 25 mm length and 10 mm diameter is selected for making holes on the work piece as shown in figure 4.

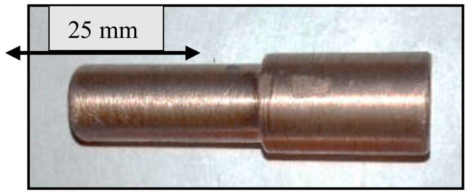


Figure 4. Copper Electrode

EDM oil is used as a dielectric medium. Digital weighing balance having least count of 0.01 gm is used for measuring weights of the work pieces for calculation of the MRR. Here total number of experiments to be done on the work piece are decided based on Design of Experiments.

5. Optimization using Taguchi Method

Dr. Genechi Taguchi was a Japanese Scientist who has done more research on improving quality of manufactured products. Taguchi adopted the DOE Technique. He proposed the Quality Engineering Method which is known as Taguchi Method or Taguchi Approach. He developed a method for designing experiments to find the effects of different parameters on mean and variance of the performance. Taguchi approach is a form of DOE with special application principles [4]. There are three S/N ratios in Taguchi method namely Lower is better (LB), Nominal is best (NB) and Higher is better (HB).In the present study, objective is to obtain higher Material Removal Rate (MRR) hence the required quality characteristic for higher MRR is Larger the Better.

5.1 Design of Experiments (DoE)

This is the systematic approach to investigate the process which was introduced by R.A. Fisher in England, early 1920's and then it was standardized by Taguchi. Following factors and levels are selected for the experiments.

Table 1. Selected Factors and their Levels

Sr. No	Factors	Levels		
		Level 1	Level 2	Level 3
1	Current (A)	10	15	20
2	Voltage (V)	30	40	50
3	$T_{ON\ (\mu S)}$	1	3	4
4	$T_{OFF\ (\mu S)}$	1	2	3

Taguchi created a set of tables of numbers. These tables are known as Orthogonal Arrays, which are used to layout the experiments of particular factor constituent. Here the experiments are conducted based on Taguchis' L_9 Orthogonal Array as below.

Table 2. L_9 (3^4) Orthogonal Array Standard Layout

Experiment Number	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3. L_9 Design Matrix and Experimental Results for Higher MRR

Exp. No.	Current (A)	Voltage (V)	Pulse on-time (µs)	Pulse off-time (µs)	W_i (gm)	W_f (gm)	MRR (mm^3/min)	SNRA1	MEAN1
1	10	30	1	1	498	489	11.14	20.9377	11.14
2	10	40	3	2	489	482	7.88	17.9305	7.88
3	10	50	4	3	482	474	2.20	6.8485	2.20
4	15	30	3	3	474	466	7.09	17.0129	7.09
5	15	40	4	1	466	457	1.75	4.8608	1.75
6	15	50	1	2	457	450	13.56	22.6452	13.56
7	20	30	4	2	450	442	2.27	7.1205	2.27
8	20	40	1	3	442	434	18.50	25.3434	18.50
9	20	50	3	1	434	427	7.86	17.9085	7.86

The above values of SN Ratios and Means are obtained through MINITAB 17.0 Software.

6. Experimental Results and discussion

Figure 5 & 6 shows the SS-316L plate on which the throughout holes are made using EDM and Copper Electrode respectively.

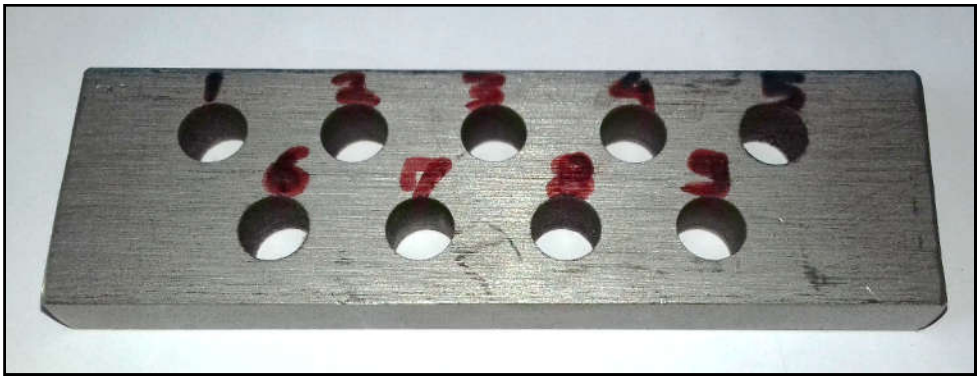


Figure 5. EDMed SS-316L Work piece for optimization based on L_9 array

Figure 6. Copper Electrode after Machining

Table 4 and Figure nos. 7 and 8 indicates the Response Table for SN Ratios, main effects plot for SN Ratios (larger the better) and means for higher MRR respectively.

Table 4. Response Table for Signal to Noise Ratios - Larger is better

Level	**Current (A)**	**Voltage (V)**	**Pulse on-time (µs)**	**Pulse off-time (µs)**
1	15.239	15.024	22.975	14.569
2	14.840	16.045	17.617	15.899
3	16.791	15.801	6.277	16.402
Delta	1.951	1.021	16.699	1.833
Rank	**2**	**4**	**1**	**3**

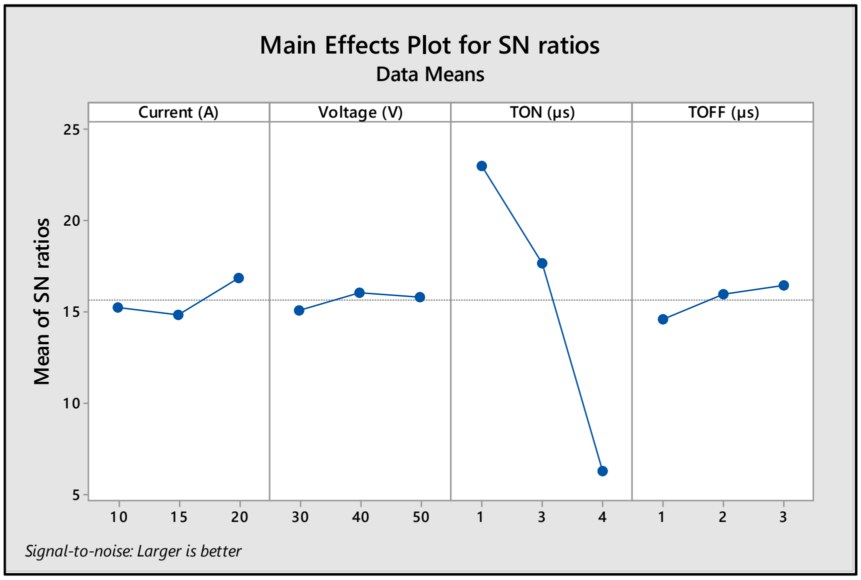


Figure 7. Main Effects Plot for SN Ratios for Higher MRR

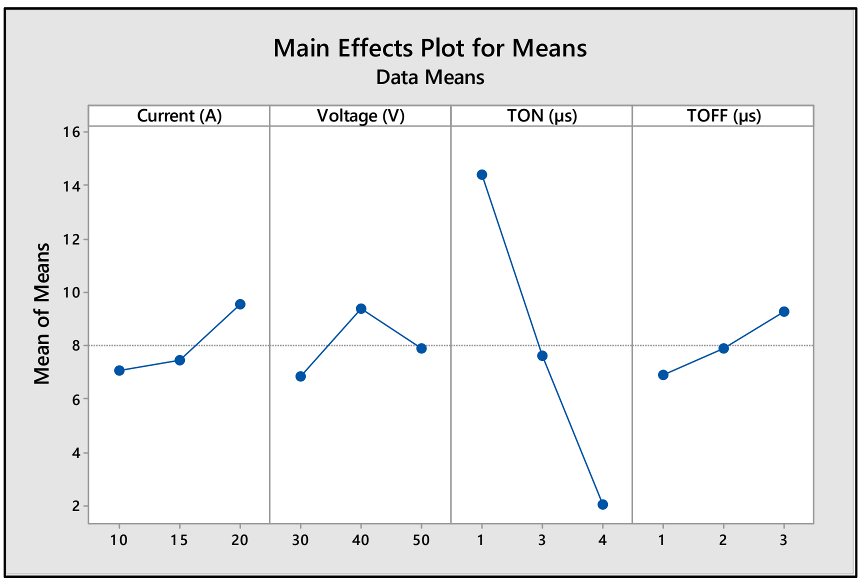


Figure 8. Main Effects Plot for Means for MRR

In this work, Optimization of process parameters for Die Sinking EDM is carried out by using Taguchi Method for Design of Experiments (DoE). The objective was to identify Optimal Parameters for Higher Material Removal Rate as a performance measure.

From table 4, it is clear that Pulse on-time since having rank 1, is the highest contribution factor for the MRR. From fig.7 and 8, MRR has the highest value at Level 3 for Current, Level 2 for voltage, level 1 for Pulse on-time and level 3 for pulse off-time.

Hence following table shows the optimal machining process parameters for MRR. In table 3, parametric combination for experiment number 8 is the Optimal Setting.

Table 6. Optimal Process Parameters

Response	Optimal Process Parameters				Value of MRR for optimal setting (mm^3/min)
	Current (A)	Voltage (V)	Pulse on-time (μs)	Pulse off-time (μs)	
MRR	20	40	1	3	18.50

7. Conclusion

In this research, influence of Process parameters as Current, Voltage, Pulse on-time and Pulse off-time are investigated. MRR is selected as a Response Measure. From table 4, it is observed that Pulse on-time is having the highest effect for increasing the MRR. 8^{th} no. combination of process parameters from table 3 as A3B2C1D3 gives higher MRR. For the optimum process parameters maximum material removal rate observed is 18.50 (mm^3/min).

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