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Experimental Analysis of Process Parameters in Wire-Cut Electric Discharge Machining

Y Venkata Naga Chandana

Assistant Professor, Department of Mechanical Engineering, Mahatma Gandhi Institute of Technology, India
Email: yvnchandana_mct@mgit.ac.in

Wire Electrical Discharge Machining (Wire EDM) is a controlled machining process which is used to manufacture geometrically intricate shapes with greater accuracy and good surface finish that are difficult to machine with the help of conventional machining processes. Wire EDM is now growing as an important process in various fields like medical devices, aerospace industry and manufacturing industry. Work has been done to use the technology for fabricating micro components. Wire EDM is a non-conventional metal removal process as well as one of the best manufacturing process suitable for producing jigs, fixtures and dies, and this process is capable to cut a workpiece having oblique and unique form. The main objective of this work is to analyze the prominent process parameters like pulse-on time, pulse-off time, wire feed rate and wire tension using Minitab Statistical software and to apply Taguchi and ANOVA analysis on the machined SS316 piece in Wire EDM. Studied the various process parameters by machining different materials in Wire EDM such as Stainless Steel 316, to reduce the Machining Time, to achieve the better surface roughness, wire wear ratio and Material Removal Rate.

1. Introduction

Whenever sparking takes place between two electrical contacts, a small amount of material is removed from each of the contacts. This fact is realized, and the attempts were to harness and control the spark energy to employ it for useful purposes, say for machining of metals. It was found that the sparks of short duration and high frequency are needed for efficient machining. Further, it was also observed that if the discharge is submerged in dielectric, the energy can be concentrated into a small area. As soon as the potential across the electrodes crosses the breakdown voltage, the sparking takes place at the point of least electrical resistance. It usually occurs at the smallest inter-electrode gap. After each discharge, the capacitor recharges and the spark appear at the next narrowest gap. Occurrence of each spark generates heat energy which is shared in different modes by work piece, tool, dielectric, debris and other parts of the system. The dielectric serves some important functions. It cools down the tool and work piece, cleans or flushes away the inter electrode gap and localizes the spark energy into a small cross-sectional area. Energy content in each spark and frequency of sparking are governed by the conditions in the inter electrode gap.

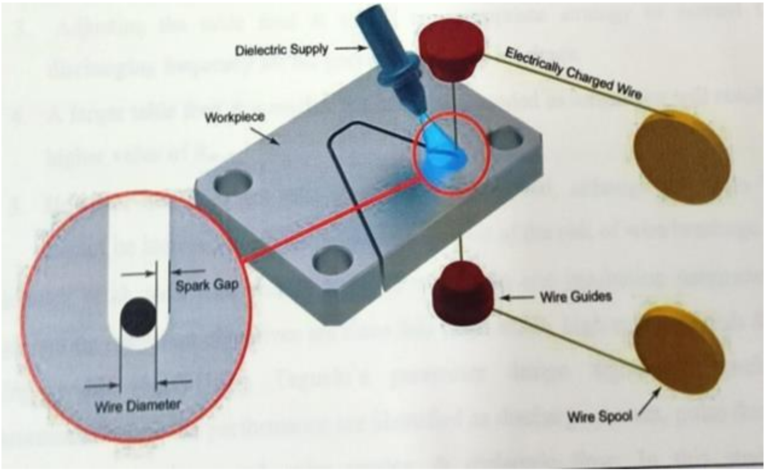

Fig. 1 Principle of Wire EDM process

Wire electrical discharge machining is a high-precision method for cutting nearly any electrically conductive material. A thin, electrically charged EDM wire held between upper and lower mechanical guides forms one electrode, while the material being cut forms the second electrode. Electrical discharge between the wire and the workpiece creates sparks that rapidly cut away material. Submerging the workpiece and wire in deionized water, allows cutting debris to be flushed away.

As the charged wire never makes physical contact with the workpiece in EDM machining, there are no cutting forces involved, making it possible to manufacture extremely small and delicate parts. Parts that require levels of accuracy and intricacy that traditional machining cannot achieve can easily be produced via wire EDM.

Features of Wire EDM

1. Forming electrode adapted to product shape is not required.
2. Electrode wear is negligible.
3. Machined surfaces are smooth.
4. Geometrical and dimensional tolerances are tight. he produced to close tolerances.
5. Straight holes can be produced to close tolerances.
6. Machine can be operated unattended for a long time at high operating rate.
7. Complex structures can be machined with high machining accuracy.

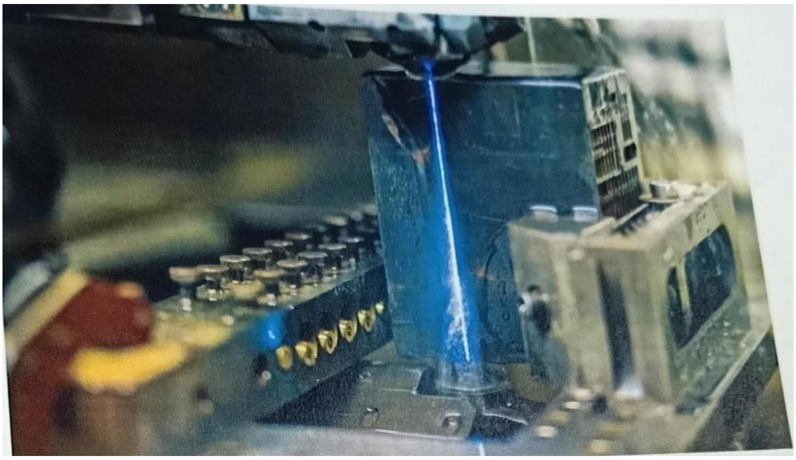

Fig.2 Spark Generation in wire EDM

2. Literature Review

2.1 Parametric optimization in wire cut EDM on 316 stainless steels

EDM offers numerous diversities. Wire cut EDM is one of the most emerging modern techniques for machining materials that offers more hardness while cutting and resists to generate intricate shapes by pedestrian methods. The optimum employment of the capacity of wire cut EDM requisites orthodox selection of machining parameters choosing SS316 as work piece. Using TAGUCHI'S L9 orthogonal array, no. of experiments to be conducted are finalized and Pulse-on time (T_{on}), Pulse-off time (T_{off}), Peak-current (Ip) & Wire feed rate were designated as input parameters. Three different levels of each parameter were plumped for shepherding the experiments. The responses quantified were Material Removal Rate (MRR), Kerf (width of cut) and Surface Roughness (Ra). One of the Multi Criteria Decision Making (MCDM) methods namely Grey Relation Analysis (GRA) is compassed to identify the optimum input parameter to generate higher assay of MRR and lower assay of Surface roughness and Kerf.

2.2 Optimization of Process Parameters of Wire Cut EDM for Stainless Steel-316

Wire cut electrical discharge machining is a well-known non-conventional machining process based on spark erosion between work piece and the tool. This process is capable to cut hard materials and intricate shapes which cannot be formed by any other machining processes. Stainless steel is commonly used in industries due to its properties malleability, ductility and corrosion resistance. The machining of stainless steel is not a hard job but the investigation of the effect of process parameters on machining is a crucial step. The metallurgical properties and productivity of machine depends upon machining process parameters. So, optimization of process parameters is very important. This paper has tried to find the optimized procedure by variation of different parameters so that process can be carried out with maximum Material Removal Rate (MRR) and better surface finish. The objective is to optimize process parameters for maximization of MRR and minimization of surface roughness. During the experiment, Stainless Steel-316 had been used with brass wire as electrode. The experiment is designed with the help of Taguchi L’9 orthogonal array and further analysis is done with the help of ANOVA. The parameters selected for this study are Pulse on Time, Peak Current and Wire Tension. After cutting, the pieces are tested for Material removal rate, Surface Roughness and Recast Layer Thickness.

3. Methods and Materials

The machine used for experiments is electronics sprint cut Wire cut EDM. Model- ELPULS-40 ADLX, incorporated with molybdenum wire technology. The machine consists of a coordinate worktable, wire running system, wire frame, Microcomputer based control cabinet and dielectric supply system. In this machine brass wire is used to perform cutting operation and wire is wound and stored a wire drum which can rotate at a speed of 1500 rpm. Guide pulleys are mounted on wire frame and wire can run through these guide pulleys at a speed of 11 m/min in reversible directions alternatively. Work piece is mounted on the worktable with the help of clamps and bolts and the micro controller delivers the pulse signals to the servo motors which rotates accordingly and through the variable gears, lead screws and nuts, these motions will be transmitted to the worktable for performing the cutting operation.

Fig.3 Wire Cut EDM Machine Employed for research work

3.1 Chemical Composition and Physical properties:

The chemical composition of STAINLESS STEEL 316 is outlined in the following table.

Table 1. Chemical Composition

Element	Content (%)
Carbon, C	0.0-0.07
Magnesium, Mg	0.0-2.0
Silicon, Si	0.0-1.0

Phosphorous, P	0.0-0.05
Sulphur, S	0.0-0.03
Chromium, Cr	16.50-18.50
Molybdenum, Mo	2.00-2.50
Nickel, Ni	10.00-13.00
Iron, Fe	62.85
Total	100

Table 2. Physical properties

Property	Value
Density	8 g/cm^3
Melting Point	1400 degC
Modulus of Elasticity	193 GPa
Electrical Resistivity	0.74×10^{-6} µ.m
Thermal Conductivity	16.3 W/mK
Thermal Expansion	15.9×10^{-6} /K

Table. 3 Mechanical properties

Grade	316 Bar and section (up to 160mm thick)	316 sheets (up to 8mm thick)	316 Plate (8-75mm thick)
Tensile Strength (MPa)	500-700	530-680	520-670
Proof Stress (MPa)	200 Min	240 Min	220 Min
Elongation ASO (mm)	40 Min %	40 Min %	45 Min %
Hardness Brinell	215 Max HB	-	-

3.2 Input Parameters

Pulse on time: On time is control sparking current adjust range Value increase output current is bigger and cutting speed increase but surface roughness rougher' on the other hand change the value cutting speed decrease and surface roughness finer the on timetable from: (50ns - 1200ns)

Pulse off time: During machining the off time control no sparking pulse time adjust range from 450 When value increase mean sparking Off time longer and cutting status more stable but cutting speed lower without wire break the Off timetable from (4 µs -50µs).

Wire Tension: Wire feed tension adjust to setting wire feed increase or decrease use

+, - key or use keyboard direct input the value to control wire tension each step to increase or decrease 100g control range from 300g 2200g.

Wire Feed: Wire feed speed adjust to setting wire feed increase or decrease use +- key or use keyboard direct input the value to control wire feed Control ranges from 6-20 meter/minute.

Feed rate: rate control when servo mode or constant mode to control maximum cutting feed rate speed control range from 0. 1mm^2/min-500mm^2/min.

3.3 Output parameters:

3.3.1 Material removal rate: The material removal rate is defined as the amount of material removed from the workpiece per unit time. The material removal rate can be calculated from the volume of material removal or from the weight difference before and after machining. It is an indication of how fast or slow the machining rate is and an important performance parameter in micro-EDM, as this is usually a very slow process. Higher machining productivity must also be achieved with a desired accuracy and surface finish. The MRR greatly depends on the process parameters. A higher value of discharging voltage, peak current, pulse duration, duty cycle, and lower values of pulse interval can result in higher MRR. In addition to these electrical parameters, other nonelectrical parameters and material properties have significant influence on MRR.

Material removal rate (MRR) =F * D * W mm^3 / min

Where F = Feed rate (mm / min)

D = Depth of cut (mm)

W = 1 width of cut (mm)

3.3.2 Wear ratio: EWR is the ratio of the amount of material removed from the microtool electrode to the amount of material removed from the workpiece by volume. Sometimes, TWR is also calculated by dividing the difference in weight of the microtool before and after machining with the machining time, as seen in Equation. High TWR causes inaccurate machined features and poorer surface finish substantially. During micro-EDM drilling operations, tool wear results in shortened tool length; therefore, the total amount of tool feed provided is larger than the workpiece thickness. Process parameters have considerable influences on TWR. Low TWR and high surface quality are achieved at lower peak current and pulse duration. TWR also depends on several other factors such as melting point, thermal conductivity, and density of the tool material. Depending on the tool geometry and complicacy, TWR also varies. Proper optimization of the process parameters can substantially control the wear rate and improve the accuracy of the machined features.

3.3.3 Surface roughness:

Surface roughness, often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. In surface metrology, roughness is typically considered to be the high- frequency, short-wavelength component of a measured surface.

3.4 Experimental values of stainless steel 316 on Wire-cut EDM:

Experimental investigations were carried out on EDM machine using the following input parameters shown in Table 4.

Table. 4 Input parameters of STAINLESS STEEL 316 ON WEDM

S.No	Pulse On Time	Pulse Off Time	Wire Feed Rate	Wire Tension	Feed	Feed Rate	Time (Mins)
1	4	8	2	8	7.5	1.5	25.36
2	4	16	4	10	7.5	1.7	28
3	4	8	3	7	7.5	2.3	22
4	7	16	2	10	7.5	2.25	23
5	7	8	4	10	7.5	2.8	18.12
6	7	16	2	7	7.5	2.8	18.49
7	9	8	2	10	7.5	3	16.14
8	9	16	2	8	7.5	3.4	15.53
9	9	12	2	9	7.5	3.3	15.01
10	10	16	3	10	7.5	3.8	13.42
11	10	12	5	7	7.5	3.9	12.39
12	10	10	5	8	7.5	4.3	13.24

Figure 4: Stainless steel 316 workpiece material with size 150*100*10mm

Figure 5: Stainless Steel 316 workpiece after machining

4. Results and Discussion

Taguchi L9 Orthogonal array of design of experiments (DOE) for the selected input process control parameters at different levels combinations. The various parameters employed to evaluate the Material Removal Rate (MRR) are given in following Table5. The calculated MRR are presented in Table 6.

Table. 5 Feed rate and machining time for experiment performed

S.No	Pulse on time	Pulse off time	Wire Feed rate	Wire tension	Feed rate	Machining Time (min)
1	4	8	2	8	1.5	25.36
2	4	12	4	10	1.7	28
3	4	16	3	7	2.3	22
4	7	8	2	10	2.25	23
5	7	12	4	10	2.8	18.12
6	7	16	2	7	2.8	18.49
7	9	8	2	10	3	16.14
8	9	12	2	8	3.4	15.53
9	9	16	2	9	3.3	15.01

Table. 6 Calculated Material Removal Rate (MRR)

S.No.	Feed Rate mm/min	Width mm	Depth of Cut mm	MRR mm^3/min
1	1.5	12	10	180
2	1.7	12	10	204
3	2.3	12	10	276
4	2.25	12	10	270
5	2.8	12	10	336
6	2.8	12	10	336
7	3.0	12	10	360
8	3.4	12	10	408
9	3.3	12	10	396

The Main Effects Plot for SN ratios provide valuable insights into the influence of four factors - Pulse ON Time, Pulse OFF Time, Wire Feed Rate, and Wire Tension on process performance, measured by the Signal-to-Noise (SN) ratio. According to the "larger is better" criterion, higher SN ratios indicate improved performance. Among the factors, Pulse ON Time shows the most significant impact, as the SN ratio increases sharply with higher levels. This indicates that longer Pulse ON Time substantially enhances performance, making it a critical factor in the process. For Pulse OFF Time, the SN ratio exhibits a moderate upward trend as the levels increase, suggesting that longer durations between pulses contribute positively to performance, although the effect is less pronounced compared to Pulse ON Time. Similarly, the Wire Feed Rate demonstrates a slightly different trend, with the SN ratio dipping at intermediate levels but improving at higher levels, the same is shown in figure6. This indicates that an optimal or higher feed rate can positively influence the process outcome. Finally, Wire Tension shows a consistent and gradual increase in the SN ratio as tension levels rise. Although the effect of Wire Tension is less significant compared to Pulse ON Time, it still contributes to improved performance. Overall, the analysis reveals that optimizing these factors—especially Pulse ON Time—can significantly enhance process efficiency and performance.

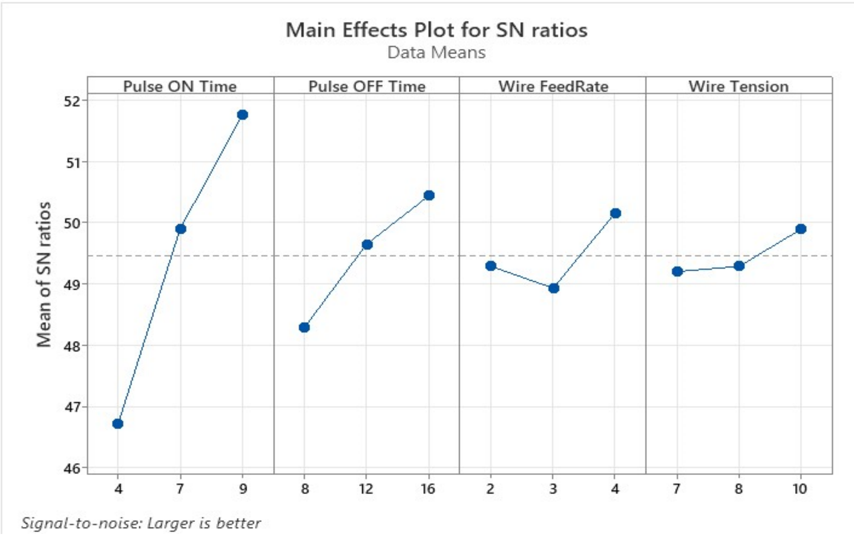

Figure 6: Main effects plot for SN ratios

5. CONCLUSIONS

In the present work the machining of STAINLESS STEEL 316 was performed in a wire EDM machining process using brass wire electrode. The conclusions drawn from the present work are as follows:

a. The influence of various input process parameters, pulse on time, pulse off time, wire tension, wire feed rate on the response characteristics, MRR, Time Output, Feed rate was investigated by using Taguchi L9 orthogonal array.

b. Wire tension has been the leading significant factor for MRR, Surface roughness and time taken for machining since the difference between the result values for all the three levels was quite, higher than the other machining parameters. Larger variation leads to delta value which defines the gap between largest and smallest response value of each parameter.

c. ANOVA results of MRR show that percentage contribution of Pulse on time is 82.31%, pulse off time is 13.3%, wire federate is 3.36% and wire tension is 1.04%.

d. Percentage contribution of process parameters for surface roughness are Wire federate is 58.22%, pulse off time is 16.41%, pulse on time is 13.8% and wire tension is 11.57%.

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