OPTIMIZATION OF WIRE CUT EDM PROCESS PARAMETERS IN SURFACE ROUGHNESS AND MACHINING TIME BY TAGUCHI METHOD

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ABSTRACT

Wire-cut Electric Discharge Machining (WEDM) is an efficient machining process in numerous applications like spacecraft, defense, transportation vehicles, micro systems, farm machinery. It is used to machine conductive and hard materials like metal matrix composites, ceramic composites and super alloys. En24 steel is a high quality engineering alloy steel containing chromium and molybdenum. It falls in a class of low alloy steel. It has high fatigue strength, abrasion and impact resistance, toughness, and torsional strength. It can be heat treated in a number of ways to give it a combination of properties. In this project, the optimization of WEDM machining parameters has done with different techniques like Taguchi Method, ANOVA. These techniques utilized for examination of impact of wire-cut EDM process parameters on Surface roughness (Ra) and Machining time on EN24 alloy. Parameters like pulse off time, pulse on time, Feed, are utilized to optimize the surface roughness (Ra) and Machining time. Taguchi's L09 orthogonal array selected for the experimentation. ANOVA utilized for advancing parameters with the goal that least surface roughness and less Machining time is acquired.

Keyword: - *Wire EDM, Surface Roughness, Machining Time, Taguchi, ANOVA.*

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1. INTRODUCTION

Manufacturers often turn to electrical discharge machining (EDM) whenever traditional machining methods reach their limit. The EDM process involves using thermal energy to remove excess material from an object, creating the required shape for a task. It is not the most popular CNC machining process available. However, engineers rely on it to create parts that are impossible to machine. EDM is similar to processes such as laser cutting. It does not require or use mechanical force to remove the excess material. This is why many people consider it to be a non-traditional manufacturing process. This process helps in molding and tooling for a wide range of industries. You may have come across terms such as spark machining, die sinking, wire erosion, or spark eroding. Some engineers and manufacturers use these terms to refer to electrical discharge machining (EDM). But what is EDM? To simply put, EDM involves removing excess material from a workpiece with the use of thermal energy. As mentioned earlier, the EDM process does not require mechanical force. This fabrication process ensures that engineers arrive at desired shapes only with the use of electrical discharges. It is a highly precise process that does not involve using a tool on the workpiece. When you need to work on hard materials like titanium or form complex shapes, EDM is often the way to go.

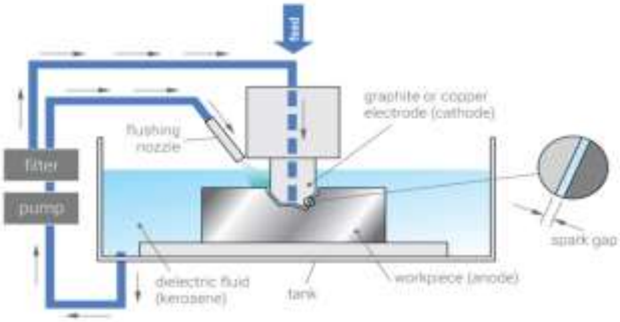

Figure1.1: Electrical Discharge Machining

1.1 Types of Electrical Discharge Machining

The EDM process is unique and conventional. However, this does not mean that there is only one approach to this process. There are three different types of EDM. This helps to assure that there are alternative methods if one type does not fit adequately. The different types of electrical discharge machining include: While there are many specialized forms of electrical discharge machining, industrial EDM machines are commonly grouped into three categories:

- Wire EDM
- Hole EDM
- Die EDM

Wire EDM

Sometimes referred to as wire erosion or spark EDM, wire EDM is a popular process. It involves the use of a brass wire or thin copper to cut the workpiece. Here, the thin wire acts as the electrode. The dielectric liquid, in this case, is usually deionized water. During the wire EDM, there is the continuous unfurling of the wire from an automated feed using a spool.

Hole EDM

The hole drilling EDM process is another type of electrical discharge machining. As the name implies, it helps explicitly in fast hole drilling. The electrodes for hole EDM are tubular, enabling the dielectric fluid to flow through the electrodes easily. Unlike the traditional drilling methods, hole EDM can machine very tiny and deep holes. Furthermore, these holes do not require any deburring. Regardless of the metal hardness or type, this process enables effective drilling of precision holes faster than the conventional methods.

Sinker EDM

This is the conventional EDM, also referred to as Ram EDM, die sinking, or cavity-type EDM. Cavity type because it creates complex cavity shapes for various casting applications such as plastic injection molding. This process uses pre-machined copper or graphite electrodes to form a “positive” of the required shape. Then, there is the pressing of the electrode into the workpiece to create a negative of the original material shape. Some factors may influence the choice of electrode material in sinker EDM. These include the electrode’s resistance to erosion and its conductivity, which is usually easier to machine graphite than copper. However, copper is stronger and more conducive.

1.2 Working of Wire-Cut EDM

EDM cutting is always through the entire workpiece. To start wire machining it is first necessary to drill a hole in the workpiece or start from the edge. On the machining area, each discharge creates a crater in the workpiece and an impact on the tool. The wire can be inclined, thus making it possible to make parts with taper or with different profiles at the top and bottom. There is never any mechanical contact between the electrode and workpiece (see above). The wire is usually made of brass or stratified copper, and is between 0.1 and 0.3 mm diameter. Depending on the accuracy and surface finish needed, a part will either be one cut or it will be roughed and skimmed. On a one cut the wire ideally passes through a solid part and drops a slug or scrap piece when it is done. This will give adequate accuracy for some jobs, but most of the time, skimming is necessary.

Roughing & Skim Cuts

A skim cut is where the wire is passed back over the roughed surface again with a lower power setting and low pressure flush. There can be from one to nine skim passes depending on the accuracy and surface finish required. Usually there are just two skim passes. A skim pass can remove as much as 0.002″ of material or a as little as 0.0001″. During roughing (i.e. the first cut) the water is forced into the cut at high pressure in order to provide plenty of cooling and eliminate eroded particles as fast as possible. During skimming (accuracy / finish cuts) the water is gently flowed over the burn so as not to deflect the wire. The wire EDM machine, also known as a “cheese cutter,” offers several unique advantages, making it a popular choice for manufacturers across a range of different industries. A wire EDM machine is a type of CNC machine that can move along four independent axes to generate taper cuts. For example, a stamping die can be machined with 1/4 degree taper or a mold with one degree taper in some areas and two degrees in another with precision. Extrusion dies or nozzles and horns can be cut with constantly changing tapers. For example, a detailed shape on the top of the work piece can transition to a simple circle on the bottom.

2. METHODOLOGY

In this work, Taguchi robust design methodology is used to obtain the optimum conditions of the experimental data. Statistical software Minitab 15.0 is used to obtain results for Analysis of Mean (ANOM) and Analysis of Variance (ANOVA). The confirmation test is conducted for optimum conditions to validate the results. The knowledge of scientific phenomenon and past experience with similar product designs and manufacturing processes form the basis of the engineering design activity.

Taguchi’s robust design:

The scientific approach to quality improvement is becoming more widespread in industrial practice. Designing high quality products and processes at low cost is an economical and technical challenge to the engineer. A systematic and efficient way to meet this challenge is a method of design optimization for performance, quality and cost called robust design.

Robust design methodology:

Robust design is an engineering methodology for improving productivity during design and development so that high quality products can be produced at low cost. The main idea of robust design method is to choose the levels of design factors to make product or process performance intensive to uncontrollable variations such as manufacturing variations, deterioration and environmental variations. Dr. Genichi Taguchi has popularized the robust design method which employs experimental design techniques to help in identify the improved factor levels. Experimental design techniques are extremely effective for improving quality in problems that involve in a large number of factors. Taguchi’s approach has been successfully applied by engineers in many leading Japanese and American companies for improving performance and competitiveness of their key products.
There are three important types of S/N ratios available depending on the type of characteristic.

- Smaller the better
- Larger the better
- Nominal the best

Smaller-the-better type:

Here the quality characteristic is continuous and non-negative that is it can take any value from 0 to ∞. Its most desired value is zero. Example of this type is the surface defect count, pollution from a power plant, electromagnetic radiation from telecommunication systems and corrosion of metals etc.

Larger-the-better type:

Here the quality characteristic is continuous and non-negative. The ideal value would like to be as large as possible. It does not have any adjustment factor. Example of this type is the mechanical strength of a wire per unit cross-section areas, the miles driven per gallon of fuel for an automobile carrying a certain amount of load. This problem can be transformed into smaller the better type problem by considering the reciprocal of the quality characteristic.

Nominal-the-best type:

In this type the quality characteristic is continuous and non-negative and it can take any value from 0 to ∞, but its target value is nonzero and finite. For this type of problems when the mean becomes zero the variances also become zero. This type of problems occurs frequently in engineering designs. Example for this type is to achieve target thickness of paint on the surface.

3. EXPERIMENTAL DESIGN AND SETUP

The process parameter and their ranges are finalized using literature and machine operator's experience. The four control factors are Pulse on Time (A), Pulse of Time (B), feed rate (C), current (D) and their corresponding levels have been selected. EN24 material is used in experimentation as a work-piece. The control factors and their levels are listed in Table 3.1.

Table 3.1: Control factors and levels

Factors/ Levels	Pulse on Time – T_{on} (μs) (A)	Pulse off Time – T_{off} (μs) (B)	Feed Rate (mm/min) (C)	Electrical Current (Amp) (D)
1	35	4	70	1
2	40	7	80	2
3	45	10	90	3

Table 3.2: Experimental design

Exp. No.	Column			
	A	B	C	D
1	35	4	70	1
2	35	7	80	2
3	35	10	90	3
4	40	4	80	3
5	40	7	90	1
6	40	10	70	2
7	45	4	90	2
8	45	7	70	3
9	45	10	80	1

Table 3.3: Experimental results to Surface Roughness and S/N ratio

S. No.	Trial		Mean	S/N ratio
	1 (μm)	2 (μm)	(μm)	
1	2.8	2.54	2.67	-8.5405
2	6.12	5.92	6.02	-15.5931
3	4.72	4.52	4.62	-13.2949
4	5.94	6.02	5.98	-15.5342
5	5.43	5.53	5.48	-14.7760
6	6.02	5.94	5.98	-15.5342
7	5.94	6.02	5.98	-15.5342
8	5.98	6.2	6.09	-15.6938
9	5.64	5.58	5.61	-14.9794

3.1. Analysis of Variance for Surface Roughness:

- Sum of squares of deviation from target for factor SS($_{Ton}$): 8.0470

The same above procedure has been used to calculate the sum of squares due to factors Toff, Feed and Discharge current

- Sum of squares of deviation from target for factor "Toff": (SS_{Toff}) = 2.9250

- Sum of squares of deviation from target for factor “Feed rate”: (SS_{fdr}) = 2.7496
- Sum of squares of deviation from target for factor “Discharge current”: (SS_{Elc}) = 6.2350
- The sum of squares due to error: SS_e is 0.1144

The mean sum of squares:

The mean sum of squares is calculated by dividing the sum of squares by the degree of freedom. In general, degree of freedom of a factor is number of levels minus one i.e.

$$M_{SSTon} = SS_{Ton} \div D_{FTon} = 4.02349$$

Similarly the mean sums of squares of the remaining factors are calculated. These areT_{off}, Feed and Discharge current

- The mean sum of squares for factor “Toff”: (M_{SSToff}) = 1.46249
- The mean sum of squares for factor “Feed”: (M_{SSFeed}) = 1.37482
- The mean sum of squares for factor “Discharge current”: ($M_{SS\ Elc}$) = 3.11749
- The mean sum of squares for error, “Error”: (MSS_{er}) = 0.01271

The F-ratio (data):

The F-ratio is calculated by dividing the mean sum of squares by the error sum of squares.

$$F_{Ton} = (MSS_{\ Ton} \div MSS_{er}) = 316.56$$

Similarly the F-ratio is calculated for remaining factors T_{off}, Feed and Discharge current

$$F_{Toff} = 115.06, \quad F_{\ Feed} = 108.16, \quad F_{Elc} = 245.26$$

The F-ratio (table):

The F-ratio from the Table for combination of F (0.05, 2, 9) is extracted is 4.26

The F-ratio test:

Compare the values of F-ratio tabulated with calculated F- ratio. If Calculated F- Ratio is greater than the tabulated, this concludes that, the selected factors and interactions are significant for the process.

Table 3.4: Basic Analysis of Variance of Surface roughness

Factor	S.S	D.O.F	M.S.S	F-ratio (data)	F-ratio (Table)	Result
T_{on}	8.0470	2	4.0234	316.53	4.26	Significant
T_{off}	2.9250	2	1.4624	115.06	4.26	Significant
Feed	2.7496	2	1.3748	108.16	4.26	Significant
Discharge current	6.2350	2	3.1174	245.26	4.26	Significant
Error	0.1144	9	0.0127			
S_t	20.0710	17				

3.1.1. Optimization of cutting parameters for surface roughness:

Taguchi’s robust design methodology has been successfully implemented to identify the optimum parameters from selected process parameter and their levels in order to reduce the surface roughness for improved performance. After analysis of data from the robust design experiments the optimum process parameters found. These optimum process parameters are validated by conducting confirmation test, which concluded that the results are within the acceptable limits of the predicted value and can be implemented in the real time application.

Table 3.5: Optimum Parameters for roughness

Pulse on time (Ton)	35 (µs)
Pulse off time (Toff)	4 (µs)
Feed rate	70 (mm/rev)
Discharge current	1 (AMP)

3.1.2. Factor response plot for performance characteristics:

The level of parameter with the highest S/N ratio is the optimal level. The individual factors effect on surface roughness found to be significant, Pulse on time (Ton) has major contribution (40.27%) followed by Discharge current (31.20%), Pulse off time (14.63%), feed rate (13.76%). After selecting the optimal level of process parameters, the final step is to predict the performance characteristics and confirmation test has conducted using optimal condition. It is found that S/N ratio of predicted and confirmation test is within 95% confidence level and objective is fulfilled. Hence these suggested optimum conditions can be adopted.

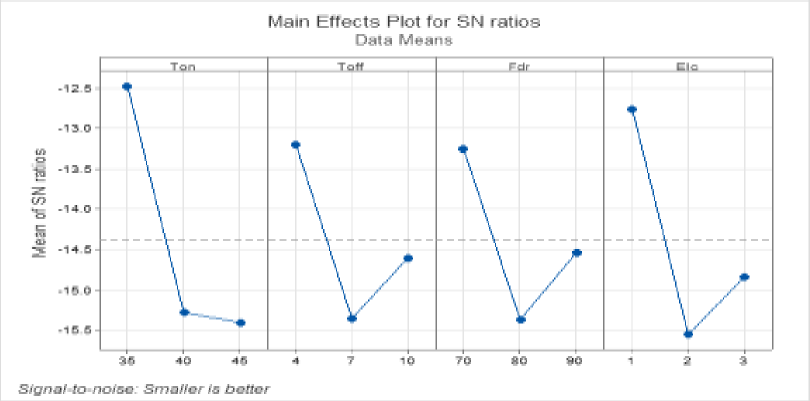

Figure 3.1: Main effect plots for Surface Roughness

3.2. Optimization of cutting parameters for Machining time

Table 3.6: Experimental results of Machining time and S/N ratio

S. No.	Trial 1 (min)	Trial 2 (min)	Mean (min)	S/N ratio
1	17	19	18	-25.1188
2	39	39	39	-31.8213
3	30	32	31	-29.8318
4	26	26	26	-28.2995
5	32	30	31	-29.8318
6	20	18	19	-25.5871
7	18	20	19	-25.5871
8	20	20	20	-26.0206
9	33	35	34	-30.6333

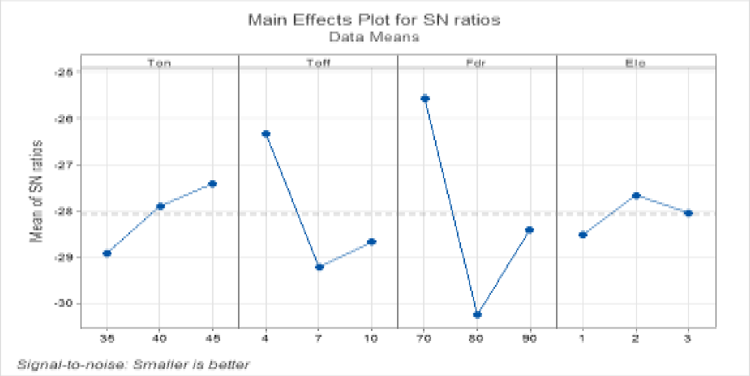

Figure 3.2: Main effect plots for Machining time

Those are Ton is high at 3rd level, S/N ratio is high at 1st level of Toff, 1st level of feedrate and 2nd level of discharge current. So, these levels are considered for optimum condition. The individual factors effect on machining time found to be significant, feedrate has major contribution (61.49%) followed by pulse off time (27.83%), Pulse on time (8.72%), Discharge current (1.66%).

4. CONCLUSIONS

Based on the results of the present experimental investigations, the following conclusions are drawn:

- The less surface roughness is observed at less pulse on time condition. Pulse on time shows favorable results compared to other process parameters.
- High surface roughness is observed in high pulse on time condition followed by moderate pulse on time condition.
- The optimum conditions obtained for surface roughness are Pulse on time at level 1 (35µs), Pulse off time at level 1 (4µs), Feed rate at level 1 (70 mm/min) and Discharge current at level 1 (1 A)
- From ANOVA, the individual factors effect on surface roughness found to be significant, Pulse on time (Ton) has major contribution (40.27%) followed by Discharge current (31.20%), Pulse off time (14.63%), feed rate (13.76%).
- In the Machining time consideration: It is observed that high signal to noise ratio is obtained at high pulse on time condition (i.e 45 µs), less pulse off time condition (i.e 4 µs), low feed rate (i.e 70 mm/min), less discharge current (i.e 1 Amp).
- The individual factors effect on machining time found to be significant, federate has major contribution (61.49%) followed by pulse off time (27.83%), Pulse on time (8.72%), Discharge current (1.66%).

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