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Application of Taguchi Method to Analysis the Influence of Cutting Mode on Surface Roughness When Electrical Discharge Machining

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Abstract— *The electrical discharge machining method, also known as electric spark machining, or spark eroding, is utilized on electric discharge and wire-cutting machines. Electrical discharge machining (EDM) is a powerful, nonconventional machining technique with the ability to machine any conductive material regardless of mechanical property [1]. The electric discharge machining method is often applied in mold manufacturing when complex details are difficult to process with other CNC machining machines [2]. When mass manufacturing occurs in industrial plants, the slowness of EDM is evident. Poor surface quality, residual stress, and heat-affected zone are among other disadvantages of this technique [1]. To improve the quality of the machined surface, we have analyzed the influence of cutting mode on surface roughness when using electric spark pulse machining. This helps in, thereby choosing the appropriate machining mode. To study the influence of cutting mode on the surface roughness of pulsed products, an experimental model according to Taguchi L9 is presented in the article. ANOVA analysis results show that the pulse process between some materials has significant differences. The solution for the smallest surface roughness of C45 steel corresponds to the pulse cycle (TON) = 5 µs, machining current (LV) = 5 A, and electrical pulse duration (WT) = 5 s. The solution for the smallest surface roughness of CT3 steel corresponds to the electric pulse cycle (TON) = 5 µs, machining current (LV) = 16 A, electric pulse time (WT) = 5 s. The plan for the surface roughness of SKD11 steel corresponds to the electric pulse cycle (TON) = 5 µs, machining current (LV) = 5 A, and electric pulse time (WT) = 1s.*

Keywords— *ANOVA, Taguchi L9, surface roughness, electric spark discharge machining.*

I. INTRODUCTION

Electrical Discharge Machining (EDM) is known as spark erosion machining uses electrical discharges to erode electrically conductive material and does not touch directly between the electrode and workpiece [4]. EDM is utilized in production for hard material pieces that are very challenging to manufacture using traditional machining techniques. The components of an EDM system are a workpiece and a shaped tool that are submerged in a dielectric fluid and connected to a power source. Sparks are produced across the space between the electrode and workpiece by applying voltage and current pulses using an EDM pulse power generator [5].

In businesses and mechanical workshops, electric spark machining is widely used. Electric spark machining accounts for about 40% to 60% of the entire process. This processing method has the highlight of using modern machinery and technology to create products with high precision[6]. The quality of machine parts is evaluated based on several criteria, and the surface quality of the part is a crucial factor that researchers focus on. When pulse shaping machining is used, the surface quality of details must meet specific requirements. Although the surface parts may look shiny and smooth to the naked eye after machining, in reality, there are bumps that need to be considered. Roughness usually refers to the level of surface roughness of a machined product and is a measure of the irregularities presented on the surface.

The surface quality of the part is evaluated by many factors. These consist of residual stresses, microhardness, surface roughness, and subsurface microstructure and composition [7]. Surface roughness (Ra) is one of the most important indicators used to evaluate the surface quality of parts. Surface roughness is typically a technical prerequisite for mechanical items in the industries. Practically, for the machine parts, surface roughness plays an important role in fatigue strength, wear resistance, tensile, and ductility [8].

While the surface texture when processed by EDM is completely different from traditional machining methods. On the surface of the detail processed by EDM, there are many spherical convexities and concavities. They are called "volcanic peaks" and "craters". They replace the peak and bottom lines of the surface profile processed by traditional methods. Between the convexities and craters is a transitional flat area, while the surface processed by traditional methods only shows regular cutting marks [9]. In EDM, surface roughness is the most measured performance compared to other performances such as tool wear and material removal rate. Surface roughness value is generally influenced by many factors such as machining parameters, workpiece properties, cutting phenomena, and type of cutting tools. The value of surface roughness is controlled by spark frequency during the machining process, which is the number of discharges per second. The higher energy applied leads to the higher amount of material removed which can also cause a rougher surface finish [8].

Therefore, determining the optimal set of parameters for the pulse shaping process to achieve the best surface roughness is extremely necessary. This study aims to analyze the pulse width to surface roughness of three types of materials: C45 steel, CT3 steel, and SKD11 steel when machining on the CM 323C machine, thereby choosing a suitable machining mode for each mentioned material.

The goal of the Taguchi approach is to minimize process variation by using a strong experimental design. The method's overarching goal is to generate high-quality goods at a minimal cost to the producer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. In order to study how various factors affect the mean and variation of a process performance characteristic—a measure of how well a process is operating—Taguchi created a method for designing experiments. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should vary. The Taguchi approach tests pairs of possibilities as opposed to needing to test every possible combination, as in the case of the factorial design. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, this saving time and resources [10].

Therefore, this method allows the use of a minimum of necessary experiments to study the influence of parameters on a certain selected response of a process (or product) and thereby quickly adjust parameters to reach optimization fastest [3]. To determine the optimal cutting parameters when machining materials, several output factors of interest such as surface roughness are measured repeatedly to ensure accurate reflection and determine the influence of technological factors on the output of interest.

II. EXPERIMENTAL EQUIPMENT FOR ELECTRIC SPARK PULSE PROCESS

The process of electric spark pulse machining with copper electrodes is carried out on the CM 323C electric pulse machine (Taiwan), (Fig. 1).

The experiments were conducted with three processing materials: C45 steel, CT3 steel, SKD11 steel, test sample size LxWxH= 140x75x14 (Fig. 2), and oil dielectric solution D323.

The SJ-400 device measures the roughness of the surface details (Fig. 4).

Fig. 1. Image of experimental equipment and copper electrode for electric spark pulse machining

Fig. 2. Image of the workpiece

Fig. 3. Detailed images of machining on electric spark pulse machine

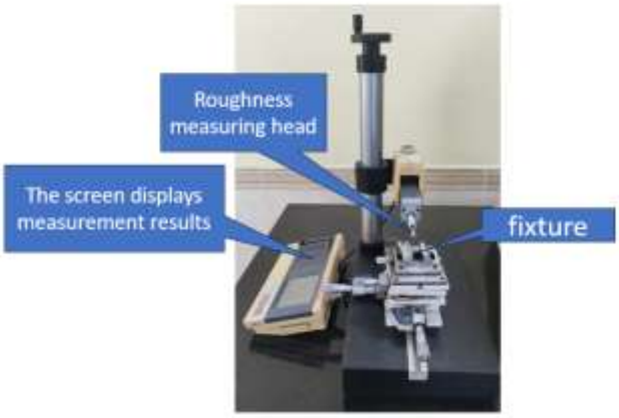

Fig. 4. Image of surface roughness measuring device

III. BUILDING AN EXPERIMENTAL CALCULATION PROCESS FOR THE ELECTRIC SPARK PULSE PROCESS

During the research, it was discovered that the anode corrodes due to electrons bombarding it from the cathode. It is worth noting that regardless of the cathode's shape, the anode corrodes in the same way. Based on this, in electric spark pulse machining, we use the cathode as a correctly shaped pole, the anode is connected to the workpiece and when the discharge process occurs, the workpiece will be corroded accordingly preformed shape [2]. This article

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considers the electrical pulse cycle (TON), machining current (LV), and electrical pulse time (WT) as the factors for the above process.

TABLE I. Experimental parameters for electric spark pulse machining

Level	TON electrical pulse cycle (μs)	LV machining current (A)	WT electrical pulse duration (s)
1	5	5	1
2	12	10	3
3	19	16	5

Use the Taguchi method to select the optimal solution based on analysis of variance (ANOVA) and noise ratio (S/N ratio). The influence of factors on output parameters is evaluated through the S/N ratio. This index is determined by the formula [3]:

$$(S/N)_i = 10\log\left[\frac{\bar{y_i}^2}{s_i^2}\right] \quad (1)$$

In which: $\bar{y_i} = \frac{1}{N}\sum_{u=1}^{N_i} y_{i,u}$ is the signal $s_i^2 = \frac{1}{1-N}\sum_{u=1}^{N_i}(y_{i,u} - \bar{y_i})^2$ is the noise, i is the experimental sequence number, u is the sequence number, $N_i$is the measurement number. The value of the S/N ratio is large (large signal, small noise) when this output parameter is close to the optimal value. In the minimal problem (the smaller the better), formula (1) is expressed as follows [3]:

$$(S/N)_i = -10\log\left[\sum_{u=1}^{N_i} \frac{{y_u}^2}{N_i}\right] \quad (2)$$

In this study, the experimental design was established according to the Taguchi L9 (3^3)method, as presented in TABLE II.

TABLE II. Experimental design according to Taguchi L9 (3^3) method

S. No.	Combination of factors and levels		
	TON Electrical pulse cycle	LV Machining current	WT Electrical pulse time
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

IV. RESULTS OF ANALYSIS OF THE INFLUENCE OF PARAMETERS ON SURFACE ROUGHNESS WHEN ELECTRIC SPARK IMPLUSE MACHINING

The results of experiments using Taguchi L9 (3^3) are presented in TABLE III. The experiments aimed to determine the surface roughness of C45 steel, CT3 steel, and SKD11 steel during electric spark pulse machining. Fig. 5 compares the surface roughness obtained under different machining conditions for each of the three materials. The findings reveal that the roughness parameters vary depending on the cutting conditions for each material during pulse machining.

The results of ANOVA analysis on surface roughness from the experimental results of pulse machining on C45 steel are shown in Fig. 6. The analysis suggests that the electric pulse cycle provides the largest S/N ratio (-7.969). at level 1, followed by the machining current with the largest S/N ratio (-4.888) at level 1, and finally, the pulse time provides the largest S/N ratio (-8.822) at level 3. ANOVA analysis was utilized to find the solution to achieve the smallest surface roughness, corresponding to case 113 (electric pulse cycle (TON) = 5 µs, machining current (LV) = 5 A, electric pulse duration (WT) = 5 s).

TABLE III. Surface roughness measurement results under different technological conditions of three materials during electric spark pulse machining

S. No.	Change code			Surface roughness		
	TON	LV	WT	C45 Steel	CT3 Steel	SKD11 Steel
1	1	1	1	1,980	0,852	3,493
2	1	2	2	3,182	1,901	2,357
3	1	3	3	2,179	2,680	2,660
4	2	1	2	2,041	2,428	3,766
5	2	2	3	3,147	4,110	3,627
6	2	3	1	3,822	3,921	3,905
7	3	1	3	1,809	1,620	1,625
8	3	2	1	2,609	2,300	2,522
9	3	3	2	6,596	7,072	5,041

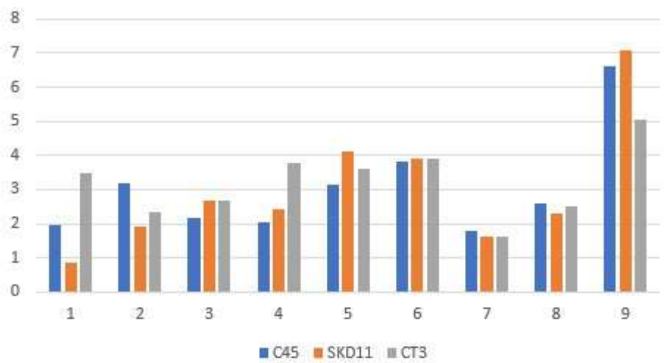
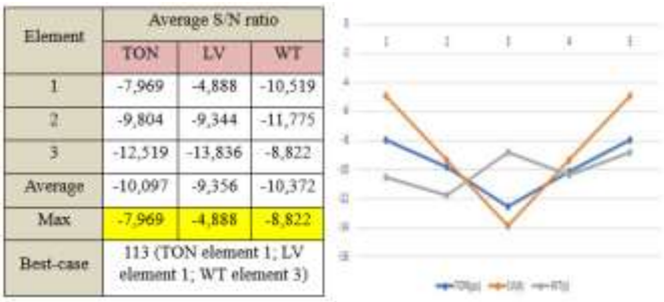


Fig. 5. Comparison chart of surface roughness of three types of materials during electric spark pulse machining



Element	Average S/N ratio		
	TON	LV	WT
1	-7,969	-4,888	-10,519
2	-9,804	-9,344	-11,775
3	-12,519	-13,836	-8,822
Average	-10,097	-9,356	-10,372
Max	-7,969	-4,888	-8,822
Best-case	113 (TON element 1; LV element 1; WT element 3)		

Fig. 6. Results of ANOVA analysis of roughness on C45 steel

The ANOVA analysis was carried out on the surface roughness of CT3 steel, obtained from the experimental results of pulse machining. Fig. 7 shows that the electric pulse cycle provides the largest S/N ratio (-4.528). and corresponds to level 1Following this is the machining current with the largest S/N ratio (-3.401) corresponding to level 3, and lastly the pulse time provides the largest S/N ratio (-4.212) corresponding to level 3 as well. ANOVA analysis was used for the above material to find a solution for the smallest surface roughness corresponding to case 133 (electric pulse cycle (TON) = 5 µs, machining current (LV) = 16 A, electric pulse duration (WT) = 5 s) during electric spark pulse machining.

Element	Average S/N ratio		
	TON	LV	WT
1	-4,528	-4,715	-5,194
2	-5,759	-4,526	-5,707
3	-4,861	-3,401	-4,212
Average	-5,049	-4,214	-5,038
Max	-4,528	-3,401	-4,212
Best-case	133 (TON element 1; LV element 3; WT element 3)		

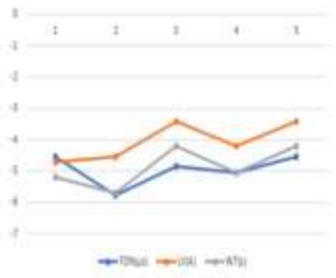


Fig. 7. Results of ANOVA analysis of roughness on CT3 steel

Element	Average S/N ratio		
	TON	LV	WT
1	-2,579	-2,131	-3,725
2	-5,424	-4,425	-5,798
3	-5,639	-6,587	-4,477
Average	-4,547	-4,381	-4,667
Max	-2,579	-2,131	-3,725
Best-case	111 (TON element 1; LV element 1; WT element 1)		

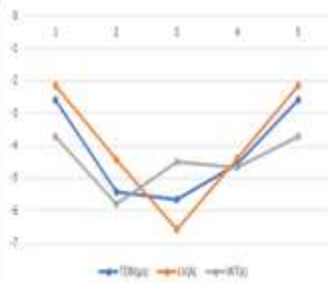


Fig. 8. Results of ANOVA analysis of roughness on SKD11 steel

According to the results of ANOVA analysis, which is used to analyze surface roughness in pulse machining on SKD11 steel. As Fig. 8, the largest S/N ratio (-2.579) was observed for the electric pulse cycle at level 1. This was followed by the machining current with the largest S/N ratio (-2.131) also at level 1, and finally, the pulse time provides the largest S/N ratio (-3.725) corresponding to level 1. This ANOVA analysis was conducted to find the solution for the smallest surface roughness while electric pulse machining, and it was found to correspond to case 111 (electric pulse cycle (TON) = 5 µs, machining current (LV) = 5 A, electric pulse duration (WT) = 1 s).

V. CONCLUSION

By analyzing the S/N noise ratio, we can conclude the influence of each parameter on machining roughness. From there, it helps to quickly identify the best machining technology parameters for producing high-quality parts. At the same time, we also individually evaluate the effects of optimal technological parameters on the quality of parts after machining.

From the results of the analysis of variance (ANOVA), conclusions were drawn about the influence of input parameters on the surface roughness of three types of materials during electric spark pulse machining as follows:

ANOVA analysis results on surface roughness of C45 steel from experimental results of electric pulse machining show that the optimal set of parameters with electric pulse cycle (TON) = 5 µs, machining current (LV) = 5A, time Electrical pulse duration (WT) = 5 s. Meanwhile, the ANOVA analysis results on the surface roughness of CT3 steel from the experimental results of electric pulse machining show that the optimal set of parameters with electric pulse cycle (TON) = 5 µs, machining current (LV) = 16 A, electrical pulse duration (WT) = 5 s. Finally, the ANOVA analysis results on the surface roughness of SKD11 steel from the experimental results of electric pulse machining show that the optimal set of parameters is with electric pulse cycle (TON) = 5 µs, machining current (LV) = 5A., electric pulse duration (WT) = 1s.

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