**A Study on the Machining Parameters Optimization of Electrical Discharge Machining to Improve Material Removal Rate and Surface Roughness for Al-Cu**

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**الخلاصة**

الهدف من هده الورقة هو إيجاد الظروف المثلى لمتغيرات التشغيل بالشرر الكهربي (EDM), معدن التشغيل كان سبيكة الالومينيوم نحاس والنحاس النقي كان أداة تشغيل ومن خلال التجارب التي تمت على آلة ROBOFORM 2-LC وباستخدام طريقة (Taguchi) لتصميم عدد التجارب ولتحليل تأثير كل متغير على خصائص التشغيل ولتوقع الخيار الأمثل لكل المتغيرات مثل قطبية الشغلة، مدة تفريغ الشحنة، كثافة التيار, كفاءة الأداء. وفي تحليل التباين (ANOVA) باستخدام اختبار F للتحقق من أي متغيرات التشغيل المؤثرة على خصائص الأداء وإيجاد النسبة المئوية لكل هذه المتغيرات على معدل إزالة المعدن MRR وعلى نعومة السطح Ra. عموما وجد أن كثافة التيار تؤثر بشكل ملحوظ على معدل إزالة المعدن MRR وعلى نعومة السطح Ra.

**ABSTRACT**

The objective of this research is to determine the optimal setting of the process parameters on the electro-discharge machining (EDM), The aluminum copper cast alloy were used as a workpiece and pure copper were used as the electrode. The experiments were done on an FORM 2-LC machine by using Taguchi methodology. The Taguchi method is used to formulate the experimental layout and analyze the effect of each parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter such as polarity, Pulse-on time, discharge currant and duty factor. Analysis of variance (ANOVA) used F-test to investigate which process parameters significantly affect the performance characteristics, and the percent contribution of these parameters on material removal rate (MRR) and surface roughness (Ra). In general, it is found that the discharge currant significantly affects the MRR and Ra.

***Key words****: Electrical discharge machining (EDM), Taguchi method, Material Removal Rate (MRR), Surface Roughness (Ra)*

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1. **Introduction**

Electrical Discharge Machining (EDM) is defined as the non-traditional process of material removal of electrically conductive materials to produce the part with intricate shapes and profiles. This process is done by applying high-frequency pulsed, AC, or DC current to the workpiece through an electrode or wire, which melts and vaporizes the workpiece material. Positioned very precisely near the workpiece, the electrode never touches the workpiece but discharges its potential current through an insulating dielectric fluid (distill water or oil) across a very small spark gap. The spark is reported to be in the range of 8000 to 12000°C, and it vaporizes and melts the workpiece material. This process is used when the workpiece material is too hard, or the shape or location of the detail cannot easily be conventionally machined. This makes many formerly difficult projects more practical and many times it can be the only feasible way to machine a part or material [1].

To get the perfect result of the machining process by using the EDM it is needed to find the correct parameter setting. Until now, there is no perfect parameter setting for any type of materials. So, it is important to find the best parameter setting before start the machining process in order to achieve the maximum result in its material removal rate (MRR) and surface roughness (Ra).

In this work, Aluminum Copper cast Alloys (Al-Cu) 201.0 has been used as the workpiece material. There is many process will be studied to optimize the machining of Al-Cu cast Alloys 201.0 by using EDM machine. The main focused in this work is to optimize the maximum material removal rate and minimum surface roughness.

The first factor is intensity (I) it represents the maximum value of the discharge current intensity. The intensity values used in the EDM machine programming are power levels of the generator, these corresponding with values of the peak intensity. The second factor is ON time which is defined as the sparks occur time generated during a pulse which to perform the machining process. The third factor is OFF time and defined as the interval time between spark in a single pulse. The fourth factor is polarity of the workpiece.

1. **Experimental work**

***A Experimental Planning (Taguchi Method)***

Taguchi method uses special design of orthogonal array to study the entire parameters space with only a small number of experiments. In selecting an appropriate OA, the prerequisites are (i) selection of process parameters and interactions to be evaluated (ii) selection of number of levels for the selected parameters, and (iii) evaluation of total degree of freedom based upon number of parameters and their levels. The non-linear behavior of the process parameters, if exists, can only be revealed if more than two levels of the parameters are investigated. Therefore, parameter A was analyzed at two levels and parameter B, C & D were analyzed at three levels. Experimental parameters and their levels selected for the study are tabulated in Table Ι and all other parameters are kept constant.

**Table I** Machining parameters and their levels

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Observed values** | **Level** | | | **Control factor** | **Symbol** |
| **3** | **2** | **1** |
| **Maximum** | **Intermediate** | **Minimum** |
| 1. MRR  2. Ra | -  2400  23  0.95 | Positive  1200  12.5  0.8 | Negative  800  9  0.5 | Workpiece polarity  Pulse on time, µsec.  Discharge current, A  Duty factor | A  B  C  D |

The experimental procedure using the Taguchi approach can be explained as follows:

1. The number of factors and interactions to be considered in the experiment and the number of levels of the factors were found.
2. The appropriate orthogonal array was Selected (OA) to:-

* The required degree of freedom Design Of Experiments (DOF) from the factors and interactions was determined, the degrees of freedom of a factor are one less than the number of levels of the factor. The DOF of a particular orthogonal array is obtained by the sum of the individual DOF for each column in the array [2,3].
* The appropriate orthogonal array is the one whose DOF is equal to or more than the required DOF of the factors. The smallest array satisfying this requirement is normally chosen for efficiency.

1. With the appropriate orthogonal array chosen, and the linear graph that fits the relationships of the factors of interest was choose. The factors can then be assigned to the columns of the orthogonal array according to the linear graph.
2. The experiments and analyze the results was conducted. And a confirmation experiment was run finally by using the results obtained.Hence, the selection of the appropriate OA, assigning factors to columns and the total degrees of freedom need to be computed, describing each trial condition and deciding the order and repetitions of trial conditions. The total number of DOF needs to be determined to select an appropriate orthogonal array for the experiments. The DOF are defined as the number of comparisons that need to be made to determine which level is better, and specifically how much better it is. A two-level parameter has one degree of freedom. The present analysis does not include the interaction between process parameters, so there are two DOF due to three process variables. The selection of the OA is subject to the condition that the DOF for the orthogonal array should be greater than or at least equal to those for the process parameters. In the present study, the interaction between the machining parameters is neglected. Therefore, there are 11 DOF arising from one two-level machining parameter and three three-level machining parameters in the EDM process. Once the DOF are known, the next step is selecting an appropriate OA to fit the specific task. The DOF for the OA should be greater than or at least equal to those for the process parameters. In this study, a L18 OA was chosen because it has 11 degrees of freedom, more than the 7 degrees of freedom in the machining parameters. This array has 4 columns and 18 rows. Each machining parameter is assigned to a column and 18 machining parameter combinations are required. Therefore, only 18 experiments are needed to study the entire machining parameter space using the L18 OA. The experimental combinations of the machining parameters using this array are shown in Table ΙΙ [2,3].

**Table II** Design of experimental layout using an L18 orthogonal array.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Duty Factor**  **D** | **Discharge current**  **C** | **Pulse-on time**  **B** | **workpiece polarity**  **A** | **No.** |
| 1 | 1 | 1 | 1 | 1 |
| 2 | 2 | 1 | 1 | 2 |
| 3 | 3 | 1 | 1 | 3 |
| 1 | 1 | 2 | 1 | 4 |
| 2 | 2 | 2 | 1 | 5 |
| 3 | 3 | 2 | 1 | 6 |
| 2 | 1 | 3 | 1 | 7 |
| 3 | 2 | 3 | 1 | 8 |
| 1 | 3 | 3 | 1 | 9 |
| 3 | 1 | 1 | 2 | 10 |
| 1 | 2 | 1 | 2 | 11 |
| 2 | 3 | 1 | 2 | 12 |
| 2 | 1 | 2 | 2 | 13 |
| 3 | 2 | 2 | 2 | 14 |
| 1 | 3 | 2 | 2 | 15 |
| 3 | 1 | 3 | 2 | 16 |
| 1 | 2 | 3 | 2 | 17 |
| 2 | 3 | 3 | 2 | 18 |

**Signal-To-Noise Ratio**

Optimization of the observed values was determined by comparing the *S/N* ratio, which was also based on the Taguchi method. The higher observed values such as MRR are called ‘the higher the better’ (HB), while the lower observed values such as Ra are ‘the lower the better’ (LB). Calculating the deviation of the performance characteristic from the desired value, the *S*/*N* ratio ηij for the *i*th performance characteristic in the *j*th experiment can be expressed as:

**η**ij**=** - 10 log Lij ………………………………………………………….. **(1)**

As mentioned earlier, there are three categories of quality characteristics, i.e. the-lower-the-

better, the-higher-the-better, and the-nominal-the-better. The loss function of the higher-the-better performance characteristic can be expressed as:

HB: Lij=  …………………………………..… **(2)**

On the other hand, the-lower-the-better quality characteristics for the loss function *Lij* of the lower-the-better performance characteristic can be expressed as:

LB: Lij= ………………………….…… **(3)**

Where *L****ij*** is the loss function of the *i*th performance characteristic in the *j*th experiment, *n* the number of tests, and *y****ijk*** is the experimental value of the *i*th performance characteristic in the *j*th experiment at the *k*th test [2,3,4].

***B. Experimental Procedures And Parameters***

The experiments were carried out on a standard EDM machine; model FORM 2-LC. workpiece material used in this paper was Al-Cu cast Alloys 201.0 (specimens φ 20mm X 20mm) was used as work piece material with commercial grade kerosene as the dielectric fluid. Solid Cu electrodes (φ 20mm X 80mm) were used for the experimentation. Work piece was weighed on digital balance (accuracy 1 mg) to get the initial weight before machining. time taken to complete the operation at 30 mint and the work piece was weighed again. Taguchi design and average value of each output parameter were statistically analyzed using Minitab 15 software.

The experimental procedure using the Taguchi approach can be explained as follows:

1. The number of factors and interactions to be considered in the experiment and the number of levels of the factors were found.
2. The appropriate orthogonal array was Selected (OA) to:-
   * The required degree of freedom Design Of Experiments (DOF) from the factors and interactions was determined, the degrees of freedom of a factor are one less than the number of levels of the factor. The DOF of a particular orthogonal array is obtained by the sum of the individual DOF for each column in the array [2,3].
   * The appropriate orthogonal array is the one whose DOF is equal to or more than the required DOF of the factors. The smallest array satisfying this requirement is normally chosen for efficiency.
3. With the appropriate orthogonal array chosen, and the linear graph that fits the relationships of the factors of interest was choose. The factors can then be assigned to the columns of the orthogonal array according to the linear graph.
4. The experiments and analyze the results was conducted. And a confirmation experiment was run finally by using the results obtained.Hence, the selection of the appropriate OA, assigning factors to columns and the total degrees of freedom need to be computed, describing each trial condition and deciding the order and repetitions of trial conditions. The total number of DOF needs to be determined to select an appropriate orthogonal array for the experiments. The DOF are defined as the number of comparisons that need to be made to determine which level is better, and specifically how much better it is. A two-level parameter has one degree of freedom. The present analysis does not include the interaction between process parameters, so there are two DOF due to three process variables. The selection of the OA is subject to the condition that the DOF for the orthogonal array should be greater than or at least equal to those for the process parameters. In the present study, the interaction between the machining parameters is neglected. Therefore, there are 11 DOF arising from one two-level machining parameter and three three-level machining parameters in the EDM process. Once the DOF are known, the next step is selecting an appropriate OA to fit the specific task. The DOF for the OA should be greater than or at least equal to those for the process parameters. In this study, a L18 OA was chosen because it has 11 degrees of freedom, more than the 7 degrees of freedom in the machining parameters. This array has 4 columns and 18 rows. Each machining parameter is assigned to a column and 18 machining parameter combinations are required. Therefore, only 18 experiments are needed to study the entire machining parameter space using the L18 OA. The experimental combinations of the machining parameters using this array are shown in Table ΙΙ [2,3].
5. **Results And Discussions**

The mean effects plots of the S/N ratios for the output measures are obtained using Minitab 15 software. Plots with the steeper slope along with longer lines shows that the factor has significant impact on the output parameter.

***A. Analysis of Material Removal Rate (MRR)***

The average values of S/N ratios for MRR at different levels are plotted in figure Ι. keeping the objective as “larger is better”. In order to study the significance of the parameters in effecting the quality characteristic of interest i.e. Table ΙΙΙ. shown initial machining condition. The comparison of the *S*/*N* ratios between the initial machining parameters and the optimal machining parameters is also shown in Table Ιv. It is shown clearly that the MRR and S/N ratios are greatly improved through this study.



**Fig. Ι** Mean effect plot for S/N ratios for material removal rate (MRR)

It is clear from figure Ι that MRR is maximum at the 2nd level of parameter A, 1st level of parameter B, 3rd level of parameter C and 3rd level of parameter D. The S/N ratio analysis suggests the same levels of the parameters (A2, B1, C3and D3) as the best levels for maximum MRR.

**Table ΙΙΙ.** initial machining condition based on result of MRR

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **factors** | **Level** | **Level Description** | **MRR g**/min | **S/N Ratio** |
| A  B  C  D | 2  1  3  3 | +  800  23  0.95 | 0.2494 | -12.0620 |

**Table Ιv.** Optimummachining condition: MRR Predicted values

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **factors** | **Level** | **Level Description** | **MRR g/min** | **S/N Ratio** |
| A  B  C  D | 2  1  3  3 | +  800  23  0.95 | 0.3871 | -8.2435 |

***B. Analysis of Surface Roughness (Ra)***

The average values of S/N ratios for Ra at different levels are plotted in Figure ΙΙ keeping the objective as “smaller is better”. In order to study the significance of the parameters in affecting the quality characteristic of interest i.e. Table v. shown initial machining condition. The comparison of the *S*/*N* ratios between the initial machining parameters and the optimal machining parameters is also shown in Table vΙ. It is shown clearly that the Ra and S/N ratios are greatly improved through this study.



**Fig. Ι**Ι Mean effect plot for S/N ratios for Surface Roughness (Ra)

It is clear from figure ΙΙ that Ra is minimum at the 1st level of parameter A, 3rd level of parameter B, 1st level of parameter C and 1st level of parameter D. The S/N ratio analysis suggests the same levels of the parameters (A1, B3, C1and D1) as the best levels for maximum Ra.

**Table v.** initial machining condition based on result of Ra

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **factors** | **Level** | **Level Description** | **Ra )µm)** | **S/N Ratio** |
| A  B  C  D | 1  3  1  1 | -  2400  9  0.5 | 9 | -19.0848 |

**Table vΙ.** Optimum machining condition: Ra Predicted values

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **factors** | **Level** | **Level Description** | **Ra )µm)** | **S/N Ratio** |
| A  B  C  D | 1  3  1  1 | -  2400  9  0.5 | 8.33 | -18.4129 |

***C. Data Analysis***

In this study, all the analysis based on the taguchi method is done by Taguchi DOE software (Minitab15) to determine the main effects of the process parameters, to perform the analysis of variance (ANOVA) and to establish the optimum conditions. The main effects analysis is used to study the trend of the effects of each of the factors.

**Table vΙΙ.** Analysis of Variance for MRR

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Parameter (z)** | **DOF (FZ)** | **Sum of square(SZ)** | **Variance(VZ)** | **F-ratio(FZ)** | **F0.05; n1,n2** | **Percent**  **(PZ)** |
| A  B  C  D  Error  Total | 1  2  2  2  10  17 | 0.014959  0.007678  0.034716  0.005509  0.010625  0.073487 | 0.014959  0.003839  0.017358  0.002754  0.001062 | 14.08 \*  3.61  16.34 \*\*  2.59 | 4.96  4.10  4.10  4.10 | 20.35 %  10.44 %  47.24 %  7.49 %  14.45 %  100 |

**Table vΙΙΙ.** Analysis of Variance for Ra

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Parameter (z)** | **DOF(FZ)** | **Sum of squar(SZ)** | **Variance(VZ)** | **F-ratio (FZ)** | **F0.05; n1,n2** | **Percent**  **(PZ)** |
| A  B  C  D  Error  Total | 1  2  2  2  10  17 | 5.227  16.041  412.374  2.271  28.062  463.976 | 5.227  8.021  206.187  1.136  2.806 | 1.86  2.86  73.48 \*\*  0.40 | 4.96  4.10  4.10  4.10 | 1.12 %  3.45 %  88.87 %  0.48 %  6.01 %  100 |

**Table Ι**X. Summarization of significant parameters on the machinablity of EDM

|  |  |  |
| --- | --- | --- |
| **Ra** | **MRR** | **parameter** |
| \*\* | \*  \*\* | A  B  C  D |

**Conclusions**

From the experiments concerned with electrical discharge in oil as a dielectric, it was found that:

1. Taguchi method indicate optimal experimental from all experiments, the experimental results for the (MRR) number twelve is the best through the higher signal to noise ratio which calculate (-12.0620), and there machining parameters was [Workpiece polarity(+), Discharge current (23 A), Pulse-on time (800 µs) and Duty factor (0.95)]. And the experimental results for the (Ra) number sixteen is the best through the higher signal to noise ratio which calculate (-19.0848), and there machining parameters was [Workpiece polarity(+), Discharge current (9 A), Pulse-on time (2400 µs) and Duty factor (0.5)].
2. By using Taguchi Analysis Predicted values :

* Improve the MRR from 0.2494 g/min to 0.3871 g/min by increase 55.2% and improve the Ra from 9µm to 8.3 µm decreases by 7.7%.
* Improve signal to noise ratio (S/N) MRR from -12.0620 to -8.2435 by increase 31% and signal to noise (S/N) Ra from -19.0848 to -18.4129 by increase 3.5%.

1. Analysis of variance (ANOVA) investigate the process parameters significantly affect the performance characteristics. the most effective parameters the discharge currant of EDM mainly affects the MRR and Ra.
2. Due the experiments it was found that the surface roughness is quit rough, and to improving the quality of this surface roughness is possible by using rough and finishing machining stages.

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