Optimization of Machining Parameters for Surface-roughness and Precision in EDM Using Response Surface Method

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Abstract. The quality of the components of the machining process is determined by the value of surface roughness and dimensional precision. This study uses the Central Composite Design experimental method on the Response Surface Method. To determine the variation of experiments, three factors and three levels were used, the specimens used were mild steel with a total of 20 experimental variations in the EDM (Electrical Discharge Machining) machining process. Then the surface roughness and dimensional precision are tested. Optimization is done by the method of non-linear programming, where the first response is surface roughness and the second response is the precision of the dimensions of the length of the machining process. The results of the analysis show that the strong current influences the surface roughness and dimensional precision. While on time and off time do not really affect the surface roughness or precision dimensions. Optimization with non-linear programming techniques produces a minimum surface roughness of 3.805880 (µm) and dimensional precision of the maximum machining time is 175.2290 (minutes) with a current adjustment of 3 (Amperes), on-time 100 (µs), and off-time 20 (µs).

Keywords: surface roughness, dimensional precision, current, on time, off time response surface method, non-linear programming

1. Introduction

Types of EDM (Electrical Discharge Machining) processes that are often found in industry are Wire Cut and Shinking EDM types. This type of wire cut uses copper wire with a diameter of 0.10 mm - 0.30 mm for the cutting process[1]. Whereas the type of shinking uses electrodes that are in accordance with the mold cavity to be made. In the manufacturing industry, EDM Sinking is widely used for the manufacture of products such as dies for plastic molds which demand quality in the form of surface roughness resulting from smooth cutting and high precision [2]. In the manufacture of dies with the EDM process, feeding does not only occur on the workpiece but also occurs on the electrode, this causes the electrode wear. With the occurrence of wear on the electrode resulting in the accuracy of the resulting dimensions is reduced and tool wear that occurs configuration cannot be determined so that this will be able to enhance the resulting surface roughness.[3] These two undesirable things happen in the process of making dies so they need to be minimized[4]. The parameters of the electric current (pulse current), on-time and off-time can have an influence on surface roughness and electrode wear so that it will also affect the precision of the workpiece[5]. In the manufacture of dies with the EDM process, feeding does not only occur on the workpiece but also occurs on the electrode, this causes the electrode wear[6]. With the occurrence of wear on the electrode resulting in the accuracy of the resulting dimensions is reduced and tool wear that occurs configuration cannot be determined so that this will be able to enhance the resulting surface roughness. These two undesirable things happen in the process of making dies so they need to be minimized[1][7]. The role of dies in manufacturing processes such as deep drawing, forging, coining...
is very influential, especially on the quality of dimensional accuracy (precision) and surface smoothness of dies[4][8]. Dies in manufacturing process for the coining process[9][10], the material used must be resistant to wear, deformation, compression and cracking[11][12]. Mild steel material which has a tensile strength between 370 N / mm² - 500 N / mm² can be used for making dies and molds[10][13] because it has the properties mentioned above. To improve product quality on dies, it is required to achieve high precision and surface smoothness[14]. The parameters of the electric current (pulse current)[9], on-time and off-time can have an influence on surface roughness and electrode wear so that it will also affect the precision of the workpiece[15][16]. To achieve maximum quality of production results, an experiment was conducted with the aim of obtaining optimization of roughness and precision on workpieces produced by EDM[17] with the type of ARISTECH ZNC E.D.M. LS. 550.

The purpose of this study is to determine the effect of pulse current variations, on-time variations, and off-time variations on surface roughness and precision of EDM products so that optimal results are obtained and to determine which parameters are most influential on surface roughness and the precision of EDM products in order to obtain optimal results.

2. Methods
This experiment conducted using flow diagram shown in figure 2.

![Flow Diagram](image)

Figure 1. Flow Diagram
2.1 Tools and Materials
Material used in this experiment is steel with a tensile strength between 370 N/mm² - 500 N/mm² with dimensions of 150 mm x 150 mm x 15 mm. This experimental using EDM type ARISTECH ZNC E.D.M. LS. 550. This is the electrode design used and Surface Roughness Tester.

2.2 Research variable
Independent variables used in this experiment are pulse current, on-time and off-time. Dependent variables in this experiment are surface roughness and dimensional precision. The combination and level experimental variable shown in Table 1.

| Parameter     | Level |
|---------------|-------|
| Pulse Current | 3     |
| On-Time       | 100   |
| Off-Time      | 20    |

3. Result and Discussion
3.1 Determination of the Number of Trials
The design used in this study is CCD (Central Composite Design) with a number of factors of three and three levels for each factor. CCD was introduced as an alternative design for a $2^k$ factorial design, which is composed of:

1) Factorial design $2^k = 2^3 = 8$
2) The central point is $n_0$ ($n_0 \geq 1$), used following the default in the minitab program which is 6
3) $\alpha = \pm \sqrt{k} = \pm \sqrt{3} = \pm 1.682$

Two axial points on the axis for each variable design, then the axial point is 6. From the sum of the calculations above, the number of experiments conducted in this study was 20 times with a combination of experiments as follows.

| No. | $x_1$ | $x_2$ | $x_3$ | Current | On Time | Off Time |
|-----|-------|-------|-------|---------|---------|----------|
| 1   | -1    | -1    | -1    | 3       | 100     | 20       |
| 2   | 1     | -1    | -1    | 9       | 100     | 20       |
| 3   | -1    | 1     | -1    | 3       | 150     | 20       |
| 4   | 1     | 1     | -1    | 9       | 150     | 20       |
| 5   | -1    | -1    | 1     | 3       | 100     | 60       |
| 6   | 1     | -1    | 1     | 9       | 100     | 60       |
| 7   | -1    | 1     | 1     | 3       | 150     | 60       |
| 8   | 1     | 1     | 1     | 9       | 150     | 60       |
| 9   | $-\alpha$ | 0    | 0     | 0.95    | 125     | 40       |
| 10  | $\alpha$ | 0    | 0     | 11.05   | 125     | 40       |
| 11  | 0     | $-\alpha$ | 0    | 6       | 82.96   | 40       |

Figure 2. Electrode sketch in AutoCAD software
3.2 Optimization of Response Value

The optimization process is carried out in stages, starting from determining the minimum value of the response of surface roughness then determining the minimum value of the dimension precision response to time using Linggo software. From the calculation results it is known that the minimum value achieved for surface roughness is 3.805880 (µm), and is obtained at current settings 3 (Amperes), on-time 100 (µs), and off-time 20 (µs) [18]. While the maximum length of time achieved for a depth of 3 mm and a precision dimension of 8 mm x 8 mm is 174,9380 (minutes), and is obtained at current settings 3 (Amperes), on-time 100 (µs), and off-time 20 (µs).

3.3 Validation of Surface Roughness Response and Dimension Precision

To find out the extent of the accuracy of the minimum values for surface roughness, then the validation of the parameter values is in accordance with the results of optimization, namely the minimum parameters [19]. From the results of the optimization, the surface roughness value is 3.805880 (µm). These conditions can be achieved at currents 3 (Amperes), on-time 100 (µs), and off-time 20 (µs). The results obtained from the validation experiments conducted for surface roughness response can be seen in the following table.

| No. | Current | On Time | Off Time | Surface Roughness Results |
|-----|---------|---------|----------|---------------------------|
|     |         |         |          | 1     | 2     | 3     | Average |
| 1   | 3       | 100     | 20       | 3.94  | 3.40  | 3.52  | 3.62     |
| 2   | 3       | 100     | 20       | 3.42  | 3.51  | 3.93  | 3.62     |
| 3   | 3       | 100     | 20       | 3.42  | 3.20  | 3.71  | 3.44     |

Rata - rata 3.56

To test whether the resulting surface roughness value still matches the expected optimization value, it is necessary to do a statistical test of the data. The hypothesis for surface roughness that occurs is stated as follows:

H₀ : µ₁ = µ₀ (µ₀ = 3.805880 [µm]).
H₁ : µ₁ ≠ µ₀ (µ₀ = 3.805880 [µm]).

By conducting a t test, using MINITAB 15 software at a confidence level of 95%, the output obtained as shown in table 4 below:

| Variable | N | Mean | StDev | SE Mean | 95% CI          | T    | P    |
|----------|---|------|-------|---------|----------------|------|------|
| Ra       | 3 | 0.102| 0.102 | 0.0589  | (3.3077, 3.8145) | -4.16| 0.053|
From table 4 it is known that the predicted interval value of the response is 3.307 to 3.814. In addition, it is also seen that the value of P = 0.053 is greater than 0.05, then H0 is accepted. This means that statistically it can be said that on average the surface roughness value of the results of repeated experiments is the same as the results of the study. From the optimization results obtained, the dimension precision value for the time of machining process is 174,9380 (minutes). These conditions can be achieved at currents 3 (Amperes), on-time 100 (µs), and off-time 20 (µs).

| No. | Current | On Time | Off Time | Precision results | Duration (minute) |
|-----|---------|---------|----------|-------------------|-------------------|
| 1   | 3       | 100     | 20       | 2.94              | 8.09              |
| 2   | 3       | 100     | 20       | 2.95              | 8.09              |
| 3   | 3       | 100     | 20       | 2.99              | 8.08              |
|     |         |         |          | Average           | 2.96              |
|     |         |         |          |                   | 8.10              |
|     |         |         |          |                   | 171.33            |

To test whether the precision value of the time generated is still in accordance with the expected optimization value, it is necessary to do a statistical test of the data. The hypothesis is stated as follows:

\[ H_0 : \mu_1 = \mu_0 (\mu_0 = 175,2290 \text{ [minute]}) \]

\[ H_1 : \mu_1 \neq \mu_0 (\mu_0 = 175,2290 \text{ [minute]}) \]

By t-test, using MINITAB 15 software at 95% confident interval, the output is obtained as shown in the table 6 in the following:

| Variable | N  | Mean  | StDev  | SE Mean | 95% CI       | T    | P     |
|----------|----|-------|--------|---------|--------------|------|-------|
| Ra       | 3  | 171.333| 1.528  | 0.882   | (167.539, 175.128) | -4.09| 0.055 |

From table 6 it is known that the predicted interval value of the response is 167,539 to 175,128. In addition, it is also seen that the value of P = 0.055 is more than 0.05, then H0 is accepted. This means that statistically it can be said that on average the dimensions of the dimensions of the precision of the length of time the machining process results of repeated experiments are carried out the same as the results of the study[20].

4. Conclusion
From the results of processing and analysing research data, several conclusions can be drawn as follows.

1) The mathematical model for the response of surface roughness (\( \hat{y}_1 \)) is as follows:
\[
\hat{y}_1 = -0.77601 + 1.66789 * \text{pulse} + 0.00049 * \text{on time} + 0.00995 * \text{off time} - 0.07442 * (\text{pulse})^2
\]

2) The mathematical model for the dimension precision response to the length of time the EDM machining process (\( \hat{y}_2 \)) is as follows:
\[
\hat{y}_2 = 514.136 - 125.107 * \text{pulse} - 0.300 * \text{on time} - 0.387 * \text{off time} + 8.207 * (\text{pulse})^2
\]

3) Surface roughness and dimensional precision of the results of the EDM process depend on the parameter values used.

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