Optimization of process parameters in Electro Discharge Machining of AISI 304 stainless steel

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Abstract. Due to the profound use of AISI 304 stainless steel in household appliances optimization of process parameters in Electro Discharge Machining of AISI 304 is mostly needed for quality improvement. In this experiment AISI 304 stainless steel has been taken for machining with EDM oil dielectric. Three controllable parameters like peak current (Iₚ), pulse on time (Tₒn) and Flushing pressure (Fₚ) at three levels were taken for optimization. Material Removal Rate (MRR) was taken as response parameter and was measured for various combinations of controllable parameters. Taguchi optimization technique with L₉ orthogonal array was used to optimize the specified controllable parameters. It was found that peak current of 15Amp, pulse on time of 200ms and Flushing pressure of 9Kgf/cm² bears the optimal quality characteristics. At these levels Material Removal Rate was found to be 16.250mm³/min.

Keywords: EDM, Taguchi methodology, MRR

1. Introduction

Electric Discharge Machining is one advanced manufacturing process. It is the removal of segments of electrically conductive metals by electrical pulses between two terminals (electrode and work piece) within the dielectric. It is utilized for materials that are too hard for ordinary machining process such as Tungsten and Titanium. As there is no physical contact between the tool and the job, thus the job is not subjected to any mechanical forces during machining. Thus, thin and delicate work pieces can be machined properly. As AISI 304 steel have profound application in automobile industry and food handling equipment so it’s desired for the final product to have greater quality and machining process should have higher productivity. Therefore we are intended to optimize the material removal rate of the product in the EDM operation.

P. Malhotra and A. Kohli [1] studied the effect of various process parameters like pulse on time, current, pulse off time and flushing pressure on tool wear rate, MRR and surface finish of the H-11 steel using one variable at a time approach. S. Chandramouli et al. [2] optimized the EDM process separately for MRR, TWR and surface finish. Zhang et al. [3] tried various dielectrics at same condition and
analyzed various craters of different sizes and shapes. They discovered that liquid dielectrics possess greater removal efficiency. Wang et al. [4] made a comparative analysis between different dielectrics such as kerosene, distilled water and compound dielectric on Titanium alloy in order to evaluate MRR, SR and EWR. Guu et al. [5] took pulse current and gap voltage as process parameters and MRR, surface finish and de-lamination factor as responses. He studied characteristics of carbon fiber reinforced carbon composite machined in EDM. Thomas et al. [6] studied the effect of process parameters and developed the model for material removal rate through Response Surface Methodology while machining on EN31 tool steel. The model has been verified by experimental results and is observed adequate. M.J. Mohd et al. [7] optimized surface roughness using Response Surface Methodology. S.K. Singh and N. Kumar [8] optimized the EDM process parameter to get better surface finish on the Titanium alloys.

The objective of this paper is to machine AISI 304 steel by EDM by taking various parameters. Three process parameters viz. peak current ($I_p$), pulse on time ($T_{on}$) and flushing pressure ($F_p$) were taken at three stages. Machining took place according to L9 orthogonal array and for each run material removal rate was calculated. Then the three controllable parameters were optimized using MINITAB.

2. Material Selection and experimental procedure
In this experiment, AISI 304 stainless steel has been used as the work material and Cu electrode is used as the tool for the EDM process. Each work-piece material was of 25mm diameter and 10mm of width. Nine pieces of specified dimensioned work-pieces were prepared for the operation. The composition of AISI 304 stainless steel has given in table 1. In this experiment, paraffin based EDM oil was used.

| Table 1. Composition of AISI 304 stainless steel |
| Grade | C  | Si  | P  | S  | Mn | Cr  | Ni  | N  |
|-------|----|-----|----|----|----|-----|-----|----|
| 304   | 0.08 | 0.75 | 0.045 | 0.030 | 2.0 | 20.0 | 10.5 | 0.10 |

Before machining the initial weight of the work-piece was measured by weighting machine. The specified dimension of the stainless steel was fixed by a fixture inside the EDM tank which was filled by EDM oil. Various machining parameters were set on the machine. As the machining started the time was recorded by means of a stopwatch until the process finished. Again the final weight of the machined work-piece was measured. Finally the material removal rate (MRR) was measured using the equation 1. The controlling parameters were set according to orthogonal array design and MRR was measured for each run.

$$MRR = \frac{(W_i - W_f)}{\rho t}$$  \[1\]

Where,
- $W_i =$ Weight of the job(before machining)
- $W_f =$ Weight of the job(after machining)
- $t =$ Machining time
- $\rho =$ AISI 304 stainless steel work piece density = 8000 kg/m³
According to the orthogonal design experiments were carried out in a random order so as to avoid systematic error. Three laser parameters at three levels were taken into consideration for finding effective MRR for the machining. Levels of various laser parameters are given in table 2.

Table 2. Process parameters and their limits

| Parameter          | Unit  | Level 1 | Level 2 | Level 3 |
|--------------------|-------|---------|---------|---------|
| Peak Current (I_p) | Ampere|  5      |  10     |  15     |
| Pulse on time (T_{on}) | millisecond |  50    |  100    |  150    |
| Flushing Pressure (F_p) | Kgf/cm² |  6   |  9      |  12     |

3. Result and discussion

The orthogonal array with input parameters and responses were shown in table 3. Taguchi method uses S/N ratio which reduces variability and can be calculated as,

\[
S/N \text{ ratio} = -10 \log_{10} \sum_{i=1}^{n} \left( \frac{1}{Y_i^2} \right) / n
\]

(Larger is better)

Where, Y = Response
n = no. of runs
Table 3. S/N Ratios as calculated in the Minitab

| Obs. no. | Ip  | T_{on} | F_{p} | MRR  | S/N Ratio |
|----------|-----|--------|-------|------|-----------|
| 1        | 5   | 100    | 6     | 3.030| 9.628     |
| 2        | 5   | 150    | 9     | 3.232| 10.189    |
| 3        | 5   | 200    | 12    | 4.440| 12.947    |
| 4        | 10  | 100    | 9     | 5.000| 13.947    |
| 5        | 10  | 150    | 12    | 5.537| 14.587    |
| 6        | 10  | 200    | 6     | 7.031| 16.940    |
| 7        | 15  | 100    | 12    | 9.375| 19.439    |
| 8        | 15  | 150    | 6     | 11.805| 21.441   |
| 9        | 15  | 200    | 9     | 16.250| 24.217   |

The main effect plot for S/N ratio for all the three parameters were obtained in the MINITAB software during the analysis. In the machining process the last observation yields the highest MRR, having corresponding input variables values viz. 15 amp., 200 ms and 9 kgf/cm². For this observation the value of MRR is 16.250mm³/min.

Figure 3. Main effect plot for S/N ratio

It is clear from figure 3 that peak current at 3rd level, pulse on time at 3rd level and Flushing pressure at 2nd level have the highest S/N ratio. So Ip at 15 amp, T_{on} at 200 ms and F_{p} at 12 Kgf/cm² bears the optimal solution to get the desired response.
We can observe from Figure 3 that the MRR increases with the increase in the peak current. This MRR increases such rapidly due to the high concentration of electrical energy in the space between the job and copper electrode, thus resulting in sudden melting and then vaporization of metal. MRR also increases as the pulse on time increases. However, it is also clear from the figure that material removal rate decreases with the increase in flushing pressure. One possible cause behind this decrement is that we took the value of flushing so high that jet stream was unable to properly remove the material.

The linear model of the different S/N ratio is developed by regression analysis which is a statistical measure for predicting the relationship among variables. In this analysis we got the following important values.

1. Standard deviation (S) = 0.6093
2. R-Sq = 99.6%
3. R-Sq(adj) = 98.5%

As R-Sq is close to 100%, this shows the reliability of our experiment with accurate results. The calculated value of S/N ratio from Taguchi analysis is found to be 24.217 which is the highest among any of the calculated values in the table. Hence the corresponding input factors are the most optimized controllable parameters. These factors at their optimized levels are also predicted by the Taguchi analysis on the Minitab software, which is depicted in Table 4.

| IP  | TON | FP  | SNRA |
|-----|-----|-----|------|
| 15  | 200 | 9   | 24.218 |

By taking the optimized controllable parameters the predicted value of the S/N ratio by Taguchi analysis is 24.218 which is greater than all individual S/N ratio thus satisfying the experiment.

4. Conclusion
Analyzing results, we concluded that the peak current is the highest influencing factor in determining MRR. MRR is directly proportional to the peak current and pulse on time but depends inversely on the flushing pressure. It was found that peak current of 15 Amp, pulse on time of 200 ms and Flushing pressure of 9Kgf/cm² bears the optimal quality characteristics. At these levels Material Removal Rate was found to be 16.250 mm³/min.

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