Optimization of process parameters on EN24 Tool steel using Taguchi technique in Electro-Discharge Machining (EDM)

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Abstract. In the field of manufacturing sectors, electric discharge machining (EDM) is widely used because of its unique machining characteristics and high meticulousness which can’t be done by other traditional machines. The purpose of this paper is to analyse the optimum machining parameter, to curtail the machining time with respect to high material removal rate (MRR) and low tool wear rate (TWR) by varying the parameters like current, pulse on time ($T_{on}$) and pulse off time ($T_{off}$). By conducting several dry runs using Taguchi technique of $L_9$ orthogonal array (OA), optimized parameters were found using analysis of variance (ANOVA) and the error percentage can be validated and parameter contribution for MRR and TWR were found.

Keywords: EDM, Material removal rate, Tool wear rate, Taguchi technique, ANOVA

1. Introduction

In this rapidly developing world, quality plays a major role for the growth of manufacturing industries. To achieve this many industries are still employing several standards and technique for maintaining their product quality. When it comes to manufacturing sector surface finish is the key to quality of the product. Traditional machining process cannot produce the kind of surface finish that can be produced by unconventional machining. EDM is one of the kinds of non-traditional machining in which the metal is removed by producing powerful electric spark discharged between the tool (cathode) and the work material (anode). Here, the tool and the material are separated by an inter electrode gap (IEG) of 0.005 to 0.05 mm. Due to this gap, when connected to an external supply, the spark is produced with an interval of 10 to 30µs. With this spark, the temperature increases up to 12000˚C. This in turn erodes the metal by vapourisation. The whole process takes place in a tank with dielectric fluid where the tool and work material are submerged. The dielectric fluid acts as a coolant which carries the scrap and chips produced during machining. The MRR and TWR can be varied by adjusting the machining input characteristics like current, pulse off time and pulse on time in order to find the optimum responses. The Taguchi technique is employed in this paper to optimize the parameters, which is to increase the MRR and to reduce the TWR. Trezise (1982) suggested the fundamental limits on machining accuracy counts entirely on dimensional consistency of the WEDM wire besides positional accuracy of the work table in EDM process. Many trials have been made by adopting various techniques with...
different input parameters on the same tool and work piece, to get high MRR and low TWR. Lin et al (2000) described that electrode wear rate (EWR) and MRR can be improved by optimizing the EDM process parameters using Taguchi techniques with Fuzzy logics. Her et al (2002) achieved the optimal surface roughness (R_s) by employing BaTiO_3 in EDM using regression analysis and validated using genetic algorithm (GA). Wang et al (2003) proposed the evolution of hybrid artificial neural network (HANN) and GA for optimizing the EDM parameters to overcome the difficulties present in the traditional solving techniques. Tosun et al (2004) have developed an investigation on optimizing the WEDM parameters like kerf (Width) and MRR. He also revealed that the optimum machining conditions can be obtained on minimizing the kerf (width) and maximizing the MRR. Luis et al (2005) investigated the use of input variables like pulse current and time, open-circuit voltage, duty cycle and flow pressure of the di-electric medium in order to increase the MRR over tungsten carbide materials. Kansal et al (2007) have suggested that peak current and concentration of silicon powder has significant gain on MRR, whereas nozzle flushing does not have any effect on MRR. Kuppan et al (2008) have proposed a RSM to prove the influence of input parameters to maximise the MRR. Chiang et al (2008) have employed certain input parameters in ceramic materials to check the MRR, EWR, and surface roughness in EDM by developing the mathematical models. Jaharah et al (2008) has chosen I_p, T_on, T_off as the design factor to analyze the EDM process performance on AISI H3 tool steel as workpiece to minimize the output variables like surface roughness and to maximize the MRR. Kanagarajan et al (2008) had studied the performance of EDM on same output parameters using I_p, T_on, electrode rotation and flushing pressure as input parameter on tungsten carbide/cobalt cemented carbide using the RSM approach and have validated the results by experimentally conducting it. Pradhan et al (2009) developed a neuro fuzzy model to enhance MRR in D2 die steel by varying the current, pulse on time and duty cycle. Anil et al (2010) have studied the effect of abrasives mixed with dielectric fluid in MRR and R_s by grey relational analysis. Pradhan et al (2011) have presented a research work about the effect of second order response model of machining parameters have significant impact on surface roughness estimated using CCD technique. Jahan et al (2011) have concluded that, in micro-EDM breakdown strength decreases with increase in powder material concentration in dielectric fluid which causes no change in MRR, whereas using semi conduction abrasive have high breakdown strength and has significant gain in MRR. Khan et al (2011) performed a study on Ti15-3 alloy in minimizing the surface roughness using ANN in EDM process. Azizul et al (2012) have described that duty factor and discharge current interaction has been the main contributing factor for lower surface roughness. Raghuraman et al (2013) have proposed that optimization of process parameters can be estimated accurately with fewer errors in grey relational analysis technique. Jothimurugan et al (2013) have studied about the contribution of kerosene-servotherm of different proportion when compared with EDM oil. The kerosene-servotherm has greater impact on MRR than the contribution of EDM oil, also he concluded that silver plated copper electrode increases the MRR and decreases the TWR than copper electrode. Shashikanth et al (2014) have presented a research paper in the impact of machining parameters using non traditional optimization technique for establishing the second order response model. Chandramouli et al (2014) have investigated about the effect of MRR, TWR and R_s by preferring the input characteristics such as pulse off time, current and pulse on time. Laxman et al (2014) have studies about the impact of performance index called grey relational grade in optimization of high MRR and low TWR. The prime goal of this paper is to identify the best machining parameter of EN24 tool steel using Taguchi’s technique and to find out the best optimized value with corresponding contribution parameter for high MRR and low TWR.

2. Experimental Setup
In this work, the experiments on EN24 tool steel were conducted on V5030 GRACE Precision die sinking electrical discharge machining with Nickel plated copper as an electrode. The machine is computer controlled consisting of a servo motor with servo feed mechanism, a magnetic worktable with dielectric supply system. The machine has 10 current setting ranges from 3 to 27 amps with pulse on time (T_on) and pulse off time (T_off) settings on board. The work piece is EN24 tool steel of 25mm in
diameter and 30mm in length, which has a hardness of 193BHN and HRC = 45, density = 7850 kg/m³, thermal conductivity of 25 w/mk. For lubrication and cooling purposes, EDM oil with specific gravity of 0.762 was used as a dielectric medium. The machining has been done with straight polarity. The trials with respect to levels and factors are calculated by Taguchi’s technique. After completing all the trials using the data obtained from MINI TAB software of L9 OA, the nominal MRR and best TWR has been calculated using the following formulae,

MRR = \[(W_b - W_a) / T\]  \hspace{1cm} (1)

Where \(W_a\) = weight of the work piece after machining in ‘grams’
Where \(W_b\) = weight of the work piece before machining in ‘grams’
\(T\) = time taken in ‘sec’

TWR = \[(W_{TB} - W_{TA}) / T\]  \hspace{1cm} (2)

Where \(W_{TA}\) = weight of the tool after machining in ‘grams’
Where \(W_{TB}\) = weight of the tool before machining in ‘grams’
\(T\) = time taken in ‘sec’

3. Machining Levels
The table 1 represents the levels and factors of the process parameters, by which the machining processes are done. Figure 1 represents the EDM machine.

| Coding | Factors/Levels | Units | Levels |
|--------|----------------|-------|--------|
| A      | Current        | A     | I 3    | II 7  | III 11 |
| B      | Pulse On Time  | (µs)  | II 5   | II 6  | II 7   |
| C      | Pulse Off Time | (µs)  | II 4   | II 5  | II 6   |

Figure 1. EDM Grace V5030

4. Results and Discussion
In this section, the experimental results regarding optimal MRR and TWR has been calculated with the help of distinctive process parameters such as current (A), pulse on time (µs) and pulse off time (µs), by Taguchi’s technique and the results are given in table 2.
Table 2. Experimental results for MRR measured

| Current (A) | Pulse On Time (µs) | Pulse Off Time (µs) | MRR (g/min) |
|------------|-------------------|--------------------|-------------|
| 3          | 5                 | 4                  | 0.0200      |
| 3          | 6                 | 5                  | 0.0200      |
| 3          | 7                 | 6                  | 0.0233      |
| 7          | 5                 | 5                  | 0.0183      |
| 7          | 6                 | 6                  | 0.0180      |
| 7          | 7                 | 4                  | 0.0110      |
| 11         | 5                 | 6                  | 0.0290      |
| 11         | 6                 | 4                  | 0.0230      |
| 11         | 7                 | 5                  | 0.0265      |

4.1 Influences on MRR

The S/N ratio for MRR (i.e.) larger is better, is calculated by the formulae,

\[ \text{LB} = \eta = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^{-2}\right] \]  \hspace{1cm} (3)

Where \( \eta \) represents S/N ratios for observed values, \( y_i \) shows the experimentally recorded values of the \( i^{th} \) experiment and \( n = 1 \) is the repeated number of experiment in L\(_9\) OA. MRR is highly influenced by the current (A), (i.e.) the MRR increases with the gain in current with respect to the optimum pulse on time and pulse off time. To spot out the optimal MRR for EN24 tool steel, three input characteristics current (A), pulse on time (µs) and pulse off time (µs) values were tabulated according to Taguchi’s L\(_9\) OA as shown in the table 1. Nine experimental trials were conducted on the work piece by Ni-plated copper electrode. As per the eqn (1) for MRR, the weight before and after machining were recorded with respect to machining time of 3 mins. The recorded values and the calculated MRR are tabulated in table 3. By using MINITAB analysis software the recorded values are fed as input, to find out the S/N ratio and the mean variance graph, which helps in spotting out the optimal value of MRR and their respective contribution value of the process parameter. The S/N ratio and the mean variance values are shown in table 3.

Table 3. S/N ratio results for optimum MRR

| Current (A) | Pulse On Time (µs) | Pulse Off Time (µs) | MRR (g/min) | SNRA1   |
|------------|--------------------|---------------------|-------------|---------|
| 3          | 5                  | 4                   | 0.0200      | -33.9794|
| 3          | 6                  | 5                   | 0.0200      | -33.9794|
| 3          | 7                  | 6                   | 0.0233      | -32.6529|
| 7          | 5                  | 5                   | 0.0183      | -34.7510|
| 7          | 6                  | 6                   | 0.0180      | -34.8945|
| 7          | 7                  | 4                   | 0.0110      | -39.1721|
| 11         | 5                  | 6                   | **0.0290**  | **-30.7520** |
| 11         | 6                  | 4                   | 0.0230      | -32.7654|
| 11         | 7                  | 5                   | 0.0265      | -31.5351|
The graph for S/N ratio is shown in figure 2 and it is clear that optimum MRR of machining of EN24 tool steel occurs at current = 11 (A), pulse on time = 5 (µs), and pulse off time = 6 (µs) (i.e.) MRR = 0.029 g/min.

4.2. Finding response factor in MRR

4.2.1. S/N ratio. In the traditional optimization technique, the desirable values are represented by the condition signal and undesirable values are represented by the term noise. Irrespective of the response, a good performance occurs, when the S/N ratio gets bigger. The S/N ratio for each variable is accounted by taking the mean of S/N ratios at the equating level. Table 4 and 8 shows the response table for S/N ratio of MRR and TWR, respectively obtained for different variables. From table 4, it’s found that A3 B1 C3 is the optimum level combination for higher MRR and current has the greater influence on MRR followed by pulse off time and pulse on time.

Table 4. Response table of S/N ratio for MRR

| Level | Current | Pulse ON Time | Pulse OFF Time |
|-------|---------|---------------|---------------|
| 1     | -33.54  | -33.16*       | -35.31        |
| 2     | -36.27  | -33.88        | -33.42        |
| 3     | -31.68* | -34.45        | -32.77*       |
| Max – Min | 4.59   | 1.29          | 2.54          |
| Rank  | 1       | 3             | 2             |

* Optimum level

4.2.2. Percentage contribution of significant parameter. Analysis of variance (ANOVA) is employed in this paper for finding the effects of different parameters through an analysis. In this analysis, F-ratio is defined as the mean square error to the residual error. It helps in finding how much significant, the parameter is, in this experiment. The percentage contribution is defined as how much share the each variable contributes on the output variables (MRR and TWR). From the table 5, it’s observed that the current, pulse on time and pulse off time affects the MRR by 75.15%, 4.44% and 16.78%.
Table 5. Results of ANOVA for MRR

| Source                  | Degrees of freedom | Sum of Squares | Variance | F-ratio | Percentage (%) |
|-------------------------|--------------------|----------------|----------|---------|----------------|
| Current (A)             | 2                  | 2.25 * 10^-4   | 1.125 * 10^-4 | 5.95   | 75.15          |
| Pulse ON Time (µs)      | 2                  | 1.69 * 10^-4   | 0.845 * 10^-4 | 4.47   | 4.44           |
| Pulse OFF Time (µs)     | 2                  | 0.1 * 10^-4    | 0.05 * 10^-4  | 0.265  | 16.78          |
| Error                   | 2                  | 0.378 * 10^-4  | 0.189 * 10^-4 | ------ | 3.63           |
| Total                   | 8                  | 0.08 * 10^-4   | -----      | ------  | 100.00         |

4.2.3. Effect of input parameters on MRR. From the figure 2, it can be understood that as the current increases, the inter electrode gap (IEG) will be full of electrons emitted by the cathode, this makes the resistance to drop, thereby if all the energy gathered hasn’t been spent, arcing occurs which reduces the current density thereby less corrosion takes place, initially. Then the gathered energy is enough to remove the excess electrons, which hinders the resistance, and it makes the MRR to increase considerably. As the pulse off time increases, the gathered pressure drops instantaneously thereby allowing the material to evaporate, this increases the MRR. And when the pulse on time increases, frequent washing of IEG is required, else the accumulated metal debris will bridge the gap, in turn leads to short circuits, so the MRR decreases.

4.3. Influences on TWR.
The S/N ratio for TWR (i.e.) the smaller is better, is calculated by the formula,

\[
SB = \eta = -10\log\left[1/n\sum_{i=1}^{n} y_i^2\right]
\] (4)

TWR is the key factor for economic machining and for better surface finish. In the case of TWR the value must be minimal (i.e.) smaller is better in terms of S/N ratio. Similar to MRR the TWR is calculated as per the eqn (2), by weighing the tool for each and every trial for the difference in weights with respect to machining time of 3 mins as per Taguchi’s L9 OA. The recorded values are represented in the table 6.

Table 6. Experimental results for TWR

| Current (A) | Pulse On Time (µs) | Pulse Off Time (µs) | Weight Before Machining (g) | Weight After Machining (g) | Difference In Weights (g) | TWR (g/min) |
|-------------|--------------------|--------------------|----------------------------|---------------------------|--------------------------|-------------|
| 3           | 5                  | 4                  | 234.56                     | 234.46                    | 0.099                    | 0.0330      |
| 3           | 6                  | 5                  | **234.46**                 | **234.39**                | **0.069**                | **0.0233**  |
| 3           | 7                  | 6                  | 234.39                     | 234.27                    | 0.129                    | 0.0433      |
| 7           | 5                  | 5                  | 234.27                     | 234.11                    | 0.159                    | 0.0530      |
| 7           | 6                  | 6                  | 234.11                     | 233.96                    | 0.155                    | 0.0515      |
| 7           | 7                  | 4                  | 233.96                     | 233.74                    | 0.219                    | 0.0730      |
| 11          | 5                  | 6                  | 233.74                     | 233.52                    | 0.224                    | 0.0745      |
| 11          | 6                  | 4                  | 233.52                     | 233.27                    | 0.252                    | 0.0841      |
| 11          | 7                  | 5                  | 233.27                     | 233                      | 0.269                    | 0.0898      |
Similarly, the recorded values of TWR have been fed into MINITAB software for analysis of S/N ratio and its graph was shown in figure 3 and the S/N ratio for TWR has been given in table 7.

Table 7. S/N ratio for optimal TWR

| Current (A) | Pulse On Time (µs) | Pulse Off Time (µs) | TWR (g/min) | SNRA1 |
|------------|--------------------|--------------------|-------------|-------|
| 3          | 5                  | 4                  | 0.0330      | 29.6297 |
| **3**      | **6**              | **5**              | **0.0233**  | **32.6529** |
| 3          | 7                  | 6                  | 0.0433      | 27.2702 |
| 7          | 5                  | 5                  | 0.0530      | 25.5145 |
| 7          | 6                  | 6                  | 0.0515      | 25.7639 |
| 7          | 7                  | 4                  | 0.0730      | 22.7335 |
| 11         | 5                  | 6                  | 0.0745      | 22.5569 |
| 11         | 6                  | 4                  | 0.0841      | 21.5041 |
| 11         | 7                  | 5                  | 0.0898      | 20.9345 |

Figure 3. S/N graph for optimal TWR

From the figure 3, the optimal TWR level have been found (i.e.) TWR = 0.0233 g/min which is obtained at current = 3A, pulse on time = 6 (µs), and pulse off time = 5(µs) for EN24 Tool Steel.

4.4. Analysis of S/N ratio for TWR

4.4.1. Response table and ANOVA for TWR. From table 8, it’s clear that A1 B2 C2 is the optimum level combination for lower TWR and also the current plays a significant role on TWR followed by pulse on time and pulse off time.

Table 8. Response table of S/N ratio for TWR

| Level | Current | Pulse On Time | Pulse Off Time |
|-------|---------|---------------|---------------|
| 1     | **29.85*** | 25.90         | 24.62         |
| 2     | 24.67   | **26.64***    | **26.37***    |
| 3     | 21.67   | 23.65         | 25.20         |
| Max – Min | 8.19   | 2.99          | 1.74          |
| Rank  | 1       | 2             | 3             |

*Optimum level
From table 9, it's noted that the current, pulse on time and pulse off time affects the TWR by 54.1%, 21.42% and 2.32%.

| Source             | Degrees of freedom | Sum of Squares | Variance  | F-ratio | Percentage (%) |
|--------------------|--------------------|----------------|-----------|---------|----------------|
| Current (Amps)     | 2                  | $2.336 \times 10^{-3}$ | $1.168 \times 10^{-3}$ | 2.32    | 54.10          |
| Pulse ON Time (µs) | 2                  | $9.247 \times 10^{-4}$ | $4.623 \times 10^{-3}$ | 9.19    | 21.42          |
| Pulse OFF Time     | 2                  | $9.566 \times 10^{-4}$ | $4.778 \times 10^{-3}$ | 9.49    | 2.32           |
| Error              | 2                  | $1.006 \times 10^{-3}$ | $0.503 \times 10^{-3}$ | -----   | 22.16          |
| Total              | 8                  | $4.317 \times 10^{-3}$ | -----     | -----   | 100.00         |

4.4.2. Effect of input parameters on TWR. In figure 3, it clearly states that, as the current increases, there will be a continuous flow of electrons to the anode and similarly ions towards the cathode. The most of the ions has more kinetic energy, which is converted to heat energy and the bombardment of ions in the cathode take place, thereby the TWR increases. When pulse on time increases, the electrolyzing current in between the IEG is more, as this increases the TWR. And TWR decreases when the pulse off time increases. This is because of the pressure drop allows the electrons to move towards anode, rather than moving towards the cathode.

5. Conclusion

From the above discussions it is clear that the optimum MRR (MRR = 0.029 g/min) is achieved at A, B, and C, whereas the optimal TWR (TWR = 0.0233 g/min) is achieved at A, B, and C. Through many calculations and analysis for optimum MRR and TWR, it has been concluded that the optimum MRR value for EN24 tool steel is achieved by varying the different levels of input parameters such as current (A), pulse on time (µs) and pulse off time (µs) by using the Minitab and also by applying the Taguchi’s technique. So the conclusion of this work is that, the optimal value of MRR was determined at levels A, B, and C (current discharge at 11A, pulse on time 5µs, and pulse off time 6µs), whereas for TWR the optimal value is contributed by the three process parameters at levels A, B, and C (current discharge at 3A, pulse on time 6 µs, and pulse off time 5µs).

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