Optimizing process parameters of die sinking EDM in AISI D2 steel by using TOPSIS using EDM oil as dielectric

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Abstract. A prodigious research work is being effectuated to endorse the optimal machining parameters while entailing present day machining techniques to bring outclassy products. This research work insisted on suggesting the optimum process parameters of die sinking EDM with 8mm diameter copper electrode during machining AISI D2 steel using TOPSIS. Taguchi’s L9 Orthogonal Array method was adopted to design 9 experiments in total and Pulse on time (T\textsubscript{on}), Servo voltage (SV) and Peak current (I\textsubscript{p}) are chosen as input parameters. Three levels of each parameter were selected for designing the experimentation. EDM oil which is a synthetic oil is selected as dielectric and all the values of Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (SR) for each experiment were noted as the output responses. Analysis of Variance (ANOVA) was done to recommend the impact of each input parameter on output responses. Analytical Hierarchy Process (AHP) was used to select the weightage of each response and then Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) which is a multi-criteria decision analysis method, was accompanied for determination of ideal parameters for machining AISI D2 steel. Eventually it is described that the amalgamation of level 3 of pulse on time, level 3 of Peak Current and level 3 of servo voltage propounds the optimum result.

1. Introduction
Machining is significantly acknowledged to manufacture numerous components that regale our everyday needs besides many engineering and industrial applications. As conventional machining process is meager to meet the supposition of current manufacturing experts, advanced machining processes are chosen to proficiently consummate the task with meliorated outcomes. Greatness goes to EDM i.e. Electric Discharge Machine for producing myriad state of the art materials that are grueling to achieve. copious applications such as medical and surgical equipment, motorized industries, aerospace industries and die making and so on to name a few use the same technique. EDM can also produce byzantine shapes during machining [1, 2]. An inter electrode gap is always maintained which does not bound the hardness of workpiece in the process of machining. Electrically conductive electrode materials such as Copper, Brass, Graphite, and Tungsten etc., removes the material [3]. EDM, being a thermo electrical machining process, performs melting and vaporizing of work surface to remove material. The positive terminal in the case in question is the work piece that is supposed to be machined with the electrode being the negative terminal to the source of power. As the electrode moves closer to the workpiece, due to ionization in the inter-electrode gap, the electrons from
electrode moves with very high velocity towards the workpiece and strikes that triggers an electric spark of temperature about 10000°C. Hence such elevated temperature initiates material removal by the said mechanism [4]. The characteristics of EDM are probed by accomplishing parametric optimization of myriad input considerations like Pulse on time, Peak Current, Servo Voltage, Pulse off time, Duty cycle, etc., In the trending scenario of research decision making models that fit into multi criteria framework like Grey Relational Analysis (GRA), Fuzzy logic Multi-attribute Utility Theory (MAUT), TOPSIS, AHP etc, have become popular and are used for optimizing various non conventional manufacturing process parameters [5-7]. A material having relatively high wear along with abrasion resistance like AISI D2 steel has been utilized to make dies for stamping, punches and many other engineering and industrial applications which is high carbon high chromium tool steel in this study. Hence it is significant to machine such steel by die sinking EDM. Researchers found that Taguchi’s orthogonal array is a successful tool for designing the experiments which gives a matrix of combination of input parameters called Taguchi orthogonal arrays. These arrays are balanced and thus the unbiased evaluation can be done.

Routara et al. [8], in their research on the characteristics of machining of T6 – Al7075, carried out 9 experiments exerting Taguchi’s L9 orthogonal array. The input parameter used were spark gap, peak current and pulse off time at each level to record the output responses in terms of metal removal rate, surface roughness and tool wear rate. The study makes use of ANOVA to determine the significance of the above said parameters with relation to the output responses and further TOPSIS was chosen as an optimizing technique. Kannan et al. [9] used TOPSIS method for optimizing parameters for machining in Laser Beam Machining so as to design micro elliptical profiles on aluminum based composite. Their study made use of Taguchi’s L9 orthogonal array method. Rahul et al. [10] performed 25 experiments using Taguchi’s L25 orthogonal array in die sinking EDM. They used a rod of pure copper with a circular cross section of 20 mm diameter as electrode for machining Inconel 718 plates. The dielectric used was EDM oil with 0.763 gravity, the input parameters being Duty factor, Peak current, Open circuit voltage, Pulse on time and flushing pressure while White layer thickness and Micro hardness, Surface Roughness, Material Removal Rate, Surface crack density and Electrode Wear Rate, were chosen as Output responses. They also used optimization techniques like PCA along with TOPSIS for optimizing the process parameters. Dewangan et al. [11] in their studies came up with the optimization of the process parameters for micro EDM by using Fuzzy – TOPSIS approach. They have proposed that their research can be used the field of manufacturing and medical applications.

2. Experimental details

2.1. Choice of workpiece, tool and machining process

An ASKAR Microns V3525 die sinking EDM shown in figure.1 comprising a robust table to fix the work, CNC operated system and a motor operated pumping system for fluid circulation is used to execute the work. The input parameter employed can be enumerated as pulse on time, Servo Voltage and Peak current with three levels each. The values of available pulse on time in this machine range from 100 µs to 800 µs among which 300 µs, 400 µs and 500 µs are selected for current experimentation. The available metrics for Peak current ranges from 1 A to 8 A among which 6 A, 7 A and 8 A are chosen and finally the available metrics range for servo voltage is from 40 V to 80 V among which 40 V, 50 V and 60 V are chosen as explained in table 1. For experimentation, a work piece of AISI D2 Steel with a dimension of 100mm x 60 mm x 5mm was chosen. EDM oil is taken as dielectric fluid and an 8mm Copper rod is selected as electrode (tool). A weighing machine with 1mg least count is utilized to measure the weight of work and tool during process. A stop watch with 1 micro sec tolerance is used to note down the time for process and the SR measurement was facilitated by the use of Talysurf machine for running length of 4mm.
The computation of MRR and TWR is done by the given equations (a) and (b) [12].

\[
MRR = \frac{W_b - W_a}{t} \text{mg} \text{min}^{-1} \tag{a}
\]

\[
TWR = \frac{T_b - T_a}{t} \text{mg} \text{min}^{-1} \tag{b}
\]

Where,
- \(W_b\) is the work-material’s weight prior to machining,
- \(W_a\) is the work-material’s weight post machining,
- \(T_b\) is the copper electrode’s weight prior to machining,
- \(T_a\) is the copper electrode’s weight post machining and
- \(t\) is time taken for Manufacturing in minutes.

2.2. Control parameters and their levels

| Input parameter          | Level 1 | Level 2 | Level 3 |
|--------------------------|---------|---------|---------|
| Pulse on time in µs      | 300     | 400     | 500     |
| Peak current in A        | 6       | 7       | 8       |
| Servo Voltage in V       | 40      | 50      | 60      |

2.3. Design of experiments

Experiments are conducted using Taguchi’s L9 Orthogonal Array [13, 14] with the various combinations of input parameters for each experiment conducted as depicted in the table 2 given below.

| Experiment | Input Parameters |
|------------|------------------|
|            | Ton(µs) | SV (V) | IP(A) |
| 1          | 300     | 40     | 6     |
3. Results and discussions

At the end of each experiment, responses were calculated by using weighted machine and a stop watch for calculation of MRR and TWR and $R_a$ is calculated using Talysurf roughness tester. The results are listed below in the table 3.

Table 3: Measured values of response parameters

| Experiment | MRR ($10^{-3}$ gm/min) | TWR ($10^{-3}$ gm/min) | SR ($R_a$) in microns |
|------------|------------------------|------------------------|-----------------------|
| 1          | 4.854                  | 0.3258                 | 2.031                 |
| 2          | 4.083                  | 0.3348                 | 3.07                  |
| 3          | 7.022                  | 0.3702                 | 2.96                  |
| 4          | 5.373                  | 0.2178                 | 2.09                  |
| 5          | 6.48                   | 0.6782                 | 3.24                  |
| 6          | 4.62                   | 0.1632                 | 3.25                  |
| 7          | 5.301                  | 0.1633                 | 3.19                  |
| 8          | 5.136                  | 0.052                  | 3.24                  |
| 9          | 9.961                  | 0.1008                 | 2.63                  |

3.1. S/N ratio computation

Once the collection of all experimental data is completed the S/N ratio values for output responses such as MRR, TWR and Surface Roughness were obtained where “larger the better” for MRR and “smaller the better” for TWR and SR is preferred to yield ideal solution. Based on this analysis S/N ratios were carried out as represented in table 4.

Signal to Noise ratio for each of the responses are listed as in table 4.

Table 4: S/N ratios of different experiments for output responses

| Experiment | S/N ratio of MRR        | S/N ratio of TWR        | S/N ratio of SR        |
|------------|-------------------------|-------------------------|------------------------|
| 1          | -4.707328971            | -2.372166505            | -0.94685397           |
| 2          | -3.732958027            | -2.258288692            | -2.373037969          |
| 3          | -7.164959285            | -1.862471284            | -2.221158769          |
| 4          | -5.332166343            | -4.381673763            | -1.024936445          |
| 5          | -6.586539902            | -0.284401965            | -2.60652074           |
| 6          | -4.417489557            | -6.198095553            | -2.620245752          |
| 7          | -5.246942285            | -6.193907454            | -2.538050523          |
| 8          | -5.04987912             | -16.48647414           | -2.60652074           |
| 9          | -9.966087602            | -9.930909111            | -1.763628307          |
3.2. Analysis of Variance (ANOVA)

In order to obtain the contributing percentage of the factors influencing machining performance and their significance ANOVA is performed [15]. Table 5 depicts the results of ANOVA for MRR and it can be observed that pulse on time has more influence on MRR. Table 6 is depicting the results of ANOVA for TWR which showcases that Current influences more on TWR whereas ANOVA results for SR are represented in Table 7 which explains that Pulse on time is influencing SR the most.

The tables below depict the results of ANOVA that was employed for the output responses and their interrelationships.

### Table 5: ANOVA results for MRR

| Source            | DF | Seq. SS     | Adj. MS       | F     |
|-------------------|----|-------------|---------------|-------|
| Current           | 2  | 4.183020652 | 2.091510326   | 0.40557 |
| Pulse on time     | 2  | 8.600307968 | 4.300153984   | 0.833855|
| Pulse off time    | 2  | 5.206145528 | 2.603072764   | 0.504769|
| Residual Error    | 2  | 10.31391864 | 5.156959322   |       |
| Total             | 9-1=8 | 28.30339279 |               |       |

### Table 6: ANOVA results for TWR

| Source            | DF | Seq. SS     | Adj. MS       | F     |
|-------------------|----|-------------|---------------|-------|
| Current           | 2  | 130.4682149 | 65.23410743   | 6.809792 |
| Pulse on time     | 2  | 7.05514015  | 3.527757008   | 0.368263 |
| Pulse off time    | 2  | 46.57416245 | 23.28708122   | 2.43094 |
| Residual Error    | 2  | 19.15891288 | 9.579456438   |       |
| Total             | 9-1=8 | 203.2568042 |               |       |

### Table 7: ANOVA results for SR

| Source            | DF | Seq. SS     | Adj. MS       | F     |
|-------------------|----|-------------|---------------|-------|
| Current           | 2  | 0.311698023 | 0.155849012   | 0.350314 |
| Pulse on time     | 2  | 1.646243971 | 0.823121985   | 1.850193 |
| Pulse off time    | 2  | 0.81152758  | 0.40576379    | 0.912066 |
| Residual Error    | 2  | 0.889768586 | 0.444884293   |       |
| Total             | 9-1=8 | 3.65923816  |               |       |

3.3. Analytical Hierarchy Process (AHP)

Analytical Hierarchy Process (AHP) has been considered to be one of the suitable and widespread decision-making analytical tools for solving multifaceted problems by providing measures of consistency of preference [4]. The steps included in the AHP weight calculation are:

*Step 1: Formulation of hierarchal structure as is evident from the figure below (figure 2).*
Figure 2 Hierarchical Structures with different levels

Step 2: To perform the pair-wise comparisons.
Here, we indulge in framing the pair wise comparison matrices and normalized comparison matrices by taking relative importance of different attributes as shown in tables 8, 9, 10 and 11 below:

**Table 8: Relative importance of different attributes**

| Criteria | 1 | 2 | 3 |
|----------|---|---|---|
| MRR      |   |   |   |
| TWR      |   |   |   |
| SR       |   |   |   |

Scale of Relative Importance has been used to design pair wise comparison matrix. The same is depicted in the table below.

**Table 9: Pair wise comparison matrix**

| Scale       | Importance level          |
|-------------|---------------------------|
| 1           | Equal importance          |
| 3           | Moderate                  |
| 5           | Strong                    |
| 7           | Very strong               |
| 9           | Extreme                   |
| 2,4,6,8     | Intermediate              |
| 1/3,1/5,1/7,1/9 | Values with inverse comparison |

**Table 10: Pair wise comparison matrix**

| Response | MRR | SR  | TWR |
|----------|-----|-----|-----|
| MRR      | 1.00| 3.00| 5.00|
| SR       | 0.33| 1.00| 3.00|
| TWR      | 0.20| 0.33| 1.00|
| Sum      | 1.53| 4.33| 9.00|

**Table 11: Normalized pair wise matrix**

|         | MRR | SR  | TWR  | Criteria weights |
|---------|-----|-----|------|------------------|
| MRR     | 0.65| 0.69| 0.56 | 0.63             |
| SR      | 0.22| 0.23| 0.33 | 0.26             |
| TWR     | 0.13| 0.08| 0.11 | 0.11             |
| Sum     | 1.53| 4.33| 9.00 |                  |

Step 3: Determining the weights of the attributes.
Geometric mean was used to achieve the same as in table 12.
Table 12: Criteria weights

|          | Weighted Sum Value | Criteria weights | Ratio between weighted sum value and criteria weights |
|----------|--------------------|------------------|------------------------------------------------------|
| MRR      | 0.63               | 0.26             | 0.11                                                 |
| SR       | 0.21               | 0.26             | 0.32                                                 |
| TWR      | 0.13               | 0.09             | 0.11                                                 |

Step 4: Determination of lambda max ($\lambda_{max}$), consistency index (CI) and consistency ratio (CR).

From the table 12, the value of lambda max can be determined by taking the average of ratios between sum value and criteria weights and it is found to be, $\lambda_{max} = 3.04$

The formula, $CI = \frac{\lambda_{max} - n}{n-1}$ has been employed to calculate the consistency index (CI)

Where $n$ = number of attributes = 3

Therefore $CI = 0.01936$.

The relation $CR = \frac{CI}{RI}$ has been used for determination of the consistency ratio (CR). Since, CR is less than 0.1; we can assume that our matrix is reasonably consistent.

3.4. TOPSIS method

With an aim to identify the alternatives that provide with positive ideal solution, Hwang and Yoon developed the TOPSIS technique, where it is believed that positive ideal solution augments benefit criteria and curtails the cost criteria. Antipode to it, negative ideal solution augments the cost criteria and curtails the benefit criteria. The following steps demonstrate the selection procedure of TOPSIS for coming up with a best alternative among the available ones:

Step 1: Calculate normalized matrix

Normalized matrix for all the three output responses can be calculated by using equation (c) as given below and all the values are as projected in table 13.

$$\bar{X}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}$$

Table 13: Normalized matrix

|          | Weightage |          |          |          |
|----------|-----------|----------|----------|----------|
|          | 0.63      | 0.11     | 0.26     |          |
| Experiment| MRR       | TWR      | SR       |          |
| 1        | 0.2650263 | 0.338049 | 0.234005 |
| 2        | 0.22293   | 0.347388 | 0.353715 |
| 3        | 0.3833981 | 0.384119 | 0.341041 |
| 4        | 0.2933635 | 0.225989 | 0.240803 |
| 5        | 0.3538052 | 0.703699 | 0.373302 |
| 6        | 0.25225   | 0.169336 | 0.374454 |
| 7        | 0.2894323 | 0.16944  | 0.367541 |
| 8        | 0.2804234 | 0.053955 | 0.373302 |
| 9        | 0.5438663 | 0.10459  | 0.30302  |
Step 2: Calculate weighted normalized matrix
Weighted Normalized matrix for all the three output responses can be calculated by using equation (d) given below and all the values are as projected in table 14.

\[ V_{ij} = \bar{X}_{ij} \ast W_j \]  

(d)

Step 3: Calculating the ideal best and ideal worst value
It is always expected to have better MRR and less TWR as well as SR. So the highest among all the \( V_j \) values is treated as the ideal best for MRR and the lowest is treated as the ideal worst. Similarly the lowest among all the values of \( V_j \) is treated as the ideal best for TWR as well as SR and the highest is treated as the ideal worst for both TWR and SR.

The ideal best solution and ideal worst solutions of all the three output responses can be calculated by using equations (e) and (f) respectively and the same are as shown in table 14

\[ V_j^+ = \left\{ \Sigma_{i=1}^{m} V_{ij} \text{ where } j \in J, \Sigma_{i=1}^{m} V_{ij} \right\} \]  

(e)

\[ V_j^- = \left\{ \Sigma_{i=1}^{m} V_{ij} \text{ where } j \in J, \Sigma_{i=1}^{m} V_{ij} \right\} \]  

(f)

Step 4: Calculating the Euclidean distance from the ideal best.
Euclidean distance from the ideal best can be determined by using the relation (g) as given below

\[ S_i^+ = \left[ \Sigma_{j=1}^{n} (V_{ij} - V_j^+)^2 \right]^{0.5} \]  

(g)

And all the Euclidean distances from the ideal best are as given in the table 14.

Step 5: Calculating the Euclidean distance from the ideal worst.
Euclidean distance from the ideal worst can be determined by using the relation (h) as given below

\[ S_i^- = \left[ \Sigma_{j=1}^{n} (V_{ij} - V_j^-)^2 \right]^{0.5} \]  

(h)

And all the Euclidean distances from the ideal worst are as given in the table 14.

Step 6: Calculating the performance score
The performance scores for all the three output responses can be calculated by using the relation (i) as given below,

\[ P_i = \frac{S_i^-}{S_i^+ + S_i^-} \]  

(i)

And all the performance scores are as given in table 14

| Table 14: Normalized decision matrix |
|-------------------------------------|
| Experiment | MRR | TWR | SR | Si+ | Si- | Si+ +Si- | Pi | Rank |
|------------|-----|-----|----|-----|-----|----------|----|------|
| 1          | 0.1669666 | 0.037185 | 0.060841 | 0.178427 | 0.060453 | 0.23888 | 0.253069 | 7    |
| 2          | 0.1404459 | 0.038213 | 0.09196 | 0.207102 | 0.039563 | 0.246666 | 0.160393 | 9    |
| 3          | 0.2415408 | 0.042253 | 0.088671 | 0.110967 | 0.107385 | 0.218351 | 0.491797 | 2    |
| 4          | 0.184819 | 0.024859 | 0.062609 | 0.158957 | 0.077057 | 0.236014 | 0.326493 | 4    |
| 5          | 0.2228973 | 0.077407 | 0.097059 | 0.144074 | 0.082452 | 0.226526 | 0.363985 | 3    |
| 6          | 0.1589175 | 0.018627 | 0.097358 | 0.187742 | 0.061614 | 0.249356 | 0.247093 | 8    |
| 7          | 0.1823423 | 0.018638 | 0.095561 | 0.164502 | 0.072196 | 0.23698 | 0.305014 | 6    |
| 8          | 0.1766667 | 0.005935 | 0.097059 | 0.169875 | 0.080126 | 0.250001 | 0.32054 | 5    |
| 9          | 0.3426358 | 0.011505 | 0.078785 | 0.018788 | 0.213468 | 0.232257 | 0.919105 | 1    |
It is observed that the value of relative closeness is at its maximum at experiment 9, the value of which can be observed being 0.919105 corresponding to the input process parameters Pulse on time 500 micro seconds, Peak Current 8 A and Servo Voltage 60 V.

4. Conclusion

The substantial goal of this study is ascertaining parameters for optimum process while machining AISI D2 steel on die sinking EDM. The researchers incorporated Taguchi’s L9 OA in order to carry out the 9 experimentations for intuitions the parameters like Material Removal Rate, Tool Wear Rate and Rₐ that best suit our research requirement.

It is observed from ANOVA results that Pulse on time plays influencing role in enhancing MRR as well as SR while Peak Current has more impact on TWR.

In order to arrive at a choice of selecting the weightage of all the response parameters, what has been employed is the AHP. Further the study makes use of TOPSIS for determining the best possible input parameters in the range of current study as a technique for optimization.

The results of AHP – TOPSIS suggested that pulse on time, Tₚₜ (500 µs, Level 3), Peak Current, Iₚ (8 A, level 3) and Servo Voltage (60 V, level 3) is the optimal combination of input process parameters.

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