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# Investigations on Tool Wear Rate of AISI D2 Die Steel in EDM using Taguchi Methods

Arjun kumar R.S. Jadoun Sushil Kumar Choudhary
Department of Industrial & Production Engineering, College of Technology,
G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India, Pin-26314

**Abstract**

EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The workpiece material selected in this study is AISI D2 Die Steel. The input parameters are voltage, current, pulse on time and pulse off time. $L_9$ orthogonal array was selected as per the Taguchi method. The data have been analyzed using Minitab15 Software. The effect of above mentioned parameters upon machining performance characteristics such as Tool Wear Rate (TWR) are studied and investigated on the machine model C-3822 with PSR-20 Electric Discharge Machine. The copper alloy was used as tool material.The results obtained showed that the optimum condition for tool wear rate (TWR) is A3, B2, C2, D3 i.e. Ton (40µs),Toff (8 µs), Ip (8 amp) and Vg (60V). The order of process parameters influencing the tool wear rate is Toff>Ip>Ton>Vg. Hence, pulse off parameter has more contribution to tool wear rate whereas gap voltage has the least contribution. As per the optimal level of parameters, the optimum value of TWR is 0.117 $mm^3$/min. These results were validated by conducting confirmation experiments and found satisfactory.

**Keywords:** EDM,TWR, MRR, ANOVA, Taguchi method, AISI D2 Die steel, copper electrode

## 1-INTRODUCTIONS

### 1.1 Introduction of EDM

At present time metal manufacturing working industries are facing challenges from these advanced materials viz. super alloys, ceramics, and composites, that are hard and difficult to machine, requiring high precision, surface quality which increases machining cost. To meet these challenges, non-conventional machining processes are being employed to achieve higher metal removal rate, better surface finish and greater dimensional accuracy, with less tool wear. Electro Discharge Machining is a non-conventional or non-traditional machining process which is used for machining hard materials which are difficult to machine by conventional machining process. EDM can be used in machining difficult cavities and contours.There are various types of products which can be produced using EDM with high precision and good surface quality, such as dies, moulds, parts for aerospace, automobile and surgical instruments etc.In Electrical Discharge machining process using thermal energy by generating a spark to erode the workpiece. Material is remove from the workpiece by series of rapidly recurring discharge between two electrode separated by dielectric liquid subjected to an electric voltage. The workpiece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. EDM process showing in the figure-1

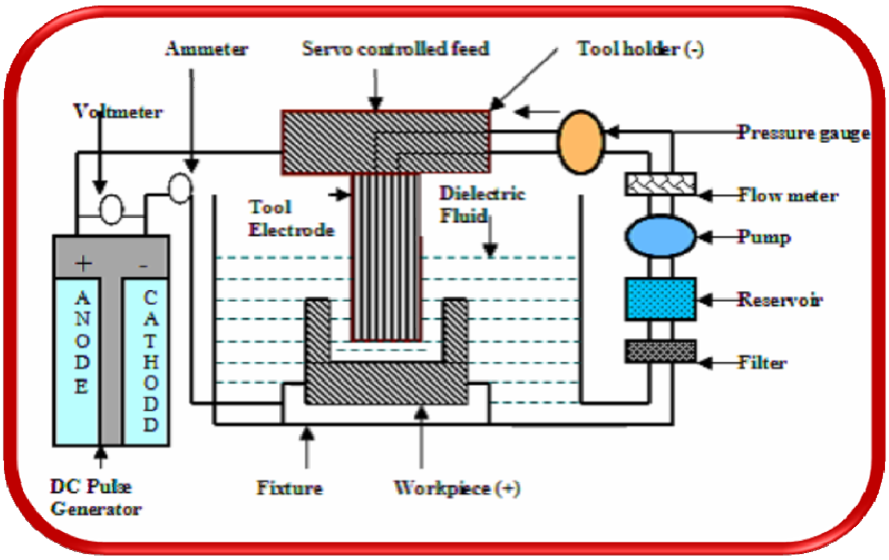


Fig.1 Line digram of EDM [S.K Choudhary & R.S Jadoun (2014)]

**1.2 Process Parameters:** The process parameters in EDM are used to control the performance measures of the machining process. Process parameters are generally controllable machining input factors that determine the conditions in which machining is carried out. These machining conditions will affect the process performance result, which are gauged using various performance measures.

**Table: 1 Process Parameters of EDM**

| S. No. | Process Parameters | Parameters Discription |
|---|---|---|
| 1. | Pulse On-time | The pulse on time represents the duration of discharge and is the time during which the electrode material is heated by the high temperature plasma channel. |
| 2. | Pulse off-time | The pulse off time represents the duration when no discharge exists and the dielectric is allowed to demonize and recover its insulating properties. |
| 3. | Arc Gap | The Arc gap is distance between the electrode and workpiece during the process of EDM. It may be called as spark gap. Spark gap can be maintained by servo system |
| 4. | Duty cycle | Duty factor is a percentage of the pulse duration relative to the total cycle time (Pulse-on time +.pulse-off time ) |
| 5. | Discharge Current | It is a measure of the amount of electrical charges flowing between the tool and workpiece electrode. Discharge current is directly proportional to the Material removal rate. |
| 6. | Gap Voltage | This can be measured as two different values during one complete cycle. |
| 7. | Electrode polarity | Electrode polarity is chosen based on the requirement of electrode wear dominance at a given pulse on time. |

## 2. LITERATURE REVIEW

### 2.1 General review of EDM work

Guu Y.H. et al, [2003] proposed the electrical discharge machining (EDM) of AISI D2 tool steel was investigated. The surface characteristics and machining damage caused by EDM were studied in terms of machining parameters. Based on the experimental data, an empirical model of the tool steel was also proposed. Surface roughness was determined with a surface profilometer. Guu Y.H. [2005] proposed the surface morphology, surface roughness and micro-crack of AISI D2 tool steel machined by the electrical discharge machining (EDM) process were analyzed by means of the atomic force microscopy (AFM) technique. Pecas, P, et al. [2008] presents on EDM technology with powder mixed dielectric and to compare its performance to the conventional EDM when dealing with the generation of high-quality surfaces. Kansal, H.K, et al., [2005] study has been made to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). S.Prabhu, et al [2008] analysed the surface characteristics of tool steel material using multiwall carbon nano tube to improve the surface finish of material to nanolevel. Ko-Ta Chiang, et al [2007] methodology for modeling and analysis of the rapidly resolidified layer of spheroidal graphite (SG) cast iron in the EDM process using the response surface methodology. The results of analysis of variance (ANOVA) indicate that the proposed mathematical model obtained can adequately describes the performance within the limits of the factors being studied. Seung-Han Yang, et al [2009] proposes an optimization methodology for the selection of best process parameters in electro discharge machining. Regular cutting experiments are carried out on die-sinking machine under different conditions of process parameters

 

**Table: 2 Researchers work Contribution based on workpiece, Tool Electrode & Parameters**

| Researcher contribution year wise | Workpiece material | Electrode material | Process & performance Parameters |
|---|---|---|---|
| **Wong et al. (1995) Investigated the influence of flushing on the efficiency and stability of machining condition.** | AISI 01 tool steel | Copper | Voltage,current, Pulse-on time Polarity, Flushing rate |
| **Ghoreishi and Atkinson (2002) Investigated and Compared the effect of high and low frequency forced axial vibration, electrode rotation and combination of these methods on performance measures.** | Tool and die steel A1S101 | Copper | Open voltage, Discharge voltage, tool Polarity, Amplitude of ultrasonic & low frequency vibration, electrode rotation, frequency of vibration |
| **Zhang et al. (2006) Applied ultrasonic to improve the efficiency in EDM in gas medium** | AISI 1045 steel | Copper | Open voltage, Pulse duration, Discharge current, Gas pressure, Wall thickness, actuation amplitude |
| **Kansal et al. (2007) Effect of Silicon Powder Mixed EDM on Machining Rate of AISI D2 Die Steel** | AISI 1045 steel | Copper | Peak current, pulse on time, pulse off time, concentration of powder, gain, and nozzle flushing |
| **Jia Tao et al. (2008) Experimental Study of the Dry and Near-Dry Electrical Discharge Milling Processes** | AISI H13 tool steel | Copper | Discharge Current , pulse duration ,pulse interval Gap Voltage , Open circuit Voltage, Polarity, Electrode rotary speed ,Depth of cut Electrode diameter ,Pressure of the dielectric fluid |
| **Iqbal & Khan (2010) Influence of Process Parameters on Electrical Discharge Machined Job Surface Integrity.** | Stainless steel AISI 304 | Copper | Voltage, feed rate, Rotational speed of the electrode |
| **B. Sidda Reddy et. al. (2010) Parametric study of electrical Discharge machining of ASI304 Stainless steel.** | Stainless steel AISI 304 | Copper | Current, Open Circuit voltage, Servo and Duty cycle. |
| **Vishwakarma M. et. al.(2012) Response surface approach for optimization of Sinker Electric Discharge Machine process parameters on AISI 4140 alloy steel** | AISI 4140 Grade steel alloy. | Copper | Discharge current, Pulse-on time, Duty Cycle, Gap Voltage, flushing Pressure |
| **Belgassim and Abusada (2012) Optimization of the EDM Parameters on the Surface Roughness of AISI D3 Tool Steel.** | AISI D3 Tool Steel | Copper | Pulse current Pulse –on time, Pulse –off time & gap voltage |
| **Gurule & Nandurkar (2012) Effect of Tool Rotation on Material Removal Rate during Powder Mixed Electric Discharge Machining of Die Steel.** | Die steel D2 | copper | Pulse current, Pulse –on time, Pulse –off time, Suspension of Al powder concentration,Tool rotation, flushing pressure, |
| **Arjun kumar, R.S Jadoun & S.K choudhary (2015) Investigations on Material Removal Rate of AISI D2 Die Steel in EDM using Taguchi Methods** | AISI D2 Die steel | Copper | Pulse-on time, pulse-off time, current, voltage, |

## 3. RESEARCH METHODLOGY

### 3.1 Experimental Setup

The experiments were conducted using the Electric Discharge Machine model C- 3822 WITH PSR-20.The polarity of the electrode was set as nigative while that of workpiece was positive. The dielectric fluid used was EDM oil or kerosene oil (specific gravity-0.820). The EDM consists of the following parts:

- Power generator and control unit: - The power supply control the amount of energy consumed.
- The tool holder: – The tool holder holds the tool with the process of machining.
- The servo system to feed the tool: - The servo control unit is provided to maintain the pre determined gap between the electrode and workpiece.
- Working tank with work holding device:-All the EDM oil kept in the working tank is used to the supply the fluid during the process of machining.
- Dielectric reservoirs pump and circulation system: - Dielectric reservoirs & pump are used to circulate the EDM oil for every run of the experiment & also used the filter the EDM oil.

**Fig.2Experimental setup of EDM**

**3.2 Selection of the Workpiece**

**AISI D2 Die steel** is an air hardening, high-carbon, high-chromium tool steel. It has high wear and abrasion resistant properties. AISI $D_2$ Die Steel is one of the most widely used materials in all industrial applications such as: Stamping or Forming Dies, Punches, Forming Rolls, Knives, slitters, shear blades, Tools , Scrap choppers ,Tyre shredder etc. AISI D2 Die Steel block of 50 mm x50mm x5mm size has been used as a work piecematerial for the present experiments. This is shows in fig 3.

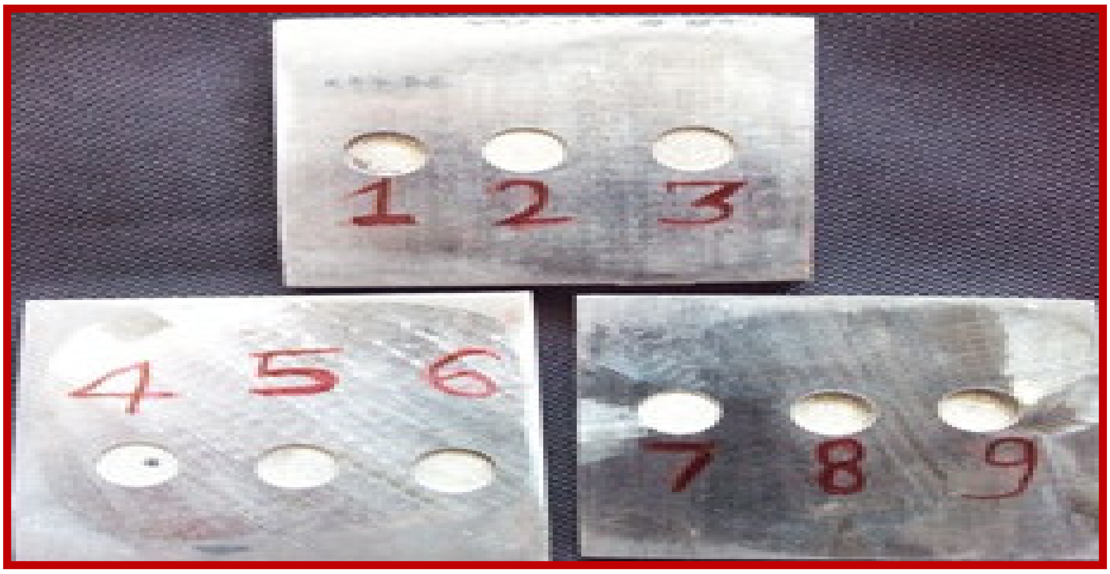


**Fig.3 A View of Work piece Machined by EDM**

**Table-3 Chemical composition of AISI D2 Die Steel**

| Element | Chemical Compositions (wt %) |
|---|---|
| Carbon (C) | 1.50 |
| Silicon (Si) | 0.30 |
| Cromium (Cr) | 12.00 |
| Molybdenum (Mo) | 0.80 |
| Vanadium (V) | 0.90 |
| Ioron (Fe) | 84.5 |

**Table-4 Mechanical Properties of AISI D2 Die Steel**

| AISI D2 Die Steel | |
|---|---|
| Density (gm./cc) | 7.7 |
| Thermal Conductivity (W/m °C) | 20.0 |
| Modulus of elasticity (MPa) | $210 \times 10^3$ |
| Specific heat (J/kg °C) | 460 |

### 3.3 Selection of tool electrode

The tool material used in Electro Discharge Machining can be of a variety of metals like copper, brass, aluminium alloys, silver alloys etc. The selection of particular electrode material depends primarily upon the specific cutting application and upon the material being machined. Main characteristics of the tool electrode material should have high thermal conductivity, high electric conductivity, high melting point and high density etc. Theese properties avaliable in the copper tool electrode so used in this experiment is copper. The tool electrode is in the shape of a cylinder having a diameter of 8 mm. This is shows in fig.4.

**Fig.4 Copper Tool Used For Experiments**

**Table-4 Mechanical properties of tool electrode**

| Copper (99% pure) | |
|---|---|
| Thermal Conductivity (w/mk) | 391 |
| Density (gm/cc) | 1083 |
| Electrical Resistivity (ohm-cm ) | 1.69 |
| Specific heat capacity (j/gm-◦c) | 0.385 |

### 4. RESULTS & DISCUSSION

The effects of the machining parameters in electrical discharge machining on the machining characteristics of D2 Die Steel work piece has been investigated in this study.Tool Wear Rate (TWR) are considered as responses while machining variables are pulse on time, pulse off time, current and voltage. Taguchi method is used to develop empirical models correlating process variables and their interactions with the said response functions. The significant parameters that critically influence the machining characteristics are examined and the variations of responses with the process parameters are studied.

### 4.1 Data Analysis for Tool Wear Rate (TWR)

In this section, the data of TWR obtained from experiments are analysed.As mentioned earlier, experiments are carried out varying the process parameters (pulse on time, pulse off time, current and voltage) in EDM of D2 Die Steel.The experiments are conducted by Minitab15 software based on L9 Orthogonal array (OA) consisting 9 number of experiments. The raw data for TWR is presented in Table-5.

 

**Table-5 Experimental results for TWR**

| Exp. No | Pulse ON Time (µs) | Pulse OFF Time (µs) | Peak Current (amp) | Gap Voltage (volt) | Tool Weight (gm) | |
|---|---|---|---|---|---|---|
| | | | | | $W_b$ | $W_a$ |
| 1 | 20 | 7 | 6 | 40 | 29.8217 | 29.8216 |
| 2 | 20 | 8 | 8 | 50 | 29.8269 | 29.8238 |
| 3 | 20 | 9 | 10 | 60 | 29.8201 | 29.8166 |
| 4 | 30 | 7 | 8 | 60 | 29.8210 | 29.8201 |
| 5 | 30 | 8 | 10 | 40 | 29.8166 | 29.8129 |
| 6 | 30 | 9 | 6 | 50 | 29.8216 | 29.8210 |
| 7 | 40 | 7 | 10 | 50 | 29.8129 | 29.8121 |
| 8 | 40 | 8 | 6 | 60 | 29.8238 | 29.8217 |
| 9 | 40 | 9 | 8 | 40 | 29.83246 | 29.82690 |

After taking the raw data from table-5, we conclude the tool wear rate by applying the formula which is discussed in materials and methods. The S/N ratio and mean ratio are to be given by the Minitab15 software.

**Table-6 Average Table for TWR**

| Exp. No | Ton µs | Toff µs | Ip amp | Vg volt | TWR $mm^3/min$ | S/N Ratio | Mean ratio |
|---|---|---|---|---|---|---|---|
| 1 | 20 | 7 | 6 | 40 | 0.001124 | 58.9847 | 0.001124 |
| 2 | 20 | 8 | 8 | 50 | 0.034831 | 29.1607 | 0.034831 |
| 3 | 20 | 9 | 10 | 60 | 0.039326 | 28.1064 | 0.039326 |
| 4 | 30 | 7 | 8 | 60 | 0.010112 | 39.9033 | 0.010112 |
| 5 | 30 | 8 | 10 | 40 | 0.041573 | 27.6238 | 0.041573 |
| 6 | 30 | 9 | 6 | 50 | 0.006742 | 43.4242 | 0.006742 |
| 7 | 40 | 7 | 10 | 50 | 0.008989 | 40.9258 | 0.008989 |
| 8 | 40 | 8 | 6 | 60 | 0.023596 | 32.5432 | 0.023596 |
| 9 | 40 | 9 | 8 | 40 | 24.0863 | 24.0863 | 24.0863 |

Taguchi method (smaller is better criteria) is applied to analyse the effect of individual parameters. On the basis of response table it is finding that the pulse off time is more contribution to metal removal rate.The main effect plot for S/N ratio and main effect plot for means shows that the indivisiual effects of the different parameters which is used in these experiments.

**Table-7 Response for S/N Ratio Smaller is better (TWR)**

| Level | Pulse-on time (A) | Pulse-off time (B) | Current (C) | Voltage (D) |
|---|---|---|---|---|
| 1 | 38.75 | 46.60 | 44.98 | 36.90 |
| 2 | 36.98 | 29.78 | 31.05 | 37.84 |
| 3 | 32.52 | 31.87 | 32.22 | 33.52 |
| Delta | 6.23 | 16.83 | 13.93 | 4.32 |
| Rank | 3 | 1 | 2 | 4 |

**Table-8 Response for Means (TWR)**

| Level | Pulse on time (A) | Pulse off time (B) | Current (C) | Voltage (D) |
|---|---|---|---|---|
| 1 | 0.025094 | 0.006742 | 0.010487 | 0.035056 |
| 2 | 0.019476 | 0.033333 | 0.035805 | 0.016854 |
| 3 | 0.031686 | 0.036180 | 0.029963 | 0.024345 |
| Delta | 0.012210 | 0.029438 | 0.025318 | 0.018202 |
| Rank | 4 | 1 | 2 | 3 |

From the main effect plot for S/N ratios shows in fig.5 that the tool wear rate is linearly vary with the process parameters. MRR with respect to Toff, it is decreases rapidly initially and after that it is increase. TWR also decreases with respect to the current. Whereas Ton factor is less contribution to metal removal rate shows in fig.41.Gap voltage is also less contribution to tool wear, at initial level of the voltage the TWR increase slightly and after that it is falls down.

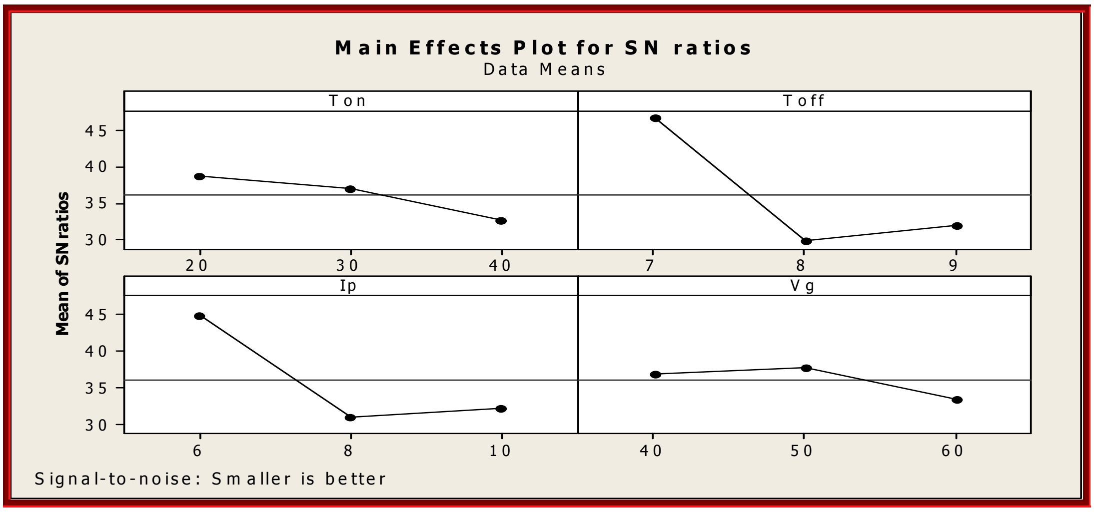


**Fig.5 Main Effect Plot for S/N Ratio of TWR**

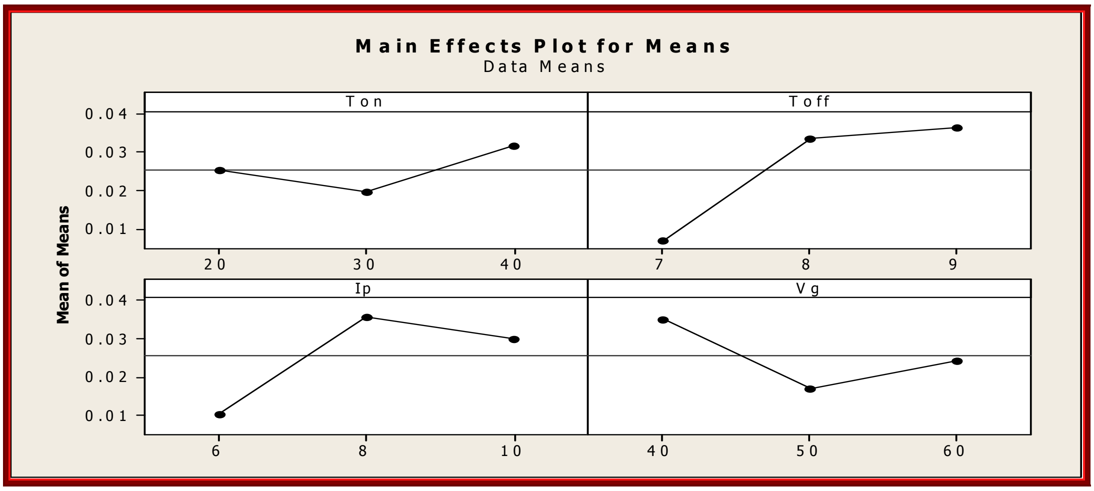


**Fig.6 Main Effect Plot for Means Ratio of TWR**

### 4.2.1 Selection of Optimal Settings for TWR

Tool Wear Rate (TWR) is Smaller-the-better type quality characteristic. Therefore lower values of TWR are considered to be optimal. It is clear from Fig.5 and Fig.6 that tool wear rate is lowest at third level of pulse on time, second level of pulse off time, second level of current and third level of voltage. Process parameters and their selected optimal levels are given below:

| | | |
|---|---|---|
| Pulse on time (Ton) | A (3) | 40µs |
| Pulse off time (Toff) | B (2) | 8 µs |
| Current (Ip) | C (2) | 8 amp |
| Voltage (Vg) | D (3) | 60 Volt |

### 4.2.2 Analysis of Variance (ANOVA) For Tool Wear Rate (TWR)

The S/N ratios for TWR are calculated as given in Equation.1. Taguchi method is used to analysis the result of response of machining parameter for smaller is better (SB) criteria.

$$SB:\eta = -10 \log \left[ \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right] \ldots\ldots\ldots\ldots (1)$$

The analysis of variances for the factors are Ton, Toff, Ip and vg as shown in Table-7

**Table-9 ANOVA for S/N Ratio (TWR)**

| Source | DOF | Seq SS | Adj SS | Adj MS | F | P(%) |
|---|---|---|---|---|---|---|
| Pulse on(Ton) | 2 | 61.901 | 61.901 | 30.950 | 2.729 | 6.6 |
| Pulse off(Toff) | 2 | 504.639 | 504.639 | 252.319 | 22.246 | 54.3 |
| Current ($I_p$) | 2 | 358.476 | 358.476 | 179.238 | 15.803 | 38.6 |
| Voltage ($V_g$) | 2 | 30.966 | 30.966 | 15.483 | 1.365 | 3.3 |
| Residual error | 0 | 22.684 | | | | |
| Total | 8 | 929.297 | | | | |

**Table-10 ANOVA for Means (TWR)**

| Source | DOF | Seq SS | Adj SS | Adj MS | F | P(%) |
|---|---|---|---|---|---|---|
| Pulse on(Ton) | 2 | 0.000224 | 0.000224 | 0.000112 | 9.334 | 6.6 |
| Pulse off(Toff) | 2 | 0.001582 | 0.001582 | 0.000791 | 6.592 | 47.04 |
| Current ($I_p$) | 2 | 0.001054 | 0.001054 | 0.000527 | 43.916 | 31.34 |
| Voltage ($V_g$) | 2 | 0.000502 | 0.000502 | 0.000251 | 20.917 | 14.92 |
| Residual error | 0 | 0.000024 | | | | |
| Total | 10 | 0.003363 | | | | |

Seq, SS, sum of squares;
DOF, Degree of freedom;
Adj MS, Adjusted Mean square
P, Percentage contribution;
Significance at 95% confidence level

**4.3 Optimal Design for TWR**

In the experimental analysis, main effect plot of S/N ratio is used for estimating the S/N ratio of TWR also with optimal design condition. As shown in the graphs, there are highest values which affect the tool wear rate which are the pulse on (A1), pulse-off (B1), current (C1) and voltage (D2) respectively. After evaluating the optimal parameter settings, the next step of the Taguchi approach is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. Theestimated S/N ratio using the optimal level of the design parameters can be calculated.

$n_{opt} = n_m + \sum_i^a (\bar{n}_i - n_m)$

Where $n_m$ = the total mean of S/N ratio

$\bar{n}_i$ = mean S/N ratio at optimum level

a = number of design parameters that effect quality characteristics

Based on the above equation the estimated multi response signal to noise ratio can be obtained.

$n_{opt} = 36.08 + (32.52-36.08) + (29.78 - 36.08) + (31.05 - 36.08) + (33.52 - 36.08)$
$= 18.63$

$$\text{Correspond ing value of TWR } = y^2{}_{opt} = 10^{\frac{-n_{opt}}{10}}$$

$$\text{Correspond ing value of TWR } = y^2{}_{opt} = 10^{\frac{-18.63}{10}}$$

$$\mathbf{y = 0.117\ mm^3/min}$$

As per the optimal level again the experiment is performed as A3, B2, C2 and D3.And the optimal vale of TWR is 0.117 $mm^3$/min.

**4.4 Effects of Process Parameters on Metal Removal Rate (MRR)**

From above main effect plot of MRR we can conclude the optimum condition for MRR is A2, B1, C3, D1 i.e. Pulse-on (30µs) and Pulse-off (7 µs), Current (10 amp), Voltage (40V).

Pulse on time factor have more contribution for removing the material after that current have been giving there contribution for that. The increasing order of influence parameters are showed in below.

Ton (30µs) > Ip (10 amp) > Vg (40V) > Toff (7 µs)

### 4.5 Effects of Process Parameters on Tool Wear Rate (TWR)

It is clearly indicate that Vg not important for influencing TWR and the value of Toff and Ip is most affected the TWR and as well as into Toff significant is shown in bold and otherwise not significant. The delta values of Ton, Toff, Ip and Vg are 6.23, 16.83, 13.93 and 4.32 respectively, in Table-9. The case of TWR Smaller is better, so from this table it is clearly definite that Toff is the most important factor then Ip and last is voltage. From above main effect plot of TWR we can conclude the optimum condition for TWR is A3, B2, C2, D3 i.e. Pulse-on (40µs) and Pulse-off (8 µs), Current (8 amp), Voltage (60V).The increasing order of influence parameters are showed in below.

Toff(8 µs) > Ip(8 amp) > Ton(40µs) > Vg (60 volt)

## 5. CONCLUSION

In this study the experiment was conducted by considering four variable parameters namely current, pulse on time, pulse off time and voltage. The objective was to find the Tool Wear Rate (TWR) to study the effects of the variable parameters on these characteristics. The tool material was taken as copper and the workpiece was chosen as AISI D2 Die Steel. Using the Taguchi method an $L_9$orthogonal array was created and the experiments were performed accordingly. In the case of Tool wear rate the most important factor is pulse off time then current and after that voltage. The result obtained for TWR is A3, B2, C2, D3 i.e. Pulse-on (40µs) and Pulse-off (8 µs), Current (8 amp), Voltage (60V).As per the optimal level of parameters the optimum value of TWR is 0.117 $mm^3$/min.

## 6. FUTURE SCOPE OF WORK

The present study is extremely useful for minimizing TWR. Future study on this method may evaluate the following aspects.

- Instead of copper electrode other electrode material like, brass or graphite, Copper tungsten, tungsten carbide may be used, in EDM process.
- Different grades of tool steels may be used for the optimization of machining parameters for the interest of industries.
- In this study, only four machining parameters (pulse-on time, pulse-off time, Current, Voltage, are chosen. A detailed study may be done, considering other parameters also.
- There are several optimization tools, viz. RSM, ANN, ANFIS, GA and WPCA may be employed for the optimization procedure.
- This optimization procedure of machining parameters may be used for other nonconventional machining process like WEDM, ECM, AJM, USM, PAM &other hybrid EDM etc.

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**Authers Biography**

**Er. Arjun Kumar** is currently working as teaching personnel of Industrial & Production Engineering Department, College of Technology, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India. He received his B.Tech degree in Mechanical Engineering from Uttaranchal Institute of Technology, Dehradun (affiliated to U.T.U) in 2011 & M. Tech degree in Manufacturing Engineering and Management from G.B. Pant University of Agriculture & Technology, Pantnagar in 2014.

**Dr. R.S Jadoun** is Professor and Head of Industrial & Production Engineering Department, College of Technology, G.B. Pant University of Agriculture & Technology, Pantnagar, since 2010. He has served the Government of Bihar / Jharkhand as Dy. Collector. He has about 29 years of teaching, research and administrative experience. He has published more than 30 research papers in journals of national and international repute. His teaching & research area include manufacturing process, unconventional machining process, welding, Industrial Engineering etc.

**Er. Sushil Kumar Choudhary** is Pursuing Ph.D in the Department of Industrial & Production Engineering, College of Technology, G.B Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India; He received his B.Tech degree in Mechanical Engineering from UPTU, Lucknow, India, & M.Tech degree in Industrial & Production Engineering from Integral University, Lucknow, India. His teaching & research area include manufacturing process, unconventional machining process, welding, Industrial Engineering, etc. His publications include international journal, conference more than 20 technical research papers and one international book. .

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