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# Optimization of Machine Process Parameters on Material Removal Rate in EDM for AISI P20 tool Steel Material using RSM

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**Abstract—***In the present study, response surface methodology was used to investigate the relationships and parametric interactions between the measurable and controllable variables on the material removal rate (MRR) in die sinking EDM for AISI P20 tool steel material. For conducting the experiments, three process variables viz. discharge current ($I_p$), pulse duration ($T_{on}$) and duty cycle ($T_{au}$) were considered and copper was used as the electrode material. Total 20 experiments were carried out for different combinations of process parameters. Analysis was carried out using the response surface method and Anova analysis. These data have been utilized to fit a quadratic mathematical model (RSM) for each of the responses, which can be represented as a function of the process parameter. Moreover, an attempt has been made to optimize the material removal rate in the studied region.*

## 1. INTRODUCTION

Electrical discharge machining (EDM) is an electro-thermal non-traditional manufacturing process based on removing material from a part by means of a series of repeated electrical discharges between a tool, called the electrode, and the part being machined in the presence of a dielectric fluid. At present, EDM is a widespread technique used in manufacturing industry for high-precision machining of all types of conductive materials, such as metals, metallic alloys, graphite, or even some composite and ceramic materials.

The most common methods to evaluate machining performance in the EDM operation are based on the following performance characteristics: material removal rate (MRR). A Proper selection of these machining parameters can result in a higher. Earlier, the desired machining parameters are determined based on experience or on handbook values. But these selected machining parameters are not always optimal or near optimal for that particular EDM environment. Therefore in EDM, it is very important to select machining parameters for achieving optimum machining performance [1]. Various techniques, both conventional and non-conventional processes are employed to predict the optimum response parameters of the process. [2]Vishal Parashar, A.Rehman, J.L.Bhagoria, Y.M.Puri carried out the effect input parameters like gap voltage, pulse ON time, pulse OFF time, wire feed and dielectric flushing pressure over the MRR for an Stainless Steel grade 304L in WEDM operations. Experimentation was planned as per Taguchi's L'32 (21 X 44) mixed orthogonal array. From experimental results, the MRR was determined for each machining performance criteria. Analysis of variance (ANOVA) technique was used to find out the variables affecting the MRR. Variation of the MRR with machining parameters was mathematically modeled by using the regression analysis method. Finally, the developed model was validated with a new set of experimental data and appeared satisfactory result. [3]Mohd Amri Lajis, H.C.D. Mohd Radzi, A.K.M. Nurul Amin in their paper, used EDM for cutting of Tungsten Carbide with a graphite electrode by using Taguchi methodology to predict the optimal choice for each EDM parameter such as peak current, voltage, pulse duration and interval time. It was found that these parameters have a significant influence on machining characteristic such as metal removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR). The analysis of the Taguchi method revealed that, in general the peak current significantly affects the EWR and SR, while, the pulse duration mainly affects the MRR. [4]Vishnu D Asal et al. conducted experiment on Process parameters of EDM by using the ANOVA method. In this experiment, two level of current, tool material, and spark gap are kept as the main variable. They use the material of S.S.304 as the work piece and copper and brass as the tool electrode and also DEF-92 as dielectric fluid. The design of experiment is used to design the EDM experiments. The various tool of DOE are used to analyze the final result of the experiment with the help of graphs in research. The analysis is being done with the help of mini-tab 15 software. ANOVS is performed to identify the statistical significance of parameters. [5] Chandramouli S et al. conducted investigating EDM process parameters by using the Taguchi method and select the optimum result from that. The effect of various process parameter on machining performance is investigated by the Taguchi method. They use the input parameters as current, pulse time on, and pulse time off and the other side of Material removal rate (MRR), Tool wear rate (TWR), and surface roughness (SR). The taguchi method is used to formulate the experimental layout, ANOVA method is used to analysis the effect of input parameters on machining characteristics and find the optimum process parameters.

[6] Raghuraman S et al. Performed on mild steel IS 2026 by using the taguchi method. In this paper the input process parameters such as current, pulse time ON, pulse time OFF and the other side of the output parameters selected as Material removal rate, tool wear rate and the surface roughness of the work piece material. They used the work piece material as mild steel 2026 and the electrode as copper. In this paper the main objective of to find the maximum MRR and select the best process parameters. For this getting result they use the Taguchi DOE and use the L9 orthogonal array and analysis on them. The confirmation experiments were carried out to validate the optimal results. Thus, the machining parameters for EDM were optimized for achieving the combined objectives of higher rate of material removal, lower wear rate on tool, and lower surface roughness on the work material considered in this work. The obtained results show the taguchi Gray relational Analysis is being technique to optimize the machining parameters for EDM process. [7] Luis et al. have studied the influence of pulse current, pulse time, duty cycle, open-circuit voltage and dielectric flushing pressure, over the MRR and other response variable on tungsten carbide. To attain high removal rate in EDM, a stable machining process is required, which is partly influenced by the contamination of the gap between the workpiece (hardened steel 210CR12) and the electrode, and it also depends on the size of the eroding surface at the given machining regime

[8]. Palanikumarin, in his work using Response Surface Method (RSM) modeled the surface roughness in machining of glass fibber reinforced plastic (GFRP) composite materials [9]. He employed four factors five level central composite, rotatable design matrix for experimental investigation and for validation of the model; he used ANOVA. Little research has been reported about EDM on AISI D2 steel yet for the modeling by, surface response methodology. In this paper, surface response approach is used for development of a model and analysis of MRR, with peak current, pulse on time and pulse off time as input parameters. A central composite design (CCD) for combination of variables and response surface method (RSM) have been used to analyse the effect of the three parameters, pulse current (Ip), pulse on time (Ton) and pulse off time (Toff), on the MRR of EDM process.

Little research has been reported about EDM on AISI P20 tool steel yet for the modeling by, surface response methodology. In this paper, surface response approach is used for development of a model and analysis of MRR, with discharge current, pulse duration and duty cycle as input parameters. A central composite design (CCD) for combination of variables and response surface method (RSM) have been used to analyse the effect of the three parameters, discharge current (Ip), pulse duration (Ton) and duty cycle (Tau), on the MRR of EDM process.

## 2. EXPERIMENTATION

The experimental work was conducted on work electric discharge machine (ACTSPARK SP1, China) die-sinking type with servo-head (constant gap) and positive polarity for electrode is used for experimentation. Commercial grade EDM-30 oil (specific gravity of 0.80 at 25C, viscosity of 3.11 × 10-6 $m^2 s^{-1}$ at 38 ˚C) was used as dielectric fluid. Lateral flushing with a pressure of 0.3 $kgf/cm^2$ was used. During experiments, square holes of dimensions 15 mm × 15 mm were machined with a depth of 3 mm. The shop-floor data thus obtained during the experiment are then used to calculate the values of MRR.

### 2.1 Electrode and work materials

The electrode used in the present study was copper with a cross-sectional dimension of 15 mm × 15 mm. The major properties of the electrode materials are shown in Table 1. The workpiece material used in the present study was AISI P20 tool steel material. Their chemical compositions are shown in Table 2.

**Table 1: Major properties of electrode materials.**

| Electrode material | Thermal Conductivity (W/cm °C) | Melting point (°C) | Electrical resistivity (ohm cm) | Specific heat capacity (J/g °C) |
|---|---|---|---|---|
| Copper | 3.91 | 1083 | 1.69 | 0.385 |

**Table 2 Chemical composition of work metal element weight %.**

| | C | Mn | Si | Cr | Mo | Cu | P | S |
|---|---|---|---|---|---|---|---|---|
| AISI P20 tool steel | 0.28 to 0.40 | 0.60 to 1.00 | 0.20 to 0.80 | 1.40 to 2.00 | 0.30 to 0.55 | 0.25 | 0.03 | 0.03 |

## 3. RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for modelling and analysis of problems in which output or response influenced by several variables and the goal is to find the correlation between the response and the variables. It can be used for optimizing the response [10]. It is an empirical modelization technique devoted to the evaluation of relations existing between a group of controlled experimental factors and the observed results of one or more selected criteria. A prior knowledge of the studied process is thus necessary to achieve a realistic model. We selected only three experimental factors capable of influencing the studied process yield: three factors discharge current (Ip), pulse duration (Ton) and duty cycle (Tau).

The first step of RSM is to define the limits of the experimental domain to be explored. These limits are made as wide as possible to obtain a clear response from the model. Discharge current (Ip), pulse duration (Ton) and duty cycle (Tau) are the machining variable, selected for our investigation. The different levels retained for this study are depicted in Table 3.

In the next step, the planning to accomplish the experiments by means of response surface methodology (RSM) using a Central Composite Design (CCD) with three variables, eight cube points, four central points, six axial points and two centre point in axial, in total 20 runs. Total numbers of experiments conducted with the combination of machining parameter are presented in Table 4. The central composite design used since it gives a comparatively accurate prediction of all response variable averages related to quantities measured during experimentation [11]. CCD offers the advantage that certain level adjustments are allowed and can be used in two-step chronological response surface methods [12]. In these methods, there is a possibility that the experiments will stop with fairly few runs and decide that the prediction model is satisfactory.

The mathematical model is then developed that illustrate the relationship between the process variable and response. The behavior of the system is explained by the following empirical second-order polynomial model.

$$Y= \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j$$

where Y is the corresponding response MRR produced by the various process variables of EDM; the Xi (1, 2,…, n) are coded levels of n quantitative process variables; and the terms $\beta_0$, $\beta_i$, $\beta_{ii}$ and $\beta_{ij}$ are the second-order regression coefficients. The second term under the summation sign of this polynomial equation is attributable to the linear effect, whereas the third term corresponds to the higher-order effects; the fourth term of the equation includes the interactive effects of the process parameters.

Analysis of variance (ANOVA) for the adequacy of the model is then performed in the subsequent step. The F ratio is calculated for 95% level of confidence. The value which are less than 0.05 are considered significant and the values greater than 0.05 are not significant and the model is adequate to represent the relationship between machining response and the machining parameters. Since the EDM process is non-linear in nature [13] the linear polynomial will be not able to predict the response accurately therefore the Second-order model (quadratic model) is used. It is observed from the adequacy test by ANOVA that linear terms Ip, Ton and Tau interaction term Ip with Ton and Ip with Tau and square terms $Ip^2$ and $Ton^2$ are significant. The levels of significant are depicted in the Table 5. The fit summary recommended that the quadratic model is statistically significant for analysis of MRR. For the appropriate fitting of MRR, the non-significant terms (p-value is greater than 0.05) are eliminated by backward the elimination process. The ANOVA Table for the curtailed quadratic model for MRR is shown in Table 6, the reduced model results indicate that the model is significant ($R_2$ and adjusted $R_2$ are 99.5% and 99.23%, respectively), and lack of fit is non-significant (p-value is less than 0.05). After eliminating the non-significant terms, the final response equation for MRR is given as follows.

$$MRR = 8.56 - 3.670\,Ip - 0.01205\,Ton - 0.0964\,Tau + 0.1026\,Ip^2 + 0.000030\,Ton^2 - 0.000687\,Ip*Ton + 0.04647\,Ip*Tau$$

The final model tested for variance analysis (F-test) indicates that the adequacy of the test is established. The computed values of response parameters, model graphs are generated for the further analysis in the next section.

**Table 3: Different variables used in the experiment and their levels**

| | Levels | | |
|---|---|---|---|
| Factors | -1 | 0 | +1 |
| Ip (A) | 2 | 5 | 8 |
| Ton (µs) | 100 | 200 | 300 |
| Duty Cycle (%) | 75 | 85 | 95 |

Table 4 - Planning matrix of the experiments with the optimal model data.

| | **Ip** | **Ton** | **Tau** | **MRR (mm3/min)** |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 2.0962 |
| 2 | 0 | 1 | 0 | 2.4578 |
| 3 | -1 | -1 | 1 | 0.3170 |
| 4 | -1 | 1 | 1 | 0.0146 |
| 5 | 1 | -1 | -1 | 4.6926 |
| 6 | -1 | 0 | 0 | 0.0868 |
| 7 | 0 | 0 | 0 | 2.4264 |
| 8 | 0 | 0 | 0 | 2.4120 |
| 9 | 0 | 0 | 1 | 3.3504 |
| 10 | -1 | 1 | -1 | 0.0434 |
| 11 | 0 | 0 | 0 | 2.4686 |
| 12 | 0 | 0 | 0 | 2.4686 |
| 13 | -1 | -1 | -1 | 0.0868 |
| 14 | 0 | -1 | 0 | 3.4662 |
| 15 | 1 | 1 | 1 | 9.3724 |
| 16 | 1 | 1 | -1 | 3.8976 |
| 17 | 0 | 0 | -1 | 1.3144 |

| | | | | |
|---|---|---|---|---|
| 18 | 1 | 0 | 0 | 7.0778 |
| 19 | 0 | 0 | 0 | 2.6410 |
| 20 | 1 | -1 | 1 | 10.5712 |

**Table 5: ANOVA table for MRR (after backward elimination)**

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 8.56 | 1.58 | 5.43 | 0.000 |
| Ip | -3.670 | 0.313 | -11.72 | 0.000 |
| Ton | -0.01205 | 0.00606 | -1.99 | 0.070 |
| Tau | -0.0964 | 0.0174 | -5.55 | 0.000 |
| Ip2 | 0.1026 | 0.0161 | 6.37 | 0.000 |
| Ton2 | 0.000030 | 0.000015 | 2.09 | 0.058 |
| Ip * Ton | -0.000687 | 0.000306 | -2.24 | 0.044 |
| Ip * Tau | 0.04647 | 0.00306 | 15.19 | 0.000 |
| S = 0.259590 R-Sq = 99.51% R-Sq(adj) = 98.43% | | | | |

**Table 6: Analysis of Variance for MRR**

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 7 | 164.828 | 164.828 | 23.547 | 349.43 | 0.000 |
| Linear | 3 | 142.533 | 142.533 | 47.511 | 705.05 | 0.000 |
| Square | 2 | 6.409 | 6.409 | 3.205 | 47.56 | 0.000 |
| Interaction | 2 | 15.885 | 15.885 | 7.943 | 117.87 | 0.000 |
| Residual Error | 12 | 0.809 | 0.809 | 0.067 | | |
| Lack-of-Fit | 7 | 0.650 | 0.650 | 0.093 | 2.93 | 0.127 |
| Pure Error | 5 | 0.159 | 0.159 | 0.032 | | |
| Total | 19 | 165.637 | | | | |

For analysis the data, the checking of goodness of fit of the model is very much required. The model adequacy checking includes the test for significance of the regression model, test for significance on model coefficients, and test for lack of fit. For this purpose, analysis of variance (ANOVA) is performed. The fit summary recommended that the quadratic model is statistically significant for analysis of MRR.

The check of the normality assumptions of the data is then conducted, it can be seen in Fig. 1 that all the points on the normal plot come close to forming a straight line. This implies that the data are fairly normal and there is no deviation from the normality. This shows the effectiveness of the developed model. Notice that the residuals are falling on a straight line, which means that the errors are normally distributed. In addition, Fig. 1 illustrate that there is no noticeable pattern and unusual structure. This implies that the proposed model is adequate to illustrate the pattern of MRR.

## 4. RESULTS AND DISCUSSION

The effect of the machining parameters (Ip, Ton and Tau) on the response variables MRR have been evaluated by conducting experiments as described in Section 2. The results are put into the Minitab software 17 for further analysis following the steps summarized in Sect. 3. The second-order model was proposed in find the correlation between the MRR and the process variables taken into account. The analysis of variance (ANOVA) was used to check the sufficiency of the second order model. The results obtained from the experiments are compared with the predicted value calculated from the model in fig 1. It can be seen that the regression model is reasonably well fitted with the observed values. The residues, which are, calculated as the difference between the predicted and observed value lies in the range of - 0.46 to 0.378.

Fig. 2 shows the estimated response surface for MRR in relation to the process parameters of discharge current and pulse on time. It can be seen from the figure, the MRR tends to increase, significantly with increase in discharge. For lower value of discharge current the MRR is very small, it is due to the reason that at low current, a small amount of heat is produced out of which some heat is absorbed by machine components, dielectric fluid in the tank surroundings environment etc and left heat is utilized to melt and vaporize workpiece material. But as the current increased, more intermittent arc discharge occurring with higher energy. This is due to their dominant control over the input energy i.e. with the increase in pulse current generates strong spark which create the higher temperature cause the more material to melt and vaporize the workpiece material. This heat increases the MRR.

The effect of Ton and Tau is on the estimated response surface of MRR is depicted in the Fig. 3, MRR usually increases with Ton up to a maximum value after which that it starts to decrease. In this experiment from the graph it is clear that Ton at 100 µs gives maximum MRR after that it decreases. This is due to the fact that with higher Ton, the plasma formed between the Inter electrode gap (IEG) actually hinders the energy transfer and thus reduces MRR. Increase in duty cycle means increase in pulse on time and decrease in pulse off time. It is observed that increase in duty cycle leads to increase in MRR. It is due to the reason that with an increase in pulse on time, total machining time and hence total current utilization time increases. Increase in pulse on time retains the spark for more time in spark gap. This means more time the heat is available to melt and vaporize the work material.

The effect of Ip and Tau is on the estimated response surface of MRR is depicted in the Fig. 4. It can be seen from the figure, the MRR tends to increase, significantly with increase in discharge current for any value of duty cycle.

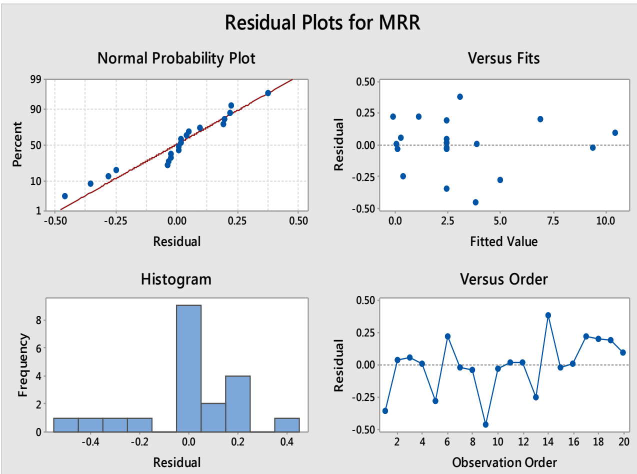


**Fig. 1: Residual plots for MRR**

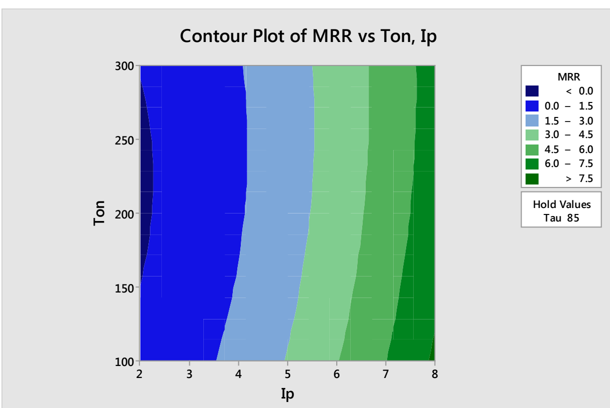


**Fig. 2: Effect of Ip and Ton on MRR**

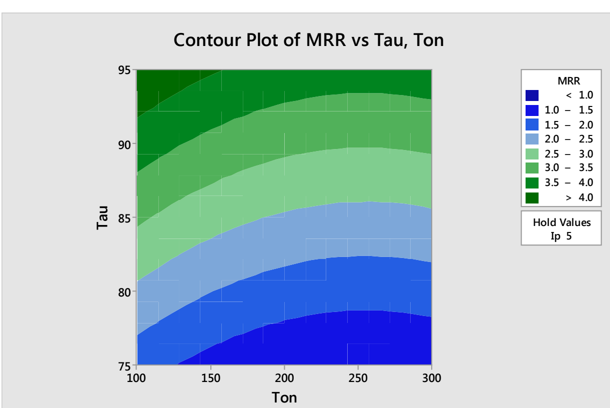


**Fig. 2: Effect of Ton and Tau on MRR**

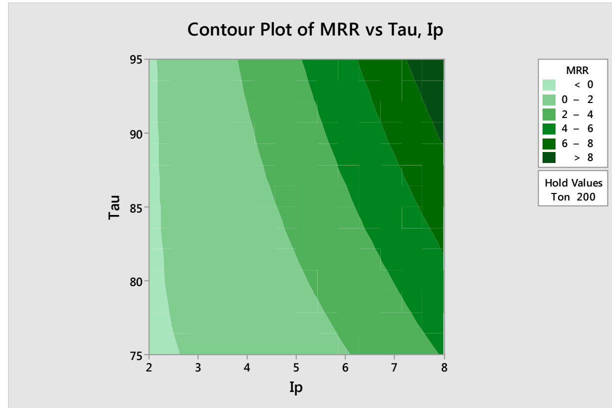


**Fig. 3: Effect of Ip and Tau on MRR**

## Optimization using desirability approach

Each response in the research work are expressed separately as linear and nonlinear functions of input variables such as Ip, Ton and Tau. Now, aim is to maximize the response MRR and simultaneously maintain other responses in EDM process. As shown in Fig. 5. optimal values of input parameters is obtained by response optimizer by maximization desirability function. To determine optimal solution of input variables in order to satisfy the above criteria of MRR maximization, it had been solved by Response optimizer desirability maximization function in Minitab 17 environment.

The above graph shows optimization plot for MRR. from the graph it is clear that highest value 10.4769 is obtained for the following combination of the variables :

Ip = 8 A

Ton = 100 μs

Tau = 95 %

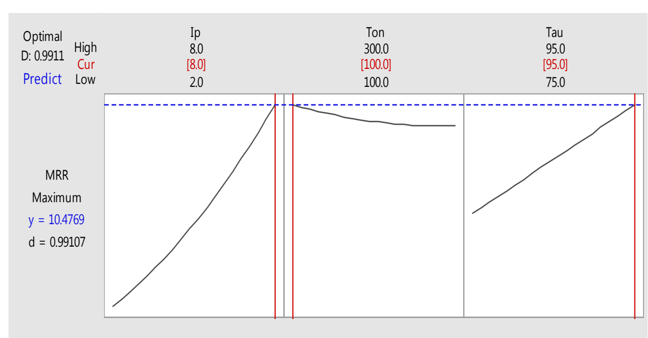


**Fig. 5: Optimization Plot**

The optimum predicted value for MRR = 10.4769 obtained for 0.991067 % desirability.

## 5. CONCLUSIONS

EDM has become an important machining process in manufacturing industries to machine intricate shapes of hard materials. However, the selection of right combination of input parameters in EDM is difficult as the process involves a large number of control variables. The present study develops MRR models for three different parameters namely discharge current, pulse duration and duty cycle for EDM process of AISI P20 tool steel using response surface method to determine the optimal machining parameters to achieve high production of machined components. The second-order response models have been validated with analysis of variance. It is found that all the three machining and some of their interactions have significant effect on MRR considered in the present study. Finally, an attempt has been made for optimum machining conditions to produce the best possible MRR within the experimental constraints.

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