CHAPTER-6

CHAPTER-6: Experimental Results and Analysis – Response Surface Methodology (RSM) 85--132

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CHAPTER 6

EXPERIMENTAL RESULTS AND ANALYSIS - RESPONSE SURFACE METHODOLOGY

The present chapter gives the application of the Response Surface Methodology. The scheme of carrying out experiments was selected and the experiments were conducted as per the design matrix suggested by Box Behnken Design (BBD) as shown in Table 6.1. Table 6.2–6.3 indicated the different runs and the corresponding values of the responses obtained. This chapter concentrates on analysis of results of main experimentation, in order to identify individual as well as interaction effects of process parameters on various responses i.e. surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio. Design Expert 9.0.5 © software is used to check adequacy of fitted model and carry out regression and graphical analysis using ANOVA. Also the multi-response optimization of process parameters was done using desirability approach. The predictions from this model were validated by conducting experiments. Figure 6.1 shows the flowchart of the various steps involved in the analysis of results and optimization. These steps are discussed in the following sections and sub sections.

6.1 ASSESSMENT OF THE ADEQUACY OF MODEL FITTING

To assess for adequacy of the model, three different tests viz. sequential model sum of squares, lack of fit test and model summary statistics have been performed for surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio responses. The sequential sum of squares shows contribution of the terms of increasing complexity to the model. This test selects the highest order polynomial where the terms are not aliased. Generally, a model with highest F-value and lower p-value is selected [29]. The lack of fit test is a measure of the failure of the model to represent data in the experimental domain at which points are not included in the regression and variations are observed in the model that cannot be accounted by random error [29]. For the model to be fit, this test should indicate insignificant lack of fit. A p-value, greater than 0.05 nullifies the lack of fit of the model to the response
data and the model can be utilized for prediction of response parameter for 95% of confidence interval.

![Flowchart](image)

**Figure 6.1** Experimental Methodology and analysis of results

Model summary statistics gives details about standard deviation, $R^2$, Predicted $R^2$ and Prediction error sum of squares (PRESS) of the model. Generally, a model
with lesser standard deviation, $R^2$ closer to 1 and smaller value of PRESS is selected [29].

Tables 6.4 -6.8 show the data related to sequential model sum of squares, lack of fit test and model summary statistics for surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio respectively. Quadratic models are recommended for surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio, by the Design Expert® software after performing above mentioned three tests.

6.2 ANALYSIS OF VARIANCE AND MATHEMATICAL MODELS OF RESPONSE CHARACTERISTICS

Analysis of variance is carried out to statistically analyze the results. ANOVA checks the values of $R^2$ as it explains the ratio of the variability explained by the model to the total variability inherent in the observation data of experiments. It also shows adequate precision which measures signal to noise ratio. Process variables having $p$-value < 0.05 are considered significant terms for the given response parameters. The backward elimination process eliminates the insignificant terms to adjust the fitted quadratic models and in the present work backward elimination process with $\alpha$ to exit = 0.050 is used to eliminate the insignificant terms.

The hierarchy of different models is preserved to develop the mathematical models as it is observed that only hierarchical models are invariant under linear transformations [54]. Principle of Hierarchy explains that although a factor as a main effect is found to be insignificant as regards to its contribution towards the response parameter, but; if its higher order terms viz. interaction or quadratic terms are significant, main effect will be included in the analysis as a term of significance. The results and analysis for different responses from the application of ANOVA test are discussed in following sections.
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Table 6.4 Adequate model selection for Surface roughness

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<td>0.9939</td>
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### Table 6.8 Adequate model selection for Wire wear ratio

#### Sequential Sum of Squares

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#### Lack of Fits

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#### Model Summary Statistics

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Suggested:建議
Aliased:伴走

6.2.1 Empirical modeling and Analysis of variance for output responses

The output responses SR, CR, DD, GC and WWR are very much important for deciding the quality and conditions of the machining components which are manufactured from EDM-wire cut machine tool. From the ANOVA tables the influencing parameters on the output responses (SR, CR, DD, GC and WWR) and interactions are investigated and non-prompting parameters are eliminated by backward elimination method.

Table 6.9 ANOVA for Surface roughness

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<tr>
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<tr>
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Standard Deviation 0.076 R – Squared 0.9173
Mean 2.77 Adj. R – Squared 0.9048
C.V. % 2.74 Pred. R- Squared 0.8898
PRESS 0.35 Adeq. Precision 35.972
Table 6.10 ANOVA for Cutting rate

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| Standard Deviation | 0.052 | R – Squared | 0.9546 |
| Mean               | 0.76  | Adj. R – Squared | 0.9465 |
| C.V. %             | 6.87  | Pred R- Squared | 0.9321 |
| PRESS              | 0.18  | Adeq. Precision | 45.358 |
Table 6.11 ANOVA for Dimensional deviation

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<th>P – Value Prob. &gt; F</th>
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Standard Deviation 0.04  R – Squared 0.9196
Mean 0.67  Adj. R – Squared 0.9009
C.V. % 7.01  Pred R- Squared 0.8631
PRESS 0.16  Adeq. Precision 30.836
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Table 6.12 ANOVA for Gap current
## Table 6.13 ANOVA for Wire wear ratio

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<th>P – Value</th>
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<td></td>
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Based on the values of “Prob.>F” less than 0.05 i.e. the model terms are significant and 95% confidence interval. The following conclusions were drawn.

- From Table 6.9 it can be observed that the individual parameters ON, OFF, IP, SV, interactions AC and higher order terms A² and C² are the influencing parameters on the SR.
➢ From Table (6.10) it can concludes that process parameters ON, OFF, IP, SV and interaction BC, BD, B^2 and C^2 are the most effective parameters on the CR.

➢ The ANOVA Table (6.11) reveals that, the ON, OFF, IP, SV and interactions DF and higher order terms B^2 and C^2 are the most influencing parameters on the DD.

➢ Table (6.12) reveals that, the ON, OFF, IP, SV and interactions AC, BC and BD and higher order terms B^2 and C^2 are the most influencing parameters on the GC.

➢ Table (6.13) reveals that, the ON, OFF, IP, SV and interactions AD and higher order terms A^2 and F^2 are the most influencing parameters on the WWR.

➢ The P-values for Lack-of-Fit in the ANOVA Table 6.9 to Table 6.13 is more than 0.05. By means of that it can be conclude that the all the models are adequately fits the data.

➢ From the ANOVA Table 6.9 to Table 6.13, it can be reveals that the Pred. R-Squared values are in agreement with Adj. R-Squared values and its difference is always very less, R^2 values are always approaches to unity, Standard deviation values are having very less value, small values of PRESS and all these values are in agreement with the standard values.

➢ Based on the proposed second-order polynomial model, the effects of the process variables on the output responses (SR, CR, DD, GC and WWR) have been determined by using Design expert 9.0.5 software. The empirical model for correlating the output responses (SR, CR, DD, GC and WWR) and the considered process variables is obtained as follows:

➢ Surface roughness (Ra) = + 17.06464 – 0.14464 X ON – 0.021719 X OFF – 0.97382 X IP - 0.00346667 X SV +0.0051875 X ON X OFF + 0.000438021 X ON^2 + 0.15794 * IP^2

➢ Cutting rate (mm/min) = + 8.00449 + 0.023533 * ON – 0.26515 * OFF – 0.32925 * IP – 0.015443 * SV + 3.23437 E - 003 * OFF * IP + 2.21875 E - 004 * OFF * SV + 1.7554E - 003 * OFF^2 + 7.63411 E - 003 * IP^2
- Dimensional deviation = +2.96726 + 0.016429 * ON − 0.074516 * OFF − 0.22873 * IP − 7.57143E-003 * SV + 4.47619E-004 * SV * WP + 5.59727E − 004 * OFF^2 + 9.41558E-003 * IP^2

- Gap current(Amps) = + 11.65680 − 4.35417E − 004 * ON − 0.26515 * OFF − 0.54682 * IP − 0.015443 * SV + 1.84375 E − 003 * ON * IP + 3.23437 E − 003 * OFF * IP + 2.21875 E − 004 * OFF * SV + 1.75545 E − 003 * OFF^2 + 7.63411 E - 003 * IP^2

- Wire wear ratio = + 0.32954 − 6.08817 E - 003 * ON − 1.33854 E - 003 * OFF + 4.14583 E - 003 * IP + 1.10683 E - 003 * SV + 0.015238 * WP − 1.07500 E − 005 * ON * SV + 3.01042E - 005 * ON^2 − 6.93287 E - 004 * WP^2

6.2.2 Predicted Vs Actual plot for output responses (SR, CR, DD, GC and WWR):

![Predicted vs. Actual plot for Surface roughness](image)
Fig 6.3 Predicted Vs Actual plot for Cutting rate

Fig 6.4 Predicted Vs Actual plot for Dimensional deviation
Fig 6.5 Predicted Vs Actual plot for Gap current

Fig 6.6 Predicted Vs Actual plot for Wire wear ratio
From all the Figure 6.2, Figure 6.3, Figure 6.4, Figure 6.5 and Figure 6.6, it is revealed that there is a slight deviation between predicted values and actual values. By means of this graphs it can be conclude that the experimental values are nearer to the expected values.

6.3 EFFECT OF PROCESS PARAMETERS ON PROCESS RESPONSES (SR, CR, DD, GC AND WWR):

This following chapters mainly deals with the effect of each process parameter and interaction effects on the output responses i.e. surface roughness (SR), cutting rate (CR), dimensional deviation (DD), gap current (GC) and wire wear ratio (WWR).

Effect of Pulse on time (A-ON) on Surface roughness (SR), Cutting rate (CR), Dimensional deviation (DD), Gap current (GC) and Wire wear ratio (WWR)

![Graph showing effect of pulse on time on surface roughness](image)

Fig 6.7 Effect of Pulse on time on SR
Fig 6.8 Effect of Pulse on time on CR

Fig 6.9 Effect of Pulse on time on DD
From the ANOVA Table 6.9 to Table 6.13 and from Figure 6.7 to Figure 6.11, it can be concluded that, the ON is the most influencing parameter on the output responses.
and above figures also reveals that when the pulse on time increases, the output responses (SR, CR, DD, GC and WWR) are also increased. These results also agree with the standard results and agreement with literature survey [16, 17]. The main reason is that, when pulse on time increases, the number of sparks impinges on the surface of the work piece increases and also removes larger crater size of the material with the faster rate. So that surface roughness increases due to the larger craters removal and due to faster removal of chips, the cutting rate also increases. Due to larger crater size of chips removed because of each spark, the dimensions of the component may not be maintained exactly as per the requirements, so that dimensional deviation is increases with the increase of pulse on time. The gap current is increases with the increase of pulse on time due to the more of current is developed and is transferred to the workpiece. The WWR is increased with the increase of pulse on time. The reason is that, when pulse on time increases the number of sparks increase and it leads to more heat developed at the wire electrode and this heat is transferred to the work piece. Due to this larger amount of wire wear will takes placed which increases wire wear ratio

**Effect of Pulse off time (B-OFF) on Surface roughness (SR), Cutting rate (CR), Dimensional deviation (DD), Gap current (GC) and Wire wear ratio (WWR)**

![Graph showing the effect of pulse off time on surface roughness](Fig 6.12)
Fig 6.13 Effect of Pulse off time on Cutting rate

Fig 6.14 Effect of Pulse off time on Dimensional deviation
Fig 6.15 Effect of Pulse off time on Gap current

Fig 6.16 Effect of Pulse off time on Wire wear ratio
From the ANOVA Table 6.9 to Table 6.13 and from Figure 6.12 to Figure 6.16, it is concluded that, the pulse off time is the most influencing parameter on the output responses. When the pulse off time increased all the output responses (SR, CR, DD, GC and WWR) are also decreased. These results also in agreement with the standard results and agreement with literature survey [49]. The main reason is that, when pulse off time increased, the gap time between two successive sparks is also increased. So that the number of sparks impinges on the surface of the work piece is decreased and also removes smaller crater size of the material with the slower rate. So that surface roughness is decreased. Due to the smaller craters removal and slower rate of removal of chips, the cutting rate is also decreased. When the smaller size of chips removed due to each spark, dimensions of the component may maintained exactly as per the requirements. So that dimensional deviation is decreased with the increase of pulse off time (OFF). The gap current is decreased with the increased of OFF, due to the lesser amount of current is developed and is transferred to the workpiece. The WWR is decreased with the increase of OFF. The reason is that, when OFF increased the number of sparks reduces and it leads to lower amount heat developed at the wire electrode and transferred to the work piece. Due to this smaller amount of wire electrode erosion will take place and WWR is decreased.

**Effect of Peak current (C-IP) on Surface roughness (SR), Cutting rate (CR), Dimensional deviation (DD), Gap current (GC) and Wire wear ratio (WWR)**

![Fig 6.17 Effect of Peak current on Surface roughness](image)
Fig 6.18 Effect of Peak current on Cutting rate

Fig 6.19 Effect of Peak current on Dimensional deviation
Fig 6.20 Effect of Peak current on Gap current

Fig 6.21 Effect of Peak current on Wire wear ratio
From the ANOVA Table 6.9 to Table 6.13 and from Figure 6.17 to Figure 6.21, it is concluded that the peak current is the influencing parameter on the output responses (SR, CR, DD, GC and WWR). These results also in agreement with the standard results and agreement with literature survey [3]. When peak current increased, the amount current supplied in between wire electrode and work piece is also increased. So that the number of sparks impingement on the surface of the work piece increased and also removes larger crater size of the material with the faster rate. So that surface roughness increased due to the larger craters removal and faster removal of chips, the cutting rate is also increased. As larger size of chips removed due to each spark, dimensions of the component may not be maintained exactly as per the requirements. So that dimensional deviation is increases with the increase of peak current. The gap current is increased with the increase of peak current due to the more amount of current is developed and is transferred to the workpiece. The WWR is increased with the increase of peak current. The reason is that, when peak current is increased the more amount of heat developed at the wire electrode and transferred to the work piece. Due to this larger amount wire electrode erosion will be take place.

**Effect of Spark gap set voltage (D-SV) on Surface roughness (SR), Cutting rate (CR), Dimensional deviation (DD), Gap current (GC) and Wire wear ratio (WWR)**

![Effect of on Spark gap set voltage on Surface roughness](Image)
Fig 6.23 Effect of Spark gap set voltage on Cutting rate

Fig 6.24 Effect of Spark gap set voltage on Dimensional deviation
Fig 6.25 Effect of Spark gap set voltage on Gap current

Fig 6.26 Effect of Spark gap set voltage on Wire wear ratio
From the ANOVA Table 6.9 to Table 6.13 and from Figure 6.22 to Figure 6.26, it is concluded that the spark gap set voltage is the influencing parameter on the output responses (SR, CR, DD, GC and WWR). These results also in agreement with the standard results and literature survey [63]. When spark gap set voltage is increased, the amount current supplied in between wire electrode and work piece is decreased, due to the larger discharge waiting time. Because of this, the number of sparks impingement on the surface of the work piece is decreased and also removes smaller crater size of the material with the slower rate. So that surface roughness and cutting rate also decreases. Due to smaller size of chips removed because each spark, dimensions of the component may be maintained exactly as per the requirements. So that DD is decreased with the increase of SV. The gap current is decreased with the increase of SV due to the increase of discharge waiting time and it leads to smaller current is developed and transferred in between wire electrode and work piece. The WWR is decreased with the increase of SV. The reason is that, when spark gap set voltage is increased the lower amount heat developed at the wire electrode and transferred to the work piece. Due to this smaller amount wire electrode erosion will takes be place.

**Parameter Interactions effect on Surface roughness (SR), Cutting rate (CR), Dimensional deviation (DD), Gap current (GC) and Wire wear ratio (WWR):**

The Figure 6.27 gives the information about the effect of interaction (ON X IP) on the surface roughness. From the Figure 6.27 it can be concluded that, the SR is increased with the increase of ON time from 108Mu to 128Mu by keeping peak current (IP) is constant at 11 Amps. In another case the surface roughness is also increased with the increase of peak current from 11 Amps to 15 Amps by keeping ON at 108Mu is constant. So in both cases the surface roughness is increasing. Based on these results, it is concluded that the interaction (ON X IP) effect is weak.
The Figure 6.28 gives the information about the effect of interaction (IP X OFF) on the cutting rate. From the Figure 6.28 it can be conclude that, the cutting rate
is decreases with the increase of pulse off time from 47Mu to 63Mu by keeping peak current is constant at 11 Amps. In another case the cutting rate is increased with the increase of peak current from 11 Amps to 15 Amps by keeping pulse off time at 47Mu is constant. So the cutting rate is different in different cases. Based on this result, it is concluded that the interaction (IP X OFF) is effecting the cutting rate.

**Fig 6.29** Interaction plot between Pulse off time and Spark gap set voltage for Cutting rate

The Figure 6.29 gives the information about the effect of interaction (SV X OFF) on the cutting rate. From the Figure 6.17 it can be concluded, that the cutting rate is decreased with the increase of pulse off time from 47Mu to 63Mu by keeping spark gap set voltage is constant 18 Volts. In another case the cutting is also decreased with the increase of spark gap set voltage from 18Volts to 58 Volts by keeping pulse off time 47Mu is constant. So in both cases the cutting rate is decreasing. Based on this results it is concluded that the interaction (SV X OFF) is not effecting on the cutting rate.
Fig 6.30 Interaction plot between Spark gap set voltage and Water pressure for DD

The Figure 6.30 gives the information about the effect of interaction (WP X SV) on the dimensional deviation. From the Figure 6.30 it can be concluded that, the dimensional deviation is decreased with the increase of spark gap set voltage from 18Volts to 68Volts by keeping water pressure is constant at 8 Kg/Cm². In another case the dimensional deviation is increased with the increase of water pressure from 8 Kg/Cm² to 14 Kg/Cm² by keeping spark gap set voltage at 18Volts is constant. So in both cases, the dimensional deviation is different. Based on this results it is concluded, that the interaction (WP X SV) is effecting on the dimensional deviation.

The Figure 6.31 gives the information about the effect of interaction (IP X ON) on the gap current. From the Figure 6.31 it can be conclude that the gap current is increased with the increase of pulse on time from 108Mu to 128Mu by keeping peak current is constant at 11 Amps. In another case the gap current is also increased with the increase of peak current from 11 Amps to 15 Amps by keeping 108Mu is constant. So in both cases the gap current is increasing. Based on this result, it is concluded that the interaction (IP X ON) effect is weak.
Fig 6.31 Interaction plot between Peak current and Pulse on time for Gap current

Fig 6.32 Interaction plot between Peak current and Pulse off time for Gap current
The Figure 6.32 gives the information about the effect of interaction (IP X OFF) on the gap current. From the Figure 6.32 it can be concluded that, the gap current is decreased with the increase of pulse off time from 47Mu to 63Mu by keeping peak current is constant at 11 Amps. In another case the gap current is also increased with the increase of peak current from 11 Amps to 15 Amps by keeping at 47Mu is constant. So the gap current is different in different cases. Based on this result, it is concluded that the interaction (IP X OFF) effect is high.

The Figure 6.33 gives the information about the effect of interaction (SV X OFF) on the gap current. From the Figure 6.33 it can be concluded that, the gap current is decreased with the increase of pulse on time from 47Mu to 63Mu by keeping spark gap set voltage is constant at 18 Volts. In another case the gap current is also increased with the increase of spark gap set voltage from 18Volts to 68 Volts by keeping pulse off time at 47 Mu is constant. So the cutting rate is different in each case. Based on this result, it is concluded that, the interaction (SV X OFF) is effective on the gap current.
Fig 6.34 Interaction plot between Spark gap set voltage and Pulse on time for Wire wear ratio

The Figure 6.34 gives the information about the effect of interaction (SV X ON) on the WWR. From the Figure 6.34 it can be concluded that, the WWR is increased with the increase of pulse on time from 108Mu to 128Mu by keeping spark gap set voltage is constant at 18 Volts. In another case the WWR is also increased with the increase of spark gap set voltage from 18Volts to 58 Volts by keeping pulse off time 108Mu is constant. So in both cases the WWR is increasing. Based on these results, it is concluded that the interaction (SV X ON) is effect is less on the WWR.

6.4 Multi-Response Optimization Using Desirability Function

Derringer G. and Suich [64] describe a multiple response method called desirability. It is an attractive method for industry for optimization of multiple quality characteristic problems. The method is attractive because it is intuitive and simple. The inputs are mean response estimates, target value, and upper and lower acceptability bounds. The individual desirability is combined using the geometric mean. The desirability of a product characteristic value depends on the lower and upper ranges of product specification. Improper selection of ranges can result in a
very different “optimum.” The basic idea of the desirability function approach is to transform a multiple response problem into a single response problem by means of mathematical transformations. The desirability function involves transformation of each estimated response variable $\hat{y}$ to a desirability value $d_i$, where $0 \leq d_i \leq 1$. The value of $d_i$ increases as the “desirability” of the corresponding response increases. The procedure followed in this work for simultaneous optimization of the multiple responses is a modification of the method developed by Montgomery D.C [65].

Step-1 Calculate the individual desirability ($d_i$) for each response ($\hat{y}$).

Step-2 Combining individual desirability to obtain composite desirability (DG) for given weights of surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio. Composite desirability is the weighted geometric mean of individual desirability for the given responses.

Step-3 Maximizing the composite desirability and identifying the optimal parameter combinations.

$$d_i = \begin{cases} = 0 & \hat{y} < A_i \\ = (\hat{y} - A_i)/(t_i - A_i) & A_i < \hat{y} < t_i \\ = 1 & \hat{y} > t_i \end{cases}$$

If the target ($t_i$) is to minimize a response, the individual desirability ($d_i$) is calculated as

$$d_i = \begin{cases} = 0 & \hat{y} < t_i \\ = (B_i - \hat{y})/(B_i - t_i) & t_i < \hat{y} < B_i \\ = 1 & \hat{y} > B_i \end{cases}$$

Where,

$$A_i = \text{lower limit value of response } \hat{y}$$
B_i = upper limit value of response \( \hat{y} \)

If the object for the response is a target value, then individual desirability \( (d_i) \) is calculated as:

\[
d_i = \left\{ \begin{array}{ll}
\frac{\left( \hat{y} - A_i \right)}{t_i - A_i} & \text{if } \hat{y} \leq t_i \\
\frac{B_i - \hat{y}}{B_i - t_i} & \text{if } t_i \leq \hat{y} \leq B_i \\
0 & \text{if } \hat{y} < A_i \\
0 & \text{if } \hat{y} > B_i 
\end{array} \right.
\]

If the importance is same for each response, the composite desirability (DG) the geometric mean of all desirability functions and is given by

\[
DG = (d_1 \times d_2 \times d_3 \times \ldots \ldots \times d_n)^{\frac{1}{n}}
\]

Where \( n = \) no. of responses

It can be extensive to reflect the possible difference in the importance of different responses by giving weights. Where the weight \( w_i \) satisfies \( 0 < w_i < 1 \) and \( w_1 + w_2 + \ldots = 1 \)

\[
DG = (d_1^{w_1} \times d_2^{w_2} \times \ldots \ldots \times d_n^{w_n})^{\frac{1}{n}}
\]

The factor settings with maximum total desirability are considered to be optimal parameter combination. In the present work, desirability function is utilized to determine the optimum parameter combinations for optimization of surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio.

Table 6.14 illustrates the constraints for carrying out optimization of responses i.e. surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio respectively. Goals to maximize, minimize or to keep the response at a target value and limits for control factors are established for each response individually in order to accurately determine their impact on individual desirability. Weights are assigned to give added emphasis to upper / lower bounds or to emphasize a target
value. The default value “1” of weight is assigned to a goal to adjust the shape of its particular desirability function. The default value “3” taken by design expert® software is used to designate importance of objective function. The ultimate objective of optimization is to find a good set of conditions that will meet all the goals. It is not necessary that the value of desirability is always 1.0 as this value is completely dependent on the manner in which lower and upper limits are set relative to the actual optimum [60]. The data is used for carrying out multi-objective optimization of surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio using design expert® are presented in Table 6.2 and Table 6.3. Table 6.15 and Table 6.16 shows the values of 10 levels combinations of process parameters that will give high value of composite desirability (ranged from 0.565 to 0.560), and the predicted values of responses obtained are also given.

Figure 6.35 to Figure 6.37 shows the three dimensional response surface, optimized bar histograms and ramp graphs for overall desirability of all the responses i.e. surface roughness, cutting rate, dimensional deviation, gap current and wire wear ratio. The near-optimal region was located close to the right hand center region of the plot, which had a composite desirability value greater than 0.556 that gradually reduced as we moved left and upwards.

Figure 6.35 3D surface plot of composite Desirability for all responses
### Table 6.14 Constraints of input parameters and responses

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Target</th>
<th>Lower limit</th>
<th>Upper limit</th>
<th>Lower weight</th>
<th>Upper weight</th>
<th>Importance</th>
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<td>1</td>
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### Table 6.15 Optimal solutions for Surface roughness, Cutting rate

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<th>WP</th>
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<th>CR</th>
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Table 6.16 Optimal solutions for Dimensional deviation, Gap current and Wire wear ratio

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<th>IP</th>
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Figure 6.36 Bar histogram plot of composite Desirability for all responses
Confirmatory experiments are carried out at the optimized value of response characteristics to check the validity of optimization results. Table 6.17 shows the results obtained from confirmatory experiments. The error between the predicted values and the experimental observations lies within ± 10%. Thus, confirmatory experiments confirm excellent reproducibility of the results.

Table 6.17 Experimental validations of developed models with optimal parameter settings

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<tr>
<th>Responses</th>
<th>Predicted</th>
<th>Experimental</th>
<th>Error (%)</th>
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<td>Surface roughness(μm)</td>
<td>2.72</td>
<td>2.61</td>
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<td>Cutting rate(mm/min)</td>
<td>0.846</td>
<td>0.842</td>
<td>4.728</td>
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<td>Dimensional deviation</td>
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<td>Gap current (Ampere)</td>
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<td>1.762</td>
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<tr>
<td>Wire wear ratio</td>
<td>0.076</td>
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