7. Multi-Objective Optimization by Multi-Response Signal-to-Noise Ratio Technique

7.1 Introduction

Parametric optimization of EDM is a significant area of research. Optimization of EDM process, by many researchers, was considered as single optimization problem and the best combination of process parameters was found by considering each performance measure as a separate objective. As a result, the best combination of input parameters for maximum material removal rate (MRR) was not suitable for minimum surface roughness (SR). So, it was left again to the operator to decide the combination of input parameters for the best cutting efficiency (high MRR and low SR). In literature, there are many references in which Taguchi’s method has been employed as one of the single objective optimization technique for parametric optimization of EDM (Huang, 1999; Chen & Tzeng, 2003; Puri & Bhattacharya, 2003; Lin et al., 2006; Singh et al., 2007; Bhaduri et al., 2009; Dev et al., 2009; Yusoff et al. 2009). Optimization of process parameters of EDM is a multi-objective optimization task as, in practice, high value of MRR is desired along with low value of SR. Since the nature of performance measures is conflicting, traditional Taguchi’s method can not give a factor/level combination of input parameters that satisfies the desired conditions for performance measures. Researchers have employed various multi objective optimization techniques based on goal programming, simulated annealing (SA), grey relation and genetic algorithms (GA) for the parametric optimization of EDM. (Kirkpatric et al., 1983; Tarng, 1995; Deb et al., 2002; Su et al., 2004; Mandal et al., 2004; Feggou and Dayong, 2004; Kuriakose and Shunmugan, 2005; Yang et al., 2009).

Most of these techniques increase the complexity of the computation process and it is therefore not readily understood by engineers with limited mathematical and statistical skills. Multi-response signal-to-noise ratio (MRSN) is a very simple, systematic and effective multi-response optimization technique. This technique was
developed by Ming-Ru Chen. Lack of available literature and some peculiar qualities of this technique has motivated the author of this thesis to employ this technique in the present work. Ramakrishnan and Karunamoorthy (2006, 2008) and Bharti et al. (2011b) employed this technique to obtain the optimum settings of input parameters during electro discharge machining of heat treated tool steel and D2 steel successfully.

In this work, three cases v.i.z. high cutting efficiency, high surface finish and normal machining have been taken by observing the industrial requirement. The optimum factor/level combinations of process parameters for each case have been found. ANOVA has been employed to see the level of significance of each process parameters in each case. Finally, experimental verification of results obtained has been done and improvement in performance measures has been reported.

### 7.2 Multi-Response Signal-to-Noise Ratio (MRSN) Technique

In MRSN technique, following three steps are performed prior to the application of traditional Taguchi’s method-

**Step I: Determination of normalized quality loss for each performance characteristic**

Normalized loss function corresponding to each performance characteristic is determined by the following equation

$$N_y = \frac{L_y}{L_i} \tag{7.1}$$

where $N_y$ is the normalized loss function for the $i^{th}$ performance characteristic in the $j^{th}$ experiment, $L_y$ is the loss function for the $i^{th}$ performance characteristic in the
$j^{th}$ experiment and $\overline{L}_i$ is the average quality loss function for the $i^{th}$ performance characteristic.

**Step II: Determination of total normalized quality loss**

A weighting method is applied to determine the total normalized quality loss by following equation

$$TN_j = \sum_{i=1}^{p} w_i N_i$$  \hspace{1cm} (7.2)

where $w_i$ is the weighting factor for the $i^{th}$ performance characteristic, $p$ is the number of performance characteristic and $j$ is the number of experiments.

**Step III: Determination of multi-response signal-to-ratio (MRSN)**

Total normalized loss function is converted into MRSN by following equation

$$MRSN = -10 \log(TN_j)$$  \hspace{1cm} (7.3)

After calculating MRSN, traditional Taguchi’s method is employed to optimize the process parameters with the difference that MRSN is used in place of S/N.

Loss function can be expressed by following equation

$$L_q = \exp \left( \frac{-S/N}{10} \right)$$  \hspace{1cm} (7.4)

For S/N, equation (6.1) and (6.2) may be referred.

Calculated values of performance measures and their corresponding S/N ratios for each experimental run are shown in table 6.1, 6.2 and 6.3 (previous chapter).
7.3 Multi-Response Optimization

In practice, an optimal factor/level combination of input parameters is desired at which value of one performance measure is maximum and the values of other performance measures is minimum. This becomes a case of multi-response optimization. MRSN technique has been employed as a multi-objective optimization technique in the present work. **Case 1: High cutting efficiency** i.e. more weightage is given to MRR as compared to SR and TWR. The weights taken are $w_1=0.6, w_2=0.3, w_3=0.1$. **Case 2: High surface finish** i.e. more weightage is given to SR as compared to MRR and TWR. The weights taken are $w_1=0.3, w_2=0.6, w_3=0.1$. **Case 3: Normal machining** i.e. equal weightage is given to MRR and SR. The weights taken are $w_1=0.45, w_2=0.45, w_3=0.1$. In all cases $w_1$, $w_2$ and $w_3$ are weights for MRR, SR and TWR respectively. Giving more weightage to MRR does not imply that SR is ignored and vice-versa. In this study it is observed that TWR is very less as compared to MRR, hence weightage given to TWR is 0.1. The values of MRSN for case 1, case 2 and case 3 are reported in table 7.1. ANOVA results and Mean MRSN ratio for case-1 are reported in Table 7.2 and Table 7.3 respectively. By analyzing these two tables, it is evident that discharge current is the most significant factor, having percentage contribution of 79.51, followed by gap voltage, pulse-on-time, duty cycle and shape factor. Flushing pressure and tool electrode lift time are observed as insignificant factors. The mean MRSN ratio of parameters A to G is maximum at A2, B3, C3, D1, E2, F2 and G3. Hence combination A2B3C3D1E2F2G3 is recommended as optimal factor/level combination for case 1. Since in case 1, more weightage is given to MRR as compared to SR, the levels of pulse-on-time and discharge current are identified as B3 and C3. Higher level of discharge current and pulse-on-time induce more spark energy which results in high MRR.
<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Case-1 MRSN(dB)</th>
<th>Case-2 MRSN(dB)</th>
<th>Case-3 MRSN(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>-1.0964</td>
<td>0.2626</td>
<td>-0.4699</td>
</tr>
<tr>
<td>2.</td>
<td>0.9331</td>
<td>0.0252</td>
<td>0.4554</td>
</tr>
<tr>
<td>3.</td>
<td>0.4950</td>
<td>-0.7608</td>
<td>-0.1781</td>
</tr>
<tr>
<td>4.</td>
<td>-1.2924</td>
<td>-0.4058</td>
<td>-0.8717</td>
</tr>
<tr>
<td>5.</td>
<td>0.6522</td>
<td>-0.3700</td>
<td>0.1111</td>
</tr>
<tr>
<td>6.</td>
<td>1.9399</td>
<td>0.3340</td>
<td>1.0632</td>
</tr>
<tr>
<td>7.</td>
<td>-2.8737</td>
<td>-1.2171</td>
<td>-2.1239</td>
</tr>
<tr>
<td>8.</td>
<td>1.3377</td>
<td>-0.0037</td>
<td>0.6154</td>
</tr>
<tr>
<td>9.</td>
<td>1.2672</td>
<td>-0.4129</td>
<td>0.3464</td>
</tr>
<tr>
<td>10.</td>
<td>-4.0113</td>
<td>-2.0894</td>
<td>-3.1558</td>
</tr>
<tr>
<td>11.</td>
<td>0.7827</td>
<td>0.5067</td>
<td>0.6425</td>
</tr>
<tr>
<td>12.</td>
<td>1.6327</td>
<td>-0.1107</td>
<td>0.6741</td>
</tr>
<tr>
<td>13.</td>
<td>1.6484</td>
<td>0.4125</td>
<td>0.9866</td>
</tr>
<tr>
<td>14.</td>
<td>2.0673</td>
<td>0.1819</td>
<td>1.0230</td>
</tr>
<tr>
<td>15.</td>
<td>-2.7758</td>
<td>-1.0674</td>
<td>-2.0051</td>
</tr>
<tr>
<td>16.</td>
<td>1.4709</td>
<td>0.7178</td>
<td>1.0781</td>
</tr>
<tr>
<td>17.</td>
<td>1.0006</td>
<td>-0.3558</td>
<td>0.2697</td>
</tr>
<tr>
<td>18.</td>
<td>0.2108</td>
<td>0.7902</td>
<td>0.4908</td>
</tr>
<tr>
<td>19.</td>
<td>1.4952</td>
<td>0.9054</td>
<td>1.1903</td>
</tr>
<tr>
<td>20.</td>
<td>1.1470</td>
<td>-0.4288</td>
<td>0.2880</td>
</tr>
<tr>
<td>21.</td>
<td>-0.8067</td>
<td>0.4571</td>
<td>-0.2206</td>
</tr>
<tr>
<td>22.</td>
<td>1.0347</td>
<td>0.9189</td>
<td>0.9764</td>
</tr>
<tr>
<td>23.</td>
<td>2.1156</td>
<td>0.7382</td>
<td>1.3725</td>
</tr>
<tr>
<td>24.</td>
<td>-1.2406</td>
<td>0.0693</td>
<td>-0.6348</td>
</tr>
<tr>
<td>25.</td>
<td>1.3808</td>
<td>0.2372</td>
<td>0.7715</td>
</tr>
<tr>
<td>26.</td>
<td>-1.7356</td>
<td>-0.6353</td>
<td>-1.2202</td>
</tr>
<tr>
<td>27.</td>
<td>1.2630</td>
<td>0.4674</td>
<td>0.8470</td>
</tr>
<tr>
<td>28.</td>
<td>1.3524</td>
<td>0.6917</td>
<td>1.0095</td>
</tr>
<tr>
<td>29.</td>
<td>-2.1940</td>
<td>-0.8539</td>
<td>-1.5754</td>
</tr>
<tr>
<td>30.</td>
<td>2.6149</td>
<td>1.2102</td>
<td>1.8560</td>
</tr>
<tr>
<td>31.</td>
<td>2.2840</td>
<td>1.0027</td>
<td>1.5963</td>
</tr>
<tr>
<td>32.</td>
<td>-0.8950</td>
<td>0.2950</td>
<td>-0.3406</td>
</tr>
<tr>
<td>33.</td>
<td>2.2245</td>
<td>1.1639</td>
<td>1.6619</td>
</tr>
<tr>
<td>34.</td>
<td>2.0101</td>
<td>0.7026</td>
<td>1.3073</td>
</tr>
<tr>
<td>35.</td>
<td>-3.0301</td>
<td>-1.4654</td>
<td>-2.3179</td>
</tr>
<tr>
<td>36.</td>
<td>1.7284</td>
<td>0.6453</td>
<td>1.1531</td>
</tr>
</tbody>
</table>
Table 7.2: Analysis of Variance for MRSN in Case-1.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F-ratio</th>
<th>Percentage contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape factor (A)</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>16.2241</td>
<td>1.3635</td>
</tr>
<tr>
<td>Pulse-on-time(B)</td>
<td>2</td>
<td>1.91</td>
<td>0.955</td>
<td>10.3293</td>
<td>1.7362</td>
</tr>
<tr>
<td>Discharge current(C)</td>
<td>2</td>
<td>87.566</td>
<td>43.783</td>
<td>473.5601</td>
<td>79.5982</td>
</tr>
<tr>
<td>Duty cycle(D)</td>
<td>2</td>
<td>1.57</td>
<td>0.785</td>
<td>8.4906</td>
<td>1.4271</td>
</tr>
<tr>
<td>Gap voltage(E)</td>
<td>2</td>
<td>5.18</td>
<td>2.59</td>
<td>28.0136</td>
<td>4.7087</td>
</tr>
<tr>
<td>Flushing pressure(F)</td>
<td>2</td>
<td>0.13</td>
<td>0.065</td>
<td>0.7030</td>
<td>0.1182</td>
</tr>
<tr>
<td>Time interval(G)</td>
<td>2</td>
<td>0.11</td>
<td>0.055</td>
<td>0.5948</td>
<td>0.1000</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>2.034</td>
<td>0.092455</td>
<td></td>
<td>10.9481</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>110.01</td>
<td></td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>
Table 7.3: Mean MRSN ratio table for case-1.

<table>
<thead>
<tr>
<th>Machining parameters</th>
<th>Mean S/N</th>
<th>Select ed level</th>
<th>Optimum Level/factor combination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level-1</td>
<td>Level-2</td>
<td>Level-3</td>
</tr>
<tr>
<td>A-Shape factor</td>
<td>0.1882</td>
<td>0.5971</td>
<td>2</td>
</tr>
<tr>
<td>B-Pulse-on-time</td>
<td>0.2836</td>
<td>0.1818</td>
<td>0.7128</td>
</tr>
<tr>
<td>C-Discharge current</td>
<td>-0.3783</td>
<td>0.7344</td>
<td>0.8220</td>
</tr>
<tr>
<td>D-Duty cycle</td>
<td>0.8832</td>
<td>-0.2938</td>
<td>0.5888</td>
</tr>
<tr>
<td>E-Gap voltage</td>
<td>0.5132</td>
<td>0.5565</td>
<td>0.1084</td>
</tr>
<tr>
<td>F-Flushing pressure</td>
<td>0.5816</td>
<td>0.6240</td>
<td>-0.0275</td>
</tr>
<tr>
<td>G-Tool electrode lift time</td>
<td>-0.4051</td>
<td>0.4549</td>
<td>1.1284</td>
</tr>
</tbody>
</table>

ANOVA results and Mean MRSN ratio for case 2 are shown in Table 7.4 and Table 7.5 respectively. By analyzing these two tables, it is evident that discharge current is most significant factor having a percentage contribution as 30.8142 followed by shape factor, pulse-on-time, gap voltage and duty cycle. Flushing pressure and tool electrode lift time are observed as insignificant factors. The mean MRSN ratio of parameters A to G is maximum at A2, B2, C2, D1, E2, F2 and G1. Hence combination A2B2C2D1E1F2G1 is recommended as optimal factor/level combination for case-2. It is observed that the significant factor level of pulse-on-time, discharge current and gap voltage reduces from B3 to B2, from C3 to C2 and from E2 to E1 respectively when we go from case-1 to case-2.. This is because low discharge current, lesser pulse-on-time and low gap voltage induce less spark energy and as a result surface finish improves and MRR decreases.
Table 7.4: Analysis of Variance for MRSN in Case-2.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F-ratio</th>
<th>Percentage contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape factor (A)</td>
<td>1</td>
<td>2.605</td>
<td>2.605</td>
<td>0.6576</td>
<td>12.1900</td>
</tr>
<tr>
<td>Pulse-on-time(B)</td>
<td>2</td>
<td>1.313</td>
<td>0.6565</td>
<td>0.1657</td>
<td>6.1441</td>
</tr>
<tr>
<td>Discharge current(C)</td>
<td>2</td>
<td>6.585</td>
<td>3.2925</td>
<td>0.8312</td>
<td>30.8142</td>
</tr>
<tr>
<td>Duty cycle(D)</td>
<td>2</td>
<td>0.855</td>
<td>0.4275</td>
<td>0.1079</td>
<td>4.0009</td>
</tr>
<tr>
<td>Gap voltage(E)</td>
<td>2</td>
<td>1.154</td>
<td>0.577</td>
<td>0.1456</td>
<td>5.4001</td>
</tr>
<tr>
<td>Flushing pressure(F)</td>
<td>2</td>
<td>0.155</td>
<td>0.0775</td>
<td>0.0195</td>
<td>0.7253</td>
</tr>
<tr>
<td>Time interval(G)</td>
<td>2</td>
<td>0.191</td>
<td>0.0955</td>
<td>0.0241</td>
<td>0.8938</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>87.142</td>
<td>3.961</td>
<td></td>
<td>39.2092</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>21.237</td>
<td></td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Table 7.5: Mean MRSN ratio table for case-2.

<table>
<thead>
<tr>
<th>Machining parameters</th>
<th>Mean S/N</th>
<th>Select level</th>
<th>Optimum Level/factor combination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level-1</td>
<td>Level-2</td>
<td>Level-3</td>
</tr>
<tr>
<td>A-Shape factor</td>
<td>-0.1979</td>
<td>0.34</td>
<td>2</td>
</tr>
<tr>
<td>B-Pulse-on-time</td>
<td>0.1783</td>
<td>0.2321</td>
<td>-0.1972</td>
</tr>
<tr>
<td>C-Discharge current</td>
<td>-0.4883</td>
<td>0.5500</td>
<td>0.1516</td>
</tr>
<tr>
<td>D-Duty cycle</td>
<td>0.2856</td>
<td>-0.0694</td>
<td>-0.0030</td>
</tr>
<tr>
<td>E-Gap voltage</td>
<td>0.3035</td>
<td>0.0418</td>
<td>-0.1321</td>
</tr>
<tr>
<td>F-Flushing pressure</td>
<td>-0.0104</td>
<td>0.1502</td>
<td>0.0734</td>
</tr>
<tr>
<td>G-Tool electrode lift time</td>
<td>0.1523</td>
<td>0.0853</td>
<td>-0.0244</td>
</tr>
</tbody>
</table>

ANOVA results and Mean MRSN ratio for case 3 are shown in Table 7.6 and Table 7.7 respectively. By analyzing these two tables, it is evident that discharge current is most significant factor followed by gap voltage, shape factor and pulse-on-time. Duty cycle, flushing pressure and tool electrode lift time are observed as insignificant factors. The mean MRSN ratio of parameters A to G is maximum at A2,
B3, C2, D1, E1, F1 and G3. Hence combination A2B3C2D1E1F1G3 is recommended as optimal factor/level combination for case 3.

Table 7.6: Analysis of Variance for MRSN in Case-3.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F-ratio</th>
<th>Percentage contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape factor (A)</td>
<td>1</td>
<td>2.14</td>
<td>2.14</td>
<td>4.6039</td>
<td>4.0492</td>
</tr>
<tr>
<td>Pulse-on-time(B)</td>
<td>2</td>
<td>1.37</td>
<td>0.685</td>
<td>1.4736</td>
<td>2.5922</td>
</tr>
<tr>
<td>Discharge current(C)</td>
<td>2</td>
<td>34.904</td>
<td>17.452</td>
<td>37.5458</td>
<td>66.0435</td>
</tr>
<tr>
<td>Duty cycle(D)</td>
<td>2</td>
<td>1.18</td>
<td>0.59</td>
<td>1.2693</td>
<td>2.2327</td>
</tr>
<tr>
<td>Gap voltage(E)</td>
<td>2</td>
<td>2.79</td>
<td>1.395</td>
<td>3.0011</td>
<td>5.2791</td>
</tr>
<tr>
<td>Flushing pressure(F)</td>
<td>2</td>
<td>0.15</td>
<td>0.075</td>
<td>0.1613</td>
<td>0.2838</td>
</tr>
<tr>
<td>Time interval(G)</td>
<td>2</td>
<td>0.09</td>
<td>0.045</td>
<td>0.0968</td>
<td>0.1703</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>10.226</td>
<td>0.464818</td>
<td></td>
<td>19.3491</td>
</tr>
<tr>
<td>Total</td>
<td>52.85</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

Table 7.7: Mean MRSN ratio table for case-3.

<table>
<thead>
<tr>
<th>Machining parameters</th>
<th>Mean S/N</th>
<th>Select level</th>
<th>Optimum Level/factor combination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level-1</td>
<td>Level-2</td>
<td>Level-3</td>
</tr>
<tr>
<td>A-Shape factor</td>
<td>-0.0582</td>
<td>0.4289</td>
<td>2</td>
</tr>
<tr>
<td>B-Pulse-on-time</td>
<td>0.1912</td>
<td>-0.0564</td>
<td>0.4212</td>
</tr>
<tr>
<td>C-Discharge current</td>
<td>-0.3328</td>
<td>0.4446</td>
<td>0.4442</td>
</tr>
<tr>
<td>D-Duty cycle</td>
<td>0.4983</td>
<td>-0.2316</td>
<td>0.2894</td>
</tr>
<tr>
<td>E-Gap voltage</td>
<td>0.3343</td>
<td>0.2648</td>
<td>-0.0431</td>
</tr>
<tr>
<td>F-Flushing pressure</td>
<td>0.3683</td>
<td>0.2496</td>
<td>-0.0619</td>
</tr>
<tr>
<td>G-Tool electrode lift time</td>
<td>-0.4345</td>
<td>0.2853</td>
<td>0.7052</td>
</tr>
</tbody>
</table>
7.4 Verification of Experiments

To verify the optimality of input parameters level combination chosen, experiments have been performed and the predicted optimum value of MRSN is compared with experimental values. The predicted optimum value of MRSN is calculated by the following equation

\[ \eta_{opt} = \eta_m + \sum_{j=1}^{P} (\eta_i - \eta_m) \], where \( \eta_m \) is the mean of MRSN ratio in all experimental runs, \( \eta_i \) is MRSN ratio corresponding to optimum levels and \( P \) is the number of input parameters.

The results of confirmatory experiments are reported in table 7.8, table 7.9 and table 7.10 for case-1, case-2 and case-3 respectively.

Table 7.8: Results of confirmatory experiments for Case-1.

<table>
<thead>
<tr>
<th>Level</th>
<th>Initial setting</th>
<th>Optimum values</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Predicted</td>
<td>Experimental</td>
</tr>
<tr>
<td>MRR</td>
<td>A2B1C2D1E2F3G2</td>
<td>A2B3C3D1E2F2G3</td>
<td>A2B3C3D1E2F2G3</td>
</tr>
<tr>
<td>SR</td>
<td>38.6360</td>
<td>-</td>
<td>49.25</td>
</tr>
<tr>
<td>TWR</td>
<td>7.19</td>
<td>-</td>
<td>6.5</td>
</tr>
<tr>
<td>MRSN(dB)</td>
<td>0.4013</td>
<td>-</td>
<td>0.3732</td>
</tr>
<tr>
<td></td>
<td>2.0101</td>
<td>2.9677</td>
<td></td>
</tr>
</tbody>
</table>
Table 7.9: Results of confirmatory experiments for Case-2.

<table>
<thead>
<tr>
<th>Initial setting</th>
<th>Optimum values</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted</td>
<td>Experimental</td>
</tr>
<tr>
<td>Level</td>
<td>A2B1C2D1E2F3G2</td>
<td>A2B2C2D1E1F2G1</td>
</tr>
<tr>
<td>MRR</td>
<td>38.6360</td>
<td>43.6523</td>
</tr>
<tr>
<td>SR</td>
<td>7.19</td>
<td>5.8012</td>
</tr>
<tr>
<td>TWR</td>
<td>0.4013</td>
<td>0.3441</td>
</tr>
<tr>
<td>MRSN(dB)</td>
<td>2.0101</td>
<td>1.5871</td>
</tr>
</tbody>
</table>

Table 7.10: Results of confirmatory experiments for Case-3

<table>
<thead>
<tr>
<th>Initial setting</th>
<th>Optimum values</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted</td>
<td>Experimental</td>
</tr>
<tr>
<td>Level</td>
<td>A2B1C2D1E2F3G2</td>
<td>A2B3C2D1E1F1G3</td>
</tr>
<tr>
<td>MRR</td>
<td>38.6360</td>
<td>45.6793</td>
</tr>
<tr>
<td>SR</td>
<td>7.19</td>
<td>6.2639</td>
</tr>
<tr>
<td>TWR</td>
<td>0.4013</td>
<td>0.3611</td>
</tr>
<tr>
<td>MRSN(dB)</td>
<td>2.0101</td>
<td>2.089</td>
</tr>
</tbody>
</table>

The results show that there is considerable improvement in MRR, SR and TWR with respect to the initial settings of input parameters. Initial settings can be taken any setting of parameters. The purpose of initial setting is to see the improvement in performance measures at optimum values with respect to initial settings. Since case-1 represents high cutting efficiency (i.e. more weightage is given to MRR as compared to SR), improvement in MRR (i.e. 27.47%) is more than improvement in SR (i.e. 10.61%). Case-2 represents high surface finish (i.e. more weightage is given to SR as compared to MRR), so improvement in SR (i.e. 19.31%) is more than improvement in MRR (i.e. 12.98%). In case-3, improvement in MRR and SR is 18.23% and
12.88% respectively. Improvement in TWR is less in case-1 (i.e. 7.02%) as compared to case-2 (i.e. 14.25%) and case-3 (10%). This is because settings of input parameters in case-1 lead to high MRR and high TWR.

7.5 Conclusions

Multi-response signal-to-noise (MRSN) ratio approach has been employed as multi-objective optimization technique for parametric optimization of EDM and is found very simple, systematic and effective. On the basis of industrial requirement, three cases have been taken viz. high cutting efficiency (case-1), high surface finish (case-2) and normal machining (case-3). A2B3C3D1E2F2G3, A2B2C2D1E2F2G1 and A2B3C2D1E1F1G3 are recommended as optimum factor /level combinations for case-1, case-2 and case-3 respectively. Predicted results have been experimentally verified and the improvement in MRR (with respect to initial setting of input parameters) is found as 27.47%, 12.98% and 18.23% in case-1, case-2 and case-3 respectively. Surface finish has also been improved considerably (with respect to initial setting of input parameters) which is as 10.61%, 19.31% and 12.88% in case-1, case-2 and case-3 respectively.