INVESTIGATION OF EFFECT OF SPEED, FEED AND DEPTH OF CUT ON MULTIPLE RESPONSES USING VIKOR ANALYSIS

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Abstract- MCDM/MADM methods are most commonly used multi objective problem solving tools used in the manufacturing industries. In the present work one of the MCDM/MADM method called VIKOR analysis has been used for setting the process parameters while turning of AA7075 on CNC turret lathe. The experiments were done as per the standard taguchi’s L9 orthogonal array. The output characteristics of material removal rate (MRR) and the surface roughness characteristics (Rₐ, Rₖ and R₉) were measured at different combinations of process parameters speed, feed and depth of cut. The VIKOR analysis found that speed of 2000 rpm, feed of 0.2 mm/rev and depth of cut of 1 mm is the optimal combination for attaining the maximum material removal rate and minimum surface roughness characteristics simultaneously. It is concluded from the ANOVA results that feed has the highest influence on the multi response value and followed by depth of cut and speed.

Keywords- Material Removal Rate (MRR), Surface Roughness (Rₐ), VIKOR analysis and ANOVA.

I. INTRODUCTION

The taguchi method is a commonly used statistical tool for improving the quality in the industries. Taguchi used a design called orthogonal array (OA) to perform experiments and employed the signal-to-noise ratio as the quality measurement index. The signal-to-noise (S/N) ratios consider both mean and variance of the quality characteristics, to determine the optimal setting of process parameters. Apart from the advantages, taguchi method has a major disadvantage that it can be applied for optimizing the single responses only but not for multi responses. In the present work, a new method VIKOR analysis has been employed for optimizing the multiple responses. This method can be applied to derive an integrated quality measurement of several conflicting responses. The best alternative determined by the vikor method is nearest to the ideal solution and farthest from the negative ideal solution. Similarly, the best alternative according to the vikor method has the maximum group utility for decision makers and ensures the least regret. This method first normalizes the experimental results then calculates the ideal and negative ideal solutions of the responses. The corresponding utility and regret measures may be determined by considering the individual weights for the responses. The vikor index is obtained by weighing the utility and regret measures of each response. The developed vikor index value can help the engineers to determine the optimal setting of parameters.

II. EXPERIMENTAL DETAILS

In the present work the specimens of AA7075 are taken in cylindrical form for conducting the experiments. The chemical and mechanical properties of AA7075 are given in the tables 1 and 2. For conducting the experiments; speed, feed and depth of cut are considered as process parameters at three different levels. The work specimens are machined on CNC turret lathe (DX-200, SEIMENS make Input power: 20KW, Spindle speed: 50-3500 rpm). Taguchi’s standard L9 Orthogonal array has been followed...
for conducting the experiments. The selected parameters with their levels and the L9 OA are given in the tables 3 and 4.

**Table 1. Chemical properties of AA7075**

| Element | % |
|---------|---|
| Al      | 87.1-91.4 |
| Zn      | 5.1-6.1   |
| Cu      | 1.2-2.0   |
| Cr      | 0.18-0.28 |
| Fe      | 0.5 max   |
| Mg      | 2.1-2.9   |
| Mn      | 0.3 max   |

**Table 2. Mechanical properties of AA7075**

| Property         | Value |
|------------------|-------|
| Density (gm/cm³) | 2.8   |
| UTS (Psi)        | 83000 |
| Yield strength (Psi) | 73000 |
| BHN              | 150   |
| Rockwell         | 1387  |

**Table 3. Cutting parameters and their levels**

| Parameter      | Level-1 | Level-2 | Level-3 |
|----------------|---------|---------|---------|
| Speed          | 1000    | 1500    | 2000    |
| Feed           | 0.2     | 0.3     | 0.4     |
| Depth of cut   | 0.5     | 0.75    | 1       |

**Table 4. L9 OA with actual experiments**

| S.No. | s (rpm) | f (mm/rev) | d (mm) |
|-------|---------|------------|--------|
| 1     | 1000    | 0.2        | 0.5    |
| 2     | 1000    | 0.3        | 0.75   |
| 3     | 1000    | 0.4        | 1      |
| 4     | 1500    | 0.2        | 0.75   |
| 5     | 1500    | 0.3        | 1      |
| 6     | 1500    | 0.4        | 0.5    |
| 7     | 2000    | 0.2        | 1      |
| 8     | 2000    | 0.3        | 0.5    |
| 9     | 2000    | 0.4        | 0.75   |

### III. METHODOLOGY

The VIKOR method was first introduced by Zeleny, in the year 1982. It is a Serbian name pronounced as Vlse Kriterijumska Optimizacija Kompromiso Resenje. This method is applicable to multi criteria decision making in a complex decision making problem. The basic thought of this VIKOR method is multi-criteria optimization and compromise the solution for finding a final solution. Basically it is an aggregated statistical procedure to find the solution close to ideal and negative ideal solution. This method is focused on ranking the set of alternatives from the different problems criteria that help the decision makers reach a final solution. The best optimal solution is the result corresponding to smallest VIKOR indexed value.

**Step 1.** Normalize the decision matrix, The Normalized matrix may be defined as, $f = (f_{ij})_{mn}$

Where,

$$f_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}^2}$$

$i = 1,2,\ldots,m; j = 1,2,\ldots,n$ and $x_{ij}$ is the corresponding value of the $j^{th}$ attribute.

**Step 2.** Determination of ideal and negative-ideal solutions.

The ideal (best) solution represented by $f^*$ and the negative ideal (Worst) solution represented by $f^-$ are determined as follows:

$$f^* = \left\{ \left( \text{max } f_{ij}/ j \in J \right) \text{ or } \left( \text{min } f_{ij}/ j \in J' \right) \right\}$$

$$f^- = \left\{ \left( \text{min } f_{ij}/ j \in J \right) \text{ or } \left( \text{max } f_{ij}/ j \in J' \right) \right\}$$

where, $J = \{ j = 1,2,\ldots,n \}, f_{ij}$ if desired response is large. $J' = \{ j = 1,2,\ldots,n \}, f_{ij}$ if desired response is small.

**Step 3.** Calculation of utility measure and regret measures.
The utility measure and the regret measure for each result are calculated by the following equations

\[ S_i = \sum_{j=1}^{n} w_j \frac{(f_i^* - f_{ij})}{(f_j^* - f_{ij})} \] \hspace{1cm} \text{Eq}(2)

\[ R_i = \max \left[ w_j \frac{(f_i^* - f_{ij})}{(f_j^* - f_{ij})} \right] \] \hspace{1cm} \text{Eq}(3)

Where, \( S_i \) is the utility measure, \( R_i \) is the regret measure and \( w_j \) is the corresponding weight of the \( j^{th} \) attribute.

**Step 4.** Calculation of VIKOR index.

The VIKOR index is calculated as the following relation.

\[ Q_i = \vartheta \left( \frac{(S_i - S^*)}{(S^* - S^{'})} \right) + (1 - \vartheta) \left( \frac{(R_i - R^{'})}{(R^* - R^{'})} \right) \] \hspace{1cm} \text{Eq}(4)

where \( Q_i \) is the VIKOR Index or multi-performance characteristic index (MPCI) of the \( i^{th} \) result of the alternatives and \( \vartheta \) is the maximum weight of the group utility in general \( \vartheta = 0.5 \).

\( S^* = \max S_i \), \( S^{' } = \min S_i \), \( R^* = \max R_i \), \( R^{' } = \min R_i \)

A smaller the VIKOR Index is the better result for the multi responses problem.

**Step 5.** Rank the order and find the optimal combination.

### IV. RESULTS AND DISCUSSIONS

The measured experimental results of material removal rate (MRR) in \( \text{cm}^3/\text{min} \) and surface roughness characteristics in \( \mu \text{m} \) are shown in the table 5. The experimental results were normalized using the equation 1 of the methodology.

| S.No. | MRR | \( R_a \) | \( R_q \) | \( R_z \) |
|-------|-----|---------|---------|---------|
| 1     | 9.21| 2.11    | 2.446   | 9.04    |
| 2     | 24.85| 5.023  | 6.07    | 22.68   |
| 3     | 32.57| 9.17    | 10.5    | 36.103  |
| 4     | 20.57| 2.036   | 2.363   | 8.546   |
| 5     | 39   | 7.16    | 8.27    | 26.94   |
| 6     | 24.85| 11.59   | 13.41   | 43.963  |
| 7     | 41.14| 3.35    | 3.87    | 13.263  |
| 8     | 27   | 7.25    | 8.346   | 26.086  |
| 9     | 39.85| 11.75   | 13.563  | 45.376  |

| S.No. | MRR | \( R_a \) | \( R_q \) | \( R_z \) |
|-------|-----|---------|---------|---------|
| 1     | 0.1008| 0.0938  | 0.0941  | 0.1040  |
| 2     | 0.2722| 0.2234  | 0.2335  | 0.2610  |
| 3     | 0.3567| 0.4079  | 0.4040  | 0.4155  |
| 4     | 0.2253| 0.0905  | 0.0909  | 0.0983  |
| 5     | 0.4271| 0.3185  | 0.3182  | 0.3101  |
| 6     | 0.2722| 0.5155  | 0.5159  | 0.5060  |
| 7     | 0.4506| 0.1490  | 0.1489  | 0.1526  |
| 8     | 0.2957| 0.3225  | 0.3211  | 0.3002  |
| 9     | 0.4365| 0.5226  | 0.5218  | 0.5223  |

From the normalized data of the responses given in table 6 the positive and negative ideal solutions were determined and given in the table 7.

| Parameter | MRR | \( R_a \) | \( R_q \) | \( R_z \) |
|-----------|-----|---------|---------|---------|
| \( f_i^* \) | 0.4506| 0.0905  | 0.0909  | 0.0983  |
| \( f_i^{' } \) | 0.1008| 0.5226  | 0.5218  | 0.5223  |
The utility and regret measures are predicted from the tables 6 and 7 and by using the equations 2 and 3. For calculating \( S_i \) and \( R_i \) values equal weights are assigned i.e. 0.25 for the material removal rate (MRR) and for surface roughness characteristics the results are shown in the table 6.

**Table 8. \( S_i, R_i \) and \( Q_i \) Values of responses**

| S.No. | \( S_i \) | \( R_i \) | \( Q_i \) | Rank |
|-------|----------|----------|---------|------|
| 1     | 0.257    | 0.25     | 0.566   | 6    |
| 2     | 0.3829   | 0.1275   | 0.3712  | 3    |
| 3     | 0.6193   | 0.1870   | 0.6388  | 7    |
| 4     | 0.1610   | 0.1610   | 0.3221  | 2    |
| 5     | 0.4052   | 0.1319   | 0.3938  | 4    |
| 6     | 0.9876   | 0.2550   | 1       | 9    |
| 7     | 0.0994   | 0.0338   | 0       | 1    |
| 8     | 0.4974   | 0.1342   | 0.4509  | 5    |
| 9     | 0.76     | 0.25     | 0.8604  | 8    |

The table 8 shows \( S_i, R_i \) and the vikor index \( (Q_i) \). For the calculated vikor index \( (Q_i) \), lower-the-better characteristic is employed and the results are given in the table 7.

**Table 9. The mean values of S/N ratios of \( Q_i \)**

| S. No | S  | I  | D  |
|-------|----|----|----|
| 1     | 5.815 | 7.392 | 3.954 |
| 2     | 5.978 | 7.874 | 6.585 |
| 3     | 4.112 | 1.733 | 5.994 |
| Delta | 1.866 | 6.141 | 2.631 |
| Rank  | 3   | 1   | 2   |

The main effect plot is drawn and shown in the figure 1. In the figure, it is observed that the main effect is due to feed, depth of cut and speed respectively. The optimal combination for achieving the maximum material removal rate and minimum surface roughness are found at speed of 2000 rpm, feed at 0.2 mm/rev and depth of cut of 1 mm respectively.

**Figure 1. Main effect plot for means of \( Q_i \)**

ANOVA is employed to the calculated vikor index to find the influence of the process parameters on the combined index value. From the results shown in the table 10, it is clear that the feed is the highest contributing factor and speed is the lowest contributing factor in effecting the multi response value.

**Table 10. ANOVA results of \( Q_i \)**

| Source | DF | Seq SS | Adj SS | Adj MS | F     | Contribution |
|--------|----|--------|--------|--------|-------|--------------|
| S      | 2  | 0.02815| 0.02815| 0.01407| 0.68  | 3.94         |
| F      | 2  | 0.48333| 0.48333| 0.24166| 11.76 | 67.66        |
| D      | 2  | 0.16166| 0.16166| 0.08083| 3.93  | 22.63        |
| Error  | 2  | 0.04112| 0.04112| 0.02056|       |              |
| Total  | 8  | 0.71425|        |        |       |              |

S= 0.143380; \( R^2 = 94.24\% \)\( R^2 \) (Adj) = 76.97%

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V. CONCLUSIONS

From the vikor analysis and ANOVA the following conclusions can be made:

- The optimal combination of process parameters for achieving the minimum vikor index value is obtained at speed of 2000 rpm, feed at 0.2 mm/rev and depth of cut of 1 mm respectively.
- The ANOVA results concluded that the feed is the major influencing factor and speed is the minor influencing factor on the vikor index value.
- The VIKOR analysis is a most effective multi objective tool and it can be apply to all the industrial problems which involves in multiple responses.

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