Multi-Response Optimization of Surface Roughness and MRR in Turning using Taguchi Grey Relational Analysis (TGRA)

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ABSTRACT

Turning operation is one of the important machining operations carried out in different manufacturing industries. Optimization of turning parameters is valuable to maintain accuracy, cost and time. Surface roughness and material removal rate measure quality and machining time respectively. In this paper response characteristics surface roughness and material removal rate are optimized using Taguchi Grey relational analysis. 18 experimental runs based on an L18 mixed-orthogonal array of Taguchi method were performed. A grey relational grade obtained from the grey relational analysis is used to find out optimized parameters with the multiple performance characteristics.

Key words: Optimization, Mixed-orthogonal array, GRA, Turning, Surface roughness, MRR

INTRODUCTION

In industrial manufacturing, turning is one of the most fundamental machining operations. Turning process can produce various shapes of materials such as straight, conical, curved, or grooved work pieces. In general, turning uses simple single-point cutting tools. Many researchers have studied the effects of optimal selection of machining parameters in turning. Tzeng and Chen (1) used grey relational analysis to optimize the process parameters in turning of tool steels. They performed Taguchi experiments with eight independent variables including cutting speed, feed, and depth of cut, coating type, type of insert, chip breaker geometry, coolant, and band nose radius. The optimum turning parameters were determined based on grey relational grade, which maximizes the accuracy and minimizes the surface roughness and dimensional precision.

Similarly, Deng (2) proposed use of principle of grey relational analysis to solve engineering problems. He measures the degree of approximation among sequences using grey relational grade. The grey relational grade can provide knowledge of the factors affecting response variables. The researchers have applied grey relational analysis (GRA) to different machining processes. Dilbag et al. (3) studied the effect of rake angle, cutting speed, feed rate and nose radius on surface finish and concluded that feed is the most influential factor on surface roughness. Bauachaet al. (4) investigated the influences of cutting speed, feed and depth of cut on cutting forces and surface roughness using the Taguchi technique during turning of AISI 52100 bearing steel with CBN tool. Results indicated that the depth of cut is a dominant factor affecting cutting forces and surface roughness followed by feed and depth of cut. Wang et al. (5) applied Taguchi and Grey relational technique to optimize turning process parameters to achieve minimum surface roughness and tool wear. Huang and Liao (6) applied grey relational analysis to determine the optimal selection of machining parameters for the Wire Electrical Discharge Machining (Wire-EDM) process. Kao and Hocheng (7) developed the application of the grey relational analysis for optimizing the electro polishing of 316L stainless

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steel with multiple performance characteristics. Mahdavinejad et al. (8) optimized tuning parameters of AISI 304 stainless steel using Design of Experiment and also conducted an ANOVA test to determine the effect of each parameter on surface roughness and tool wear. Tosun (9) reported the use of grey relational analysis for optimizing the drilling process parameters for the work piece surface roughness and the burr height is introduced. This study indicated that grey relational analysis approach can be applied successfully to other operations in which performance is determined by many parameters at multiple quality requests. Al-Refaie et al. (10) used Taguchi method grey analysis (TMGA) to determine the optimal combination of control parameters in milling the measures of machining performance being the MRR and SR. Raykar et al. (11) developed multi objective optimization using GRA for surface roughness, power consumption, material removal rate and cutting time of High Speed Turning of Al 7075. Reddy et al. (12) applied Taguchi grey relational analysis to optimize the process parameters of Wire EDM on multiple performance characteristics such as Material removal rate, surface finish. The combination of wire tension, pulse on time, pulse off time, lower flush, wire tension, and higher flush is required to maximise material removal rate while minimising surface roughness and kerf breadth, according to the experimental results. Singh et al. (13) investigated the influence of the machining parameters during milling upon the surface roughness and material removal rate of AISI 11 steel. Ali Rizvi and Ali (14) also applied Taguchi technique coupled with GRA to optimize the turning variables for the simultaneous improvement of productivity, root mean square roughness and average surface roughness 16MnCr5 steel.

As a result, the goal of this paper is to show how to apply grey relational analysis to pick optimal turning circumstances based on multi-performance factors, such as surface roughness. In addition, the most effective factor and the order of importance of the controllable factors to the multi-performance characteristics in the turning process were determined.

**EXPERIMENTAL DETAILS**

IS: 2062, Gr. B Mild Steel bar is a product standard of Bureau of Indian Standards. It establishes requirements for hot-rolled medium and high-tensile structural steels. IS 2062 steels are mostly utilised in the construction industry. Chemical composition and mechanical properties of IS: 2062 are shown in Table 1 and Table 2 respectively.

| GRADE | C (Max.) | Mn (Max.) | Si(Max.) | P(Max.) | S(Max.) | C.E % (Max.) |
|-------|----------|-----------|----------|---------|---------|--------------|
| B     | 0.22     | 1.5       | 0.04     | 0.045   | 0.045   | 0.41         |

| GRADE | UTS (MPA) Min. | Y.S. (MPa) Min. | El % Min 5.65 Sqrt(So) | Bend Test |
|-------|----------------|-----------------|-------------------------|-----------|
| B     | 410            | 240             | 23                      | 2T        |

The cutting experiments were carried out on an experimental lathe setup using a Carbide Tool WIDACUT ISO-3 R 1616 cutting tool and High Speed Steel Tool for the machining of the IS: 2062, Gr. B Mild Steel bar, which is 22 mm in diameter. Metrix surface roughness tester was used to measure the Surface roughness Ra (µm) of the machined samples. Process parameters and experimental results are shown in the Table 3 and Table 4 respectively.
### Table 3: Selected process parameters and their levels

| Process parameters | Unit | Levels   |
|--------------------|------|----------|
| Cutting Tool       |      | HSS      |
|                    |      | Carbide  |
| Cutting Speed (v)  | RPM  | 124      |
|                    |      | 186      |
|                    |      | 274      |
| Feed (f)           | mm/rev | 0.03    |
|                    |      | 0.06     |
|                    |      | 0.12     |
| DOC (d)            | mm   | 0.5      |
|                    |      | 0.75     |
|                    |      | 1.0      |

### Table 4: Experimental results of responses

| Exp. No | Cutting Tool | Cutting Speed (v) | Feed (f) | Depth of cut (d) | Experimental results of responses |
|---------|--------------|------------------|----------|-----------------|----------------------------------|
|         |              |                  |          |                 | MRR (mm³/sec) | Surface Roughness (μm) |
| 1       | HSS          | 274              | 0.03     | 1.00            | 7.17      | 0.15                     |
| 2       | HSS          | 274              | 0.06     | 0.75            | 10.12     | 6.85                     |
| 3       | HSS          | 274              | 0.12     | 0.50            | 12.34     | 6.45                     |
| 4       | HSS          | 186              | 0.03     | 1.00            | 5.01      | 5.51                     |
| 5       | HSS          | 186              | 0.06     | 0.75            | 7.09      | 8.38                     |
| 6       | HSS          | 186              | 0.12     | 0.50            | 8.66      | 7.58                     |
| 7       | HSS          | 124              | 0.03     | 0.75            | 2.50      | 4.14                     |
| 8       | HSS          | 124              | 0.06     | 0.50            | 3.15      | 5.49                     |
| 9       | HSS          | 124              | 0.12     | 1.00            | 14.63     | 8.91                     |
| 10      | Carbide      | 274              | 0.03     | 0.50            | 3.37      | 3.23                     |
| 11      | Carbide      | 274              | 0.06     | 1.00            | 16.11     | 3.58                     |
| 12      | Carbide      | 274              | 0.12     | 0.75            | 21.69     | 6.09                     |
| 13      | Carbide      | 186              | 0.03     | 0.75            | 3.43      | 4.35                     |
| 14      | Carbide      | 186              | 0.06     | 0.50            | 4.43      | 6.67                     |
| 15      | Carbide      | 186              | 0.12     | 1.00            | 20.21     | 8.68                     |
| 16      | Carbide      | 124              | 0.03     | 0.50            | 1.38      | 7.75                     |
| 17      | Carbide      | 124              | 0.06     | 1.00            | 6.70      | 2.90                     |
| 18      | Carbide      | 124              | 0.12     | 0.75            | 8.95      | 8.57                     |

**Figure 1:** Material after Experiment
**METHODOLOGY OF GREY RELATIONAL ANALYSIS**

**Grey relational analysis**

Original Taguchi method has been designed to optimize a single performance characteristic. The Grey relational analysis based on the Grey system theory can be used to solve complicated multiple performance parameters effectively. As a consequence, complex output optimization can be reduced to a single Grey relational grade optimization. Grey relation analysis is used to find out whether there is consistency between the changing trends of two factors or not, and to find out the possible mathematical relationship among the factors or in the factors themselves.

**Data pre-processing**

Data pre-processing is normally required since the range and unit in one data sequence may differ from the others. Data pre-processing is also necessary when the sequence scatter range is too large or when the directions of the target in the sequences are different. Data pre-processing is the process of converting a sequence from one that is similar to the original. Depending on the characteristics of a data sequence, there are various methodologies of data pre-processing available for the grey relational analysis. If the original sequence’s goal value is infinite, it has the property of "greater is better." The original sequence can be normalized as follows:

\[ x_i^*(k) = 1 - \frac{|x_i^o(k) - x_i^o|}{\max x_i^o(k) - \min x_i^o(k)} \quad \text{[iii]} \]

The original sequence can also be easily normalised using the most basic approach, which is to divide the value of the original sequence by the first value of the series:

\[ x_i^*(k) = \frac{x_i^o(k)}{x_i^o(1)} \quad \text{[iv]} \]

Where, \( i = 1 \ldots m; \ k = 1 \ldots n \). \( m \) is the number of experimental data items, and \( n \) is the number of parameters. \( x_i^o(k) \) denotes the original sequence, \( x_i^*(k) \) the sequence after the data pre-processing, \( \max x_i^o(k) \) the largest value of \( x_i^o(k) \), \( \min x_i^o(k) \) the smallest value of \( x_i^o(k) \), and \( x_i^o \) is the desired value of \( x_i^o(k) \).

**Grey relational coefficient and grey relational grade**

In grey relational analysis, the measure of the relevancy between two systems or two sequences is defined as the grey relational grade. When only one sequence, \( x_o(k) \), is available as the reference sequence, and all other sequences serve as comparison sequences called a local grey relation measurement. After data pre-processing is carried out, the grey relation coefficient \( \xi(k) \) for the \( k \)th performance characteristics in the \( i \)th experiment can be expressed as follows,

\[ \xi(k) = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{\min} + \Delta_{\max}} \quad \text{[v]} \]

Where, \( \Delta_{\min}(k) = |x_o^o(k) - x_i^*(k)| \) and \( \Delta_{\max} = 1.00 \), \( \Delta_{\min} = 0.00 \) and \( \Delta_{\max} \) is the deviation sequence of the reference sequence \( x_o^o(k) \) and the comparability sequence \( x_i^*(k) \). \( \xi \) is the distinguishing or identification coefficient defined in the range \( 0 \leq \xi \leq 1 \) (the value may be adjusted based on the practical needs of the system). A value of \( \xi \) is smaller and the distinguished ability is the larger. The purpose of defining this coefficient is to show the relational degree between the reference sequence \( x_o^o(k) \) and the comparability sequence \( x_i^*(k) \), and \( \xi = 0.5 \) is generally used. After determining the grey relational coefficient, the average value of the grey relational coefficients is commonly used to
determine the grey relational grade. This is how the grey relationship grade is defined:

\[ \gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \]

However, in a real engineering system, the relative importance of various factors varies. In the real condition of unequal weight being carried by the various factors, the grey relational grade in Eq. [i] was extended and defined as recommended by Deng (1982).

\[ \gamma_i = \frac{1}{n} \sum_{k=1}^{n} w_k \xi_i(k) \]

Where \( \sum_{k=1}^{n} w_k = 1 \) and \( w_k \) denotes the normalized weight of factor \( k \). Here, the grey relational grade \( \gamma_i \) represents the level of correlation between the reference sequence and the comparability sequence. If the two sequences are identical by coincidence, then the value of grey relational grade is equal to 1.

The grey relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence. As a result, if one comparability sequence is more essential to the reference series than the others, the grey relational grade for that comparability sequence and reference sequence will be greater than the grey relational grade for another comparability sequence and reference sequence. Grey relational analysis is actually a measurement of absolute value of data difference between sequences, and it could be used to measure approximation correlation between sequences.

RESULTS AND DISCUSSION

We know from the analysis of machining process that the lower surface roughness as well as higher value of material removal rate provides better quality of the machined surface. Thus, the data sequences surface roughness has “smaller-the-better” characteristics while material removal rate has “higher-the-better”. Table 05 lists all of the sequences following data pre-processing of surface roughness and material removal rate by using Eq. [ii]. Then, the deviation sequence, \( \Delta_{\text{ad}}(k) = |x_i(k) - x_0(k)| \), has been determined and are shown in Table 05. Grey relational coefficient and Grey relational grade values of each experiment of the full factorial design were calculated by applying equation [v] and [vi]. Table 05 also shows the Grey relational coefficient and grey relational grade for each experiment using full factorial design. From the Evaluated grey relational grades, it is clear that second level of cutting tool (i.e. carbide), third level of Cutting Speed (i.e. 274 RPM), third level of Feed (i.e. 0.12 mm/rev) and second level of depth of cut (i.e. 0.75 mm) are the optimal parameters for the IS: 2062, Gr. B Mild Steel as shown in the Table 6.

**Table 05: Evaluation grey relational grades**

| Exp. No. | MRR | Surface Roughness | MRR | Surface Roughness | MRR | Surface Roughness | Grey relational grade | Evaluated grey relational grades | Rank |
|----------|-----|------------------|-----|------------------|-----|------------------|------------------------|-------------------------------|------|
| 1        | 0.29| 0.72             | 0.0411| 1                | 0.71| 2                |
| 2        | 0.44| 0.24             | 0.57 | 0.77             | 0.467| 0.395           | 0.44                  | 11                           |
| 3        | 0.54| 0.29             | 0.47 | 0.72             | 0.52 | 0.41             | 0.47                  | 7                            |
| 4        | 0.18| 0.39             | 0.83 | 0.62             | 0.378| 0.49             | 0.42                  | 12                           |
| 5        | 0.29| 0.07             | 0.94 | 0.94             | 0.41 | 0.347            | 0.38                  | 18                           |
| 6        | 0.36| 0.16             | 0.65 | 0.85             | 0.437| 0.371            | 0.41                  | 13                           |
| 7        | 0.06| 0.55             | 0.95 | 0.46             | 0.346| 0.523            | 0.44                  | 9                            |
| 8        | 0.09| 0.4              | 0.92 | 0.61             | 0.353| 0.45             | 0.41                  | 14                           |
Table 06: Response table for the Grey relational grade

| Process parameters | Grey relational grade | Max-Min |
|--------------------|-----------------------|---------|
|                    | Level 1 | Level 2 | Level 3 |        |
| Tool               | 0.46    | 0.51*   | -----   | 0.05   |
| Cutting Speed      | 0.44    | 0.45    | 0.57*   | 0.13   |
| Feed               | 0.48    | 0.46    | 0.51*   | 0.05   |
| Depth of cut       | 0.47    | 0.56*   | 0.42    | 0.14   |
| Total mean Grey relational grade = 0.48 |

* optimal turning parameters

Figure 2: Grey relational grade graph

CONCLUSION

The multi-response optimization problem has been transformed into a single equivalent objective function optimization problem using this approach. The higher grey relational grade is said to be close to the optimal. According to performed experiment design, it is clearly observed that experiment no. 12 has the highest Grey relation grade. Thus, the Twelfth experiment gives the best multi-performance characteristics of the turning process among the 54 experiments.
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CONFLICT OF INTEREST
The authors declare that there is no conflict of interests regarding the study or this article.

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