

# Optimization of machining parameters for turning process by using grey relational analysis

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## Abstract

This paper presents an optimization of process parameters of turning operation using multi-response optimization Grey Relational Analysis (GRA) method instead of single response optimization. These parameters were optimized based on a three level two factor factorial design with three center points was used for the experimental design with Grey Relational Analysis. The machining parameters such as cutting speed, feed rate, and depth of cut were chosen for experimentation. The performance characteristics chosen for this study are material removal rate (MRR), tool life, and surface roughness. Experiments were conducted using coated carbide tool (KC5010) as the tool and martensitic stainless steel (AISI 420) as the workpiece. Experimental results have been improved through this approach.

**Keywords:** GRA; MRR; Tool life; Surface roughness

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## 1. Introduction

Machining is the main manufacturing process for the manufacture of mechanical products, such as press tools, thereby contributing to the plurality of product cost. Frugality in machining is influenced by the tool wear of the cutting tool, which in turn affects the production time and total product cost. Machining generates high temperature between the cutting tool and workpiece as well as between the cutting tool and chip which cause various phenomena, including tool wear, dimensional deviation of the machined parts, and damaged surface integrity [1].

The turning process is a process where the material is removed from the workpiece using a single-point cutting edge to produce a surface of revolution [2]. The machine tool on which this is accomplished is called a lathe and the process variables generally adjusted by the operator are cutting speed, feed rate, and depth of cut. Turning material with hardness above 45 HRC using single point tool is referred to as hard turning [3]. Under a small feed rate and fine depth of cut with proper cutting tools under dry conditions or minimizing the use of cutting fluid in order to obtain better surface quality and surface integrity close to those obtained by grinding [4]. Hard turning is performed at small values of feed rate (0.05–0.2 mm/rev) and depth of cut (0.05–0.3 mm), using small values of both feed rate and depth of cut, the undeformed chip thickness and the ratio of the undeformed chip thickness to the radius of the cutting edge are obtained in such processes [5]. Hard turning consumes less energy and enhances surface quality [6].

Stainless steel is a difficult-to-cut material and is widely used in aerospace and automotive applications because of its high strength, high fracture toughness, high fatigue, and corrosion resistivity as compared to plain carbon steels. Stainless steel is classified as one of the corrosion alloy steel with at least 10% chromium. Generally, all stainless steel is known as a highly corrosion-resistant material because of the chromium-rich oxide film formed on the surface. Other elements such as nickel and niobium could improve the corrosion resistance of this material. At ambient temperature,

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stainless steel has a much lower thermal conductivity compared to carbon steel and therefore higher temperatures are being generated at the cutting tool edge when machining stainless steel when compared to carbon steel [7].

The Grey theory established by Dr. Deng includes Grey relational analysis, Grey modeling, prediction and decision making of a system in which the model is unsure or the information is incomplete [8]. It provides an efficient solution to the uncertainty, multi-input and discrete data problem. The relation between machining parameters and machining performance can be found out using the Grey relational analysis and this kind of interaction is mainly through the connection among parameters and some conditions that are already known. Also, it will indicate the relational degree between two sequences with the help of Grey relational analysis. Moreover, the Grey relational grade will utilize the discrete measurement method to measure the distance [9].

Multi-attribute decision-making techniques like GRA have not yet been implemented widely to find the optimal setting during turning process. The present work is a stride in this direction. An effort has been made to find an optimal set of process variables using multi-objective optimization using GRA to get maximum MRR, tool life and minimum SR.

## 2. Experimental setup, procedure and equipment

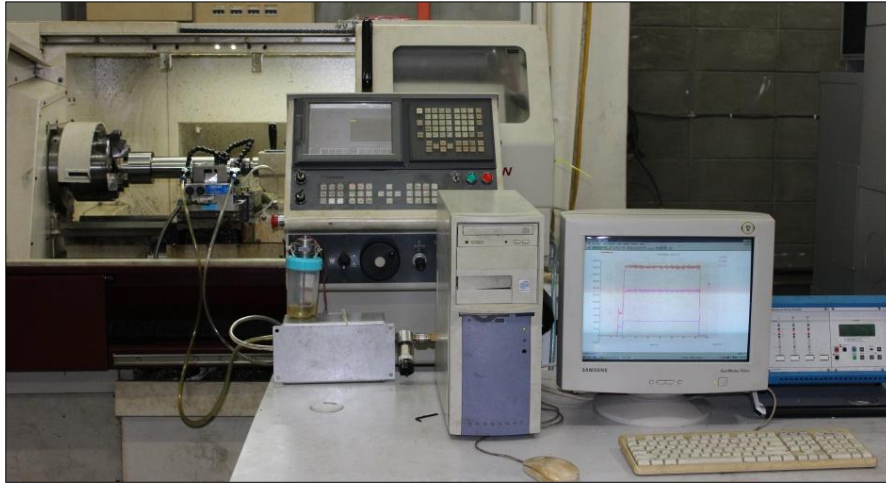
The experiments were conducted using a 2-axis CNC lathe turning machine. Cutting tool and workpiece materials were coated carbide tool (KC5010) and martensitic stainless steel (AISI 420) respectively. Experiments were conducted at various cutting speeds (100, 135 and 170 m/min) and feed rates (0.16, 0.20 and 0.24 mm/rev). All experiments were performed at a constant depth of cut of 0.2 mm. Three level two factor factorial design with three center points was used for the experimental design. The response variables material removal rate, surface roughness, and tool life. The equipment and machines that were used in this work are illustrated in figure1.

**Table 1** Process parameters and experimental conditions

	Level/ Factors	High	Centre	Low
	Coded no	+1	0	-1
[A]	Cutting speed (m/min)	170	135	100
[B]	Feed rate (mm/rev)	0.24	0.2	0.16
[C]	Depth of cut	0.2		

**Table 2** Experimental plan and results

Standard	Cutting speed (m/min)	Feed rate (mm/rev)	Tool life (min)	Total material removed (cm <sup>3</sup> )	Surface roughness (μm)
1	100	0.16	33.7	107.8	0.38
2	135	0.20	8.3	44.8	0.41
3	135	0.20	7.4	40.0	0.38
4	135	0.20	8.2	44.3	0.38
5	135	0.24	3.9	25.3	0.46
6	100	0.20	31.7	126.8	0.47
7	170	0.20	2.2	15.0	0.37
8	100	0.24	20.1	96.5	0.49
9	170	0.24	1.5	12.2	0.43
10	170	0.16	6.8	37.0	0.35
11	135	0.16	8.4	36.3	0.37



**Figure 1** Alpha 1350 S CNC lathe and dynamometer

### 3. Analysis method

#### 3.1. Grey rational analysis

Initiator of the Grey system theory (1982) widely used for measuring the degree of relationship between sequences by Grey relational grade [10]. In GRA, the experimental values of the measured quality characteristics are normalized in a range from zero to one [11]. This is known as grey relational generation. Then the grey relational coefficient (GRC) is calculated. The overall Grey relational grade is then computed by averaging the Grey relational coefficient corresponding to each performance characteristic. As a result, optimal combination of process parameters is evaluated considering the highest Grey relational grade by using the Taguchi method. The overall performance characteristic depends on the computation of the grey relational grade (GRG). Thus, a multiple response process optimization is transformed into a single objective problem [12]. The highest GRG will be evaluated as the optimal parametric combination. Typically the normalization process involves two concepts into the *Taguchi's* technique (nominal the smaller is the better and higher is the better) [13]. The “higher is the better” concept is used for normalizing the MRR and tool life by using Eq1, while the lower is the better concept is used for normalizing the variables SR by using in Eq2.

$$x_i^*(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \dots \dots \dots (1)$$

$$x_i^*(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \dots \dots \dots (2)$$

The terms  $x_i(k)$  is the  $i^{th}$  series in the original value of  $k$ ; order  $x_i^*(k)$  is the  $i^{th}$  series and  $k$  order after normalization,  $\min x_i(k)$  is the minimum value in the  $i^{th}$  series,  $\max x_i(k)$  is the maximum value in the  $i^{th}$  series. Table 3 shows the normalized results of experimental results obtained for performances.

**Table 3** Normalization (data pre-processing) of the experimental results

Exp no	MRR	Tool life	SR
1	0.834205934	1	0.78571429
2	0.284467714	0.21118	0.57142857
3	0.242582897	0.18323	0.78571429
4	0.280104712	0.208075	0.78571429
5	0.114310646	0.074534	0.21428571
6	1	0.937888	0.14285714
7	0.02443281	0.021739	0.85714286
8	0.735602094	0.57764	0
9	0	0	0.42857143
10	0.216404887	0.164596	1
11	0.210296684	0.214286	0.85714286

**3.2. Grey rational coefficients (GRC)**

Normalization creates a new matrix of difference vectors. From this matrix, a GRC is calculated, expressed as:

$$\vartheta_i(k) = \frac{(\Delta_{min} + \zeta \Delta_{max})}{(\Delta_{oi}(k) + \zeta \Delta_{max})} \quad (3)$$

The term  $\vartheta_i(k)$  denotes GRC for the  $k$  output parameter and  $\Delta_{oi}(k) = |x_0^*(k) - x_i^*(k)|$  is the deviation sequence. Lastly,  $\Delta_{min} = \min |x_0^*(k) - x_i^*(k)|$  whereas  $\Delta_{max} = \max |x_0^*(k) - x_i^*(k)|$  and  $\zeta =$  weighting coefficient that is 0.5.

**3.3. Grey Relational Grades (GRG)**

**Table 4** GRG for each experimental run

Expt. no	Grey Relational Coefficient			GRG ( $\gamma$ )	Rank
	MRR	Ttool life	SR		
1	0.750983	1	0.7	0.81699432	1
2	0.411342	0.387952	0.5384615	0.44591859	9
3	0.397641	0.379717	0.7	0.4924525	7
4	0.409871	0.387019	0.7	0.49896349	6
5	0.360831	0.350763	0.3888889	0.36682755	11
6	1	0.889503	0.3684211	0.75264127	2
7	0.338853	0.338235	0.7777778	0.48495527	8
8	0.65411	0.542088	0.3333333	0.50984349	5
9	0.333333	0.333333	0.4666667	0.37777778	10
10	0.389531	0.374419	1	0.58798318	3
11	0.387686	0.388889	0.7777778	0.51811758	4

Finally, the GRG is obtained by averaging the GRC corresponding to each performance measures. Thus by applying (Eq 4), all GRGs can be computed

$$(\gamma)_i = \frac{1}{n} \sum_{k=1}^n \vartheta_i(k) \quad (4)$$

The term  $\gamma$  denotes the Grey Relational Grade (GRG) while  $n$ , is the number of output parameters. Table 4 presents the grey relational coefficients and grades for each response.

#### 4. Results and discussion

Table 5 shows the mean of the GRG for each level of the machining parameters chosen for this study. The orthogonal experiment design separates out the effect of each machining parameter on the GRG at different levels. For example, the mean of GRG for the factor A at level 1 can be calculated by taking the average of the GRG for the experiment no. 1, 6 and 8, respectively (shown in Table 4). Similarly, mean of the GRG for each level of other machining parameters can also be computed. In addition, the total mean of the GRG for the 11 experiments is also calculated and listed in Table 5. The total mean value of the GRG is 0.5320. As stated by Fung, "the grey relational grade represents the level of co-relation between the reference sequence and the comparability sequence" [14]. The greater value of the GRG means that the comparability sequence has a stronger correlation to the reference sequence. Therefore, the optimal level of the machining parameters is the level with the greatest GRG value. The level value marked asterisks (\*) in response table, indicates that they results in a better turning performance. Based on the GRG given in Table 5, the optimal machining performance for MRR, tool life, and SR was obtained for cutting speed (level 1), feed rate (level 1) and depth of cut (any level because it has same values). Accordingly, the level constitution of optimal machining parameters are A1, B1 and C1 in the case of multiple performance characteristics optimization for turning process, since higher GRG values yield better quality. The difference between the maximum and the minimum value of the GRG for turning process machining parameters is also calculated and tabulated in Table 5. The tabulated results are follows: 0.2287 for cutting speed, 0.22288 for feed rate, and 0 for depth of cut, respectively. The most significant factor affecting performance characteristics is determined by comparing these values. This comparison gives the level of significance of the process parameters over the multiple performance characteristics. The most effective controllable factor was the maximum of these values. As per Table 5, the maximum value among the controllable factors is for peak cutting speed. This higher value indicates that the cutting speed has the strongest effect on the multiple performance characteristics among the other machining parameters. The order of importance of the machining parameters to the multiple performance characteristics in the turning process, in sequence can be ranked as: factor A (cutting speed), B (feed rate), C (depth of cut).

**Table 5** Response table for GRG

Machining parameters	Grey Relational Grade			Main Effect Max-Min	Rank
	Level 1	Level 2	Level 3		
Cutting speed	0.693159694*	0.464455942	0.4835721	0.2287038	1
Feed rate	0.641031692*	0.534986226	0.4181496	0.2228821	2
Depth of cut	0.4459186	0.4459186	0.4459186	0	3

Total mean value of GRG = 0.532; \* Levels for optimum GRG

#### 5. Conclusion

The GRA based on the 2-Level Factorial Design was proposed as an approach to investigate the optimization of turning processes parameters. The optimal machining parameters were determined by Grey Relational Grade (GRG) for the multi-performance characteristics; MRR, tool life and surface roughness. According to the response table of the average GRG, the optimal process parameters were; 100 m/min cutting speed, 0.16mm/rev feed rate, 0.2mm depth of cut.

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## Compliance with ethical standards

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### *Disclosure of conflict of interest*

The author declared that there was no conflict of interest during the cause of this study and producing and submitting this manuscript for publication.

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