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MULTI- RESPONSE OPTIMIZATION OF TURNING PARAMETERS USING THE GREY-BASED TAGUCHI METHOD

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ABSTRACT
Optimization of machining processes is essential for achieving of higher productivity and high quality products in order to remain competitive. This study investigates multi-response optimization of turning process for an optimal parametric combination to provide the minimum surface roughness (Ra) with the maximum material-removal rate (MRR) using a Grey–Based Taguchi method. Turning parameters considered are cutting speed, feed rate and depth of cut. Nine experimental runs based on Taguchi's L_9 (3^4) orthogonal array were performed followed by Grey relational analysis to solve the multi-response optimization problem. Based on grey relational grade value, optimum levels of parameters have been identified. The significance of parameters on overall quality characteristics of the cutting process has been evaluated by the analysis of variance (ANOVA). The optimal parameter values obtained during the study have been validated by confirmation experiment.
Keywords: Grey Relational analysis, Taguchi method, Multi-response optimization

1. INTRODUCTION
Determination of optimal machining parameters is continuous engineering task which goals are to reduce the production costs and to achieve the desired product quality. In turning process, surface quality is one of the most important performance measures. Surface roughness (*Ra*) is a widely used index of product quality and in most cases a technical requirement for mechanical products. Achieving the desired surface quality is of great importance for the functional behavior of a part. At the same time higher material removal rate (*MRR*) is considered as the factor that directly affects the production cost and the machining hour rate. In a turning operation, it is an important task to select cutting parameters to achieve high cutting performance for a particular machine and environment. Hence, multi-response optimization method based on a combination of Grey relational analysis (GRA) and the Taguchi method was employed in this paper to determine the optimal values of cutting speed, feed and depth of cut in order to obtain better surface roughness and increased material removal rate in the finish turning operation [1].

2. EXPERIMENTAL PROCEDURE
Experimental research was performed on lathe machine "Georg Fisher NDM-16". Test samples were carbon steel bars DIN Ck45 with 100 mm in diameter and 380 mm in length. Chemical composition and mechanical properties of DIN Ck45 steel is given in Table 1. and Table 2. Experiments were carried out by the external machining turning tool with the holder mark DDJNL 3225P15 and the coated inserts type DNMG 150608-PM4025 under dry cutting conditions. The tool geometry was:

rake angle 17°, clearance angle 5°, main cutting edge 93° with nose radius 0,8 mm. Before each cut, the insert was changed to eliminate the effect of tool wear. Surface roughness measurements were performed with Surftest Mitutoyo SJ-201P. The surface roughness measured in the paper is the arithmetic mean deviation of surface roughness of profile *Ra* [2]. The material removal rate of the work piece is the volume of the material removed per minute, $MRR=Vfd$ (cm^3/min). It can be calculated by using three main cutting parameters. Namely, cutting speed V (m/min), feed rate f (mm/r) and depth of cut d (mm). Taguchi-based experimental design has been used to study the entire parameter space with a limited number of experiments, a L_9 (3^4) orthogonal arrays with three levels (coded by: 1; 2 and 3) of three main cutting parameters, Table 3.

Table 1. Chemical composition

Mat.	C	Si	Mn	P	S	Ni	Mo
Ck45	0,467	0,309	0,657	0,014	0,021	0,039	0,0087

Table 2. Mechanical properties

Mat.	Rm (MPa)	Re (MPa)	% of El.	HB
Ck45	650	420	24,2	179

Table 3. Cutting parameters and their limits

Symbol	Parameters	Levels		
	Coding – Orthogonal array	1	2	3
A	X1 = V (m/min)	400	450	500
B	X2 = f (mm/rev.)	0,1	0,15	0,2
C	X3 = d (mm)	0,4	0,8	1,2

3. RESULTS AND DISCUSSIONS

3.1. Grey Relational Analysis

In grey relational analysis the first step is to perform the grey relational generation in which the results of the experiments are normalized in the range between 0 and 1 due to different measurement units. Normalizing the experimental data for each response characteristic is done according to the type of performance response. Thuse, the normalized data processing for *Ra* corresponding to smaller-the-better criterion can be expressed as [1,3,4]:

$$x_i(k)=\frac{\max y_i(k)-y_i(k)}{\max y_i(k)-\min y_i(k)}\,. \tag{1}$$

The normalized data processing for *MRR* corresponding to larger-the-better criterion can be expressed as:

$$x_i(k)=\frac{y_i(k)-\min y_i(k)}{\max y_i(k)-\min y_i(k)}\,. \tag{2}$$

Where, i = 1, 2, 3, ..., m, m is the number of experimental runs in Taguchi orthogonal array, m = 9 for L_9 . k = 1, 2, ..., n, n is the number of responses, in the present work surface roughness and material removal rate are selected, then n = 2. Min y_i (k) is the smallest value of y_i (k) for the k^{th} response. Max y_i (k) is the largest value of y_i (k) for the k^{th} response. x_i (k) is the value after grey relational generation. The normalized values of surface roughness and material removal rate calculated by Eq. (1) and (2) are shown in Table 4. The second step is to calculate the grey relational coefficient based on the normalized experimental data to represent the correlation between the desired and actual experimental data by using the following equation:

$$\xi_i(k)=\frac{\Delta_{\min}+\varsigma\Delta_{\max}}{\Delta_{0i}(k)+\varsigma\Delta_{\max}}\,. \tag{3}$$

Where Δ_{oi} = $\|x_0(k) - x_i(k)\|$ is difference of the absolute value between $x_0(k)$ and $x_i(k)$, $x_0(k)$ is the reference sequence of k^{th} quality characteristics. Δ_{min} and Δ_{max} are respectively the minimum and maximum values of the absolute differences (Δ_{oi}) of all comparing sequences. ζ is a distinguishing coefficient, $0\le \zeta \le 1$. In the present case, ζ = 0.5 is used. The grey relation coefficient of each performance characteristic is shown in Table 4. After averaging the grey relational coefficients, the grey relational grade γ_i can be calculated as follows:

$$\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\xi_i(k)\,. \tag{4}$$

Where, i = 1, 2, 3 ... 9, (L_9 orthogonal array is selected), $\xi_i(k)$ is the grey relational coefficient of k^{th} response in i^{th} experiment and n is the number of responses. The optimum level of the process parameters is the level with the highest grey relational grade. The grey relational grade is presented in Table 4. calculated by Eq. (4). The highest grey relational grade is the rank of 1.

Table 4. Grey relational coefficient, grey relational grade and corresponding S/N ratios

Exp. No.	Cutting parameters L_9 (3^4) orthogonal array			Measured data of responses		Normalized values of responses		Grey relational coefficient		Grey relational grade		
	V (m/min)	*f* (mm/rev)	*d* (mm)	$\overline{Ra}$ (µm)	*MRR* (cm^3/min)	*Ra* S-T-B	*MRR* L-T-B	*Ra*	*MRR*	Grade	Rank	S/N Ratio L-T-B
1.	400	0,1	0,4	0,77	16	1,0000	0,0000	1,0000	0,3333	0,6667	3	-3,5218
2.	400	0,15	0,8	1,33	48	0,5912	0,4000	0,5502	0,4545	0,5023	8	-5,9795
3.	400	0,2	1,2	2,14	96	0,0000	1,0000	0,3333	1,0000	0,6667	2	-3,5218
4.	450	0,1	0,8	1,11	36	0,7518	0,2500	0,6683	0,4000	0,5341	7	-5,4468
5.	450	0,15	1,2	1,13	81	0,7372	0,8125	0,6555	0,7273	0,6914	1	-3,2056
6.	450	0,2	0,4	2,01	36	0,0948	0,2500	0,3558	0,4000	0,3779	9	-8,4520
7.	500	0,1	1,2	1,19	60	0,6934	0,5500	0,6199	0,5263	0,5731	4	-4,8352
8.	500	0,15	0,4	1,05	30	0,7956	0,1750	0,7098	0,3774	0,5436	5	-5,2944
9.	500	0,2	0,8	1,93	80	0,1532	0,8000	0,3713	0,7143	0,5428	6	-5,3075

The multi-response optimization problem has been transformed into a single equivalent objective function optimization problem using Grey relational analyses. Accordingly, optimal combination of process parameters is evaluated considering the highest grey relational grade by using the Taguchi method.

3.2. Analysis of S/N ratios

Table 4. shows the S/N ratio based on the larger-the-better criterion for the overall Grey relational grade calculated using equation (5):

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right]. \quad (5)$$

where n is the number of measurements, and y_i is the measured characteristic value [5]. The mean response for the Grey relational grade with its grand mean and the main effect plot of the Grey relational grade are very important because the optimal process condition can be evaluated from this plot, Fig. 1. and Table 5.

Table 5. Response table for the mean Grey relational grade

Parameter	Grey relational grade			
	Level 1	Level 2	Level 3	Delta
A (*V*)	**0,6119**	0,5345	0,5532	0,0774
B (*f*)	**0,5913**	0,5791	0,5291	0,0622
C (*d*)	0,5294	0,5264	**0,6437**	0,1173

Total mean value of the grey relational grade =**0.5665**

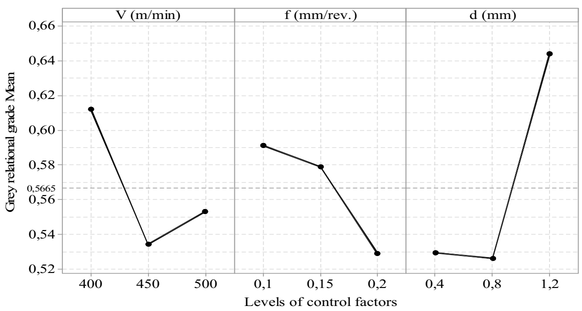

Figure 1. Mean plot for the Grey relational grade

As indicated in Fig. 1. and Table 5., the optimal parameter condition for turning of the C45 carbon steel regarding surface roughness and material removal rate multiple performance characteristics are levels: A-level 1, B-level 1, C-level 3. Namely, cutting speed of *V*=400 m/min, feed rate of *f*= 0,1 mm/rev. and depth of cut *d*=1,2 mm. By using the grey relational grade value, ANOVA is indicated for identifying the significant factors. In addition to degree of freedom (*DF*), mean of squares (*MS*), sum of squares (*SS*), *F*-ratio and contribution (*C*) associated with each factor was presented. The higher the percentage contribution was, the more important the factor was for affecting the performance characteristics. The results of ANOVA for the grey grade values are represented in Table 6. The results of the ANOVA indicate that the percentage contribution of cutting speed-*V*, feed rate-*f* and the depth of cut-*d* influencing the multiple performance characteristics were 12,63%, 8,41%, and 34,62%, respectively. From the percentage contribution of the ANOVA, the cutting speed and depth of cut were two parameters significantly influencing the grey relational grade. And the depth of cut was the most effective factor on the performance. After the optimal level of turning parameters has been identified, a verification test needs to be carried out in order to check the accuracy of analysis. Table 7. shows the comparison of the estimated grey relational grade with the actual grey relational grade obtained in verification experiment using the optimal cutting parameters A1B1C3. Namely, surface roughness *Ra* was improved from 2,01 μm to 1,11 μm and the material removal rate *MRR* was also improved from 36 cm^3/min to 48 cm^3/min considering initial cutting conditions. In conclusion, it is clearly shown that the multiple performance characteristics in turning C45 carbon steel were significantly improved by increase in grey relational grade of 0.1835.

Table 6. Results of ANOVA

Symbol	*DF*	*SS*	*MS*	*F*	*C* (%)
A	2	0,009792	0,004896	0,28	12,63
B	2	0,006515	0,003258	0,19	8,41
C	2	0,026836	0,013418	0,78	34,62
Error	2	0,034371	0,017186	-	44,34
Total	8	0,077515	-	-	100

Table 7. Results of confirmation test

	Initial parameters	Optimal process condition	
		Prediction	Experiment
Factor levels	A2B3C1	A1B1C3	A1B1C3
Ra(μm)	2,01	-	1,11
MRR(cm^3/min)	36	-	48
S/N ratio	-8,4520	-2,67106	-5,01424
Grey rel. grade	**0,37792**	**0,713898**	**0,56142**

Improvement in Grey relational grade = **0.1835**

4. CONCLUSIONS

Multi-response optimization of turning process has been used to obtain optimal parametric combination that provides the minimum surface roughness (*Ra*) with the maximum material-removal rate (*MRR*). The application of grey relational analysis based on the Taguchi method directly integrates the multiple quality characteristics into a single performance characteristic called grey relational grade. By applying the Taguchi method the number of experiments is drastically reduced. A L_9 (3^4) Taguchi orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters considering grey relational grade. Effectiveness of this method was verified by the test experiment. The response characteristics of the turning operations, such as the material removal rate and the surface roughness are greatly enhanced by using this method.

5. ACKNOWLEDGMENTS

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