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A GREY RELATIONAL ANALYSIS METHOD FOR MULTI-ATTRIBUTE DECISION MAKING IN TURNING MACHINE (METAL CUTTING)

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ABSTRACT

The present investigation is undertaken to make a decision on parametric optimization of multi-responses such as metal cutting of material removal rate during machining hardened cast iron steel using mild carbon steel under normal environment through grey relational analysis combined with Taguchi method. Also predicted mathematical models of 2nd order have been developed for responses and checked for their accuracy. The second-order mathematical model presented a higher R^2 value and represents the best fit of the model. The model indicates good correlations between the experimental and predicted results. The proposed grey-based Taguchi methodology has been proved to be efficient for solving multi-attribute decision-making problems as a metal cutting in a turning machine

Keywords: Design of experiment, taguchi method, grey relational analysis, analysis of variance, turning machine

INTRODUCTION

A turning machine is a machine that works by clamping a workpiece tightly and rotating a workpiece to machine metal. A workpiece machined with a lathe moves along the length of the workpiece being machined. Machining consists of Face turning, chamfering, stripping, thread turning, as well as drilling on a lathe, etc. This requires rotational speed, feed rate, and depth of cut. including coolant for efficient turning, Lathes are therefore widely used. It can be produced in a variety of ways. A lathe is a basic machine tool that has been around since ancient times. Cylindrical processing or mainly two-dimensional work lathes are constantly being developed. In the beginning, living things and nature such as people and water were used as strength. Later, steam engines were used as propulsion. Before electric motors changed the rotational speed by using a belt pulley until the present is a gear system and change the speed by electronic, electric, or inverter and larger from the millimeter level to thousands of millimeters or tens of meters the lathe is the originator of many other tools, machines. The lathe used for the performance test is shown in Figure 1 (Surapong Bangphan, 2014).

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Figure 1 Lathe used to determine the test efficiency (Surapong Bangphan, 2014)

In turning consists of speed and the movement of the cutting tool that characterizes the parameters. The parameters selected for each working basis depend on the material from which the workpiece is made. Tool material tool sizes and values related to turning Machining parameters affect the operating process as (Surapong Bangphan, 2014)

1. Cutting speed the speed of the workpiece surface will be edge angle relationship of the cutting tool during cutting surface measurement in feet per minute (FSM).

2. Spindle of the speed rotation speed of the spindle of the speed to the workpiece in revolutions per minute (RPM). The spindle of the speed must be related to the machining speed at the time of rotation of the workpiece. Depending on the size being machined In machining, the cutting speed must be controlled. The spindle speed may vary according to the machining force, and the size of the workpiece while the tool is machined. If the rotating shaft speed is a specified value, then the cutting speed will vary accordingly.

3. Feed rate, cutting tool speed the movement is related to the workpiece as it is being used by the machining tool. The feed rate is measured in units. millimeters per rev (mm/rev)

4. Depth of cut for tools between the radius of the workpiece while machining the machine Width depth feeds will require a low feed rate or excessive tool depth will reduce tool life. Therefore, the general characteristics of common areas of multi-stage machines, such as tool movement that exceeds the specified cutting depth range, etc. (Surapong Bangphan, 2014).

Study Material

The material used to make the workpiece will choose cast iron steel for making.

An experiment to determine the best value for material removal rate (MRR) with a workpiece diameter of 25.4 mm and length of 76.2 mm is shown in Figure 2.

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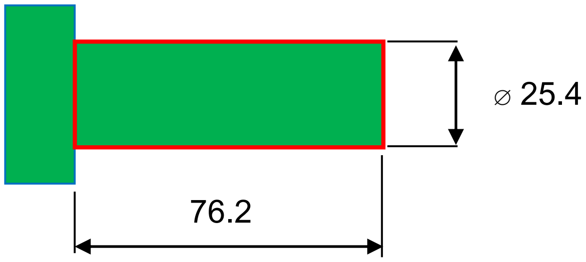

Figure 2 Examples of workpiece dimensions to be machined (Surapong Bangphan, 2014)

Therefore, this research was to apply the Taguchi method and grey relational analysis for multi-attribute decision making in turning machines (metal cutting) to assist in the analysis to determine the rate of removal of scrap material from the steel specimens tested with the tool lathe is made of high-speed steel material. The controlling factors are spindle of speed, feed rate and depth of cut to analyze the results of the machining of parts in production lathes.

Taguchi Method

Experimental design by Taguchi method. It is an application of experimental design, control Factors. Factors that cannot be controlled. (Uncontrollable Factor) or noise factor, which these variables are also a source of variation. The influence caused by these variables cannot be eliminated. Therefore, the main function of the Taguchi method is to reduce product variation. By selecting the control factor, the raw experimental results are converted into a signal-to-noise ratio (S/N ratio), which is very important. There are three types of S/N ratio characteristics: small the better type problem, nominal the best type problem, and Larger the Better type problem and the benefit of the Taguchi method is a reduction in the number of trials. This saves time and costs in experimenting. Help make experimenting easier and more convenient, and reliable results make the product more reliable (Surapong Bangphan, 2014), (Roy, R. K, (2001).

Recently, some researchers have used genetic algorithm, data envelopment analysis, desirability function approach etc. for multi response optimization in various fields of engineering (Md. Israr Equbal et al, 2014). Grey based Taguchi method is a new method forwarded by Deng Ju-long. (1989) from China to solve multi response optimization problems. Deng first proposed grey relational analysis in 1982 to fulfill the crucial mathematical criteria for dealing with poor, incomplete and uncertain systems (Md. Israr Equbal et al, 2014). In recent years grey relational analysis becomes a powerful tool to analyze the processes with multiple performance characteristics. A.K. Sood et al. (2010) studied the effect of process parameters on multiple performance characteristics of FDM build part by using Taguchi method with gray relational analysis. K. Jangraa et al. (2011) optimizes the material removal rate (MRR) and surface roughness simultaneously for WEDM of WC-Co composite by the use of Grey relational analysis. Tarang et al. (2002) utilized the grey-based Taguchi method to optimize the process parameters of submerged arc welding in hard facing, considering multiple weld qualities. Huang et al. (2003) successfully optimized the machining

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parameters in wire EDM using the grey relational analysis along with Taguchi method. Based on the above survey we can conclude that the grey relational analysis is a better approach for optimization of multi response characteristics in different fields. Therefore, grey relational analysis is utilized in this study, for multiple- optimization of the turning machine (metal cutting) according with (Md. Israr Equbal et al, 2014).

Grey Relational Analysis (GRA)

Grey relational analysis (GRA) utilizes a specific concept of information. It defines situations with no information as black, and those with perfect information as white (Chan, J. W. K.; Tong, T. K. L, 2007). Additionally, an analysis of variance (ANOVA) was also utilized to examine the most significant influential factors for the Ra and MRR in the turning process (Franko Puh et al, 2016). Confirmation test was conducted using the optimum cutting parameters determined by the Taguchi optimization method. Based on this analysis, valuable remarks about presented optimization approach are pointed out in the conclusion of this study. Many researchers have studied the effects of optimal selection of machining parameters in turning. According with Franko Puh et al. (2016).

EXPERIMENTAL PROCEDURE

Variable to Study

When the experiment designer knows the number of control factors (Control Factor) and the control factor level (Control Factor Level) for which they are designed. By taking these two values into consideration when choosing an Orthogonal Array, an Orthogonal Array can be used to determine the influence of multiple factors effectively in determining the control factor or variables that are designed in the Orthogonal Array appropriately. as following steps.

Consider the variables affecting the lathe turning process consisting of 3 variables at 3 levels as shown in Table 1. For the variables that do not need to be studied, the method of controlling the variables must be determined to allow the variance due to external factors. The least occurring, such as temperature outside and the experimental site, as well as operators, etc.

Table 1 Control factors. (Surapong Bangphan, 2014)

Control Factors	Experimental Level			MRR
	1	2	3	
Spindle of Speed (rev/min)	220	380	510	-
Feed Rate (mm/rev)	1.033	1.147	1.392	-
Depth of Cut (mm)	0.5	0.6	0.75	-

Note: The experimental level was set at 3 levels. The 3 factors consisted of the 1st, 2nd and 3rd spindle speeds of 220, 380 and 510 rpm (the turning spindle speed of the lathe was between 220 and 510 rpm). , The feed rates of levels 1,2 and 3 are 1.033,1.147 and 1.392 mm/rev (normally the optimum feed rates are between 1.033 and 1.392 mm/rev). 3 are 0.5, 0.6 and 0.75 mm (in the designation the depth of cut is

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between 0.5 and 0.75 mm), because the tool lathe is made of high-speed steel and the material being tested is high-speed steel.

Taguchi Method

The Taguchi's robust parameter design is used to determine the levels of factors and to minimize the sensitivity to noise. That is, a parameter setting should be determined with the intention that the product response has minimum variation while its mean is close to the desired target. Taguchi's method is based on statistical and sensitivity analysis for determining the optimal setting of parameters to achieve robust performance (Byrne D.M., and S. Taguchi, 1986). The mean and the variance are combined into a single performance measure known as the Signal-to-Noise (S/N) ratio (Byrne D.M., and S. Taguchi, 1986), The turning machine (metal cutting) were considered the quality characteristic with the concept of "the larger the better". The S/N ratio used for this type response. Assuming the S/N ratio, the goal is the maximum value of the response and is the appropriate value when only the limit tolerances below are listed, which can be obtained is given by:

$$S/N_L = -10\log\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \tag{1}$$

Suppose a problem of type the small the better (variance of responses). This assumes the S/N ratio of that target value. A zero response and an appropriate value when detailed just for the upper limit tolerance, can be obtained is given by:

$$S/N_S = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \tag{2}$$

Where n is the number of measurements, and y_i is the measured characteristic value. 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. The dashed line is the value of the total mean of the S/N ratio and mean effect plot. According to the research of (Franko Puh et al, 2016).

A research study was conducted on the factors suitable for turning by tool lathe made of high-speed steel and components of high-carbon alloy steel, using Taguchi method.

The Taguchi method experimental design in this experiment, the factors affecting the turning process of a lathe with a turning tool lathe and the specimens were examined. A total of 3 factors, with each factor having 3 levels. L-9 (3^3) Orthogonal arrays (OAs) were used in the first experiment and the second iteration was performed to confirm the results to determine efficacy. Therefore, the experiment was performed equal to 9 runs, and the total iteration of the experiment was equal to 9 runs or 9 trial sequences. The number of trials depending on the level of the given factors is shown in Table 2 and Table 3. The Orthogonal L-9 (3^3) Array sequence was used in this study (Roy, R. K, 2001).

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Table 2 L-9 (3^3) Orthogonal array.

Trial order	Factors			MRR
1	220	1.033	0.50	-
2	220	1.147	0.60	-
3	220	1.392	0.75	-
4	380	1.033	0.60	-
5	380	1.147	0.75	-
6	380	1.392	0.50	-
7	510	1.033	0.75	-
8	510	1.147	0.50	-
9	510	1.392	0.60	-

Taguchi Orthogonal Array

Taguchi's orthogonal sequence was designed with 3 variables, 3 levels applied to turning parameters using Minitab release 20.00 as a calculation aid, shown in Table 3.

Table 3 Taguchi Orthogonal array.

Trial order	Factors			MRR
1	1	1	1	-
2	1	2	2	-
3	1	3	3	-
4	2	1	2	-
5	2	2	3	-
6	2	3	1	-
7	3	1	3	-
8	3	2	1	-
9	3	3	2	-

Material removal rate (MRR)

The material removal rate (MRR) is a measurement from before and after the weight of the workpiece is used to calculate and the relationship between the material removal rate can be found as follows:

Starting Weight – Final Weight / Production time (3)

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MRR is the calculation of the value obtained from the experiment to consider the adjustment with the S/N ratio, Minitab release 20.00 will be used to help in the calculation.

Grey Relational Generation

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. Data pre-processing converts the original sequences to a set of comparable sequences. Normalizing the experimental data for each quality characteristic is done according to the type of performance response. Thus, the normalized data processing for MRR corresponding to smaller-the-better criterion can be expressed as: (Franko Puh et al, 2016).

$$x_i^*(k) = \frac{\max\ y_i(k) - y_i(k)}{\max\ y_i(k) - \min\ y_i(k)} \tag{4}$$

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

$$x_i(k) = \frac{y_i(k) - \min\ y_i(k)}{\max\ y_i(k) - \min\ y_i(k)} \tag{5}$$

where, i = 1, 2, 3, ..., *m*, *m* is the number of experimental runs in Taguchi orthogonal array, in the present work L9 orthogonal array is selected then m = 9. k = 1, 2, ...,n, n is the number of quality characteristics or process responses, in the present work material removal rate are selected, then n = 1 (Franko Puh et al, 2016).

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 material removal rate calculated by Equation (4), (5) respectively (Franko Puh et al, 2016).

Grey Relational Coefficient and Grey Relational Grade

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. 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. Based on the normalized experimental data the Grey relation coefficient can be calculated using the following equations: (Franko Puh et al, 2016).

$$\xi_i(k) = \frac{\Delta_{\min} + \varsigma\,\Delta_{\max}}{\Delta_{0i}(k) + \varsigma\Delta_{\max}} \tag{6}$$

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$$\Delta_{0i}(k) = \left\| x_0(k) - x_i(k) \right\|, \tag{7}$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \left\| x_0(k) - x_i(k) \right\|, \tag{8}$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \left\| x_0(k) - x_i(k) \right\|, \tag{9}$$

where

$\Delta_{0i} = \left\| x_0(k) - x_i(k) \right\|$ is difference of the absolute value between $x_0(k)$ *and* $x_i(k), x_0(k)$ is the reference sequence of the kth quality characteristics (Franko Puh et al, 2016).

$\Delta_{\min}$ *and* $\Delta_{\max}$ are respectively the minimum and maximum values of the absolute differences (Δ_{0i}) of all comparing sequences (Franko Puh et al, 2016).

ζ is a distinguishing coefficient, $0 \le \zeta \le 1$, the purpose of which is to weaken the effect of Δmax when it gets too big and thus enlarges the difference significance of the relational coefficient. In the present case, $\zeta = 0{,}5$ is used due to the moderate distinguishing effects and good stability of outcomes (Franko Puh et al, 2016).

The Grey relation coefficient of each performance characteristic. After averaging the Grey relational coefficients, the Grey relational grade y_i can be calculated as follows:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i\,(k), \tag{10}$$

where, γ_i = 1, 2, 3 ... 9, (L9 orthogonal array is selected), $\xi_i(k)$ is the Grey relational coefficient of k^{th} response in ith experiment and n is the number of responses. The optimum level of the process parameters is the level with the highest Grey relational grade (Franko Puh et al, 2016).

Then an optimal level of process parameters is determined using higher grey relational grade that indicates the better product quality. To obtain this, average grade values for each level of process parameter is to be find out which can be shown as mean response table. From, mean response table, higher values of average grade values is chosen as optimal parametric combination for multi-responses (Amlana Panda et al, 2016).

After optimal combination is find out, the next step is to perform the analysis of variance (ANOVA) for judging the significant parameters affecting the multi-responses at 95% confidence level and thus giving important information on the experimental data. As the effect of each parameter on multiresponse cannot be assessed by Taguchi method, thus the ANOVA analysis will be helpful to find out the percentage of contribution to identify the effects. The procedure of ANOVA is to separate out the total variability of the response (sum of squared deviations about the grand mean) into each

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parameter contributions and error (Datta et al, 2008). The P-value (probability of significance) is generally calculated based on F value or Fisher's F- ratio to get the information of significance on the selected response if its value is less than 0.05. The degrees of freedom (DF) are required to evaluate the mean square (MS) and measure the availability of independent information to evaluate sum of squares (SS). In an ANOVA analysis, mean square deviation and F-value is calculated by MS = SS/DF and F = MS for a source parameter/MS for the error (Amlana Panda et al, 2016).

After optimal combination of process parameters are found out, the next step is very the improvement of Grey relational grade through conducting confirmatory experiment. The predicted value of Grey relational grade for optimal level can be obtained as follows,

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{0} \left(\bar{\gamma} - \gamma_m\right), \tag{11}$$

where γ_m is the total mean grey relational grade, $\bar{\gamma}_i$ is the mean grey relational grade at the optimal level of each parameter, and o is the number of the significant process parameters (Sahoo & Sahoo,2013).

The higher value of the Grey relational grade corresponds to an intense relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. The Grey relational coefficients and Grey relational grade calculated by Equation (6), (10) respectively. The highest Grey relational grade is the rank of 1. Therefore, the experiment number 5 is the best combination of turning parameters for material removal rate among the nine experiments (Franko Puh et al, 2016).

The multi-objective optimization problem has been transformed into a single equivalent objective function optimization problem using Grey relational analysis. Accordingly, optimal combination of process parameters is evaluated considering the highest Grey relational grade by using the Taguchi method. According to the research of (Franko Puh et al, 2016).

RESULTS AND DISCUSSION

Study the Efficiency of a Lathe Turning Process with a Tool Lathe Made of High-Speed Steel.

When turning the workpiece with a lathe in which the material of the cutter is made of high-speed steel The efficiency of the material removal rate according to the design conditions was tested by the Taguchi method for all nine experiments, and the specimens were measured for weight and timekeeping. Turning time is recorded by timing and measuring the final value of all turning operations. Material removal rate (MRR) was calculated using the relationship between (Initial weight - Final weight / Turning or production time) and from the analysis, it was found that the experiment that achieved the optimum conditions as Experiment 8, with the first factor being: The spindle speed is 510 rpm, the second factor is the feed rate of 1.147 mm/rev and the third factor is the 0.50 mm deep feed distance. The minimum chip removal rate is 0.99

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g/s for 7.07 min. The highest material removal rate was at the 4th experimental order, with the first factor being: The spindle speed was 380 rpm, the second factor was the feed rate of 1.033 mm/rev and the third factor was a 0.60 mm deep feed distance. The highest material removal rate was 2.25 g/s for 9.78 min. The rest of the experiments for each factor at each level are shown in Table 4.

Table 4 The value obtained from the first observation. (Surapong Bangphan, 2014)

Job No.	A	B	C	D	E	F	G	H
1	220	1.033	0.50	15.91	669	648	21	1.32
2	220	1.147	0.60	15.5	670	650	20	1.29
3	220	1.392	0.75	11.92	668	650	18	1.51
4	**380**	**1.033**	**0.60**	**9.78**	**657**	**635**	**22**	**2.25**
5	380	1.147	0.75	9.05	659	641	18	1.99
6	380	1.392	0.50	8.95	672	655	17	1.90
7	510	1.033	0.75	9.84	666	654	12	1.22
8	**510**	**1.147**	**0.50**	**7.07**	**669**	**662**	**7**	**0.99**
9	510	1.392	0.60	8.16	667	655	12	1.47

Note:

A = Spindle speed (RPM)

B = Feed rate (mm/rev)

C = Depth of cut (mm)

D = Time (sec)

E = Initial weight (g)

F = Final weight (g)

G = Different of weight (g)

H = Material removal rate (MRR)

Result Analysis

After determining all the observed values as shown in Table 4. The S/N ratios and mean values were calculated and heterogeneous graphs were analyzed by the Minitab release program. 20.00 The S/N ratio for the MRR was programmed. Minitab release 20.00 by Taguchi method, which in this paper will be based on a total analysis by Taguchi method by deciding the main effect for process parameters. The operation was performed with Analysis of Variance (ANOVA), and regression coefficient analysis. Decision coefficient and the best parameter setting The main effect analysis was used in this study, the trend for each factor effect is shown in Figure 3. Machine performance is a key factor of the individual L-9 (3^3) variance analysis, which can be calculated by forecasting. The observed values are shown in Table 5 (Surapong Bangphan, 2014).

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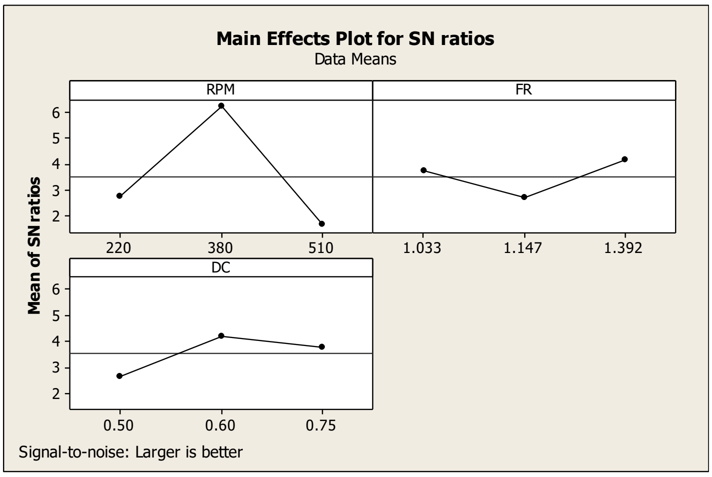

Figure 3 Effects of Control Factors on the S/N Ratio (Surapong Bangphan, 2014)

Table 5 Results and observed values for cast iron steel.

Run No.	A	B	C	MRR	S/N	MEAN
1	220	1.033	0.50	1.32	2.41148	1.32
2	220	1.147	0.60	1.29	2.21179	1.29
3	220	1.392	0.75	1.51	3.57954	1.51
4	380	1.033	0.60	2.25	7.04365	2.25
5	380	1.147	0.75	1.99	5.97706	1.99
6	380	1.392	0.50	1.90	5.57507	1.90
7	510	1.033	0.75	1.22	1.72720	1.22
8	510	1.147	0.50	0.99	-0.08730	0.99
9	510	1.392	0.60	1.47	3.34635	1.47

(Surapong Bangphan, 2014)

Confirmation the Experiment

The second experiment was repeated with the same factor by performing the same procedure as shown in Table 6.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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Table 6 Values obtained from repeated experiments.

Run No.	A	B	C	D	E	F	G	H
1	220	1.033	0.50	15.95	670	650	21	1.31
2	220	1.147	0.60	15.59	670	651	19	1.22
3	220	1.392	0.75	11.99	668	650	18	1.50
4	**380**	**1.033**	**0.60**	**9.80**	**657**	**636**	**21**	**2.14**
5	380	1.147	0.75	9.00	659	642	17	1.88
6	380	1.392	0.50	9.10	672	655	17	1.87
7	510	1.033	0.75	9.75	666	655	11	1.13
8	**510**	**1.147**	**0.50**	**7.00**	**669**	**663**	**6**	**0.86**
9	510	1.392	0.60	8.10	667	656	11	1.36

(Surapong Bangphan, 2014)

From Table 6, the results obtained from the experimental iterations were slightly different for turning times and lower material removal rates. The weight value before and after was not much different. This may be due to the control of the turning process and the inspection of the tools used in the experiment and the operators, thus reducing the values. The calculation of coefficients and analysis of variance are shown in Tables 7 and 8, respectively.

Table 7 Coefficient model for the S/N ratio.

Estimated Model Coefficients for S/N ratios				
Term	Coef	**SE Coef**	**T**	**P**
Constant	**3.5316**	**0.2139**	**16.509**	**0.004**
A 220	-0.7974	0.3025	-2.636	0.119
A 380	**2.6669**	**0.3025**	**8.815**	**0.013**
B 1.033	0.1958	0.3025	0.647	0.584
B 1.147	-0.8311	0.3025	-2.747	0.111
C 0.50	-0.8986	0.3025	-2.970	0.097
C 0.60	0.6689	0.3025	2.211	0.158
S = 0.6418 R-Sq = 98.0% R-Sq(adj) = 92.1%				

(Surapong Bangphan, 2014)

From Table 7, the coefficient results for the S/Nn ratio of the turning process at a significant level of 5%(0.05) are significant for the spindle speed at 380 rpm. Of the turning process at a significant level, 5% (0.05) is the significant spindle speed. The remaining factors were insignificant for the turning process in this study.

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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Table 8 ANOVA for S/N Ratio.

Analysis of Variance for S/N ratios					
Source	**DF**	**Adj SS**	**Adj MS**	**F**	**P**
A	**2**	**33.7311**	**16.8655**	**40.95**	**0.024**
B	2	3.3983	1.6991	4.13	0.195
C	2	3.9229	1.9614	4.76	0.174
Residual Error	2	0.8238	0.4119		
Total	8	41.8760			

(Surapong Bangphan, 2014)

The coefficient estimation model for the S/N ratio, the constant P-Value of 0.004, and the adjustment of the decision coefficient of 92.1 % are shown in Table 7. The P-Value P- Value of the S/N ratio is shown in Table 7. The value of 0.024 is shown in Table 8. The regression coefficient for the %MRR S/N ratio is

$$\% \text{ MRR} = 3.5316+A220(-0.7974)+A380(2.6669)+B1.033(0.1958)+B1.147(-0.8311)$$
$$+C0.50(-0.8986)+C0.60(0.6689) \quad (12)$$

Multi-Objective Optimization Using Grey Relational Analysis

The grey correlation analysis is used to optimize the cutting force and surface roughness all together. The basic steps are: performing dimensionless processing on the test results; analyzing the results of the dimensionless processing to obtain the grey correlation coefficient; solving the average grey correlation coefficient to obtain the grey correlation degree (Shi K, Zhang D and Ren J,2015).

Implementation of Methodology to Find Multi-Response Parametric Optimization

The experimental data have been normalized for both flank wear and surface roughness using Equation (4) and presented in Table 9 called grey relational generations.

Table 9 Grey relational generation values.

Run No.	**MRR**
	Larger the better
Ideal sequence	1
1	0.648
2	0.719
3	0.500
4	0.000
5	0.203

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6	0.211
7	0.789
8	1.000
9	0.609

From the normalized data set of Table 9, Grey relational coefficients have been computed using Equation 6. The value of distinguishing coefficient is taken as 0.5 as equal weighting has been given to both quality characteristics. The results are shown in Table 10. Grey relational grade (GRG) has been found out using Equation 6 from the results of grey relational coefficients. The result of GRG is presented in Table 10. This result is utilized for optimizing the multi-responses as it is converted to a single grade. According to the research of (Amlana Panda et al, 2016).

Table 10 Grey relational coefficients and grey relational grade values.

Run	Evaluation of Δ_{0i}	Grey relational coefficient	GRG	Rank
	1	1	1	
1	0.352	0.587	0.763	7
2	0.281	0.640	0.781	6
3	0.500	0.500	0.750	9
4	1.000	0.333	0.833	2
5	0.797	0.386	0.784	4
6	0.789	0.388	0.782	5
7	0.211	0.703	0.809	3
8	0.000	1.000	1.000	1
9	0.391	0.561	0.757	8

From the value of GRG, the effects of each process parameters at different levels are plotted and shown in Figure 5 and mean grey relational grade is presented in Table 4. The optimal parametric combination is chosen based on higher mean grey relational grade values from Table 11. The higher value of grey relational grade implies a stronger correlation to the reference sequence and better performance. Thus, the optimal settings for multi-responses becomes FR3-DC1-SS2 i.e. feed rate of 1.147 mm/rev, depth of cut of 0.50 mm, and spindle speed of 380 rpm respectively. The higher values of mean grey relational grade (Figure 4) gives the minimum values of flank wear and surface roughness. The difference of maximum and minimum values of mean GRG for turning parameters were as 0.090 for depth of cut, 0.092 for feed rate and 0.067 for cutting speed respectively (Table 11). This result indicates that the feed rate has the most influencing effect on multi-responses compared to depth of cut and cutting speed in hard turning operation. The sequence of importance of process parameters on multi-responses are feed rate > spindle speed > depth of cut. According to the research of (Amlana Panda et al, 2016).

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Table 11 Main effects on mean grey relational grade.

Factors	Mean Grey relational grade			Max-Min	Rank
	Level 1	**Level 2**	**Level 3**		
SS	0.765	0.799	0.855	0.090	2
FR	0.802	0.855	0.763	0.092	1
DC	0.848	0.790	0.781	0.067	3

Total mean grey relational grade = 0.806

Figure 4 Main effect plot of grey relational grade

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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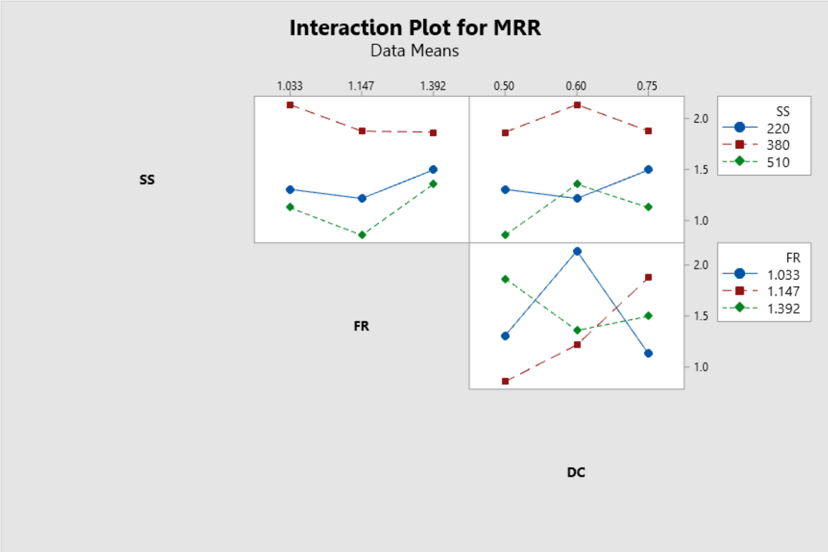

Figure 5 Interaction plot of material removal rate

However, choosing the level the appropriate variable in the case of multiple responses, for example in the case of cutting work to have a material removal rate value and need to have a distance. Excess cutting at the same time, cannot be determined the level of variables that are suitable for a good response can be achieved. The same due to both the material removal rate value and the excess cuts will have a co-effect. (Interaction) between factors occur in the process as shown in Figure 5. The co-effect of the factors of material removal rate and the cutting distance is exceeded accordingly. It can be seen that every factor has the joint effect.

To analyze the factor response from the gray correlation analysis, the result was selected from the mean of the greatest average gray relation grade in the. Each level of that variable. Therefore, from Table 11, the conditions for turning with a tool life are suitable: Configure the variable spindle speed at level 2 (380 rpm), feed rate at level 3 (1.147 mm/rev), and depth of cut at level 1 (0.5 mm). The above factor values can be used to test and predict the turning results of the workpiece from the Taguchi equation above. To compare the experimental results obtained as shown in Table 12.

Table 12 Taguchi prediction experiment and relative analysis Gray.

methodology	Response	Factors	Optimal value
Taguchi method	MRR	SS_2, FR_3, DC_1	1.681
Grey relational analysis	MRR	SS_2, FR_3, DC=	0.890

Analysis of variance (ANOVA) table is formulated considering grey relational grade value which has been shown in Table 13. This table gives the significance of process parameters on multi-responses. From the ANOVA table, it is revealed that feed is the insignificant process parameters affecting multi responses as its p-value is more than 0.05 at 95% confidence level. Spindle speed, feed rate and depth of cut does not show any significance on responses simultaneously. According to the research of (Amlana Panda et al, 2016).

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Table 13 Results of ANOVA on grey relational grade.

source	DF	Adj SS	Adj MS	F-Value	P-Value	Remarks
SS	2	0.0125	0.0063	0.88	0.531	Insignificant
FR	2	0.0128	0.0064	0.90	0.526	Insignificant
DC	2	0.0080	0.0040	0.57	0.638	Insignificant
Error	2	0.0142	0.0071			
Total	8	0.0475				

Mathematical model

Multiple regression model has been developed for responses such as material removal rate (MRR) at 95% confidence level considering spindle of speed (SS), feed late (FR) and depth of cut (DC) as input parameters. The model adequacy has been checked by evaluating its determination coefficients (R^2) value. The more is the R^2 value i.e. when approaches or close to one, the greater is the significance of model. From the experimental results, second order mathematical models for material removal rate (MRR) are presented in Equation (4),(5),(6), (7), (8),(9),(10) and (11) along with their R^2 value respectively.

Second order model

$$MRR = 0.806530+(-0.042009SS1)+(-0.006622SS2)+(-0.004851FR1)+(0.048339FR3) +(0.041919DC1)+(-0.016305DC2),$$

$$R^2= 70.24 \% \qquad (13)$$

Conclusion

The primary aim of this study was to obtain the optimal set of parameters which affect the metal cutting performance of a co-continuous high- speed steel in the presence of multiple responses. Initially, the outcome of varying three factors—namely, spindle speed, feed rate and depth of the multiple responses of the coefficient of tool life and wear rate was studied using a Taguchi L9 OA and GRA approach. From the response table of the grey relational grades, the optimal set of parameters for enhanced metal cutting performance were identified. The ANOVA for GRG indicated that the p values of all parameters were less than 0.05 and, hence, significant. Finally, confirmation tests were performed to verify the improvement of 37.66% in GRG, from 0.5134 for the initial design parameters (SS2, FR3, DC1), to 0.890 for the optimal parameters (SS2, FR3, DC1).

This research aims to study the selection of suitable variables in machining. Cast iron steel from a turning machine using Taguchi's method and analysis. The gray relationship the results of the experimental design L9 (3^3) so that the experimental values can be taken. To predict the experimental results and find suitable parameters for turning machine, it was found that using the Taguchi method provides a material removal rate of 1.681 cubic meters per minute from the Taguchi process can be used to generate the prediction equation of the material removal rate with confidence values were 98 % and 70.24%, respectively, for the gray correlation analysis. Factors can be taken to find the removal rate of the work, 0.890 cubic meters per minute from the comparison results. Taguchi method and gray correlation analysis showed that using the method Gray affinity analysis can improve the material removal rate of cast iron steel, decreased by 0.791 cubic meters per minute (as a percentage reduction equal to 79.00 %).Therefore from this experiment, the gray affinity analysis method is also applied to suitable variables in arc lathe workpieces cast iron steel by turning machine.

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