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Optimization of turning process parameters by using grey-Taguchi

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Abstract

The main objective of this study is to improve toughness and hardness of engineering material by changing the machining parameters of turning process. By applying Taguchi method the quality of manufactured goods, and engineering designs are developed by studying variations. In this work, an attempt has been made to solve the correlated multiple criteria optimization problem of turning process by considering three different process parameters viz. cutting-speed, feed and depth of cut.. Grey Relational Analysis has been adopted to convert multiple objectives of the optimization problem into a single objective function, denoted as Grey Relational Grade. The overall Grey Relational Grade has been optimized by using Taguchi method. Analysis of variance (ANOVA) has been conducted for Grey relational grade (GRG) to find the optimal process parameters. Signal to Noise (S/N) Ratio has been found for GRG to find the optimal levels of the process parameters. Finally a conformation test has been made for three different materials and the results have been plotted.

Keywords: Turning, Optimization, Grey-Taguchi and ANOVA

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1. Introduction

The machine tool industry in India has made tremendous progress, however, the metal cutting industries using various machine tools continue to suffer from a major drawback of not utilizing the machine tools at their full potential. A major cause leading to such a situation is not to run the machine tools at their optimum operating conditions. Unfortunately the manufacturing engineers in India continue to choose the operating conditions solely on the basis of handbook values and/or manufacturers recommendations and/or worker experience. To produce a quality product, the manufacturing engineer can employ off-line techniques also apart from on-line quality control methods. The quality control activities at the manufacturing stage are on-line quality control methods. The quality control methods that are connected at the design stage are off-line quality control methods. Considerable advantages can be obtained by achieving product quality at the initial stage instead of controlling quality at the manufacturing process stage.

The Taguchi experimental design method is a well- known, unique and powerful technique for product/process quality improvement. It is widely used for analysis of experiment and product or process optimization. In the grey relational analysis, the measured values of the experimental results of surface finish and chip hardness were first normalized in the range between zero and one, which is also called grey relational generation (Deng, 1989). Next, the grey relational coefficients were calculated from the normalized experimental results to express the relationship between the desired and actual experimental results. The grey relational grades were computed by averaging the grey relational coefficient corresponding to each performance characteristic. The optimal process parameters is predicted as the level with highest grey relational grade

Turning is a form of machining or a material removal process used to shape materials. The turning process requires a turning machine or lathe, work piece, fixture, and cutting tool (Sirpurkar et al., 2012). The work piece is attached to the rotating fixture of the machine, and allowed to rotate at high speeds. The cutting tool feeds into the rotating work piece and cuts away material in the form of small chips to create the desired shape (Krishnakanth et al., 2012). In the machining process, dimensional accuracy and surface finish are the most significant technical requirements of the customer (Agarwal & Singh, 2008). A reasonably good surface finish is desired to improve the tribological properties, fatigue strength of the product. Feed rate has greater influence on the surface roughness parameter (Ra) followed by cutting speed and the percentage of volume fraction of SiC in machining of AL/SiC particulate composites (Nalbant et al., 2007) . Feed rate had the highest effect on surface roughness, spindle speed had a moderate effect, and depth of cut had an insignificant effect. This would indicate that feed rate and spindle speed might be included alone in future studies, although the literature review would caution against ruling out depth of cut altogether (Islam, 2011). This work proposes an optimization of different variables in typical turning operation. The multi-response optimization of the turning process for an optimal parametric combination is obtained to yield the minimum cutting forces and surface roughness with the maximum material-removal rate (MRR) using a combination of a Grey relational analysis (GRA) and the Taguchi method (Chen & Shi-bo Lin, 2008). The Grey-based Taguchi method was applied for the multiple performance characteristics of turning operations. A grey relational analysis of the hardness and the surface roughness obtained from the Taguchi method reduced from the multiple performance characteristics to a single performance characteristic which is called the grey relational grade. The optimization of the complicated multiple performance characteristics of the processes can be greatly simplified using the Grey-based Taguchi method (Quazi et al., 2013).

2. Experimental work

The block diagram of the experimental plan is shown in Figure 1. Three EN grade steels whose chemical composition shown in Table 1 is used in this study. A carbide cutting tool has been used in this work.

Roughness measurement has been done using a portable microprocessor based stylus-type profilometer, *Talysurf* (Taylor Hobson, Surtronic 3+, UK) shown in Figure 2. It is equipped with a diamond stylus having a tip radius 5 μm. The measuring stroke always starts from the extreme outward position. The profilometer has been set to a cut-off length of 0.8 mm, filter 2CR, and traverse speed 1 mm/sec and 4 mm traverse length. Roughness measurements, in the transverse direction, on the work pieces have been repeated four times and average of four measurements of surface roughness parameter values has been recorded. The measured profile has been digitized and processed through the dedicated advanced surface finish analysis software. Hardness measurements were carried out using a Rockwell hardness testing machine. The initial hardness and surface roughness of the three materials is also shown in Table 1.

Table 1. Chemical composition of materials

Material	Chemical Composition					Hardness	Roughness (μm)
	C	Mn	Cr	Ni	Mo		
EN -8	0.4	0.8	-	-	-	87	6
EN-31	1.5	0.52	0.85	-	-	84	4
EN-36	0.15	0.45	0.85	3.37	0.17	96	3.5

Experiments have been carried out using Taguchi's L9 Orthogonal Array (OA) experimental design which consists of 9 combinations of spindle speed (288, 598 and 938 rpm), longitudinal feed rate (0.15, 0.3 and 0.45 mm/rev) and depth of cut (DOC) (1.0, 1.5 and 2.0mm). According to the design catalogue (Peace G., S., 1993) prepared by Taguchi, L9 Orthogonal Array design of experiment has been found suitable in the present work.

Figure 2. Surface Roughness Measuring instrument

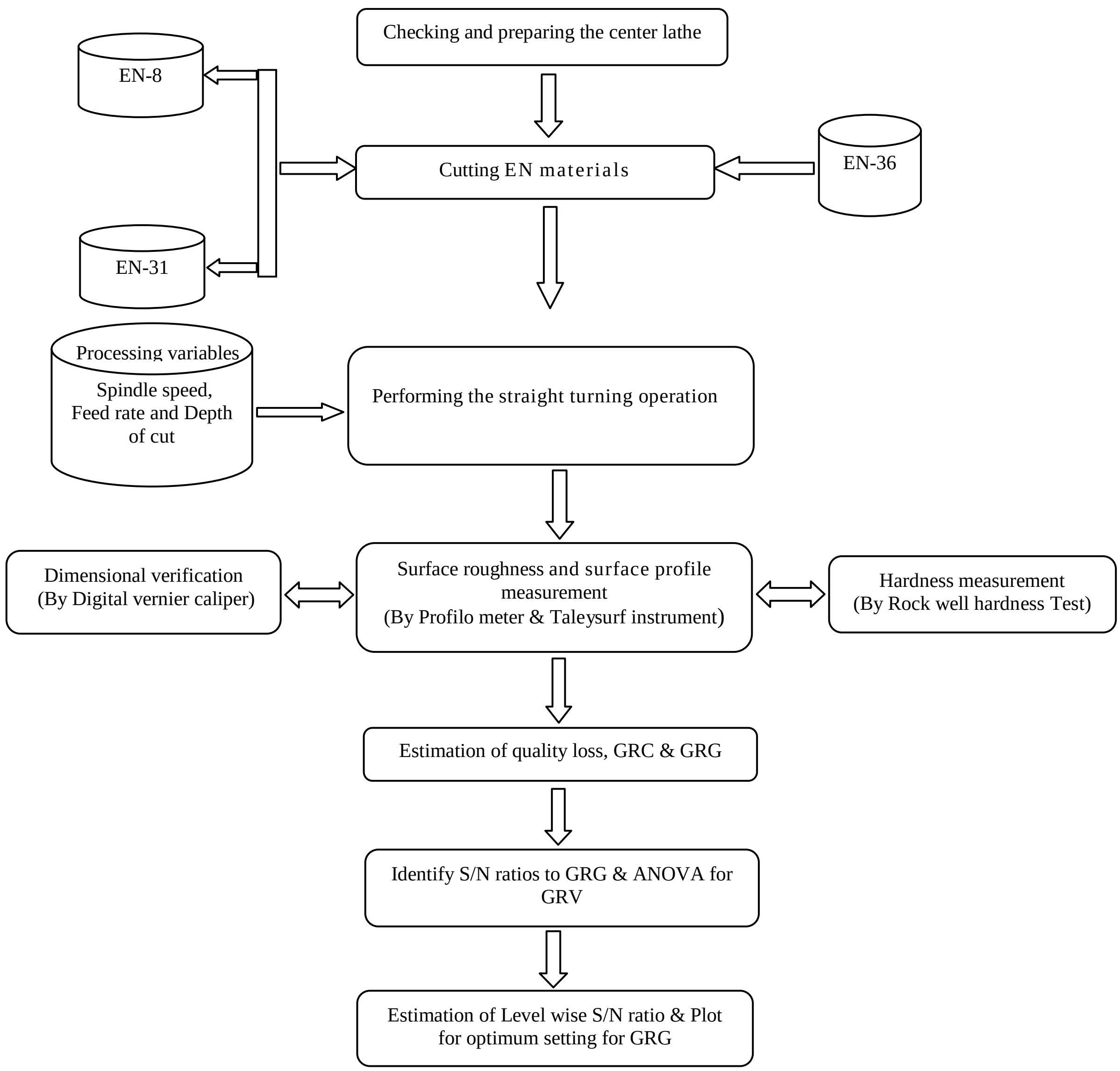

Figure1. Block diagram for process plan

2.1 Experimental setup

Check the center lathe and make it ready for performing the machining operation and then cut EN materials (EN -8, EN -31, EN -36) by power saw and performing the initial turning operation on lathe to get desired dimensions of the work piece. Perform the straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like spindle speed, feed and depth of cut. After turning operation check the dimensions of the work pieces by digital Vernier calipers. Measure the hardness value of work pieces by Rock well hardness Test equipment. Measure the surface roughness value and surface profile of the work pieces with the help of a portable stylus type profilometer and Taleysurf instrument.

3. Taguchi method

The common approaches to tackle modeling, and process optimization problem in molding include multiple regression analysis, response surface methodology (RSM) and artificial neural network (ANN) in combination with some optimization algorithm like genetic algorithm (GA), Fuzzy regression model, Swarm intelligence, etc. In most of the cases, the optimization has been performed using single objective function. The major limitation of the aforesaid methods is the requirement of enormous data for developing an adequate and best-fit model. This results in an increase of experimentation cost and loss of considerable time.

If there is an experiment having 4 factors which have three levels, then total number of experiment is 81. Then results of all experiment will give 100 accurate results. In comparison to above method the Taguchi orthogonal array make list of nine experiments in a particular order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments reduced to 9 instead of 81 with almost same accuracy.

Taguchi's experimental procedure and analysis consist of several steps .The DOE is sometimes too complex, time consuming and not as easy to use more trials have to be carried out when the number of process factors increases. The Taguchi Method uses special, highly fractionated factorial designs and other types of fractional obtained from orthogonal (balanced) arrays to study the entire experimental region of interest for the experimenter, with the minimum number of trials as compared with the classical DOE, especially with a full factorial design. In Taguchi method, ANOVA is performed to find the effective parameters in turning process.

The basic idea behind ANOVA is to break up the total variability (of the experimental results) into components of variance, and assess their significance. The variation components will be those associated with random variation, commonly referred as residual; the residual can be seen as the amount of variance we would expect if none of the factors had any effect. This can be expressed by:

Total variation= variation due to factor effects + residual

The significance of the variation components associated with factor effects is assessed by comparison with the residual. The usual F-test for comparing variances is utilized for this purpose. According to Taguchi, the use of the F-ratios in an ANOVA analysis is only helpful for the qualitative evaluation of whether factorial effects exist.

Taguchi recommends the use of signal to noise ratio (SNR) which estimates the inverse of the coefficient of variation, that is, estimates the ratio μ/σ, with μ being the process mean and σ the process standard deviation. For practical purposes we compute for each experimental trial the measure (Equation (1)):

$$SNR= 10 \log_{10} (\bar{y}^2/s^2) \quad (1)$$

where $\bar{y}$ and s are respectively the sample mean and sample standard deviation of the (n) observations in each trial.

Table 2 shows the turning process parameters as per orthogonal array (OA) design and the values of hardness and roughness estimated.

Trial	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)	Material	Hardness	Roughness
1	288	0.15	1.0	EN-8	87.33	6
2	598	0.30	1.5	EN-31	86	4.0666
3	938	0.45	2.0	EN-36	95.33	3.0666
4	288	0.15	1.5	EN-36	97.66	4.4666
5	598	0.30	2.0	EN-8	86.66	4.1
6	938	0.45	1.0	EN-31	83	2.8333
7	288	0.15	2.0	EN-31	86.66	5.1666
8	598	0.30	1.0	EN-36	96.33	3.4
9	938	0.45	1.5	EN-8	81.66	3.3666

Table 3 and 4 shows analysis of variance (ANOVA) has been conducted to evaluate the response magnitude in (%) of each parameter in the orthogonal experiment. It is used to identify and quantify the sources of different trial results from different trial runs (i.e. Different cutting parameters). Basic property of ANOVA is that the total sum of the squares (total variation) is equal to the sum of the SS (sums of the squares of the deviations) of all the condition parameters and the error components, i.e., adding the variations of each factor (Equation (2)).

$$SS\ total = SS\ (speed) + SS\ (feed) + SS\ (doc) + SS\ (material) + SS\ (error) \quad (2)$$

Table 3. Turning process parameters and their levels

Level	Speed (rpm)	Feed(mm/rev)	DOC(mm)	Material
1	288	0.15	1.0	EN -8
2	598	0.35	1.5	EN -31
3	938	0.45	2.0	EN -36

Table 4. Process Parameters as per OA Design

Trail	Speed(rpm)	Feed(mm/rev)	DOC(mm)	Material
1	288	0.15	1.0	EN-8
2	598	0.30	1.5	EN-31
3	938	0.45	2.0	EN-36
4	288	0.15	1.5	EN-36
5	598	0.30	2.0	EN-8
6	938	0.45	1.0	EN-31
7	288	0.15	2.0	EN-31
8	598	0.30	1.0	EN-36
9	938	0.45	1.5	EN-8

4. Optimization using Grey Relational Analysis coupled with Taguchi Method

Taguchi method makes use of a special design of orthogonal array (OA) to examine the quality characteristics through a minimal number of experiments (D.C Montgomery, 1997). The success of Taguchi methods is partly a consequence of experimentation being tailored to the application. The Grey system theory is mainly utilized to study uncertainties in system models, analyze relations between systems establish models and make forecasts and decisions. Multi-objective optimization problem is converted into single objective optimization problem using Grey Relational Analysis. The Grey Relational Analysis coupled with Taguchi method is adopted to optimize the process parameters of turning operation. The experimental results are first normalized to convert the experimental data to grey relational coefficients.

The Turning process parameters and three materials are optimized using Grey –Taguchi to get the maximum hardness and surface roughness. Taguchi method is a powerful tool in quality optimization for manufacturing process.

4.1Methodology used in Grey Relational Analysis:

4.1.1 Getting experimental data: The experimental value for the four output responses are tabulated and are taken to optimization.

4.1.2 Normalization of experimental data: As the desired objective is to maximize hardness and surface roughness, hence the experimental data is normalized by using the higher-the-better (HB) criterion. Higher-the-better (HB) criterion, the normalized data can be expressed as Equation (3):

$$x_i(y) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{3}$$

Here $x_i(k)$ is the value after the grey relational generation, min y_i (k) is the smallest value of y_i (k) for the k^{th} response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response .

4.1.3 Calculation of quality loss Estimates: An ideal sequence is x_0 (k) for the responses. The quality loss for each i^{th} trial is estimated as $x_0(k)$ - $x_i(k)$.

4.1.4 Calculation of Grey Relational Coefficients: The purpose of grey relational grade is to reveal the degrees of relation between the sequences say, [$x_0(k)$ and $x_i(k)$,i=1, 2,3.......,16]. The grey relational coefficient ξ_i (k) can be calculated as

$$\zeta_i(k) = \frac{\Delta_{\min} + \psi\Delta_{\max}}{\Delta_{0i} + \psi\Delta_{\max}} \tag{4}$$

The above relations (Equation 4) can be shown in Table 5.

Table 5. Normalization of experimental data, Calculation of Quality Loss Estimates and Grey Relational Coefficients

Trail	Normalization of experimental data		Calculation of Quality Loss Estimates		Grey Relational Coefficients		
	Hardness value	Surface Roughness	Hardness value	Surface Roughness	Hardness value	Surface Roughness	Overall Grey Relational Grade
1	0.3544	0.000	0.6456	1.0000	0.43633	0.333	0.38465
2	0.2713	0.611	0.7288	0.3895	0.40692	0.562	0.484524
3	0.8544	0.926	0.1456	0.0737	0.77444	0.872	0.823001
4	1.0000	0.484	0.0000	0.5158	1.00000	0.492	0.746114
5	0.3125	0.600	0.6875	0.4000	0.42105	0.556	0.488304
6	0.0838	1.000	0.9163	0.0000	0.35305	1.000	0.676523
7	0.3125	0.263	0.6875	0.7368	0.42105	0.404	0.412654
8	0.9169	0.821	0.0831	0.1789	0.85745	0.736	0.796942
9	0.0000	0.832	1.0000	0.1684	0.33333	0.748	0.540682

4.1.5. Finding out the Grey Relational Grade: By averaging the grey relational coefficients, the overall grey relational grade can be computed and it can be shown in table 6.

4.1.6. Finding S/N Ratios to GRG: There are three types of S/N ratios Normal – the – best, Higher- the- better , and Lower- the- better criterion. By taking HB criterion the S/N ratios are calculated.

The formula for calculating S/N Ratios:

$$\text{S/N (Higher-the-Better)} = -10\log\frac{1}{t}\sum_{i=1}^{t}\frac{1}{y_{2i}} \quad (5)$$

Here t is the number of measurements, y_i is the measured ith characteristic value, i.e., i^{th} quality indicator.

4.1.7 Plot for optimum setting for GRG:

Plot has been drawn for the level wise GRG values.

The grey relational grade γ_i can be computed as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\zeta_i(k) \quad (6)$$

Hence n = number of process responses.

Table 6. Analysis of Variance (ANOVA) of overall grey relational grade

Source	Degree of Freedom	Sum of Sq	Mean Sq	F – ratio	Rank
Speed	2	0.012306	0.006153	0.270516	3
Feed	2	0.050072	0.025036	1.100703	2
D.O.C	2	0.00115	0.000575	0.02528	4
Material	2	0.186689	0.093345	4.103875	1
Residual	3	4.44E-16	1.48E-16	6.51E-15	-
Total	11	0.2502	0.022745	-	-

5. Results and discussions

The optimal factor setting becomes material EN-36, feed 4.5 mm/rev, speed 598rpm and depth of cut 1.5 mm obtained in the grey- Taguchi method. The variation of S/N ratio with overall grey relation grade for four parameters i.e speed (A), feed (B), depth of cut (C) and material (D) has shown in Figure 3.

The optimal setting of process parameters to get the maximum mechanical properties will be material EN-36, Feed at o.45 rev/min, Speed is at 598 rpm and depth of cut is at 1.5 mm and the optimal levels for each process parameters using GRG has shown in Table 7. The methodology proposed in this work shown that the material must have a significant effect on optimization of selected properties such as hardness and surface roughness. The feed rate and speed had a moderate effect on the above properties. However depth of cut had a least significant. This would indicate that material, feed rate, cutting speed might be included in future studies. This method of parameter optimization can be accomplished with minimum down time, however the practical application of this optimization technique more effect. The grey based-Taguchi technique proposed in this work has been found efficient for solving multi-attribute decision-making problem, i.e., for multi-objective product as well as process optimization for continuous quality improvement.

Table 7. Optimum levels of each process parameter using GRG

S. No.	Process Parameters	Optimum Values	Optimum Values
1	Speed	3	598
2	Feed	2	0.45
3	Depth of Cut	4	1.5
4	Material	1	EN-36

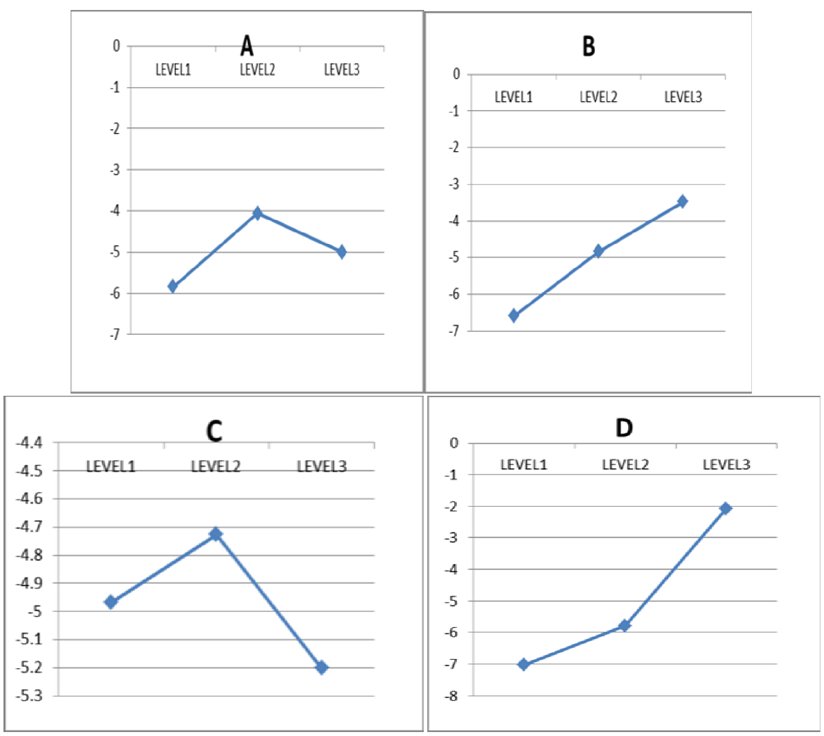

Figure 3. S/N Ratio plot for overall grey Relational Grade

6. Conclusions

In the above study, the use of GRA-based hybrid Taguchi method has been proposed and adopted for the solution of multi-objective optimization in a turning process. Application of GRA can eliminate multi co linearity of the output responses and transform these correlated responses into uncorrelated quality indices called Grey Relational Grade. Absence of correlation between the responses is the basic assumption for applying Taguchi optimization technique. It can be recommended that the GRA based hybrid Taguchi method is good, for example, in the case of (chemical and pharmaceutical) industries when there are hundreds of response variables.

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