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Multi-Objective Optimization in Traverse Cut Cylindrical Grinding

[1]Ramesh Rudrapati ,[2]AsishBandyopadhyay ,[3]Pradip Kumar Pal

[1]Ph.D. Scholar,[2,3]ProfessorMechanical Engineering Department, Jadavpur University, Kolkata – 700032,West Bengal, India.

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ABSTRACT

Present work aims to study the effects of grinding parameters on surface roughness (R_a and R_q) in traverse cut cylindrical grinding process, while grinding of stainless steel. Experiments have been conducted as per L_9 orthogonal array of Taguchi method. Grey based Taguchi method has been used to optimize the grinding parameters to minimize surface roughness parameters R_a and R_q simultaneously. The analysis of signal to noise ratio has been applied to investigate the effects of grinding parameters and optimize them. From the results of this study, longitudinal feed is identified as the most influential grinding parameter on surface roughness. The optimization methodology used in the present study of cylindrical grinding process is very useful to determine the optimum grinding parameters for minimum surface roughness.

Introduction

In the manufacturing industry, surface finish of any machined product is very important to determine the product's quality, in so far as cylindrical jobs are concerned, it is obviously true as well. Cylindrical grinding is one of the important manufacturing processes, used for producing accurate and good surface finish cylindrical rods. Obtaining the better surface finish jobs in cylindrical grinding is mainly depends on correct selection of grinding parameters. Optimum parameter selection is difficult task in cylindrical grinding process because of its complexity while solving it. But, through systematic optimization methodology like design of experiments (DoE), it is possible to select optimum parametric combination. The present work is an attempt to optimize grinding parameters to minimize surface finish by using DoE's Taguchi method.

Good surface finish is demanded in many engineering and domestic applications, because, it is an important aspect of tolerance of finished part; it minimizes friction and wear, thereby enhancing operating hours of the components. The arithmetic average height parameter (Ra) is an important roughness parameter, which most universally accepted and used roughness parameter to describe the quality of machined part. Review of available literature shows that Ra has been focus of most of the studies, but, R_a parameter alonely can't provide full description of surface. Root mean square roughness (Rq) is also an important parameter used to specify quality of the machined part. It is more sensitive than Ra. If the number of roughness parameters used is increased, full description of the surface profile can be obtained [1]. The present study aims at consideration of two roughness parameters R_a and R_q simultaneously for the surface roughness generated in cylindrical grinding operation.

Extensive literature survey has been made on optimization of process parameters in different machining operations for single objective optimization problem using Taguchi method [2] and multi objective optimization by using Taguchi method combined with grey relation analysis [3, 4]. Some of the previous studies are included here,

Taguchi methodology's tools such as the orthogonal array, signal to noise ratio, factor effect analysis and analysis of variance were used to analyze and optimize the process parameters such as speed, feed, infeed and mode of dressing in surface grinding[5]. Similar technique was used in CNC milling operation to optimize the surface roughness, this study considers feed rate, spindle speed and depth of cut as control factors, operating chamber temperature as noise factor and the usage of different tool inserts in the same specification, which introduced tool condition and dimensional variability. Finally, significant factors on surface roughness were found by using analysis of variance and optimal cutting combination determined by seeking the best surface roughness [6]. Reference [7] used application of Taguchi method, analysis of variance for minimization of delamination influenced by drilling parameters and drill point

- Corresponding author: Ramesh Rudrapati
- E-mail address: rameshrudrapati@gmail.com
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angle. The optimum drilling parameter combination was obtained by using the analysis of signal-to-noise ratio. The conclusion reveled that, Taguchi method and analysis of variance is very useful to found influential drilling parameters and optimum drilling conditions.

Grey relational analysis is a systematic methodology to analyze multiple objectives which was used in electrical discharge machining to optimize the machining parameters to predict the material removal rate, surface roughness and electrode wear ratio simultaneously [8]. Similar work was reported [9], where, grey relational analysis and Taguchi methodology is used to investigate the multi –response optimization of turning process for an optimal parametric combination to yield the minimum cutting forces and surface roughness with the maximum material removal rate. Reference [10] also was used grey relational analysis to optimize the multi performance characteristics in face milling operation to minimize the cutting for and surface roughness and maximize the tool life.
With all the viewpoints, this study proposes an optimization approach using orthogonal array of Taguchi method and grey relational analysis, a multi-objective integration method, to optimize traverse cut cylindrical grinding conditions. Therefore, the optimum multi-objective grinding variables can then be achieved through the analysis of variance of signal to noise ratio in the Taguchi experiment. Present work definitely contributes the optimum solution of compromising technique for multiple cylindrical grinding objectives with profound insight.

Grey relational analysis

Grey relational analysis was proposed by Deng in 1989, it is a method of measuring the sequences using a Grey relational grade. Optimization of multiple performance characteristics is not straight forward and much more complicated than of single performance characteristics. To solve the multiple performance characteristics problems, grey relational analysis is coupled with Taguchi method. This grey based Taguchi technique has been widely used in different fields of engineering to solve multi-objective problems. Furthermore a statistical analysis of signal to noise ratio (S/N) is performed to found out the significant process parameters. The optimal combination of the process parameters can then be predicted from response table for S/N ratio table. Grey theory provides the following steps to optimize the process parameters [11, 12].

1. Normalization of surface roughness parameters R_a and R_q for the experimental work.
2. Performance of grey relational and to calculate grey relational coefficient.
3. Calculation of grey relational grade by averaging the grey relational coefficient.
4. Parameter analysis performs by using Taguchi method for the input parameters with grey relational grade and to find the significant parameters.
5. Selection of optimal levels of process parameters.
6. Verification of the optimal levels by confirmation experiments.

Experimental procedure

Experiments are conducted on the HMT made Cylindrical grinding machine. The machine consists of high speed grinding wheel, head stock and tail stock etc.; work piece is fixed in between the head stock and tail stock, which is driven by a stepper motor.

Cylindrical block of 38mm diameter and 50mm length stainless material is chosen as a work piece. In a long stainless steel bar four such samples have been made by turning; suitable grinding allowance has been kept; between two samples, a recess of small depth and suitable width has been provided; three such samples have been used. Aluminum oxide grinding wheel has been selected for present experimentation. Three control variables work speed, longitudinal feed and infeed are selected on the basis of capacity of grinding machine, grinding wheel and work material for present investigation. Based on the preliminary experiments conducted by using one variable at a time approach, the feasible range for grinding parameters is selected for present analysis is shown in Table 1.

Table 1. Grinding parameters and their levels

Parameters	Levels		
	1	2	3
A:infeed (mm/cycle)	0.04	0.05	0.06
B: longitudinal feed (mm/s)	70	80	90
C: work speed (rpm)	80	112	160

Design of experiments

The application of design-of-experiments (DoE) requires careful planning, prudent layout of the experiment, and expert analysis of results. Taguchi has standardized methods for each of these DoE application steps. In the present investigation, there are six degrees of freedom owing to the three-level of grinding parameters infeed, longitudinal feed and work speed are selected, while interaction between the parameters is neglected. Once the degrees of freedom are known, the next step is to select an appropriate orthogonal array. The degrees of freedom for the orthogonal array should be greater than or at least equal to those of the process parameters. In this study, an L_9 orthogonal array is used because it has eight degrees of freedom in the grinding parameters. Each process parameter is assigned to a column and nine grinding parameters. There are hence nine experiments needed to study the entire process parameter space by using the L9 orthogonal array [13]. The L_9 orthogonal array for the process parameters is shown in Table 2.

After experimentation, surface roughness readings have been taken using the Talsurf profile meter. Measured surface roughness values are shown in Table 3.

Table 2. L_9 orthogonal array

Experiments	A (infeed)	B (Longitudinal feed)	C (work speed)
1	Level 1	Level 1	Level 1
2	Level 1	Level 2	Level 2
3	Level 1	Level 3	Level 3
4	Level 2	Level 1	Level 2
5	Level 2	Level 2	Level 3
6	Level 2	Level 3	Level 1
7	Level 3	Level 1	Level 3
8	Level 3	Level 2	Level 1
9	Level 3	Level 3	Level 2

Table 3. Output responses

Experiments	surface roughness	
	R_a (μm)	Rq (μm)
1	0.836	1.22
2	0.860	1.33
3	0.652	0.99
4	0.966	1.25
5	0.830	1.00
6	0.761	0.96
7	0.750	1.26
8	0.816	0.97
9	0.950	1.31

Multi response optimization using grey relational analysis

The Grey theory has been first developed since 1982 [14] to construct the system uncertainty for relation analysis, modeling, forecasting, decision and control. GRA is mainly utilized in finding the major relations in the system to access the alternatives before multi-attribute decision making, and it considers simultaneously the overall relational rating regarding each alternative and also selects the most valuable degrees as the best alternative [15]. Data pre- processing steps of GRA can be expressed as:

Step 1: In the grey relational analysis, when the range of the sequence is large or the standard value is enormous, the function of factors is neglected. However, if the factors goals and directions are different, the grey relational analysis might also produce incorrect results. Therefore, one has to preprocess the data which are related to a group of sequences, which is called "grey theory relational generation" [13].

For Lower-the-better quality characteristics data preprocessing is calculated by:

$$Xi\ (k) = \frac{\max Yi\ (k) - Yi\ (k)}{maxYi\ (k) - minYi(k)} \qquad (1)$$

where Xi(k) is the value after grey relational generation while min Yi(k) and max Yi(k) are respectively the smallest and largest values of Yi(k) for the k^{th} response.

Step 2: Generation of Grey Relation Co-efficient

By normalizing grey relational co-efficient (GRC) is calculated as

$$\xi i(k) = \frac{\Delta \min + r\Delta max}{\Delta 0ik + r\Delta max} \qquad (2)$$

where Δoi = ||x0(k) _ xi(k)|| = difference of the absolute value between x0(k) and xi(k) and here r is distinguish co efficient which is used to adjust the difference of the relational coefficient, usually r is within the set {0, 1}. $\xi_i(k)$ is Grey Relation Co-efficient.

Step 3: determine the grey relational grade for each experiment combination

$$\alpha i = \sum_{k=1}^{n} \xi i(k)\ /\ n \qquad (3)$$

Where n is the number of performance characteristics.

Step 4: Grey relational ordering

In relational analysis, the practical meaning of the numerical values of grey relational grades between elements is not absolutely important, while the grey relational ordering between them yields more subtle information. The combination yielding the highest grey relational grade is assigned an order of 1 while the combination yielding the minimum grade is assigned the lowest order. The ordering of the present grey grades is shown in the last column.

Analysis and discussion of experimental results

Traverse cut cylindrical grinding process mainly used for making the cylindrical parts with good surface roughness. In the data pre- processing of grey relational analysis, surface roughness parameters R_a and R_q are taken as the lower the better criteria. L_9 orthogonal array (OA) is used for the design of experiments. Equation (1) is used to normalize the experimental data after grey relational generation is tabulated in the Table 4. Grey-relational coefficient is calculated by using (2). The value of 'r' is taken as 0.5 since both the output parameters are of equal importance. The grey relational grade can be calculated by using equation (3), which is shown in the Table 4.

Table 4. Grey relational generations

S.No	Surface roughness	
	R_a (μm)	Rq (μm)
1	0.414013	0.297297
2	0.33758	0
3	1	0.918919
4	0	0.216216
5	0.433121	0.891892
6	0.652866	1
7	0.687898	0.189189
8	0.477707	0.972973
9	0.050955	0.054054

Table 5. Grey relational coefficients

S.No	Surface roughness	
	R_a (μm)	Rq (μm)
1	0.460411	0.41573
2	0.430137	0.333333
3	1	0.860465
4	0.333333	0.389474
5	0.468657	0.822222
6	0.590226	1
7	0.615686	0.381443
8	0.489097	0.948718
9	0.345055	0.345794

Table 6. Grey relational grades

S.No.	Grey relational grade	Order
1	0.664048	8
2	0.663031	9
3	0.777778	1
4	0.666667	4
5	0.664477	7
6	0.677297	3
7	0.681305	2
8	0.665808	5
9	0.665592	6

Discussion on Results

After obtaining the grey relational grade, Taguchi methodology combines with the grey relational analysis to found out the significant parameters. Taguchi methodology is a significance, where, to control the process parameters and their levels during the process optimization. The concept of signal to noise ratio in the Taguchi method is very useful are the improvement of quality through variability reduction and the improvement of measurement [16, 17].

L_9 orthogonal array along with grey relational grade values put into the MINITAB 16.1 software. Analysis of variance test (Table 7) is conducted on grey relational grade and the response table for signal to noise (S/N) ratios is also developed shown in Table 8 and corresponding plot is shown in Fig. 1 by using the applications of Taguchi methodology. As grey relational grade is to be maximized for obtaining optimum parametric combination, the S/N ratio is calculated using higher-the-better (HB) criterion and given by [18]:

$$S/N = -10\log(1/n\sum 1/y\wedge 2) \quad (4)$$

where 'y' is the observed data and 'n' is the number of observations.

Table 7 presents that ANOVA table for surface roughness. An ANOVA table consists of sum of squares, corresponding degrees of degrees of freedom, the F-ratios corresponding to the ratios of two mean squares and the performance factor from each of the control factors. These performance factors can be used to assess the importance of each factor for good surface roughness. In the present study ANOVA test is conducted at 95% confidence interval. If P value in the ANOVA table is less than 0.05, corresponding control variable is treated as significant on surface roughness. From Table 7, it is noted that input variables does not have much influence on surface roughness.

Table 7. Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	0.279	0.279	0.139	0.79	0.560
B	2	0.463	0.463	0.231	1.30	0.434
C	2	0.493	0.493	0.246	1.39	0.419
Residual Error	2	0.355	0.355	0.177		
Total	8	1.591				

Table 8. Response table for S/N ratio (Larger is better)

	A	B	C
1	-3.103	-3.470	-3.491
2	-3.486	-3.551	-3.542
3	-3.467	-3.034	-3.022
Delta	0.383	0.517	0.520
Rank	3	2	1

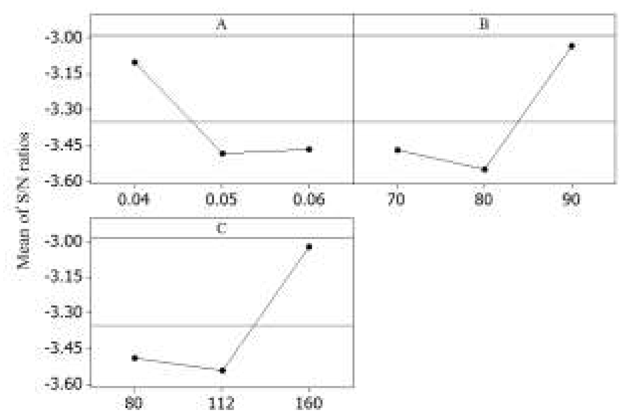

Fig. 1 Main effects plot for S/N ratios

From the response table for S/N ratios (Table 8) and corresponding main effects plot Fig. 1), it is found that level 1 of infeed, level 3 of longitudinal feed and level 3 of work speed indicated as optimized conditions for low surface roughness parameter R_a and Rq.

Confirmatory experiments

After obtaining the optimal level of process parameters, three confirmatory experiments are conducted to validate the Taguchi based Grey relational analysis. The optimized process combination is found to be acceptable through the results of the above confirmatory experiments.

Conclusions

The followings are the conclusions, drawn based upon the tests conducted on stain less steel in cylindrical grinding process.

1. Conducting the experiments based on the L9 orthogonal array and analyzing the multi-objective optimization problems using GRA based methodology is simple and cost reduction methodology, needs only nine experiments to analysis.

2. From the response table for S/N ration and corresponding main effects plot, it is found that work speed is the significant factor and next longitudinal feed followed by infeed on surface roughness.
3. Optimum cutting conditions obtained from the above -said response table, and main effect plot is A1B3C3 for simultaneously optimization of surface roughness parameters R_a and R_q within the experimental range
4. The validation experiment confirms the improvement of grinding process (improved surface roughness).
5. Proposed GRA cum Taguchi methodology used in the present study is very useful for optimizing the surface roughness parameters R_a and R_q simultaneously in the cylindrical grinding process.

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