Optimization of Machining Parameters and Tool Angle on Surface Quality of Turning Operation Using Taguchi Grey Relational Analysis

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Abstract

Turning is an operation using a lathe machine and used to remove metal from the outer diameter of a rotating cylindrical workpiece and reduce the workpiece's diameter while it is rotating. In turning operation, there are various parameters available and there have been several studies and researches that examine the way of optimizing turning parameters to achieve preferable performance. Surface roughness quality is one of the most expected performances. This study aims to optimize the tool angle and machining parameters such as depth of cut, feed, and speed on turning operation to achieve the best surface roughness quality. Turning operations are performed based on the orthogonal array for stainless steel. The optimization of parameters and angle tool in this research used Taguchi Grey relational analysis. This method is expected to minimize the surface roughness of the work piece on turning operation. The Taguchi Grey relational analysis method in this research is meant to calculate and analyze the optimal condition for combined parameters and tool angle to get the optimal surface quality. The result shows that the optimum cutting conditions were cutting speed 70 m/min, depth of cut 0.4 mm, the feed rate 0.2 mm/rev, and cutting-tool angle 91º.

Keyword: grey relational analysis; taguchi method; turning operation

Abstrak

Pembubutan adalah suatu operasi dengan menggunakan mesin bubut dan digunakan untuk menghilangkan logam dari diameter luar benda kerja silinder yang berputar dan mengurangi diameter benda kerja saat sedang berputar. Dalam operasi pembubutan, terdapat berbagai parameter yang tersedia dan terdapat beberapa studi dan penelitian yang mengkaji cara mengoptimalkan parameter pembubutan untuk mencapai kinerja yang diinginkan. Kualitas kekasaran permukaan adalah salah satu kinerja yang paling diharapkan. Penelitian ini bertujuan untuk mengoptimalkan sudut pahat dan parameter pemesinan seperti kedalaman potong, pemakanan, dan kecepatan operasi pembubutan untuk mencapai kualitas kekasaran permukaan terbaik. Operasi pembubutan dilakukan berdasarkan susunan ortogonal untuk baja tahan karat. Optimasi parameter dan alat sudut dalam penelitian ini menggunakan analisis relasional Taguchi Grey. Metode ini diharapkan dapat meminimalkan kekasaran permukaan benda kerja pada operasi pembubutan. Metode analisis relasional Taguchi Grey dalam penelitian ini bertujuan untuk menghitung dan menganalisis kondisi optimal untuk parameter gabungan dan sudut pahat untuk mendapatkan kualitas permukaan yang optimal. Hasil penelitian menunjukkan bahwa kondisi pemotongan optimum adalah kecepatan potong 70 m / menit, kedalaman potong 0,4 mm, laju pengumpanan 0,2 mm / putaran, dan sudut pahat 91º.

Kata kunci: analisis relasional *grey*; metoda taguchi; pembubutan

1. Introduction

The manufacturing process has a variety of parameters that can impact the final outcome. When any particular parameters are chosen as an object to be tested, it must be guaranteed that the parameters really affect the process. There are many approaches to verify that the parameters substantially affect the outcome of the manufacturing process, one of the most used approaches is among all Taguchi methods of Grey relational analysis.

In 1940, Dr. Genichi Taguchi introduced the Taguchi technique. This approach is used in the process of optimization. This technique is only used for single optimization when first detected, but there are some scientists who develop the techniques in some cases of multi-response optimization. Signal to Noise (SN Ratio) and Orthogonal Array (OA) are two components of the Taguchi process. The Taguchi Approach uses orthogonal arrays to study a large number of variables with a limited number of experiments from the design of experiment theory. Orthogonal arrays significantly diminished the number of experimental structures to be studied. In comparison to simple process optimization criteria, Taguchi also suggests the use of signal-to-noise. The reasoning is that while the mean (signal) needs to be maximized in terms of its similarity to nominal value, it can also be important to minimize the differences in the phase (noise). It accomplishes these objectives concurrently.

There are some parameters that can affect the outcome of the workpiece, particularly surface quality in the turning operation in the manufacturing phase. It is important to ensure and refine these parameters that the surface efficiency of the turning process is actually affected. In order to ratify and optimize the parameters that influence the surface quality of the turning process, this study will focus on the Taguchi approach with Grey relational analysis.

2. Method

Research Variable

The variables used in this research to obtain experimental data are Independent variable and Response variable. independent variable is a valuable variable that can be monitored and determined based on the research's certain considerations. It leads to the research's objectives four factors will be included as the Independent variable in this study. Each aspect is divided into three levels as it is shown in Table 1.

Table 1. Variable Factor

Parameters	Level 1	Level 2	Level 3
Cutting Speed (m/min)	70	80	90
Depth of Cut (mm)	0.4	0.6	0.8
Feed (mm/rev)	0.2	0.3	0.4
Tool Cutting Edge Angle (°)	45	62.5	91

The response variable is a variable with a value that cannot be managed or predicted at the beginning and is influenced by the treatment received. This variable can be identified after experimenting. Surface roughness will be used as response variables in this study.

Initial Observation

This observation is carried out on a workpiece surface that has been machined. The workpiece that will be measured is aluminum 6061 with a diameter of 25 mm and length 60mm. Here is an observation by machining the workpiece using a CNC lathe machine to determine the optimal parameters and tool angle. Machining parameters have much influence on the object that has been machined. This happens because each different parameter will produce different results. The surface will be calculated using Taguchi Grey Relational Analysis to determine which parameter is the most optimal.

Problem Identification

In identifying this thesis's writing, the author wanted to concentrate on optimizing surface roughness in turning operations with different machining parameters and tool angle. The aim of this research is to optimize aluminum 6061 material surface quality using turning operations by analyzing machining parameters and tool angle using the Taguchi Grey relational analysis method.

Taguchi Orthogonal Arrays

The experiment was carried out by combining the parameters on Table 1: feed rate, depth of cut, cutting speed, and tool cutting edge angle. It was substituted into Table 2, and several parameter combinations add the table to get accurate results. There will be four parameters and three levels of each parameter (P = 4 and L = 3). L9(34) orthogonal array will be used in this research.

Table 2. L9(34) Orthogonal Array

Experiment Number	A	B	C	D	X
1	1	1	1	1	X_1
2	1	2	2	2	X_2
3	1	3	3	3	X_3
4	2	1	2	3	X_4
5	2	2	3	1	X_5
6	2	3	1	2	X_6
7	3	1	3	2	X_7
8	3	2	1	3	X_8
9	3	3	2	1	X_9

The result of the substitution and added experiment are shown in Table 3.

Table 3. Taguchi Orthogonal Array

Experiment Number	Cutting Speed (m/min)	Depth of Cut (mm)	Feed Rate (mm/rev)	Tool Cutting Edge Angle (º)
1	70	0.4	0.2	45
2	70	0.6	0.3	62.5
3	70	0.8	0.4	91
4	80	0.4	0.3	91
5	80	0.6	0.4	45
6	80	0.8	0.2	62.5
7	90	0.4	0.4	62.5
8	90	0.6	0.2	91
9	90	0.8	0.3	45
10	90	0.6	0.2	45
11	90	0.6	0.2	62.5
12	90	0.6	0.3	45
13	90	0.6	0.3	62.5
14	90	0.6	0.3	91
15	90	0.6	0.4	45
16	90	0.6	0.4	62.5
17	90	0.6	0.4	91

3. Result And Discussion

Experiment Data

The raw material of aluminum 6061 was a machining process by a computer numerical control turning machine (CNC). Roughness of the surface had been calculating using a tester of surface roughness, then entered in Table 4.2 as below.

Table 4. Experimental Result Data

Experiment Number	**Cutting Speed (m/min)**	**Depth of Cut (mm)**	**Feed Rate (mm/rev)**	**Tool Cutting Edge Angle (º)**	**Surface Roughness 1 (µm)**	**Surface Roughness 2 (µm)**
1	70	0.4	0.2	45	3.220	3.302
2	70	0.6	0.3	62.5	10.257	10.658
3	70	0.8	0.4	91	6.614	5.952
4	80	0.4	0.3	91	3.271	3.109
5	80	0.6	0.4	45	10.534	14.157
6	80	0.8	0.2	62.5	6.982	6.434
7	90	0.4	0.4	62.5	15.625	15.115
8	90	0.6	0.2	91	1.553	1.720
9	90	0.8	0.3	45	6.834	6.557
10	90	0.6	0.2	45	3.182	3.253
11	90	0.6	0.2	62.5	2.459	2.520
12	90	0.6	0.3	45	6.254	6.758
13	90	0.6	0.3	62.5	6.912	7.561
14	90	0.6	0.3	91	3.126	3.264
15	90	0.6	0.4	45	12.890	12.631
16	90	0.6	0.4	62.5	17.098	15.838
17	90	0.6	0.4	91	5.809	5.743

Figures 1 below shows the results of aluminum 6061 materials that have been undergone a machining process using a CNC machine and the surface measurement process.

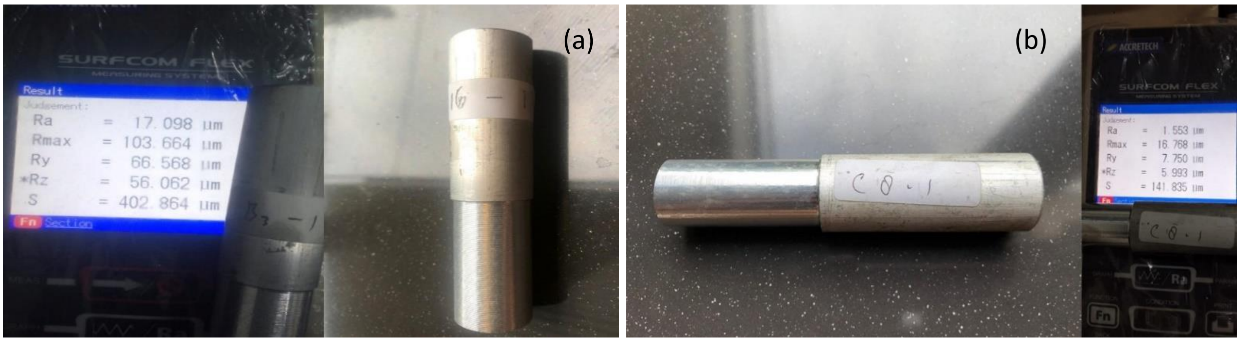

Figure 1. (a) Experiment 16-1, roughness 17.098 µm and (b) Experiment 8-1, roughness 1.553 µm

Grey Relational Value

Table 5 below shows the calculated normalized values of responses. In this regard, Grey relational analysis data must be preprocessed into quantitative indexes in order to normalize raw data for further analysis.

Table 5. Normalized Values of Responses

Experiment Number	Surface Roughness 1 (µm)	Surface Roughness 2 (µm)	Grey Relational Value (Normalized) 1	Grey Relational Value (Normalized) 2
1	3.220	3.302	0.893	0.888
2	10.527	10.658	0.423	0.367
3	6.614	5.952	0.674	0.700
4	3.271	3.109	0.889	0.902
5	10.534	14.157	0.422	0.119
6	6.982	6.343	0.651	0.666
7	15.625	15.115	0.095	0.051
8	1.553	1.720	1.000	1.000
9	6.813	6.557	0.660	0.657
10	3.182	3.253	0.895	0.891
11	2.459	2.520	0.942	0.943
12	6.264	6.758	0.697	0.643
13	6.912	7.561	0.655	0.586
14	3.126	3.264	0.899	0.891
15	12.890	12.631	0.271	0.227
16	17.098	15.838	0	0
17	5.809	5.743	0.726	0.715

Grey Relational Grade

Grey relational grade is a weighted sum of Grey relational coefficients. The optimum condition for parameters that have been combined is the parameter combination with the higher Grey relational grade. Table 6 shows the result of the Grey relational grade.

S/N Ratio

The S/N ratio was used for obtain the optimal combination for multiple response optimization. To find the accurate value of the S/N ratio, the data was executed in the MINITAB software, and it shown in the Table 7 and Table 8 as a response table for Grey relational grade, while Figure 2 exhibits the main effect plot of SN ratios for Grey Relational Grade

Table 6. Grey Relational Grade

Experiment Number	Grey Relational Grade
1	0.820
2	0.453
3	0.615
4	0.827
5	0.413
6	0.594
7	0.350
8	1.000
9	0.594
10	0.824
11	0.897
12	0.603
13	0.570
14	0.826
15	0.400
16	0.333
17	0.642

Table 7. S/N Ratio

Experiment Number	Grey Relational Grade	S/N Ratio	Rank
1	0.820	1.804	6
2	0.453	6.902	13
3	0.615	4.267	8
4	0.827	1.733	3
5	0.413	7.685	14
6	0.594	4.568	11
7	0.350	9.109	16
8	1.000	0.113	1
9	0.594	4.563	10
10	0.824	1.762	5
11	0.897	1.041	2
12	0.603	4.434	9
13	0.570	4.924	12
14	0.826	1.741	4
15	0.400	7.974	15
16	0.333	9.542	17
17	0.642	3.906	7

Table 8. Response Table for Grey Relational Grade

Level	Cutting Speed	Depth of Cut	Feed Rate	Tool Angle
1	4.324	4.215	1.857	4.704
2	4.662	4.548	4.050	6.104
3	4.465	4.466	7.081	2.352
Delta	0.338	0.332	5.223	3.662
Rank	3	4	1	2

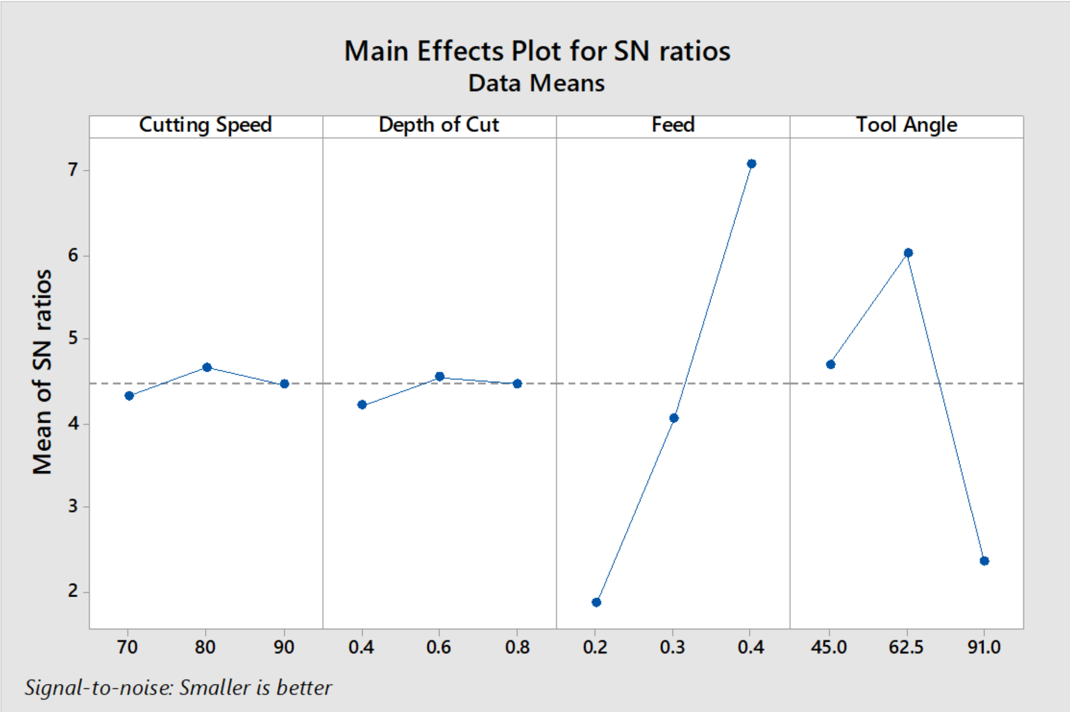

Figure 2.. Main Effects Plot of S/N Ratio for GRG

According to the Taguchi methodology, the Grey relational grade table responses of S/N ratio was used to analyze control parameters on the multiple characteristics value. This result was given in table 4.7. The most influential parameter affecting the performance characteristics is determined by comparing the maximum and the minimum value of the Grey relational grade. Therefore, the feed rate was the most critical parameter that influences the overall Grey relational grade.

Since the smallest S/N ratio gives the best outcome, as shown in the Figure 2, the optimum cutting conditions were cutting speed 70 m/min, depth of cut 0.4 mm, the feed rate 0.2 mm/rev, and cutting-edge tool angle 91°. To validate these results, two sample experiments were performed in accordance with these findings. The outcomes of optimized workpieces were carried out twice, and the surface roughness is 1.628 µm for the first trial and 1.531 µm for the second trial, as shown in Figure 3 below.

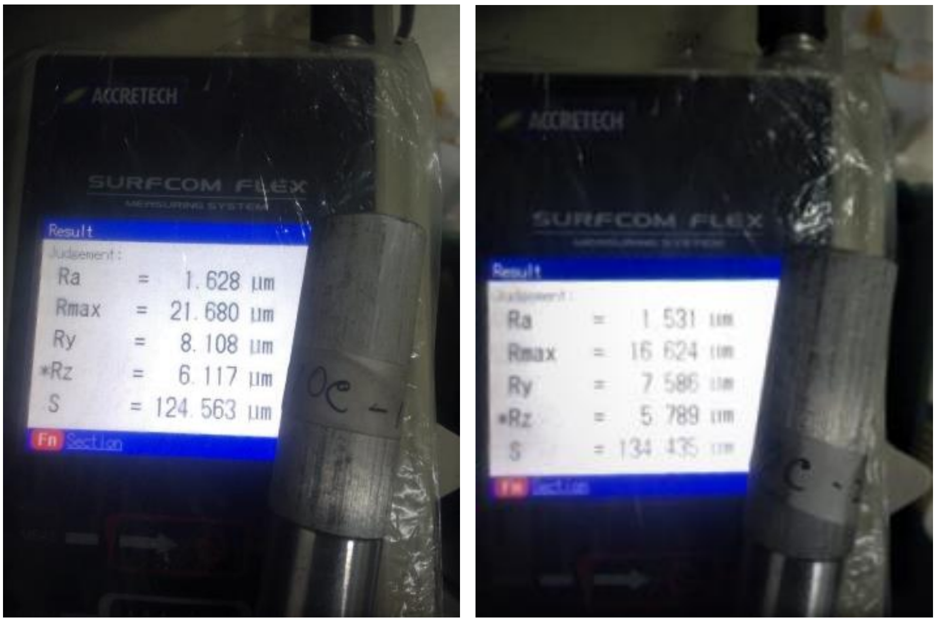

Figure 3. Optimized Result 1 and 2

Analysis of Variance (ANOVA)

The effects of individual parameters cannot be assessed only using the Taguchi method. So, the contribution percentage of each parameter is specified using the analysis of variance (ANOVA). Analysis of variance was completed in order to see effects of the experimental factors in multiple characteristics of performance. An analysis of variance was done in MINITAB software, it showed on the Table 8.

Table 9. Results of ANOVA for GRG

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Cutting Speed	2	0.174	0.13%	0.8765	0.4382	0.35	0.714
Depth of Cut	2	0.342	0.25%	0.0969	0.0484	0.04	0.962
Feed	2	76.138	55.78%	88.9415	44.4708	35.72	0.000
Tool Angle	2	49.873	36.54%	49.8727	24.9363	20.03	0.001
Error	8	9.960	7.30%	9.9599	1.2450		
Total	16	136.486	100.00%				

4. Conclusion

After completing the machining process and obtaining results, there are some conclusions from the research, which are:

1. Based on the Grey Relational Grade's response table, the optimum cutting conditions were cutting speed 70 m/min, depth of cut 0.4 mm, the feed rate 0.2 mm/rev, and cutting-edge tool angle 91°.
2. The results of optimized workpieces were carried out twice and the surface roughness was 1.628 µm for the first trial and 1.531 µm for the second trial.
3. Based on the outcome Analysis of Variance for Grey Relational Grade, the ANOVA indicated that feed rate, cutting speed, tool angle, and depth of cut influenced the Grey relational grade values by 55.78%, 0.13%, 36.54%, and 0.25% respectively. The feed rate had the most percentile contribution to multiple performance characteristics at 55.78%. The cutting speed has the most negligible contribution, only 0.13%

Recommendation

Further research could consider more factors and different materials in the study to view how the factors would influence surface roughness.

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