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Analysis and Optimization of Boring Process using Taguchi and Grey Relational Analysis

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ABSTRACT

The optimization of computer numerical control(CNC) boring operation parameters for aluminum alloy 6063 T6 using Taguchi and Grey Relational Analysis(GRA) optimization technique. Machining industry is playing a crucial role in the present manufacturing scenario and boring is an operation which is quite highly used nowadays to enlarge and achieve greater accuracy of the internal holes. In the present work an attempt is made to select the combination of optimum cutting parameters which results in better surface finish (minimum surface roughness i.e. Ra and Rq) and Circularity (Cr). Machining with optimum cutting parameters will result in minimum machining time and enhance the productivity. Three parameters viz. cutting speed, feed and depth of cut of boring bar has been taken as control factors. The cutting trials are performed as per Taguchi L_{27}(3^3) orthogonal method to deal with the response from multi-variables. Taguchi orthogonal array is designed with three levels of boring parameters with the help of software Minitab 16.Grey Relational Analysis is performed for finding out the optimal parameter setting for the Al alloy 6063 T6 material. Additionally, for analyzing the data, the analysis of variance (ANOVA) technique is used to find the significant factors and their individual contribution in the response function i.e. surface roughness and Circularity.

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I. Introduction

The manufactures ultimate goals are to produce high quality product with less cost and time constraints. To achieve these goals, one of the consideration by optimizing the machining process parameters either with the conventional optimization techniques or with the evolutionary optimization techniques.

Max turnplusturning center(MC) is defined as multifunction CNC machine with automatic tool changing capabilities and rotating cutting tools. In general, these machines relatively use light cuts, maintain close tolerances and are often capable of high production rates. Increased productivity and versatility are major advantages of MC; the ability to perform drilling, boring, turning, reaming and threading operations on a single machine eliminates the need for a number of individual machine tools ,thus reducing capital equipment and labor requirements.

Boring is one of the important machining operation or a mass reducing process of enlarging the pre drilled or cast holes with a single point tools or tools with multiple cutting edges. Common applications of boring include enlarging or finishing of cored, pierced ,or drilled holes ,contoured internal surfaces and can be used to cut tapered holes.

Because of the limitations on tooling design imposed by the fact that the work piece mostly surrounds the tool, boring is inherently somewhat more challenging than turning in terms of:

- Decreasing tool holding rigidity
- Increased clearance angle requirements(limiting the amount of support that can be given to the cutting edge)
- Difficulty of inspection of the resulting surface(size, form, surface roughness)

These are reasons why boring is viewed as an area of machining practice in its own right separate from turning. With its own tips, tricks, challenges and body of expertise, despite the fact that they are in some ways identical.

In Boring operation, Surface roughness is an important quality parameter of bored surface. It is important to select proper machining parameter for achieving selected quality targets or optimal machining performance. Usually, the desired machining parameters are determined based on experience or on handbook values. However, this does not ensure that the selected machining parameters result in optimal or near optimal machining performance for that particular CNC turning center and environment.

II. Literature Review

A.M. Badadhe et al. made an attempt to select the combination of optimum cutting parameters which resulted in better surface finish. Machining with optimum cutting parameters always results in minimum machining time and hence increases the productivity. Four parameters viz. spindle speed, feed, depth of cut and length to diameter (L/D) ratio of boring bar had been taken as control factors. The cutting trials were performed as per Taguchi 3^4 (L9) orthogonal array method to deal with the response from multi-variables. AISI 1041 (EN9) carbon steel was used as a job material which was cut by using standard boring bars of various sizes each having

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a tungsten carbide inserts of same insert radius. The Analysis of Variance (ANOVA) was carried out to find the significant factors and their individual contribution in the response function i.e. surface Roughness.

Shyan Lin, et al. used Taguchi method and Grey Relational Analysis for multi response (Surface Roughness Average, Surface Roughness Maximum and Roundness) optimization of CNC Boring operation parameters for aluminum alloy 6061T6 work piece material. Nine experimental runs based on an Orthogonal Array of Taguchi method and steps required for optimization of GRA were performed. Then an optimal parameter combination of the CNC boring operation was obtained via GRA. Additionally, ANOVA was also applied to identify the most significant factor. Both the approaches gave the same results and was straight forward techniques.

Harsimran Singh Sodhi et al. carried out the study on Mild Steel hollow bars having dimensions of 42 mm diameter and 70mm length, on CNC boring machine by using carbide tool of 0.6mm nose radius for investigating the cutting parameters of Boring operation for achieving minimum surface roughness using Taguchi Method.

Kanase Sandip S et al. proposed an innovative method to reduce tool chatter is and enhance surface finish in boring operation. The results proved that the particle damping technique has vast potential in the reduction of tool chatter. Also the suppression in tool chatter by using impact damper boring bars is very significant. Boring bars with impact damping are also relatively cheaper than other damped boring bars. It is therefore concluded that impact damping has a good effect in improving surface finish in boring operation.

III. Taguchi Method

The method that Taguchi developed in 1960 for enhancing product quality has been widely implemented throughout industry to upgrade manufacturing products/processes. The Taguchi method evaluates product quality by applying the signal-to-noise ratio and, in doing so, the optimal factor/level combination obtained from the Taguchi method can be determined to reduce simultaneously the quality variation and bring the mean close to the target value.

IV. Grey Relational Analysis:

Grey relational analysis uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. Therefore, a grey system means that a system in which part of information is known and part of information is unknown.

Grey Relational Analysis is used for solving inter relationships among the multiple responses. In this approach a grey relational grade is obtained for analyzing the relational degree of the multiple responses. Shyan lin et al. have attempted grey relational approach to solve multi-response problems in Taguchi methods.

Optimization steps in Grey Relational Analysis

Grey data processing must be performed before grey correlation coefficients can be calculated. A series of various units must be transformed to be dimensionless. Usually, each series is normalized by dividing the data in the original series by their average. Let the original reference sequence and sequence for comparison be represented as *x0(k)* and *xi(k)*, *i*=1, 2, ..., *m*; *k*=1, 2, ..., *n*, respectively, where *m* is the total number of experiment to be considered, and *n* is the total number of observation data. Data preprocessing converts the original sequence to a comparable sequence. Several methodologies of preprocessing data can be used in grey relation analysis, depending on the characteristics of the original sequence. The original data has the quality characteristic as 'smaller the better', then original data is pre-processed as 'smaller the better'.

Xi * (K) = max.xi(o) (k) – Xi (o) (k)/max.xi(o) (k)-min.xi (o)(k) ……(1).

Where max $xi^{(0)}$ (k) and min $xi^{(0)}$(k) are the maximum and minimum values respectively of the original sequence $xi^{(0)}$(k). Comparable sequence xi* (k) is the normalized sequence of original data.

Grey Relational Grade

The grey relational coefficient

γ = Δmin + ξΔmax/Δoi(k) + ξΔmax … (2)

where

a) j=1,2,…n; k=1,2,…m, n is the number of experimental data items and m is the number of responses.

b) $y_0(k)$ is the reference sequence ($y_0(k)$ = 1, k=1,2,…m); $y_j(k)$ is the specific comparison sequence.

c) $\Delta_{oj}= \| xo^*(k) - xi^*(k) \|$

d) $\Delta_{oj} = \min\min \| xo^*(K) - xi^*(K) \|$
∀ jei∀ k

e) $\Delta_{oj} = \max\max \| xo^*(k) - xi^*(K) \|$
∀ jei∀ k

f) ξ is the distinguishing coefficient which is defined in the range 0< ξ <1(the value may adjusted on the practical needs of the system)=0.5

The grey relational grade is γ is expressed as

$\gamma = {}_{1/y}\sum_{i}{}^{m} = 1\ \gamma ij$ …(3)

Where γi_j the grey relational grade for the j^{th} experiment and k is the number of performance characteristics. The grey relational grade shows the correlation between the performance sequence and the comparability sequence. The evaluated grey relational grade varies from 0 to 1and equals 1 if these two sequences are identically coincident. The higher grey relational grade implies the better quality; on the basis of grey relational grade, the factor effect can be estimated and the optimal level for each controllable factor can also be determined.

Also, the original sequence is normalized by a simple method in which all the values of the sequence are divided by the first value of the sequence.

$X_i*^{(k)}$=xi(o)(k)/xi(o)(1) ……………(4)

A grey relational grade is a weighted sum of the grey relational coefficients, and is defined as follows.

$\gamma (x_0*, x_i^*) = \sum n_{k=1\beta}\gamma(x_0*^{(k)}, x_i^{*(k)})$

$\sum n_{k=1\beta} = 1$ ……………..(5)

Here, the grey relational grade represents the level of correlation between the reference and comparability sequences. If the two sequences are identical, then the value of the grey relational grade equals to one. The grey relational grade also indicates the degree of influence exerted by the comparability sequence on the reference sequence. Consequently, if a particular comparability sequence is more important to the reference sequence than other comparability sequences, the grey relational grade for that comparability sequence and the reference sequence will exceed that for other grey relational grades. The GRA is actually a measurement of the absolute value of data difference between the sequences, and can be used to approximate the correlation between the sequences.

Based on this study, one can select a combination of the levels that provide the largest average response. Therefore, the selected combination will be the optimal parameter combination of the CNC Boring operation.

Most influential factor

Grey relational analysis is applied to find the most influential factor among the Boring process parameters that affect the Cutting speed, Feed rate ,Depth of cut and Surface Roughness and Circularity. The values of the factor level in twenty seven experimental runs are set to the comparability sequences for three controllable factors .The data preprocessing was employed according to equation 4 and the normalized results were tabulated .The deviation sequences were calculated using the same method . To obtain the grey relational co-efficient the deviation sequences and the distinguishing coefficient were substituted in equation 2. Additionally, the grey relational coefficient are arranged using equal weighting to obtain grey relational grade. The grey relational grades obtained are arranged in matrix form shown as follows.

$$\gamma = \begin{bmatrix} \gamma(Ra,A) & \gamma(Ra,B) & \gamma(Ra,C) \\ \gamma(Cr,A) & \gamma(Cr,B) & \gamma(Cr,C) \\ \gamma(Rq,A) & \gamma(Rq,B) & \gamma(Rq,C) \end{bmatrix}$$

V. **Experimentation**

The Aluminum alloy 6063T6 is selected as the work piece material for Boring operation. The following process parameters are selected for the present work: Cutting speed - (A), feed rate – (B), depth of cut – (C),Boring bar –S16 and the tungsten carbide inserts are used for the trials. Cutting conditions – Dry. The Aluminum alloy 6063T6 work piece material is 64.5 mm in diameter and of length 100 mm is machined on Max turn plus turning center using tungsten carbide inserts. The Boring parameters are chosen based on the information provided by the referred journals and the limitations imposed by the work piece material, tool material and machine and the workpiece is machined as per these parameters, which are tabulated in Table 1. The Surface Roughness and Circularity are measured by Talysurf surface tester and Coordinate measuring machine respectively. The standard L27 orthogonal array is applied, for each trial, readings are recorded and the results of the experiments for twenty seven trials are reported in Table 2.

Material

Aluminum alloy 6063T6 is one of the most widely used alloys in the 6000 Series. This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applied range from transportation components to machinery and equipment applications to recreation products.

Schematic of machining

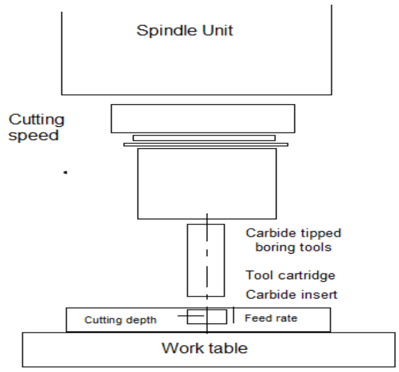

Fig.(**1**) shows the machining setup of the boring process via a turning center. The experiments were carried out on a rigid computer numerical control (CNC) machine center with an 11 kW spindle motor at 6000rpm (machine type of Sinumerik 828 d, manufactured by M.Tab private ltd. India).

Table 1. Experimental Factors and Factor Levels

Levels of Experimental factors	**Experimental control factors**		
	A Cutting speed(m/min)	B Feed rate (mm/rev)	C Depth of cut(mm)
1	70	0.05	0.4
2	85	0.10	0.5
3	100	0.15	0.6

Table 2. Orthogonal Array $L_{27}(3^3)$ of the Experimental Runs and Results.

Run no.	**A/spindle speed(rpm)**	**B/feed rate (mm/rev)**	**C/depth of cut(mm)**	**Ra(μm)**	**Cr(mm)**	**Rq(μm)**
1	346	0.05	0.4	1.6095	0.002	2.2135
2	346	0.05	0.5	2.5857	0.003	3.288
3	346	0.05	0.6	1.9535	0.106	2.576
4	346	0.1	0.4	4.1962	0.011	5.5613
5	346	0.1	0.5	3.1	0.012	4.111
6	346	0.1	0.6	4.0612	0.106	4.994
7	346	0.15	0.4	4.623	0.08	5.757
8	346	0.15	0.5	4.406	0.024	5.377
9	346	0.15	0.6	3.508	0.002	4.953
10	420	0.05	0.4	2.308	0.061	3.218
11	420	0.05	0.5	1.532	0.003	2.782
12	420	0.05	0.6	1.3	0.024	2.352
13	420	0.1	0.4	3.116	0.015	4.277
14	420	0.1	0.5	2.693	0.002	3.642
15	420	0.1	0.6	3.255	0.151	4.635
16	420	0.15	0.4	3.5642	0.131	4.764
17	420	0.15	0.5	3.1607	0.032	4
18	420	0.15	0.6	2.567	0.032	3.521
19	494	0.05	0.4	1.217	0.008	1.6031
20	494	0.05	0.5	2.399	0.003	4.432
21	494	0.05	0.6	2.703	0.001	4.251
22	494	0.1	0.4	3.833	0.042	5.415
23	494	0.1	0.5	3.382	0.089	4.828
24	494	0.1	0.6	2.857	0.002	4.092
25	494	0.15	0.4	3.0957	0.044	3.951
26	494	0.15	0.5	2.3187	0.028	3.185
27	494	0.15	0.6	4.0247	0.01	5.5769

In this study, in order to control in order to properly control the depth of cut, first the internal diameter of the work pieces has been fixed to 12 mm via end Drilling and the cutting depth of work piece is17 mm. Furthermore, the cutting speed (m/min), the feed rate (mm/rev) and the depth of cut (mm) can be regulated in this experiment of the CNC boring operations.

Experimental parameters and Designs

The effects of CNC boring parameters on the surface roughness had been less discussed by research. Usually, the desired boring operation parameters can be determined from experience, a handbook or recommendation from the manufacturer.

In this study, the experiment is conducted with three controllable 3-level factors and three response variables.

Twenty seven experimental runs based on the orthogonal array L_{27} (3^3) are required. Table **1** presents three controlled factors of the cutting speed (i.e., A(m/min)), the feed rate (i.e., B (mm/rev)), and the depth of cut (i.e., C (mm)) with three levels for each factor. Table **2** shows the twenty seven cutting experimental runs according to the selected orthogonal table. After CNC boring operations, three quality objectives of the work pieces are chosen, including the Mean surface Roughness (Ra), Root mean Square Surface Roughness (Rq) and Circularity (Cr).

Best experimental run

The experimental results for Surface Roughness (Ra and Rq) and circularity are listed in Table 2. Typically smaller values of Ra, Rq and Cr are desirable. Thus the data sequences have the smaller – the – better characteristic, the smaller – the-better methodology was employed for data pre-processing.

The values of the Ra, Rq and Cr are set to be the reference sequence $x_0^{(0)}(k)$, k = 1-3. Moreover, the results of 27 experiments are the comparability sequences $x_i(0)^{(k)}$, i = 1…,27, k = 1-3. Table 3 listed all of the sequences after implementing the data preprocessing using

Xi*(K)=max.xi(o)(k)–Xi(o)(k)/max.xi(o)(k)-min.xi(o)(k) (1)

The reference and the comparability sequences are denoted as $x_0^{*\,(k)}$ and $x_i^{*(k)}$,respectively.

Table 3. The sequences after Data Preprocessing.

Reference/comparability Sequence	**Ra**	**Cr**	**Rq**
Reference Sequence	1	1	1
	0.884762	0.993333	0.853054
	0.59815	0.986667	0.594381
	0.783764	0.3	0.765786
	0.125308	0.933333	0.047112
	0.447152	0.926667	0.396254
	0.164944	0.3	0.183683
	0	0.473333	0
	0.063711	0.846667	0.09148
	0.327363	0.993333	0.193553
	0.679683	0.6	0.611233
	0.907516	0.986667	0.716194
	0.975631	0.846667	0.819712
	0.442454	0.906667	0.356292
	0.566647	0.993333	0.50916
	0.401644	0	0.270108
	0.310863	0.133333	0.239052
Comparability	0.429331	0.793333	0.422976
Sequence	0.603641	0.793333	0.538289
	1	0.953333	1
	0.652965	0.986667	0.318977
	0.563711	1	0.362551
	0.231944	0.726667	0.082332
	0.364357	0.413333	0.223645
	0.518497	0.993333	0.400828
	0.448415	0.713333	0.434772
	0.676541	0.82	0.619177
	0.175661	0.94	0.043357

Table 4. listed the deviation and grey relational coefficients and the deviation sequence Δ_{oi}, Δ_{oi} max(k) and $\Delta_{oi\ min}$(k) for i= 1 to 27 , k=1-3 can be calculated as $\Delta_o(1)=\|1-1.6095\|= 0.6095$.

The distinguishing co-efficient can be substituted for grey relational co-efficient in equation 3

$$\gamma = \frac{1}{y}\sum_{i=1}^{m} \gamma_{ij}$$

Table 4. The calculated Grey Relational Coefficient and Grey Relational Grade for 27 comparability sequences.

Δ_{0i}(Ra)	**γ (Ra)**	**Δ_{0i} (Cr)**	**γ (Cr)**	**Δ_{0i} (Rq)**	**γ (Rq)**	**GRG**
0.6095	0.83787691	0.998	0.90050083	1.2135	0.8300668	0.85614819
1.5857	0.59710938	0.997	0.90110257	2.288	0.6389371	0.71238302
0.9535	0.73363472	0.894	0.96770721	1.576	0.7539765	0.81843947
3.1962	0.40507618	0.989	0.90594558	4.5613	0.4296377	0.58021984
2.1	0.518599	0.988	0.90655462	3.111	0.543146	0.65609988
3.0612	0.41629897	0.894	0.96770721	3.994	0.4678854	0.61729721
3.623	0.37326341	0.92	0.94998239	4.757	0.4178544	0.58036673
3.406	0.38878773	0.976	0.91392748	4.377	0.4413589	0.58135804
2.508	0.46961454	0.998	0.90050083	3.953	0.4709153	0.61367688
1.308	0.65026447	0.939	0.93743483	2.218	0.6486675	0.74545559
0.532	0.86558566	0.997	0.90110257	1.782	0.7166446	0.82777762
0.3	0.96069145	0.976	0.91392748	1.352	0.7992494	0.89128945
2.116	0.51648631	0.985	0.90838666	3.277	0.5272036	0.65069219
1.693	0.57882722	0.998	0.90050083	2.642	0.5938851	0.69107104
2.255	0.49883192	0.849	1	3.635	0.4958177	0.66488322
2.5642	0.46358297	0.869	0.98538546	3.764	0.485405	0.64479113
2.1607	0.51067419	0.968	0.91890971	3	0.5543553	0.66131307
1.567	0.60041439	0.968	0.91890971	2.521	0.6085519	0.709292
0.217	1	0.992	0.90412337	0.6031	1	0.96804112
1.399	0.63183305	0.997	0.90110257	3.432	0.51314	0.68202521
1.703	0.57718025	0.999	0.8998999	3.251	0.5296385	0.66890622
2.833	0.43675315	0.958	0.92521441	4.415	0.4388901	0.60028589
2.382	0.48372481	0.911	0.95604396	3.828	0.4803996	0.64005612
1.857	0.5529508	0.998	0.90050083	3.092	0.5450324	0.66616136
2.0957	0.51916974	0.956	0.92648574	2.951	0.5594521	0.6683692
1.3187	0.64804166	0.972	0.91641182	2.185	0.6533582	0.73927055
3.0247	0.41944088	0.99	0.90533736	4.5769	0.4286741	0.58448412

If all the process parameters have equal weighting, is set to be 0.5.The grey relational co-efficient and the grey relational grade can be calculated using the equations 2

$$\gamma = \frac{\Delta \min + \zeta \Delta \max}{\Delta oi(k) + \zeta \Delta \max}$$

This investigation employs the response table of the Taguchi method to calculate the average grey relational grades for each factor level, as illustrated in Table 5

Since the grey relational grades represented the level of correlation between the reference and the comparability sequences, the larger grey relational grade means the comparability sequence exhibiting a stronger correlation with the reference sequence.

Table5. The Response Table for Grey Relational Grade

Levels	A	B	C
1	0.6684	0.79672	0.6994
2	0.7207	0.6407	0.6879
3	0.6908	0.6426	0.6927

Based on this study,one can select a combination of the levels that provide the largest average response.Based on this study, one can select a combination of the levels that provide the largest average response. In Table 5**,** the combination of A2, B1, and C1shows the largest value of the grey relational grade for the factors A, B, and C, respectively. Therefore, A2-B1-C1with a cutting speed of 85m/min, a feed rate of 0.05mm/rev, and depth of cut of 0.4 mm is the optimal parameter combination of the CNC boring operation.

Most Influential Factor

For finding the most influential factor, data preprocessing is performed and results are normalized as follows as per the Equation no (4). $X_i{*}^{(k)}$= xi(o)(k)/xi(o)(1)

Table 7. The calculated Grey Relational Coefficients and Grey Relational Grade for Experimental factors to Experimental Results of the Ra

	γ Ra A	γ Ra B	γ Ra C
	1	1	1
	0.606836	0.562463	0.724197
	0.814128	0.784856	0.765818
	0.368085	0.562211	0.368085
	0.502708	0.913387	0.580661
	0.380639	0.598403	0.477769
Grey Relational	0.333331	0.859288	0.333331
coefficient	0.35014	0.748126	0.386257
	0.442476	0.48727	0.579405
	0.809634	0.642423	0.683253
	0.781314	0.941835	0.758445
	0.697413	0.802164	0.574873
	0.56453	0.924149	0.500039
	0.67085	0.704648	0.68868
	0.536585	0.972113	0.641851
	0.48336	0.49814	0.435292
	0.555231	0.429369	0.567389
	0.710722	0.356876	0.907953
	0.58227	0.76175	0.793338
	0.937153	0.613828	0.795589
	0.788133	0.534369	0.83918
	0.495346	0.671469	0.403925
	0.581576	0.885043	0.523743
	0.729379	0.776119	0.772889
	0.653829	0.420027	0.50343
	0.98642	0.333338	0.830816
	0.465979	0.609565	0.483364
Grey Relational Grade	0.623262	0.681231	0.626651

Table 6. The Sequences after data preprocessing for the Reference Sequences and Comparability Sequences
Comparability sequence Reference sequence

Exp.Run	A	B	C	Ra	Cr	Rq
1	1	1	1	1	1	1
2	1	1	1.25	1.6065	1.5	1.4854
3	1	1	1.5	1.2137	53	1.1638
4	1	2	1	2.6071	5.5	2.5124
5	1	2	1.25	1.9261	6	1.8573
6	1	2	1.5	2.5232	53	2.2562
7	1	3	1	2.8723	40	2.6009
8	1	3	1.25	2.7375	12	2.4292
9	1	3	1.5	2.1795	1	2.2376
10	1.21	1	1	1.4339	30.5	1.4538
11	1.21	1	1.25	0.9518	1.5	1.2568
12	1.21	1	1.5	0.8077	12	1.0626
13	1.21	2	1	1.9360	7.5	1.9322
14	1.21	2	1.25	1.6731	1	1.6454
15	1.21	2	1.5	2.0224	75.5	2.0939
16	1.21	3	1	2.2145	65.5	2.1522
17	1.21	3	1.25	1.9638	16	1.8071
18	1.21	3	1.5	1.5949	16	1.5910
19	1.43	1	1	0.7561	4	0.7242
20	1.43	1	1.25	1.4905	1.5	2.0023
21	1.43	1	1.5	1.6794	0.5	1.9205
22	1.43	2	1	2.3815	21	2.4464
23	1.43	2	1.25	2.1013	44.5	2.1812
24	1.43	2	1.5	1.7751	1	1.8487
25	1.43	3	1	1.9234	22	1.7849
26	1.43	3	1.25	1.4406	14	1.4389
27	1.43	3	1.5	2.5006	5	2.5194

Table 8. The calculated Grey Relational Coefficients and Grey Relational Grade for Experimental factors to Experimental Results of the Cr.

	γ Cr A	γ Cr B	γ Cr C
	1	1	1
	0.98671734	0.98657718	0.99328859
	0.41666793	0.41408451	0.4180791
	0.89193875	0.91304348	0.89156627
	0.88135648	0.90184049	0.88622754
	0.41666793	0.41880342	0.4180791
	0.48780618	0.49830508	0.48684211
	0.77151427	0.80327869	0.77486911
	1	0.9483871	0.98666667
	0.55913759	0.55471698	0.55639098
Grey Relational	0.9923555	0.98657718	0.99328859
coefficient	0.77495697	0.76963351	0.77894737
	0.85525567	0.86982249	0.85057471
	0.99427488	0.97350993	0.99328859
	0.33333325	0.33333333	0.33333333
	0.3661969	0.37027708	0.36453202
	0.7152636	0.73869347	0.71497585
	0.7152636	0.73869347	0.7184466
	0.93523267	0.9245283	0.925
	0.99805848	0.98657718	0.99328859
	0.97563104	0.98657718	0.97368421
	0.65490348	0.65919283	0.64912281
	0.46304194	0.4637224	0.46105919
	0.98861494	0.97350993	0.98666667
	0.64355634	0.65919283	0.63793103
	0.74711501	0.76963351	0.74371859
	0.91226261	0.9483871	0.91358025
Grey Relational Grade	0.75841198	0.76262588	0.75716474

Table 9. The calculated Grey Relational Coefficients and Grey Relational Grade for Experimental factors to Experimental Results of the Rq

	γ Rq A	γ Rq B	γ Rq C
	1	1	1
	0.609038	0.768273	0.762583
	0.821985	0.698928	0.692217
	0.333327	0.340406	0.333327
	0.468688	0.562441	0.554627
	0.375779	0.507937	0.500015
	0.320824	0.327768	0.320824
	0.346026	0.398294	0.390723
Grey Relational	0.37927	0.514134	0.506215
coefficient	0.759135	0.632354	0.624955
	0.946243	0.991322	0.991045
	0.833276	0.640856	0.63353
	0.512831	0.45572	0.447871
	0.636701	0.663785	0.656676
	0.462141	0.567871	0.560078
	0.446248	0.403845	0.396238
	0.560389	0.583526	0.575805
	0.667233	0.895578	0.892577
	0.518049	0.738939	0.732779
	0.568267	0.509229	0.501306
	0.605472	0.649896	0.642651
	0.426075	0.350509	0.343329
	0.500922	0.456006	0.448155
	0.642421	0.691238	0.684433
	0.679175	0.498593	0.490671
	0.985467	0.805149	0.800129
	0.409211	0.433628	0.425862
Grey Relational Grade	0.585711	0.595786	0.589208

$$\gamma = \begin{bmatrix} 0.6232 & 0.6812 & 0.6266 \\ 0.7584 & 0.7626 & 0.7571 \\ 0.5857 & 0.5957 & 0.5892 \end{bmatrix}$$

By comparing Row 1, Row 2 and Row 3,some conclusions can be drawn from this matrix. In the first row γ(Ra, B)> γ(Ra, C> γ(Ra, A),it means that the order of importance for the controllable factors to the Ra, in sequence is the factor B , C and A. From the second row, γ(Cr, B)> γ(Cr, A)> γ(Cr, C), it means that the order of importance for the controllable factors to the Cr, in sequence ,is the factor B , A and C. Similarly, based on the third row, γ(Rq, B)> γ(Rq, C)> γ(Rq, A),the order of importance for the controllable factors to the Rq , in sequence , is the factor B,C and A. Additionally, in the matrix , it also shows that the sequences for the γ(Ra) and the γ(Rq) are similar.

The most influential factors that affect the output variables are determined by identifying the maximum values in each row. Hence, based on the maximum values in the matrix of grey relational grade, it can be found that the factor B, feed rate has the most influence on Ra and Rq with γ values of 0.6812 and 0.5957 respectively. Though feed rate is more influential than other factors but the factor A cutting speed also has a considerable effect on Circularity.

Analysis of Variance

The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence.

Study of ANOVA table for a given analysis helps to determine which of the parameters need control.

Table 10. ANOVA Results for Ra, Cr and Rq

Source	Degree of freedom	Sum of Squares	Mean Squares	F	P	%Contribution
Speed	2	0.9014	0.4507	1.91	0.174	7.408
Feed	2	6.4868	3.2433	13.77	0.01	53.308
Depth of cut	2	0.0696	0.03481	0.15	0.864	0.572
Residual Error	20	4.7106	0.2355			38.811
Total	26	12.1685				100.00

Additionally, Table10 gives the results of the analysis of Variance(ANOVA) for the Ra, Cr and Rq using the calculated values from the grey relational grade of Table 5 and response table of Table 5. According to Table 10, the factor B, the federate with 53.308% of contribution, is the most significant controlled parameters for the CNC boring operations; the cutting speed is with 7.408% contribution and the depth of cut with 0.572%of contribution if the minimization of Ra , Cr and Rq are simultaneously considered.

Confirmation Test Results

Table 11. Optimal parameters and their values

Cutting parameters	Optimal levels	Optimal values
A:cutting speed(m/min)	2	85
B: feed rate(mm/rev)	1	0.05
C: depth of cut(mm)	1	0.4

Table 12 . Results of the confirmation run

Location	Average Roughness(Ra) Value (μm)	Average Roughness(Ra) Value(μm)	RMS Roughness (Rq) value (μm)	RMS Roughness (Rq)Value(μm)	Circularity (mm)
1	1.128		1.400		
2	1.106	1.79	2.462	1.918	0.027
3	1.664		1.637		
4	3.272		2.175		

VI. Conclusion

1. From the Response table of the average grey relational grade, it is found that the largest value of the grey relational grade for the cutting speed of 85 m/min, the feed rate of 0.05 mm/rev, and the depth of cut of 0.4 mm. It is the recommended levels of the controllable parameters of the CNC boring operations as the minimization of the Ra, Cr, and Rq are simultaneously considered.
2. The order of importance for the controllable factors to the minimum Average Roughness(Ra) in sequence of B, C, A for the RMS Roughness(Rq) in sequence of B,C,A, and for the minimum Circularity (Cr) in sequence of B, A, C.
3. During the experimental investigation, it is observed from the table of ANOVA that the percentage contribution to the CNC Boring operation in sequence is the feed rate, the cutting speed and the depth of cut. Hence, the feed rate is the most influential controlled factor among the three CNC Boring operation when the minimization of surface Roughness (Ra), RMS Roughness (Rq) and the Circularity (Cr) are simultaneously considered.
4. The values of Mean Surface Roughness (Ra), RMS Roughness (Rq) and the Circularity (Cr) are found to be less than the values corresponding to the optimal parameter setting after the results of the confirmation run.

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