

Multi-objective Optimization of Machining Parameters in CNC End Milling of Stainless Steel 304

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ABSTRACT: This study investigates the optimization of CNC end milling operation parameters for stainless steel 304 using Taguchi methodology and Grey Relational Analysis approach. Surface Roughness (Ra), Material Removal Rate (MRR) were selected as the quality, productivity target respectively. The experiments were conducted based on Taguchi's L_9 orthogonal array by selecting cutting speed (mm/min), feed rate (mm/rev) and depth of cut (mm) at three levels. The grey relational analysis was used to obtain multi objective relation between the machining parameters and performance characteristics. Response table and graphs were used to find the optimal levels of parameters in CNC end milling process and found to be $V_c2-f1-d3$. The confirmation experiments were carried out to validate the optimal results. Thus, the machining parameters for CNC end milling were optimized for achieving the combined objectives like lower surface roughness and higher rate of material removal rate on Stainless Steel 304 in this work. It has been observed that depth of cut is most significant factor followed by feed and cutting speed.

KEYWORDS: CNC end milling, Optimization, Surface roughness, Material removal rate, Grey relational analysis.

I. INTRODUCTION

As a basic machining process, milling is most commonly used in industries and machine shops today for machining parts to precise size and shapes, which are used to mate with other parts in die, aerospace, automotive and machinery design.[1] Among different types of milling processes, end milling is most important milling operation due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish. Also, it is capable of producing a variety of configurations using milling cutter.[2] Small and medium size industries are manufacturing different parts of main assembly for global industries and consumers.[3] The usage of alloy steel increasing day to day in fields of engineering especially the stainless steel materials for precision components which demands high accuracy, high quality and frequently varying quality requirement.[4] Stainless steel possesses some properties, such as low thermal conductivity and high ductility that make them be classified under materials of poor machinability that exhibit a lot of difficulties during cutting.[5] It has long been recognized that conditions during cutting, such as feed rate(mm/rev), cutting speed(m/min) and depth of cut(mm), should be selected scientifically to optimize the economics of machining operations and to improve productivity.[3] In this paper, stainless steel 304 is taken for the study to determine the machining parameters and to optimize cutting parameters using Taguchi based grey relational analysis to find optimal parameter combination.

V. S. Thanhgarasu et al. [3] optimized the cutting parameters for high speed CNC milling, in which he used Taguchi based Box-Behnken RSM (Response Surface Methodology) to develop prediction formula and Multi Objective Genetic Algorithm (MOGA). Result obtained shows that Ra is more affected by the upward variation of the depth of cut and feed rate than that of the spindle speed but has a significant influence over the responses. Ahmad Humdan et al. [6] described the performance of coated carbide tool using Taguchi methodology when high speed machining of stainless steel considering machining parameters lubrication mode, fee rate, cutting speed and depth of cut. He found 25.5% reduction in cutting forces and 41.3% improvement on the surface roughness performance. Aditya Kulkarni et al. [7]

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worked to establish the relationship with the parameters of CNC turning like cutting speed (m/min), feed (mm/rev), depth of cut (mm), nose radius (mm) and cutting fluid concentration (%) to the response namely power consumption in turning of AISI 1040 steel using Taguchi L_{27} orthogonal array. He has observed that cutting speed is most significant factor followed by depth of cut and cutting fluid concentration on power consumption. Shreemoy Kumar Nayak et al. [8] study aims at investigating the influence of different machining parameters such as cutting speed (V_c), feed (f) and depth of cut (a_p) on different performance measures during dry turning of AISI 304 austenitic stainless steel. ISO P30 grade uncoated cemented carbide inserts was used a cutting tool. He made further attempt to simultaneously optimize the machining parameters using grey relational analysis. The recommended parametric combination based on the studied performance criteria.

II. MATERIAL

The work piece material selected for this study was Stainless Steel 304 which is used for a wide variety of home, commercial and industrial application such as sink, stove, utensils, chemical container, heat exchanger, body part of machines, dyeing industries, architectural paneling, railing. Work piece material is in form of rectangular box having dimensions 30mm x30mm x10mm. Chemical composition is evaluated using Chemical Spectrometry at System Services, Satara. The steel contains both chromium (usually 18%) and nickel (usually 8%) metals as the main non-iron constituents. Stainless steel has higher corrosion resistance and poor thermal conductivity.

Table 1: Chemical composition of stainless steel 304 (%)

C	Mn	Si	P	S	Cr	Ni	N	Fe
0.08 max	2.0	0.75	0.045	0.03	18-20	10.5	0.1	balance

III. METHODOLOGY

Taguchi's method is one of the efficient experimentation technique in improving quality and cutting down cost at same time. In Taguchi's method, quality is measured by deviation of a characteristic from its target value. A loss function is developed for this deviation. Since the elimination of the noise factors is impractical and often impossible, the Taguchi method seeks to minimize the effects of noise and to determine the optimal level of important controllable factors based on concept of robustness. Taguchi method uses a special design of orthogonal array to study the entire parameters space with only a small no of experiments. To determine optimal level of controlled multiple factors simultaneously Grey Relational Analysis method is used. Steps of Grey Relational Analysis are as follow:

Step 1: The first step of grey relational analysis is to normalize (in the range between 0 and 1) the experimental data according to the type of performance response. If the target value of the original sequence is infinite, it has a "the-larger-the-better" characteristic.

$$X_{ij} = \frac{(Y_{ij}) - \min(Y_{ij})}{\max(Y_{ij}) - \min(Y_{ij})} \quad \text{--Eq. 1}$$

If the target value of the original sequence is zero, it has a "the-smaller-the-better" characteristic.

$$X_{ij} = \frac{\max(Y_{ij}) - (Y_{ij})}{\max(Y_{ij}) - \min(Y_{ij})} \quad \text{--Eq. 2}$$

In this present study, surface roughness was to minimize using "the-smaller-the-better" characteristic and material removal rate was to increase using "the-larger-the-better" characteristic. Where X_{ij} and Y_{ij} are the normalized data and observed data, respectively, for i^{th} experiment using j^{th} response. The smallest and largest values of Y_{ij} in the responses are $\min(Y_{ij})$ and $\max(Y_{ij})$, respectively. Larger normalized results mean to the better performance and the best normalized result should be equal to 1. Evaluated values using Eq.1

Step 2: After pre-processing the data, the Grey Relation Coefficient (GRC) for j^{th} the response characteristics in the i^{th} experiment can be expressed as following:

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$$GRC = \frac{\Delta_{min} + \gamma \Delta_{max}}{\Delta_i(k) + \gamma \Delta_{max}}$$

--Eq. 3

where,

- Y_{ij} = denotes reference sequence.
- X_{ij} = denotes the comparability sequence.
- $\Delta_i(k)$ = difference in absolute value between Y_{ij} and X_{ij}
- Δ_{min} = smallest value of Δ_i .
- Δ_{max} = largest value of Δ_i .
- $\gamma = [0,1]$ is the distinguish factor : 0.5 is widely accepted.

Step 3: After calculating GRC, the Grey Relational Grade (GRG) is obtained as:

$$GRG = \frac{1}{m} \sum_{i=1}^m GRC_i$$

--Eq. 4

Here m is the number of responses. The GRC and corresponding GRG for each experiment for milling operation are calculated. The higher value of GRG is near to the product quality for optimum process parameters. The highest grey relational grade is assigned an order of 1 and ranking is done in decreasing order.

IV. EXPERIMENTAL PLAN

Figures The experimentation was carried out at Morya Engineering, Satara on CNC vertical machining center (JYOTI VMC 850) having 12 kW power and maximum spindle speed of 8000 rpm. Figure 1 shows experimental setup for machining stainless steel 304 using end mill cutter. All experimental runs were carried out under wet condition. Maker of the insert selected for experimentation is KYOCERA; carbide insert LOMU 150508 ER-GH with tool holder MEW 1000-W750-15-2T having high cutting speed and long tool life with multi-layer MEGACOAT NANO (CVD) coating. Surface roughness after machining was measured using Mahr Perthometer M2 roughness tester. Roughness measuring principle of tester was based on stylus method having 0.5 mm/sec measuring speed.



Figure 1: Photographic view of experimental setup for machining

The experiments were carried out with controllable 3-level factors and two response variables. The literature survey and KYOCERA catalogue identified the milling parameters and their levels for experiment. Based on Taguchi's design of experiment and orthogonal array L_9 (3^3) total 9 experiments were carried out. For each experimental run three

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replication were performed in order to get more accurate and precise results. Table 2 shows three controlled factors i.e. cutting speed (V_c) (m/min), feed (f) (mm/rev), depth of cut (a_p) (mm) with three levels for each factor.

Table 2: Process parameters and their levels

Sr. No.	Factors	Level 1	Level 2	Level 3
1	Cutting Speed (V_c) (m/min)	60	75	90
2	Feed (f) (mm/rev)	0.15	0.20	0.25
3	Depth of cut (a_p) (mm)	0.50	1.00	1.50

V. EXPERIMENTAL RESULT AND ANALYSIS

All nine experimental runs are tabulated in Table 3 along with input parameters setting. For each run three repetition were performed and respective Ra and MRR were calculated. Later their average was calculated and obtained values of surface roughness and material removal rate is listed in Table 3.

Table 3: Taguchi L_9 Orthogonal Array for experimental runs and results

Run No.	V_c (m/min)	f (mm/rev)	a_p (mm)	Ra (μm)	MRR (cm^3/min)
1.	60	0.15	0.5	0.513	0.211
2.	60	0.20	1.0	0.572	0.758
3.	60	0.25	1.5	0.421	1.183
4.	75	0.15	1.0	0.450	0.562
5.	75	0.20	1.5	0.444	1.438
6.	75	0.25	0.5	0.477	0.658
7.	90	0.15	1.5	0.404	1.207
8.	90	0.20	0.5	0.480	0.519
9.	90	0.25	1.0	0.544	0.951

In order to bring all obtained values of surface roughness and material removal rate in 0 to 1 range, normalization process (step 1) was carried out. The indication of the better performance for material removal rate is “higher the better” whereas it is “lower the better” for surface roughness. Thus to evaluate normalized values of surface roughness and material removal rate Eq. 2 and Eq. 1 is used respectively and are given in Table 4 along with their deviations.

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Table 4: Evaluation of Normalized value and Deviation value for Ra and MRR

Run No.	Ra (μm)	Normalized values for Ra	Deviation values for Ra	MRR (cm^3/min)	Normalized values for MRR	Deviation values for MRR
1.	0.513	0.351	0.649	0.211	0	1
2.	0.572	0	1	0.758	0.446	0.554
3.	0.421	0.898	0.120	1.183	0.792	0.208
4.	0.450	0.726	0.274	0.562	0.286	0.714
5.	0.444	0.761	0.239	1.438	1	0
6.	0.477	0.565	0.435	0.658	0.364	0.636
7.	0.404	1	0	1.207	0.812	0.188
8.	0.480	0.547	0.453	0.519	0.251	0.749
9.	0.544	0.166	0.884	0.951	0.603	0.397

Further, from computed deviations Grey Relational Coefficients are evaluated using Eq. 3 (step 2) for both surface roughness and material removal rate. Grey Relation Grade (GRG) is average of grey relational coefficients of surface roughness and material removal rate as given in Eq. 4 (step 3) which is further ranked in decreasing order to point out best input parameter combination yielding better performance characteristic as shown in Table 5.

Table 5: Evaluation of Grey Relational Coefficient and Grade values along with rank

Run No.	Grey relational coefficient		Grey relational grade	Rank
	Ra	MRR		
1.	0.435	0.333	0.384	9
2.	0.333	0.474	0.403	8
3.	0.830	0.706	0.768	3
4.	0.645	0.411	0.528	4
5.	0.676	1	0.838	2
6.	0.534	0.440	0.487	5
7.	1	0.726	0.863	1
8.	0.524	0.400	0.462	6
9.	0.361	0.557	0.459	7

VI. RESULT DISCUSSION

Table 5 shows the grey relational grade for each experimental run. Higher the grey relational grade better is the product quality. Therefore on the basis of GRG and their rank the factor effects can be estimated and optimal level for each controllable factor can also be determined. The mean of grey relational grade for each level of parameter is summarized and shown in Table 6. The higher value of GRG means comparability sequence has a stronger correlation to the reference sequence.

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Table 6: Response table for Grey Relational Grade

Input factors	Average grey relational grade by factor level			Max-Min	Rank
	Level 1	Level 2	Level 3		
Cutting speed (V_c)	0.518	0.617*	0.594	0.099	2
Feed (f)	0.591*	0.567	0.571	0.024	3
Depth of cut (d)	0.444	0.463	0.823*	0.379	1

Total mean value of grey relational grade = 0.576

* Indicate optimal parameter levels

By using Minitab 15 the Main Effect Plot graph for GRG for the level of processing parameters was plotted in Fig. 2. Basically the larger the grey relational grade, the better is the multiple performance characteristics. In case of speed, as it increases from 60 m/min to 75 m/min also GRG goes up from 0.518 to 0.617 and further GRG reduces to 0.594 as speed increases from 75 m/min to 90 m/min. In case of feed, GRG falls down from 0.591 to 0.567 and further slightly increases to 0.571 as feed changes from 0.15 mm/rev to 0.20 mm/rev and 0.20 mm/rev to 0.25 mm/rev respectively. In case of depth of cut, as depth of cut changes from 0.50 mm to 1.0 mm GRG climbs up from 0.444 to 0.463 which further sharply shifts to 0.823 as depth of cut increases from 1.0 mm to 1.5 mm. Therefore, from Fig. 2 we can conclude that, the optimal process parameters for multi-objective optimization are as follows: Cutting speed at level 2 (75 m/min), feed at level 1 (0.15 mm/rev) and depth of cut at level 3 (1.5 mm) i.e. v2-f1-d3.

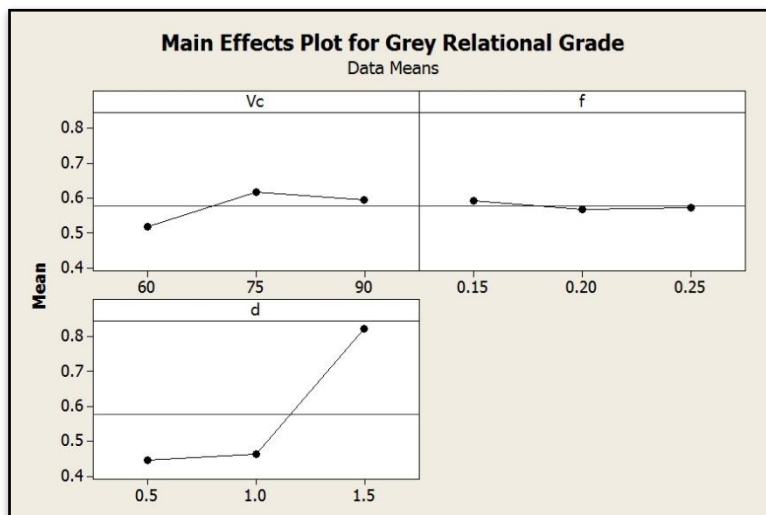


Figure 2: Main Effect Plot for Grey Relational Grade

Interaction plot for Grey Relational Grade was plotted using Minitab 15 as shown in Figure 3. When the effect of one independent factor depends on the level of the other independent factor, we can use an interaction plot to visualize possible interactions. Fig. 3 shows that effect of speed (consider at 70 m/min) changes as feed and depth of cut changes i.e. GRG changes. Parallel lines in an interaction plot indicate no interaction. The greater the difference in slope between the lines, the higher the degree of interaction.

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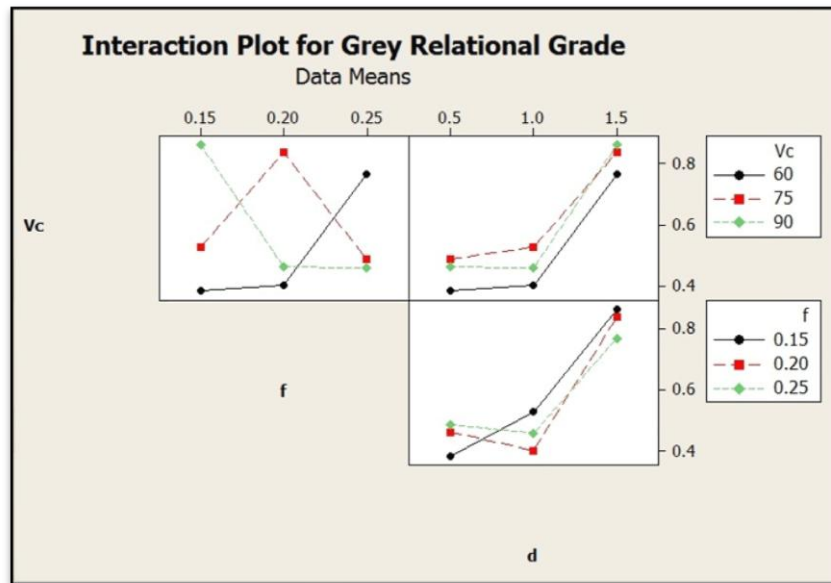


Figure 3: Interaction plot for grey relational grade

Confirmatory Test: A confirmation test has been carried out to verify the improvement of the performance characteristic using the optimal level of machining parameters. Table 8 shows comparison of the initial experimental run result with the validation experimental run result obtained in experiment using the optimal cutting parameters.. Table 8 shows that after optimization of process parameters surface roughness has reduced by 24.86 % and material removal rate has increased by 23.99 %. Thus it can be concluded that the quality characteristic can be improved through this study.

Table 8: Comparison result of initial and validation machining run

	Optimal machining parameters	
	Initial experiment	Optimum experiment
Setting level	V _c 1-f2-d2	V _c 2-f1-d3
Surface Roughness (Ra)	0.572	0.431
Material removal rate (MRR)	0.758	1.103

VII. CONCLUSION

In this study, the effects of cutting speed, feed and depth of cut on surface roughness and material removal rate during end milling of Stainless steel 304 were investigated using Taguchi's experimental design method combined with Grey relational analysis. The following conclusions can be made from performed experimental research:

- Based on Grey Relational Grade analysis, the optimal process parameters for multi-objective optimization are as follows: Cutting speed at level 2 (75 m/min), feed at level 1 (0.15 mm/rev) and depth of cut at level 3 (1.5 mm) i.e. v2-f1-d3.
- Confirmatory test result was satisfactory and has yielded reduction in surface roughness by 24.86 % and increase in material removal rate by 23.99 %. Thus we can observe improvement in performance characteristic.
- It has been established that Taguchi based Grey Relational Analysis is an effective multi-objective optimization tool.

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