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Optimization of Cutting Parameters in End Milling Process using Grey Taguchi Method

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***Abstract:** This study is made to find out the most dominating factor among the controllable parameters in the end milling process. The experiments were performed on aluminium 6061 in the CNC end milling machine. The controllable factors considered are feed rate, depth of cut, cutting speed. The response variables selected are surface finish and material removal rate. Taguchi method is used for optimization with the help of minitab software. Additionally ANOVA is also applied to find out the most contributing factor.*
***Keywords**: ANOVA, Taguchi method, Signal to Noise ratio, DOE*

I. INTRODUCTION

Machining is the process of metal removing from the surface of the job to get the desired size and shape and surface finish. A specialist in machining process is known as machinist. To meet the specifications set out in the engineering drawings or blueprints machining requires attention to many details for a work piece. Attention is needed to achieve correct dimensions on the work piece. The inaccuracies in the desired outcome may be due to the inappropriate fixtures of the workpiece or wrong positioning of the tool. The surface finish can be adjusted according to the requirements by compromising with the cutting speed. In machining is any process in which a cutting tool is used to remove small chips of material from the work piece. The removal of material is due to the action of the cutting edge on the work surface. The size of the chip varies according to the selected parameter for cutting. Heat generated during machining is taken care off by the help of the proper coolant.

A. Grey Based Taguchi Method

The integrated grey based Taguchi method combines the algorithm of Taguchi method and grey relational analysis to determine the optimum process parameters for multiple responses. The concept of the Taguchi method is that the parameters design is performed to reduce the sources of variation on the quality characteristics of product, and reach a target of process robustness. It utilizes the orthogonal arrays from experimental design theory to study a large number of variables with a small number of experiments. The experiments are conducted based on orthogonal arrays, which provide a set of well balanced (minimum) experiments. Taguchi's Signal to Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. The standard S/N ratios generally used are Nominal-is-Best (NB), Lower-is-Better (LB) and Higher-is-Better (HB). The optimal setting is the parameter combination which has the highest S/N ratio. The objectives of the present work are lower surface roughness (SR) and higher material removal rate (MRR), hence the S/N ratio for surface roughness is lower is better (LB) and for MRR is higher is better (HB).

S/N ratio for SR = $-10\log_{10}$ [mean of sum of squares of measured data]

S/N ratio for MRR = $-10\log_{10}$ [mean of sum squares of reciprocal of measured data]

B. Grey Relational Analysis

The grey relation analysis is used to convert the multiple response optimization problems into a single response optimization problem. In the present work the objectives are to obtain lower surface roughness and higher MRR, the grey relation analysis convert this multi-objective problem into single objective problem by using overall grey relation grade. The optimal parametric combination is then evaluated by maximising the overall grey relational grade. The overall grey relation grade is an average of grey relational coefficients of each selected response. The grey relational coefficient represents the correlation between the desired and actual experimental data. The grey relational coefficient is calculated based on experimental results of each selected response. In calculating the grey relational coefficient first the experimental data i.e. the quality characteristics of surface roughness and material removal rate are normalized ranging from zero to one, this process is known as grey relational generation. The experimental data for each quality characteristic is converted into S/N ratio. These S/N ratios for each quality characteristics are normalized using the following grey relational generation equations

The normalized data corresponding to lower-the-better (LB) criterion can be expressed as:

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

The normalized data corresponding to higher-the-better (HB) criterion can be expressed as:

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

Where,

i = 1, 2, 3,...... m, m = number of experimental runs in Taguchi orthogonal array, in the present work L9 orthogonal array is selected then m = 9. k = 1, 2,..... n, n = number of quality characteristics or process responses, in the present work surface roughness and material removal rate are selected, then n = 2. y_i (k) is the S/N ratio based on the experimental data. Min y_i (k) is the smallest value of y_i (k) for the k^{th} response. max y_i (k) is the largest value of y_i (k) for the k^{th} response. x_i (k) is normalized S/N ratios.

Based on the normalized S/N ratios of the experimental data the grey relation coefficient can be calculated using the following equation:

The grey relational coefficient,

$$\xi_i(k) = \frac{\Delta_{min} + \psi\Delta_{max}}{\Delta_{oi}(k) + \psi\Delta_{max}}$$

The grey relation coefficient values are used to find the grey relation grade. The grey grade for each experimental run can be obtained by accumulation the grey relation coefficient of each quality characteristic. The average grey grade for the i^{th} experimental run for all n responses is given by

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$$

Where,

i = 1,2,3 ... 9, [L9 orthogonal array is selected]

$\xi_i(k)$ is the grey relational coefficient of k^{th} response in i^{th} experiment

n = Number of responses.

Where $\Delta_{oi} = \| x_0(k) - x_i(k) \|$ is difference of absolute value x_0(k) and x_i(k).

X_0(k) is reference sequence k^{th} quality characteristics.

ψ is distinguishing coefficient lies between 0 to 1.

Δ_{min} = smallest value of $\Delta_{oi} = \forall j^{min} \in i\ \forall k^{min} \|x_0(k) - x_i(k)\|$

Δ_{max} = largest value of $\Delta_{oi} = \forall j^{max} \in i\ \forall k^{max} \|x_0(k) - x_i(k)\|$

The higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

Metal used for carrying out the experiment is Aluminium 6061. Some of the physical and chemical properties of AL 6061is listed in the table below.

Table 1. Typical properties of AL6061

Properties	Metric
Density	2.67 g/cm^3
Melting point	588 ^{o}C
Co-efficient of thermal expansion	23.4 ($10^{-6}/^0$C)
Yield strength	48 MPa
Shear strength	83 MPa
Elastic modulus	70-80 GPa
Fatigue strength	62 MPa
Poisons ratio	0.33
Elongation	25%
Rockwell Hardness number	60

II. LITERATURE REVIEW

Abhishek Kumbhar et al. [1] were carried out "Multi-objective Optimization of Machining Parameters in CNC End Milling of Stainless Steel 304". They described that the effects of cutting speed, feed rate and depth of cut on surface roughness and material removal rate during end milling of Stainless steel 304 were investigated utilizing Taguchi's experimental design method coalesced with Grey relational analysis. The conclusions can be made from performed experimental research that 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 rate 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 copacetic and has yielded reduction in surface roughness by 24.86 % and increment in material removal rate by 23.99 %. Thus we can observe amendment in performance characteristic. It has been established that Taguchi predicated Grey Relational Analysis is an efficacious multi-objective optimization implement..

Jatin and Sharma [2] studied effect of machining parameters on output characteristics of CNC milling using Taguchi optimisation technique. The effect of different machining parameters such as cutting speed, feed and depth of cut on surface roughness in end milling has been studied. The L9 orthogonal array has been selected for experimentation. The study shows that feed rate and cutting speed are most dominant factor than the depth of cut for surface finish. High cutting speed and low feeds gives best surface finish; depth of cut should be low but not so low that it will lead to vibration of tool.

Prajina et. al [3] carried out multi response optimization of CNC end milling using response surface methodology and desirability function. In this work, second-order quadratic models were developed for cutting forces, surface roughness and machining time; considering the spindle speed, feed rate, and depth of cut and immersion angle as the cutting parameters using central composite design. It is found that feed has significant effect on cutting force and it has to be kept minimum for least force and better surface finish and machining time. Cutting speed has significant effect on machining time and surface roughness. Speed has to be kept maximum for combined optimization of forces, roughness and machining time. With less power good surface finish is obtained at minimum time if cutting speed is kept maximum and depth of cut minimum.

Shelar and Shaikh [4] carried out CNC milling operation AISI 316 stainless steel. In this work three levels and three parameters are considered; and L27 orthogonal array was carried out by using two different insert coatings. For the experimentation the wet conditions is taken. The machining parameters such as cutting speed (m/min), feed rate (mm/min),depth of cut (mm) and responsive output parameters such as Surface Roughness, material removal rate, dimensional accuracy and flatness was selected.

Lohithaksha M Maiyar, et al [5] "this study investigated the parameter optimization of end milling operation for Inconel 718 super alloy with multi-replication criteria predicated on the Taguchi orthogonal array with the grey relational analysis. Nine experimental runs predicated on an L9 orthogonal array of Taguchi method were performed. Cutting celerity, victual rate and depth of cut are optimized with considerations of multiple performance characteristics namely surface roughness and material abstraction rate. A grey relational grade obtained from the grey relational analysis is utilized to solve the terminus milling process with the multiple performance characteristics. the analysis of variance (ANOVA) is additionally applied to identify the most paramount factor. Conclusively, substantiation tests were performed to make a comparison between the experimental results and developed model. Experimental results have shown that machining performance in the cessation milling process can be ameliorated efficaciously through this approach. It has been established that grey relational analysis is an efficacious optimization implement for machining of Inconel 718 alloy in end milling. It has been found that the optimal cutting parameters for the machining process lies at 75m/min for cutting velocity, 0.06 mm/tooth for aliment rate and 0.4 mm for depth of cut. Further it has been observed that there is a 64.8% increase in material abstraction rate and at the same time a 9.52% decrease in surface roughness. This inspirits applying the grey concept for optimizing multi replication processing with multiple factors. Analysis of variance shows that the cutting velocity is the most consequential machining parameter followed by aliment rate affecting the multiple performance characteristics with 56.88% and 34.64% influence respectively.

Harshraj D. Wathore P, P. S. Adwani [18] "this paper presents the study of the parameter optimization of end milling operation for H13 die steel with multi response criteria based on the Taguchi L9orthogonal array with the grey relational analysis. Surface roughness and material removal rate are optimized with consideration of performance characteristics namely cutting speed, feed rate and depth of cut. A grey relational grade obtained from the grey relational analysis is be used to solve the end milling process with the multiple performance characteristics. Additionally, the analysis of variance (ANOVA) is to be applied to identify the most significant factor. The important conclusions drawn from the present work are summarized as Multi-response problem was successfully converted into single response problem i.e. grey grade successfully which helped in optimization of both parameters simultaneously. The optimal cutting parameters for the machining process lies at 2500 rpm for cutting speed, 0.3 mm/revolution for feed rate and 1.2mm for depth of cut.

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Analysis of variance shows that depth of cut is the most significant machining parameter followed by cutting speed, affecting selected response characteristics i.e. surface roughness and material removal rate, with 60.11% and 30.40% influence respectively. Taguchi grey relational analysis does not involve any complicated mathematical theory or computation and thus can be employed by the engineers without a strong statistical background.

Sanjeev Kumar pal, Rahul Davis[19] “the present work prosperously demonstrated the application of Grey relational analysis for optimization of process parameters in end milling of the two materials as Al 6061 and Al 6463 (aluminium alloys). The conclusions can be drawn from the present work were as the highest Grey relational grade of 1.0 was observed for the experimental Process, shown in replication Table.

The average Grey relational grade, which be tokens the coalescence of control factors. The order of paramount for the controllable factors to the minimum surface roughness, in sequence, is the aliment rate and depth of cut. However, it is observed through ANOVA that the spindle haste is the most influential control factor among the four end milling process parameters investigated in the present work, when minimization of surface roughness is considered.

Shreemoy Kumar Nayak et al.[21].The investigation was carried out the effect of machining parameters during dry turning of AISI 304 austenitic stainless steel. For this study HMT heavy duty lathe machine was used. They have adopted L27 orthogonal array with three machining parameters like cutting speed, feed rate and depth of cut and three importance characteristics of machinability such as material removal rate (MRR), cutting force and surface roughness (Ra) were measured. For the optimization of machining parameters, Grey relational analysis was used

Ghhani J. A. et al. [22] optimized cutting parameters in end milling process while machining hardened steel AISI H13 with Tin coated P10 carbide insert tool under semi finishing and finishing conditions of high speed cutting. The effect of milling parameters such as cutting speed, feed rate and depth of cut along with their interactions on the process is studied using Taguchi method of experimental design (DOE).The study indicated the suitability of Taguchi method to solve the stated problem with minimum number of trials as compared with a full factorial design.

III. OBJECTIVE

The objective of the research is to analyze effects of signal variables on response variables. The detailed points are

A. To maximize the material removal rate so that productivity can be increased.
B. To minimize the surface roughness.
C. To find out the most influential variable out of cutting speed, feed rate, depth of cut.
D. To find out the correct combination of cutting speed, feed rate and depth of cut.
E. To analyse the percentage contribution of each input parameter on the results of output parameter

IV. EXPERIMENTAL DETAILS

To reach the above objective, we use DOE to prepare orthogonal array. Now using this set of data, we perform the experiments in CNC machine.

Table 2
Process parameters and their levels.

Process parameters	Units	Levels		
		1	2	3
Cutting speed (A)	m/min	120	235	380
Feed rate (B)	mm/min	0.08	0.14	0.20
Depth of cut (C)	mm	1	3	6

With the help of above table L9 orthogonal array is prepared. It is done by making different combination of cutting speed, feed rate and depth of cut. Although, 27 such combinations can be made with the help of 3 input parameters but here we are considering only 9 combinations.

Table .3
Experimental design using L9 orthogonal array and their responses.

Exp. No.	A	B	C	Surface Roughness, SR (μm)	Material Removal Rate, MRR(mm3/sec)
1	1	1	1	1.35	36.68
2	1	1	2	2.4	192.6
3	1	1	3	3.1	550.31
4	1	2	1	2.45	215.53
5	1	2	2	3.15	754.39
6	1	2	3	1.4	179.61
7	1	3	1	3.2	697.06
8	1	3	2	1.45	203.31
9	1	3	3	2.7	871.33

Initially signal to response ratios are computed for MRR on higher the better criterion and surface roughness is calculated on lower the better criterion. Now the normalized values of signal to noise ratio is calculated on the basis of formula discussed above. Similarly deviation sequence, grey relational coefficient, grey relational grade is calculated.

Table 4
Grey Relational Grade

Exp. No.	S/N ratio		Normalised ratios values of S/N		Grey relational coefficient		Grey Relational grade
	SR	MRR	SR	MRR	SR	MRR	
1	-2.606	-31.2886	0	0	0.3333	0.3333	0.333
2	-7.604	-45.6931	0.6666	0.5235	0.6	0.5120	0.5560
3	-9.8272	-54.8121	0.9632	0.8549	0.9314	0.7751	0.8533
4	-7.783	-46.6702	0.6905	0.5590	0.6177	0.5313	0.5745
5	-9.9662	-57.5519	0.9817	0.9545	0.9648	0.9166	0.9407
6	-2.9225	-45.0866	0.0421	0.5014	0.343	0.5007	0.4218
7	-10.1029	-56.8654	1	0.9295	1	0.8765	0.9382
8	-3.227	-46.1632	0.0828	0.5405	0.3528	0.5211	0.437
9	-8.6272	-58.8037	0.8031	1	0.7175	1	0.858

From the above table we can see that our multiobjective optimization has been reduced to single objective optimization. Thus we can apply Taguchi method on grey relational grade obtained from above table. Here we are applying Taguchi method with the help of Minitab 19 software. Taguchi method is applied on the basis of higher the better criterion on the grey relational grade obtained from grey relational analysis.

V. RESULT

Table5. Response table (mean) for overall grey relational grade.

Level	Cutting speed	Feed Rate	Depth of Cut
1	0.5156	0..5363	0.6575
2	0.5485	0.5428	0.5169
3	0.5363	0.6071	0.5117
Delta	0.1065	0.0708	0.1458
Rank	2	3	1

From the above table, we can affirm that DOC has maximum influence on MMR an d SR.

To find out the exact contribution of each parameter on the output we apply ANOVA. It is applied with the help of Minitab 19 software.

Table 6. Results of the ANOVA

Source	DoF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
Cutting speed	2	0.04082	8.79%	0.04082	0.02041	3.03
Feed rate	2	0.01451	3.12%	0.01451	0.00725	1.08
Depth of cut	2	0.39547	85.18%	0.39547	0.19773	29.32
Error	2	0.01349	2.90%	0.01349	0.00674	
Total	8	0.46428	100.00%			

VI. CONCLUSION

From the experiments performed above we found that the depth of cut has the maximum influence on the MRR and SR By applying the grey relational grade we found that combination 5 is the best combination for the minimizing surface roughness and maximizing MRR. The results of ANOVA are presented in Table 6 from ANOVA, it is clear that depth of cut (85.18%) influences more on milling of Aluminium 6061 followed by cutting speed (8.79%) and feed rate (3.12%).

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