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A Hybrid Approach for Simulataneous Optimization of Process Parameters in Machining Aluminium Alloys

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Abstract
This paper presents the application of Taguchi method with logical fuzzy reasoning for multiple output optimization of CNC end milling process of Aluminium7075-T6. The machining parameters (cutting speed, feed rate, depth of cut) are optimized with considerations of the multiple performance measures (surface roughness, material removal rate).The Signal to Noise ratios calculated using Taguchi optimization were used in Fuzzy logic approach which determines the Comprehensive output measure for each combination. The result analysis shows that cutting speed of 8000 rpm, feed rate of 1050 mm/min and 1mm of depth of cut are the most favorable cutting parameters for high speed CNC end milling process.

Keywords: comprehensive output measure (COM), high speed CNC end milling, material removal rate, Taguchi-fuzzy hybrid approach, surface roughness

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INTRODUCTION
The manufacturing arena today requires the use of optimum resources in any machining operation to effectively meet the quality and productivity of the product. In true quality sense, a customer usually considers several correlated quality characteristics of a product. Accordingly, variability of a product's response has to be reduced and man needs to be brought close to the target.

This paper presents the simultaneous optimization technique of blending fuzzy logic with the Taguchi method to simultaneously upgrade the machining parameters in CNC end milling process. High machining rate gives poor surface finish. Low machining rate provides better surface finish but results in very poor material removal rate (MRR). Accomplishing higher material evacuation rate alongside better surface finish is considered as a multi-target optimization problem. Taguchi optimization method is sent to upgrade single performance attributes. Subsequently Taguchi methodology is coordinated with fuzzy logic to improve multiple output parameters all the while. [1]

Taguchi optimization manages to improve single performance characteristic. The meaning of performance attributes in Taguchi optimization varies for example, lower-the-better, higher-the-better and nominal-the-better which contains some degree of uncertainty and vagueness. The class of every performance characteristic may not be same. The engineering unit for depicting each performance attribute might be distinctive and the significance of each performance characteristic might differ. The fuzzy logic is ended up being valuable in handling dubious and indeterminate data. In this study, a fuzzy optimization of various performance characteristics has been created in light of fuzzy logic which transforms optimization of different performance characteristic into improvement of a solitary performance characteristic. [2]

OPTIMIZATION OF MULTIPLE PERFORMANCE CHARACTERISTICS WITH FUZZY LOGIC

Taguchi's method utilizes orthogonal exhibit designs to study the whole parameter space with just a small series of investigations where test results are changed into a signal-to-noise ratio. This Signal to Noise proportion measures the deviation of the performance characteristics from the mean value. It is divided into 3 types – the lower-the-better, the higher-the better, and the nominal-the-best. Notwithstanding the type of the performance characteristic, a larger Signal to Noise ratio represents better performance attribute. By this idea, the optimal level of each process parameters can be resolved. A statistical analysis of variance (ANOVA) is applied to decide the commitment of every parameter to the performance characteristic. An affirmation test is directed to confirm the experimental results acquired. [3]

Taguchi method is used for the optimization of a single performance output as it involves achieving of a trade-off between several multiple conflicting problems and variables. For example: the category of each performance characteristic may not be same; the engineering unit for describing each performance characteristic may be different; and the importance of each performance characteristic may vary. The Taguchi technique is not a straightforward approach to optimize multiple performances characteristic. In this study, the fuzzy logic optimization technique is used to optimize the process parameters simultaneously for better surface roughness and material removal rate. Initially, fuzzy rules are derived based on the performance requirement of the process. The Signal to noise ratio of each performance characteristic calculated from Taguchi technique is fuzzified and then converted into single measure (COM) through fuzzy reasoning based on the defined fuzzy rules.

CNC END MILLING PROCESS

Milling operation removes material by relative motion between rotary tool with one or multiple cutting edges and a stationary workpiece.

There are three important input parameters of milling operation – speed, feed rate, depth of cut.

The feed is provided in the direction normal to the axis of rotation of tool and depth of cut is given along the direction of axis rotation of tool. Speed indicates the rotational speed of the tool.

These three parameters predominantly influence the performance characteristics of the milling operation.

Hence, it is necessary to optimize these parameters to improve the performance characteristics. [4–8]

Process Parameters

The process parameters chosen for the present work are shown in Table 1.

Table 1. *Machining Parameters and Their Levels.*

Process parameters	Level 1	Level 2	Level 3
Speed (rpm)	4000	6000	8000
Feed (mm/min)	520	1050	1760
Depth of cut (mm)	0.5	0.75	1

Fig. 1. *Vertical Milling Machine.*

Work Material

The work material selected for the study was Aluminium7075-T6 which is used extensively Aircraft bearing components, rocket, propeller, airframes. The chemical composition of this material is 5.6–6.1% zinc, 2.1–2.5% magnesium, 1.2–1.6% copper and less than 0.5% silicon, iron, manganese, titanium, chromium, and other metals. No heat treatment is carried out.

Tool Insert Details

Inserts are removable cutting tips which are not brazed or welded to the tool body The insert material selected for machining Aluminium7075-T6 was APMT 1135 PDTR LT 30. The specification details of insert material used are as follows:

A – SHAPE (80^o Diamond); P - Clearance angle (11^o); M – Tolerance; T – Insert type (Screw down clamping; No chip breaker); 11 – Length; 35 – Thickness (3.5 mm); PDTR – PVD Coating; LT-30 Multi-Material machining.

Experimental Setup

The experimental setup was carried out at Tool and Die center, PSG Industrial Institute, Coimbatore on a Makino vertical machining centre S33 Machine as shown in Figure 1. Aluminium7075-T6 bar (Length: 740 mm, Width: 53 mm, Height: 20 mm) is used for the experimentation. [9]

Machining Performance Evaluating Factors

The performance attributes considered for assessment are Surface completion and Material removal rate. A surface roughness analyzer is utilized to decide the average roughness values for the sample length.

This device when it makes contact on a surface, measures the Ra value in microns. The material removal rate is calculated so as to utilize Volume of Material removed and divided by milling time.

OPTIMIZATION OF CNC END MILLING PARAMETERS

The Taguchi optimization methodology is coupled with fuzzy logic method to improve the process parameters all in while.

Orthogonal Array Experiment

L27 orthogonal array of Taguchi technique has been utilized for conducting the experiments and is shown in Table 2

Table 2. *Experimental Layout Using an L27 Orthogonal Array.*

Test run	Speed (RPM)	Feed (mm/min)	Depth of cut (mm)	Surface roughness (μm)	S/N ratio for surface roughness	Material removal rate (mm^3/min)	S/N ratio for material removal rate	Comprehensive output measure
1	4000	520	0.500	0.275	11.202	3625.441	71.187	0.426
2	4000	520	0.500	0.340	9.369	3623.738	71.183	0.387
3	4000	520	0.500	0.347	9.196	3625.082	71.186	0.383
4	4000	1050	0.750	0.877	1.117	10978.680	80.811	0.453

5	4000	1050	0.750	0.883	1.077	10976.740	80.809	0.444
6	4000	1050	0.750	0.812	1.810	10978.800	80.811	0.469
7	4000	1760	1.000	1.730	-4.766	24546.110	87.800	0.502
8	4000	1760	1.000	1.622	-4.225	24530.870	87.794	0.519
9	4000	1760	1.000	1.750	-4.863	24536.360	87.796	0.497
10	6000	520	0.750	0.323	9.610	5435.643	74.705	0.496
11	6000	520	0.750	0.268	11.372	5435.747	74.705	0.530
12	6000	520	0.750	0.290	10.721	5434.851	74.704	0.516
13	6000	1050	1.000	0.460	6.727	14636.730	83.309	0.697
14	6000	1050	1.000	0.502	5.973	14642.320	83.312	0.619
15	6000	1050	1.000	0.528	5.541	14635.690	83.308	0.617
16	6000	1760	0.500	0.935	0.584	12271.270	81.778	0.472
17	6000	1760	0.500	0.925	0.677	12270.620	81.777	0.474
18	6000	1760	0.500	0.875	1.155	12273.710	81.780	0.483
19	8000	520	1.000	0.235	12.523	7248.610	77.205	0.612
20	8000	520	1.000	0.217	13.244	7252.432	77.210	0.639
21	8000	520	1.000	0.222	13.086	7248.372	77.205	0.633
22	8000	1050	0.500	0.408	7.741	7253.714	77.209	0.514
23	8000	1050	0.500	0.408	7.761	7323.982	77.295	0.517
24	8000	1050	0.500	0.357	8.931	7322.555	77.293	0.539
25	8000	1760	0.750	0.770	2.269	18428.090	85.310	0.580
26	8000	1760	0.750	0.715	2.912	18402.800	85.298	0.600
27	8000	1760	0.750	0.582	4.696	18404.540	85.299	0.662

Signal-to-Noise Ratio

Taguchi's Signal to Noise ratio decides the deviation between experimental value and desired value. To get optimal machining performance, the minimum Surface Roughness is required in this way lower the-better characteristic is picked.

For "lower the better" type of machining quality characteristic, the S/N proportion is given by

$$S/N\ Ratio = -10*Log\left[1/n*(y_1^2+y_2^2+\ldots+y_n^2)\right] \quad Eq. (1)$$

Where $y_1, y_2, \ldots, y_n$ are the responses of the SR taken for a trial condition repeated n times. The S/N ratios were computed using Eq. (1) for each of the 27 trials.

For "higher the better" type of machining quality characteristic, the S/N ratio is given by

$$S/N\ Ratio = -10*Log\left[1/n*(1/y_1^2+1/y_2^2+\ldots+1/y_n^2)\right] \quad Eq. (2)$$

Where, $y_1, y_2, \ldots, y_n$ are the responses of the MRR taken for a trial condition repeated n times. The S/N ratios were computed using Eq. (2) for each of the 27 trials.

Table 2 shows that the surface roughness, and material removal rate and their Signal to Noise ratio for each combination of parameters. The Signal to Noise ratios of Surface roughness and material removal rate are used in fuzzy logic to optimize and identify the bets levels of parameters that provides better surface roughness and better material removal rate.[2, 5]

Single Characteristic Optimization

Taguchi optimization method can be used to obtain the optimal level of process parameters for single performance characteristics. The technique used in Taguchi optimization is a signal to noise ratio will be calculated for each combination of parameters based on the performance characteristic. A low value of surface roughness is always preferred. Hence, lower the better loss function is selected. In case of material removal rate, a high value will be always preferred. So, Higher the better loss function is selected for material removal rate. The levels having highest average of signal to noise ratio for each parameter is considered to be the optimum level for respective parameters. The Signal to Noise ratios of surface roughness and material removal rate was calculated, as shown in Table 2.

The statistical analysis of variance shows the response of Signal to Noise ratio over the three factors shown in Table 3. It can be inferred that the surface roughness values are influenced by three factors- speed, feed rate and depth of cut. The surface-finish is maximum at S3, F1 and D1, respectively. As a result, the factor/level combination S3F1D1 was recommended. The results of ANOVA for the S/N ratios of surface roughness are also shown in Table 3. [9]

It can be seen that the contribution of feed to the surface roughness was the largest (74.60%) followed by Speed (20.60%). Thus, feed rate was most important factor followed by cutting speed as far as surface roughness is concerned. The same analysis procedure can also be applied to optimize the CNC end milling conditions for the material removal rate.

The levels that gave the largest average response were S-1, F-3, D-3 for the material removal rate. A combined analysis of both ANOVAs showed that the optimal factor/level combination, or the most important factor, for one quality was usually different from that for another quality. In such a case, an engineering judgement that refers to past experience is the only real guarantee of correct decision-making in the CNC end milling process.

Table 3. *The Response Table and ANOVA of S/N Ratios of Surface Roughness.*

Variable	Level			DOF	Sum of Squares	Mean sum of squares	F-value	Percentage contribution (%)
	1	2	3					
Speed	2.212	5.817	8.129	2	160	80.00	6.35	20.6
Feed	11.146	5.186	-0.173	2	577.22	288.61	22.92	74.6
Depth of cut	6.29	5.065	4.804	2	11.3	5.70	0.452	1.46
Error				2	25.18	12.59		3.34
Total				8	773.7	96.70		100

Fuzzy Logic Implementation and Results for Multiple Responses in CNC End Milling Process

A fuzzy logic unit (FLU) includes a fuzzifier, membership functions, a fuzzy rule base, a derivation framework, and a defuzzifier. In the first place, the fuzzifier utilizes membership functions to fuzzify the S/N ratios. Next, the derivation framework performs a fuzzy reasoning on fuzzy tenets to produce a fuzzy value. The defuzzifier changes the fuzzified values into a Comprehensive Output Measure.

In this study, fuzzy logic is conveyed in view of the two-input–one-yield fuzzy logic unit. The fuzzy rule base comprises of a group of if–then control rules with two inputs, Surface Roughness (SR) and Material Removal Rate (MRR), and one yield Comprehensive Output Measure (COM), i.e., If SR is low and MRR is low, then COM is Very Low. [4]

- If SR is low and MRR is middle, then COM is low.
- If SR is low and MRR is high, then COM is middle.
- If SR is middle and MRR is low, then COM is low.
- If SR is middle and MRR is middle, then COM is middle.
- If SR is middle and MRR is high, then COM is high.
- If SR is high and MRR is low, then COM is middle.
- If SR is high and MRR is middle, then COM is high.
- If SR is high and MRR is high, then COM is very high.

In this work, three fuzzy subsets (low set, middle set, high set) are assigned in the two inputs (surface roughness, material removal rate) as shown in Figures 2 and 3 and five subsets (very low set, low set, middle set, high set, very high set) are assigned in the output as shown in Figure 4.

By taking the max-min compositional operation, the fuzzy reasoning of these yields a fuzzy output. The membership function of the output of fuzzy reasoning can be expressed as

$$\mu_{C0}(y)=(\mu_{A1}(x_1)\wedge\mu_{B1}(x_2)\wedge\mu_{C1}(y))\vee..(\mu_{An}(x_1)\wedge\mu_{Bn}(x_2)\wedge\mu_{Cn}(y)) \quad \text{Eq. (3)}$$

Where Λ is the minimum operation and V is the maximum operation. Centroid defuzzification method is used to defuzzify the output values into Comprehensive Output Measure (COM).

$$Y_0=\Sigma y\mu_{c0}(y)/\Sigma\mu_{c0}(y) \quad \text{Eq. (4)}$$

The design of experiments is orthogonal.

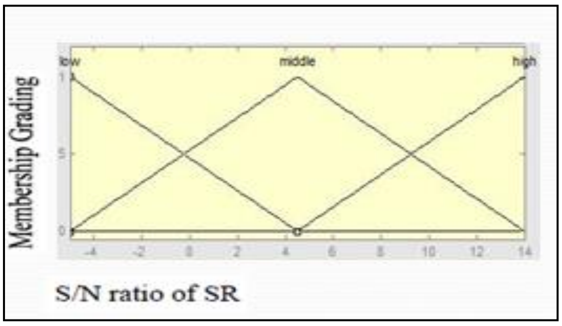

Fig. 2. *Membership Functions for SR.*

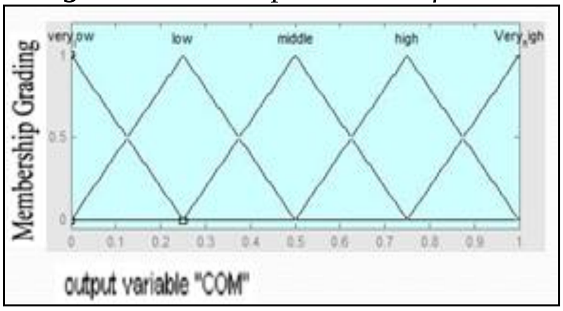

Fig. 3. *Membership Functions for MRR.*

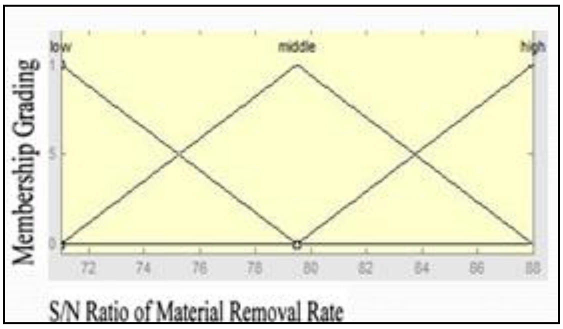

Fig. 4. *Membership Functions for COM.*

Table 4. *Comprehensive Output Measure Table.*

Parameter	Comprehensive output measure(COM)		
	Level 1	**Level 2**	**Level 3**
Speed (rpm)	0.453	0.545	0.588
Feed(mm/min)	0.514	0.541	0.532
Depth of Cut (mm)	0.466	0.527	0.593

So it is possible to infer the effect of each level of parameters separately. The mean of the Comprehensive Output Measure for each parameters of levels 1, 2 and 3 are calculated by taking average of Comprehensive Output Measures of experiments having corresponding levels (Table 3).The mean of the Comprehensive Output Measure for each level of the machining parameters is summarized and called the Comprehensive Output Measure table (Table 4).

Analysis of Variance (ANOVA) of COM

The statistical analysis of variance ANOVA is used to determine the percentage contribution of each input parameter to the performance characteristics. This is accomplished separating the variation from the comprehensive output measure values, which is measured by the sum of the squared deviations from the total mean of the COM, into contributions by each of the process parameter and the error. The total sum of the squared deviations SST from the total mean of the COM is calculated. The total sum of the squared deviations SST is decayed into two sources: the total of the squared standard deviations SSd because of every procedure parameter and the whole of the squared error SSe. The percentage contribution by each of the process parameter in the total of squared deviations SST can be utilized to assess the significance of each process parameter that impacts the performance characteristics.

The change of the process parameter significantly affects the performance attributes when the F-value is large. The p-values were computed to decide the noteworthy parameters that impact the surface roughness and material removal rate.

Table 5. *The Response Table and ANOVA S/N Ratios of Comprehensive Output Measure (COM).*

Variable	Level 1	Level 2	Level 3	DOF	Sum of squares	Mean sum of squares	F-value	Percentage contribution (%)
Speed	0.453	0.544	0.588	2	0.0856	0.0428	4.65	47.6
Feed	0.513	0.541	0.532	2	0.0035	0.0017	0.1847	1.94
Depth of Cut	0.466	0.527	0.592	2	0.0722	0.0361	3.92	40.1
Error				2	0.0185	0.0092		10.36
Total				8	0.1798	0.0224		100

The results of ANOVA for COM (Table 5) indicate that speed is the most significant machining parameter in affecting the multiple performance characteristics followed by depth of cut. Based on the above discussion, the optimal machining parameters are the cutting speed at level 3 (S = 8000 rpm), feed rate at level 2 (F = 1050 mm/min), depth of cut at level 3 (D = 1 mm) or S-3, F-2, D-3 in short.

CONCLUSION

The hybrid Taguchi-fuzzy approach is used in this study to optimize the end milling conditions of AI7075-T6. The surface finish depends on the number of factors like speed, feed, depth of cut, etc. So, these factors have to be controlled efficiently for a good surface finish. The most important performance characteristics of any machining operation are surface finish and material evacuation rate. Surface finish and Material removal rate are conflicting phenomenon. Increase in Material removal rate decreases the surface completion. Fuzzy integrated with Taguchi optimization technique can be applied to optimize the process parameters simultaneously for better surface finish and Material removal rate. Based on the experimental results the conclusion can be drawn as follows:

- The most important factors affecting the End milling process have been identified as speed and depth of cut.

- The factors that yield the best combination of process variables: Speed – level 3 (8000 rpm), Feed – level 2 (1050 mm/min), Depth of cut – level 3 (1 mm).
- The contribution to output of each factors are; cutting speed - 47.60%, Depth of cut – 40.10% and Feed – 1.94%.

It can be concluded that the hybrid optimization technique developed in this study can be used to optimize process parameters simultaneously for multiple performance characteristics in machining of aluminum alloys.

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