Optimisation of Cutting Parameters to obtain the Optimum Surface Roughness and Metal Removal Rate in CNC End Milling using TOPSIS based Taguchi Method

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Abstract- CNC Milling is the most common and versatile technology among different machining processes, characterized by an extensive range of metal cutting capacity that places it in a central role in the manufacturing industries. This research is to obtain the optimum parameters to get minimum surface roughness and maximum metal removal rate in CNC end milling simultaneously by multi response optimization using TOPSIS based Taguchi' s method. Data is collected from CNC milling machine which is run by different samples of experiments. The input of the model consists of feed rate, cutting speed and depth of cut while the output of the model is surface roughness and metal removal rate. Design of experiments for conducting to measure surface roughness and metal removal rate was determined by Taguchi experimental design method. Orthogonal arrays of Taguchi, signal-to-noise ratio and analysis of variance are employed to find the optimum parameters to minimizing the surface roughness and metal removal rate using MINITAB-17 software. Analysis has been done and results were predicted and percentage of error has been calculated. Percentage of contribution for each parameter was obtained by Analysis of Variance.

Keywords – Taguchi, TOPSIS, ANOVA, CNC End Milling, optimization, surface roughness, metal removal rate.

I. Introduction

The Computer Numerical Control (CNC) machine refers to the automation of machine tools to produce the good quality of work pieces. The production of low cost and good quality of work pieces compose of various factors. The research study found that the parameters are the main factors of lathing to get the job done. Meanwhile it is the factor of fixing the output parameters (surface finish and metal removal rate). If the selection of parameters is not correct, it will cause the low quality production. This will cause the impact of cost of production which could not compete to market effectively. Even though the machine tool industry in India has made tremendous progress, the metal cutting industries continue to suffer from a major drawback of not running the machine tools at their optimal operating condition. The problem of arriving at the optimum levels of the process parameters has attracted the attention of the researchers and practicing engineers for a very long time. In order to get the optimum parameters (cutting speed, feed rate, depth of cut), a large number of tests are needed requiring a separate set of tests for each and every combination of cutting tool and work piece material. Most researchers have investigated the effects of these cutting parameters on tool by the one-variable-at-a-time approach. The present work takes into account the simultaneous variation of speed, feed rate and depth of cut and predicts the surface roughness and metal removal rate of the material. Among different types of milling processes, end milling is one of the most vital and common metal cutting operations used for machining parts because of its capability to remove materials at faster rate with a reasonably good surface quality. Also, it is capable of producing a variety of configurations using milling cutter.

The design of experiments (DOE) approach using Taguchi technique has been successfully used by researchers in the study of optimization of cutting parameters [1-7].

In the manufacturing sector, simultaneously solving and assessing multi-response problems has become an important issue. This paper demonstrates the utilization of the TOPSIS technique, which was used by researchers [8-12], multi-objective optimization method, for optimizing the cutting parameters in CNC end milling. This method can transform and resolve the multi-response issue into an equivalent single response issue.

II. Experimental Work

Aluminum is used as the work piece material and cutting tool material is 10mm high speed steel (HSS).
Machining is performed on LMW JV55 CNC Milling Machine.

2.1 Selection of orthogonal array–

A major step in the DOE process is the selection of orthogonal array based on number of factors and number of levels for each factor. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. The degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters [1]. In present work three factors and four level were considered. Therefore degrees of freedom were calculated as shown below.

1. Number of factors =3
2. Numbers of levels = 4
3. Degrees of freedom of each factor = 4-1=3
4. Total degrees of freedom = Sum of the degrees of freedoms of all factors. = 3+3+3=9

Minimum numbers of experiments to be conducted = 9+1= 10. Based on the required minimum number of experiments the nearest orthogonal array fulfilling the condition is L16.

Table-1 Process Parameters and Levels

Factors	Level 1	Level 2	Level 3	Level 4
Speed(rpm)	**1500**	**2000**	**2500**	**3000**
Feed(mm/min)	**550**	**600**	**650**	**700**
DOC(mm)	**0.1**	**0.2**	**0.3**	**0.4**

Table-2 L16 orthogonal array and output responses (MRR & Ra)

Expt No.	Speed (rpm)	Feed (mm/min)	DOC (mm)	Width (mm)	MRR (mm^3/min)	Ra (µm)
1	1500	550	0.1	10	550	3.289
2	1500	600	0.2	10	1200	3.527
3	1500	650	0.3	10	1950	4.100
4	1500	700	0.4	10	2800	3.363
5	2000	550	0.2	10	1100	2.133
6	2000	600	0.1	10	600	3.017
7	2000	650	0.4	10	2600	2.380
8	2000	700	0.3	10	2100	2.584
9	2500	550	0.3	10	1650	2.080
10	2500	600	0.4	10	2400	1.938
11	2500	650	0.1	10	650	2.333
12	2500	700	0.2	10	1400	2.206
13	3000	550	0.4	10	2200	1.818
14	3000	600	0.3	10	1800	1.945
15	3000	650	0.2	10	1300	2.393
16	3000	700	0.1	10	700	2.166

Metal removal rate is measured using

MRR = DOC x width x feed

Surface roughness is measured using SURFTEST SJ-210.

Fig 1. Work piece after machining

2.2. TOPSIS Method–

TOPSIS -Techniques for order preferences by similarity to ideal solution TOPSIS

TOPSIS method has been applied to over the multi-response into single response. The steps for the TOPSIS method [14] are as follows

Step 1. Decision matrix is normalized by using the following equation:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} {a_{ij}}^2}} \quad (1)$$

Where i = 1· · · m and j = 1 · · · n a_{ij} represents the actual value of the mth value of nth experimental run and represents the corresponding normalized value.

Step 2. Weight for each response is calculated.

Step 3. The weighted normalized decision matrix is then calculated by multiplying the normalized decision matrix by its associated weights. The weighted normalized decision matrix is formed as

$$V_{ij} = W_{ij} \times r_{ij} \quad (2)$$

Where i= 1 · · · m and j = 1 · · · n represents the weight of the nth attribute or criteria.

Step 4. Positive ideal solution (PIS) and negative ideal solution (NIS) are determined as follows:

$$V^+ = (V_1^+, V_2^+, \dots\dots, V_n^+) \text{ maximum values} \quad (3)$$

$$V^- = (V_1^-, V_2^-, \dots\dots, V_n^-) \text{ minimum values} \quad (4)$$

Step 5.The separation of each alternative from positive ideal solution (PIS) and negative ideal solution (NIS) is calculated as

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)^2} \quad (5)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^-)^2} \quad (6)$$

Where i = 1, 2…m

Step 6. The closeness coefficient of each alternative(CC_i) is calculated as

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (7)$$

From the procedure we can convert multi-response (metal removal rate and surface roughness) to single response (CC_i). Therefore we can analyse that single response by Taguchi analysis using Minitab software.

Table – 3 Closeness coefficients obtained from TOPSIS

Expt No.	Speed (rpm)	Feed (mm/min)	DOC (mm)	Width (mm)	MRR (mm^3/min)	Ra (μm)	CC_i
1	1500	550	0.1	10	550	3.289	0.176604
2	1500	600	0.2	10	1200	3.527	0.277857
3	1500	650	0.3	10	1950	4.100	0.451457
4	1500	700	0.4	10	2800	3.363	0.697438
5	2000	550	0.2	10	1100	2.133	0.447087
6	2000	600	0.1	10	600	3.017	0.231180
7	2000	650	0.4	10	2600	2.380	0.849133
8	2000	700	0.3	10	2100	2.584	0.681381
9	2500	550	0.3	10	1650	2.080	0.594846
10	2500	600	0.4	10	2400	1.938	0.850502
11	2500	650	0.1	10	650	2.333	0.344954
12	2500	700	0.2	10	1400	2.206	0.511508
13	3000	550	0.4	10	2200	1.818	0.786640
14	3000	600	0.3	10	1800	1.945	0.650885
15	3000	650	0.2	10	1300	2.393	0.463137
16	3000	700	0.1	10	700	2.166	0.373235

III. RESULTS AND DISCUSSIONS

The experimental values are transformed into S/N ratios for that single response using Minitab17 software. The S/N ratio obtained for all experiments are shown in table.

Table-4 S/N ratio for CC_i

Expt No.	Speed (rpm)	Feed (mm/min)	DOC (mm)	CC_i	S/N Ratio
1	1500	550	0.1	0.176604	-15.06
2	1500	600	0.2	0.277857	-11.1236
3	1500	650	0.3	0.451457	-6.90766
4	1500	700	0.4	0.697438	-3.12988
5	2000	550	0.2	0.447087	-6.99215
6	2000	600	0.1	0.231180	-12.721
7	2000	650	0.4	0.849133	-1.42048
8	2000	700	0.3	0.681381	-3.33219
9	2500	550	0.3	0.594846	-4.51191
10	2500	600	0.4	0.850502	-1.40649
11	2500	650	0.1	0.344954	-9.24477
12	2500	700	0.2	0.511508	-5.82294
13	3000	550	0.4	0.786640	-2.08447
14	3000	600	0.3	0.650885	-3.7299
15	3000	650	0.2	0.463137	-6.6858
16	3000	700	0.1	0.373235	-8.56033

3.1 Analysis of Variance

ANOVA was used to determine the design parameters significantly influencing the output responses. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of TABLE-5 shows the percentage of contribution of each parameter on the response, indicating the degree of influence on the result.

It can be observed from the results obtained, that DOC was the most significant parameter having the highest statistical contribution (78.30%) followed by Speed (15.58%) and feed (4.51%). Contribution for each source parameter is calculated as follows

$$\%\ Contribution = \frac{\text{Seq SS of each parameter}}{\text{Total of each parameter}}$$

Table -5 % contribution for each parameter

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Speed (rpm)	3	38.990	38.990	12.9967	19.41	0.002	15.58%
Feed (mm/min)	3	11.275	11.275	3.7585	5.61	0.036	4.51%
Depth Of Cut (mm)	3	195.909	195.909	65.3030	97.55	0.000	78.30%
Error	6	4.017	4.017	0.6694			1.61%
Total	15	250.191					100.00%

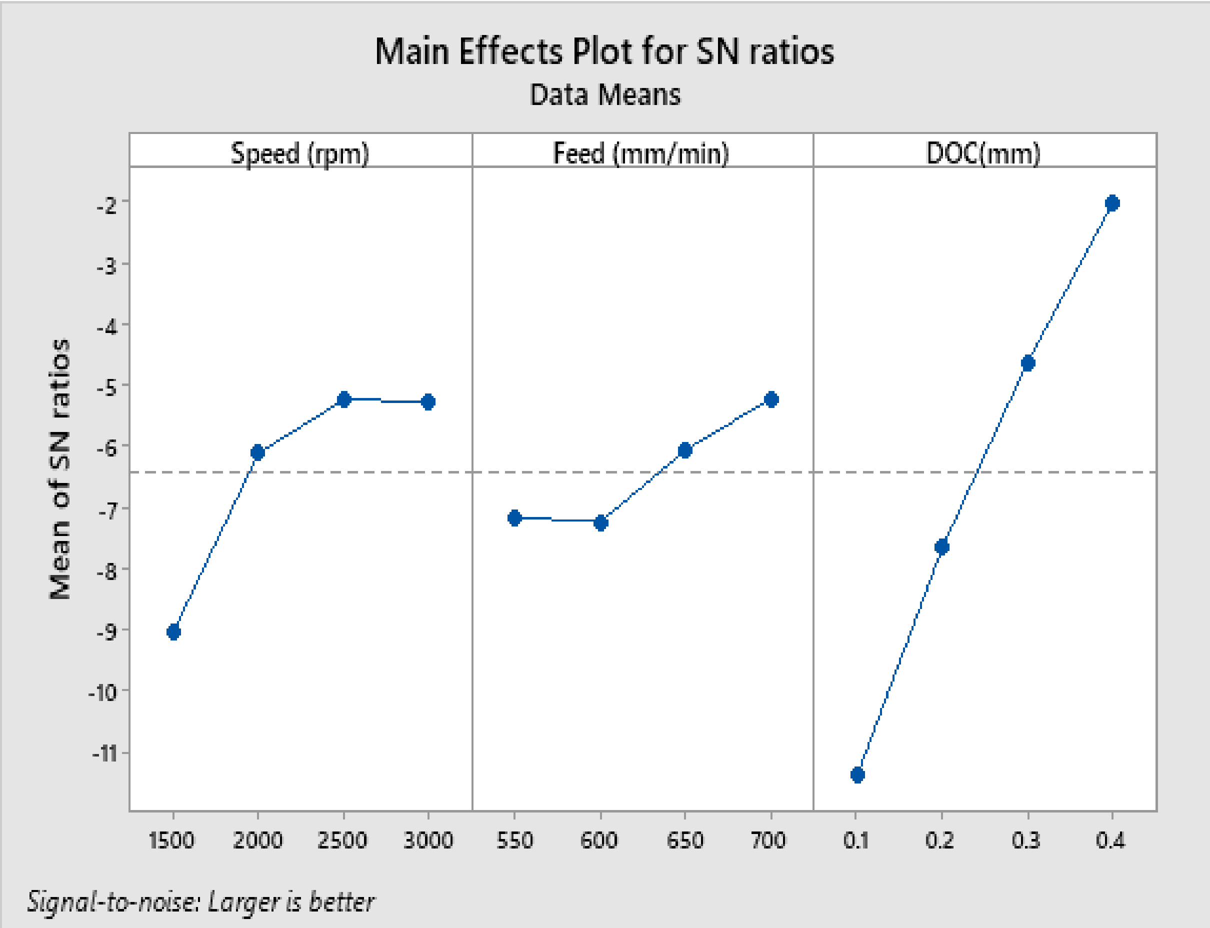

Fig.2 Main effects plot for S/N ratios

3.2 Predicting the optimum parameters

Optimum level for each factor (speed, feed and DOC) was obtained from Main effects plot shown in fig. 1. and optimum parameters are tabulated in the table 6

Table -6 optimum parameters

S.No	Factor	Level	value of corresponding level	mean of S/N dB
1	Speed	3	2500 rpm	-5.247
2	Feed	4	700 mm/min	-5.211
3	DOC	4	0.4 mm	-2.01

S/N ratio is predicted by using the equation

$$S/N_{PREDICT} = S/N_{TOTAL\ MEAN} + \sum_{i=0}^{n}(S/N_{mean\_Opt\_factor} - S/N_{total\ mean})$$

Predicted S/N ratio = 0.373683857 dB

3.3 Conformation Experiment

The conformation experiment is very important in parameter design. The purpose of conformation experiment in the present. Work was to validate the optimum factors $Speed_3$, $feed_4$ & DOC_4 .the average of three experimental results of the conformation experiment was listed in Table 7

Table- 7 conformation experiment results

Speed (rpm)	Feed (mm/min)	DOC (mm)	CC_i	s/n Ratio	predicted s/n ratio	% of Error
2500	700	0.4	0.913358	0.358736	0.37368	3.99

IV. Conclusions

In this work, CNC end milling was performed on aluminum work piece. The output responses are optimized by varying the process parameters. Cutting parameters include speed, feed & DOC with four levels. After obtaining the results the following conclusions have been drawn:

1. Analysis have been done on surface roughness and metal removal rate using Taguchi and TOPSIS.

2. The optimum parameters obtained for minimizing the surface roughness and metal removal rate are speed 1500 rpm, Feed 700 mm/min and DOC 0.4 mm.

3. ANOVA results are for achieving the optimum parameters were DOC was the most significant parameter having the highest statistical contribution (78.30%) followed by Speed (15.58%) and feed (4.51%).

4. Predicted S/N Ratio of output response has been obtained as 0.358736 dB at optimum parameters.

5. Confirmation experiment was conducted at optimum parameters and S/N ratio was obtained as 0.358736 dB. The predicted values and experimentally measured values are good in agreement with 3.99% error.

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