Investigating Effect of Machining Parameters of CNC Milling on Surface Finish by Taguchi Method

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***Abstract* – CNC End milling is a unique adaption of the conventional milling process which uses an end mill tool for the machining process. CNC Vertical End Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. During the End milling process, the material is removed by the end mill cutter. The effects of various parameters of end milling process like spindle speed, depth of cut, feed rate have been investigated to reveal their Impact on surface finish using Taguchi Methodology. Experimental plan is performed by a Standard Orthogonal Array. The results of analysis of variance (ANOVA) indicate that the feed Rate is most influencing factor for modelling surface finish. The graph of S-N Ratio indicates the optimal setting of the machining parameter which gives the optimum value of surface finish. The optimal set of process parameters has also been predicted to maximize the surface finish.**

Keywords* – *surface finish, orthogonal array, taguchi method, ANOVA, SN ratio.

I. INTRODUCTION

In present time the technology of CNC vertical milling machine has been improved significantly to meet the advance requirements in various manufacturing fields, especially in the precision metal cutting industry. This experiment gives the effect of different machining parameters (spindle speed, feed, and depth of cut) on material removal rate in end milling. The demand for high quality and fully automated production focus attention on the surface condition of the product, surface finish of the machined surface is most important due to its effect on product appearance, function, and reliability. For these reasons it is important to maintain consistent tolerances and surface finish.

Among several CNC industrial machining processes, milling is a fundamental machining operation. End milling is the most common metal removal operation encountered. It is widely used in a variety of manufacturing in industries. The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. The surface generated during milling is affected by different factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path and

other parameters. During finish milling, the depth of cut is small. Technological parameter range plays a very important role on surface roughness. In end milling, use of high cutting speed, low feed rate and low depth of cut are recommended to obtained better surface finish for the specific test range in a specified material. Material removal rate (MRR) is an important control factor of machining operation and the control of machining rate is also critical for production planners. MRR is a measurement of productivity & it can be expressed by analytical derivation as the product of the width of cut, the feed velocity of milling cutter and depth of cut. Cutting feed is the most dominated factor for surface finish. The most important interactions, that effect surface roughness of machined surfaces, are between the cutting feed and depth of cut, and between cutting feed and spindle speed. Surface Roughness is affected negatively if the applied force is increased. Surface roughness at the same feed rate becomes higher when a small nose radius is used. Effort to increase productivity and MRR was maximized by optimal selection of feed rate, geometric boundary conditions].

With the more precise demands of modern engineering products, the control of surface texture together with dimensional accuracy has become more important. This experimental investigation outlines the Taguchi optimization methodology, which is applied to optimize MRR in end milling operation. The experiment is conducted on aluminium cast heat-treatable alloy the processing of the job is done by High Speed Steel (HSS) end-mill tool under finishing conditions. The machining parameters evaluated are spindle speed, feed rate and depth of cut. The experiments are conducted by using Taguchi L_9 orthogonal array as suggested by Taguchi. Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA) is employed to analyse the effect of milling parameters on material removal rate.

II. EXPERIMENT AND DATA COLLECTION

Experiments are designed with the help of using taguchi L_9 orthogonal array. The software used for DOE (Design of experiment) is Minitab15. Experiment is divided into three main phases. These three phases are the planning phase, the conducting phase, the analysis phase.

A) *Planning phase*

2.1 *Input parameters & there levels for End Milling*

Table 1 Parameters of the setting

Control factor	Symbol
Spindle speed	Factor A
Feed Rate	Factor B
Depth of cut	Factor C

Table 2 Selected input Parameter

Control factors/levels	Level1	Level2	Level3	Units
Factor A	800	1000	1200	rpm
Factor B	60	80	100	mm/min
Factor C	0.2	0.3	0.4	mm

2.2 *Design of experiments (DOE)*

For selected input parameters experiments are designed using Taguchi L_9 orthogonal standard array. For this purpose software Minitab 15 is used

Table 3 (DOE)

Experim ent no	1 (A) Spindle speed (RPM)	2 (B) Feed Rate (mm/min)	3 (C) Depth of cut (mm)
1	800	60	0.2
2	800	80	0.3
3	800	100	0.4
4	1000	60	0.3
5	1000	80	0.4
6	1000	100	0.4
7	1200	60	0.4
8	1200	80	0.2
9	1200	100	0.3

The set of 9 experiments are shown in table-3.

2.3 *Workpiece material*

The material used for the experiment is (100 x 34 x 20 mm) 5 blocks of aluminium cast heat-treatable alloy. Whose compositions are as follows.

COMPOSITION (% By Weight)	Cu 4.5% Si 1.1% Rest Al
Yield Strength (MPa)	110
Tensile Strength(MPa)	221
Ductility (%EL in 50 mm)	8.5
Applications	Flywheel and rear axle housing, Bus and aircraft wheels, Crankcases

B) *Conducting phase*

2.4 *Experimentation*

After DOE, 9 experiments are carried out in CNC vertical End milling. After each experiment SURFACE ROUGHNESS is calculated. A quality characteristic for SURFACE ROUGHNESS is smaller is the better. The signal-to-noise ratios of each experimental run are calculated based on the following equation, which are listed in corresponding tables with the data.

The equation is:-

$$SN_i = -10 \times \log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

Where

SNi is the signal to noise ratio of ith term,

n = number of measurements in a trial/row, in this case, n=3 and *Yi* is the i^{th} measured value in a run/row.

Instruments used for measuring surface roughness

One of the measurable output characteristics is surface Roughness. Instrument used in this paper for measurement of surface Roughness is Mitutoyo Surftest SJ-201P. The surftest SJ-201P (mitutoyo) is a shop–floor type surface-roughness measuring instrument, which traces the surface various machine parts and calculates the surface roughness based on roughness standards, and displays the results. The workpiece is attached to the detector unit of the SJ-201P will trace the minute irregularities of the workpiece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of the SJ-201P.

Fig. 1 : Mitutoyo Surftest SJ-201P Instrument

The specification of this instrument are given in below.

Specification of surftest SJ201P:

Detector

Detection Method	Differential Inductance Method
Measurement range	350µm(-200µm to +150µm) 13780µin (-7880µin to +5900µin)
Stylus material	Diamond
Tip radius	5µm (2900µin), 2µm (8µin) 0.75mN (measuring force type)
Measuring force	4mN (0.4gf), 0.75mN (0.75gf) (0.75mN measuring force type)
Radius of skid curvature	40mm (1.57 in)

Drive unit

Measurement range and resolution

Measurement range	Resolution
Auto	0.01 µm to .04 µm depending on the measurement range
350 µm (14000 µin)	0.4 µm (12.8 µin)
100 µm (4000 µin)	0.1 µm (3.2 µin)
50 µm (2000 µin)	0.05 µm (1.6 µin)
10 µm (400 µin)	0.01 µm (.4 µin)

Table for response (surface roughness) and S-N ratio is shown in table-4

Table 4

	(A) Spindle speed (rpm)	(B) Feed rate (mm/min)	(C) Depth of cut (mm)	Response Surface roughness (µm)	S-N Ratio (dbi)
1	800	60	0.2	1.37000	-2.73503
2	800	80	0.3	1.80000	-5.10581
3	800	100	0.4	2.10000	-6.44465
4	1000	60	0.3	0.77000	2.26823
5	1000	80	0.4	0.79000	2.04560
6	1000	100	0.2	0.89000	1.01074
7	1200	60	0.4	0.35000	9.10920
8	1200	80	0.2	0.52000	5.67565
9	1200	100	0.3	3.09000	-2.32437

C) Analysing Phase

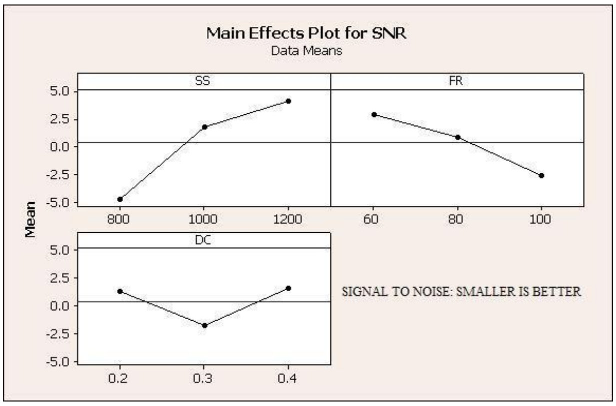
2.5 Analysis of variance (ANOVA)

The output characteristic, surface finish is analysed by software Minitab 15 and ANOVA is formed, which shows the percentage contribution of each influencing factor on surface roughness. This also signifies that which factor is more predominant in CNC END MILLING. Main effect plots for means and Main effect plots for SN ratios are plotted by help of software Minitab 15.

TABLE 5 Analysis of variance for means

source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindle speed	2	0.4243	0.4243	0.2121	13.36	0.070
Feed rate	2	0.2231	0.2231	0.1115	7.02	0.125
Depth of cut	2	29.0653	29.0653	14.5327	915.28	0.001
Residual error	2	0.0318	0.0318	0.0159		
total	8	29.7445				

From above table it can be seen that all the three factors are significantly affect the response. Feed rate has highest effect on the response spindle speed has second highest effect on response and depth of cut has least effect on response.



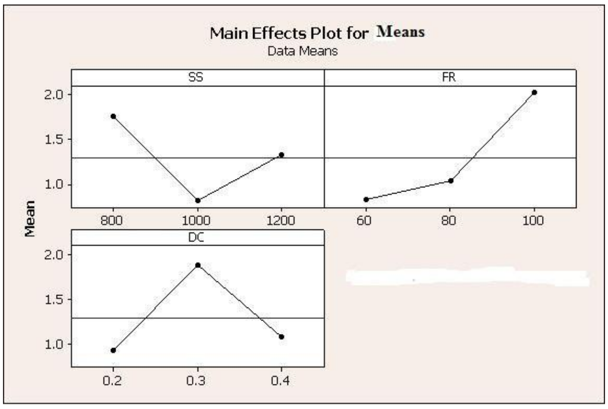


Fig. 3

The figure 2 contains the graph between SN ratio data and input parameter. The figure 3 contain the graph between mean and control factors. The objective of using the SN ratio as a performance measurement is to develop product and processes in sensitive to noise factor. The optimal combination of input machining parameter can be observed from fig 2 i.e. graph between S-N ratio and input parameter, The optimal setting of input parameter is($A_1B_3C_2$). The process parameter setting with the highest SN ratio always yields the optimum quality with minimum variation (Antony & Kaye, 1999).

2.6 Computation of Average Performance

Average performance of each factor on surface roughness is calculated by

Following expression

$$\text{Average performance of factor A at level 1} = \frac{\text{sum of roughnessvalues}}{\text{number of levels}}$$

Similar expression can be written for calculating the average performance of factor B & C.

Notations:-

A'$_1$, A'$_2$, A'$_3$= average performance of factor A at level 1, 2, 3 respectively

B'$_1$, B'$_2$, B'$_3$= average performance of factor **B** at level 1, 2, 3 respectively

C'$_1$, C'$_2$, C'$_3$= average performance of factor C at level 1, 2, 3 respectively

Table for factors A, B, C & their levels 1, 2, 3 with Surface Roughness is shown below.

A'$_1$ = 1.75

A'$_2$ = 0.81

A'$_3$ = 1.32

B'$_1$= 0.83

B'$_2$= 1.04

B'$_3$= 2.03

C'$_1$= 0.93

C'$_2$= 1.88

C'$_3$= 1.08

TABLE 6 Response table for Signal to Noise Ratio

LEVEL	SPINDLE SPEED	FEED RATE	DEPTH OF CUT
1	-4.7618	2.8808	1.3171
2	1.7749	0.8718	-1.7206
3	4.1535	-2.5861	1.5700
DELTA	8.9153	5.4669	3.2907
RANK	1	2	3

Table 7 Response table from Mean

LEVEL	SPINDLE SPEED	FEED RATE	DEPTH OF CUT
1	1.7567	0.8300	0.9267
2	0.8167	1.0367	1.2922
3	0.7256	1.4322	1.0800
DELTA	1.0311	0.6022	0.3656
RANK	1	2	3

2.7 Calculation of Optimum Surface Finish.

Let T' = average result for 9 runs of SURFACE FINISH

$$T' = \frac{\sum_{i=1}^{9} SURFACE\ FINISH}{9}$$

=1.2977

$SF_{OPT} = T' + (A_1 - T') + (B_3 - T') + (C_2 - T')$

=3.0723 µm

III. RESULT AND DISCUSSION

1) From the graph of S-N ratio it can be observed that optimal value of surface finish is obtained at first level of factor A, third level of factor B and second level of factor C.
2) Optimal value of surface finish is 3.0723 µm.
3) From the ANOVA it can be seen that percentage contribution of feed rate is maximum and it means Feed rate is the most dominating factor for modelling surface finish.
4) Taguchi robust design is suitable for modelling surface finish in CNC milling.

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