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(Research Article)

Parametric Optimization of Face Milling to Improve Surface Roughness using AISI 1010 Steel

Aakash N. Samani[1*], Prof. Parag Paija[2]

[1, 2]Department of Mechanical Engineering, B.H. Gardi College of Engineering & Technology, Gujarat Technological University, Rajkot, India*

Abstract

Milling is the machining process of using rotary cutters to remove material from a workpiece by advancing in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes. Face Milling is the most common milling operation and can be performed using a wide range of different tools. Cutters with a 45-degree entering angle are most frequently used, but round insert cutters, square holder cutters and side and face mills are also used for certain conditions. This study has been undertaken to investigate the optimum parameter using Design of Experiments through Taguchi method to improve surface roughness of AISI 1010 steel in the milling process using L27 Orthogonal array. In this work an attempt has made to find optimum cutting parameters in Milling Machine from Spindle Speed, Feed & Depth of Cut to improve Surface Roughness with the help of Vertical Machining Centre Batliboi for a Specific material AISI 1010 Steel (commonly known as Black Bar). The Results obtained with Roughness tests though Roughness Tester(Mitutoyo) are Validated with the help of Minitab Software.

Keywords – Milling, Surface Roughness, Taguchi, S/N Ratio, ANOVA, Parametric Optimization.

1. Introduction

Roughness is very good predictor in performance of mechanical parts since there are irregularities in surface may form nucleation sites for cracks or corrosion [1]. It is difficult and expensive to control during manufacturing. In Face milling of steel, it is found that parameters like feed rate, cutting speed and depth of cut influence surface roughness and tool vibrations [2].

Researchers mainly focused on determining the cutting force, tool wear and surface roughness if the milling process. Some results suggested that reduction in tool vibrations reduce the level of surface roughness. Objective is to set optimum parameters using HSS tool on AISI 1010 Steel using different variable parameters with minimum possible Surface roughness.

*Corresponding Author: e-mail: samaniaakash@gmail.com
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2. Design of experiments

Design of Experiments is a statistical method to resolve complex and costly situations with considering minimal number of experiments and the results to be verified by statistical methods [3]. DOE provides breakthrough improvements in product quality and process efficiency. With respect to manufacturing terms when we consider numbers of variables we can narrow the experiments to minimal numbers. Thus, we can maintain the most important information with performing few experiments. The most important process of DOE is determining independent variables values at which experiments are to be performed. DOE is fundamentally divided into four parts. They are:

1. Planning Phase
2. Designing Phase
3. Conducting Phase
4. Analyzing Phase

Planning Phase consists problem recognition and formulation. Development of few new Products; Improvements of existing processes or products, Improvements or the process/product performance with needs of customers and Reduction of existing Process speed related Problems carried out in Planning Phase.

In Designing Phase user selects most appropriate Design of experiment. Experiments can be statistically designed by Orthogonal approach array by Taguchi method, ANOVA method, within which one can pick full factorial, partial factorial. Size of experiments is dependent on number of factors to be chosen and numbers of level of each factor.

Conducting Phase involves trial experiments to be carried out and evaluation of results. Some considerations are need to be studied before are Selection of Suitable location for carrying out experiments which is not affected by external source i.e. vibration, atmosphere, etc.

After the Experiments in Conducting Phase results are verified by assessing the outcomes and analyzing the derived conclusions. Objectives to be achieved are Determining that Design parameters or variables that affect the means process performance, Influence performance variability and chances of further improvements.

3. Taguchi methodology

The Taguchi technique from Dr. Genichi Taguchi [4], a Japanese Engineer is a guide and reference for many Industrialists, Engineers, Scientists which is essential improvement technique for product or process experimentation or development.

In 1940 after first world war Japanese established Electrical Communication Laboratory(ECL) with Dr. Genichi Taguchi to improve their poor and totally unsuitable long-distance communication purpose and enhancing product quality. Dr. Taguchi started new methods to optimize the process of engineering experimentations. He developed techniques, which we now know as ‘Taguchi Techniques.

It’s a great philosophy for quality control in manufacturing industries. Its work is creating entire genre of engineers who believes in quality. The consequences are far from this philosophy and founded on three simple and fundamental concepts.

- Quality should be designed into the product, not inspected.
- Best Quality is achieved by minimizing the deviations from target. The Product design should be immune to uncontrollable environmental factors.
- Quality cost should be measured as a function of deviation from standard and losses should be system wide.

These three are principles of the quality measures and he also recommended three-stage procedure as below.

- Concept Design: Science and Engineering knowledge is used to generate basic process or product design.
- Parameter Design: In these Stage different parameters related to process is selected and studied to minimize performance variation.
- Tolerance Design: In these stage tolerance of process conditions and sources of variability are set.

4. Selection of variables

Among The different parameters such as tool geometry, speed, feed, depth of cut, coolant flow rate selected parameters for experiments are Cutting Speed, Feed Rate and Depth of Cut. In L27 orthogonal array Levels for each variable are 3[5].

As there is also dry milling is also used without the effect of coolant in some process and due to the low depth of cut it would not be such hard effect of load which needs cooling so coolant flow rate is not considered in this Selection of Variables, though it might be considerable in future aspect.

Table 1. Process Parameters and their Levels

Process Parameter	L1	L2	L3
Spindle Speed(RPM)	1200	1600	2000
Feed Rate(mm/min)	50	75	100
Depth of Cut(mm)	0.50	0.10	0.15

5. Experimental setup

The Experiments were carried out at NSIC (National Small Industries Corporation) Rajkot where Batliboi Trainer VMC (Vertical Machining Centre) was used to carry out experimental setup.

Specifications of Machine are:

- Maximum Travel on X axis : 200mm
- Maximum Travel on Y axis : 125mm
- Maximum Travel on Z axis : 200mm
- Maximum Spindle Speed : 2000 RPM
- Spindle Taper : BT 30
- Accuracy : 10 µm

Figure 1. Baltiboi VMC

Figure 2. FANUC Controller

For Tool selection there's different types of cutter available in market such as Side Face Cutter, End Mill, Insert Edge Cutters etc. To Carry out these experiments Insert Edge cutter of 50mm diameter was selected according to the requirement of the cutting size with the considerations of Industrial use.

Figure 3. Insert Cutter

R_a is the arithmetic average of the absolute values of the roughness profile ordinates, also known as Arithmetic Average (AA), Centre Line Average (CLA) [6]. The average roughness is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. Roughness is measured in microns(μm)

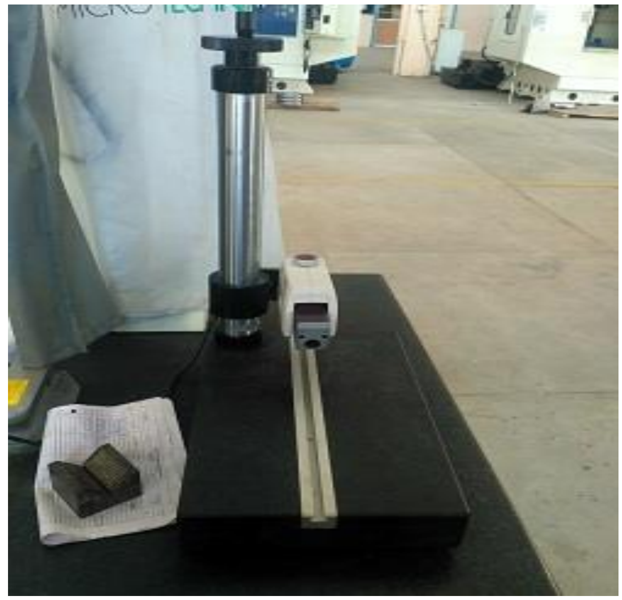

Figure 4. Mitutoyo Ra Tester

6. Experimental design

The Experiments were designed according to Taguchi's Design of Experiments under the selection of three levels of three factors chosen which were Spindle Speed, Feed Rate and Depth of Cut and The Roughness tests were concluded after measuring through the Mitutoyo Roughness tester (Fig 4) recorded in Table 2 and also the experiments are conducted for partial factorial design [7]. Figure 5 contains few selected experimental plates on which the experiments were carried out.

Figure 5. Trail Experiments

Table 2. Experimental Design

Experiment No.	Speed (RPM)	Feed Rate (mm/min)	Depth of Cut(mm)	RA(µm)
1	1200	50	0.50	0.198
2	1200	50	0.10	1.822
3	1200	50	0.15	1.120
4	1200	75	0.50	1.780
5	1200	75	0.10	0.239
6	1200	75	0.15	0.449
7	1200	100	0.50	1.557
8	1200	100	0.10	1.542
9	1200	100	0.15	2.456
10	1600	50	0.50	1.578
11	1600	50	0.10	1.356
12	1600	50	0.15	0.884
13	1600	75	0.50	0.392
14	1600	75	0.10	0.672
15	1600	75	0.15	0.705
16	1600	100	0.50	0.664
17	1600	100	0.10	0.552
18	1600	100	0.15	1.115
19	2000	50	0.50	0.119
20	2000	50	0.10	0.108
21	2000	50	0.15	0.188
22	2000	75	0.50	0.175
23	2000	75	0.10	0.298
24	2000	75	0.15	0.300
25	2000	100	0.50	0.380
26	2000	100	0.10	0.159
27	2000	100	0.15	0.216

7. Optimization of machining parameters using TAGUCHI's S/N ratio analysis

The outcome of Experimental work of Surface Finish (Ra) is analyzed using Taguchi Design in Minitab software and S/N ratio values are determined. The Optimum levels of influential parameters are determined based on the obtained S/N ratios.

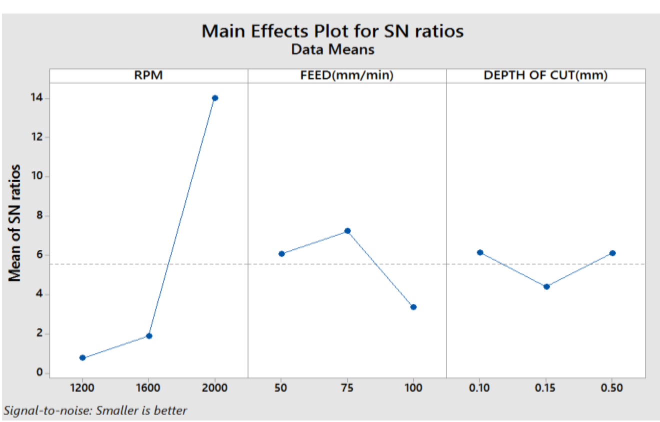

Figure 6. Main Effect Plot for S/N ratio on Surface Roughness

Table 3. Response Table for S/N Ratios

Level	Spindle Speed(rpm)	Feed (mm/min)	Depth of Cut (mm)
1	0.7598	6.0821	6.1460
2	1.8807	7.2349	4.4015
3	14.0152	3.3386	6.1082
Delta	13.2555	3.8963	1.7446
Rank	1	2	3

The Response Table for Signal-to-Noise Ratios contains a row for the average signal-to-noise ratio for each factor level, Delta, and Rank. The table contains a column for each factor.

Delta: Delta is the difference between the maximum and minimum average response (signal-to-noise ratio or standard deviation) for the factor.

Rank: The Rank is the rank of each Delta, where Rank 1 is the largest Delta.

After assessing the S/N ratio values (Table 3), the effect of each machining parameter is separated based on S/N ratio at different levels and the values of S/N ratio for each level of each factor and effect of parameter on response(Ra) in the rank wise are summarized in Table 4[11].

Table 4. S/N Ratios

Exp. Run	Surface Roughness Ra(µm)	S/N for Ra
1	0.198	14.0667
2	1.822	-5.2110
3	1.120	-0.9844
4	1.780	-5.0084
5	0.239	12.4320
6	0.449	6.9551
7	1.557	-3.8458
8	1.542	-3.7617
9	2.456	-7.8046
10	1.578	-3.9621
11	1.356	-2.5783
12	0.884	1.0710
13	0.392	8.1343
14	0.672	3.4526
15	0.705	3.0362
16	0.664	3.5566
17	0.552	5.1612
18	1.115	-0.9455
19	0.119	18.4891
20	0.108	19.3315
21	0.188	14.5168
22	0.175	15.1392
23	0.298	10.5157
24	0.300	10.4576
25	0.380	8.4043
26	0.159	15.9721
27	0.216	13.3109

The formula for the smaller the better S/N Ratio using base 10 log is given by

$$S/N = -10 \times \log(\Sigma(Y2)/n)$$

where
Y = responses for the given factor level combination
n = number of responses in the factor level combination.

Optimal combination of conditions resulting in the best possible solution. Optimization can help you find, for example, the optimal performance of a server or the best method

For the selected milling process of AISI 1010 Steel from Selected Variables on different Levels Optimal Control Parameters are listed in Table 5 to achieve best surface roughness.

Table 5: Optimum Control Parameters Values for S/N Ratio Analysis

Speed (RPM)	2000
Feed Rate (mm/min)	50
Depth of Cut (mm)	0.10

8. Optimization of impact of each parameter on process using ANOVA

To evaluate the impact of Each Parameter on the process Analysis of Variance method is utilized and the output of the ANOVA and the Results are in the table 6 and 7 respectively [8].

Table 6. ANOVA results

Source	DF	Contribution	F-Value	P-Value
Speed(RPM)	2	43.46%	8.78	0.002
Feed(mm/min)	2	6.74%	1.36	0.279
DOC(mm)	2	0.28%	0.06	0.945
Error	20	49.52%		
Total	26	100%		

Table 7. Model summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.526138	50.48%	35.62%	9.75%

9. Conclusions

The Experimental Investigation on 27 experiments Table 6 from the ANOVA results shows that speed is most effective parameter using Level 3(2000 RPM) we get the best surface roughness. Taguchi's S/N ratio analysis using Minitab 18 software confirms the optimum parameters are Speed-2000RPM, Feed- 50 mm/min, Depth of Cut 0.10mm.

With Optimization Analysis of Variance Method Contribution of each parameter on process is also evaluated which concludes the work with result the speed is having 43.46% and Feed and Depth of Cut is having 6.74% and 0.28% contribution respectively.

10. Future scope

After the test of ANOVA, it shows the effects of machining parameters was total 50.48% and effect of only Spindle Speed was 43.46% which could be used for improvisation in future aspects to either decrease the error range in machine which could be happening due to lots of reason in either machining or due to human error, parameter selections etc.

S/N ratio gets higher with increase in speed which could cause the effect on Surface and roughness might be used for future study.

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Biographical notes

Prof. Parag Paija has received M.Tech. in CAD/CAM from Nirma University, Ahmedabad. He is Assistant Professor in Mechanical department of B. H. Gardi College of Engineering & Technology, Rajkot, Gujarat, India..

Aakash N. Samani has completed M.E. in CAD/CAM from Gujarat Technological University in 2018. He was a student at B. H. Gardi College of Engineering & Technology, Rajkot, Gujarat, India.