Taguchi method for surface quality improvement

Quality Systems and Measurement

Table of contents

Abstract: 2
List of Symbols Used 3
Factors Mapping 3
Figures 4
Tables 4

1. INTRODUCTION 4

2. BACKGROUND RESEARCH 5
2.1 CNC Machining and Surface Quality 5
2.2 Design of Experiments 5
2.3 The Taguchi Method 6
2.4 Design 6
2.5 Surface Roughness Optimisation 6

3. DATA COLLECTION 7
3.1 Taguchi Experimental Results Table 7
Surface Roughness Measurements - 7
3.2 Factor level layout (L8 OA — from the table) 7

4. Data analysis and results discussion : 8
4.1 Level Means 9
4.2 Factor Ranking 9
4.3 Optimal Level Selection 9
4.4 Predicted Ra at Optimal Settings 9
4.5 Result Discussion 10
Factor B – Spindle Speed 10
Factor A – Face Mill Diameter 10
Factor F – Conventional vs Climb 10

5 CONCLUSION 11

Abstract:

The proposed report explores the application of the Taguchi L8 orthogonal array to determine the machining parameters which contribute to surface quality most to the limited surface quality during face milling on a CNC machine. The surface roughness (Ra) was taken four times in each run and averaged to be analyzed. Findings indicate that the spindle speed and face mill diameter are the most important considerations that influence Ra whereas feedrate plays a negligible role in the tested range. A2 - B2 - C1 - D2 - E1 - F2 - G1 was determined as the best parameter combination and the approximate value of Ra is 0.105 mm. Confirmation run is advisable to authenticate the improvement that is predicted.

List of Symbols Used

- ➔ **A–G**: Machining parameters (factors) in L8 orthogonal array
- ➔ **Ra**: Average roughness (mm)
- ➔ **OA**: Orthogonal Array
- ➔ $\mathbf{y_u}$: Measured roughness
- ➔ **n**: Number of measurements
- ➔ **m**: Mean
- ➔ **μ**: Grand mean
- ➔ **η**: Signal-to-noise (S/N) ratio
- ➔ **Δ**: Difference in level
- ➔ **Σ**: Summation symbol used in the Taguchi prediction formula

Factors Mapping

Factor	Meaning	Levels
A	Face mill diameter	1 = Ø25 mm, 2 = Ø16 mm
B	Spindle speed	1 = 3000 rpm, 2 = 4500 rpm
C	Feedrate	1 = 1000 mm/min, 2 = 2000 mm/min
D	Cutting depth	1 = 1 mm, 2 = 2 mm
E	Stepover	1 = 10 mm, 2 = 5 mm
F	Conventional/Climb	1 = Conventional, 2 = Climb
G	Coolant	1 = On, 2 = Off

Figures

Figure 1. Surface Roughness Effect Plot(Ra)

Tables

Table 1. Roughness Measurements

Table 2. Factor Level's Deviations from Average

1. INTRODUCTION

The quality of surface is a significant demand of CNC machining, as it influences the performance, life of the components and dimensional accuracy. Spindle speed, feedrate, tool diameter and cutting depth are parameters used in face milling to affect chip formation and tool work piece interaction which determine the ultimate surface roughness (Zhang, NMM3517 Lecture Materials).

In order to study these effects effectively the Taguchi method employs orthogonal arrays in undertaking studies on several factors using fewer experiments compared to complete factorial designs (Taguchi Method Lecture Slides). Seven machining parameters are examined in this work to utilize an L8 orthogonal array to identify the best settings under which to maximize surface quality.

2. BACKGROUND RESEARCH

2.1 CNC Machining and Surface Quality

Precision and repeatability of Computer Numerical Control (CNC) machining is very common. Surface quality This parameter is influenced by spindle speed, feedrate, tool diameter, depth of cut, and coolant use in face milling where the effect of surface quality is usually determined by average roughness (Ra). The factors affect the chip-formation, vibration, and heat generation which determine the end-surface texture. Good surface finish is also desired to minimise friction, fatigue life and to decrease further finishing. It is therefore needed to understand the effects of machining parameters on roughness in order to optimise the process.

2.2 Design of Experiments

DOE gives us a systematic approach to the investigation of the effects of a response in relation to a set of factors. Although full factorial designs will test all combinations of factors, as the number of factors grows so does the impracticability of the test. This necessitates more efficient methods of experimentation.

2.3 The Taguchi Method

The Taguchi is a fractional factorial DOE technique that is aimed at determining the effects of the factors with much fewer experiments. It also employs standardised orthogonal arrays (OAs), including L4, L8, L9, or L16, in order to give equal and statistically significant coverage of factor levels. Having an orthogonal array permits the factors to be manipulated independently and equally through the experiments and the analysis to be robust without exerting significant effort on the experiment.

Taguchi also draws a distinction between control factors, which are those variables which one may control when machining, and noise factors which are the sources of uncontrollable variation, e.g., tool wear, temperature, or material variation. Taguchi optimisation pays attention to finding settings of control factors that reduce the effect of noise and achieve constant and high-quality output.

2.4 Design

Another characteristic of the Taguchi method is that Signal-to-Noise (S/N) ratios are used in order to measure performance robustness. Taguchi provides three S/N criteria depending on the goal:

- Larger-is-better
- Smaller-is-better
- Nominal-is-better

To improve surface quality, the smaller-is-better S/N ratio is more commonly used since lower values of Ra represent a better surface finish.

2.5 Surface Roughness Optimisation

The Taguchi method is especially effective in CNC milling where one can study a series of machining parameters at the same time without the need to have a tiresome number of experiments. The method determines the significant influence of the parameters on the surface roughness by means of computing the level means and analysis of the main effects. After optimum levels are determined, an additive model of Taguchi is applied to forecast the results of the expected performance under optimum conditions and these could be checked by a confirmation run.

3. DATA COLLECTION

3.1 Taguchi Experimental Results Table

Surface Roughness Measurements -

Run	A	B	C	D	E	F	G	Ra_1	Ra_2	Ra_3	Ra_4	Avg Ra (mm)
1	1	1	1	1	1	1	1	0.528	0.528	0.499	0.518	**0.5128**
2	1	1	1	2	2	2	2	0.422	0.606	0.492	0.489	**0.5022**
3	1	2	2	1	1	2	2	0.525	0.133	0.386	0.318	**0.3405**
4	1	2	2	2	2	1	1	0.239	0.456	0.369	0.359	**0.3595**
5	2	1	2	1	2	1	2	0.517	0.437	0.353	0.479	**0.4458**
6	2	1	2	2	1	2	1	0.241	0.138	0.470	0.222	**0.2700**
7	2	2	1	1	2	2	1	0.147	0.212	0.215	0.174	**0.1870**
8	2	2	1	2	1	1	2	0.204	0.179	0.213	0.203	**0.1985**

Table 1. Roughness Measurements

$$Total\ Average = 1/14\ .\ \sum(Means\ of\ A1\text{–}G2)$$

Total Average=0.3520375

3.2 Factor level layout (L8 OA — from the table)

Run → A B C D E F G

1 → 1 1 1 1 1 1 1

2 → 1 1 1 2 2 2 2

3 → 1 2 2 1 1 2 2

4 → 1 2 2 2 2 1 1

5 → 2 1 2 1 2 1 2

6 → 2 1 2 2 1 2 1
7 → 2 2 1 1 2 2 1
8 → 2 2 1 2 1 1 2

4. Data analysis and results discussion :

Factor Level	Machining Parameter	Calculation	Result
A2	Face mill Ø16 mm	0.3520 − 0.2753	**0.0767**
B2	Spindle speed 4500 rpm	0.3520 − 0.2714	**0.0807**
C1	Feedrate 1000 mm/min	0.3520 − 0.3501	**0.0019**
D2	Cutting depth 2 mm	0.3520 − 0.3326	**0.0195**
E1	Stepover 10 mm	0.3520 − 0.3305	**0.0216**
F2	Climb milling	0.3520 − 0.3249	**0.0271**
G1	Coolant ON	0.3520 − 0.3323	**0.0197**

Table 2. Factor Level's Deviations from Average

Total below average:

0.0767 + 0.0807 + 0.0019 + 0.0195 + 0.0216 + 0.0271 + 0.0197 = 0.2472

Predicted Ra: 0.3520 − 0.2472 = 0.1048 mm

4.1 Level Means

The level means were calculated by averaging the Ra values for the four runs in which each factor level appeared. For each factor (A–G), Level 1 and Level 2 means were compared to determine the influence on surface roughness. The differences between level means indicate the relative effect strength. Factors A, B, F, E, G, and D show measurable differences, while factor C demonstrates almost no change across levels.

4.2 Factor Ranking

Ranking based on absolute differences between Level 1 and Level 2 means shows:

- **B (Spindle speed)** — most influential
- **A (Face-mill diameter)** — second most influential
- **F (Climb/Conventional)** — moderate effect
- **E (Stepover)** — small effect
- **G (Coolant)** — small effect
- **D (Cutting depth)** — minor effect
- **C (Feedrate)** — negligible effect

4.3 Optimal Level Selection

- **A2** (16 mm face mill)
- **B2** (4500 rpm)
- **C1** (1000 mm/min)
- **D2** (2 mm depth)
- **E1** (10 mm stepover)
- **F2** (Climb milling)
- **G1** (Coolant ON)

4.4 Predicted Ra at Optimal Settings

Using the Taguchi additive model, the predicted Ra at the optimal parameter combination was calculated. The overall mean Ra across all runs was used as a baseline, and deviations for each chosen level were summed. The resulting predicted surface roughness is:

Predicted Ra ≈ 0.105 mm

4.5 Result Discussion

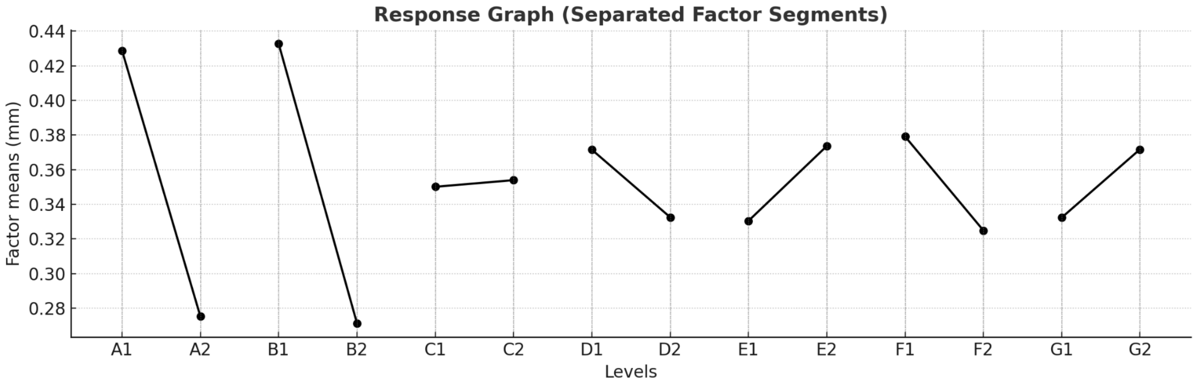

Figure 1. Surface Roughness Effect Plot (Ra)

The main effect plot shows the change in the average surface roughness (Ra) with each factor of machining (A-G) between Level 1 and Level 2. All the points indicate the average value of Ra of all the experimental runs at the given level. The more the inclination between the Level 1 and Level 2, the greater the impact of that factor on surface roughness.

Factor B – Spindle Speed

Factor B displays the most negative slant between Level 1 and Level 2.

It shows the largest effect. It means that higher spindle speeds (3000 rpm to 4500 rpm) have a far greater negative effect on Ra. Faster spindle speeds produce better chip removal, decreased rubbing and smoother cut so it is not surprising that this factor will dominate the result.

Factor A – Face Mill Diameter

The decrease in the Ra with the change of Level 1 (Ø25 mm) to Level 2 (Ø16 mm) is also large in Factor A.

A smaller cutter will decrease tool deflection and vibrations that enhance stability and offer a finer surface finish. The high change in the Ra attests to the fact that tool geometry is a significant influence on obtaining machining quality.

Factor F – Conventional vs Climb

Factor F is shifted downwards significantly, which means that the climb milling (Level 2) provides better surface finish, compared to traditional milling. Climb milling decreases rubbing on tool entry and also decreases tearing of the surface.

The changes in factors E, G and D between levels are minimal, which means that stepover, coolant condition, and cutting depth do not have much impact on the surface roughness throughout the tested conditions. Equally, the main-effect line of (C) is nearly flat indicating that the level of Ra does not change with either feed level. All in all, these aspects have significantly less significant effects than spindle speed, tool diameter and milling strategy.

5 CONCLUSION

The Taguchi analysis reveals that the spindle speed (B) has the greatest effect on the surface roughness, and then face mill diameter (A). Faster spindle speeds of the machine minimize friction and enhance the chip formation, giving a smoother surface whereas the small cutter diameter minimizes tool vibration which is a significant source of poor finish.

The effect of (C) is nearly negligible in the tested range, i.e. both levels of the feed can stabilize the cutting regime and have no significant effect on Ra. The impact of factors D, E, F, and G is smaller because they have a second impact on tool load and thermal stability.

The optimal surface roughness of 0.105 mm as predicted is less than any experimental situation and thus this is an indication that a confirmation run is required. The Taguchi model presupposes the additive nature of effects and little interactions among them, so the experimental validation of real machining conditions might yield some different output.