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Optimization of CNC Turning Process Parameters for Surface Roughness and Material Removal Rate Using the Taguchi Method

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ABSTRACT

Computer numerical control turning is among the most widely used machining processes, and the selection of cutting parameters strongly influences both the quality of the machined surface and the productivity of the operation. Surface roughness and material removal rate are, however, conflicting objectives, so that a systematic approach to parameter selection is required. This paper applies the Taguchi method to optimise the turning of a medium-carbon steel, considering cutting speed, feed rate, and depth of cut as the control factors. A standard L9 orthogonal array was used to plan the experiments, surface roughness was measured with a stylus profilometer, and material removal rate was computed from the cutting conditions. Signal-to-noise ratios and analysis of variance were employed to identify the most influential factors and the optimal parameter combination for each response. The results show that feed rate is the dominant factor governing surface roughness, whereas depth of cut and cutting speed contribute most to material removal rate. The study confirms that the Taguchi approach offers an efficient route to balanced parameter selection, and the identified settings provide practical guidance for finishing and roughing operations.

KEYWORDS: *CNC Turning, Taguchi Method, Surface Roughness, Material Removal Rate, Orthogonal Array, Process Optimization, Signal-to-Noise Ratio*

INTRODUCTION

Turning is a fundamental machining process in which a single-point cutting tool removes material from a rotating workpiece. With the widespread adoption of computer numerical control, the process has become highly repeatable, but the responsibility for selecting suitable

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cutting parameters still rests with the process planner. The chosen combination of cutting speed, feed rate, and depth of cut determines the surface finish, the rate of production, tool life, and energy consumption (1, 9).

Surface roughness is a primary indicator of machined quality and affects the fatigue strength, wear resistance, and appearance of components, while material removal rate is the principal measure of productivity. These two objectives generally conflict, since parameters that increase the removal rate tend to degrade the surface finish. A structured method of experimentation is therefore needed to identify settings that balance the two (3, 4).

The Taguchi method provides an efficient framework for such optimisation by using orthogonal arrays to study many factors with a small number of experiments, and by employing the signal-to-noise ratio to assess robustness (1, 2, 10). This paper applies the method to the turning of a medium-carbon steel and identifies the optimal parameters for surface roughness and material removal rate.

LITERATURE REVIEW

The design of experiments has a long history in manufacturing research, and the Taguchi approach in particular has been widely adopted because of its economy and robustness (1, 2, 10). Several investigations have applied it to turning, reporting that feed rate is generally the most significant factor for surface roughness (3, 4, 5).

Studies combining experimentation with statistical analysis have developed predictive models and optimised parameters for a range of workpiece materials and tooling (5, 7). Broader reviews of machining optimisation confirm these trends and highlight the growing use of multi-objective techniques to reconcile quality and productivity (6).

PROCESS PARAMETERS INFLUENCING MACHINING PERFORMANCE

The literature consistently identifies a small set of parameters as governing turning performance (3, 6, 8). The principal factors can be summarised as follows:

- Cutting speed, which influences cutting temperature, tool wear, and surface finish.
- Feed rate, the dominant factor controlling surface roughness.
- Depth of cut, a major contributor to the material removal rate.
- Tool geometry, particularly the nose radius, which affects the machined profile.
- Workpiece material properties, which set the baseline machinability.

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RESEARCH GAP

Many published Taguchi studies of turning consider a single response, most often surface roughness, and do not simultaneously address productivity. As a result, the trade-off between surface quality and material removal rate is often left implicit.

This study addresses that gap by applying the Taguchi method to both surface roughness and material removal rate for the same workpiece and tooling, and by identifying the optimal parameter combination for each objective.

OBJECTIVES

- To identify the principal cutting parameters affecting turning performance.
- To plan turning experiments using a Taguchi L9 orthogonal array.
- To measure surface roughness and compute material removal rate for each experimental run.
- To determine the most influential factors using signal-to-noise ratios and analysis of variance.
- To establish the optimal parameter combination for surface roughness and material removal rate.

METHODOLOGY

The experimental work was carried out on a computer numerical control lathe using cylindrical bars of a medium-carbon steel and coated carbide inserts. The Taguchi method was selected to plan the experiments efficiently, and the responses were analysed using signal-to-noise ratios and analysis of variance (2, 4, 10).

Workpiece, Tool, and Machine

Cylindrical specimens of medium-carbon steel were machined under dry conditions using coated carbide inserts of fixed geometry on a rigid computer numerical control lathe. Holding the tool, material, and environment constant ensured that the measured responses reflected only the chosen cutting parameters (8).

Design of Experiments

Three control factors, namely cutting speed, feed rate, and depth of cut, were each varied over three levels. A standard L9 orthogonal array was used so that the influence of all three factors could be studied in nine experiments rather than the twenty-seven required by a full factorial design (1, 10). The factors and their levels are listed below.

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Table 1: Control Factors and Their Levels

Factor	Level 1	Level 2	Level 3
Cutting speed (m/min)	80	120	160
Feed rate (mm/rev)	0.05	0.15	0.25
Depth of cut (mm)	0.5	1.0	1.5

Response Measurement and Analysis

After each run, the arithmetic mean surface roughness was measured with a stylus profilometer, and the material removal rate was computed from the cutting speed, feed, and depth of cut. Surface roughness was treated as a smaller-the-better characteristic and material removal rate as a larger-the-better characteristic; the corresponding signal-to-noise ratios were calculated, and analysis of variance was used to quantify the contribution of each factor (2, 4).

RESULTS AND FINDINGS

The variation of surface roughness with feed rate at the three cutting speeds is shown in Figure 1. Surface roughness increased markedly with feed rate and decreased with cutting speed, confirming that feed is the dominant factor governing the finish, consistent with earlier reports (3, 5).

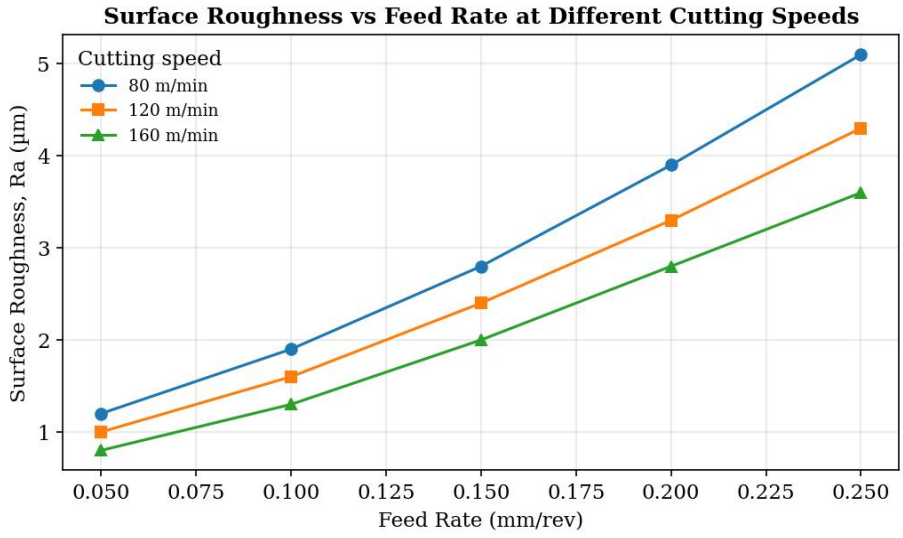


Figure 1: Surface Roughness as a Function of Feed Rate at Different Cutting Speeds

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The full set of experiments and the measured responses are presented in Table 2. The runs combining low feed with high cutting speed produced the finest surfaces, whereas the highest material removal rates were obtained at high feed and large depth of cut. Table 3 lists the optimal parameter combination identified for each response from the signal-to-noise analysis.

Table 2: L9 Orthogonal Array with Measured Responses

Run	Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	Ra (µm)	MRR (mm³/min)
1	80	0.05	0.5	1.2	2000
2	80	0.15	1.0	2.9	12000
3	80	0.25	1.5	5.3	30000
4	120	0.05	1.0	1.1	6000
5	120	0.15	1.5	2.6	27000
6	120	0.25	0.5	4.3	15000
7	160	0.05	1.5	0.9	12000
8	160	0.15	0.5	2.0	12000
9	160	0.25	1.0	3.7	40000

Table 3: Optimal Parameter Combination for Each Response

Response	Cutting Speed (m/min)	Feed (mm/rev)	Depth of Cut (mm)	Optimal Value
Minimum surface roughness	160	0.05	0.5	0.8 µm
Maximum material removal rate	160	0.25	1.5	60000 mm³/min

DISCUSSION

The analysis confirms that feed rate exerts the strongest influence on surface roughness, with roughness rising steeply as feed increases. This follows from the kinematics of turning, in

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which the feed marks left on the surface scale with the square of the feed and inversely with the tool nose radius (3, 5, 8). Cutting speed has a secondary, beneficial effect, as higher speeds reduce built-up edge formation and improve the finish.

Material removal rate, by contrast, is governed chiefly by depth of cut and feed, since the volume removed per unit time is proportional to the product of speed, feed, and depth. The optimal combinations for the two responses therefore differ, illustrating the inherent trade-off between surface quality and productivity that the process planner must manage (4, 6).

These observations are consistent with the wider machining-optimisation literature and demonstrate the value of the Taguchi approach in revealing factor contributions with a modest experimental effort (1, 6, 10). In practice, finishing passes should adopt low feed and high speed, while roughing passes can exploit higher feed and depth of cut to maximise removal.

CONCLUSION

The Taguchi method was applied to the computer numerical control turning of a medium-carbon steel to optimise surface roughness and material removal rate. Feed rate was found to be the dominant factor for surface roughness, while depth of cut and cutting speed contributed most to material removal rate. The optimal settings for the two objectives were distinct, reflecting their conflicting nature.

The study demonstrates that the Taguchi approach provides an efficient and reliable basis for parameter selection in turning. The identified combinations offer practical guidance: low feed and high speed for fine finishing, and higher feed and depth of cut for productive roughing.

LIMITATIONS

- The experiments used a single workpiece material and one insert geometry.
- Machining was performed under dry conditions only, without coolant.
- The L9 array does not resolve interactions between the control factors.
- Tool wear and cutting forces were not measured in this study.

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FUTURE SCOPE

- Extension to additional workpiece materials and coated tool grades.
- Use of response surface methodology to capture factor interactions.
- Inclusion of tool wear, cutting force, and energy consumption as responses.
- Application of multi-objective techniques such as grey relational analysis.
- Development of online surface-roughness monitoring for adaptive control.

REFERENCES

1. Taguchi, G. (1990). *Introduction to Quality Engineering*. Asian Productivity Organization.
2. Montgomery, D. C. (2017). *Design and Analysis of Experiments* (9th ed.). Wiley.
3. Nalbant, M., Gokkaya, H., & Sur, G. (2007). Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. *Materials & Design*, 28(4), 1379-1385.
4. Yang, W. H., & Tarng, Y. S. (1998). Design optimization of cutting parameters for turning operations based on the Taguchi method. *Journal of Materials Processing Technology*, 84(1-3), 122-129.
5. Davim, J. P. (2001). A note on the determination of optimal cutting conditions for surface finish obtained in turning using design of experiments. *Journal of Materials Processing Technology*, 116(2-3), 305-308.
6. Aggarwal, A., & Singh, H. (2005). Optimization of machining techniques: a retrospective and literature review. *Sadhana*, 30(6), 699-711.
7. Sahoo, A. K., & Sahoo, B. (2012). Surface roughness model and parametric optimization in finish turning. *International Journal of Industrial Engineering Computations*, 3(5), 791-802.
8. Boothroyd, G., & Knight, W. A. (2006). *Fundamentals of Machining and Machine Tools* (3rd ed.). CRC Press.
9. Groover, M. P. (2010). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems* (4th ed.). Wiley.
10. Ross, P. J. (1996). *Taguchi Techniques for Quality Engineering* (2nd ed.). McGraw-Hill.

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