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Optimization of Process Parameters to Improve Surface Roughness for SS 431/301 on CNC Machine

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ABSTRACT

Manufacturing engineers and production personnel play a crucial role in maintaining a competitive edge through efficient production processes. This project employs the Taguchi parameter optimization approach to enhance CNC lathe machining by minimizing surface roughness. Key parameters optimized include cutting speed, feed rate, and depth of cut. An L9 orthogonal array was used to determine the optimal combination of these parameters for the lowest surface roughness. Surface roughness for each combination was measured and evaluated using signal-to-noise (S/N) ratios. The results indicate that the Taguchi method is an effective technique for optimizing machining parameters, leading to improved surface quality. This study highlights the importance of systematic parameter optimization in achieving superior product quality and performance in manufacturing processes. By identifying the optimal settings for cutting speed, feed rate, and depth of cut, significant improvements in surface roughness were achieved, demonstrating the practical benefits of the Taguchi method in industrial applications. Future work could explore additional parameters and their interactions to further enhance machining performance.
Keywords:
CNC lathe, surface roughness, Taguchi method, parameter optimization, orthogonal array, signal-to-noise ratio.

1. INTRODUCTION

Machining processes play a pivotal role in modern manufacturing, enabling the production of precise components with desired surface finishes. Achieving optimal surface finish is crucial in various industries, including aerospace, automotive, and medical, as it directly impacts the functionality, aesthetics, and performance of machined parts.

Stainless steel, renowned for its corrosion resistance, strength, and durability, is extensively utilized in engineering applications. However, machining stainless steel poses challenges due to its inherent hardness and propensity to work harden during cutting operations. Therefore, understanding the effects of machining parameters on surface finish is imperative to enhance productivity and quality in stainless steel machining processes.

This project investigates how machining parameters—speed, feed rate, and depth of cut—affect surface finish quality in stainless steel using CNC lathe machining. Understanding these effects is crucial for enhancing productivity and achieving desired surface finishes in engineering applications. By systematically varying these parameters and analyzing their impact on surface finish, this study aims to identify optimal machining conditions for stainless steel components. A more methodical approach to setting parameters should be used to ensure that the operation meets the desired level of quality without sacrificing production time. Rather than just setting a very low feed rate to assure a low surface roughness, for example, an experimental method might determine that a faster feed rate, in combination with other parameter settings, would produce the desired surface roughness and will also not affect production rate.

1.1 PROBLEM STATEMENT

Work on our project was done to estimate following problems observed

1. The surface finish while Finishing, Turning, milling on a CNC Lathe machine is not uniform and optimal.
2. Poor quality workpieces.
3. Every time a new material is machined, the optimal parameter must be determined.

1.2 OBJECTIVES

1. To Investigate experimentally the machining parameters (Speed, Feed, Depth of cut) For Finishing, Turning Milling on CNC Machine.
2. To measure surface finish for all experiment.
3. To recommend the optimum values of machining parameters for better surface finish.

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2. LITERATURE REVIEW

Navneet K Prajapati et al. (2013) [1]

Aim of this experimental investigation is to evaluate the effects of the process parameters on AISI 316 austenitic stainless steel work piece surface roughness and material removal rate by employing design of experiment using L27 array and Analysis of Variance (ANOVA) using PVD coated Cermets tool on CNC lathe under dry environment. The AISI 316 austenitic stainless steel is the most widely used grade among the other grades of austenitic stainless steel. It is used for aerospace components and chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for the milder chemicals.

K. Chandrasekaran et.al (2013) [2]

Martensitic stainless steels (AISI410) are widely used in engineering applications. AISI 410 has good mechanical properties because of high chromium content and high carbon content. A surface property such as surface roughness (SR) is critical to the function-ability of machined components. AISI410 are generally regarded as more difficult to machine material and results in poor surface finish. Optimized machining parameters are very important for controlling the required surface quality

PG Benardos et al. (2002) [3]

In this paper, a neural network modeling approach is presented for the prediction of surface roughness (Ra) in CNC face milling. The data used for the training and checking of the networks' performance derived from experiments conducted on a CNC milling machine according to the principles of Taguchi Design of Experiments (DoE) method. The factors considered in the experiment were the depth of cut, the feed rate per tooth, the cutting speed, the engagement and wear of the cutting tool, the use of cutting fluid and the three components of the cutting force

M Kaladhar et al.(2010)[4]

This paper deals with the optimization of machining parameters in turning of AISI 202 austenitic stainless steel using CVD coated cemented carbide tools. During the experiment, process parameters such as speed, feed, depth of cut and nose radius are used to explore their effect on the surface roughness (Ra) of the work piece. The experiments have been conducted using full factorial design in the Design of Experiments (DOE) on Computer Numerical Controlled (CNC) lathe. Further, the analysis of variance (ANOVA) was used to analyze the influence of process parameters and their interaction during machining.

Aman Aggarwal et al.(2005) [5]

In this paper an attempt is made to review the literature on optimizing machining parameters in turning processes. Various conventional techniques employed for machining optimization include geometric programming, geometric plus linear programming, goal programming, sequential unconstrained minimization technique, dynamic programming etc. The latest techniques for optimization include fuzzy logic, scatter search technique, genetic algorithm, Taguchi technique and response surface methodology.

J Bala Raju et al.(2013) [6]

In the present research, modelling the distribution of the resulting surface roughness values, in fine turning of aluminium 6061, using wiper insert tools has been undertaken these study will enable the assessment of process variability with respect to surface roughness in fine turning. Thought some studies on these particular aspect have been done , a different approach has been used in the current study. The important parameters discussed here are cutting speed, feed , depth of cut , nose radius and rake angle.

B Kantharaj et al.(2012) [7]

The purpose of this paper is to study the effect of speed, feed and depth of cut on surface roughness (Ra) and cutting force (Fc) in turning mild steel using high speed steel cutting tool. Experiments were conducted on a precision centre lathe and the influence of cutting parameters was studied using analysis of variance (ANOVA) based on adjusted approach. Based on the main effects plots obtained through full factorial design, optimum level for surface roughness and cutting force were chosen from the three levels of cutting parameters considered. Linear regression equation of cutting force has revealed that feed, depth of cut, and the interaction of feed and depth of cut significantly influenced the variance. In case of surface roughness, the influencing factors were found to be feed and the interaction of speed and feed. As turning of mild steel using HSS is one among the major machining operations in manufacturing industry, the revelation made in this research would significantly contribute to the cutting parameters' optimization.

M. S. Ranganath et al.(2014) [8]

The manufacturing industries are very much concerned about the quality of their products. They are focused on producing high quality products in minimum cost. Surface roughness is one of the crucial parameters that have to be controlled within suitable limits for

a particular process. Therefore, prediction or monitoring of the surface roughness of machined components has been an important area of research.
In the present research, modelling the distribution of the resulting surface roughness values, in fine turning of Aluminium 6061, using wiper insert tools has been undertaken. This study will enable the assessment of the process variability with respect to surface roughness in fine turning. Though some studies on this particular aspect have been done, a different approach has been used in the current study. The important parameters discussed here are cutting speed, feed depth of cut, nose radius and rake angle. In the second part of this study, predictive equations for use in predicting the surface roughness values have been developed in terms of five important variables cutting speed, feed, depth of cut, nose radius and rake angle.

3. METHODOLOGY

Taguchi methodology

The Taguchi method, developed by Genichi Taguchi, focuses on reducing process variation through robust experimental design to produce high-quality products at low cost. Using orthogonal arrays, the method efficiently investigates how different parameters affect a process's mean and variance, minimizing the number of experiments needed. It is ideal for scenarios with an intermediate number of variables (3 to 50), few interactions between variables, and significant contributions from only a few variables.
Orthogonal arrays allow for systematic exploration of numerous factors, providing comprehensive insights with minimal tests. This helps manufacturers identify optimal parameter combinations for best results. The method also employs the signal-to-noise (S/N) ratio, comparing desired performance (signal) to background unpredictability (noise), to assess and enhance process robustness. Additionally, the Taguchi method incorporates a loss function to calculate the cost of deviating from target performance, guiding efforts to minimize variance and improve quality.
Overall, the Taguchi method offers a structured and efficient approach to quality improvement and process optimization, enabling consistent production of high-quality products cost-effectively.

3.1 Process parameters:

1. **Cutting Speed:** Cutting speed refers to the speed at which the cutting tool engages with the workpiece. It is the linear speed of the tool related to the workpiece at the point of contact and is typically measured in (m/min)
   - **Calculation:**

     Conting speed can be calculated by using the formula $V = \frac{\pi.D.N}{1000}$

     Where,
     - V = Cutting Speed (m/min)
     - D = Diameter of the workpiece (mm)
     - N = Speed (RPM)

2. **Feed Rate:** Feed rate is the distance the cutting tool along the length of the workpiece per revolution of the spindle. It is usually measured in millimeters per revolution (mm/rev) or inches per revolution (in/rev)
   - **Calculation:**

     Feed rate can be calculated using formula:

     $$F=N.\ f$$

     Where:
     - F = Feed rate (mm/min or in/min)
     - N = Spindle speed (RPM)
     - f = Feed per tooth (mm/tooth or in/tooth)

3. **Depth of Cut:** Depth of cut is the thickness of the material layer removed in one pass of cutting tool. It is the critical parameter influencing the volume of material removed and is measured in millimeters (mm) or inches (in)
   - **Calculation:**

     Depth of cut is generally set based on the machining operation and workpiece geometry. It does not have a direct formula for calculation but is chosen based on machining strategy and tool capabilities.

3.2 Material Selection for Experiment:

- A Literature Review finds that material is selection is not covered in many studies material selection is a vital elements in optimization procedures. Choose materials with broad industrial applications that are not overly focused, allowing for further optimization. Stainless steel is widely recognized popular material.
- The selection of stainless steel 431/301 for our project on optimization process parameters to improve surface roughness on CNC machine was likely based on several important factors here’s detailed explanation of why these Material might have been chosen:

3.3 Chemical composition of stainless steel:

Grade	Constituent	Chromium (Cr)	Nickel (Ni)	Silicon (Si)	Manganese (Mn)	Phosphorus (P)	Sulphur (S)
SS431	%Composition	15-17%	1.5-2.5%	1%Max	1.00%Max	0.040%Max	0.03%Max
SS301	%Composition	16-18%	6-8%	1%Max	2.00%Max	0.045%Max	0.03%Max

3.4 Physical properties of stainless steel:

Grade	Properties	Metric
SS431	Density	7.8 g/cm^3
	Module of Elasticity	200 Gpa
	Electrical Resistivity	720 nΩ.m
	Melting Point	1482 °C
SS301	Density	7.8 g/cm^3
	Module of Elasticity	193 Gpa
	Electrical Resistivity	695 nΩ.m
	Melting Point	1421 °C

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3.5 Mechanical properties of Stainless steel:

- **SS431:**
  - Tensile Stress - 862 Mpa
  - Yield Stress - 655 Mpa
  - Elongation - 20 %
  - Hardness - 285 HB (Brinell)
- **SS301:**
  - Tensile Stress - 1276 Mpa
  - Yield Stress - 965Mpa
  - Elongation - 9.00%
  - Hardness - 285 HB (Brinell)

3.6 Response parameters:

- **Surface Roughness (Ra):**

Surface roughness is a quantitative measure of a surface's texture, defined by the vertical deviations from its ideal form. It is one of the primary surface texture parameters that influences how a surface interacts with its surroundings and other surfaces.

- **Importance:**

Surface roughness is an important parameter because it directly affects:
Friction and Wear: Rougher surfaces tend to have higher friction and wear rates.

- **Fatigue Resistance**: Smoother surfaces improve fatigue resistance by lowering stress levels.
- **Corrosion Resistance**: Surface roughness can influence the rate and nature of corrosion.

- **Aesthetics**: A product's visual appeal is frequently influenced by its surface finish.
- **Mechanical Performance**: Controlling surface roughness is critical for parts that interact or fit together.

3.7 Factors Affecting Surface Roughness in CNC Lathe Machining:

1. Cutting Parameters
2. Tool Geometry
3. Tool Material & Coating
4. Machine Tool Condition
5. Coolant and Lubrication

4. ANALYSIS & EXPERIMENTAL RESULT

4.1 Design of Experiment Using Taguchi Method:

The Taguchi method is robust design approach for optimizing process parameters to improve quality and performance. It uses a systematic, statistical method to determine the optimal settings of control factors, thereby minimizing variation and improving the overall quality. In the context of our project on improving surface roughness for stainless steel 431/301 on a CNC machine, the Taguchi method helps identify the best combination of machining parameters.

4.1.1 Identification of Control Factors and Levels:

We select the control factors that significantly affect the surface roughness and defined there levels.

- **Control Factors:**
  - A: Cutting Speed (m/min)
  - B: Feed Rate (mm/rev)
  - C: Depth of Cut (mm)
- **Levels:**

For each factor, we choose three levels

- Cutting Speed: 1600,1800,2000 m/min
- Feed Rate: 0.10,0.15,0.20 mm/rev
- Depth of cut: 0.4,0.5,0.6 mm

4.1.2 Selection of Orthogonal array:

Orthogonal arrays are used in the Taguchi method to design experiments efficiently. They allow for the systematic and balanced study of multiple factors and their interactions with a minimal number of experiments. An orthogonal array ensures that each factor is independently assessed while covering all possible combinations of factor levels.

- **Selecting the L9 Orthogonal Array:**

  The L9 orthogonal array is suitable for experiments with three factors, each at three levels. It significantly reduces the number of experiments needed while still allowing for the study of each factor and their interactions. Here's why the L9 array was selected:

1) **Efficiency:**
- Instead of conducting 27 experiments (full factorial), only 9 experiments are needed.
- This reduction saves time, resources, and effort.

2) **Balance and Orthogonality:**
- Each level of each factor is tested the same number of times (3 times), ensuring balanced representation.
- The orthogonal array structure ensures that the factors are varied independently of each other, allowing clear identification of the effects of each factor on the response variable (surface roughness).

3) Applicability:

- The L9 array is specifically designed for three factors at three levels each, matching the requirements of your experiment.
- It allows for the analysis of main effects and some interactions without requiring an excessive number of trials.

4) Statistical Significance:

- The L9 array provide statistically significant insights into the effects of the factors and their optimal levels.
- The Taguchi method, utilizing orthogonal arrays, helps in identifying not only the optimal settings but also the robustness of the process.

4.1.3 Structure of L9 orthogonal Array:

Experiment	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of cut (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table No. 4.1.3 Structure of L9 orthogonal Array

4.2 Signal to Noise (SN) Ratio:

Definition: The Signal-to-Noise (S/N) ratio is a statistical measure used in the Taguchi method to quantify the robustness of a process by comparing the desired signal (mean performance) to the undesired noise (variability). In essence, the S/N ratio aims to maximize the desired outcome while minimizing the variability caused by uncontrollable factors.

Formula:

The S/N ratio varies depending on the type of characteristic being optimized:

- **Higher is Better:** Used when the goal is to maximize the response.

$$\text{S/N ratio} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

- **Nominal is Best:** Used when the goal is to achieved a target value.

$$\text{S/N ratio} = 10\log\left(\frac{\bar{y}^2}{\frac{1}{n-1}\sum_{i=1}^{n}(y_i-\bar{y})^2}\right)$$

- **Smaller is Better:** Used when the goal is to minimized the response.

$$\text{S/N ratio} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}y_i^2\right)$$

Where,

- Yi are the observed value of the response characteristics.
- n is the number of observations.

4.2.1 Importance of S/N ratio:

1. **Optimization and Robustness:**
   - The S/N ratio helps identify the best combination of controllable process parameters (cutting speed, feed rate, depth of cut) that result in least variation in surface roughness, ensuring consistent quality.
2. **Noise Reduction:**
   - By considering the variability (Noise), the S/N Ratio ensures that the chosen parameters are robust against uncontrollable environmental factors, leading to reliable and predictable outcomes.
3. **Efficiency:**
   - The Taguchi method, combined with the S/N ratio, allow for efficient experimentation by reducing the number of trials needed to determine optimal settings. This saves time, resource, and cost associated with extensive experimentation.
4. **Quantitative Measure:**
   - The S/N ratio provides a quantitative measure to compare different sets of parameters, making it easier to identify the best combination objectively rather than relying on subjective judgment.
5. **Enhance Quality Control:**
   - By minimizing surface roughness variability, the overall quality and performance of the machined parts are enhanced, leading to better customer satisfaction and reduced rework or rejection rates.

4.2.2 S/N Ratio for Response Characteristics:

- The parameters that influence the output are divided into two categories: controllable and uncontrollable elements. Looking at the amount of variance in the response allows you to rapidly identify control aspects that may contribute to lower variation. The uncontrolled elements are the primary sources of variation in the operational environment. The table shows the response characteristics for this experiment.

Response Name	Response Type
Surface Roughness	Smaller is Better

Table No. 4.2.2 Response Characteristics

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4.3 Signal to Noise (S/N) Ratio Calculation for "Smaller is Better" Response.

Experiments and Response Values:

Experiment	Cutting Speed (m/min)	Feed Rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (µm)
1	1600	0.10	0.4	0.446
2	1600	0.15	0.5	1.270
3	1600	0.20	0.6	1.610
4	1800	0.10	0.5	2.700
5	1800	0.15	0.6	1.390
6	1800	0.20	0.4	2.020
7	2000	0.10	0.6	3.140
8	2000	0.15	0.4	2.120
9	2000	0.20	0.5	2.940

Table no.4.3 Experiments and Response Values:

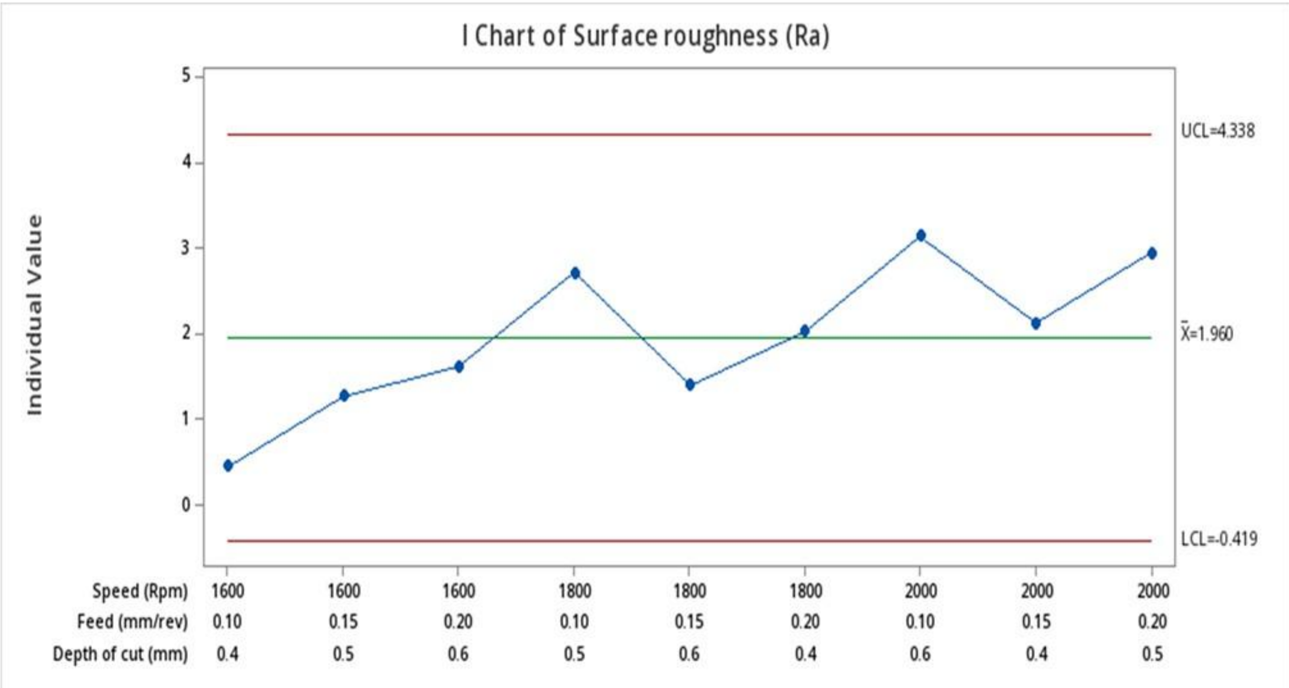

Fig. I chart of Surface Roughness

- **S/N Ratio Formula for "Smaller is Better"**

For "Smaller is Better" response, the S/N ratio is given by:

$$\text{S/N ratio} = -10 \log \left(\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right)$$

Where:

- Yi is the observed surface roughness value for the í-th experiment.
- n is the number of observations (1 in this case for each experiment).

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4.3.1 Experimental Values of S/N Ratio:

Experiment	Cutting Speed (m/min)	Feed (mm/)	Depth of Cut (mm)	Surface Roughness(µm)	S/N Ratio (dB)
1	1600	0.10	0.4	0.446	7.0133
2	1600	0.15	0.5	1.270	-2.0760
3	1600	0.20	0.6	1.610	-4.1365
4	1800	0.10	0.5	2.700	-8.6272
5	1800	0.15	0.6	1.390	-2.8602
6	1800	0.20	0.4	2.020	-6.1070
7	2000	0.10	0.6	3.140	-9.9385
8	2000	0.15	0.4	2.120	-6.5267
9	2000	0.20	0.5	2.940	-9.3669

Table No. 4.3.1 Experimental Values of S/N Ratio

CONCLUSION AND FUTURE SCOPE

Conclusion:

The project successfully demonstrated the application of the Taguchi method for optimizing CNC machining parameters to improve the surface roughness of stainless-steel grades 431 and 301. By systematically investigating the effects of cutting speed, feed rate, and depth of cut, we identified the optimal combination of parameters that minimized surface roughness. The use of an L9 orthogonal array allowed for efficient experimentation, reducing the number of trials while providing robust and reliable data.

The analysis of the Signal-to-Noise (S/N) ratios indicated that the optimal parameters were a cutting speed of 1600 m/min, a feed rate of 0.10 mm/rev, and a depth of cut of 0.4 mm. These settings consistently resulted in the best surface finish, as confirmed through additional validation experiments. The findings highlighted the significant impact of these parameters on surface roughness and demonstrated the effectiveness of the Taguchi method in process optimization.

Implementing the optimized parameters in practical CNC machining operations will lead to improved surface quality, increased efficiency, and cost savings. The reduced need for trial-and-error adjustments enhances production consistency and reliability, providing manufacturers with a clear and actionable set of guidelines for machining stainless steel 431/301.

Overall, this project contributes valuable insights into the optimization of CNC machining processes, offering a practical framework that can be applied to various materials and machining conditions. The successful application of the Taguchi method in this context underscores its utility in achieving high-quality manufacturing outcomes, ultimately benefiting the broader manufacturing industry.

Future Scope:

Future Scope of the Project

The optimization of CNC machining parameters for stainless steel 431 and 301 has provided valuable insights and practical guidelines for improving surface roughness. However, there are several areas for future exploration and development that can further enhance the findings and broaden the impact of this project:

1. Extended Material Range:

Future studies could extend the methodology to other stainless-steel grades and different materials such as titanium alloys, aluminum alloys, and composite materials. This would help to generalize the optimization techniques and validate their applicability across a wider range of materials.

2. Advanced Cutting Tools and Coatings:

Investigate the effects of using advanced cutting tools and coatings, such as diamond-coated tools or tools with specialized geometries, on surface roughness. This could lead to even better surface finishes and longer tool life, particularly for hard-to-machine materials.

3. Integration with Industry 4.0 Technologies:

Incorporate Industry 4.0 technologies such as machine learning, IoT (Internet of Things), and real-time monitoring to further optimize

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machining parameters. Smart sensors and data analytics could provide continuous feedback and enable adaptive control of machining processes for consistent quality improvement.

4. Multi-Objective Optimization:

Expand the optimization framework to consider multiple objectives simultaneously, such as minimizing surface roughness, tool wear, and machining time. Multi-objective optimization techniques can help find a balanced solution that meets various performance criteria.

5. Tool Wear and Life Analysis:

Include the study of tool wear and tool life as additional response parameters. Understanding how different machining parameters affect tool longevity could lead to more cost-effective and sustainable machining practices.

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