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OPTIMIZATION PROCESS PARAMETERS IN CNC TURNING USING ANOVA AND GREY RELATIONAL ANALYSIS

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ABSTRACT

Turning operations play a vital role in modern manufacturing by shaping components through controlled material removal. The quality of machined parts is primarily influenced by surface roughness, MRR, and dimensional accuracy. Improper selection of machining parameters can lead to poor surface finish, reduced productivity, increased tool wear, and higher production costs. Therefore, optimizing these parameters is essential for achieving high-quality and cost-effective manufacturing. This study is undertaken to optimize CNC turning parameters to improve machining performance. The objective is to identify the most significant factors affecting surface roughness, accuracy, and MRR, and to establish the optimal combination of spindle speed, feed rate, and depth of cut. A structured methodology is adopted, incorporating literature review, experimental design, statistical analysis, and validation. A Taguchi-based experimental is used for systematically plan experiments and evaluate the influence of process parameters. The Signal-to-Noise (S/N) ratio is employed to assess process robustness, while Analysis of Variance (ANOVA) is applied to determine the statistical importance and part of each factor. To address the multi-response optimization problem, Grey Relational Analysis (GRA) is utilized to convert multiple performance characteristics into a single relational grade, enabling the identification of optimal machining conditions. Confirmation experiments are conducted to verify the effectiveness of the optimized parameters. The results are expected to identify key influencing factors, determine optimal cutting conditions, and enhance surface quality, dimensional accuracy, and productivity. This study provides practical insights for improving CNC turning operations and contributes to the advancement of machining optimization techniques.

KEYWORDS: CNC turning, Analysis of Variance (ANOVA), Signal-to-Noise Ratio, Grey Relational Analysis, Taguchi Method, Surface Roughness, Material Removal Rate (MRR)

1. INTRODUCTION

CNC Turning (Computer Numerical Control Turning) is an advanced machining process used to produce cylindrical or tapered components from materials such as metals, plastics, and wood. In this process, a CNC lathe rotates the workpiece at controlled speeds while a cutting tool removes unwanted material to achieve the required shape and size. Owing to its precision and versatility, CNC turning is extensively used in industries such as aerospace, automotive, and general engineering for manufacturing components like shafts, bushings, fasteners, and other precision parts.

A CNC turning service involves the application of computer-controlled technology to perform accurate and repeatable machining operations. The process begins with the creation of a part design using Computer-Aided Design

(CAD) software. This design is then translated into machine-readable instructions through Computer-Aided Manufacturing (CAM) software, resulting in a CNC program. The program defines essential machining parameters, including cutting-speed, feed-rate, depth of cut, tool selection, and tool path.

The CNC lathe is a sophisticated machine equipped with a rotating spindle to hold the workpiece, a turret that accommodates multiple cutting tools, and precision-controlled axes that enable accurate tool movement. During machining, tools such as inserts, boring bars, and threading tools are employed to progressively shape the material. The entire operation is executed automatically according to the programmed instructions, ensuring consistent and precise material removal.

CNC turning offers several advantages, including high accuracy, improved productivity, and excellent repeatability. It allows the production of complex geometries with tight tolerances while minimizing human intervention and error. Furthermore, the automation of the process ensures uniform quality across large production batches. This level of consistency and reliability is particularly crucial in sectors such as aerospace and automotive, where component performance and safety are of paramount importance.

2. PROBLEM STATEMENT

Surface quality, typically evaluated through surface roughness, is a vital parameter in machining and a primary indicator of product performance and acceptability. Along with dimensional accuracy and tool durability, it significantly affects the functionality, reliability, and service life of machined components. Achieving a smooth surface finish while preserving tool life is essential for maintaining both quality standards and cost efficiency.

Surface roughness is governed by multiple factors, including the hardness of the workpiece, cutting tool geometry, and machining parameters such as cutting speed, feed rate, and depth of cut. Among these, process parameters are particularly important because they can be directly controlled and optimized. With increasing demands for higher productivity and improved product quality, CNC machining has become a preferred choice in modern manufacturing environments.

Although CNC turning offers excellent precision and repeatability, the generation of surface roughness is a complex and dynamic process. It is influenced by controllable variables—such as spindle-speed, feed-rate, and depth of cut—as well as un-controllable factors like tool geometry, machine vibrations, and the material characteristics of both the tool and workpiece. A clear understanding of these interactions is necessary for effective process control and optimization.

To improve machining outcomes and overall productivity, it is significant to enlarge reliable analytical models for surface roughness. This study adopts a structured methodology that combines multi-objective optimization with robust statistical design techniques. The Taguchi method is used to design experiments and determine optimal parameter levels, while Analysis of Variance (ANOVA) is applied to review the significance of each factor. This integrated approach enables the identification of the most effective machining conditions to attain the preferred surface quality.

3. SELECTION OF RAW MATERIAL

Following a comprehensive review of prior studies, a range of potential materials was examined for this work, including Inconel 718, aluminum bronze, EN8D carbon steel, brass (63/37), AISI 4340 steel, OHNS steel, AISI 304 stainless steel, EN8 steel, Al7075 alloy, and Aluminum 6061. These materials were selected for consideration due to their broad industrial usage and diverse mechanical and machining characteristics.

After evaluating the study objectives and machining requirements, Aluminum 6061 was chosen as the workpiece material. This alloy is widely utilized in aerospace, automotive, and general manufacturing sectors because of its balanced properties. It provides good machinability, moderate strength, and strong resistance to corrosion, which are essential for consistent machining performance.

Furthermore, Aluminum 6061 is well-suited for CNC turning operations as it allows stable cutting conditions and produces a relatively smooth surface finish. Its ability to maintain dimensional accuracy across different machining parameters makes it an appropriate material for optimization studies. These characteristics ensure reliable experimental results and make it a practical choice for analyzing the influence of machining parameters on performance outcomes.

Selection of Cutting Tool

A variety of cutting tools were reviewed based on earlier studies and industrial applications, including tungsten carbide tools, carbide inserts, coated carbide tools ($TiCN/Al_2O_3/TiN$), uncoated carbide tools, and cubic boron nitride (CBN) tools. Each tool type offers distinct benefits depending on machining conditions and workpiece material. Considering the properties of Aluminum 6061 and the objective of achieving high surface quality and productivity, a **cemented carbide insert** was selected. This tool is preferred due to its high hardness, strong wear resistance, good thermal conductivity, and capability to operate efficiently at higher cutting speeds and feed rates. It also contributes to improved surface finish and dimensional precision, making it suitable for CNC turning applications.

Materials and Methods

The methodology adopted in this study is designed to be systematic and efficient, focusing on optimizing machining parameters with minimal experimental effort. Established methods are applied with appropriate references, while only key procedural aspects are highlighted.

Taguchi Method

The Taguchi method, introduced by Genichi Taguchi, is a robust experimental design technique used to enhance quality by minimizing variability. It employs orthogonal arrays to study multiple process parameters with a reduced number of experiments. The method also uses Signal-to-Noise (S/N) ratios to evaluate performance and identify optimal parameter settings that are less sensitive to external disturbances.

Grey Relational Analysis (GRA)

Grey Relational Analysis is used for multi-response optimization problems. Based on grey system theory, it deals with incomplete or uncertain information by converting multiple performance measures into a single grey relational grade. This enables simultaneous optimization of responses such as surface roughness and MRR. When combined with the Taguchi method, GRA overcomes the limitation of single-response optimization.

Analysis of Variance (ANOVA)

ANOVA is a statistical technique used to evaluate the significance and contribution of process parameters. In this study, it is performed using Minitab to examine the result of cutting-speed, feed-rate, and depth of cut on machining responses. It helps identify the most influential factors and supports parameter optimization.

Surface Roughness

Surface roughness represents the quality of the machined surface and is subjective by cutting conditions, tool geometry, material properties, and machine stability. It is measured using techniques such as stylus profilometry. Improved surface finish enhances wear resistance, corrosion resistance, and overall component performance.

Material Removal Rate (MRR)

MRR is an indicator of machining efficiency, representing the quantity of material removed per unit time. It depends on cutting parameters such as speed, feed, and depth of cut. While higher MRR increases productivity, it must be balanced with surface quality and tool life.

Signal-to-Noise Ratio

The S/N ratio is used within the Taguchi framework to assess process robustness. A higher S/N ratio indicates better performance with reduced variability, helping determine optimal machining conditions.

Regression Analysis

Regression analysis is applied to develop mathematical models that describe the relationship between input parameters and output responses. These models can be linear or non-linear and are useful for prediction, optimization, and understanding parameter interactions in CNC turning processes.

4.RESULTS

Analysis of Variance (ANOVA):

Analysis of Variance (ANOVA) was applied to evaluate the cause of machining parameters on the selected responses and to recognize the most important factors. This statistical technique enables the assessment of individual parameter contributions as well as their interactions, providing a clear understanding of how cutting-speed, feed-rate, and depth-of-cut affect machining performance.

The ANOVA results indicate that feed rate has the greatest influence on surface roughness (Ra), followed by spindle speed and depth of cut. Based on the statistical analysis, the optimal combination of machining parameters for minimizing surface roughness is identified as:

Feed rate: Level 1 (0.21 mm/min)
Depth of cut: Level 2 (0.18 mm)
Spindle speed: Level 1 (500 rpm)

This combination yields improved surface finish under the given machining conditions.

5. CONCLUSIONS

An experimental investigation on CNC-turning of Al Alloy 6061-T6 was successfully carried out using a Taguchi L9 orthogonal array. The study considered spindle-speed, feed-rate, and depth-of-cut as input parameters, while surface roughness (Ra) and material removal rate (MRR) were taken as performance responses. Based on the experimental analysis, the following conclusions are drawn:

1. Influence of Parameters (ANOVA Results):

Feed-rate is the most dominant factor affecting surface roughness, followed by spindle-speed and depth-of-cut.

Spindle speed has the highest influence on MRR, with feed-rate and depth-of-cut having comparatively lower effects.

2. Multi-response Optimization (GRA + ANOVA):

Grey-Relational-Analysis combined with ANOVA reveals that feed rate is the parameter influencing both surface roughness and MRR.

Spindle speed shows moderate influence, whereas depth-of-cut has the least effect on overall performance.

3. Parameter Significance:

Both feed-rate and spindle-speed significantly affect machining responses, while depth of cut plays a relatively minor role within the selected range.

4. Model Validation:

The developed predictive models demonstrate good agreement with experimental results, achieving approximately 98% accuracy for surface roughness, 85% for MRR, and 87% for grey relational grade, all within acceptable error limits.

REFERENCES

1. Y. K. Hwang, C. M. Lee "Optimization of-Turning Operations-with Multiple Performance-Characteristics Using the Taguchi-Method and Grey Relational Analysis Journal of Materials Processing Technology Year:2009
2. S. Datta, A. Bandyopadhyay, P. K. Pal "Grey-Based Taguchi Method for Optimization of Surface -Roughness in Turning"International Journal of Advanced-Manufacturing Technology Year:2008
3. K. Kaladhar, K. Venkata Subbaiah, Ch. Srinivasa Rao "Optimization of Process-Parameters in Turning of AISI 202 Austenitic Stainless-Steel Using Taguchi Method and ANOVA"International Journal of Engineering-Science and Technology Year:2011
4. M. Nalbant, H. Gökkaya, G. Sur "Application of Taguchi-Method in the Optimization of Cutting- Parameters for Surface-Roughness in Turning"Journal:Materials & DesignYear:2007
5. R. S. Pawade, S. S. Joshi, P. K. Brahmankar "Effect of Machining Parameters and Cutting Edge Geometry on Surface Roughness and Cutting-Forces in Hard Turning Using CBN-Tools" International Journal of Machine-Tools and Manufacture Year:2008
6. S. Thamizhmanii, S. Saparudin, S. Hasan "Analyses of Surface Roughness by Turning-Process Using Taguchi Method" Journal of Achievements in Materials and Manufacturing Engineering Year:2007
7. M. A. Mannan, M. S. Hussain, N. Ahmad "Optimization of Machining-Parameters in CNC Turning Using Taguchi Method" International Journal of Engineering Research and Applications Year: 2012
8. J. Paulo Davim"A Note on the Determination of Optimal Cutting-Conditions for Surface Finish Obtained in Turning Using Design of Experiments" Journal of Materials-Processing Technology Year:2001
9. B. Bhattacharyya, S. Doloi, S. S. Sorkhel "Experimental Investigation for Surface-Roughness in CNC Turning Using Taguchi Method" International Journal of Advanced-Manufacturing Technology Year:2009
10. R. Kumar, S. Chauhan "Study on Surface Roughness Measurement for Turning of Al 7075/10/SiCp Composite Using Taguchi Method" International Journal of Advanced-Manufacturing Technology Year: 2015.