International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Experimental Investigation on Machining Parameter Optimization for Surface Finish in Face Milling Using Taguchi Method

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ABSTRACT

This research focuses on optimizing milling parameters to minimize surface roughness during face milling of cast iron, stainless steel, and mild steel. The investigation considers three major variables—spindle speed, feed rate, and depth of cut—each studied at three different levels. To design the experiments efficiently, the Taguchi L9 orthogonal array method was employed. The selected workpiece were prepared in sizes of 250×150×275 mm for cast iron, 300×200×25 mm for stainless steel, and 800×400×20 mm for mild steel. All machining trials were carried out on a bed-type Huron milling machine, where cutters of 125 mm, 80 mm, and 125 mm diameters were used respectively for the three materials. A total of nine experimental runs were conducted for each workpiece as per the Taguchi design. After machining, surface roughness values were measured using a surface roughness tester to evaluate the quality of the machined surfaces. To analyze the performance, a loss function was applied to estimate the deviation between the obtained results and the desired outcomes. In accordance with Taguchi's recommendations, the results were further transformed into signal-to-noise (S/N) ratios. These ratios provide a measure of quality, where higher values correspond to better performance of the machining process. By comparing the mean S/N ratio for each factor level, the influence of spindle speed, feed, and depth of cut on surface finish was quantified. The software Minitab 19 was used to perform the S/N analysis and determine the most suitable combination of parameters. The optimization study revealed that the ideal settings were A3B1C2 for cast iron, A3B2C1 for stainless steel, and A2B2C1 for mild steel. A confirmation test validated these results, showing that the chosen parameters significantly improved the surface finish. Overall, the optimized milling conditions were successful in reducing surface roughness and enhancing machining quality.

Keywords- Surface Roughness, Face Milling, Cutting Parameters, Taguchi Method, Optimization

1. INTRODUCTION

The demand for higher productivity and better Machinability has become a constant requirement in modern manufacturing industries, as both quality and output strongly influence competitiveness in today's market. The level of product quality directly affects customer satisfaction during its usage, making it a critical concern for every production unit. At the same time, productivity remains equally significant since it is closely linked with profitability and the overall reputation of an organization. In metalworking sectors, the emphasis is on achieving superior quality and higher production rates for machined components. To meet these objectives, each stage of the process must be carefully monitored, and selected machining parameters must be evaluated against predefined quality standards. This study proposes the integration of intelligent optimization techniques to model and improve CNC machining processes effectively. Such approaches can be applied, with minimal adjustments, across a wide range of conventional machining operations. The expected benefits include enhanced precision, increased production efficiency, improved quality, capability to handle complex geometries, cost minimization, greater repeatability, reduced manufacturing expenses, and ultimately higher profitability. In this work, Taguchi's parameter design methodology is adopted as a structured framework for optimizing process variables to minimize surface roughness in face milling operations. Surface finish is considered a vital indicator of technological quality because it has a strong impact on both manufacturing cost and product performance. A finely machined surface contributes to improved fatigue life, resistance to corrosion, better wear characteristics, and reduced creep effects. Moreover, surface roughness influences friction, lubrication capability, thermal and electrical contact resistance, as well as reflective properties. For these reasons, specific surface roughness values are often prescribed, and machining conditions are carefully selected to achieve them. Surface roughness is commonly evaluated using parameters such as Ra, Rz, and Rq. In recent years, extensive research has been carried out in the field of modeling and optimizing surface roughness under varying machining conditions. For instance, Kıvak examined the influence of cutting tools, cutting speed, and feed rate on both surface roughness and tool wear in the turning of steel using the Taguchi method (TM). Similarly, Stipkovic Filho developed a predictive model relating cutting speed, feed, and depth of cut to surface roughness in steel turning by applying the response surface methodology (RSM).

2. PROBLEM IDENTIFICATION

In modern face milling practices, attaining a fine and accurate surface finish remains one of the major concerns for manufacturing industries. The roughness of a machined surface significantly affects component performance, assembly precision, and service life, particularly in cases where strict dimensional tolerances are required. The final surface quality, however, is highly dependent on multiple machining variables such as spindle speed, feed rate, depth of cut, and tool configuration. An inappropriate choice of these parameters not only results in poor finish but also accelerates tool wear and lowers overall productivity. Although numerous studies have been carried out to optimize these cutting parameters, their effects vary widely depending on the material being machined and the operating environment. Traditional optimization strategies typically rely on large numbers of trial experiments, which can be expensive and time-intensive. To overcome these challenges, the Taguchi method provides a structured and economical approach for determining the best combination of process parameters while minimizing experimental effort. While this statistical technique has been extensively applied in manufacturing research, there is still a lack of comprehensive studies that evaluate its effectiveness for reducing surface roughness in face milling under diverse machining conditions and material types. This review paper aims to fill that gap by examining past research, comparing experimental frameworks, and assessing both the advantages and shortcomings of the Taguchi approach. Furthermore, it highlights opportunities for future investigations that could advance parameter optimization and contribute to improved surface quality in milling operations.

3. RESEARCH OBJECTIVES

Based on the identified problem, the present study has been designed with the following objectives:

1. To determine the optimal cutting parameters for milling operations on different work materials such as cast iron, stainless steel, and mild steel.
2. To prepare the experimental setup for machining operations, which includes selecting a suitable milling machine capable of performing the required operations and choosing milling cutters of appropriate diameters for each of the selected materials?
3. To select the cutting parameters along with their three levels of variation for cast iron, stainless steel, and mild steel.
4. To adopt an appropriate experimental methodology that can systematically conduct the trials and meet the stated objectives.
5. To analyze the experimental results by evaluating surface roughness and thereby identify the most effective set of process parameters for milling operations.

4. METHODOLOGY

To optimize process parameters and enhance the quality of manufactured components, the Taguchi method is employed, which is fundamentally a statistical approach. Originally developed by Genichi Taguchi in collaboration with Konishi, this method was primarily intended to improve product quality and strengthen manufacturing processes. Over time, its scope of application has expanded beyond manufacturing and is now widely used in various engineering fields, including areas such as biotechnology. Taguchi’s contributions have been particularly recognized by statisticians for advancing the design of experiments and for effectively studying variation in processes. The strength of the Taguchi method lies in its systematic way of classifying parameters into control factors and noise factors. By carefully selecting and adjusting control factors, the negative impact of noise factors can be minimized, thereby achieving consistent and optimized results. To design experiments efficiently, orthogonal arrays (OA) are used. The experimental results obtained from these arrays are then analyzed to predict and evaluate the quality of the final product. In this study, the L9 orthogonal array of the Taguchi method is implemented. This array accommodates three variables—depth of cut, spindle speed, and feed rate—each tested at three levels (Level 1, Level 2, and Level 3). The use of the Taguchi method significantly reduces the number of required experiments while still providing reliable insights. Its simplicity, efficiency, and effectiveness make it a powerful tool for optimizing machining parameters and improving process performance.

5. SURFACE ROUGHNESS RESULT

In this study, milling operations were carried out on nine specimens prepared from three different materials, and the surface roughness of each specimen was measured using a surface roughness tester. To evaluate the deviation between the obtained results and the target value, a loss function was defined. As suggested by Taguchi, the loss function is used to quantify the departure of a quality characteristic from its desired value. The calculated loss function values are then converted into a Signal-to-Noise (S/N) ratio. In S/N ratio analysis, quality characteristics are generally classified into three categories: lower-the-better, larger-the-better, and nominal-the-better. The S/N ratio for each level of the process parameters is determined based on these categories. In all cases, a higher S/N ratio indicates better performance of the quality characteristic. Hence, the optimal process parameters are identified as those corresponding to the maximum S/N ratio.

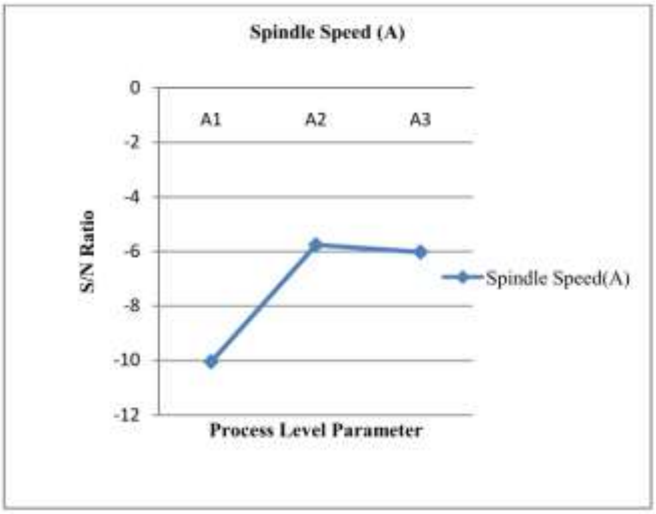

Figure 5.1 Spindle Speed (A) Vs S/N ratios for MS

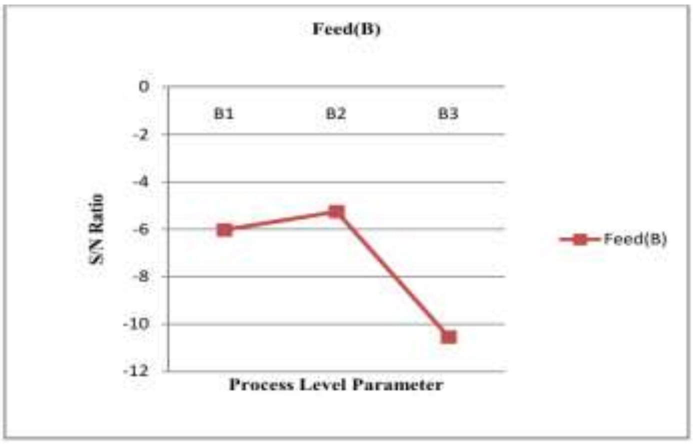

Figure 5.2 Feed (B) Vs S/N ratio for MS

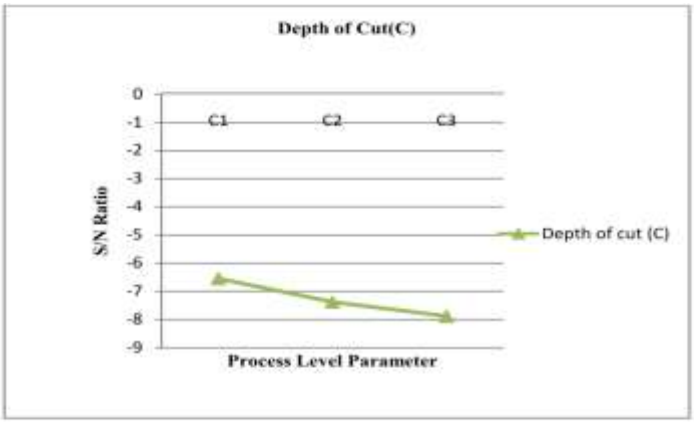

Figure 5.3 Depth of cut (C) Vs S/N ratio for MS

6. CONCLUSION

This experiment was carried out to optimize milling process parameters with the objective of minimizing surface roughness in face milling operations. Three different types of workpiece cast iron, stainless steel, and mild steel—were selected for the study. The dimensions of the workpiece were 250 × 150 × 275 mm for cast iron, 300 × 200 × 25 mm for stainless steel, and 800 × 400 × 20 mm for mild steel. To conduct the trials, the Taguchi parametric design approach was employed. This method is widely preferred because of its simplicity and effectiveness in handling engineering problems, as it reduces the number of experiments by using a suitable orthogonal array. For this study, an L9 orthogonal array was chosen with three variables, each at three levels. Milling operations were performed on a Huron milling machine using cutters of 125 mm, 80 mm, and 125 mm diameters for cast iron, stainless steel, and mild steel respectively. To evaluate the deviation of the measured values from the desired values, a loss function was defined in accordance with Taguchi's methodology. The calculated loss function was then converted into a signal-to-noise (S/N) ratio. In S/N analysis, quality characteristics are generally categorized as lower-the-better, larger-the-better, or nominal-the-better. The S/N ratio for each parameter level was computed, with higher S/N values indicating better performance. Hence, the optimum process parameters correspond to the levels with the maximum S/N ratio. To further quantify the influence of each parameter, the mean S/N ratio at every level of parameters A, B, and C was determined. Parameters showing a larger difference across their levels were considered to have a stronger effect on surface roughness. For cast iron, parameter B exhibited the greatest influence, while parameter A had the least impact. In stainless steel, parameter A showed the highest effect, whereas parameter C contributed minimally. In the case of mild steel, parameter B again had the strongest influence, while parameter C had the least effect. Based on the S/N ratio analysis, new sets of optimized operating parameters were identified by selecting the maximum level of each factor.

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