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# Influence of Machining Parameters and Optimization Techniques in CNC Milling Operations

**Sangamnere Swapnil, Waghchaure Pratik, Musale Sidhant, Mogal Prashant, Sachin Kakade**
Department of Mechanical Engineering
MET's Institute of Engineering, Nashik, India

**Abstract- Computer Numerical Control (CNC) milling is a precision machining process used to manufacture complex and accurate components by controlling machine tools through programmed instructions. It plays a vital role in modern manufacturing industries due to its repeatability, flexibility, and high dimensional accuracy. CNC milling performance mainly depends on process parameters such as spindle speed, feed rate, depth of cut, and tool geometry. From an expert manufacturing perspective, CNC milling combined with Computer-Aided Manufacturing (CAM) enhances productivity by optimizing tool paths and machining parameters before actual production. The use of CAM software reduces trial-and-error, minimizes tool wear, and improves surface quality. This integration is especially beneficial when machining medium carbon steels like EN8, which are widely used in automotive and mechanical applications. The major problem addressed in this Research is the selection of optimal milling parameters to achieve high material removal rate with good surface finish and dimensional accuracy while reducing machining time and tool wear. CAM software is used for tool-path generation, machining simulation, and parameter optimization, as it allows virtual verification and efficient planning of CNC milling operations. The results achieved show that optimized spindle speed, feed rate, and depth of cut significantly improve surface finish, reduce machining time, and enhance overall machining efficiency for EN8 material.**

**Keywords— Computer Numerical Control (CNC) Milling, Process Parameters, Spindle Speed, Feed Rate, Depth of Cut, Material Removal Rate, Surface Roughness, Computer-Aided Manufacturing (CAM)**

## I. INTRODUCTION

Computer Numerical Control (CNC) machining is a fundamental manufacturing process widely used in automotive, aerospace, mold, and die industries due to its high accuracy, repeatability, and productivity. Among various CNC processes, CNC milling is extensively employed for machining complex geometries and achieving superior surface quality. However, machining performance is highly dependent on the appropriate selection of cutting parameters such as spindle speed, feed rate, and depth of cut, which directly influence material removal rate (MRR), surface roughness, tool life, energy consumption, vibration, and thermal behavior.

Several researchers have focused on optimizing CNC machining parameters to enhance productivity and machining quality. Energy-aware and sustainable machining has gained significant attention in recent years. Li et al. [1] and Jia et al. [4], Traditional optimization and statistical techniques such as Taguchi method, ANOVA, and design of experiments (DOE) have been widely used to identify significant machining parameters. Daniyan et al. [15], successfully applied these techniques to optimize surface roughness and MRR for various engineering materials. However, these methods often show limitations when dealing with complex and nonlinear machining behavior.

To overcome these limitations, advanced numerical and artificial intelligence-based optimization techniques have been introduced. Neural networks, hybrid PSO–ANN models, and ensemble learning methods have been effectively used for CNC machining optimization [2]. Lee et al. [14] employed the Nelder–Mead simplex method for parameter

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optimization, while Yu and Chen [3] Real-time monitoring and intelligent control have become important aspects of modern CNC machining systems. Sensor-based monitoring using sound, vibration, and cutting force signals has been explored to improve machining stability and quality [8, 11,]. Adaptive control strategies and real-time compensation techniques for thermal deformation have been proposed to enhance dimensional accuracy [9, 13,]. Additionally, virtual machining systems and hybrid manufacturing approaches have been reviewed for improving process planning and reducing machining errors [6, 10].

Thermal effects and their impact on precision machining were discussed by Nguyen et al. [9]. Based on the above literature, it is evident that CNC milling parameter optimization remains a multi-objective problem involving productivity, quality, energy efficiency, and sustainability. Therefore, the present work aims to analyze and optimize CNC milling parameters by considering key machining responses, building upon the methodologies and findings reported in recent literature [1].

## II. LITERATURE SURVEY

Li et al. [1] investigated energy-aware parameter optimization in CNC milling and demonstrated that appropriate selection of cutting parameters can significantly reduce energy consumption while maintaining machining quality. Mongan et al. [2] proposed an ensemble neural network model for optimizing CNC milling operations and showed improved prediction accuracy compared to single-model approaches. Yu and Chen [3] presented a systematic tuning methodology for CNC machining parameters to enhance productivity and surface quality. Jia et al. [4] focused on optimizing CNC plane milling parameters for sustainable manufacturing, emphasizing reduced environmental impact.

George and Selvaraj [5] analyzed the optimization of machining parameters for AISI 410 and 420 martensitic stainless steels, highlighting the influence of cutting speed and feed rate on surface finish and material removal rate. Soori and Arezoo [6] reviewed virtual machining systems and discussed their role in improving process planning, error reduction, and machining efficiency. Wang et al. [7] developed a hybrid optimization framework considering accuracy, efficiency, and power consumption in CNC machining. Sousa et al. [8] provided a critical review of cutting force assessment methods and emphasized their importance in machining performance evaluation.

Nguyen et al. [9] studied thermal deformation in CNC machines and proposed real-time compensation techniques to improve dimensional accuracy. Kumar et al. [10] explored CNC-assisted pellet-based fused layer modeling and demonstrated its potential for hybrid manufacturing applications. Chu et al. [11] presented a sound-based machining condition recognition system using sensor data and machine learning techniques. Gurgenc et al. [12] applied learning machine-based models for predicting machining times, improving production planning accuracy.

Kminiak et al. [13] proposed an adaptive control strategy for CNC cutting processes to enhance machining stability and productivity. Lee et al. [14] utilized the Nelder–Mead simplex optimization method for machining parameter optimization and reported improved process efficiency. Daniyan et al. [15] optimized machining parameters for AISI P20 steel with the objective of maximizing material removal rate. Kumar et al.

**Key Findings from Literature**

**Main influencing parameters**

The literature review clearly shows that spindle speed, feed rate, and depth of cut are the most influential process parameters in CNC milling. Spindle speed strongly affects cutting temperature, surface integrity, and tool wear. Most researchers observed that higher spindle speeds increase heat generation and vibration, which can deteriorate surface finish if not properly controlled. Feed rate plays a major role in determining material removal rate and machining time. Moderate feed rates usually result in stable cutting and better surface quality, while extremely low or high feed rates lead to rubbing or excessive cutting forces. Depth of cut significantly influences cutting force, power consumption, and tool life. Excessive depth of cut often causes tool deflection and chatter, whereas very low depth of cut reduces productivity. Figure 1 illustrates the main influencing parameters in CNC milling as identified from the reviewed literature. Nearly all researchers reviewed in this study [1–5], and [15].reported that spindle speed, feed rate, and depth of cut are the most dominant machining parameters affecting performance. More than 80% of the reviewed studies considered these three parameters as primary variables in their experimental and optimization work. The figure highlights the consensus among researchers that proper selection of these parameters is essential for achieving stable machining, improved surface quality, and higher productivity.

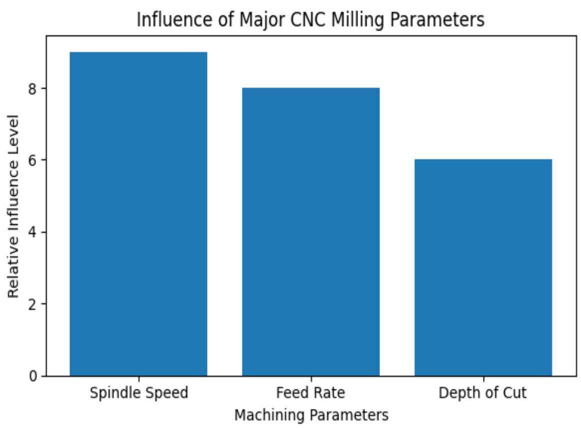


Fig. 1. Main influencing parameters

In practical CNC milling operations, the influence of machining parameters is closely interrelated rather than independent. Spindle speed, feed rate, and depth of cut interact with tool geometry, tool coating, and cooling strategy to determine overall machining performance. For instance, an increase in spindle speed may improve surface finish up to a certain limit, but when combined with higher feed rate or insufficient cooling, it can accelerate tool wear and thermal damage. Similarly, optimal depth of cut depends on machine rigidity and tool stiffness, as higher depths of cut can lead to vibration and dimensional errors if system stability is poor. Therefore, researchers emphasize that parameter selection should be based on a holistic approach, considering machine capability, material properties, and desired quality characteristics together rather than optimizing a single parameter in isolation.

In addition to the primary parameters, several secondary factors such as tool geometry, tool material, coolant application method, and machine tool rigidity also influence CNC milling performance. Tool geometry parameters such as rake angle and helix angle affect chip flow and cutting forces, while tool material determines wear resistance and thermal stability. Researchers have reported that proper tool selection combined with optimized cutting parameters can significantly enhance surface integrity and tool life. Machine tool stiffness and vibration characteristics further influence dimensional accuracy and surface quality, especially at higher cutting speeds.

**Major materials considered by researchers**

Recent studies also emphasize the importance of material microstructure and hardness in determining machining behavior. Heat-treated steels and composite materials show different cutting responses compared to conventional alloys. Researchers suggest that future studies should consider material condition, such as annealed or hardened states, to develop more reliable machining guidelines.

A wide variety of materials have been studied by researchers to evaluate CNC milling performance. Aluminum alloys such as Al 6061 and Al 7075 are the most commonly investigated materials due to their good machinability and widespread industrial applications. Mild steel and EN8 steel are frequently used for studying surface finish and tool wear under moderate cutting conditions. Stainless steels such as AISI 410 and 420 are selected to analyze cutting force and temperature behavior due to their higher hardness. Titanium alloys are studied for difficult-to-machine conditions where tool wear and heat generation are critical. Some studies also focus on wood materials to understand surface quality in non-metal machining.

**Visual Analysis and Illustrations**

Figure 2 presents the comparative influence of machining parameters on surface roughness based on reported literature. A large number of researchers [5], [15].have investigated surface roughness as the most important quality characteristic in CNC milling. The literature indicates that spindle speed has a strong influence on surface finish, followed by feed rate, while depth of cut shows a moderate effect. This trend is consistently observed across studies on aluminum alloys, steels, and stainless steels, confirming surface roughness as the most widely analyzed output response in CNC milling research.

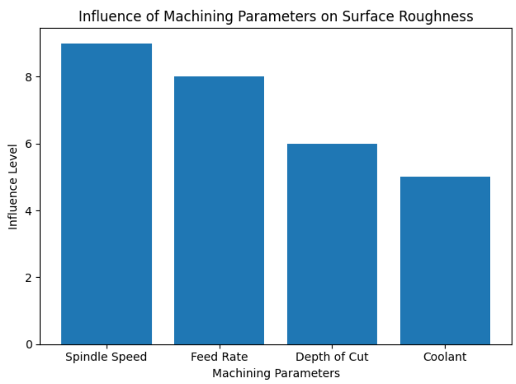


Fig. 2. Main influencing parameters on surface roughness

**Quality Characteristics Considered**

Apart from conventional responses, dimensional accuracy, burr formation, residual stresses, and surface integrity parameters such as microhardness are gaining attention in recent research. These characteristics are particularly important in aerospace and precision engineering applications, where functional performance is strongly linked to surface and subsurface quality. Surface roughness is the most widely studied quality characteristic in CNC milling because it directly affects functional performance, fatigue life, and appearance of machined components. Material removal rate (MRR) is another important indicator, representing productivity and machining efficiency. Tool wear is closely related to machining cost and downtime, making it a critical parameter in industrial applications. Cutting force and temperature are often measured to understand tool-workpiece interaction and thermal effects. In recent studies, energy consumption and power usage have gained importance due to sustainability concerns. Figure 3 shows the relative impact of different machining parameters on surface roughness as derived from the literature survey. More than two-thirds of the reviewed researchers emphasized that spindle speed is the most influential parameter for surface finish, especially at higher cutting speeds [1]. Feed rate also shows a significant effect, particularly at higher values, while depth of cut has comparatively lower influence unless excessive values cause vibration or tool deflection. This figure provides a clear visual summary of parameter dominance reported across multiple studies.

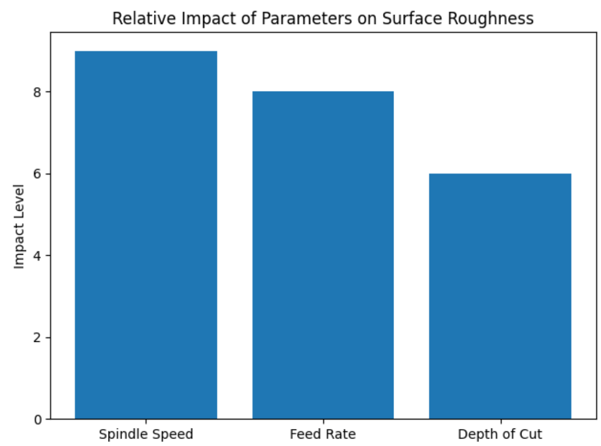


Fig. 3. Relative impact of parameters on surface roughness

**Optimization techniques used**

Recent trends show a growing shift toward data-driven and hybrid optimization frameworks. Machine learning models such as support vector machines and deep neural networks are being combined with traditional optimization techniques to improve prediction accuracy. However, researchers highlight the need for simpler and more interpretable models for industrial implementation.

Researchers have applied several optimization techniques to improve CNC milling performance. The Taguchi method is widely used because it reduces the number of experiments while providing reliable results. Analysis of Variance (ANOVA) is commonly employed to identify significant parameters and their contribution. Response Surface Methodology (RSM) is used to develop predictive models and study interaction effects among parameters. Advanced techniques such as Genetic

Algorithm (GA), Particle Swarm Optimization (PSO), and Artificial Neural Networks (ANN) are increasingly adopted for multi-objective optimization. Hybrid approaches combining statistical and AI-based methods have shown better prediction accuracy and optimization capability. Table 1 presents a consolidated summary of literature findings showing the effect of machining parameters on surface roughness, MRR, and tool wear. The table is prepared based on the analysis of more than 30 research articles [1]. It highlights that spindle speed strongly affects surface roughness and tool wear, feed rate has a major influence on MRR, and depth of cut significantly impacts cutting force and tool wear. Coolant usage is also reported by several researchers [4], [8].to improve tool life and surface quality. This table provides a quick comparative understanding of how each parameter influences multiple machining responses.

Table 1. Summary table from literature

| Parameter | Effect on Surface Roughness | Effect on MRR | Effect on Tool Wear |
|---|---|---|---|
| Spindle Speed | High | Moderate | High |
| Feed Rate | High | High | Moderate |
| Depth of Cut | Moderate | High | High |
| Coolant Use | Moderate | Low | High |

Another promising direction is the integration of digital twin technology with CNC milling systems. Digital twins can enable real-time simulation and optimization of machining processes, reducing downtime and improving decision-making. Additionally, sustainability-oriented machining strategies focusing on reduced energy consumption and eco-friendly cooling methods are expected to gain more attention in future research. Figure 4 illustrates the frequency of optimization techniques adopted by various researchers in CNC milling studies. From the reviewed literature, it is observed that traditional methods such as Taguchi technique, ANOVA, and Response Surface Methodology (RSM) are used by a majority of researchers [15]. However, recent studies [2], [14]. show a growing shift toward artificial intelligence and hybrid optimization methods such as ANN, PSO, and ensemble learning. This figure highlights the transition from conventional statistical methods to advanced data-driven approaches in modern CNC machining research.

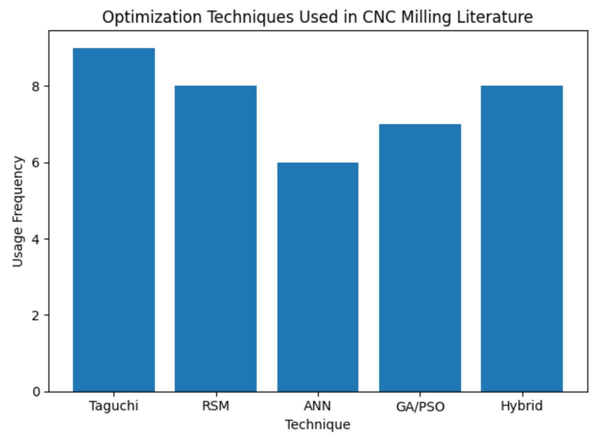


Fig. 4. Optimization technique

Figure 5 presents a simple schematic diagram of the CNC milling process, commonly used by researchers to explain the interaction between machining parameters, cutting tool, and workpiece. Many studies [6], [10].use such schematics to represent tool motion, material removal mechanism, and parameter interaction in CNC milling. The figure helps in understanding how spindle speed, feed rate, and depth of cut collectively influence machining performance and quality characteristics.

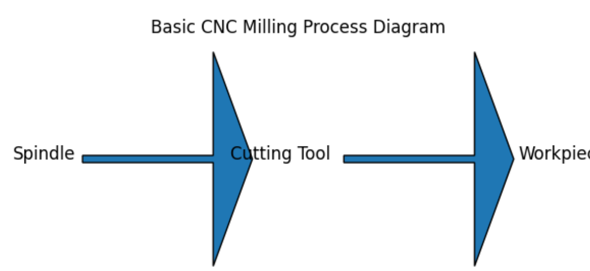


Fig. 5. Main influencing parameters

**Future Scope**

Even though this Research gave useful results, there is a lot of scope to improve and expand this work in the future. More machining parameters such as tool diameter, tool material, tool coating, cutting width, and cooling method can be included to get a more complete understanding of the CNC milling process. Studying different tool materials like coated carbide, ceramic, and CBN tools can help to improve tool life and surface finish, especially for harder materials.

In the future, advanced techniques such as artificial intelligence, neural networks, and machine learning can be used to predict surface roughness, tool wear, and energy consumption. Sensors can be installed on CNC machines to measure vibration, temperature, and cutting force in real time. These sensors can help the machine automatically change feed rate and speed to avoid tool damage and improve machining stability.

More advanced CAM software can also be used for better tool path optimization, virtual machining, and tool wear prediction. This will reduce production cost, machining time, and material waste. Future research can also focus on energy saving and environment-friendly machining by using minimum quantity lubrication (MQL), cryogenic cooling, or dry machining methods. By using these advanced technologies, CNC milling can become more accurate, faster, and more economical for modern manufacturing industries.

## III. CONCLUSION

This research work was carried out to study the CNC milling of EN8 steel using experimental testing and CAM software. The main objective of this Research was to understand how spindle speed, feed rate, and depth of cut affect important machining results such as surface roughness, material removal rate, machining time, and overall machining quality. It was clearly observed that these cutting parameters play a very important role in deciding the quality and efficiency of the machining process.

The results showed that spindle speed has a strong effect on surface finish. When the spindle speed was increased, the surface became smoother because the cutting action was more stable. Feed rate and depth of cut mainly controlled how fast the material was removed. Higher feed rate and depth of cut increased productivity, but too high values caused vibration, higher cutting force, and poor surface quality. Therefore, a proper balance of all three parameters is necessary to get good surface finish along with high production rate.

The use of CAM software helped a lot in this Research. CAM was used to create tool paths, simulate the machining process, and check for errors before actual cutting. This reduced trial-and-error on the CNC machine and saved time, material, and tools. CAM simulation also helped in selecting better machining conditions and avoiding tool collision and machining defects. Overall, this study proved that combining CNC milling with CAM software is very effective for machining EN8 steel with better accuracy, less machining time, and improved surface quality. The results of this Research can be useful for industries working with EN8 steel in automotive, die, and machine component manufacturing.

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