OPTIMIZATION OF CNC MILLING MACHINING PARAMETERS ON PROCESSING TIME AND SURFACE QUALITY USING NANJING SWANSOFT SIMULATION

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Abstract. *Time efficiency and surface quality are two key factors that determine the success of a production process in the modern manufacturing world. This study aims to optimize CNC milling machining parameters for processing time and surface quality by utilizing simulations using the Nanjing Swansoft application. The parameters analyzed include spindle speed, feed rate, and depth of cut. The simulation was performed using an aluminum workpiece and a flat end mill with a diameter of 10 mm. The simulation results show that the combination of spindle speed 1500 RPM, feed rate 300 mm/min, and depth of cut 1 mm produces a stable, efficient machining process and produces a good surface finish without cutting errors. The obtained cutting speed of 47.12 m/min is considered suitable for aluminum material. The use of the Swansoft application has proven effective as a learning medium and virtual testing of machining parameters without the risk of tool damage or high costs. Thus, this digital simulation can be a practical solution in CNC training, especially for students and novice operators, and provides a strong foundation before the machining process is carried out directly on a real machine.*

Keywords: *CNC Milling; Machining Optimization; Nanjing Swansoft; Simulation; Surface Quality.*

1. INTRODUCTION

Efficiency and quality are crucial factors in determining industrial competitiveness in the modern manufacturing era. One manufacturing process widely used for precision component production is CNC (Computer Numerical Control) milling, due to its advantages in accuracy, speed, and the ability to process a variety of complex geometric shapes.(“A Comprehensive Review on Optimization of Process Variables for CNC Milling,” 2023)However, the success of a CNC milling process is greatly influenced by the selection of appropriate machining parameters, such as spindle speed, feed rate, and depth of cut. These parameters directly affect machining time and workpiece surface quality, both of which are key indicators of production process performance. (Ali Laghari & Mekid, 2023). A common problem faced by students and novice operators in CNC machining is the difficulty in determining the optimal combination of machining parameters directly on a real machine. This is caused by various factors, such as limited practice time, the high risk of damage to tools and machines, and the significant operational costs if experiments are carried out repeatedly. Furthermore, in an industrial context, direct experiments on production machines have the potential to disrupt work schedules, which can result in production delays and a decrease in the efficiency of the overall manufacturing system. These challenges make the learning process and search for optimal parameters ineffective if only relying on physical practice in a workshop or laboratory.

Addressing these challenges requires an alternative approach that is safer, more cost-effective, and more flexible, particularly for learning and initial research. This approach should be able to simulate various machining scenarios visually and realistically, without the risk of damaging the tool or wasting material. In this context, the use of CNC simulation software such as Nanjing Swansoft is a highly relevant solution. Digital simulation can facilitate users to comprehensively test and analyze variations in machining parameters, allowing students and operators to gain a better understanding of the parameters' influence on process time and surface quality, before applying them to a real machine. One solution is the use of simulation software such as the Nanjing Swansoft CNC Simulator. This application allows users to simulate various CNC processes visually and interactively, including setting machining parameters, selecting cutting tools, and observing process results virtually. (Vichare et al., 2018) By utilizing Swansoft, students can conduct experimental analysis on various machining parameters to determine the most optimal combination in producing efficient processing time and the best surface quality.

This research takes the title "Optimization of CNC Milling Machining Parameters on Process Time and Surface Quality using Nanjing Swansoft Simulation" as a scientific effort to answer the problem. The reason for choosing this title is based on the urgency of mastering CNC technology and the use of digital simulation in the manufacturing engineering learning process. In addition, the results of this study are also expected to provide recommendations for optimal machining parameters, which are not only useful in the context of educational laboratories, but also relevant for applications in small and medium industries (SMEs).

2. LITERATURE REVIEW

2.1 CNC Milling Machine

A CNC (Computer Numerical Control) machine is a machine tool that is automatically controlled by a computer through pre-programmed numerical instructions.(Kumar et al., 2023a)A CNC (Computer Numerical Control) milling machine is an automatic machine tool controlled by a computer system to carry out the process of cutting materials precisely using a rotating cutting tool by moving the work table or cutting tool in various coordinate axes according to a predetermined program.(Kumar et al., 2023b).

This machine is used to perform various manufacturing processes such as cutting, drilling, turning, and milling with a high degree of precision. It works by moving a cutting tool (such as a chisel or endmill) to carve and remove material from the workpiece according to a predetermined program.

2.2 G-Code

G-Code (Geometric Code) is a standard programming language used to instruct CNC machines to perform certain movements, such as cutting, drilling, and tool movement. (Lynn et al., 2020) G-code contains numeric commands that control the direction of motion (X, Y, Z), cutting speed, spindle speed, and other machine functions. Using a CNC simulator in learning and training has several advantages over direct practice on the machine. These advantages relate to safety, cost efficiency, and learning effectiveness. (Knoke & Thoben, 2021).

3. RESEARCH METHODS

This research uses a quantitative approach with a focus on the simulation of the production process on a milling machine using the Nanjing Swansoft application. The research was conducted at the UM West Sumatra campus, Faculty of Engineering, Department of Mechanical Engineering, from May to August 2025. The method used consists of several structured stages as can be seen in Figure 1 of the following research flowchart:

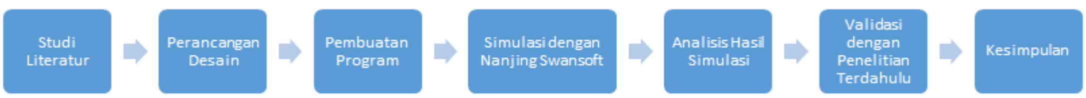

Figure 1. Research Flowchart

1. Literature Study

This stage aims to collect and review relevant theories regarding the CNC milling machining process, machining parameters (such as cutting speed, feed rate, and depth of cut), and their effects on process time and surface quality. The literature used includes scientific journals, manufacturing engineering textbooks, and references related to the use of Nanjing Swansoft software.

2. Design Planning

Based on the results of the literature study, an experimental design was conducted in the form of selecting machining parameter variables to be optimized, workpiece design, and simulation scenario formulation. This design includes the configuration of a virtual CNC machine in Nanjing Swansoft, tool selection, and cutting strategy.

3. Program Creation

At this stage, the CNC program code (G-code) is compiled based on the previously designed machining parameters and scenarios. This program will be used in the simulation to represent the actual cutting process in a virtual environment.

4. Simulation with Nanjing Swansoft

The program code was then run in the Nanjing Swansoft CNC Simulator software. Simulations were performed for each combination of machining parameters to obtain processing time data and predict surface finish. This simulation also minimizes the risk of actual errors and saves resources.

5. Simulation Results Analysis

Cutting Speed (Vc)

Cutting speed (Vc) is the ability of the cutting tool to cut the workpiece safely, producing a total in units of length/time (m/minute). (Duplak et al., 2023). Cutting speed can be calculated based on the following equation 1:

$$Vc = \frac{\mu d n}{1000}$$

Where:

Vc : Cutting speed (m/min)
d : Workpiece diameter (mm)
n : Object rotation (Rpm)
π : Constant value (3.14)

Feed Rate (F)

The speed of movement of the cutting tool relative to the workpiece in mm/minute. (Khan et al., 2017). The feeding speed can be calculated using the following 2 equations:

$$F = f \times n$$

Where:

F : Feeding speed (mm/min)
F : amount of feed or tool shift (mm/rev)
N : engine speed (Rpm)

Depth of Cut (Deep of Cut / a)

The depth of cut is determined based on the power of the machine, the power of the cutting tool, and the hardness of the material.

6. Validation Stage with Previous Research

The validation phase aims to ensure that the methods and results obtained in this study are consistent and reliable with existing scientific references. Validation was performed by comparing the process parameters and simulation results obtained from the Nanjing Swansoft application with those from relevant previous research.

4. RESULTS AND DISCUSSION

4.1 Design Planning

Design planning is the initial stage in the CNC programming and machining simulation process. In this stage, the user creates a model or design of the workpiece component that will be processed virtually using a CNC machine. Users can create workpiece designs directly in AutoCad or Solidworks applications which will later be imported into the Nanjing Swansoft application. In the design planning, specifications such as the shape, size, and radius of the workpiece design are determined. In this study, the design was designed with dimensions of 240 mm x 60 mm x 40 mm made from aluminum. The design plan in this study can be seen in Figure 2 below:

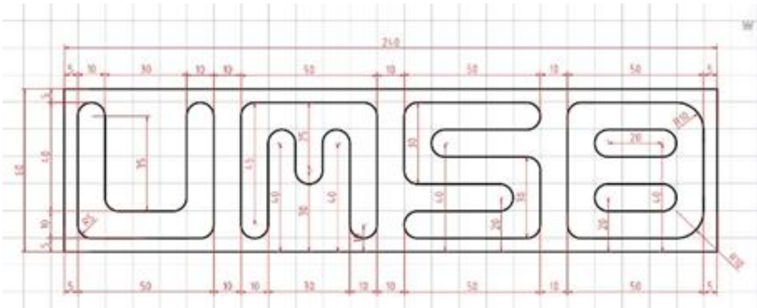

Figure 2. Design plan

4.2 Program Creation (G-Code)

At this stage, users can manually create CNC programs by typing G and M codes using the editor feature available within the Nanjing Swansoft application. The entered CNC program must match the workpiece design and must be free of syntax errors to ensure smooth and accurate simulation.

4.3 Simulation with Nanjing Swansoft Application

CNC milling simulation in the Nanjing Swansoft application begins with preparing the main materials, namely a computer with the Swansoft application installed, a workpiece design, and a CNC program in the form of G-code. The first stage is selecting the appropriate type of CNC milling machine, such as a 3-axis milling machine. Next, the user can write the CNC program manually through the in-app editor or import G-code from CAM software. The next stage is setting the machining parameters, such as the size and type of workpiece material used, the type of tool (such as a flat end mill), spindle speed, and feed rate. The workpiece used in this study is aluminum. After the parameters are set, the user determines the zero point as the initial reference for the cutting process, usually placed in the upper left corner of the workpiece surface, which can be seen in Figure 3 below:

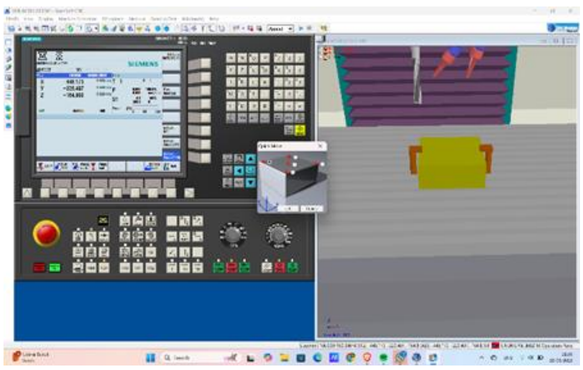

Figure 3. Determination of Zero Point

The simulation can be run by pressing the "Run Simulation" button, and the application will display the machining process visually in the form of 3D animation, complete with the movement of the cutting tool on the X, Y, and Z axes. Users can directly see the cutting path, cut depth, and estimated processing time. If errors occur such as tool collisions with the workpiece or overcuts, the system will provide a warning. After the simulation is complete, users can analyze the final workpiece results and compare them with the initial design. If the results are satisfactory, the CNC program can be saved and used for practice on a real CNC machine. This process is very useful for learning the CNC machining workflow thoroughly and safely, without the risk of damaging equipment or materials. The simulation process in Nanjing Swansoft can be seen in Figure 4 below:

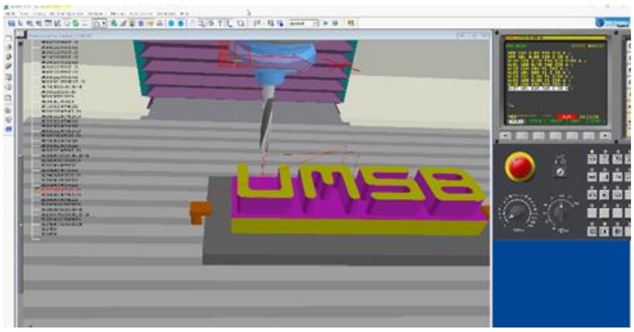

Figure 3. Determination of Zero Point

4.4 Analysis of Simulation Results

In the CNC milling simulation process using the Nanjing Swansoft application, the analysis is carried out based on the main machining parameters, namely spindle speed, cutting speed, feed rate, and depth of cut. These parameters greatly affect the final result of the workpiece, time efficiency, and durability of the cutting tool. In this simulation, an aluminum workpiece with dimensions of 240 mm × 60 mm × 40 mm is used, as well as a flat end mill type cutting tool with a diameter of 10 mm. The spindle speed used is 1500 RPM which is the rotational speed of the cutting tool towards the workpiece. This spindle speed produces a cutting speed (Vc) of approximately 47.12 m/min, calculated based on:

$$Vc = \frac{3,14\ x\ 10\ x\ 1500}{1000}$$

Vc = 47.12 m/min

The feed rate is set at 300 mm/min, meaning the cutting tool moves 300 mm per minute in the feed direction. This is balanced to produce smooth cuts without overloading the machine or tool. Meanwhile, the depth of cut is set at 1 mm per pass, which is the depth the tool enters the workpiece surface each time it cuts.

Based on visual simulations in Swansoft, the combination of these parameters resulted in efficient cutting with a smooth surface finish and relatively fast machining times. No collisions or toolpath errors were observed, and the process ran smoothly according to the programming sequence. From this simulation, it can be concluded that selecting the right parameters significantly impacts the quality of the results and the safety of the CNC milling process. The Swansoft application has proven effective in assisting parameter analysis and virtual validation of CNC programs before being applied to a real machine.

This research is based on a number of previous studies that emphasize the importance of using virtual simulation in optimizing the CNC Milling machining process. Rizki, A. and his colleagues in their research entitled "Analysis of CNC Programming Time Efficiency Using Swansoft CNC Simulator on a 3-Axis Milling Machine", found that the use of virtual simulation can reduce program checking time by up to 35% compared to conventional methods. This finding shows that Swansoft is effective as a learning tool as well as early planning in the machining process. (Soori et al., 2024). Furthermore, Yuliana, T. and Prasetyo, D. (2020) through their study entitled "Implementation of Virtual CNC Simulation to Reduce the Risk of Product Failure in Mechanical Engineering Vocational Schools", concluded that the use of virtual simulation was able to reduce the level of student errors in programming CNC machines in real life. This was because students had previously understood the tool motion path and program code through simulation. (Soliman et al., 2021). In addition, Putra, R. (2022) in his research "Swansoft-Based Virtual CNC Milling Simulation for Machining Process Effectiveness in Educational Environments", emphasized that Swansoft is very helpful in detecting program errors, such as syntax errors and potential tool collisions, before the machining process is carried out directly. (Ntemi et al., 2022) n is done directly (Ntemi et al., 2022). Thus, the use of a CNC simulator not only increases time and cost efficiency, but also minimizes the risk of errors during actual practice.

CONCLUSION

Based on the results of research and simulations conducted using the Nanjing Swansoft application, it can be concluded that the setting of machining parameters such as spindle speed, feed rate, and depth of cut have a significant influence on the process time and surface quality of the workpiece. Virtual CNC milling simulations have proven effective in helping students and novice operators to understand and test parameter combinations safely, efficiently, and risk-free. In this study, the use of a 10 mm diameter flat end mill tool, a spindle speed of 1500 RPM, a feed rate of 300 mm/min, and a depth of cut of 1 mm resulted in a stable, smooth machining process without path errors. The resulting cutting speed of 47.12 m/min also shows a suitable value for efficient aluminum machining. Through Swansoft simulations, the optimization process can be carried out interactively without the need for a physical CNC machine, making it very suitable for application in learning environments and early research. Thus, the use of simulation software such as Nanjing Swansoft can be an effective solution in supporting the manufacturing engineering education process while providing a strong foundation for real-world applications in the industry.

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