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Analysis of the Effect of Cutting Parameter Variations (Depth of Cut) on Specific Energy Consumption (SEC) in the CNC Machining and Milling Process at PT XYZ

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Abstract— *CNC milling is a widely used manufacturing process in industry due to its high precision and productivity. However, this process requires significant electrical energy consumption, requiring precise cutting parameter settings to improve energy efficiency. This study aims to analyze the effect of variations in depth of cut on Specific Energy Consumption (SEC) in the CNC milling process and to determine the most efficient cutting conditions based on the SEC value. The study was conducted at PT XYZ using a CNC milling machine with FC300 (Gray Cast Iron) workpiece material and a 63 mm diameter face mill tool using a WNMU0906 insert. The research method used was an experimental method with two depth of cut variations: 0.5 mm and 1.0 mm. Other cutting parameters, such as spindle speed of 650 rpm, feed rate of 300 mm/min, tool type, and workpiece material, were kept constant. Data obtained included voltage, electric current, machining time, cutting length, and volume of material cut. Next, calculations were made for electrical power, electrical energy, Material Removal Volume (MRV), Material Removal Rate (MRR), cutting force, cutting power, and Specific Energy Consumption (SEC). The results showed that increasing the depth of cut from 0.5 mm to 1.0 mm increased electrical power from 2.794 kW to 3.036 kW, electrical energy from 7.684 kWh to 8.349 kWh, MRV from 1,014.65 cm³ to 2,029.30 cm³, MRR from 6.149 cm³/min to 12.299 cm³/min, cutting force from 253 N to 506 N, and cutting power from 0.542 kW to 1.084 kW. Despite the increase in electrical energy consumption, the SEC value decreased from 0.0076 kWh/cm³ to 0.0041 kWh/cm³, or approximately 46.05%, indicating an increase in energy efficiency. This is due to the greater increase in the volume of material cut compared to the increase in electrical energy used.The study concluded that variations in the depth of cut affect the Specific Energy Consumption (SEC) value in the CNC machining and milling process. A depth of cut of 1.0 mm is the most efficient cutting condition because it produces the lowest SEC value, thereby increasing both energy efficiency and machining productivity.*

Keywords— *CNC machining and milling, depth of cut, Specific Energy Consumption (SEC), Material Removal Rate (MRR), energy efficiency.*

I. Introduction

The development of the manufacturing industry demands production processes that are not only productive but also energy efficient. In CNC machining and milling, the selection of cutting parameters influences the quality of the machining results, productivity, and energy consumption. One parameter that has a significant influence is the depth of cut because it determines the volume of material removed on each cutting pass.

This study aims to analyze the effect of variations in depth of cut on Specific Energy Consumption (SEC) in the CNC machining and milling process at PT XYZ. The method used was an experiment with two variations of depth of cut: 0.5 mm and 1.0 mm, while other cutting parameters were kept constant. Data analyzed included electrical power consumption, electrical energy, Material Removal Volume (MRV), Material Removal Rate (MRR), cutting force, cutting power, and SEC value.

The results showed that increasing the depth of cut from 0.5 mm to 1.0 mm increased electrical power from 2.794 kW to 3.036 kW, electrical energy from 7.684 kWh to 8.349 kWh, and increased the MRV from 1,014.65 cm³ to 2,029.30 cm³ and MRR from 6.149 cm³/min to 12.299 cm³/min. Despite the increase in energy consumption, the SEC value decreased from 0.0076 kWh/cm³ to 0.0041 kWh/cm³, indicating a 46.05% increase in energy efficiency.

This study demonstrated that increasing the depth of cut within the test range can increase productivity while reducing specific energy consumption. Therefore, a 1.0 mm depth of cut is recommended as the most efficient cutting condition based on the Specific Energy Consumption (SEC) value.

II. Literature Review

II.1. Machining Process

The machining process is a manufacturing process that forms components by removing part of the workpiece material using a cutting tool to obtain the shape, size and surface quality according to specifications. According to Rochim (2007), this process produces a certain geometry through chip formation which is influenced by cutting parameters, such as cutting speed, feed rate, and depth of cut. Meanwhile, Widarto (2008) stated that the success of the machining process is influenced by the interaction between the machine, tool, workpiece, and the selection of appropriate cutting parameters.

As technology develops, many machining processes are carried out using Computer Numerical Control (CNC) machines which offer higher levels of accuracy, productivity and consistency than conventional machines. Based on the working principle, the machining process includes turning (lathe) to form cylindrical components, milling to produce flat

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planes, grooves and contours, drilling to make holes, and grinding as a finishing process to obtain dimensional accuracy and high surface quality.

In this research, the process used is CNC machining milling. Milling process performance is influenced by cutting parameters, especially depth of cut, which determines the volume of material cut, cutting force, power requirements and process productivity. The efficiency of energy use in the machining process can be evaluated using Specific Energy Consumption (SEC), namely the amount of energy required to remove one unit volume of material. The smaller the SEC value, the more efficient the machining process is. Therefore, choosing the right cutting parameters is an important factor to increase productivity as well as energy efficiency in the CNC machining milling process.

II.2. CNC Machines

Computer Numerical Control (CNC) is a machine tool controlled by a computer system using numeric codes (G-code and M-code) to automatically control machine movements. According to Widarto (2008), CNC machines can control axis position, spindle rotation, and feed rates with a higher level of accuracy and consistency than conventional machines. The use of CNC machines increases productivity, machining quality, and process efficiency, making them widely used in the manufacturing industry.

This study used a CNC milling machine, a machine that utilizes a rotating tool to cut material according to a predetermined program. Machine performance is influenced by cutting parameters such as spindle speed, feed rate, and depth of cut, which influence cutting force, power consumption, productivity, and Specific Energy Consumption (SEC).

The main components of a CNC machine that play a role in the machining process include the Machine Control Unit (MCU) as the controller of all machine operations, the spindle as the main driver of the tool, the servo motor as the driver of the X, Y, and Z axes, the tool holder as the tool clamp, the machine table as the place and clamp of the workpiece, and the coolant system that functions to reduce cutting temperatures and extend the tool's life. The synergy between these components allows the machining process to take place precisely, stably, and efficiently, resulting in high product quality.

II.3. CNC Machining and Milling

CNC machining and milling is a machining process that uses a rotating multi-point cutting tool to remove material from the workpiece to achieve the desired shape, dimensions, and surface quality. According to Widarto (2008), the primary motion in the milling process comes from the tool rotation, while the feed motion is driven by the machine table or the workpiece. The use of a Computer Numerical Control (CNC) system enables the machining process to proceed automatically with a higher level of accuracy, consistency, and productivity than conventional machining.

The milling process involves several operations, such as face milling, plain milling, end milling, and slot milling, which are selected according to the surface shape and machining requirements. In this study, the face milling process was used because it is effective in producing flat surfaces with a high material removal rate.

The performance of the CNC milling process is influenced by cutting parameters, such as spindle speed, feed rate, cutting speed, depth of cut, and width of cut. These parameters affect cutting force, surface quality, tool life, power consumption, and Material Removal Rate (MRR). One indicator used to evaluate the energy efficiency of the milling process is Specific Energy Consumption (SEC), which is the energy required to remove a unit volume of material. The lower the SEC value, the more efficient the machining process. Therefore, selecting the right cutting parameters is a crucial factor in increasing productivity and energy efficiency in CNC milling.

II.4. Material Removal Rate (MRR)

Material Removal Rate (MRR) is the rate of material removal in a machining process, which states the volume of material cut per unit time (mm^3/minute). MRR is used as a productivity indicator because it shows the process's ability to remove material effectively. The higher the MRR value, the greater the volume of material processed, thus increasing productivity and tending to reduce machining time. According to Rochim (2011), the MRR value is influenced by cutting parameters such as depth of cut (ap), width of cut (ae), and feed rate (F). In the milling process, MRR is calculated using the equation:

$$MRR = MRV/t$$

where MRR = Material Removal Rate (mm^3/minute), MRV = Material Removal Volume (mm^3) and t = Machining time (minutes). Increasing cutting parameters generally increases the MRR value, which under certain conditions can also decrease the Specific Energy Consumption (SEC) because the volume of material removed is greater than the energy used.

II.5. Specific Energy Consumption (SEC)

Specific Energy Consumption (SEC) is a parameter used to evaluate energy efficiency in machining processes by stating the amount of energy required to remove a unit volume of material. The lower the SEC value, the more efficient the machining process because less energy is used per volume of material. According to Dahmus and Gutowski (2004), SEC is an important indicator in assessing the energy performance of manufacturing processes and is influenced by cutting parameters, material characteristics, machine conditions, tool type, and the Material Removal Rate (MRR) value. In the CNC milling process, SEC is calculated using the equation:

$$SEC = E/MRV$$

where SEC = Specific Energy Consumption (kWh/cm^3), E = Electrical energy used (kWh) and MRV = Material Removal Volume (cm^3). The SEC value will decrease if the increase in the volume of material removed is greater than the increase in energy consumed, so this parameter is widely used as an indicator of energy efficiency in CNC machining milling processes.

II.6. Power Consumption in CNC Machines

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Power consumption on a CNC machine is the amount of electrical power used during the machining process to operate the spindle, servo motor, control system, coolant pump, and other supporting components. Groover (2010) states that power usage is comprised of idle power and cutting power, which occurs during the material cutting process. The amount of power consumption is influenced by cutting parameters, such as depth of cut, feed rate, and spindle speed, as well as the characteristics of the workpiece material.

Where Pc is cutting power (kW), Fc is cutting force (N), Vc is cutting speed (m/min), V is voltage (Volts), and I is current (Amperes). Power consumption analysis is the basis for evaluating energy efficiency and is used as one of the main parameters in calculating Specific Energy Consumption (SEC) in CNC machining and milling processes.

III. Research Methodology

III.1. Research Flow Chart

The following is a process flow diagram for the study "Analysis of the Effect of Cutting Parameter Variations (Depth of Cut) on Specific Energy Consumption (SEC) in the CNC Machining and Milling Process at PT XYZ," which systematically illustrates the experimental research process, from problem identification to determining the depth of cut that produces the best SEC value.

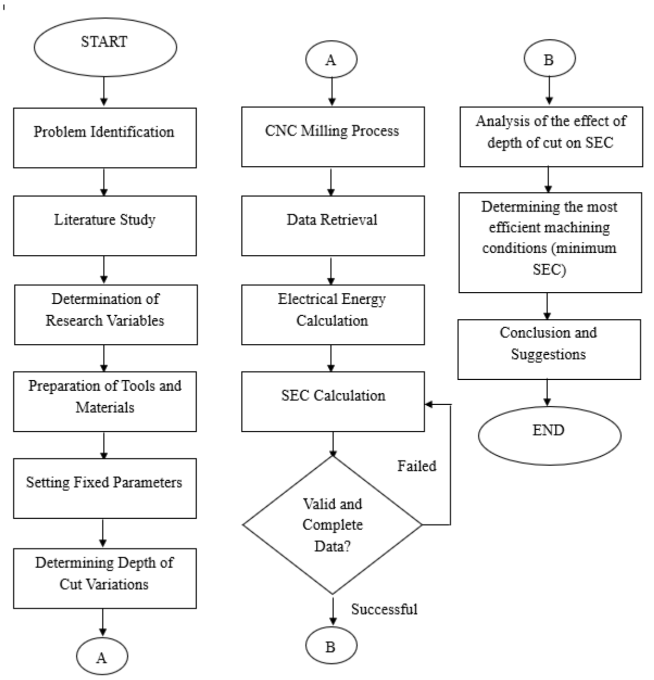

Figure 1. Research Flow Chart

III.2. Data Collection

Data collection was conducted experimentally to analyze the effect of variations in depth of cut on Specific Energy Consumption (SEC) in the CNC milling process. During testing, cutting parameters such as cutting speed, feed rate, tool type, and workpiece material were kept constant, while the depth of cut was varied according to the research design.

Prior to testing, the CNC milling machine, workpiece, tool, and measuring tools were prepared and checked to ensure all equipment was functioning properly. Next, a CNC program was created with the same cutting path for each experiment. Testing was then conducted by measuring electrical power and recording machining time for each depth of cut variation.

The data obtained included cutting parameters, electrical power, machining time, and the volume of material removed. This data was then used to calculate the Material Removal Rate (MRR), electrical energy, and Specific Energy Consumption (SEC). The test results were analyzed in tables and graphs to determine the effect of variations in depth of cut on the energy efficiency of the machining process and to determine the cutting conditions that produce the lowest SEC value.

III.3. Equipment Used

The main equipment used in this study included a CNC milling machine, an end mill, and a workpiece. The CNC milling machine was used for machining with varying depths of cut, while other cutting parameters were kept constant throughout the test to allow objective comparison of the results.

Data measurements were performed using a power meter to measure electrical power consumption, a vernier caliper to measure the dimensions of the workpiece, and a stopwatch to record the machining time for each test variation. The data obtained served as the basis for calculating energy consumption and productivity of the machining process.

In addition, a computer or laptop equipped with software such as Microsoft Excel was used to develop the CNC program, process the data, and present the research results in tables and graphs. All test data was recorded on an observation sheet to support the analysis of Material Removal Rate (MRR) and Specific Energy Consumption (SEC).

III.4. Research Location and Time

This research was conducted at PT XYZ, located at Jalan Raya Narogong KM 12.5 Cikiwul, Bantargebang, Bekasi City, West Java 17152, Indonesia, and operates in the automotive component and precision metal manufacturing sector. Data collection took place in the production area, which utilizes CNC machining and milling machines as its primary processing facility. During the research, the author worked in the DTM (Dies & Tools Manufacturing) Division for two months.

III.5. Data Specifications

The data specifications in this study cover the types and characteristics of data obtained through direct observation and measurement during the CNC machining and milling process. The collected data included cutting parameters, electrical parameters, machining time, cutting area dimensions, and tool and workpiece material specifications. The independent variable used was the depth of cut, varying between 0.5 mm and 1.0 mm, while the dependent variable was Specific Energy Consumption (SEC). To ensure that changes in the SEC value were only affected by variations in the depth of cut, other cutting parameters, such as feed rate, cutting speed, tool

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type, cutter diameter, workpiece material, and machine operating conditions, were kept constant throughout the testing process.

TABLE 1. Research Data Specifications

No.	Parameter	Unit	Description
1	Depth of Cut	0,5 mm and 1,0 mm	Independent variables of the study
2	Electrical Voltage	220 V	Operating Voltage of the CNC Milling Machine
3	Electrical Current	12,7 A and 13,8 A	Measured current during the machining process
4	Machining Time	165 minutes	Machining time for each depth of cut variation
5	Cutting Length	2.230 mm	Length of the workpiece cutting path
6	Cutting Width	910 mm	Width of the cutting area
7	Tool Type	Face Mill 40 mm	Tool used in the milling process
8	Cutter Diameter	63 mm	Cutting tool diameter
9	Insert Type	WNMU0906	Insert used in the cutter
10	Workpiece Material	FC300 (Cast Iron)	Workpiece material being machined

The tool specifications used in this study consist of a 63 mm diameter Face Mill tool with a WNMU0906 type insert. The tool is used for face milling on FC300 (Cast Iron) material. The workpiece material used is FC300 (gray cast iron). In this study, a specific cutting force (Kc) value of 1,100 N/mm² was used, which is a commonly used approach value for gray cast iron material in the milling process.

IV. Results and Discussion

IV.1. Test Result Data

This study was conducted to analyze the effect of cutting parameter variations in the form of depth of cut (ap) on the Specific Energy Consumption (SEC) value in the CNC machining milling process. Testing was carried out using a CNC Milling machine with two variations of cutting depth, namely 0.5 mm and 1 mm using a cutter diameter of 63 mm. The workpiece material used was FC300 (Gray Cast Iron) with the condition that other cutting parameters were kept constant so that the effect of changes in the SEC value only came from variations in the depth of cut.

TABLE 2. Test Data

No.	Dept of Cut (mm)	Voltage (V)	Current (A)	Machining Time (minutes)	Cutting Length (mm)	Cutting Width (mm)
1	0,5	220	12,7	165	2.230	910
2	1,0	220	13,8	165	2.230	910

The tool specifications used include:
- Tool type: Face Mill
- Cutter diameter: 63 mm
- Insert: WNMU0906
- Workpiece material: FC300 (Cast Iron)
- Specific cutting force (Kc) of 1,100 N/mm²

IV.2. Calculation of Electric Power Consumption

Electric power consumption is calculated based on the results of measuring the voltage and electric current of the CNC milling machine using the following equation.

$$\boxed{P = V \times I}$$

Description:
- P = Electrical power (Watts)
- V = Electrical voltage (Volts)
- I = Electrical current (Amperes)

a. Electrical Power Depth of Cut Variation of 0.5 mm
Given V = 220 Volt and I = 12.7 Ampere, then:
P = V × I = 220 × 12.7 = 2,794 W = 2.794 Kw

b. Electrical Power Depth of Cut Variation of 1 mm
Given V = 220 Volt and I = 13.8 Ampere, then:
P = V × I = 220 × 13.8 = 3,036 W = 3.036 kW
The calculation results show that increasing the depth of cut from 0.5 mm to 1 mm increases electrical power consumption from 2.794 kW to 3.036 kW. This occurs because a greater depth of cut removes more material, increasing the cutting load and the machine's power requirement.

IV.3. Electrical Energy Calculation

Electrical energy is the total energy consumed by a CNC milling machine during the machining process. The amount of energy is influenced by the machine's electrical power and machining time, and is used as the basis for calculating Specific Energy Consumption (SEC).

$$E = P \times t$$

Description:
- E = Electrical energy (kWh)
- P = Electrical power (kW)
- t = Machining time (hours)

a. Electrical Energy Depth of Cut Variation of 0.5 mm
Given P = 2.794 Kw and t = 2.75 Hours, then:
E=P×t = 2,794x2,75=7,684 kWh

b. Electrical Energy Depth of Cut Variation of 1 mm
Given P = 3.036 Kw and t = 2.75 Hours, then:
E=P×t = 3,036x2,75=8,349kWh

Increasing the depth of cut from 0.5 mm to 1.0 mm increases electrical energy consumption from 7.684 kWh to 8.349 kWh or approximately 8.66%. This increase occurs because the larger cutting load requires higher electrical power, namely from 2.794 kW to 3.036 kW, while the machining time for both variations remains the same (2.75 hours). These results indicate that the greater the depth of cut, the greater the electrical energy required during the machining process.

IV.4. Material Removal Volume (MRV) Calculation

Material Removal Volume (MRV) is the volume of material removed from a workpiece during the machining process. The MRV value is used to determine the amount of

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material removed and is one of the main parameters in calculating the Material Removal Rate (MRR) and Specific Energy Consumption (SEC).

$$MRV = ap \times ae \times L$$

Description:
- MRV = Material Removal Volume (mm³)
- ap = Depth of Cut (mm)
- ae = Width of Cut (mm)
- L = Length of cutting path (mm)

a. MRV Depth of Cut Variation of 0.5 mm
Given ae = 910 mm and L = 2.230 mm, then:
MRV=ap×ae×L =0,5×910×2.230 =1.014.650 mm^3
= 1.014,65 cm^3

b. MRV Depth of Cut Variation of 1 mm
Given ae = 910 mm and L = 2.230 mm, then:
MRV=ap×ae×L =1×910×2.230 =2.029.300 mm^3
=2.029,30 cm^3

Based on the calculation results, the MRV at a depth of cut of 0.5 mm is 1,014.65 cm³, while at a depth of cut of 1.0 mm it is 2,029.30 cm³. Increasing the depth of cut from 0.5 mm to 1.0 mm increases the MRV value by 100%. This shows that the greater the depth of cut, the greater the volume of material cut, thus increasing the productivity of the machining process.

IV.5. Material Removal Rate (MRR) Calculation

Material Removal Rate (MRR) is the rate of material removal during a machining process, indicating the volume of material that can be cut in a unit of time. The MRR value is used to evaluate the productivity of a machining process because the higher the MRR value, the greater the volume of material that can be removed in a given time.

$$MRR = MRV/t$$

Description:
- MRR = Material Removal Rate (mm³/minute)
- MRV = Material Removal Volume (mm³)
- t = Machining time (minutes)

a. MRR Depth of Cut Variation of 0.5 mm
Given MRV = 1.014.650 mm^3, t = 165 minutes, then:
MRR=MRV/t =1,014,650/165=6,149 mm³/minute
=6.149 cm³/minute

b. MRR Depth of Cut Variation of 1 mm
Given MRV = 2.029.300 mm^3, t = 165 minutes, then:
MRR=MRV/t = 2.029.300/165=12.299mm³/minute
=12,299 cm³/minute

Based on the calculation results, the MRR at a depth of cut of 0.5 mm is 6,149 cm³/minute, while at a depth of cut of 1.0 mm it is 12,299 cm³/minute. Increasing the depth of cut from 0.5 mm to 1.0 mm increases the MRR value by 100%. This shows that the greater the depth of cut, the higher the material removal rate because the volume of material being cut is greater with a fixed machining time, so that the productivity of the machining process increases.

IV.6. Specific Energy Consumption (SEC) Calculation

Specific Energy Consumption (SEC) is a parameter used to measure the efficiency of energy use in machining processes. SEC indicates the amount of electrical energy required to remove a unit volume of material from the workpiece. The lower the SEC value, the more efficient the machining process is because less energy is used to remove material.

$$SEC = E/MRV$$

Description:
- SEC = Specific Energy Consumption (kWh/cm³)
- E = Electrical energy used (kWh)
- MRV = Material Removal Volume (cm³)

a. SEC Depth of Cut Variation of 0.5 mm
Given E = = 7,684 kWh and MRV = 1.014,65 cm³, then SEC = E/MRV = 7,684 / 1.014,65
= 0,0076kWh/cm³

b. SEC Depth of Cut Variation of 1 mm
Given E = = 8,349 kWh and MRV = 2.029,30 cm³ then SEC = E/MRV = 8,349/2.029,30
= 0,0041kWh/cm³

Based on the calculation results, the SEC value at a depth of cut of 1.0 mm is lower than that of 0.5 mm, which is down from 0.0076 kWh/cm³ to 0.0041 kWh/cm³. This decrease occurs because the increase in the volume of material cut (MRV) is much greater than the increase in electrical energy used. Although electrical energy increases from 7.684 kWh to 8.349 kWh, the volume of material cut increases twofold, from 1,014.65 cm³ to 2,029.30 cm³. As a result, the energy required to remove each unit volume of material becomes smaller. Thus, the variation of the depth of cut of 1.0 mm is the most efficient machining condition in this study because it produces the lowest SEC value.

IV.7. The Effect of Depth of Cut Variation on Specific Energy Consumption (SEC)

Based on the test results in figure 1, increasing the depth of cut from 0.5 mm to 1.0 mm reduced the Specific Energy Consumption (SEC) value from 0.0076 kWh/cm³ to 0.0041 kWh/cm³, or approximately 46.05%. This decrease indicates that the machining process has become more efficient because less energy is required to remove each unit volume of material.

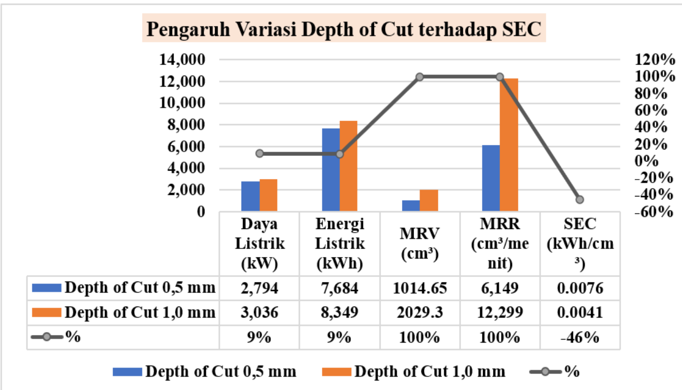

Fig. 1. Comparison of the Effect of Depth of Cut Variation on SEC

The decrease in the SEC value occurred due to an increase in the Material Removal Volume (MRV) from 1,014.65 cm³ to 2,029.30 cm³ and the Material Removal Rate (MRR) from

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6,149 cm³/minute to 12,299 cm³/minute. Although the electrical power increased from 2,794 kW to 3,036 kW and the electrical energy from 7,684 kWh to 8,349 kWh, the increase in the volume of material cut outweighed the increase in energy used.

Thus, a depth of cut of 1.0 mm yielded the lowest SEC value, making it the most efficient machining condition in this study. These results indicate that increasing the depth of cut can improve both productivity and energy efficiency in CNC milling processes.

Thus, it can be concluded that variations in the depth of cut affect the Specific Energy Consumption (SEC) value in the CNC machining milling process. Increasing the depth of cut from 0.5 mm to 1.0 mm decreases the SEC value from 0.0076 kWh/cm³ to 0.0041 kWh/cm³, thus indicating an increase in energy efficiency. Therefore, a depth of cut of 1.0 mm is the most efficient machining condition in this study, because it is able to increase productivity with lower energy requirements per unit volume of material.

IV.8. The Effect of Depth of Cut Variation on Cutting Power

The machining process in this study was carried out using a CNC Machining Center machine with a 63 mm diameter Face Mill tool equipped with 5 WNMU0906 type inserts. The workpiece material used was FC300 (Gray Cast Iron). The cutting parameters applied were spindle rotation of 650 rpm, feed rate of 300 mm/minute, width of cut of 30 mm, number of active cutting inserts of 5 pieces, and variations in depth of cut of 0.5 mm and 1 mm.

a. Calculating Feed per Tooth

Feed per tooth is the amount of feed received by each cutting edge (insert) in one spindle rotation.

$$f_z = \frac{V_f}{n \times z}$$

$$f_z = \frac{300}{650x5}$$

$$f_z = 0{,}092 \text{ mm/tooth}$$

Description:
- fz = Feed per tooth (mm/tooth)
- Vf = Feed rate (mm/minute)
- z = Number of inserts
- n = Spindle rotation (rpm)

This means that each insert cuts 0.092 mm of material with each spindle rotation.

b. Cutting Speed Calculation

$$V_c = \frac{\pi D n}{1000}$$

$$V_c = \frac{3.14 \times 63 \times 650}{1000}$$

$$V_c = 128.58 \text{ m/min}$$

Description:
- Vc = Cutting speed (m/min)
- D = Cutter diameter (mm)
- n = Spindle speed (rpm)

c. Cutting Force Calculation

$$F_c = K_c \times h_m \times a_p \times z_e$$

Description:
- Fc = Cutting force (N)
- Kc = Specific cutting force of material = 1,100 N/mm²
- hm = Average chip thickness (mm)
- ap = Depth of cut (mm)
- ze = Number of active cutting inserts

Since the face mill entry angle is close to 90°, the average chip thickness is equal to the feed per tooth.

$$H_m = f_z = 0.092 \text{ mm}$$

- Depth of Cut = 0,5 mm
  $F_c = 1100 \times 0.092 \times 0.5 \times 5 = 253$ N
- Depth of Cut = 1 mm
  $F_c = 1100 \times 0.092 \times 1 \times 5 = 506$ N

These results indicate that increasing the depth of cut from 0.5 mm to 1 mm causes the cutting force to increase by approximately 100%. This occurs because the greater the depth of cut, the larger the chip cross-sectional area formed, resulting in increased cutting resistance and greater force required to cut the FC300 material.

d. Cutting Power Calculation

$$P_c = \frac{F_c \times V_c}{60000}$$

Description:
- Pc = Cutting power (kW)
- Fc = Cutting force (N)
- Vc = Cutting speed (m/min)

- Depth of Cut = 0,5 mm

$$P_c = \frac{253 \times 128.58}{60000}$$

$$P_c = 0{,}542 \text{ kW}$$

- Depth of Cut = 1 mm

$$P_c = \frac{506 \times 128.58}{60000}$$

$$P_c = 1{,}084 \text{ kW}$$

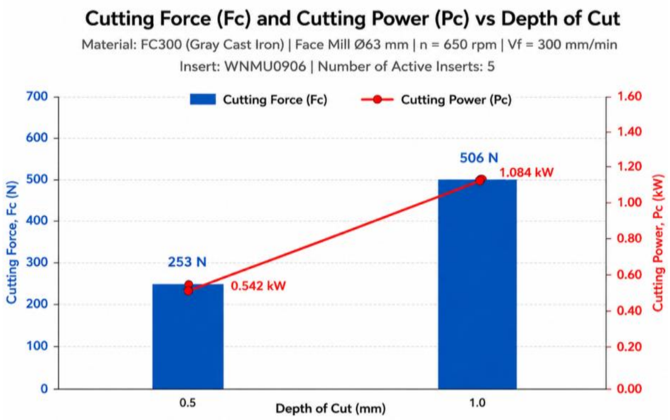

Fig. 2. The Effect of Depth of Cut Variation on Cutting Power

Based on the calculation results, the feed value per tooth is 0.092 mm/tooth and the cutting speed is 128.58 m/minute. With 5 active inserts and a specific cutting force of FC300 material of 1,100 N/mm², the cutting force increases from 253 N at a depth of cut of 0.5 mm to 506 N at a depth of cut of 1.0 mm. The increase in cutting force causes the cutting power to also increase from 0.542 kW to 1.084 kW. This shows that the greater the depth of cut, the greater the cutting force and cutting power required, so the selection of the depth of cut needs to be adjusted to obtain an efficient and optimal machining process.

V. Conclusion

Based on the research results, it can be concluded that variations in the depth of cut affect the Specific Energy Consumption (SEC) value in the CNC machining milling process. Increasing the depth of cut from 0.5 mm to 1.0 mm decreases the SEC value from 0.0076 kWh/cm³ to 0.0041 kWh/cm³, which indicates an increase in the energy efficiency of the machining process. Although the electrical power increases from 2.794 kW to 3.036 kW and the electrical energy increases from 7.684 kWh to 8.349 kWh, the increase in Material Removal Volume (MRV) from 1,014.65 cm³ to 2,029.30 cm³ and Material Removal Rate (MRR) from 6.149 cm³/minute to 12.299 cm³/minute causes the energy required to remove each unit volume of material to be lower. Thus, a depth of cut of 1.0 mm was the most efficient machining condition in this study because it produced the lowest SEC value while increasing machining process productivity. The results of this study indicate that increasing the depth of cut within the tested parameter range can be a strategy to improve energy efficiency and productivity in CNC machining and milling processes.

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