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Relationship between Cutting Depth and Spindle Speed on Cutting Accuracy of Aluminum 6061 on the TU-3A Retrofit CNC Machine

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ABSTRACT

In the Mechanical Engineering Laboratory of the State Polytechnic of Malang, CNC machines experience decreased performance caused by abrasion and wear on mechanical components such as spindles, bearings, and rails, as well as electronic damage, outdated hardware and software, and inadequate maintenance. This study aims to evaluate the effect of cutting parameters on the roundness of machining results. The results of data analysis show that the depth of cut has a significant effect on roundness, with an F value of 8.05 and a P value of 0.030, which means significant at the 0.05 level. In contrast, spindle speed does not have a significant impact on roundness, with a P value far above 0.05. In addition, the interaction between depth of cut and spindle speed does not show a significant effect on roundness, with an F value of 2.08 and a P value of 0.206.

Keywords: CNC TU-3A, Depth of cut, Spindle Speed, Roundness

1. Introduction

The Department of Mechanical Engineering of Malang State Polytechnic has a CNC laboratory established in 1993. This laboratory is equipped with 6 CNC machines of the EMCO Production Milling series TU-3A type. The TU-3A CNC machine is a 3-axis training milling machine designed to train the basics of CNC operation and programming. The configuration of various machine parameters, including spindle speed, feed rate, depth of cut, and type of cutting edge used, can affect power consumption and the quality of the resulting surface roughness [1], [2], [3], [4].

The working principle of the CNC Milling machine produced by the EMCO TU-3A series is that it cuts through a knife that rotates against the material which is mounted on a table that moves transversely or horizontally, while on the attachment is a knife that moves up and down. These differences in movement can be written in terms or symbols such as the transverse direction of the Y axis, the horizontal direction of the X axis, and the vertical direction of the Z axis **[5], [6], [7]**.

Over time, CNC machines in the Mechanical Engineering Laboratory of the State Polytechnic of Malang experienced a decrease in abrasion performance due to wear and tear of mechanical components such as spindles, bearings, and rails. This decrease in performance is also caused by damage to the electronic or control system, obsolete hardware and software, and lack of maintenance, so that some CNC machines can no longer be used. Meanwhile, technology in the manufacturing industry, especially CNC machines, continues to develop rapidly. To improve usability and repair existing damage, repair efforts need to be made through retrofitting on the EMCO TU-3A CNC Milling machine.

Retrofitting a CNC machine is the process of upgrading or updating an existing CNC machine with new components, technology, or systems to improve the performance, reliability, or functionality of the machine. Retrofits can involve replacing or adding components, software, or more modern control systems to make machines more efficient, and accurate, and meet new production requirements. CNC machines are machines that have a fairly high purchasing value, so retrofitting can provide an alternative that can be a more economical choice than buying new equipment because it can save a lot of money.

The purpose of this study is to test the performance of retrofitted components to evaluate the quality of CNC machine production results. This test will be carried out by considering parameters such as cutting depth and spindle rotation.

2. Methodology of Research

2.1. Types of Research

Figure 1. shows the TU-3A CNC machine retrofit used for data retrieval. The type of research carried out by researchers is research using quantitative data and qualitative data by analyzing the effect of depth of cut and spindle speed on the roundness. Quantitative analysis was carried out by calculating the depth of cut and spindle rotation, while qualitative analysis was used for the retrofit process and analysis of workpiece precision regarding roundness using a dial indicator.

Figure 1. TU-3A CNC Retrofit Machine

2.2. Research Variables

The research variables used in this research include the following:

a. Dependent variable: Roundness: The main variable measured in this study is the roundness of the machining results on the retrofitted CNC TU-3A machine. Roundness is measured to assess the effect of independent variables on the quality of machining results.
b. Independent variables: Depth of Cut: The depth of cut applied to the workpiece, with two levels tested: 1 mm and 1.5 mm. This variable was tested to determine the effect of depth of cut on the roundness of the machining results. Spindle Speed: The spindle rotation speed used in the test, with three levels tested: 500 rpm, 750 rpm, and 1,000 rpm. This variable was analyzed to determine its impact on the roundness of the machining results.
c. Control variables: Retrofitting CNC Machine TU-3A: The process of repairing and replacing components on the CNC machine TU-3A, which must be consistent throughout the experiment to ensure that changes in the dependent variable can be attributed to the independent variable.Workpiece: The material used in the test, which must have uniform specifications and conditions so that test results can be compared accurately. Dial Indicator: A measuring tool used to measure the roundness of the machining results accurately. This tool must be calibrated and positioned correctly for each measurement.HSS (High-Speed Steel Tool). Tool: The type of cutting edge used in the experiment, which must be consistent for all tests to avoid variations in results caused by differences in cutting tools.

2.3. Minitab Experimental Test Results with Factorial Method

To obtain more accurate analysis results, data analysis was carried out using Minitab statistical software using the DOE method, 2 factors. The analysis steps using the DOE method in Minitab include:

a. Make sure the data is organized in the Minitab worksheet. The data should include columns for depth of cut, spindle speed, and roundness of the machining result. Make sure the data has been entered correctly.
b. Open Minitab, select Stat > DOE > Factorial > Create Factorial Design then select 2-level factorial (default generators) and click OK.
c. In the Factors section, enter the name and level of each factor: Depth of Cut: 1 mm and 1.5 mm. Spindle Speed: 500 RPM, 750 RPM, and 1000 RPM. Click Designs and select 2 factors, then click OK.
d. Factors section, enter the name and level of each factor:
   - Depth of Cut = 1 mm and 1.5 mm.
   - Spindle speed = 500 Rpm, 750 Rpm and 1000 Rpm.
e. Analyze the design by selecting Stat > DOE > Factorial > Analyze Factorial Design, then enter Roundness as the response and click OK.
f. From the steps above, Minitab will produce output containing ANOVA, Pareto chart, main effects plot, and interaction plot. Minitab will produce output that includes several key elements: ANOVA (Analysis of Variance): Assesses the statistical significance of factors affecting roundness. Pareto Chart: Shows the factors that most significantly affect roundness variability. Main Effects Plot: Shows the effect of each factor (depth of cut and spindle speed) on roundness. Interaction Plot: Illustrates the interaction between depth of cut and spindle speed, and its impact on roundness.

3. Result and Discussion

3.1 TU-3A CNC Retrofit Machine

Retrofitting a CNC Machine is the process of upgrading or updating an existing CNC Machine with new components, technology, or systems to improve the performance, reliability, or functionality of the machine

[8], [9]. Figure 2**.** shows the component assembly of the TU-3A CNC CNC machine retrofits can involve replacing or adding components, software, or more modern control systems to make machines more efficient, and accurate, and meet new production requirements.

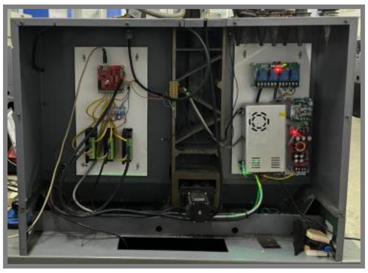


Figure 2. Component Assembly on the TU-3A CNC Machine

Before new components are placed on the TU-3A CNC Machine, the component assembly is placed on a wooden board as a work surface which aims to act as an electrical insulator so that there is no short circuit in the components caused by the back of the PCB being opened. Another advantage of using wooden boards is the ease of placing the assembled components into the TU-3A CNC Retrofit Machine.

Assembly is carried out using two work bases. The first working base contains components such as Mach 3, 3-pin to 6-pin Tb 6600 connector. Meanwhile, on the second working base, there is a 24 V power supply, step-up booster, speed drive, and relay as a spindle speed changer. After being attached to the Emco TU-3A series CNC Machine, the machine was replaced with the stepper motor on the X, Y and Z axes by making slight.

3.2 TU-3A CNC Retrofit Machine

Figure 3. shows how to calibrate the X axis using measurement vernier caliper. To calibrate the tool which is carried out on a CNC machine, you enter the command and then look at the actual reading on the caliper as in Figure 3. The X axis is given the command to move 10 mm and the actual result is 10 mm which indicates there is no difference in distance from the command.

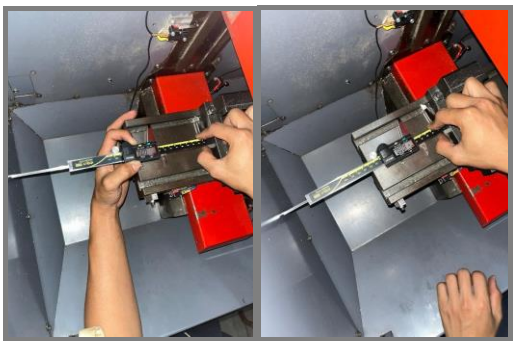


Figure 3. X-Axis Calibration for measurement vernier caliper.

Check for Accuracy: Compare the actual measurement obtained from the vernier caliper with the commanded distance. In this case, the CNC machine was commanded to move 10 mm, and the vernier caliper also shows 10 mm. Assess Calibration: If the measured distance matches the commanded distance exactly, as indicated, this suggests that the X-axis is correctly calibrated, with no significant deviation.

Figure 4. shows how to calibrate the Y axis using measurement vernier caliper, at Y-axis commands to move 5 mm and the actual result obtained is 4.99 mm, which means there is a difference of 0.01 mm.

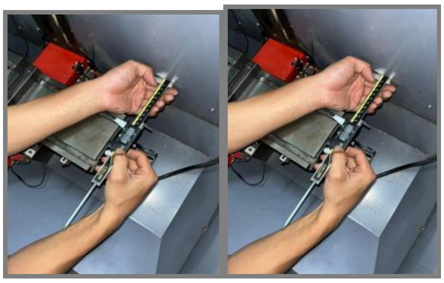


Figure 4. Y-Axis Calibration for measurement vernier caliper

Figure 5. shows how to calibrate the Z axis using measurement vernier caliper, at Z axis commands to move 15 mm and the actual result is 15.03 mm, which means there is an excess of 0.03 mm over the command given as shown in Figure 5.

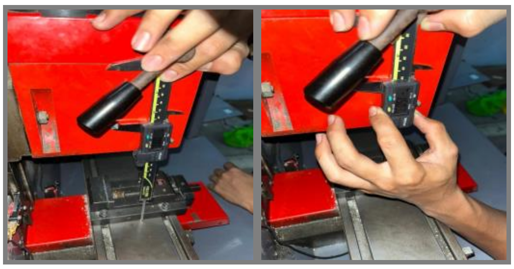


Figure 5. Z-Axis Calibration for measurement vernier caliper

3.3 Machine Specifications Before and After Retrofit

Table 1. shows the results of the TU-3A CNC EMCO 3 A Series, machine specifications before and after Retrofit. The Emco TU 3A CNC Retrofit Machine after being retrofitted with the Mach 3 module offers advantages in terms of precision, speed and ease of use, especially because it can be connected to a laptop for more efficient data transfer and more sophisticated control features.

3.4 Benefits and Challenges of the Retrofit Process

Table 2. shows the results a comparison table between the advantages and challenges of the retrofit process using the Mach 3 module for the TU-3A CNC machin

Table 1. TU-3A CNC Machine Specifications Before and After Retrofit

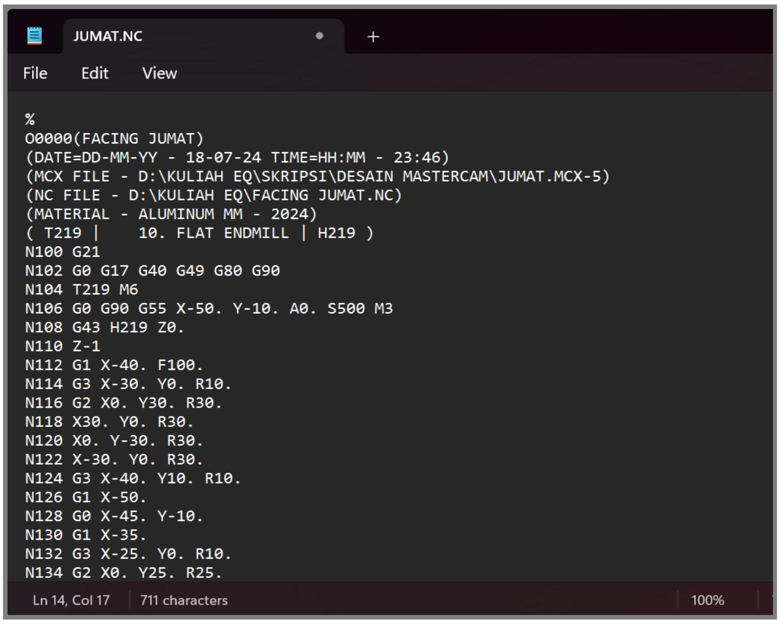
Criteria	Emco TU 3A CNC Machines (Old)	Emco TU 3A CNC Machines (Retrofit)
Spindle Speed	50 - 4000 RPM	50 - 1070 RPM
X-Axis	Manual/Stepper Motor	Direction Controlled by Mach 3
Y-Axis	Manual/Stepper Motor	Direction Controlled by Mach 3
Arah Sumbu Z	Manual/Stepper Motor	Direction Controlled by Mach 3
Controller	Built-in CNC Controller	Mach 3 CNC Controller Software
Compatibility with Laptops	Not available	Can use laptops for data transfer
Data Transfer	Using a floppy disk or serial port	Transfer data via USB or laptop network
Additional Features	Standard CNC	G-code Editor, Cutting simulation, and Homing
Ease of Use	Relatively difficult, especially for beginners	More user-friendly with Mach 3 interface
Accuracy and Precision	Good, but limited	Improved thanks to Mach 3 controller and software
Screen	Black and white screen	Laptop/computer

Table 2. Benefits and Challenges of the Retrofit Process

Aspek	Benefit	Threats
Direction of X, Y, and Z Axes	- More precise control with Mach 3 software - Smoother and more accurate axis movement	- Recalibration of all axes required after retrofit - Replace or update stepper motors
Additional Features	- Using a laptop for data transfer makes operation easier - G-code Editor, cutting simulation, and homing features improve efficiency	- Requires installation and configuration of Mach 3 software on the laptop - Must learn to master new features
Data Transfer	Data transfer via USB or network is faster and easier - Reduces the risk of data loss compared to floppy disks or serial ports	- Availability of USB or network ports on older machines may require modification
Ease of Use	- Mach 3 interface is more user-friendly and intuitive - Easier machine monitoring and control Accuracy and Precision	- Training time for users to get used to the new system
Accuracy and Precision	- Improve cutting accuracy and precision	- Need to ensure all retrofit components work in harmony - Potential technical or integration issues during the retrofit process

3.5 Setting Parameters for Depth of Cut and Spindle Speed

Figure 6. shows the machining parameter settings of depth of cut and spindle speed on a CNC Retrofit machine that has been retrofitted using Mach 3 software involves several important steps, starting from ensuring the condition of the machine, connecting the machine to a laptop, setting spindle speed parameters and depth of cut via the Spindle Control and G-code menus, to carry out movement and cutting tests. This process ensures that the CNC machine operates with the right parameters, producing optimal cuts that meet production requirements [10].



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N104 T219 M6
N106 G0 G90 G55 X-50. Y-10. A0. S500 M3
N108 G43 H219 Z0.
N110 Z-1
N112 G1 X-40. F100.
N114 G3 X-30. Y0. R10.
N116 G2 X0. Y30. R30.
N118 X30. Y0. R30.
N120 X0. Y-30. R30.
N122 X-30. Y0. R30.
N124 G3 X-40. Y10. R10.
N126 G1 X-50.
N128 G0 X-45. Y-10.
N130 G1 X-35.
N132 G3 X-25. Y0. R10.
N134 G2 X0. Y25. R25.

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Figure 6. G-code Setting Parameters of Depth of cut and Spindle Rotation

3.6 Roundness Measurement Results on Aluminum 6061 with the TU-3A CNC Retrofit Machine.

Table 3. shows the results of measuring the roundness of the Aluminum 6061 workpiece was carried out on a CNC TU-3A retrofit machine using a dial indicator tool by paying attention to several stages and testing in the form of the effect of depth of cut and spindle speed on roundness. Depth of cut is a variable that affects the roundness result. A greater depth of cut can cause higher stress on the cutting tool and increase the possibility of deviation from the ideal round shape [11].

3.7 ANOVA Analysis Results

The results of the ANOVA analysis are as in Table 4. where the significant value for the confidence level of the data used is 95% or $\alpha = 0.05$. The P value for depth of cut is 0.030, which is much smaller than 0.05. This shows that the depth of cut influences the roundness of the workpiece so the variable depth of cut changes the roundness of the workpiece. Mean while, the P value for spindle speed is 0.458, which is much greater than 0.05. This shows that spindle speed does not influence the roundness of the workpiece so changes in depth of cut have an impact on the roundness results, this shows that depth of cut is an important factor in determining the roundness quality of the workpiece. The P value for the interaction between depth of cut and spindle speed is 0.206, where greater than 0.05 indicates that there is no interaction between these two variables in influencing the roundness of the workpiece. In other words, the effect of depth of cut on roundness does not depend on spindle speed or vice versa [12].

Table 3. Roundness Measurement Results on Aluminum 6061

↓	C1	C2	C3	C4	C5	C6	C7
	StdOrder	RunOrder	PtType	Blocks	DEPTH OF CUT	SEPINDEL SPEED	KEBULATAN
1	1	1	1	1	1,0	500	0,19
2	2	2	1	1	1,0	750	0,18
3	3	3	1	1	1,0	1000	0,16
4	4	4	1	1	1,5	500	0,21
5	5	5	1	1	1,5	750	0,23
6	6	6	1	1	1,5	1000	0,17
7	7	7	1	1	1,0	500	0,20
8	8	8	1	1	1,0	750	0,16
9	9	9	1	1	1,0	1000	0,18
10	10	10	1	1	1,5	500	0,20
11	11	11	1	1	1,5	750	0,28
12	12	12	1	1	1,5	1000	0,24

Table 4. ANOVA analysis results

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0,009800	0,001960	2,80	0,121
Linear	3	0,006883	0,002294	3,28	0,101
DEPTH OF CUT	1	0,005633	0,005633	8,05	0,030
SEPINDEL SPEED	2	0,001250	0,000625	0,89	0,458
2-Way Interactions	2	0,002917	0,001458	2,08	0,206
DEPTH OF CUT*SEPINDEL SPEED	2	0,002917	0,001458	2,08	0,206
Error	6	0,004200	0,000700		
Total	11	0,014000			

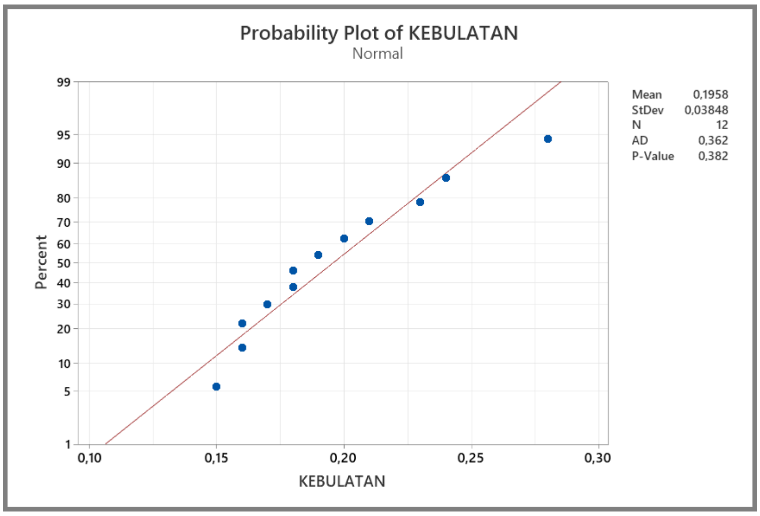

Figure 7. Normal Probability Plot Graph

3.8 Normal Probability Plot Graphic Analysis Results

Figure 7. shows the blue dots represent the roundness value for each measuring object and the red line is the theoretical line to describe the normal distribution. From the graph, it is known that the roundness data follows a normal distribution where the data points are mostly around the red line, which shows that the roundness data is close to normal, displayed by points that are close to the reference line on the probability plot and the p-value is equal to 0.382 which is greater than 0.05.

The absence of a significant effect of depth of cut and its interaction with spindle speed on workpiece roundness could be caused by several factors [13]. Among them, the variable depth of cut or spindle speed is not large enough to show a significant effect, it is possible that other factors are more dominant in influencing roundness but are not included in the analysis, such as material hardness, type and condition of cutting tools, and the presence of other more dominant factors.

The depth of cut (Factor A) shows an effect that exceeds the significance limit of 2.447. This means that the depth of cut has a significant effect on the roundness of the workpiece. This result shows that the correct depth of cut is very important to achieve optimal roundness. Practical Implication: Carefully controlling the depth of cut will greatly affect the quality of the roundness of the workpiece. If the depth of cut is not managed properly, it can cause significant deviation from the desired roundness [14].

3.9 Pareto Diagram in Analysis of the Effect of Depth of cut and Spindle speedon Roundness.

Figure 8. shows the Pareto diagram to help identify the factors that influence the measurement results, based on the results of the analysis using DOE, a picture of the Pareto diagram is obtained which shows the standard effect of two factors, namely depth of cut and spindle rotation, on the roundness of the workpiece. [15]

The red vertical line which has a value of 2.447 exceeds the line with the significance limit (α = 0.05) which indicates factors that are considered significant or influence the roundness.

Factor A is the depth of cut, indicating that depth of cut has a large influence and influences roundness at the 95% confidence level because factor A exceeds the significance limit of 2.447. so control of the depth of cut is very important to achieve optimal roundness

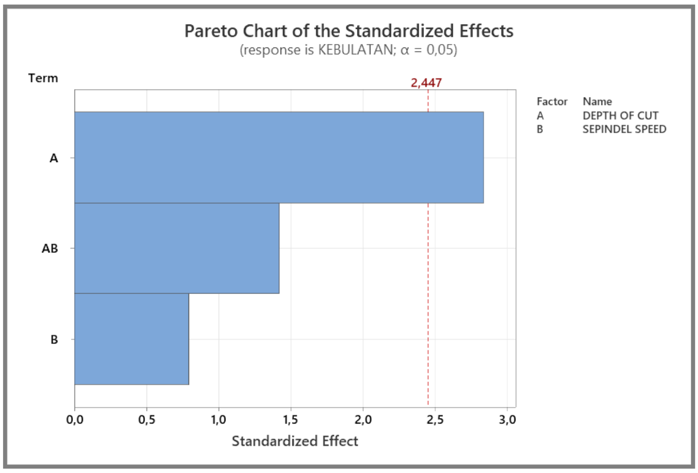

Figure 8 . Pareto chart of the Standardized Effect

Factor B is spindle speed which has a standardized effect of less than a significance of 2.447. This shows that spindle speed does not influence roundness.

The AB interaction, which is the interaction of depth of cut and spindle rotation, has a standardized effect that is very small and not significant.

3.10 Interaction Plot Graph of Measurement Results of Depth of Cut and Spindle against Roundness

Figure 9. The average value of the roundness measurement results is depicted in a graph with the horizontal axis (X) showing the depth of cut value while the vertical axis (Y) shows the average roundness measurement results.

The blue line (500 Rpm) shows that as the depth of cut increases from 1.00 mm to 1.50 mm, the average roundness increases slightly from 0.19 to 0.20. The red line (750 RPM) shows a significant increase in roundness when the depth of cut increases from 1.00 mm to 1.50 mm, from 0.17 to 0.26. The green line (1000 RPM) shows that roundness increases slightly from 0.17 at a depth of cut of 1.00 mm to 0.18 at a depth of cut of 1.50.

3.11 Factorial Plot Graph of Measurement Results of Depth of Cut and Spindle against Roundness

Figure 10. The Factorial Plot graph displays the main influence of two factors, namely the depth of cut factor and the spindle speed factor on the roundness of the 6061 aluminum workpiece.

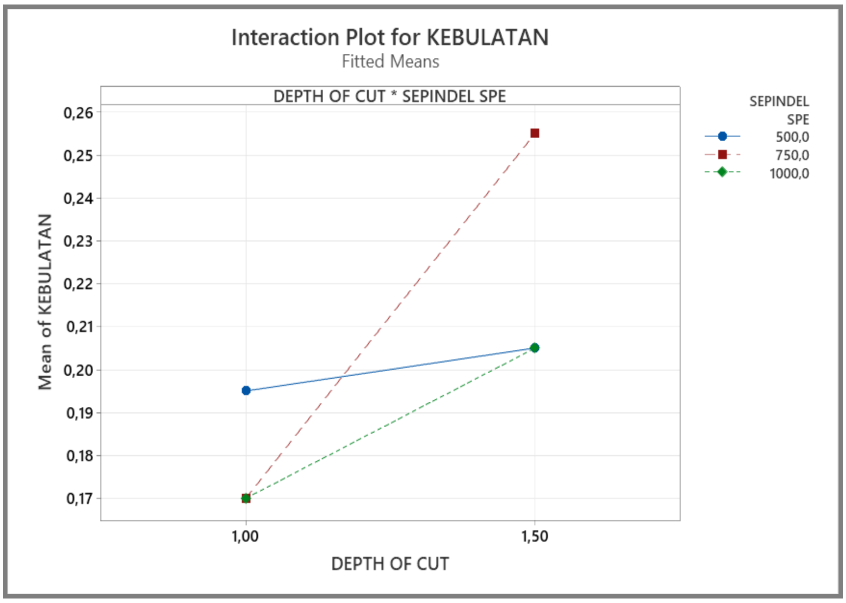

Figure 9. Interaction Plot of Roundness Measurement Results

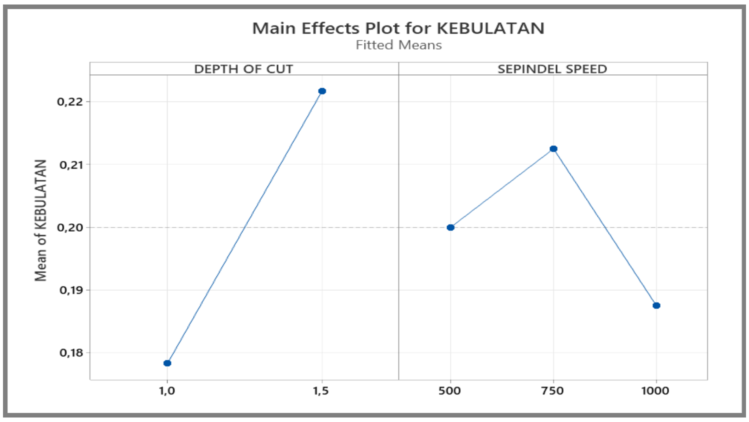

Figure 10. Factorial Plot Graph

Influence on depth of cut shows that the left X-Axis displays two depth of cut values: 1.0 mm and 1.5 mm. The Y-axis displays the average roundness of the workpiece. Increasing the depth of cut from 1.0 mm to 1.5 mm causes a significant increase in roundness from 0.18 to about 0.225. This shows that a smaller depth of cut tends to produce better roundness.

Influence on spindle speed, The right X-axis displays three spindle speed values: 500 Rpm, 750 Rpm, and 1000 Rpm. The Y-axis displays the average roundness. At a spindle speed of 500 Rpm, the average roundness is about 0.19. At a spindle speed of 750 RPM, the average roundness increases to about 0.21. Meanwhile, at a spindle speed of 1000 RPM, the average roundness drops significantly to around 0.18.

3.12 Coded Coefficient Analysis

Coded coefficient analysis is related to regression analysis on the results of roundness measurements. Table 5. shows that the P-Value is used to measure the significance of each coefficient. Where a P-Value below 0.05 is considered significant for roundness or in other words affects the roundness of the results. The P-Value for the constant has a value of 0.000 and for the spindle rotation, it is found to be 1 and 0.291, which shows that the constant has no statistical influence. Meanwhile, the P-Value for the depth of cut is 0.030, which shows that there is an influence on the roundness of the workpiece. Meanwhile, the interaction of depth of cut and spindle speed is 0.174 and 0.102, which indicates that the effect is not significant on roundness.

3.13 Analysis of the Effect of Depth of Cut on Roundness on the TU-3A CNC Retrofit Machine

Figure 7. it is known that the depth of cut was tested on two variables, namely 1.0 mm and 1.5 mm. At a depth of cut of 1.0 mm, the roundness value varies from 0.16 to 0.19 mm. In contrast, at a depth of cut of 1.5 mm, the roundness value varies from 0.16 to 0.28 mm. This difference indicates that a higher depth of cuts tends to produce larger variations in roundness.

A greater depth of cut increases the load on the cutting tool and the machine itself. Larger cutting forces can cause changes in the cutting process, including increased temperatures in the cutting zone. This increase in temperature can affect material properties and produce thermal deformation that contributes to shape imperfections, including roundness.

Based on Figure 8 from the results of the ANOVA analysis, it can be concluded that the depth of cut has an influence on the roundness of the cutting results on Aluminum 6061 using the TU-3A CNC Retrofit machine. This is shown by the depth of the cut having an F-Value of 8.05 and a P-Value of 0.030, which is below the general significance level of 0.05, indicating that the depth of the cutting variable influences the roundness results. Practical suggestions that can be done in this study are as follows: Temperature Management: Implement a cooling or lubricating system to reduce the temperature in the cutting zone and reduce the effects of thermal deformation. Load Management: Adjust other cutting parameters such as spindle speed and feed rate to manage the load on the cutting tool and machine.

3.14 Analysis of the Effect of Spindle Speedon Roundness on the TU-3A CNC Retrofit Machine

From the data obtained, the spindle speed was tested at three levels: 500 Rpm,750 Rpm, and 1000 Rpm. Overall, spindle speed does not have a significant effect on the roundness of cuts on aluminum 6061 material. Low spindle speeds (500 Rpm) tend to produce more consistent roundness, while medium spindle speeds (750 Rpm) show greater variations. High spindle speeds (1000 Rpm) can increase process efficiency but can also cause greater roundness variations due to increased temperature and cutting forces. A spindle speed that is too low or too high can cause larger variations in roundness. Therefore, choosing the right spindle speed is the key to achieving a balance between cutting quality and process efficiency.

Table 5. Coded Coefficient

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0,20000	0,00764	26,19	0,000	
DEPTH OF CUT					
1,0	-0,02167	0,00764	-2,84	0,030	1,00
SEPINDEL SPEED					
500	-0,0000	0,0108	-0,00	1,000	1,33
750	0,0125	0,0108	1,16	0,291	1,33
DEPTH OF CUT*SEPINDEL SPEED					
1,0 500	0,0167	0,0108	1,54	0,174	1,33
1,0 750	-0,0208	0,0108	-1,93	0,102	1,33

Based on Table 4. from the results of the ANOVA analysis, it can be concluded that spindle speed does not influence the roundness of the cutting results with a P-Value value of 0.458 and an f-Value of 0.89. The P-Value value is far above the data significance threshold of 0.05 indicating that the spindle speed variable does not change the roundness results.

Although spindle speed does not significantly affect roundness in this data, selecting the appropriate spindle speed is important to achieve a balance between cut quality and process efficiency. Very low or very high spindle speeds can cause variations in the final result. If surface quality is critical, consider using a lower spindle speed (500 RPM) to reduce roundness variations, especially if a lower spindle speed is acceptable in terms of process efficiency.

3.15 Interaction Analysis of the Relationship between Depth of Cut and Spindle speed and Roundness on the TU-3A CNC Retrofit Machine

In Figure 9. it is known that the effect of depth of cut and spindle speed on the roundness of cutting results on 6061 aluminum material using the TU-3A CNC retrofit machine shows that a depth of cut of 1.0 mm with a spindle speed of 1000 Rpm produces the lowest roundness value of 0.16 mm. shows the most consistent cutting results. On the other hand, a depth of cut of 1.5 mm with a spindle speed of 750 RPM produces a roundness value of 0.28 mm.

Based on Table 4. from the results of the ANOVA analysis, it can be concluded that the interaction between the depth of cut and spindle speed has an F-Value of 2.08 and a P-Value of 0.206. This shows that the interaction between the two variables is not significant. A P-Value value greater than 0.05 indicates that the interaction between the depth of cut and spindle speed does not influence the roundness of the cutting results [16].

4. Conclusion

The conclusions from the research regarding the influence of depth of cut and spindle speed on the roundness of the TU-3A CNC retrofit machine include the following:

1. In the ANOVA analysis, the cutting depth showed an F value of 8.05 and a P value of 0.030. This P value is below the general significance level of 0.05, indicating that the cutting depth has a significant effect on the roundness of the cutting results. This means that changes in the cutting depth affect how round the final result of the cutting is.From the analysis results, it can be concluded that spindle speed does not influence the roundness of the cutting results with a P-Value of 0.458 and an F-Value of 0.89. The P-Value value is far above the data significance threshold of 0.05 indicating that the spindle speed variable does not influence the roundness results. This is caused by several factors including machine stability, cutting tool condition, and the cooling strategy used during cutting.
2. From the analysis results, it can be concluded that the interaction between the depth of cut and spindle speeds an F-Value of 2.08 and a P-Value of 0.206. This shows that the interaction between the two variables is not significant. A P-Value value greater than 0.05 indicates that the interaction between the depth of cut and spindle speed does not influence the roundness of the cutting results. This shows that the interaction between depth of cut and spindle speed does not influence the roundness of the cutting results, which means that these two factors work independently in influencing roundness, which means that depth of cut and roundness does not depend on the spindle rotation, and vice versa.

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