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MACHINING TIME OPTIMIZATION OF SURFACE FINISHING CNC MILLING PROCESS ON STEEL WORKS 2311

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Abstrak

The rapid development of manufacturing technology is a challenge for manufacturing industry players, especially in CNC milling machining to be able to produce quality products and have an optimal machining time speed so that high product quantities are achieved with low production costs. Therefore, small industry players now have problems with their CNC milling machines. The existing engine is relatively smaller and there are some limitations that make it a problem such as limited engine rpm and soon. All the existing problems, further research needs to be done to optimize all the needs of the industrial world today, especially regarding the time of the production process that needs to be optimized. This research was conducted by varying all related parameters, starting from spindle speed, feed rate and depth of cut. In the implementation process, this research uses the Taguchi Orthogonal Array method to minimize experimental tests so that it is more time and cost efficient. The results obtained in this study are feed rate is the most influential parameter on machining time, followed by spindle speed and the third significant parameter is depth of cut with the smallest contribution to machining time. Then for the most optimal design, there is the 3rd parameter design which has the most optimal time, which is 55 seconds.

Keywords: *Machining Time Taguchi Method Spindel Speed Feed Rate Depth of Cut*

INTRODUCTION

More and more days in the industrial world the field of manufacturing engineering is experiencing very rapid technological advances. It is proved by the development of automation technology in the world of the manufacturing industry. With this automation system, the work of the development phase which includes planning, preparation, assembly, installation, programming, inspection, and commissioning can be done easily, quickly, and efficiently. With the rapid development of technology in the manufacturing industry, the industry to produce high quality products, the cheapest prices and has a low (fast) production process speed becomes higher [1]. With everything in the industry, small industries have a problem with equipment owned by actors. The machines owned by small industries are relatively simpler and more limited in all respects. The limitation is usually in the form of a relatively low engine rpm which is only able to reach 3000 rpm. So it is very necessary to conduct research to get fast machining time with the specifications of CNC milling machines owned by small manufacturing industry players. Small industry players have a lack of competitiveness for complex production, so it is very important to produce cost-efficient products with high flexibility [2]. One of the jobs that must be optimized is the manufacture of plastic injection concrete. Plastic injection molding is widely used to produce very complex parts and it is possible to produce many parts in one cycle [3]. 2311 steel is a tool that has a hardness value of 28 ~ 34 HRc, so 2311 steel is generally often used as a plastic dripping material because it is in the cold working category [4]. The plastic molded product has a good surface roughness of 2-63 µin or 0.05-1.6 µm (N2-N7) [5]. The process of making this plastic mold must be made with high accuracy, so a numerically controlled (CNC) machine is needed to produce accurate products with high productivity. Therefore, to reduce production costs requires high productivity or a short time. Optimization of machining time in CNC programming plays an important role in planning and scheduling the manufacturing process [6]. Research parameters that have an influence on the production process time are spindle speed, feed rate and depth of cut, but those that have the most significant influence on production process time are feed rate and spindle speed [7].

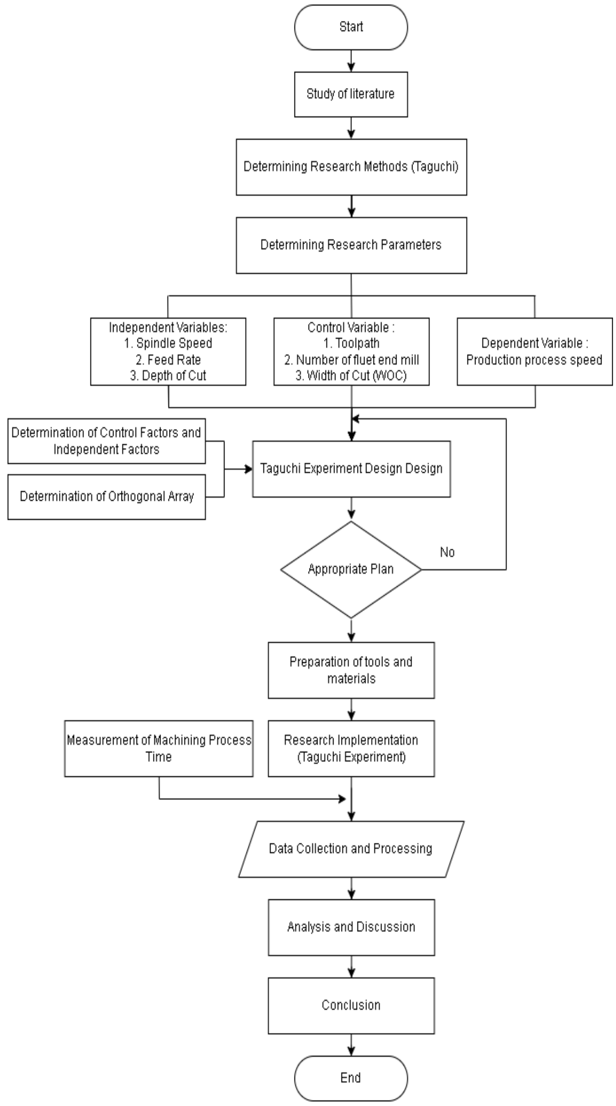
There have been many studies regarding the effect of feed rate, spindle speed and depth of cut on the production time of CNC milling machining. Research to find the optimization of cutting tools and cutting parameters to determine the energy footprint and production time shows that the cutting speed of 150.72 m/min, feeding speed of 0.37 mm/tooth and 4 mm of depth of cut have an effect on the machining time of CNC milling [8]. Then the research which aims to analyze in depth the energy composition and temporal energy requirements states that the cutting speed which affects the spindle speed and feed speed greatly affects the machining time of CNC milling, while the depth of cut only has a slight effect on the machining time [9].

From the existing studies, there are many studies that use the taguchi method to get the best production process time from machining parameter experiments. The taguchi method is often used to optimize the research process because it can save time, cost and material [10]. Optimization of the use of the taguchi method is the best combination of many factors (cutting parameters, cutting conditions, material and endmill) to produce quality products and services [11]. The taguchi method is a statistical method that can improve the quality of manufactured goods and reduce trial and error type trials using a matrix design [12].

Optimization of CNC milling machining time from various machining parameters is mostly done on raoughing cuts and for finishing cutting optimization is mostly done to get quality and optimize production time to reduce machining production costs. Optimizing this machining time can reduce the cost of making the plastic injection mold itself, where in making molds that are in accordance with the standards of the plastic industry community, Inc. (SPI) requires additional costs [5]. From the many studies conducted, it is necessary to re-adjust the existing parameter levels to maximize the results of the machining time of 2311 steel. This paper discusses the optimization of CNC milling machining time to get the lowest or fastest time. The machining parameters used in this paper are spindle speed, feed rate and depth of cut. In addition, the endmill used in this paper is carbide.

MATERIALS AND METHODS

Figure 1. Flow Chart.



This research was conducted by an experimental method using three independent variables, namely spindle speed, feed rate, and depth of cut. Where each variable is varied, such as the spindle speed used is 2185.20 rpm, 2427.98 rpm, and 2670.80 rpm. The further variable that is varied is the feed rate with values of 736 mm/min, 930 mm/min, and 1146 mm/min. The last variable to be varied is the depth of cut with values of 0.10 mm, 0.15 mm, and 0.20 mm. Then the control variables used in this study are toolpath style (zigzag), number of endmill flutes (4 flutes), and width of cut (15%, 20%, and 25%) while the dependent variable used in this study is the speed of time production process.

Testing the speed of the production process is carried out by simulation using the Swansoft application, the Fanuc 0iM type. In addition to the machine specifications that are adjusted, the cutting tools and workpiece selection in the Swansoft application are also the researchers designed previously. Before the simulation was carried out, the researcher made the NC program first using the Mastercam X5 with the adjusted parameters and also the workpiece settings and cutting tools that had been adjusted to this research design. In addition, input the program and simulation using Swansoft. So that this study has a high level of accuracy by the initial research design.

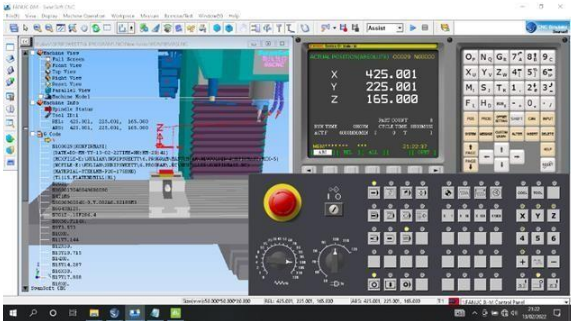


Figure 2. Simulation Process of Working on.

TOOLS AND MATERIALS

The tools used in this study is a laptop using the Mastercam X5 application for the initial program creation and Swansoft using the Fanuc 0iM machine which was used to simulate this research. The endmill or cutting tool used in this study is a carbide with a 4-flute endmill cutter with a diameter of 15 mm and a length of 95 mm. While the material used in this study is steel 2311 with a size specification of 50 mm X 50 mm X 20 mm.

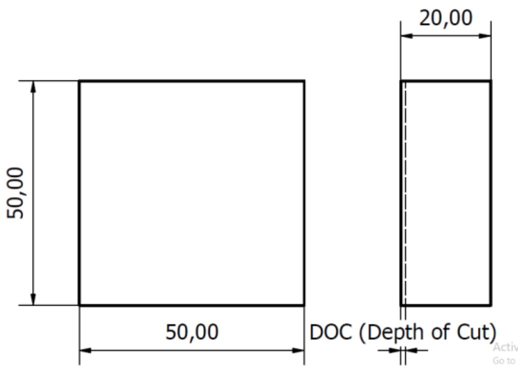


Figure 3. Test Specimen Design.

This 2311 steel material has a hardness value (prehardened) at 28 ~ 34 HRc. So that 2311 steel is generally often used as a plastic injection molding material because it is included in the cold work category. Because it is included in the category of cold work, this material does not require further heat treatment. With these characteristics, 2311 adjusted to the parameters that steel has good resistance to distortion and cracking. The following is a complete specification of 2311 Steel [4] :

Table 1. Specifications for 2311 Steel.

Grade	C	Si	Mn	S	Cr	Mo
2311 Steel	0.400	0.300	1.450	0.035	1.950	0.200

In addition to this 2311 steel material also has tensile strength of 1000 N/mm2, so this material is very suitable for plastic molds and steel forming tools.

METHOD

The experimental method used in this study is based on the Taguchi orthogonal array L9 method. The Taguchi method is a methodology in engineering that aims to improve productivity and process quality and is used to reduce costs and resources to a minimum so that it has advantages in designing production quality and production costs. Variations in parameter levels and the L9 orthogonal array used and have been adjusted to factors and levels can be seen in tables 2 and 3.

Table 2. Parameter Planning.

Cutting Parameter	Factor	Level		
		1	2	3
Spindle Speed	A	2185.2	2427.98	2670.8
Feed Rate	B	736	930	1146
Depth of Cut	C	0.1	0.15	0.2

Table 3. Othogonal Array L9 (33).

Experimental Condition	Column / Factor		
	A	B	C
1	2185.20	736	0.10
2	2185.20	930	0.15
3	2185.20	1146	0.20
4	2427.98	736	0.15
5	2427.98	930	0, 20
6	2427.98	1146	0.10
7	2670.80	736	0.20
8	2670.80	930	0.10
9	2670.80	1146	0 ,15

In the calculation of the experimental design, there are several variables that we need to determine for experiments such as spindle speed, feed rate and depth of cut. The following is a calculation of the three variables. In calculating this spindle speed using the formula (1) :

$$n = \frac{SFM}{d_1} \times 3.82 \quad (1)$$

Where SFM the Surface Feet per Minutes, n the Spindle speed in rotation per minutes, d the Blade diameter (mm). So it is needed to determine the SFM (Surface Feet per Minute) first, where this SFM must also be determined based on the WOC (Width of Cut) and this WOC is the amount of feed transfer according to the needs of the job. In this study using surface finishing work , WOC is used in the amount of 15%, 20% and 25%. From the WOC that has been determined, the SFM 412.5, 375 and 337.5 are obtained. After the SFM is obtained, it is continued in the spindle speed calculation.

$$n_1 = \frac{SFM}{d_1} \times 3.82$$

$$n_1 = \frac{337.5}{0.59} \times 3.82$$

$$n_1 = 2185.20 \text{ rpm}$$

$$n_2 = \frac{SFM}{d_1} \times 3.82$$

$$n_2 = \frac{375}{0.59} \times 3,82$$

$$n_2 = 2427.98 \text{ rpm}$$

$$n_3 = \frac{SFM}{d_1} \times 3.82$$

$$n_3 = \frac{412.5}{0.59} \times 3.82$$

$$n_3 = 2670.80 \text{ rpm}$$

So that the results from the spindle speed calculation with the value 2185.20 rpm, 2427.98 rpm and 2670.80 rpm. Furthermore, in calculating this feed rate using the formula (2) :

$$F = n \times f \times z \quad (2)$$

Where F the feed rate in mm per min, f the feeding in mm, n the Spindle Speed in revolutions per minutes and z the number of flutes endmill. So it is needed to determine f first, where f is obtained from IPT (Inch per Tooth) multiplied by IPM (Inch per Minute) which is then continued in the calculation as follows.

$$F_1 = 2185.20 \times 0.0033 \times 4$$

$$F_1 = 736 \text{ mm/min}$$

$$F_2 = 2427.98 \times 0.00377 \times 4$$

$$F_2 = 930 \text{ mm/min}$$

$$F_3 = 2670.80 \times 0.00421 \times 4$$

$$F_3 = 1146 \text{ mm/minute}$$

So the calculation of the feed rate is obtained with the results of 736 mm/minute, 930 mm/minute and 1146 mm/minute. In this study, the depth of cut was determined at 0.10 mm, 0.15 mm and 0.20 mm as the surface finishing process.

RESULT AND DISCUSSION

The following is a table of the results of the production process time from the research carried out, based on the existing parameters in seconds.

Table 4. Research Data.

NO	Control Parameters/			Working Time
	A	B	C	
1	1	1	1	90
2	1	2	2	65
3	1	3	3	55
4	2	1	2	92
5	2	2	3	75
6	2	3	1	64
7	3	1	3	116
8	3	2	1	95
9	3	3	2	79

From the results of this study, data analysis was carried out using the Minitab version 18.1 application to test for normality.

Then the calculation of machining time is carried out manually which aims to confirm whether or not the annual calculation is appropriate with the experiments carried out. This calculation uses the following formula (3) :

$$T = \frac{L}{F}\ minute \quad (3)$$

Where T the time, L the jarak tempuh endmill and F the feed rate. Which is then applied to the calculation of the first experimental design.

$$T = \frac{944\ mm}{736\ mm/min}$$
$$= 1{,}28\ minute \text{ or } 88\ second$$

Which is then calculated to find the presentation of the difference between the two results obtained and then entered in the table and can be seen in the following table.

Table 5. Comparison Results.

Experiment time	Prediction Time	Difference
90 Second	88 Second	2,27%

With a difference of 2.27%, it can be concluded that the research carried out was in accordance with the proper calculation of the prediction time. Because it is still within the reasonable range of <5%.

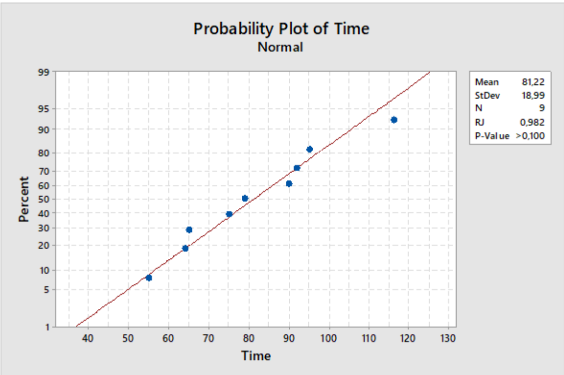


Figure 4. Normality Test.

From the results of the normality test carried out, the significance of this study was 0.100. It can be stated that the data obtained is normally distributed because the significance is greater than 0.05 (sig>0.05).

Furthermore, data analysis was carried out using the Analysis of Variant (ANOVA) analysis technique. The data from the analysis will be used to determine the effect of the independent variables (spindle speed, feed rate, and depth of cut) on machining time and to conclude the results of this study. The results of the ANOVA statistical analysis are presented in tabular form as follows :

Table 6. Analysis of Variance for S/N Ratios.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindel Speed	2	13,0080	13,0080	6,50398	74,76	0,013
Feed rate	2	19,5208	19,5208	9,76039	112,20	0,009
Depth of Cut	2	0,3333	0,3333	0,16663	1,92	0,343
Residual Error	2	0,1740	0,1740	0,08699		
Total	8	33,0360				

Table 7. Analysis of Variance for Means.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Spindel Speed	2	1146,89	1146,89	573,444	737,29	0,001
Feed rate	2	1704,22	1704,22	852,111	1095,57	0,001
Depth of Cut	2	30,89	30,89	15,444	19,86	0,048
Residual Error	2	1,56	1,56	0,778		
Total	8	2883,56				

Tables 5 and 6 are the results of the analysis of each independent variable at each level tested on Signal to Noise Ratios and Means smaller the better because researchers are looking for the fastest or most optimal production process time. The results of the analysis show that two variables have a significant effect on the time of the production process or machining, this is proven by the results of the P-value < 0.05. However, the two variables have their level of significance or influence. The variable that has the greatest influence is the feed rate, where the feed rate has the smallest P-value compared to the spindle speed. The most influential parameter contribution of 92.6% [13]. Then the second variable that affects the time of the production process is spindle speed. While the depth of cut does not have a significant effect on the time of the production process.

Table 8. Response Table for S/N Ratios (Smaller is Better).

Level	Spindel Speed	Feed rate	Depth of Cut
1	-36,72	-39,88	-38,25
2	-37,63	-37,77	-37,83
3	-39,60	-36,29	-37,87
Delta	2,88	3,59	0,43
Rank	2	1	3

Table 9. Response Table for Means

Level	Spindel Speed	Feed rate	Depth of Cut
1	70,00	99,33	83,00
2	77,00	78,33	78,67
3	96,67	66,00	82,00
Delta	26,67	33,33	4,33
Rank	2	1	3

Furthermore, it is strengthened by the results of the response tables 7 and 8 which state that the feed rate holds the most important position in influencing the machining time process with the highest delta value, spindle speed holds the second position in influencing the machining time process with a delta value below the feed rate. While the depth of cut does not affect the machining process time with the lowest or smallest delta value. Feed rate is the most significant factor on machining energy and machining time, then spindle speed and depth of cut are the second and third variables that have an influence [14].

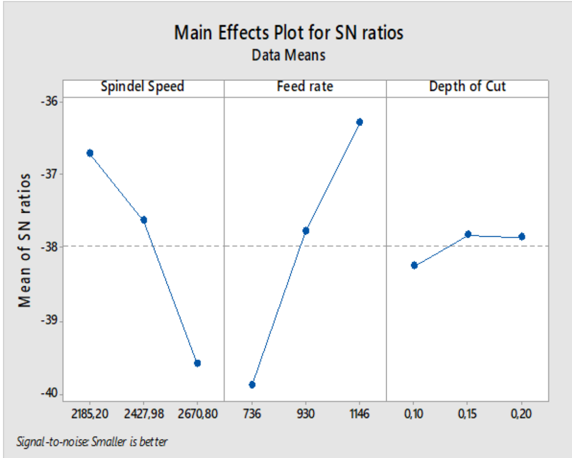


Figure 5. Graph of Main Effect Plot for S/N Ratios.

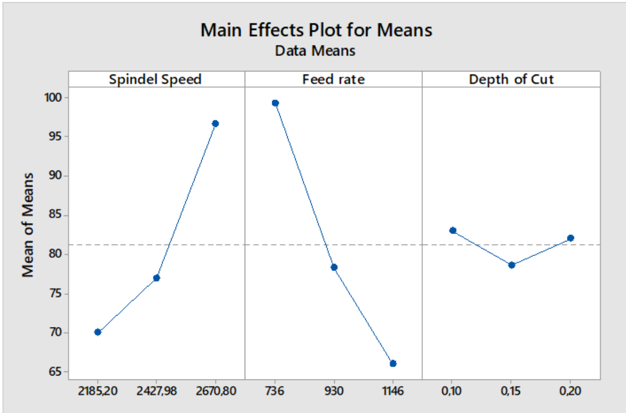


Figure 6. Graph of Main Effect Plot for Means.

Then the results of further analysis are obtained from Main Effect Plot graph data on Signal to Noise Ratio and Means to conclude that the feed rate with a speed of 1146 mm/min has the highest value on the effect of the production process time. Then the spindle speed which has the highest influence on the time of the production process is at a speed of 2185.20 rpm. Furthermore, the depth of cut parameter which has the highest influence on machining process time is at a depth of 0.15 mm.

Table 10. Analysis of Variance for Machining Time

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Spindel Speed	2	1146,89	39.77%%	1146,89	573,444	737,29	0,001
Feed rate	2	1704,22	59,10%	1704,22	852,111	1095,57	0,001

Depth of Cut	2	30,89	1,07%	30,89	15,444	19,86	0,048
Error	2	1,56	0,05%	1,56	0,778		
Total	8	2883,56	100,00%				

Based on Table 9 Analysis of Variance on Machining Time, it can be concluded that there are two factors that have a significant influence on the production process time, this is proven by the P-Value of each factor <0.05. Then the most influential factor in this table is feed rate with a contribution of 59.10%. Then the contribution of the two-spindle speeds are 39.77%% and the depth of cut which only contributes to the machining process is only 0.90%. Feed rate is the most significant factor affecting energy consumption during milling, which is then followed by spindle speed [14]. While the depth of cut has no real significance value. Feed rate and spindle speed have a significant influence on milling machining time, but from these two parameters, there are differences where the feed rate has a higher level of significance then the spindle speed [15].

Furthermore, experimental confirmation tests were carried out on the maximum value which was rated as having the most optimal time speed by making predictions on the three most optimal variables ranging from feed rate, spindle speed to depth of cut. This confirmation experiment was carried out by comparing the predicted value to the time velocity value of the confirmation experiment. From predictions that use the three most optimal values in each variable, the following results are obtained.

Table 11. Parameter Settings.

Spindle Speed	Feed rate	Depth of Cut
2185.2	1146	0.15

Tabel 12. Prediction Value

Prediction	Interval
52.22	± 2.98

After the initial prediction of the three most optimal variable values is then carried out directly tested by simulating using the Swansoft application by adjusting the existing variables, so that the following values are obtained.

Table 13. Experimental Test Confirmation

NO	Parameters/Factors			Working Time
	A	B	C	
1	1	3	2	55

Based on the values obtained, it can be concluded that the results of this confirmation experiment were successful because they were still in the range of predicted values.

CONCLUSION

Conclusions that can be drawn from the results of data analysis and wetting in this study are related to the influence of the designed CNC milling machining parameters on the machining process time, namely :

1. Spindle speed has an influence on the production process time with a significance value of 0.002 < 0.05 and presentation contribution of 39.77%%.
2. The feed rate has an influence on the production process time with a significance value of 0.001 < 0.05 and a contribution presentation of 59.10%.
3. Depth of cut has an influence on the production process time with a significance value of 0.048 < 0.05 and a contribution presentation of 1.07%.
4. Feed rate is a parameter that has the greatest influence on the time of the production process or CNC milling machining with a contribution presentation value of 59.10%.
5. The research parameter design that has the most optimal time is in the 3rd design using a spindle speed of 2185.2 rpm, a feed rate of 1146 mm/min and a depth of cut of 0.20 mm which results in a time speed of 55 seconds.

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