ANALYSIS OF THE EFFECT OF AICC PARAMETERS VARIATION ON CNC MILLING MACHINES ON MACHINING TIME AND WORKPIECE ACCURACY

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Abstract-- The global market for Computer Numerical Control (CNC) milling machines continues to grow at a significant rate, with the automotive industry being the largest end-user. The Fanuc 31i controller is one of the leading controllers in the manufacturing industry. This controller has AI nano CNC features that support high-precision movements and high-speed NC program execution. The more understanding of the AICC (AI Contour Control) parameter settings can make a significant contribution to improvement of production efficiency and quality. This research is conducted to investigate the influence of changing the "R" value in the AICC parameter on the CNC Milling machine OKK VP1200 with the Fanuc 31i controller to machining time and workpiece accuracy. The experiments were conducted on three shapes: profile-01(complex), profile-02(circle), and profile-03(square), using three test specimens with variations in AICC parameters ranging from R1 to R10. By adjusting these parameters, the actual machining time was recorded, and the accuracy of the machining process was measured using a Coordinate Measuring Machine (CMM) and later the data was analyzed. Steps in data analysis are creation of test data tables, scatter charting, and regression equation with maximum R^2. This study presents data and instructions for the application of AICC R1-R10 parameters that is adjusted to the specified tolerances or deviations. Furthermore, the research can provide the percentage of actual time compared to the programmed time if a CAM Programmer has determined the tolerance range limit or deviation of a product and determined which AICC parameters to use. The correlation between the parameter setting R values and the actual machining time is a positive correlation 2nd order polynomial regression, with R^2 values: 0.993, 0.995, and 0.983. The correlation between the parameter setting R values and the deviation of machining results is a negative correlation 4th order polynomial regression, with R^2 values: 0.993, 0.993, and 0.986. Higher AICC parameter R values result in longer machining time but smaller deviation values or better workpiece accuracy. In practice, a CAM Programmer can make predictions for two aspects based on the data in this research that are actual machining time and product accuracy.

Keywords: CNC milling machine, Fanuc 31i controller, AICC parameter, Machining time, Workpiece accuracy.

1. INTRODUCTION

In 2022, the global CNC (Computer Numerical Control) milling machine market had a value of approximately USD 76 billion. It is predicted that this market will grow and reach a value of about USD 94 billion by 2031, with an average annual growth rate of 8.52% over the forecast period from 2023 to 2031. The market segmentation of CNC milling machines begins with various types of products: Vertical CNC Milling Machines, Horizontal CNC Milling Machines, and Universal CNC Milling Machines. They are further categorized based on the number of axes, such as 3-axis, 4-axis, and others. Meanwhile, in terms of industries, the end users include Automotive, Electrical and Electronics, Aerospace and Defense, among others [1]

The CNC Milling Machine with the Fanuc 31i controller is a widely used machine configuration in the manufacturing industry for producing various parts with high precision. The Fanuc 31i controller is equipped with nano CNC AI features developed by Fanuc, ensuring high-speed and high-accuracy movement when running NC programs [2]. It supports a maximum of 4 paths and controls up to 20 feed axes, with a configuration allowing for up to 6 spindles. Additionally, the Fanuc 31i controller facilitates simultaneous axial movement across 4 axes, with the capability extended to 5 axes on the 31i-A5 model.

The use of CNC milling machines with Fanuc 31i controllers provides a variety of advantages, including the ability to produce complex shapes, smooth surfaces, and tight tolerances. The Fanuc 31i controller also offers an intuitive user interface and customizable features to meet different application needs [3]. With the Fanuc 31i controller, CNC milling machine operators can program and adjust various parameters to ensure optimal machining results in terms of machining time, accuracy, and surface quality. Features such as AICC in the Fanuc 31i controller help enhance machining efficiency and quality by optimizing axis movement and interpolation [4].

Previous research conducted by Rajput &

Sarathe focused on comparing the use of three types of CNC machine controllers: HEIDENHAIN TNC 426, SINUMERIK 840D, and Fanuc 21M, in machining materials using the same program [5]. This study aims to understand how differences in controller usage can affect production outcomes such as Material Removal Rate (MRR) and machining time. The study measured MRR and machining time results for each controller, analyzed the data, and compared the performance of the three controllers mentioned above.

Research by Hendra et al. focuses on comparing the machining process using CNC milling machines through simulations with Mastercam and SSCNC software against actual operations using Leadwell V-30 CNC milling machines. This study aims to determine the degree to which simulations can replicate or approximate the actual machining processes on CNC milling machines [6].

Another study by Saputra et al. focuses on improving efficiency and accuracy in planning machining processes using NCBrain software. Issues addressed include inaccurate time estimation, non-compliant product results, and excessive use of cutting tools during CAM (Computer-Aided Manufacturing) software planning. The study aimed to integrate CNC milling technology, cutting tools, raw materials, and machining process methods to enhance productivity, reduce production costs, and ensure timely delivery [7].

There are still very few sources of literature that discuss the function of AICC on the Fanuc 31i controller in relation to machining parameters and the quality of machining results. Meanwhile, the use of Fanuc 31i controllers is widespread in the Asian automotive industry, especially in Indonesia. Meiwa Mold is a company engaged in manufacturing injection molds and high-pressure die-casting molds, with automotive parts molds for motorcycles and cars forming the largest segment. Meiwa Mold operates in several countries, including Japan, Thailand, Indonesia, China, and Mexico. The majority of 3-axis CNC milling machines at Meiwa Mold facilities (Japan, Thailand, Indonesia, China, Mexico) use Fanuc controllers. Currently, there is still a lack of information and research specifically examining the effect of changes in AICC parameters on CNC milling machines with Fanuc 31i controller on machining time and workpiece accuracy. Therefore, this study aims to fill the knowledge gap that occurs by exploring the effect of AICC parameters on CNC Milling machines on machining time and workpiece accuracy.

This study has significant relevance in the manufacturing industry because a better understanding of the influence of AICC parameters can help CAM programmers and CNC Milling machine operators to optimize machine configurations. By effectively utilizing AICC parameters, machining time can be reduced, productivity can be improved, and workpiece accuracy can be achieved.

2. METHOD

This study applied descriptive method. Experimental research is a study intended to determine whether or not there is a consequence of "something" imposed on the subject being studied.

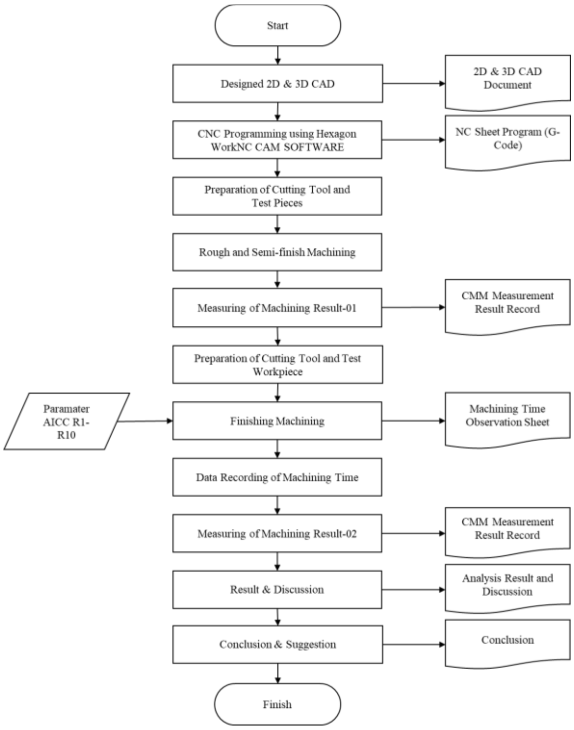

Figure 1. Research Flow Chart

The stages of research began from the manufacture of 2D and 3D CAD, the manufacture of CNC programs with CAM software, the preparation of cutting tools and test workpieces, rough and semi-finish machining, the measurement of rough and semi-finish machining results, the preparation of cutting tool finishes and test workpieces, finishing machining according to AICC parameters, the recording of machining time data, the measurement of finishing machining results, results and discussions.

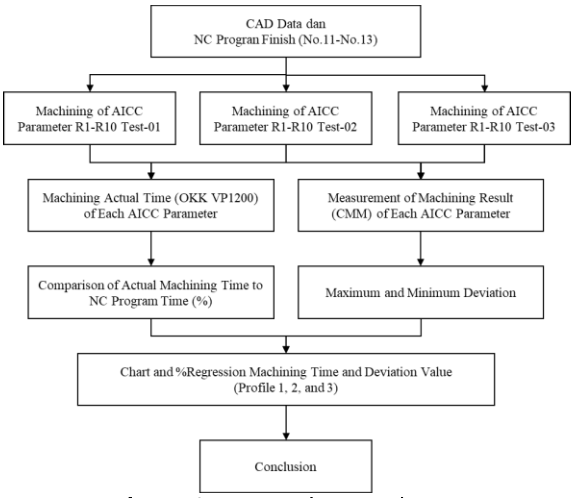

Figure 2. Research Procedures

Figure 2 shows the research procedure. The test objects with the same NC program, but with different AICC parameters will be compared with the actual machining time, and the same data cad will be compared with the machining results, then analyzed regression. Before conducting a regression analysis, a correlation analysis should first be carried out to ensure whether there is a relationship between the independent variable and the dependent variable [9]. Hypothesis on the variation of R value, where the closer the value of R10, the higher the accuracy value with slower machining time and vice versa.

This research was conducted at PT. Meiwa Mold Indonesia which is located at Jl. Irian VIA Block NN-3 & NN7 MM2100 Industrial Town Cikarang Barat, Bekasi. The time of this study, September to October 2023, the time and date follow the schedule of PT. Meiwa Mold Indonesia.

The Research Subjects consisted of Population and Sample. Population is the overall research subject. This test will be carried out on 3 test object specimens, with each test object consisting of 11 profile groups (AICC OFF, R1-R10), and each group consisting of 3 profiles. While the sample is part of the number and characteristics possessed by the population, it means that the sample is part of the population that is considered representative to be used as a data source. The sample of this study was in accordance with the population, namely three specimens of test objects with each AICC parameter R1-R10.

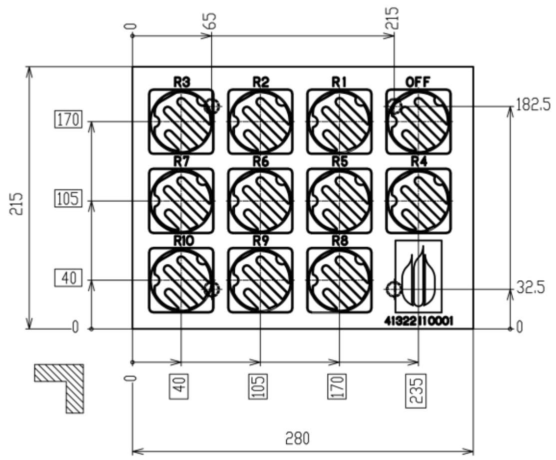

Figure 3. Drawing of Test Objects

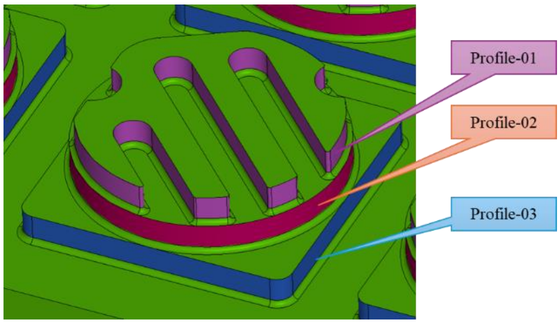

Figure 4. Test Item Profile

This study has two variables, namely the dependent variable and the independent variable. The independent variable in this study is the AICC parameter R1-R10, while the dependent variable is the machining process time and the difference between the maximum and minimum deviation values.

The data to be obtained in this study are machining time with AICC R1-R10 parameters and test object accuracy. For this reason, this study will use the OKK VP1200 CNC Milling machine with the Fanuc 31i controller for the machining process and the Mitutoyo CRYSTA apex-S CNC CMM machine for the test object measurement process using the SCANPAK method.

Figure 4. OKK VP1200 CNC Milling Machine

Figure 5. Cutting Tool Installed on Shrink Fit Tool Holder

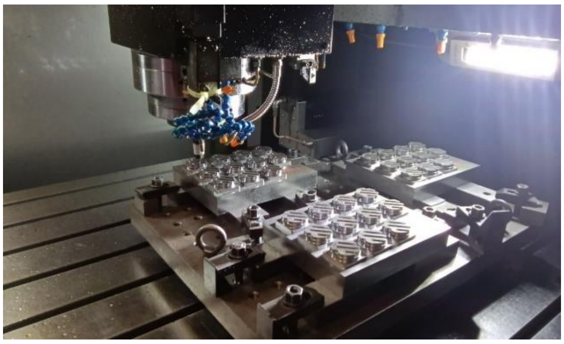

Figure 6. Machining Process

Figure 7. Mitutoyo CRYSTA APEX-S CNC CMM machine

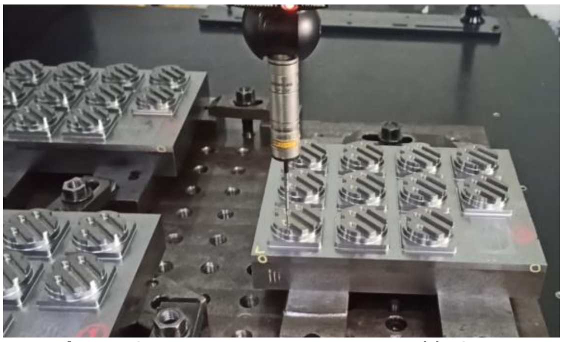

Figure 8. Measurement Process with CMM

The research instrument used in this study was an observation sheet. The observation sheet contains the actual machining time and accuracy of machined test objects that have been processed using AICC R1-R10 parameters.

The data analysis technique in this study is a descriptive quantitative analysis approach to determine whether there is a difference between the average data results before and after treatment. Steps in data analysis: 1. Creation of test data tables, 2. Scatter charting, 3. Regression equation with maximum R^2.

3. RESULT AND DISCUSSION

3.1 Result of the study

The research data results consist of actual machining times based on AICC parameters with R1-R10 settings for three test materials. These actual machining times will be compared with those in the NC Program, presenting the data as a percentage of the actual machining time compared to the NC program time. This comparison is presented in Table 1.

Table 1. Actual Machining Time Data of All Test Objects

MACHINING TIME RECORD				Result-01	Result-02	Result-03
Setting "R"	Profile	NC Program Name	NC Program Time (hh:mm:ss)	Actual Machining Time (hh:mm:ss)	Actual Machining Time (hh:mm:ss)	Actual Machining Time (hh:mm:ss)
OFF	Profile-01	aicc_fin_1101.Anc	0:07:12	0:07:38	0:07:38	0:07:38
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:03:55	0:03:54	0:03:55
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:04:51	0:04:51	0:04:51
R1	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:41	0:08:42	0:08:42
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:07	0:04:08	0:04:08
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:04	0:05:04	0:05:04
R2	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:42	0:08:43	0:08:42
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:08	0:04:08	0:04:08
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:05	0:05:05	0:05:05
R3	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:44	0:08:43	0:08:44
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:09	0:04:09	0:04:10
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:05	0:05:06	0:05:06
R4	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:45	0:08:45	0:08:44
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:10	0:04:10	0:04:10
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:08	0:05:07	0:05:06
R5	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:46	0:08:46	0:08:46
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:11	0:04:11	0:04:10
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:08	0:05:07	0:05:07
R6	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:47	0:08:47	0:08:47
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:12	0:04:11	0:04:12
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:09	0:05:09	0:05:08
R7	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:49	0:08:49	0:08:49
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:13	0:04:12	0:04:13
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:10	0:05:10	0:05:10
R8	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:51	0:08:50	0:08:51
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:14	0:04:14	0:04:14
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:11	0:05:10	0:05:10
R9	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:52	0:08:52	0:08:53
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:15	0:04:15	0:04:15
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:12	0:05:12	0:05:12
R10	Profile-01	aicc_fin_1101.Anc	0:07:12	0:08:53	0:08:54	0:08:54
	Profile-02	aicc_fin_1201.Anc	0:03:28	0:04:16	0:04:16	0:04:16
	Profile-03	aicc_fin_1301.Anc	0:04:25	0:05:13	0:05:13	0:05:13

After completing the machining process, all test objects undergo inspection. The accuracy of machining results is determined by calculating the difference between the maximum and minimum deviation values for each profile. To enhance the readability of the measurement results, they are presented in Table 2.

Table 2. Data on the Results of Measurement of All Test Objects

MEASUREMENT RESULTS			Result-01		Result-02		Result-01	
Setting "R"	Profile	NC Program Name	Maximum Deviation (mm)	Minimum Deviation (mm)	Maximum Deviation (mm)	Minimum Deviation (mm)	Maximum Deviation (mm)	Minimum Deviation (mm)
OFF	Profile-01	aicc_fin_1101.Anc	0.116	-0.210	0.114	-0.224	0.212	-0.221
	Profile-02	aicc_fin_1201.Anc	0.059	-0.030	0.061	-0.025	0.060	-0.025
	Profile-03	aicc_fin_1301.Anc	0.048	-0.105	0.041	-0.110	0.044	-0.108
R1	Profile-01	aicc_fin_1101.Anc	0.044	-0.014	0.027	-0.023	0.023	-0.019
	Profile-02	aicc_fin_1201.Anc	0.018	-0.007	0.020	-0.020	0.019	-0.012
	Profile-03	aicc_fin_1301.Anc	0.029	-0.013	0.017	-0.015	0.017	-0.006
R2	Profile-01	aicc_fin_1101.Anc	0.043	-0.013	0.022	-0.021	0.024	-0.017
	Profile-02	aicc_fin_1201.Anc	0.019	-0.004	0.018	-0.017	0.019	-0.007
	Profile-03	aicc_fin_1301.Anc	0.020	-0.006	0.015	-0.015	0.010	-0.012
R3	Profile-01	aicc_fin_1101.Anc	0.037	-0.011	0.022	-0.020	0.020	-0.019
	Profile-02	aicc_fin_1201.Anc	0.020	-0.001	0.018	-0.017	0.013	-0.009
	Profile-03	aicc_fin_1301.Anc	0.018	-0.007	0.010	-0.014	0.008	-0.012
R4	Profile-01	aicc_fin_1101.Anc	0.032	-0.014	0.020	-0.020	0.020	-0.018
	Profile-02	aicc_fin_1201.Anc	0.016	-0.004	0.019	-0.012	0.015	-0.005
	Profile-03	aicc_fin_1301.Anc	0.018	-0.004	0.007	-0.014	0.012	-0.007
R5	Profile-01	aicc_fin_1101.Anc	0.037	-0.009	0.019	-0.018	0.021	-0.015
	Profile-02	aicc_fin_1201.Anc	0.012	-0.007	0.013	-0.014	0.009	-0.005
	Profile-03	aicc_fin_1301.Anc	0.011	-0.009	0.008	-0.013	0.011	-0.007
R6	Profile-01	aicc_fin_1101.Anc	0.031	-0.014	0.020	-0.016	0.019	-0.017
	Profile-02	aicc_fin_1201.Anc	0.014	-0.003	0.018	-0.009	0.007	-0.006
	Profile-03	aicc_fin_1301.Anc	0.010	-0.007	0.007	-0.013	0.007	-0.009
R7	Profile-01	aicc_fin_1101.Anc	0.031	-0.010	0.019	-0.015	0.020	-0.014
	Profile-02	aicc_fin_1201.Anc	0.015	-0.002	0.010	-0.013	0.008	-0.004
	Profile-03	aicc_fin_1301.Anc	0.012	-0.003	0.008	-0.011	0.006	-0.008
R8	Profile-01	aicc_fin_1101.Anc	0.024	-0.006	0.015	-0.019	0.019	-0.014
	Profile-02	aicc_fin_1201.Anc	0.015	-0.001	0.010	-0.010	0.007	-0.005
	Profile-03	aicc_fin_1301.Anc	0.011	-0.004	0.006	-0.012	0.006	-0.008
R9	Profile-01	aicc_fin_1101.Anc	0.023	-0.007	0.011	-0.017	0.016	-0.014
	Profile-02	aicc_fin_1201.Anc	0.011	-0.004	0.010	-0.009	0.006	-0.006
	Profile-03	aicc_fin_1301.Anc	0.012	-0.002	0.005	-0.012	0.008	-0.005
R10	Profile-01	aicc_fin_1101.Anc	0.017	-0.010	0.013	-0.015	0.015	-0.012
	Profile-02	aicc_fin_1201.Anc	0.011	-0.001	0.005	-0.010	0.005	-0.006
	Profile-03	aicc_fin_1301.Anc	0.011	-0.003	0.004	-0.010	0.005	-0.007

The comparison of actual time with NC program for profile-01, profile-02, and profile-03. The R value to indicate the AICC parameter as the independent variable (X), while the actual time comparison with the NC program serves as the dependent variable (Y). From this data, it is evident that higher R values correspond to greater deviations between actual and NC program times, as shown in Table 3.

Table 3. Average Data of Actual Time Comparison with NC Program (%)

R	Profile-01			Profile-02			Profile-03		
	NC Program Time (second)	Average Actual Machining Time (second)	Comparison of Actual Time to NC Program (%)	NC Program Time (second)	Average Actual Machining Time (second)	Comparison of Actual Time to NC Program (%)	NC Program Time (second)	Average Actual Machining Time (second)	Comparison of Actual Time to NC Program (%)
OFF	432	458	106.019	208	235	112.981	265	291	109.811
1	432	522	120.833	208	248	119.231	265	304	114.717
2	432	522	120.833	208	248	119.231	265	305	115.094
3	432	524	121.296	208	249	119.712	265	306	115.472
4	432	525	121.528	208	250	120.192	265	307	115.849
5	432	526	121.759	208	251	120.673	265	307	115.849
6	432	527	121.991	208	252	121.154	265	309	116.604
7	432	529	122.454	208	253	121.635	265	310	116.981
8	432	531	122.917	208	254	122.115	265	310	116.981
9	432	532	123.148	208	255	122.596	265	312	117.736
10	432	534	123.611	208	256	123.077	265	313	118.113

Accuracy deviation data for profile-01, profile-02, and profile-03 are presented. The R value indicates the AICC parameter as the independent variable (X), while the deviation difference represents the dependent variable (Y). From the obtained data, it is evident that the deviation is not consistent across different R values, as shown in Table 4.

Table 4. Average Data on Difference in Deviation

R	Profile-01			Profile-02			Profile-03		
	Maximum Deviation Average (mm)	Minimum Deviation Average (mm)	Average Deviation Difference (mm)	Maximum Deviation Average (mm	Minimum Deviation Average (mm)	Average Deviation Difference (mm)	Maximum Deviation Average (mm	Minimum Deviation Average (mm)	Average Deviation Difference (mm)
OFF	0.147	-0.218	0.365	0.060	-0.027	0.087	0.044	-0.108	0.152
1	0.031	-0.019	0.050	0.019	-0.013	0.032	0.021	-0.011	0.032
2	0.030	-0.017	0.047	0.019	-0.009	0.028	0.015	-0.011	0.026
3	0.026	-0.017	0.043	0.017	-0.009	0.026	0.012	-0.011	0.023
4	0.024	-0.017	0.041	0.017	-0.007	0.024	0.012	-0.008	0.020
5	0.026	-0.014	0.040	0.011	-0.009	0.020	0.010	-0.010	0.020
6	0.023	-0.016	0.039	0.013	-0.006	0.019	0.008	-0.010	0.018
7	0.023	-0.013	0.036	0.011	-0.006	0.017	0.009	-0.007	0.016
8	0.019	-0.013	0.032	0.011	-0.005	0.016	0.008	-0.008	0.016
9	0.017	-0.013	0.030	0.009	-0.006	0.015	0.008	-0.006	0.014
10	0.015	-0.012	0.027	0.007	-0.006	0.013	0.007	-0.007	0.014

3.2 Discussion

A. Discussion of Profile-01 Data Analysis Results

Correlation of Increased Accuracy to Actual Time Percentage of Profile-01.

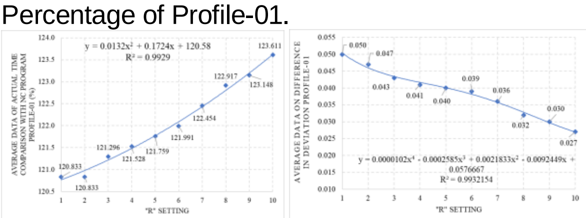

Figure 9. (a) % Time Comparison; (b) Comparison of Differences in Deviations in Profile-01

In Figure 9, graph (a) compares the actual machining time with the time in the NC program. The differences happens due to the absence of the R factor in the AICC during the calculation of the toolpath in the program, resulting in a time variance. It is important to note that while these deviations in time estimates may seem insignificant, they can have an impact when used in mass manufacturing or highly complex machining processes.

According to the chart, the smallest comparison value occurs at R1, while the largest occurs at R10. This value is inversely proportional to the deviation graph, where the deviation value is depicted in graph (b). This aligns with the hypothesis that R1 results in the fastest toolpath but with lower accuracy, whereas R10 produces the slowest toolpath with higher accuracy. The actual machining time is also influenced by acceleration and deceleration due to the complexity of contours on the workpiece. The tool accelerates on linear toolpaths and decelerates on toolpaths involving curves or changes in direction.

The decceleration is intended to prevent machine shock and errors caused by high acceleration. This aligns with the theory of the AI-Contour Control/AI-nano contour control function in the Fanuc 31i for high-speed, high-precision machining. This function helps minimize acceleration and deceleration delays, reduce servo delays due to increased feedrate, and minimize errors in the machining profile [8].

Deviation of Accuracy to Actual Time Percentage of Profile-01

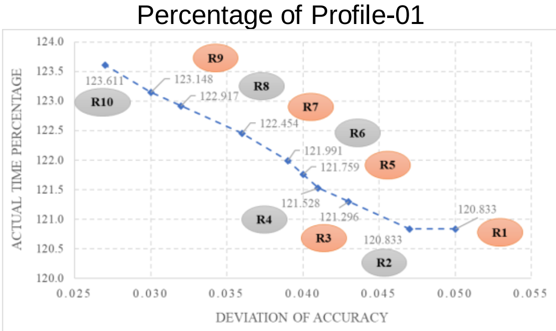

Figure 10. Actual Time Percentage and Deviation Chart

In its application in the manufacturing process, as shown in Figure 10 above, we observe an increase in accuracy percentage without a corresponding increase in machining time from R1 to R2. This makes it a viable option when the machining process encounters tolerance specifications for the workpiece, as indicated in the graph. By analyzing the chart, machining time estimates can be more accurately predicted. For instance, for a part with a tolerance of ±0.02 mm or a deviation of 0.04 mm, AICC settings with parameters R6, R7, R8, R9, or R10 can be utilized. Using R6, the estimated machining time compared to the NC program time is approximately 122%, while using R10 results in an estimated machining time around 124%. This aligns with the theory of High-Speed Machining (HSM), which involves higher cutting velocities compared to conventional machinery. The cutting speed range varies depending on parameters such as workpiece material, tool material, cutting conditions, and machine tool, with workpiece material being the most influential factor in high-density machining results [9].

B. Discussion of Profile-02 Data Analysis Results

Correlation of Increased Accuracy to Actual Time Percentage of Profile-02.

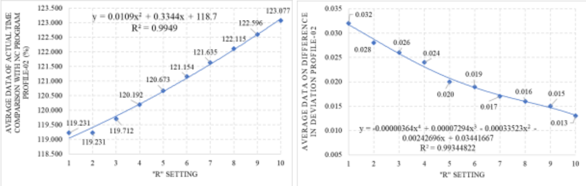

Figure 11. (a) % Time Comparison; (b) Comparison of Differences in Deviations in Profile-02

In Figure 11, graph (a) illustrates a comparison between actual machining time and the machining time programmed in NC, while graph (b) shows a comparison of minimum and maximum accuracies. Unlike profile-01 contours, the time difference for each R in circular contours remains consistent. Moreover, the accuracy deviation comparisons exhibit a patterned outcome. This consistency arises because the toolpath for circular profiles involves less variation compared to profile-01; here, the toolpath tends to decelerate as it approaches the workpiece radius. Therefore, achieving high accuracy necessitates using an R value close to the maximum.

Deviation of Accuracy to Actual Time Percentage of Profile-02

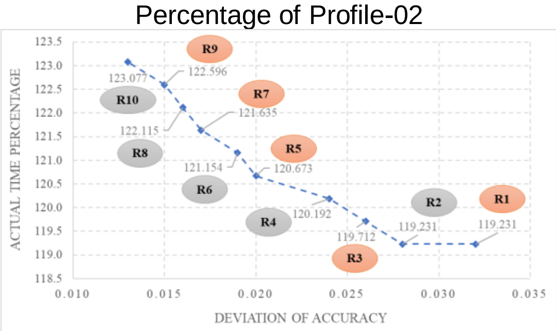

Figure 12. Actual Time Percentage and Deviation Chart

In Figure 12, similarities with profile-01 are observed, specifically an increase in accuracy from R1 to R2 without a corresponding increase in machining time. This option becomes viable when the machining process encounters workpiece tolerance specifications, as depicted in the graph. In its application in the manufacturing process, using the graph above, we can observe an increase in the percentage of time required to achieve the desired accuracy. Thus, the estimated machining time can be more accurately predicted. For example, for a part with a tolerance of ±0.015 mm or a deviation of 0.03 mm, the AICC settings with parameters R2 through R10 can be employed. Using R5, the estimated machining time compared to the NC program time is around 120.6%, while using R10 results in an estimated machining time of approximately 123%. These findings are consistent with the advantages of High-Speed Machining (HSM), which include high efficiency, precision, and superior surface quality, thereby enhancing the finishing process of hardened steel materials [10].

C. Discussion of Profile-03 Data Analysis Results

Correlation of Increased Accuracy to Actual Time Percentage of Profile-03.

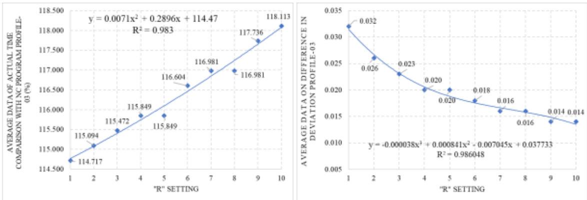

Figure 13. (a) % Time Comparison; (b) Comparison of Differences in Deviations in Profile-03

In Figure 13, graph (a) illustrates a comparison between actual machining time and the time programmed in NC, while graph (b) shows a comparison of minimum and maximum accuracies. The percentage time comparisons remain consistent for R4 and R5, and R7 and R8, while the accuracy data tends to vary across different R values. It is important to note that deceleration in this profile occurs only at the end of the square profile's corners to prevent machine shock and machining errors caused by high acceleration. Therefore, a hypothesis can be proposed that differences in time and accuracy occur specifically during the formation of corner contours on profile-03 workpieces.

Deviation of Accuracy to Actual Time Percentage of Profile-03

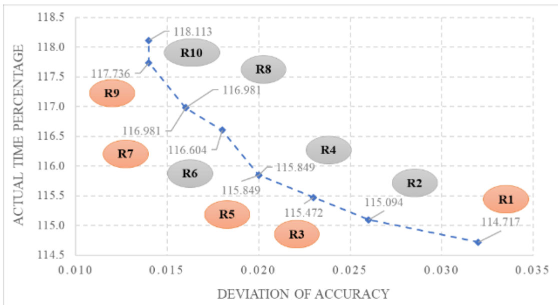

Figure 14. Actual Time Percentage and Deviation Chart

Figure 14 Almost the same as the profile-01 and profile-02, there is a significant increase in accuracy from R1 to R2, with an increase in machining time is not so significant, thus this can be an option when the machining process is faced with a workpiece tolerance specification according to the graph. In its application in the manufacturing process, using the graph above we can see an increase in the percentage of time to the desired accuracy. Thus, the estimated machining time can be better predicted. For example, a part with tolerance ±0.01 mm or 0.02 mm deviation, it can use AICC settings with parameters R5, R6, R7, R8, R9, and R10. If the AICC parameter used is R5, then the estimated machining time compared to the program NC time is around 115.8%, but if R10 is used, then the estimated machining time compared to the program NC time is around 118.1%.

4. CONCLUSION

Based on the results of the analysis of the relationship between the change in the 'R' value of the AICC parameter on the OKK VP1200 CNC Milling machine with the Fanuc 31i controller regarding machining time and workpiece accuracy, the following conclusions can be drawn: The AICC parameters R1-R10 on the OKK VP1200 CNC Milling machine with the Fanuc 31i controller significantly affect machining time, with a positive correlation observed. As the R parameter value increases, machining time increases accordingly. The correlation between the parameter setting value R and the actual machining time is a positive correlation 2nd order polynomial regression, with R^2 values: 0.993, 0.995, and 0.983, indicating that these parameters strongly influence the actual machining time by approximately 98.3% to 99.5%.

Furthermore, AICC parameters R1-R10 on the OKK VP1200 CNC Milling machine with the Fanuc 31i controller significantly affect deviation difference, showing a positive impact on workpiece accuracy. This suggests that higher R parameter values lead to improved workpiece accuracy. The correlation between the parameter setting R value and the accuracy of machining results is a 4th order polynomial regression, with R^2 values: 0.993, 0.993, and 0.986, indicating a strong negative influence of AICC parameters R1-R10 on deviation difference, with a total influence ranging from about 98.6% to 99.3%. This confirms that higher R parameter values result in smaller deviation values, indicating better workpiece accuracy.

The combination of AICC parameters R1-R10 in both roughing and finishing processes is essential for optimizing the manufacturing process. Selecting the appropriate R parameter should be based on the tolerance or accuracy requirements of the workpiece, ensuring that the produced workpiece meets specifications with optimal machining time.

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