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Simulation of CNC Milling on Chain Adjuster Design Using Fusion 360 to Enhance Process Time Efficiency

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ABSTRACT

The advancement of manufacturing technology and the growing intensity of industrial competition demand efficiency and precision in production processes. This study aims to evaluate the influence of machining parameter variations on the process time efficiency of CNC milling for a chain adjuster component. Simulations were carried out using Fusion 360 software, focusing on machining time estimation based on parameters such as spindle speed, feed rate, and depth of cut. The simulation results were compared with manual calculations based on fundamental machining formulas to assess their accuracy. The analysis shows relatively small-time differences between simulation and manual calculations, indicating that Fusion 360 can be reliably used as a tool for efficient production planning. Thus, CAM simulations not only facilitate toolpath visualization but also provide added value in machining time estimation and optimal parameter setting.

1. Introduction

The rapid advancement of manufacturing technology and the intensification of global competition have compelled industries to produce high-quality products within shorter lead times. To address these challenges, automation technologies such as Computer Numerical Control (CNC) machines are increasingly utilized due to their ability to enhance efficiency, precision, and consistency in production processes. One of the most prevalent types of CNC machines is the CNC milling machine, which can machine complex components with high accuracy, particularly in the automotive and aerospace industries.

The success of the machining process is significantly influenced by parameters such as cutting speed, spindle speed, feed rate, and depth of cutting. Improper parameter selection can lead to time inefficiency, excessive tool wear, and final outputs that do not meet required standards. Consequently, tools capable of accurately simulating the machining process are essential for determining optimal parameters prior to actual production [1].

One software platform that fulfills these requirements is Fusion 360, a CAD/CAM solution providing features for toolpath planning, machining simulation, and cycle time estimation. Through these simulations, users can evaluate process efficiency and adjust machining parameters to achieve optimal results [2].

Despite the convenience and comprehensive features offered, research specifically addressing the accuracy of time estimations in Fusion 360 compared to manual calculations remains scarce. Most previous studies have focused on the use of Fusion 360 for toolpath generation or visual simulation without validating the resulting time values. For instance, the study by Setiawan et al. (2023) focused primarily on utilizing Fusion 360 for product redesign simulation without comparing simulation results to empirical calculation data. Similarly, Burhanudin et al. (2023) emphasized the integration of G-code and CAM learning without testing the accuracy of the estimated processing time. However, precise time estimation is critical in production planning, particularly for efficiency and scheduling. This constitutes a research gap, necessitating a study that not only utilizes simulation but also validates the veracity of the generated data.

Based on this background, this study aims to analyze the influence of varying machining parameters on CNC milling process time and to compare the estimated time between Fusion 360 simulations and manual calculations. The results of this research are expected to contribute to the validation of software simulation accuracy and its practical application in manufacturing production planning.

2. Method

2.1 CNC Milling

A Computer Numerical Control (CNC) milling machine is a precision machine tool designed to perform material removal processes through computer-based control systems. This machine operates by simultaneously articulating cutting tools across multiple axes to shape workpieces in accordance with pre-programmed geometric designs. In industrial practice, CNC milling is extensively utilized for manufacturing components that require high dimensional accuracy and geometric complexities that are difficult to achieve using conventional methods. The primary advantages of this technology include consistent repeatability, production time efficiency, and versatility in processing a wide range of materials, such as metals, polymers, and composites [3].

The specific CNC milling machine employed in this research is the Supermill MK 2.0 by DTECH Engineering. This machine features axis travel capacities of 300 mm, 220 mm, and 230 mm for the X, Y, and Z axes, respectively. The clearance between the spindle and the table ranges from 120 mm to 350 mm. The working table measures 620 mm in length and 200 mm in width, integrated with three 10 mm T-slots at 60 mm intervals, and can support a maximum uniform load of 40 kg.

The maximum feed rate is 10 meters per minute, while the rapid traverse rate across all three axes reaches 15 meters per minute. The spindle is driven by a 1.5 kW motor, achieving rotational speeds of up to 6000 RPM. It utilizes a BT30 taper and is equipped with an internal air-cooling system via an integrated fan. Tool clamping is facilitated by an electronically controlled pneumatic system.

The control architecture is powered by the DTECH-AUTOMATION Controller, featuring a 15.6-inch touchscreen interface and 4 GB of high-speed storage. Furthermore, the system includes an integrated Manual Pulse Generator (MPG) with a rotary encoder for manual configuration and positioning.

The electrical power requirement for the machine is 4.4 kW, operating at a single-phase voltage of 220V with a full-load current of 20 A. Additionally, the machine necessitates a pneumatic supply of 113 liters/minute at a nominal pressure of 6.9 bar, with a minimum operational threshold of 5.5 bar. The cooling system utilizes a recirculating coolant with a 17.5-liter capacity, facilitated by a high-pressure DC-based pump.

In the CNC milling process, fundamental calculations are employed to determine the specific variables for material removal. There are several primary machining parameters that can be adjusted by the operator prior to the machining process, namely spindle speed, cutting speed, and feed rate. These parameters are subsequently processed to calculate the machining time (Tm) and the Material Removal Rate (MRR) using the following equations:

$$T_m = \frac{L+A}{Fr} \tag{1}$$

Where:

T_m: Machining time (minutes).
L : Cutting length (mm).
A : Approach and overtravel allowance, representing the additional distances before and after the cutting tool engages and disengages from the workpiece (mm).
Fr : Feed rate, or the rate of tool advancement (mm/min).

The Material Removal Rate (MRR) is a critical parameter utilized to quantify the rate of material volume reduction during the machining process. Generally, a higher MRR value signifies superior machining efficiency, which serves as a vital metric for production scheduling and the overall evaluation of manufacturing performance [4].

In this study, the machining time (Tm) is derived from simulations conducted via Fusion 360 software. The Tm value is generated automatically upon executing the simulation, serving as a primary benchmark for calculating production efficiency and validating the manufacturing process.

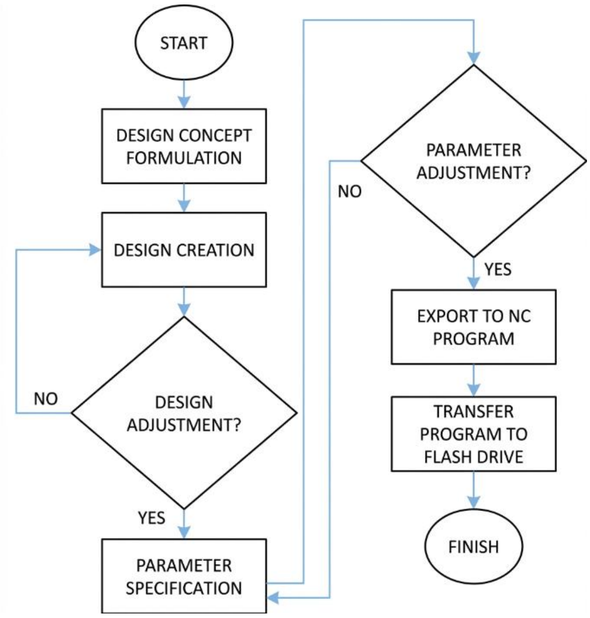

Fig. 1. Production flowchart

2.2 CNC Milling 3 Axis

A 3-axis CNC milling machine is a type of machining center that operates along three primary axes: X (horizontal left-right motion), Y (horizontal front-back motion), and Z (vertical up-down motion). This machine facilitates automated material removal by simultaneously articulating the cutting tool and the workpiece across these three axes. 3-axis CNC systems are widely utilized to fabricate components ranging from 2D profiles to moderate 3D geometries, such as cavities, slots, planar surfaces, and basic contours. Due to its efficiency, precision, and versatility in processing diverse materials, including metals, polymers, and wood, this technology is extensively adopted across various industrial sectors [5].

Fig. 2. CNC milling 3 axes

2.3 Data Collection Techniques

A critical component within the motorcycle transmission system, particularly in the power transfer mechanism from the engine to the rear wheel via the chain, is the chain adjuster. This component functions to regulate chain tension to ensure optimal operational conditions. Inappropriate chain tension, whether excessive slack or over tension, can lead to various technical issues, such as accelerated sprocket wear, the risk of chain derailment, and compromised vehicle stability. Consequently, the chain adjuster is vital for maintaining both the performance and safety of the motorcycle.

The following sections present the chain adjuster designs, including several developed variants, modeled using the Computer Aided Design (CAD) software, Autodesk Fusion 360.

Fig. 3. Chain adjuster

As illustrated in Fig. 3, the encircled component represents the chain adjuster, which is utilized to calibrate and maintain the optimal tension of the motorcycle's drive chain.

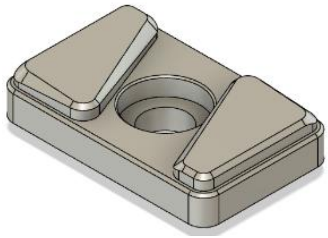

Fig. 4. Design of chain adjuster variation

Fig. 4 illustrates the modified designs of the chain adjuster specifically developed for simulation purposes.

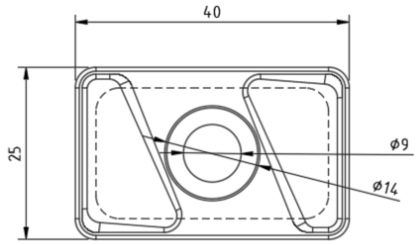

Fig. 5. The 2D top view of the modified chain adjuster design

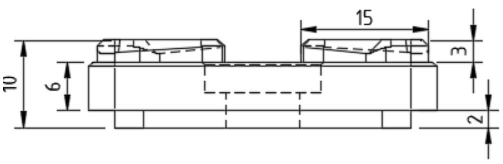

Fig. 6. Front View of the Chain Adjuster Design Variations

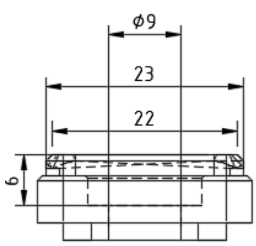

Fig. 7. Design of chain adjuster variation

2.4 Types of Tools

From the known design, it is made by machining a CNC Milling machine which uses Flat end mill and Chamfer tools.

2.4.1 End Mill

End mill is a cutting tool on CNC machines milling which can cut vertically and sideways, used to form grooves, cavities, flat surfaces, to 3D contours. It has cutting blades at the ends and sides, with various shapes such as flat, ball, and corner radius. Made from materials such as HSS or carbide, end mills are available in different sizes, flute counts, as well as protective coatings for increased durability [6].

The flat end mill used in the chain adjuster machine uses a flat end mill that has a diameter of 8mm and 6mm. The use of flat end mill type tools with a diameter of 6 mm and 8 mm in CNC milling machines provides advantages in machining efficiency and quality. 6 mm diameter end mills are generally used for working in narrow areas or geometry that require a high level of precision, due to their ability to reach small corners and produce precise details. Meanwhile, a tool with a diameter of 8 mm is more suitable for the process of removing material in larger volumes, especially in the roughing and finishing stages on large surfaces. The larger diameter provides better stability against vibrations and accelerates the cutting rate. The combination of these two sizes allows operators to optimize the entire machining process, both in terms of dimensional accuracy and work time efficiency.

Materials used in flat end mill itself is HSS (high-speed Steel) because HSS has high hardness, wear-resistance, and is able to maintain its strength at high temperatures (up to ±600°C), making it suitable for machining [7].

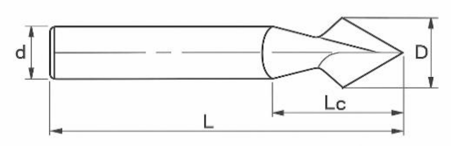

Fig. 8. Flat end mill

2.4.2 Chamfer

Chamfer End mill is a type of cutting tool used in CNC machines to make chamfer or angled angles on the edges of the workpiece, usually at an angle of 45° or as required by design. Its function is to eliminate sharp corners, beautify the appearance, and simplify the assembly or coating process. Chisels chamfer has a pointed tip with a certain angle, and is not designed for wide surface cutting, but rather for finishing on the edge [8].

Usage chamfer on the machining process chain adjuster This wears chamfer 6mm diameter with a 45O tilt angle. Materials used in chamfer itself is HSS (high-speed Steel) because HSS has high hardness, wear-resistance, and can maintain its strength at high temperatures (up to ±600°C), making it suitable for machining [7].

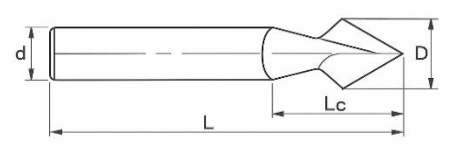

Fig. 9. Chamfer end mill

2.5 Process Time Efficiency

Time efficiency in machining processes using CNC machines milling it depends a lot on the right parameter settings. Some of the main parameters that affect the performance of the engine include the rotational speed spindle, feeding rate, cutting depth, and cutting speed. Speed spindle determines the rotation rate of the cutting tool, while the feeding rate regulates the movement of the tool against the workpiece. Depth of cut indicates how much material is taken in a single pass, and cutting speed indicates how quickly the tool interacts with the material [9].

All these parameters must be adapted to the characteristics of the material, the type of cutting tool, as well as the shape and size of the workpiece. Proper setup not only speeds up the turnaround time but also maintains tool durability and final product quality. Thus, the efficiency of the working process can be achieved thoroughly in the use of CNC milling machines.

2.6 Simulation in Fusion 360

Machining simulation is one of the important stages in the computer-aided manufacturing (CAM) planning process, especially in the context of CNC machine programming. Autodesk Fusion 360, as one of the software-based cloud which integrates CAD, CAM, and CAE, provides quite comprehensive machining simulation features. This feature allows users to visually verify the chisel path before the actual machining process is carried out. Thus, potential errors such as cutting tool collisions (tool crash), the selection of less efficient cutting strategies, or failure to achieve the tolerance dimension can be minimized from the planning stage [10].

The simulation process in Fusion 360 begins with the creation of a CAD model that represents the final shape of the workpiece. Next, the user performs the initial setup (setup) which includes the orientation of the workpiece, the reference point (work coordinate system), machine selection, as well as the types and parameters of cutting tools [11].

The machining strategy is then determined based on the geometry and material characteristics of the workpiece, which includes operations such as facing, Adaptive Clearing, contouring, and drilling. After the chisel strip (toolpath) is generated, simulations can be run to dynamically evaluate the cutting process. Fusion 360 provides visualization in the form of gradual removal of materials (material removal simulation), as well as tools to detect potential collisions or geometric errors [12].

Simulation on the Chain adjuster is carried out through two stages, namely setup 1 for the upper machining process, and setup 2 for the lower part. This process is intended to facilitate the work of each side of the component according to its shape and geometric needs.

2.7 Material Usage

The material used is Aluminum 6061. The selection of the material is based on its characteristics of being lightweight, strong, and easy to process by machine, especially in CNC workmanship Milling [13]. Aluminum 6061 belongs to the 6000 series aluminum alloy group, which is the main mixture of aluminum, magnesium, and silicon. This material has advantages in terms of corrosion resistance, good tensile strength, and dimensional stability [14].

3. Results and Discussion

3.1 Results

3.1.1 Validate Fusion 360 simulations for machining time

Fusion 360 is CAM software that is widely used in the planning and simulation of machining processes. One of the important features offered is the estimated machining time, which plays a role in production scheduling and process efficiency. This study aims to validate the accuracy of the estimated machining time generated by the Fusion 360 simulation by comparing it to the actual time in CNC machines.

The test was carried out using *a Chain adjuster* variation model with specific cutting parameters. The resulting NC program from Fusion 360 is run on a CNC machine, and the actual machining time is recorded.

3.1.2 Parameters Used

The selection of machining parameters is an important aspect of the CNC milling process. In this study, several main parameters were used, namely spindle speed, feed rate, cutting depth, and type of chisel. All parameters are determined based on the material characteristics of the workpiece as well as the capabilities of the machine used.

The parameters used for the machining process with aluminum material 6061 are with feed rate of 300 mm/min and spindle speed by 4500 rpm [13]. With this parameter, the resulting machining results in the material have a roughness of 0.7 µm as shown in the figure below.

The machining parameters used in this CNC milling process consist of spindle speed, feed rate, and feeding depth. The spindle speed is set at 4500 rpm with a cutting speed of 84.823 m/min, suitable for aluminum materials. The main cutting feed rate is 300 mm/min, indicating an aggressive cutting strategy but still within safe limits for the roughing process. The feed rate for the ramp and plunge is lowered to 1500 mm/min to maintain stability as the tool enters the material. The cooler is used in flood mode to help control the temperature and prevent the build-up of material on the chisel.

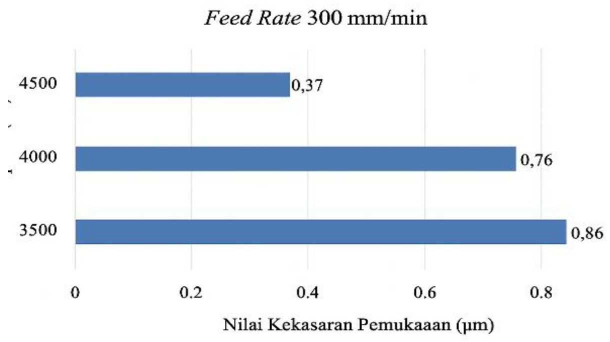

Fig. 10. Graph of surface roughness values

From the parameter data above, the researcher inserted these parameters into the settings in the 360-fusion simulation with the following display:

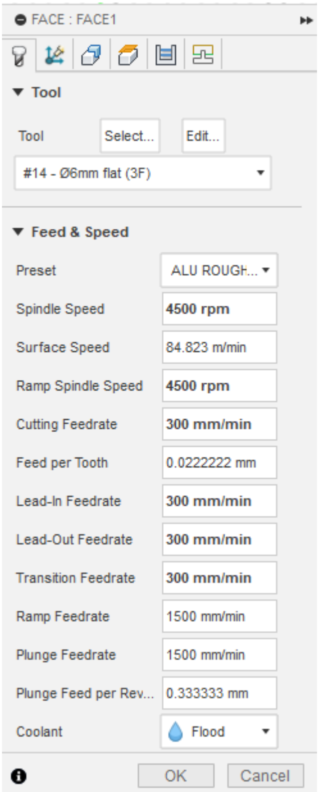

Fig. 11. Parameters used in machining chain adjuster

3.1.3 Simulation in Fusion 360

Initial testing is carried out through simulations using Fusion 360 software to determine the most optimal processing time, based on predetermined parameters. These parameters have been carefully considered and used as a reference for each step in the CNC milling machine process. The simulation is divided into two parts, each with 2 setups for the machining process on the upper and lower models. In both parts, different types of chisel blades are used, namely flat end mill with a diameter of 6 mm and *flat end mill* with a diameter of 8 mm for the same step. This division aims to compare the machining time of the two types of tools to determine the most efficient option.

The simulation performed on fusion 360 looks like this:

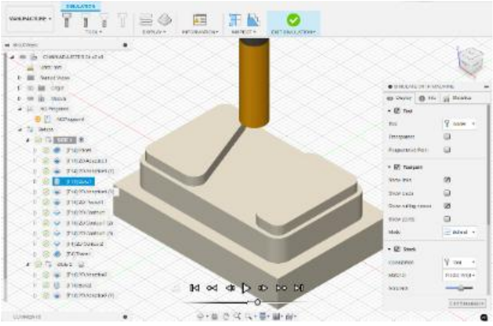

Fig. 12. Simulation view on fusion 360 setup 1 with flat end mill 6 mm

Figure 12 shows a simulation for setup 1 or the top of the chain adjuster with flat end mill tools with a diameter of 6 mm

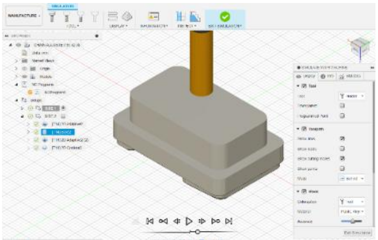

Fig. 13. Simulation view on fusion 360 setup 2 with flat end mill 6 mm

Figure 13 shows a simulation for setup 2 or below on a chain adjuster with flat end mill tools with a diameter of 6 mm

Fig. 14. Simulation view on fusion 360 setup 1 with flat end mill 8 mm

Figure 14 shows a simulation for setup 1 or the top of the chain adjuster with 8 mm diameter flat end mill tools

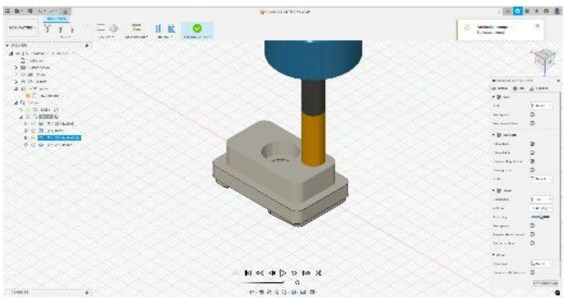

Fig. 15. Simulation view on fusion 360 setup 2 with flat end mill 8 mm

Figure 15 shows a simulation for setup 2 or the bottom of the chain adjuster with 8 mm diameter flat end mill tools

The simulation contained in the Fusion 360 software serves to visualize the course of the cutting or machining process that will be carried out by the CNC milling machine [15]. Through this feature, operators can evaluate the cutting line and estimate the course of the machining process before the process is executed in real time. In addition, the simulation also displays an automatic estimated machining time, which can be seen in the Simulate with Machine Menu Statistics, thus supporting more accurate and efficient production process planning.

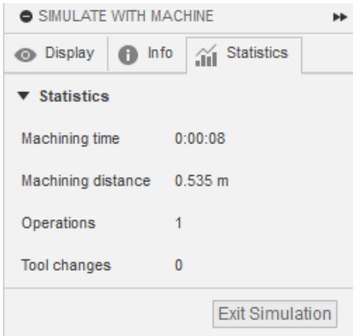

Fig. 16. Machining time on the simulation menu

The machining time displayed through the simulation in the software does not necessarily fully reflect the actual conditions when the process is performed on a CNC machine. For this reason, the time of the simulation results is compared with the machining time calculated manually using an existing formula. This comparison is done to see how accurate the simulation results are and to ascertain whether the estimated time is close to real conditions in the field.

In the results of the calculations that have been carried out on Fusion 360 and the available formulas, the results are obtained which are the results of calculations in the machining process of both versions of setup 1 and setup 2 of the chain adjuster variation design. The results of the machining time obtained are presented in the form of a table as follows:

Table 1. Machining Time Results on Flat End Mill 6 mm Setup 1

Step Name	Machining Time Result (Seconds)		
	Fusion 360	Formula	Differences
Face	96	91,98	4,02
2D Adaptive Clearing	98	114	16
2D Adaptive Clearing	69	100,98	31,98
Bore	4	2,98	1,02
2D Adaptive Clearing	8	38,22	30,22
2D Pocket	50	78	28
2D Outline	32	43,98	11,98
2D Outline	4	17,58	13,58
2D Outline	6	18,78	12,78
2D Outline	36	55,8	19,8
Trace	31	46,02	15,02

Table 1. above describes each *step* and time of machining and the difference produced by the 360 fusion simulation and the calculation of the theoretical formula in the upper machining process or setup 1 with a flat end mill diameter of 6 mm.

Table 2. describes each *step* and time of machining and the difference produced by the 360 fusion simulation and the calculation of the theoretical formula in the upper machining process or setup 2 with a flat end mill diameter of 6 mm.

Table 2. Machining Time Results on Flat End Mill 6 mm Setup 2

Step Name	Machining Time Result (Seconds)		
	Fusion 360	Formula	Differences
Face	168	177,42	13,02
2D Adaptive Clearing	27	34,8	11,4
2D Adaptive Clearing	158	108,6	45,8
Bore	26	35,4	13

Table 3. Machining Time Results on Flat End Mill 8 mm Setup 1

Step Name	Machining Time Result (Seconds)		
	Fusion 360	Formula	Differences
Face	82	91,98	9
2D Adaptive Clearing	97	114	5
2D Adaptive Clearing	64	100,98	26
Bore	17	2,98	7
2D Adaptive Clearing	9	38,22	4,2
2D Pocket	63	78	3
2D Outline	31	43,98	20,8
2D Outline	4	17,58	5
2D Outline	7	18,78	2,6
2D Outline	36	55,8	15,6
Trace	31	46,02	19,6

Table 3. above describes each *step* and time of machining and the difference produced by the 360 fusion simulation and the calculation of the theoretical formula in the upper machining process or setup 1 with a flat end mill diameter of 8 mm

Table 4. Machining Time Results on Flat End Mill 8 mm Setup 2

Step Name	Machining Time Result (Seconds)		
	Fusion 360	Formula	Differences
Face	174	177,42	7,02
2D Adaptive Clearing	19	34,8	19,4
2D Adaptive Clearing	84	108,6	28,2
Bore	100	35,4	-61

Table 4. above describes each *step* and time of machining and the difference produced by the 360 fusion simulation and the calculation of the theoretical formula in the upper machining process or setup 2 with a flat end mill diameter of 8 mm

3.2 Discussion

From the two tables presented, there is a comparison between the machining time calculated manually and those calculated using Fusion 360 software. The results of the comparison show a fairly small-time difference, which is less than 35 seconds. Although the difference is not significant, this information is still useful for the operator as a reference in estimating the time it takes to execute the machining process.

Here is a graph illustrating the comparison between the tm of the 360 fusion simulation and the theoretical calculation with flat end mill diameters of 6mm and 8mm for setup 1 and setup 2:

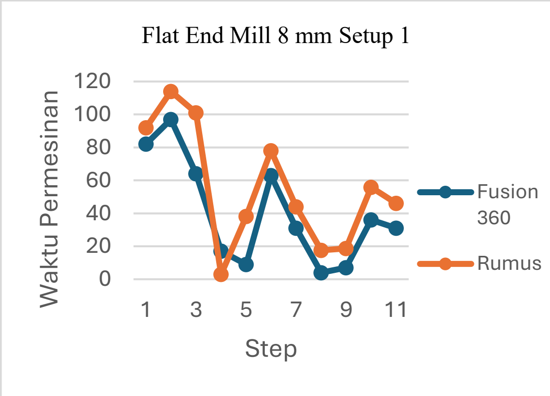

Fig. 17. Time comparison chart on calculation results flat end mill 8 setup 1

The graph above shows that there is difference in machining time produced by the 360 fusion simulation and the calculation of the theoretical formula in *setup* 1 with a 6 mm flat end mill

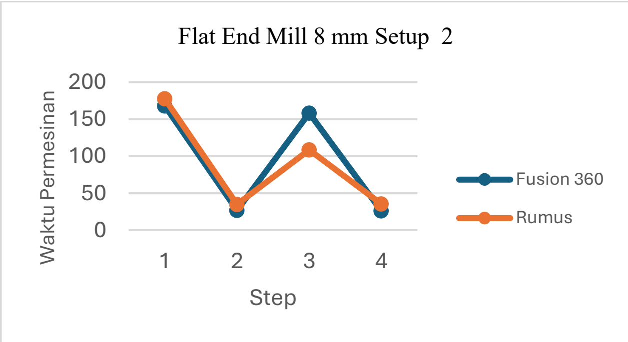

Fig. 18. Time comparison chart on calculation results flat end mill 8 setup 2

The graph above shows that there is difference in machining time generated by the 360 fusion simulation and the calculation of the theoretical formula in setup 2 with a 6 mm flat end mill

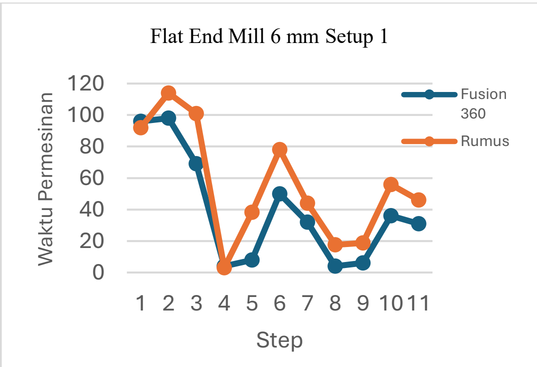

Fig. 19. Time comparison chart on calculation results flat end mill 6 mm setup 1

The graph above shows that there is difference in machining time produced by the 360 fusion simulation and the theoretical formula calculation in setup 1 with an 8 mm flat end mill

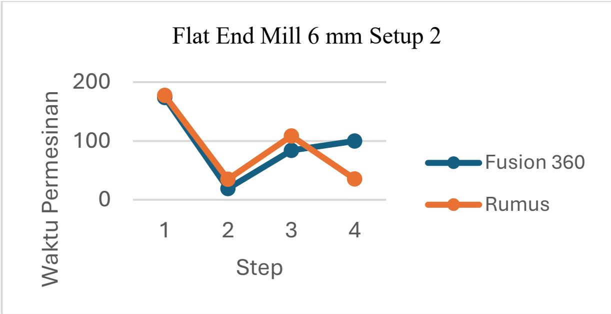

Fig. 20. Time comparison chart on calculation results flat end mill 6 mm setup 2

The graph above shows that there is difference in machining time produced by the 360 fusion simulation and the calculation of the theoretical formula in setup 2 with an 8 mm flat end mill

A comparison of the simulation results showed that the first part provided a shorter machining time than the second version, although the second part used a larger diameter chisel. This condition is influenced by several factors, one of which is the more complex design of the model in the second version, so it requires longer cutting paths and more tool movement. In addition, the cutting strategy and parameter setting in the second version tend to be more careful to maintain process stability. In contrast, the simpler design and more direct cutting paths on the first Version provide better time efficiency.

4. Conclusion

The results showed that the estimated machining time obtained from the Fusion 360 simulation had a good degree of proximity when compared to manual calculations. The time difference shown in each step of the process is within an acceptable range, for example in the simulation setup 1 on the step face with both chisel blades has a small difference, namely a flat end mill of 6mm for 4.02 seconds and a flat end mill 6mm for 9 seconds. Although the second part of the test uses a larger tool diameter, it takes longer. This is due to the toolpath factor in this machining process which uses a complex design. From the results of the simulation, it can be concluded that the simulation in Fusion 360 is suitable as a reference in estimating the actual machining process time. With this validation, the use of Fusion 360 not only helps in the visualization and planning of cutting lines but also contributes to the improvement of time efficiency as well as the accuracy of production scheduling on the CNC milling process.

This research still has some limitations that need to be considered. All analyses are carried out only through simulations using Fusion 360 and manual calculations, without any direct testing on CNC machines. This makes the estimated time results obtained not necessarily describe the actual conditions during the machining process. Several factors such as engine vibration, cutting tool wear, or other common disturbances in the field have not been taken into consideration. In addition, the focus of this research is only limited to time efficiency, so it has not discussed other things such as the quality of the machining result or the stability of the process as a whole. This limitation is expected to be the basis for the development of further research with a more complete and applicable approach.

It is recommended that a direct test be carried out on a CNC machine to compare the simulation results with actual conditions in the field. This physical test will provide a more complete picture of the accuracy of the time estimates displayed by the software, as well as allow analysis of other variables not covered in the simulation, such as cutting tool wear and process stability. In addition, it would be better if the research was expanded to include other material variations, so that it can be known how the characteristics of each material affect machining parameters and estimated working time. With this approach, the results of the research are expected to make a broader contribution to the development of simulation-based production processes.

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