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Analysis of Cutting Parameters on Machining Time in C-Axis Collet Process Using CAM Software

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Abstract

This study aims to analyze the effect of depth of cut and feed rate variations on machining time in the C-Axis collet process. The research method employed was an experimental approach using Mastercam software. This study's independent variables were variations in cut depth (0.5 mm, 0.8 mm, 1.0 mm) and feed rate (110 ft/min, 125 ft/min, 140 ft/min), while the controlled variable was a spindle speed of 1036 rpm. The tools used were 8 mm and 4 mm diameter flat endmills. The results showed that the shortest machining time was achieved in Toolpath 2 with a depth of cut of 1.0 mm and a feed rate of 140 ft/min, resulting in a time of 12.47 s. In contrast, the longest machining time occurred in Contour Toolpath 1 with a depth of cut of 0.5 mm and a feed rate of 110 ft/min, taking 141.15 s. This research can be further developed to establish standards for optimizing machining time efficiency in C-Axis processes.

Keywords: *depth of cut; feed rate; machining time; c-axis; mastercam.*

Abstrak

Tujuan penelitian ini adalah untuk menganalisis variasi kedalaman pemakanan dan kecepatan pemotongan terhadap waktu pemesinan pada proses C-Axis collet. Metode yang digunakan dalam penelitian ini adalah metode eksperimen dengan bantuan software mastercam. Variabel bebas yang digunakan dalam penelitian ini adalah variasi kedalaman pemakanan (0.5 mm, 0.8 mm, 1.0 mm) dan variasi kecepatan pemotongan (110 feet/min, 125 feet/min, 140 feet/min. Sedangkan variabel kontrol yang digunakan adalah kecepatan spindel 1036 rpm. Pahat yang digunakan yakni flat endmill diameter 8 dan diameter 4. Hasil penelitian menunjukan waktu pemesinan tercepat diperoleh pada proses toolpath 2 variasi kedalaman pemakanan 1.0 mm dan kecepatan pemotongan 140 feet/min dengan waktu 12.47s, sedangkan waktu pemesinan terlambat diperoleh pada proses toolpath contour 1 variasi kedalaman pemakanan 0.5 mm dan kecepatan pemotongan 110 feet/min dengan waktu 141,15s. Penelitian ini dapat dikembangkan untuk menemukan standar dari aspek-aspek untuk menghasilkan waktu pemesinan yang lebih efisien pada proses C-Axis.

Kata-kata kunci: *kedalaman pemakanan; kecepatan pemotongan; waktu pemesinan; c-axis; mastercam.*

1. Introduction

The manufacturing sector, particularly Computer Numerical Control (CNC) machines, has achieved remarkable progress in precision, speed, and automation. Modern CNC machines extensively utilize CAM software to generate efficient NC codes, enabling the programming of highly complex operations **[1]**. CAM software can produce NC codes for various operations in CNC turning processes, including facing, roughing, grooving, and C-Axis machining. However, achieving optimal machining time efficiency remains challenging, where proper selection of cutting parameters is crucial for obtaining optimal results **[2]**.

Previous studies have analyzed the effects of cutting parameters on machining time using Mastercam. Azahri et al. (2022) demonstrated that higher spindle speeds result in shorter machining times **[3]**. Jia et al. (2024) showed that multi-objective optimization of cutting parameters in milling processes could reduce machining time by 19.37% **[4]**. Park et al. (2018) found that feed rate optimization could improve machining time efficiency by 26% **[5]**. However, these studies primarily focused on conventional milling or traditional turning operations without addressing C-Axis CNC turning processes.

The C-Axis combines turning and milling operations, where turning tasks are performed using milling methods. In C-axis operations, the cutting tool and workpiece rotate simultaneously about their respective axes **[6]**. Collets are workpieces with complex profile designs and often require C-Axis operations. Cutting parameters such as depth of cut and feed rate significantly affect C-Axis machining time. Feed rate optimization helps reduce machining time without increasing spindle load **[7]**, while greater cut value depth leads to more efficient machining times **[8]**. CAM software is valuable for determining optimal cut and feed rate variations depth to achieve efficient machining times **[9]**.

This study aims to identify efficient machining times for C-axis CNC turning processes using CAM software, focusing on depth of cut and feed rate parameters. The research findings are expected to benefit the manufacturing industry by optimizing C-axis operations, reducing production costs, and increasing output capacity.

2. Method

This study employs a simulation-based experimental approach using Mastercam 2022 software to analyze the influence of depth of cut and feed rate on machining time in C-Axis CNC turning processes. Descriptive analysis techniques were utilized for data examination. The research methodology is illustrated in **Figure 1.**

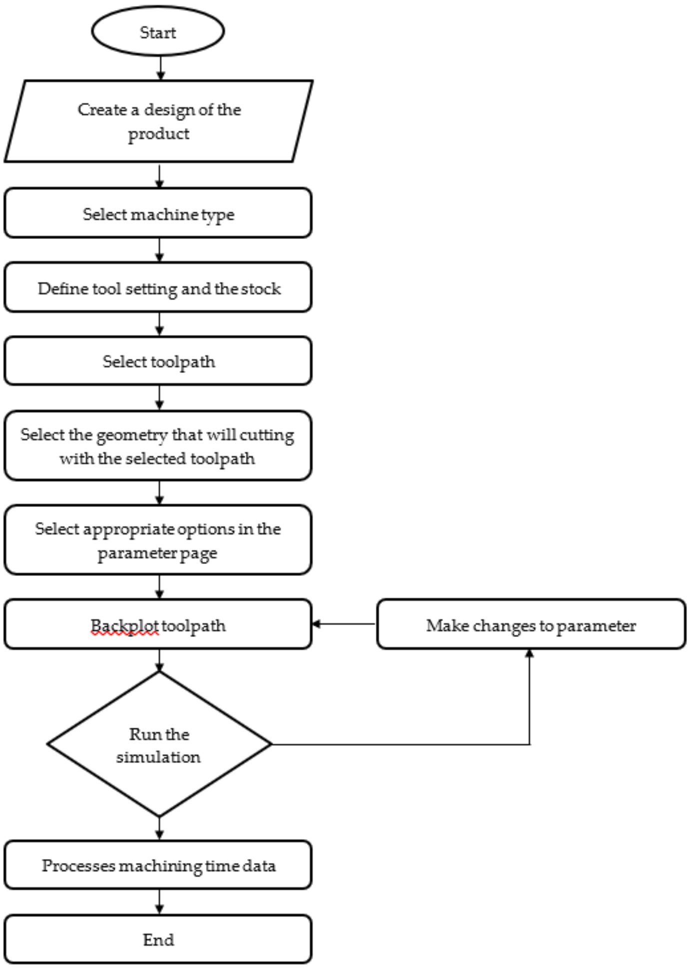

Figure 1. Research diagram

The initial step in this research involved product design, specifically creating a collet using Mastercam software. The product design requires careful and precise sketching preparation. This stage is crucial as incomplete product design prevents progression to subsequent manufacturing steps. The finalized collet design is presented in **Figure 2.**

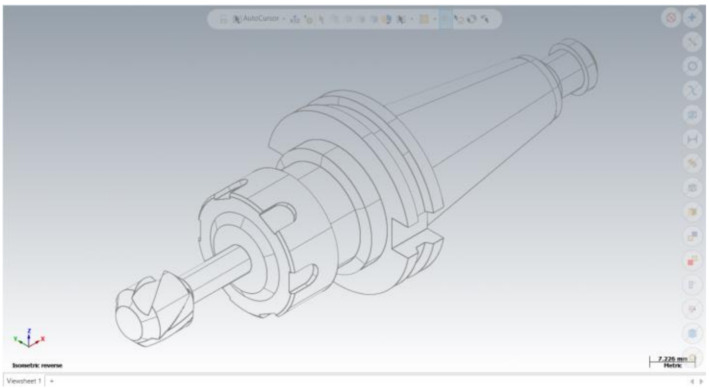

Figure 2. Collet Desain

The subsequent step involves selecting the machine type to be employed. For this study, a lathe machine was chosen, specifically one equipped with C-axis capability—a key variable in this research. The selection of a lathe was determined by the workpiece characteristics, particularly the collet design. The machine type specification is illustrated in **Figure 3.**

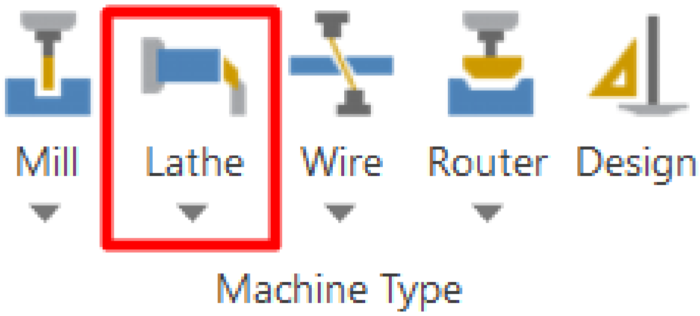

Figure 3. Machining Operation

The preparation of stock material, chuck jaws configuration, and toolpath selection must be established appropriately. The stock and chuck jaws setup involves determining the stock dimensions, chuck jaw positioning, tailstock size, and steady rest configuration. For the collet product, the selected toolpaths include facing, roughing, C-Axis operations, and finishing processes, as illustrated in **Figure 4**. The C-Axis operation serves as the primary focus of this study to identify the most efficient machining time. In the collet machining process, three distinct toolpaths are categorized as C-Axis operations: Contour 1, Contour 2, and Contour 3, which are presented in **Figure 5.**

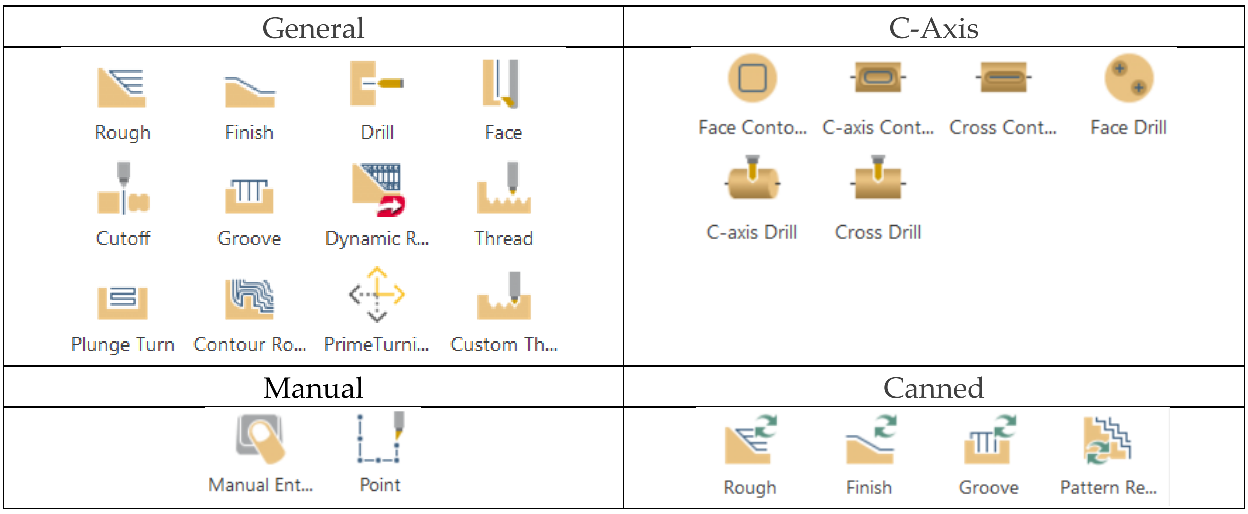

Figure 4. Types of Toolpath

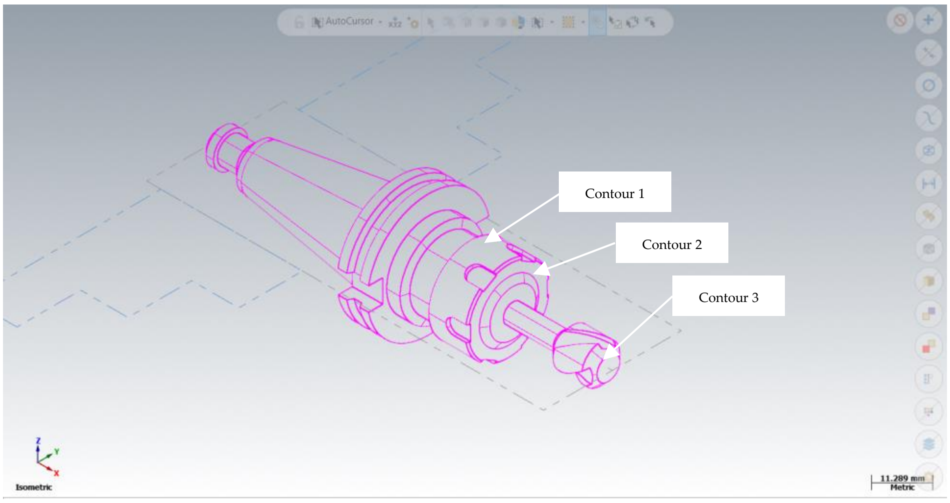

Figure 5. C-Axis Contour Processes

Medium carbon steel is commonly used to manufacture machine components and structures such as pistons, drive shafts, crankshafts, and boilers **[10]**. This material typically contains 0.3-0.5% carbon content **[11]**. Since medium carbon steel was used in this study, the depth of cut variations was set at 0.1-3.0 mm, while the feed rate ranged between 110-140 ft/min **[12]**. The control variable was a spindle speed of 1036 rpm. The tools used were 8 mm and 4 mm diameter flat endmills.

The generated toolpaths were subsequently verified using the backplot feature. Backplot visualization displays the tool's path along the selected geometry, enabling program error detection before actual processing. Any potential collision between the cutting tool and workpiece can be identified through backplot analysis.

The collet product simulation can be executed once all toolpath operations are correctly configured according to the specified parameters. Simulation failures indicate issues in the toolpath setup, necessitating reconfiguration of the geometry, tool selection, and cutting parameters until successful simulation is achieved. Finally, machining time data analysis was conducted specifically for the C-Axis operations.

3. Results and Discussion

The machining time evaluation was analyzed using Mastercam software. This research objective was accomplished by conducting simulations on the collet, focusing on the C-Axis toolpaths: Contour 1, Contour 2, and Contour 3, as illustrated in **Figures 6, 7,** and **8**, respectively.

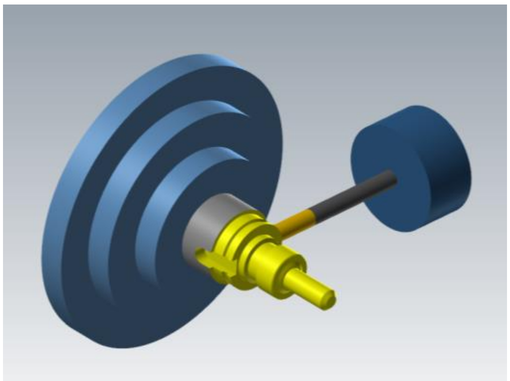

Figure 6. C-Axis Contour 1 Simulation

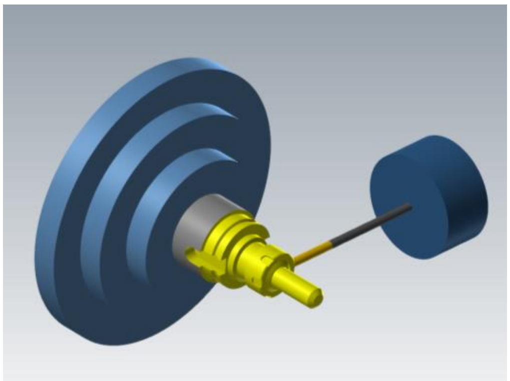

Figure 7. C-Axis Contour 2 Simulation

Figure 8. C-Axis Contour 3 Simulation

The data obtained in this study consist of numerical values. The research involves two variables, X and Y, for analysis. Variable X (depth of cut: 0.5 mm, 0.8 mm, and 1.0 mm) and variable Y (feed rate: 110 ft/min, 125 ft/min, and 140 ft/min) influence the machining time results. The test results are summarized in **Table 1.**

Table 1. Machining Time Result

Toolpath C-Axis	Depth of Cut Variation (*mm*)	Feed rate Variation (*ft/min*)	Machining Time (s)
Contour 1	0,5	110	141,15
		125	125,44
		140	113,10
	0,8	110	97,74
		125	88,25
		140	79,61
	1,0	110	71,31
		125	63,46
		140	57,29
Contour 2	0,5	110	28,86
		125	25,93
		140	23,64
	0,8	110	19,67
		125	17,72
		140	16,19

Toolpath C-Axis	Depth of Cut Variation (*mm*)	Feed rate Variation (*ft/min*)	Machining Time (s)
	1,0	110	15,08
		125	13,62
		140	12,47
Contour 3	0,5	110	74,53
		125	66,33
		140	59,88
	0,8	110	50,16
		125	44,69
		140	40,39
	1,0	110	42,04
		125	37,48
		140	33,90

The data analysis reveals that both depth of cut and feed rate parameters significantly influence machining time. As presented in **Table 1**, the shortest machining time of 12.47 s was achieved in the Contour 2 toolpath using a depth of cut of 1.0 mm and feed rate of 140 ft/min. Conversely, the longest machining time of 141.15 s occurred in Contour 1 toolpath with a depth of cut of 0.5 mm and feed rate of 110 ft/min.

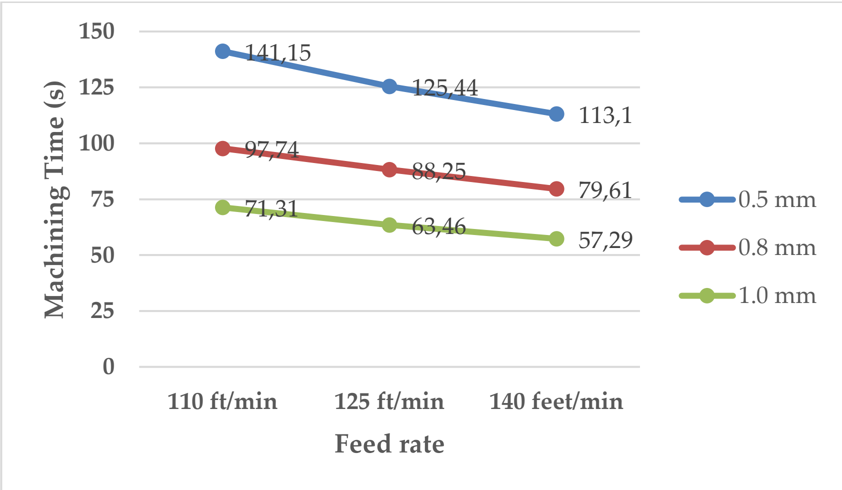

Figure 9. Graph of Relationship Between Depth of Cut and Feed Rate Against Machining Time C-Axis Contour 1

The machining time is significantly influenced by the depth of cut and feed rate parameters, as evidenced in **Figure 9**, which displays the varying machining times for the Contour 1 toolpath. The fastest machining time of 57.29 s was achieved with a depth of cut of 1.0 mm and a feed rate of 140 ft/min. Conversely, the slowest machining time of 141.15 s occurred with a depth of cut of 0.5 mm and feed rate of 110 ft/min. Contour 1 exhibited the longest machining time among all three contour toolpaths. This result can be attributed to the larger and deeper surface profile of the Contour 1 operation, as illustrated in **Figure 10**, which requires the removal of significantly more material.

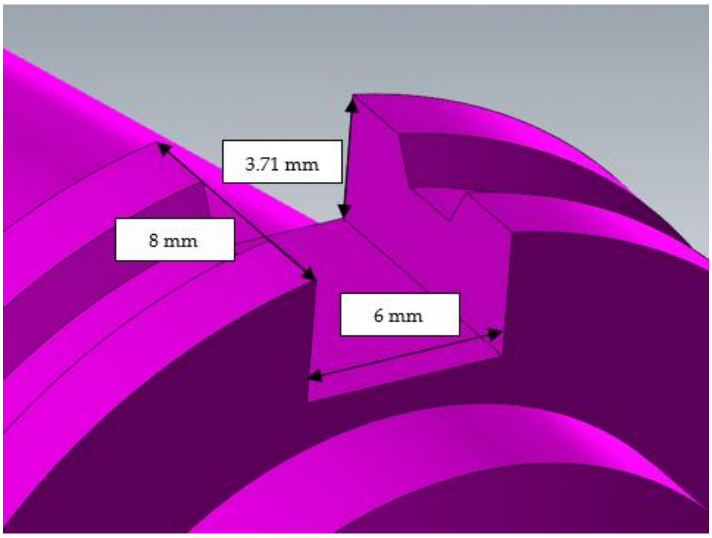

Figure 10. Dimension of Contour 1 Processes

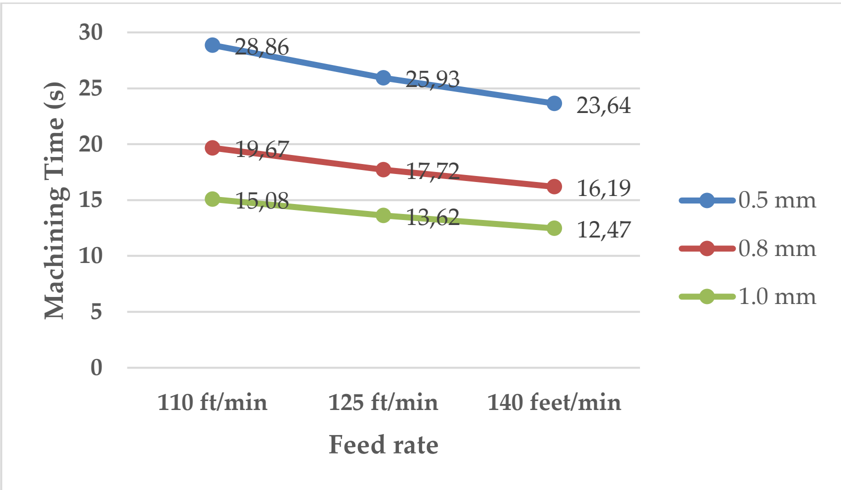

Figure 11. Graph of Relationship Between Depth of Cut and Feed Rate Against Machining Time C-Axis Contour 2

Figure 11 presents the machining results for the Contour 2 toolpath, where the fastest machining time of 12.47 s was achieved at a depth of cut of 1.0 mm and a feed rate of 140 ft/min. Conversely, the slowest machining time of 28.86 s was recorded at a depth of cut of 0.5 mm and a feed rate of 110 ft/min. Among the three contour toolpaths, Contour 2 exhibited the shortest machining time, attributed to its smaller surface profile and shallower material removal, as illustrated in **Figure 12**. This reduced geometric complexity results in significantly less machining material, optimizing processing efficiency.

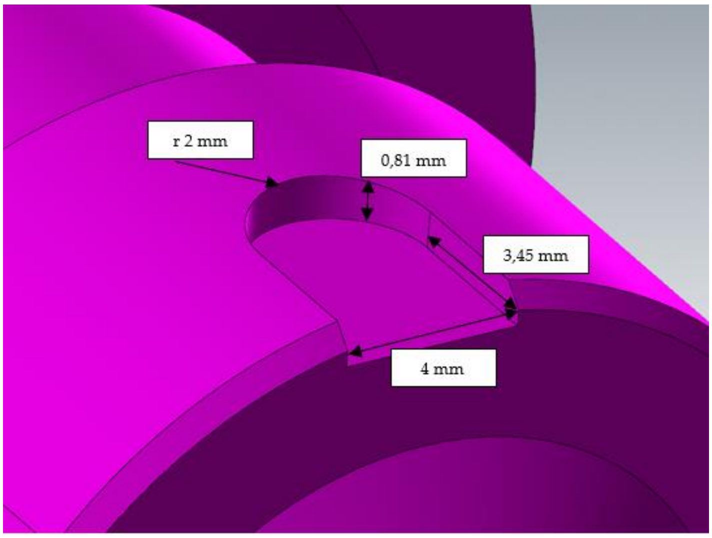

Figure 12. Dimension of Contour 2 Processes

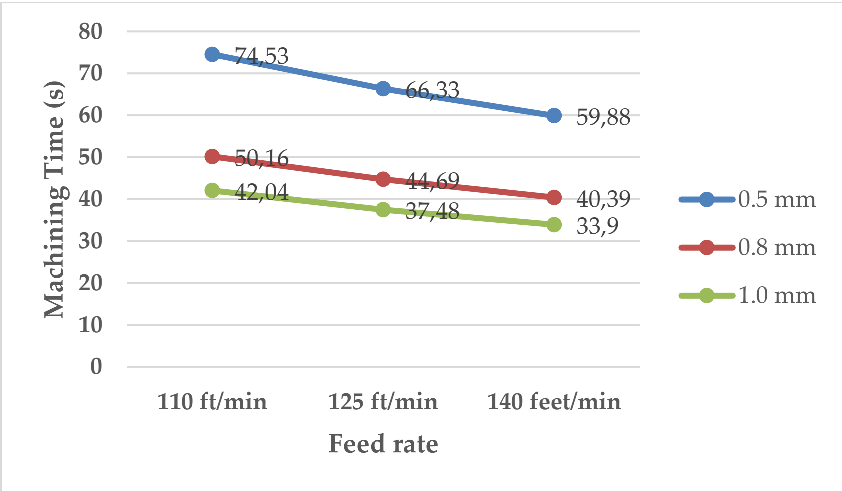

Figure 13. Graph of Relationship Between Depth of Cut and Feed Rate Against Machining Time C-Axis Contour 3

Figure 13 presents the machining results for the Contour 3 toolpath. The optimal machining time of 33.90 s was achieved at a depth of cut of 1.0 mm and feed rate of 140 ft/min, while the most extended duration of 74.53 s occurred at a 0.5 mm depth of cut and 110 ft/min feed rate. The surface profile of Contour 3 features a helical gear geometry, which exhibited intermediate machining times among the three contour toolpaths for the collet product, neither achieving the fastest nor slowest processing times.

The findings of this study align with existing research, indicating that machining time is influenced by multiple factors, including tool type, workpiece dimensions, spindle speed, depth of cut, and feed rate [6]. These results can be a reference for optimizing C-Axis CNC turning processes to achieve efficient machining times without compromising product quality.

Furthermore, this study provides a foundation for future research to establish standards for other influential aspects of machining time and processing outcomes in C-Axis CNC turning operations.

4. Conclusion

The key findings of this study can be summarized as follows:

- Lower feed rates and smaller depths of cut in C-Axis operations result in longer machining times.
- Higher feed rates and greater depths of cut in C-Axis operations significantly reduce machining time.
- Contour 1's toolpath took the longest to machine due to its larger and deeper surface profile, which required more material removal.
- The Contour 2 toolpath achieved the shortest machining time due to its smaller surface profile and shallower cuts, minimizing material removal.

5. Acknowledgement

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