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Selection of Cutting Tool Paths in Milling Machining

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***Abstract**: Milling machining is a subtractive manufacturing process that involves the removal of material from a workpiece using rotary cutters. The primary components of a milling machine include the cutting tool (end mill or face mill), workpiece clamping system, and a rigid machine structure. During milling operations, the cutting tool rotates at high speeds and engages with the workpiece to remove material along predefined paths, resulting in the desired shape and dimensions. Milling machining is a critical process in manufacturing industries, enabling the creation of precise and complex components. The selection of appropriate cutting tool paths significantly influences the quality, efficiency, and cost-effectiveness of the milling process. This report investigates various factors involved in choosing cutting tool paths and their impact on machining performance. In this study, we address the selection of tool path types based on criteria for optimizing machining time*

***Keywords**: Milling machining, manufacturing, toolpaths…*

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I. Introduction:

Milling is a subtractive manufacturing process widely utilized in industries such as automotive, aerospace, and medical device production. The efficiency and accuracy of milling operations depend not only on the choice of cutting tools but also on the selection of optimal tool paths. Different strategies for tool path selection exist, including traditional methods like contour milling, pocket milling, and profile milling, as well as more advanced techniques such as adaptive milling and high-speed machining. This report aims to analyze the factors influencing the selection of cutting tool paths and their implications for machining performance.

Milling machining finds widespread applications in various industries, including automotive, aerospace, electronics, and mold making [1-3]. Common applications include the production of complex components such as gears, engine blocks, turbine blades, and intricate molds for plastic injection molding. Additionally, milling is used for surface finishing operations, such as contouring, slotting, and profiling, to achieve tight tolerances and smooth surface finishes. Milling processes can be categorized based on the direction of cutter rotation relative to the workpiece surface, known as climb milling and conventional milling. In climb milling, the cutting tool rotates in the same direction as the feed motion, resulting in reduced cutting forces and smoother surface finishes [4-6]. Conversely, in conventional milling, the cutting tool rotates against the feed motion, leading to higher cutting forces and potential workpiece chatter [7-8]. Other specialized milling processes include high-speed machining, trochoidal milling, and adaptive milling, each offering unique advantages in specific applications.

Factors Influencing Tool Path Selection:

Workpiece Geometry: The shape and complexity of the workpiece determine the suitable tool paths. For example, contour milling is ideal for parts with straight edges, while pocket milling is suitable for creating cavities and pockets.

Material Properties: The type of material being machined affects the choice of tool paths due to variations in hardness, machinability, and chip formation characteristics. Adaptive milling strategies may be employed for difficult-to-machine materials to optimize tool engagement and chip evacuation.

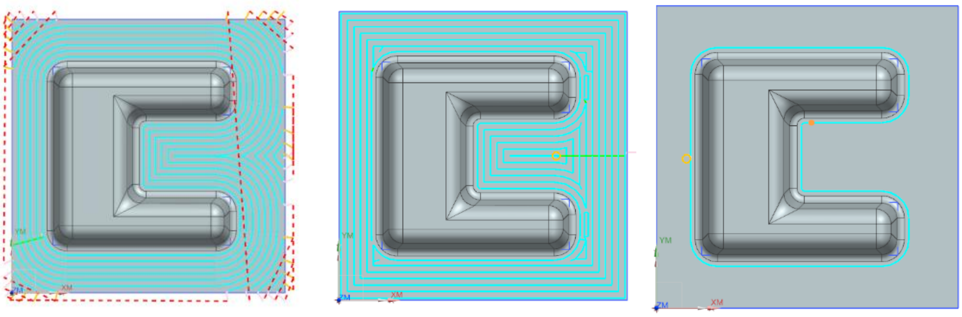
Surface Finish Requirements: Desired surface finish influences the selection of tool paths. Finishing operations often utilize high-precision tool paths such as parallel milling or scallop milling to achieve smooth surface textures and dimensional accuracy.

Machining Strategy: Different machining strategies, such as conventional milling, climb milling, and trochoidal milling, have unique characteristics that impact tool path selection. Factors such as tool wear, cutting forces, and chip evacuation are considered when determining the most suitable strategy for a given application.

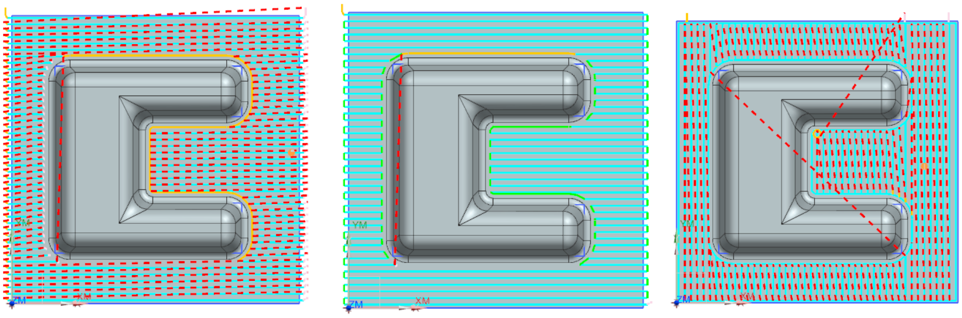
Impact on Machining Performance:

Quality: The choice of cutting tool paths directly affects the quality of machined components in terms of dimensional accuracy, surface finish, and feature integrity.

Efficiency: Optimal tool path selection improves machining efficiency by reducing cycle times, minimizing tool wear, and maximizing material removal rates.
Cost-effectiveness: Efficient tool paths contribute to cost savings by reducing machining time, tooling expenses, and energy consumption.



Follow part Follow periphery Profile



Zig Zig zag Zig with contour

Fig 1. Several typical tool paths milling

To experiment with selecting an appropriate toolpath strategy, we simulate the process on a component with dimensions (Fig 2) and material properties (Table 1, 2) as listed below.

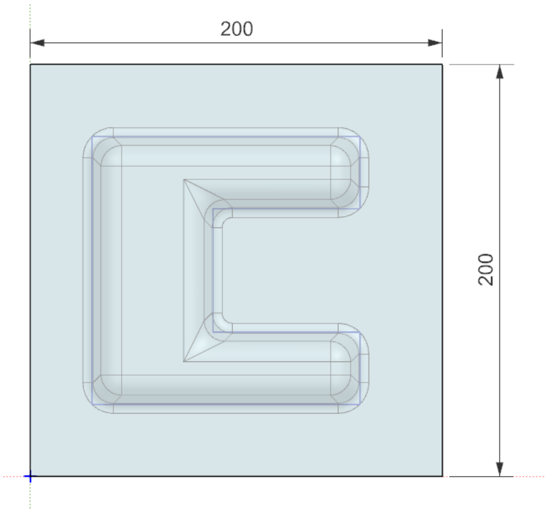


Fig 2. The dimension of part

Table 1. *Chemical composition of alloy steel En24*[4].

Element	Carbon	Silicon	Manganese	Phosphorus	Chromium	Molybdenum
Symbol	C	Si	Mn	P	Cr	Mo
Content%	0.36-0.44	0.11-0.31	0.45-0.71	0.036	1.02-1.47	0.23-0.34

Table 2. *Mechanical and physical properties of En24 alloy steel.*

Tensile Tension	855-1000 N/mm^2
Yield Stress	675 N/mm^2
Elongation	13.3%
Impact Strength	54 J
Hardness	Hardness
Elastic Modulus	207.3×109

Milling machining time is computed using the following formula

$$T = \frac{n.60.L}{f.N}$$

In that:
n = Number of cutting
L = Workpiece length + Tool approach distance + Tool retracts distance + Mandatory clearance distance
f = Feed rate
N = Cutting speed.

II. Results

Within the surface processingprepare, different toolpath techniques are proposed for clients. For surface machining, just like theportion being utilized in this consider, we frequently compare the machining times of distinctive toolpath proceduresbeneathdifferent cutting conditions.

Table 3. *Process variables and their Ranges.*

S1.No	Process Parameter		
	Cutting speed (RPM)	*Feed (mm/Min)*	*Depth of cut (mm)*
1	3900	310	1.0
2	5200	340	1.1
3	6500	355	1.2

The machining time for each cutting process is based on the simulation results.

S1.No 1

Toolpath	*Cutting time (mm:s)*
Follow part	36: 23
Follow periphery	31:05
Profile	44:03
Zig	29:07
Zig zag	33:05
Zig with contour	30:06

S1.No2

Toolpath	*Cutting time (mm:s)*
Follow part	31: 36
Follow periphery	37:21
Profile	33:06
Zig	38:40
Zig zag	30:17
Zig with contour	35:42

S1.No3

Toolpath	*Cutting time (mm:s)*
Follow part	29:18
Follow periphery	31:33
Profile	34:16
Zig	37:09
Zig zag	33:32
Zig with contour	30:31

Based on the results of the machining prepare, it is clear that each toolpath technique and cutting condition compares to anunmistakable machining term. These discoveries enable us to survey that, within thesetting of freeform surface machining, the toolpath techniques known as 'Follow Part' and 'Follow Periphery' may be considered more beneficial.

The 'Follow Part' methodologyinvolves the cutting devicefollowing the forms of the portion or workpiece beneath machining. Regularly, it includes machining along the part's edges or boundaries, loyallytaking after its layout. 'Follow Part' demonstratesappropriate for makingperplexing shapes and profiles with exactness, making it a favored choice when correctmeasurements and complicatedhighlights are basic. On the other hand, the 'Follow Periphery' approach prioritizes machining along the external boundary or border of the freeform surface or workpiece. Rather thanexploring through the complexinsidesforms of the portion, this toolpath remainsnear to the outside edges. This approach is regularlyfavored when speed and fabricevacuation rate take priority, because it can be quicker than 'Follow Part' due to its streamlineddevelopments.

III. Conclusion:

The selection of cutting tool paths plays a crucial role in the overall performance of milling machining operations. By considering factors such as workpiece geometry, material properties, surface finish requirements, and machining strategy, manufacturers can optimize tool path selection to enhance quality, efficiency, and cost-effectiveness. Future research may focus on developing advanced tool path optimization algorithms and exploring innovative machining strategies to further improve milling process performance.The comparison comes aboutdemonstrate that the ideal toolpath choice depends on components such as portion geometry, chosen toolpath sort, machine determinations, and cutting conditions. By utilizingcomparabletechniques and approaches, ready to carry out evaluations to recognizethe foremostappropriate toolpath procedure for a given machining operation. It is worth noticing that particularinnovative circumstances and optimization goals may result in changingchoice criteria. By the by, the discoveriesdisplayed in this term paper can serve as importantdirection for engineers and technologists within the decision-making handle when selecting ansuitable toolpath technique for encased freeform surface machining.

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