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Selecting a milling approach based on the toolpath strategy in pocket milling

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Abstract
Computer-Aided Manufacturing (CAM) plays a pivotal role in modern production processes across various industries. It's a technology that bridges the gap between design and manufacturing, enabling precise, efficient, and automated production. Computer-Aided Manufacturing (CAM) involves the use of software and hardware to automate and control manufacturing processes. It translates design specifications, often created using Computer-Aided Design (CAD), into instructions for machines and robots on the production floor. CAM Parameter Programming refers to the practice of defining and managing a set of parameters within CAM software that dictate how a manufacturing machine or process operates. These parameters encompass a wide range of variables, including toolpath geometry, cutting speeds, feeds, tool changes, and quality control measures. In this study, we delve into the selection of toolpath during pocket milling operations. The parameters of the toolpath directly impact the milling time, thereby facilitating a more accurate determination of machining time and power consumption.
Keywords*: Milling, Toolpath, cutting parameter.*

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I. Introduction

Computer-Aided Manufacturing (CAM) parameters play a pivotal role in CNC (Computer Numerical Control) programming, significantly influencing how CNC machines operate and produce machined parts.

Toolpath Generation: CAM parameters are used to define toolpaths, which are the precise routes that the CNC machine's cutting tool follows to shape the workpiece. Toolpath generation is fundamental as it determines the tool's movement, including cutting, drilling, and milling motions. Accurate toolpaths are essential for achieving the desired part geometry.

Cutting Speed (Spindle Speed): CAM parameters specify the rotational speed of the spindle, often referred to as cutting speed or spindle speed. Properly setting the cutting speed is crucial for efficient material removal. It ensures that the tool's rotation is optimized for the material being machined, preventing overheating and tool wear.

Feed Rate: CAM parameters define the feed rate, which is the rate at which the tool advances along the programmed toolpath.The feed rate affects the material removal rate, surface finish, and tool life. Optimizing the feed rate ensures efficient machining without compromising quality.

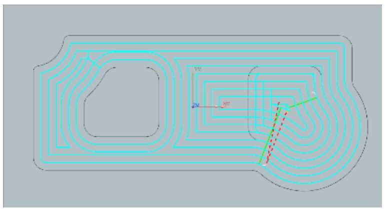
Depth of Cut: CAM parameters determine the depth of cut, which specifies how deeply the tool penetrates into the workpiece during each pass. Proper depth of cut settings control chip load, cutting forces, and tool wear. It affects the quality of the machined surface and the overall machining process.

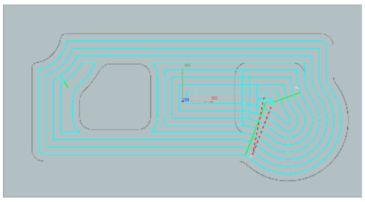
Additionally, there are several other parameters to consider, such as cooling and lubrication methods, tool change strategies, fixtures, and the generation and control of CNC data. There have been many studies on optimizing parameters for the machining process [1-4]. In this study, we will compare and give advice for choosing the type of tool path when dealing with pocket milling.

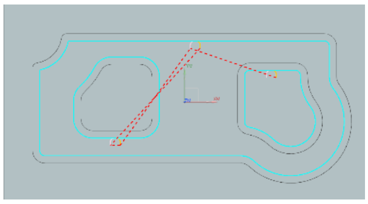
II. Toolpath Generation in CAM

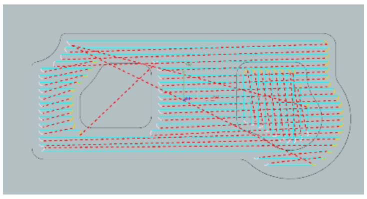
Toolpath in pocket machining refers to the specific route or trajectory that a cutting tool follows while machining or milling an enclosed pocket or cavity in a workpiece. This toolpath is essential for guiding the cutting tool through the material to remove excess material and create the desired pocket shape. The selection of an appropriate toolpath is crucial as it directly affects factors like machining time, tool life, surface finish, and overall machining efficiency. Different toolpath strategies, such as contouring, zigzag, or spiral, can be employed depending on the specific requirements of the machining process and the geometry of the pocket being machined. The choice of toolpath aims to optimize the machining operation, ensuring accurate and efficient material removal while minimizing tool wear and production time.

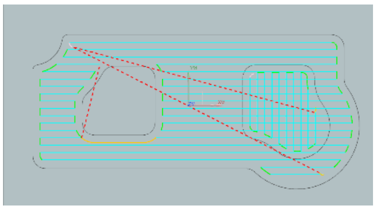
In CNC machining technology, with the support of digital control technology, various toolpath strategies have become increasingly flexible and adaptable to complex shapes, making the machining process faster and more efficient.


Follow part


Follow periphery


Profile


Zig


Zig zag

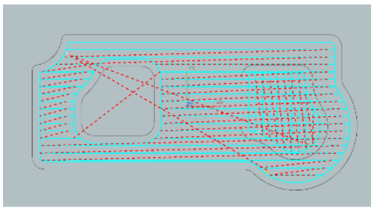

Zig with contour

Fig 1. Several typical tool paths employed in pocket milling

The machining time is determined by technological parameters such as cutting speed, depth of cut, feed rate, and toolpath strategy. Among these parameters, some are determined based on the material properties and the machine's technological capabilities. The choice of toolpath strategy also significantly influences the machining process.

In this study, we employ a physical model of the machined part with material properties as listed in the table below.

Table 1. *Chemical makeup 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

The parameters related to the mechanical properties of the material.

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

In CNC machining, as well as machining in general, machining time directly affects the efficient productivity of the machining process [5-7]. Machining time primarily determines the machine's power consumption, tool life, and wear, as well as the progress of the production process [8-10]. The selection of toolpath strategy, from approach to retract after machining, directly impacts the machining time. Depending on the characteristics of the machined part, the equipment provides users with several suitable options. Additionally, the toolpath must also be chosen to align with the current equipment's technological characteristics, the machined material, and the desired cutting mode.

III. Results

In the pocket milling process, various toolpath strategies are proposed for users. For enclosed pocket machining, like the part being used in this study, we often compare the machining times of different toolpath strategies under various cutting conditions.

Table 3. *Process variables and their Ranges.*

S1.No	Process Parameter		
	Cutting speed (RPM)	*Feed (mm/Min)*	*Depth of cut (mm)*
1	3500	320	1.0
2	4800	350	1.1
3	5000	350	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	23: 43
Follow periphery	21:04
Profile	31:03
Zig	28:07
Zig zag	26:05
Zig with contour	32:06

S1.No 2

Toolpath	*Cutting time (mm:s)*
Follow part	18: 35
Follow periphery	16:21
Profile	28:04
Zig	25:07
Zig zag	22:16
Zig with contour	27:06

S1.No 3

Toolpath	*Cutting time (mm:s)*
Follow part	16: 17
Follow periphery	14:03
Profile	25:16
Zig	23:07
Zig zag	20:27
Zig with contour	24:32

Based on the machining process results, we observe that each toolpath strategy and cutting condition leads to a specific machining time. With these results, it can be assessed that, for the enclosed pocket machining method, the toolpath strategies of Follow Part and Follow Periphery may be considered more advantageous.

Follow Part strategy involves the cutting tool following the contours of the part or workpiece being machined. It typically involves machining along the edges or boundaries of the part, tracing its outline. "Follow Part" is suitable for creating complex shapes and profiles accurately. It's often used when precision and maintaining the exact dimensions of the part are essential. In contrast, "Follow Periphery" focuses on machining along the outer boundary or perimeter of the pocket or workpiece. Instead of following the intricate interior contours of the part, the toolpath stays along the outside edges. This approach is often chosen when speed and material removal rate are priorities. It can be faster than "Follow Part" because it involves fewer complex movements.

The choice between these two strategies depends on the specific machining requirements, including part geometry, material properties, desired surface finish, and machining time. "Follow Part" is typically used for parts with intricate interior features, while "Follow Periphery" is chosen for faster material removal along the outer boundaries. Machinists often need to weigh precision against efficiency when deciding between these toolpath strategies.

IV. Discussion

The results of comparison show that the best toolpath is dependent on geometry of the part, the type of the used toolpath, the used machine characteristic, and cutting condition. With similar methods and approaches, we can conduct evaluations to determine the optimal toolpath strategy for each specific machining process. However, different technological conditions and optimization objectives may lead to different selection criteria. Nevertheless, the research results presented in this paper can serve as a reference for engineers and technologists when choosing a suitable toolpath strategy for enclosed pocket machining.

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