



The Evolution of Toolpath Technology

Historically, CAM vendors have differentiated their products based on application, functionality, and ease of use. The quality of the rough milling toolpaths that CAM systems generated, however, was not a factor in marketing and selling CAM software systems.

Background

Compared to today, the quality of early CAM software was poor. It limited the utilization of milling machines and cutting tools to 15 to 25 percent of their potential capability, making material removal costs very high. The most commonly used bulk material removal method was based simply on the boundaries of the part.

The technology available for early software developers and programmers limited their ability to develop effective bulk material removal strategies. Toolpaths had a higher percentage of poor machining practices, generated numerous high-force conditions, and delivered a limited number of machine instructions.

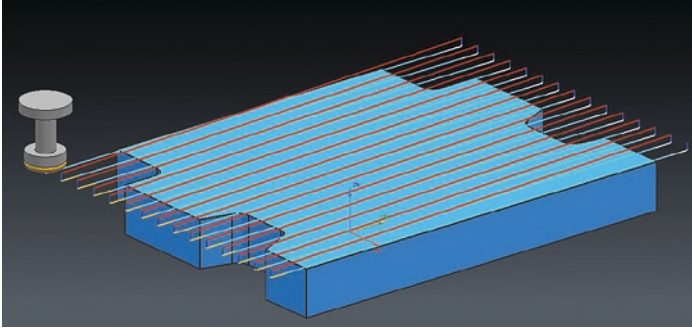
Until recently, gains in rough milling productivity were achieved using hardware, not software. When manufacturers wanted to reduce rough milling costs, they turned to more powerful, faster, and stiffer machine tools, and bigger and stronger cutting tools.

It wasn't until advances in computer science and software technology allowed machinists and software developers to implement more sophisticated and effective approaches to bulk material removal.

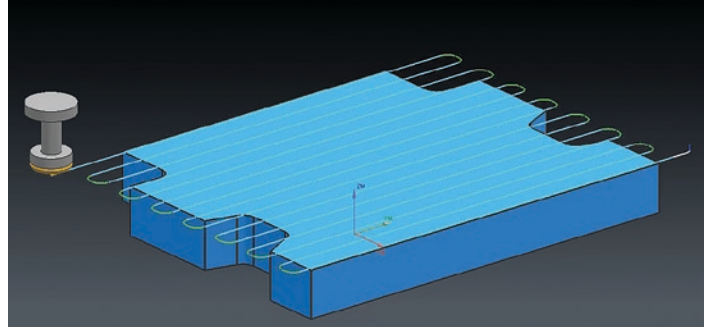
These new approaches to rough milling are proving to be extremely effective in removing unwanted material. New technology and sophisticated programming have enabled developers to implement strategies that allow for up to 100 percent use of machine and tool capability.

Shops using these new strategies are realizing substantial reductions in fixed and variable bulk material removal costs. Significantly shorter cycle times reduce machining costs, while consistent levels of low-force cutting extend tool life. Shorter machining times also translate into using less power, coolant, and shop labor.

Other benefits are also derived from using these highly effective milling



A ZIG TOOLPATH
Machine and tool capacity utilization up to 10 percent



A ZIG-ZAG TOOLPATH
Machine and tool capacity utilization up to 15 percent

strategies. Tool wear predictability allows programmers to plan tool changes. Consistently low spindle loads allow for smaller and lower-cost tools, and extend the capability of smaller and less powerful machine tools.

Software had been the limiting factor in machine and tool productivity since the advent of CNC machining. Recent advancements in language and computer science have allowed software developers to create and implement new bulk material removal strategies that fully capitalize on the capabilities of manufacturing hardware.

These new material removal strategies are changing the landscape in marketing and selling CAD/CAM software.

The Evolution of Bulk Material Removal Strategies

LOW VOLUME / HIGH FORCE / HIGH COST MATERIAL REMOVAL

Machine and tool capacity utilization up to 25 percent

The first toolpath strategy was called zig. Zig provided consistent stepovers, an even material removal rate, and a constant feedrate, but had programming problems with retracting and re-engaging, and other significant limitations.

It was effective only with square geometries, limiting its usefulness.

Developers then invented zig-zag, a faster strategy that fixed some problems with contoured geometry, but introduced new problems with uneven stepovers on the contoured portion of parts. While zig-zag solved some of the problems with its predecessor, it still had severe limitations.

Software developers then began using a simple mechanical approach to designing roughing toolpaths. The parallel offset or stepover technique uses the material boundary of the part and the desired depth and width-of-cut as the basis for creating a toolpath.

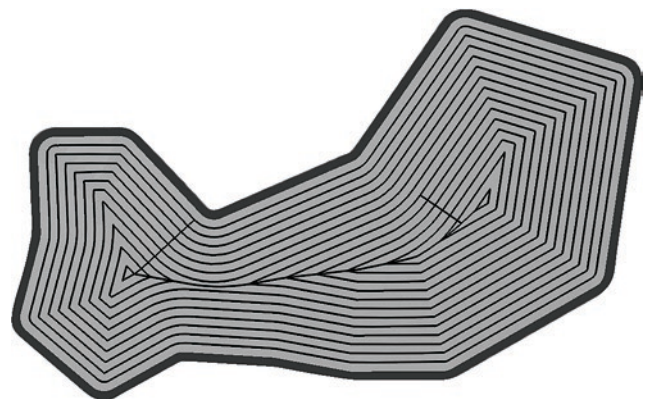
Parallel offset toolpaths are typically not very effective in removing material. They result in low material removal rates, as well as high machining, tooling, and total material removal costs.

Using the boundary of the part and the width-of-cut as the only design criteria makes it easy to

design a toolpath, but the actual material removal rate varies widely and is dependent on the shape of the part.

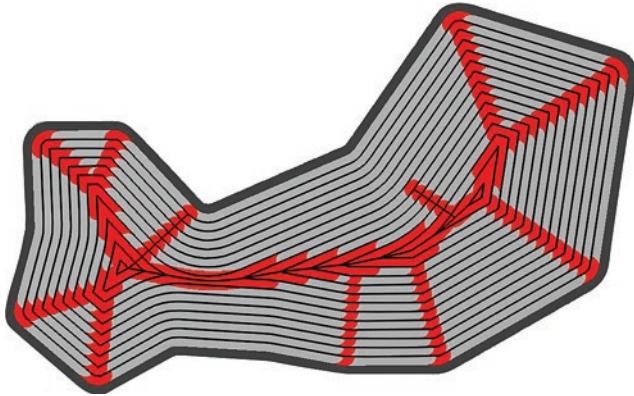
Parallel offset toolpaths for complex shapes and parts with corners have numerous high force and other poor machining conditions. Actual stepovers and material removal rates fluctuate widely from the programmed volume.

The programmed stepover and material removal rate is achieved only during ideal machining conditions. Excessive loading and high forces on the tool occur during the initial cut into the material, in corners and concave arcs, when stepping over between cuts, and when feeding into new areas of the part. Additionally, as the offset moves toward the center of the part,



A HIGH-FORCE PARALLEL OFFSET TOOLPATH
Machine and tool capacity utilization up to 25 percent

Recent advances in computer science and software technology have allowed toolpath scientists to develop and implement new bulk material removal strategies that significantly increase material removal rates and reduce total rough milling costs.



Excessive loading/high forces shown in red

the inside corner radius is eliminated, resulting in sharp corners in the tool path. Intermittent high forces on the tool create excessive heat in the cutting tool, which degrades the cutting edge of the tool and results in shorter tool life.

These numerous poor machining conditions force the use of larger and more powerful machines and stronger cutting tools with a larger diameter. Machinists are forced to use a low percentage of cutting tool capabilities by making shallow cuts with low feedrates and spindle speeds in order to minimize tool wear and breakage. The high forces and slower speeds and feeds result in low material removal rates, long cycle times, and high tooling, coolant, power, shop labor, scrap, and waste costs.

Low material removal rates with high tooling and shop costs result in the inefficient utilization of machine, cutting tool, supplies, labor, and facilities.

increase material removal rates and reduce total rough milling costs.

Advances in Rough Milling

One of the first techniques used to improve material removal rates was optimization. With this method, software detects and modifies the highest force areas in the parallel offset toolpath.

While optimizing can improve the material removal rate and tool life, it is not the most effective solution in most situations.

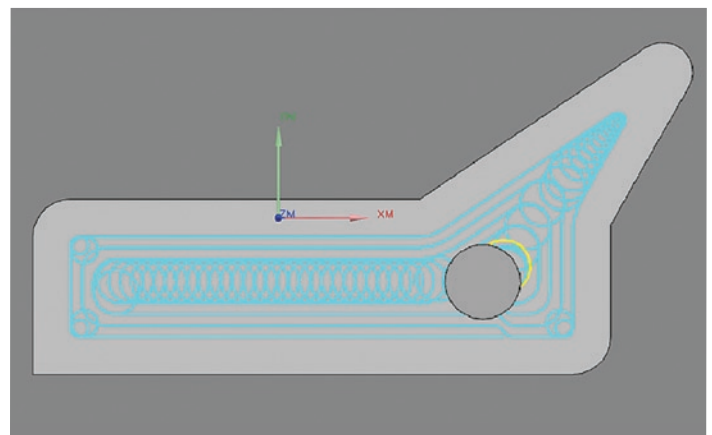
Optimization software is expensive. Programming time and costs are elevated, but total material removal costs are lower than before optimization.

Recent advances in computer science and software technology have allowed toolpath scientists to develop and implement new bulk material removal strategies that significantly

One of the first entirely new material removal strategies was the trochoidal toolpath. The trochoidal strategy uses a combination of circles and parallel offsets to create toolpaths.

The trochoidal strategy uses the circle-cutting method when the alternative would be a full-diameter cutter engagement. The use of circles can be effective with some part geometries because smaller and smaller circles work well in closed-angle areas. While the trochoidal strategy is significantly more effective than the pure parallel offset strategy, it still has some limitations, as it loses effectiveness in complex geometries.

The lower forces that occur in circles and arcs allow programmers to use higher spindle speeds and achieve higher material removal rates, so many CAM companies use the trochoidal strategy as the basis for a high-speed machining option.



A TROCHOIDAL TOOLPATH
Machine and tool capacity utilization up to 65 percent

Still, the use of the parallel offset with circles is not the most efficient material removal method. The degree of the arcs and circles dictates the forces that occur on the cutting tool. Most of these methods do not dynamically change the stepover or feedrates—the actual material removal rate and tool wear can fluctuate widely. And, since only a small portion of the cutting tool is used, tool recycling is not practical.

**HIGH VOLUME / LOW FORCE /
LOW COST MATERIAL REMOVAL**
**Machine and tool capacity utilization
up to 90 percent**

Perhaps the largest advancement in toolpath technology came when CAM software vendor Surfware created the engagement angle strategy, which maintains a constant angle of engagement between the cutting tool and the material while cutting.

This approach, named TRUeMill®, produces toolpaths with a relatively high number of ideal machining conditions, low forces, and a consistent material removal rate. Total rough milling costs are low. The engagement angle strategy allows machinists to use up to 90 percent of their machine's capabilities and 100 percent of the tool's material removal capability to reduce cycle times by 50 percent or more.

With the engagement angle strategy, chip loads are consistent so heat dissipates with the chip. Cool cutting surfaces extend tool life, and the use of the full length of the cutting surface allows tools to be recycled. Low and consistent forces on the cutting tool allow for the use of lower cost and

smaller diameter cutting tools in most applications.

While the engagement angle strategy is a significant advancement in toolpath technology, it has some limitations. Controlling the angle of engagement is not always the most efficient way to remove material in some shapes. Maintaining a constant engagement angle sometimes necessitates the width-of-cut and material removal rate to vary.

Maintaining a constant angle requires extensive math and programming code, creating large part files and relatively long path lengths.

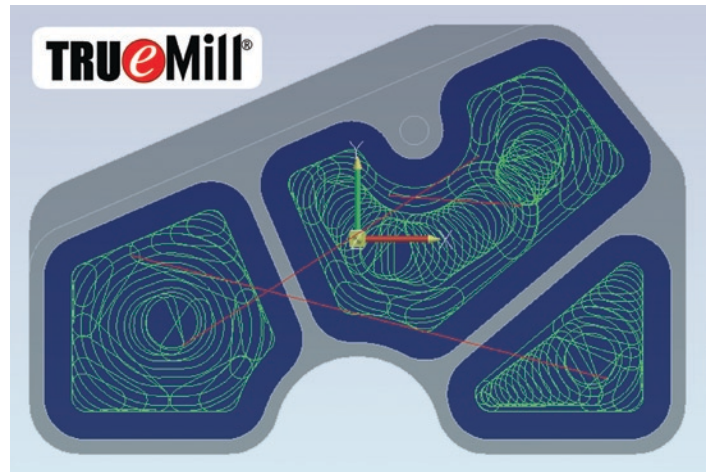
Mastercam followed the trend of offering more effective toolpaths when it released Dynamic Mill®.

While Dynamic Mill eliminates many of the poor machining conditions inherent in other Mastercam toolpaths, it has limitations. Its effectiveness varies with part complexity. And while average material removal rates are

more consistent and greater than previous Mastercam toolpaths, excessive loading and forces occur.

Total rough milling costs are lower than with previous Mastercam strategies, but average machining times are longer than other similar strategies.

The most consistent material removal rates ever achieved were realized from a new strategy introduced by third-party software developer Celeritive Technologies, Inc.



A TRUeMILL® ENGAGEMENT ANGLE TOOLPATH
Machine and tool capacity utilization up to 90 percent



DYNAMIC MILL® MODERATE FORCE HYBRID TOOLPATH
Machine and tool capacity utilization up to 75 percent

VoluMill™ is the first material removal strategy with no limitations.
Its effectiveness does not vary or diminish with part complexity.

**HIGHEST VOLUME / LOW FORCE /
LOWEST COST MATERIAL REMOVAL**
**Machine and tool capacity utilization
up to 100 percent**

Celeritive took an approach to removing unwanted material that maintains a highly consistent low-force material removal rate when they created VoluMill™. VoluMill is the first material removal strategy with no limitations. Its effectiveness does not vary or diminish with part complexity.

This novel approach to toolpath design maximizes ideal machining conditions and results in the highest material removal rate possible for any variation in machining conditions.

With VoluMill, consistently low forces during cutting generate little heat and allow for the use of the full length of the cutting tool. Low heat buildup keeps tool wear to a minimum, so tool wear is highly predictable and programmable. Using the full length of the

cutter reduces the number of passes required in thick parts and leaves the cutting tool in perfect shape for reconditioning. A true stepover allows for full width cuts without leaving material behind. The combination allows for the most effective use of all cutting styles.

This volume-based rough milling strategy is highly effective with all parts. It eliminates all of the poor, high-force machining conditions found in traditional toolpaths and maximizes ideal machining conditions with the highest percentage of straight cuts and low-force shallow arcs. Consequently, machining times are minimized.

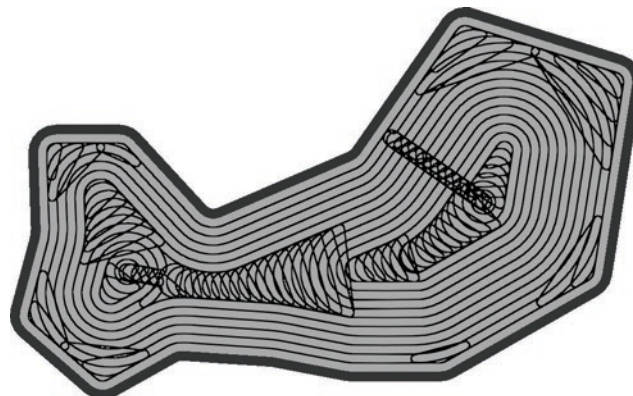
This flexibility allows programmers to achieve the highest possible material removal rate with the least tool wear. Machine tool utilization up to 100 percent is possible, along with one-fifth to one-half less tool wear. Maximum machine and cutting tool utilization results in the lowest total costs for bulk material removal.

Summary

After years of ineffective and expensive material removal strategies, advances in computer science, solids modeling, and high-level software programming have allowed software developers to advance the art of bulk material removal to the point where hardware, not software, is now the limiting factor in rough milling.

Manufacturers are lowering rough milling costs significantly with the emergence of the engagement angle and volumetric bulk material removal strategies. This important and manageable cost component of the manufacturing process is becoming a competitive differentiator in the purchase and use of CAM systems.

Toolpath engine quality is becoming a major selling factor in the CAM industry.



A VOLUMILL™ TOOLPATH
Machine and tool capacity utilization up to 100 percent

Comparing Toolpath Engine Quality

The four most important ingredients to high-volume material removal at low costs include:

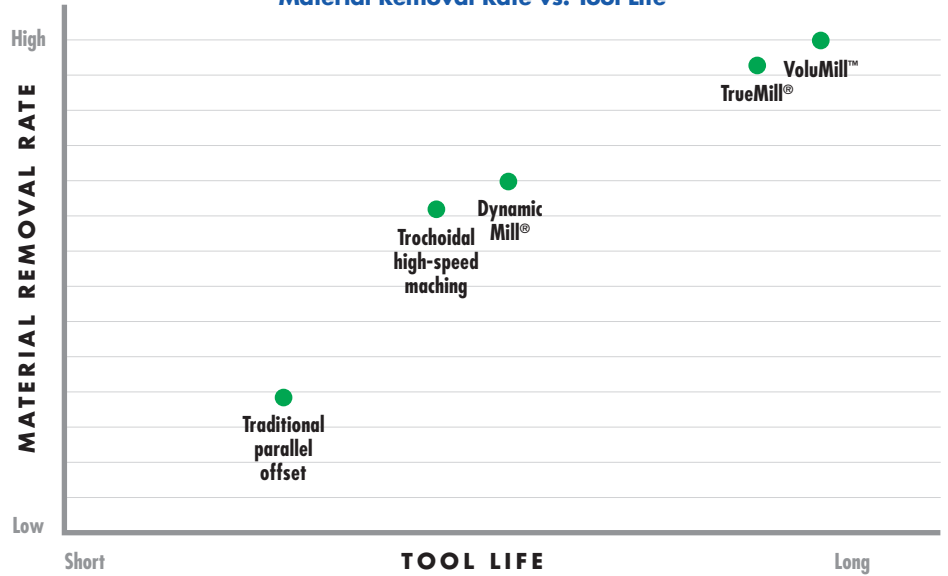
PROGRAMMING SPEED: The ease and simplicity of programming a part with a toolpath engine translates into the time it takes to program a part, which makes this a highly variable cost factor. The ease of use between engines varies widely, and tends to broaden as part complexity increases.

BREADTH OF APPLICATION: The type, size, and complexity of parts a toolpath engine is effective on vary widely between strategies, and can impact costs significantly. The breadth of application is measured by the percentage of parts a single engine can be used on.

EFFECTIVENESS: The effectiveness of a toolpath strategy is measured by the total costs for rough milling with the strategy. Roughing cycle times, spindle load, and tool life are the critical measurable factors of toolpath effectiveness.

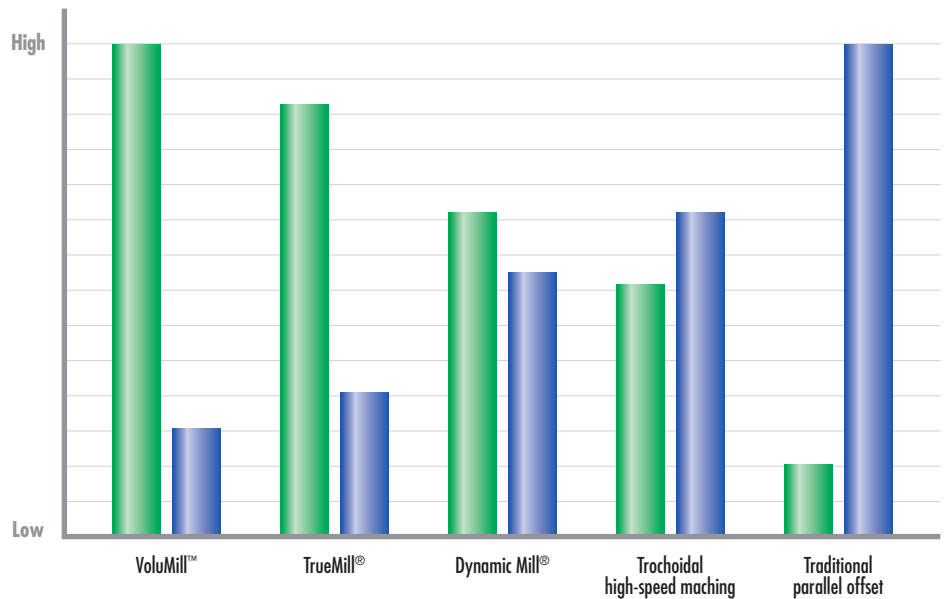
EFFICIENCY: The efficiency of a toolpath is measured by the amount of code it takes to create a toolpath program, the speed that the code can be processed, and how machine tools respond to the code.

Material Removal Rate vs. Tool Life



Material Removal Rate = The average material removal rate on all types of parts.

Tool Life = The average expected useful life under ideal conditions.



Average Material Removal Rate = The average material removal rate on all types of parts.

Total Material Removal Costs = Includes all typical costs of rough milling.



Swoosh Technologies
 1422 Elbridge Payne,
 Suite 230
 Chesterfield, MO 63017
 Local (314) 549-8110
 Toll Free (888) 318-5104
www.swooshtech.com