Increasing Productivity with Engagement-Generated Toolpaths

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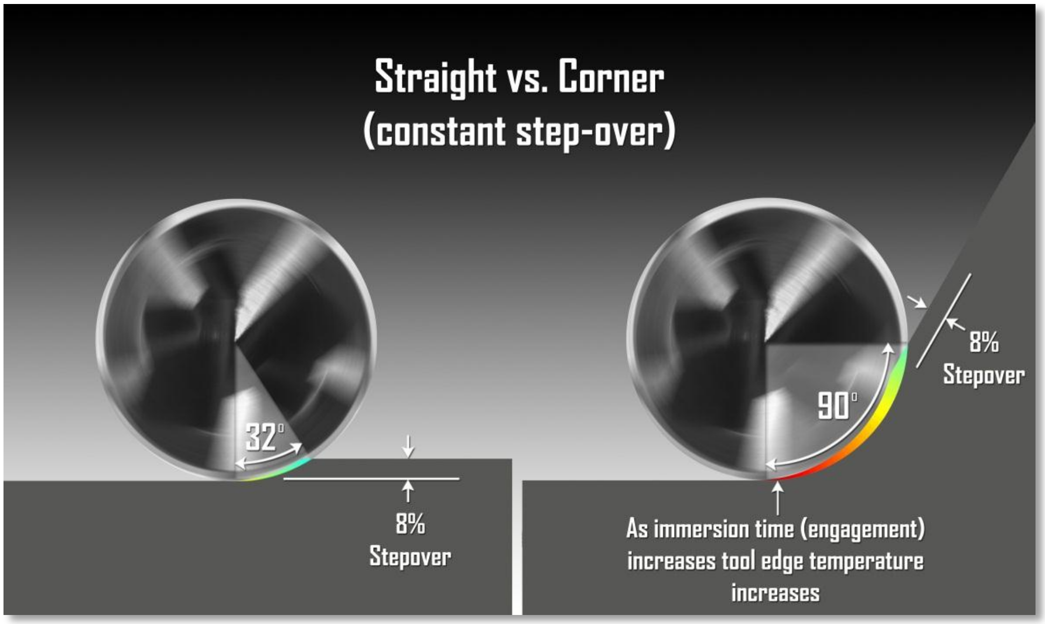
Introduction
In today's world economy, contract machine shops and manufacturers alike must deliver quality parts on time and at affordable prices. A shop's ability to increase productivity without increasing costs is crucial to winning contracts and turning a profit. A key factor in lowering part cost is reducing machining time.

A sure way to produce more parts in the same time on the same machines is to increase the material removal rate (MRR), and that means optimizing the cutting conditions throughout the toolpath. The more time a cutting tool operates at optimum cutting conditions, the higher the material removal rate will be – while also increasing tool life, and reducing machining time.

The Problem *See "Immersion Time vs. Temperature" figure – Page 3*
Maintaining optimum cutting conditions is easy in straight cuts with a constant stepover, but cutting conditions deteriorate rapidly when the cutting tool encounters turns or corners, where the engagement with the material increases significantly.

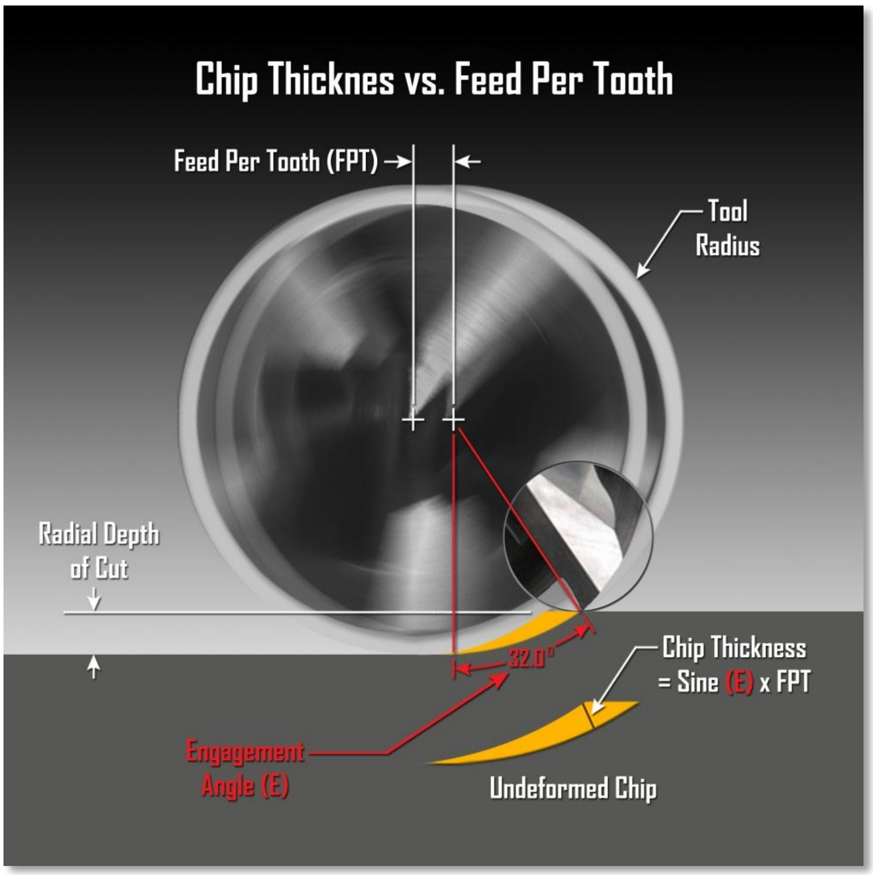
Most toolpath generators today create constant-offset or parallel-offset toolpaths, which increase engagement of the tool with the material in numerous sections throughout the entire toolpath, particularly in corners. Some newer toolpath generators create smoother looking paths, but these systems adjust the feedrate throughout the toolpath, and do not control tool engagement.



Constant step-over tool path creates wide variations in engagement

Non-engagement-generated toolpath generators slow down the feedrate every time the program foresees increased engagement conditions. The system does not maintain the optimum cutting parameters specified by the user, so the cutting conditions are no longer optimum. The CAM system is unable to create a toolpath that maintains constant cutting conditions.

The Solution *See "Chip Thickness vs. Feed per Tooth" figure – Below*
The solution is to generate a toolpath in which the cutting tool always "sees" the same cutting conditions – feed rate, engagement, cutting-edge temperature, and chip thickness – regardless of the geometry being machined. The only way to do this is with an engagement-generated toolpath.



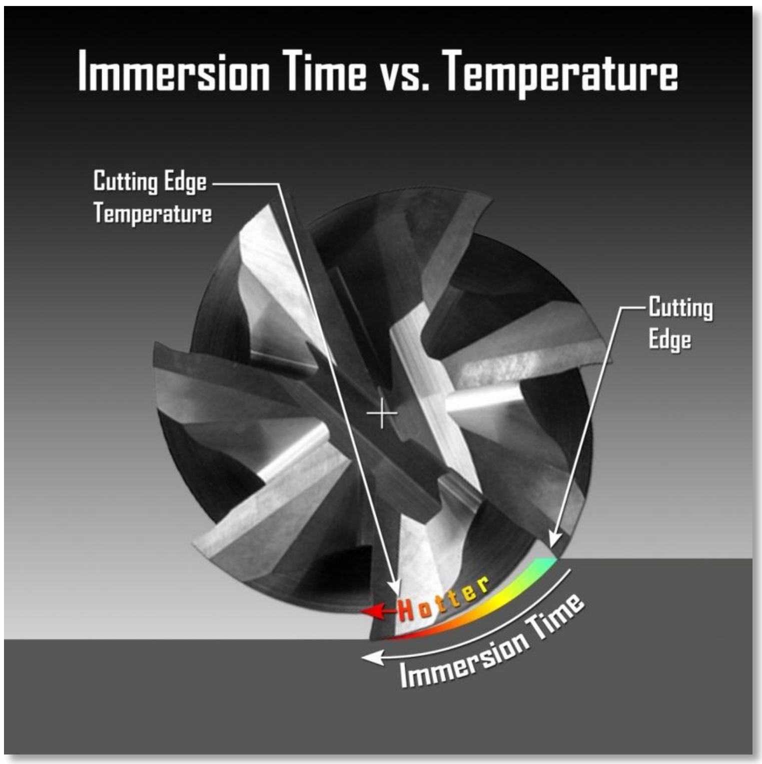
Relationship between chip thickness and feed-per-tooth

An engagement-generated toolpath closely maintains the user-specified cutting parameters to optimize the cutting conditions everywhere along the toolpath to achieve the highest possible productivity. Optimum cutting conditions create chips with the optimum geometry for the particular tool being used and the particular material being cut. The highest material removal rate (MRR) can only be achieved when the feed rate, spindle speed, depth-of-cut, and the tool's engagement with the material are held to their optimum values – creating the optimum chip.

While there are toolpath optimization schemes available to improve cutting conditions in non-engagement-generated toolpaths – either as a secondary process or one that is built into the toolpath algorithm itself – they all use the same method: They slow down the feedrate whenever they encounter increased engagement, which also automatically changes the chip thickness.

These systems usually base their feedrate adjustments throughout the toolpath on maintaining a constant material removal rate (MRR). This method not only depends on the accuracy of the calculated feedrates, but also on the ability of the machine to instantaneously follow the rapidly changing feedrate commands (the acceleration capability of the machine).

Cutting-Edge Temperatures *See "Immersion Time vs. Temperature" figure - Below*
Engagement-generated toolpaths produce constant cutting-edge temperatures, because the cutting edge is always subjected to the same engagement time with the material. They also generate a constant chip thickness, and a constant MRR at a constant feed rate.



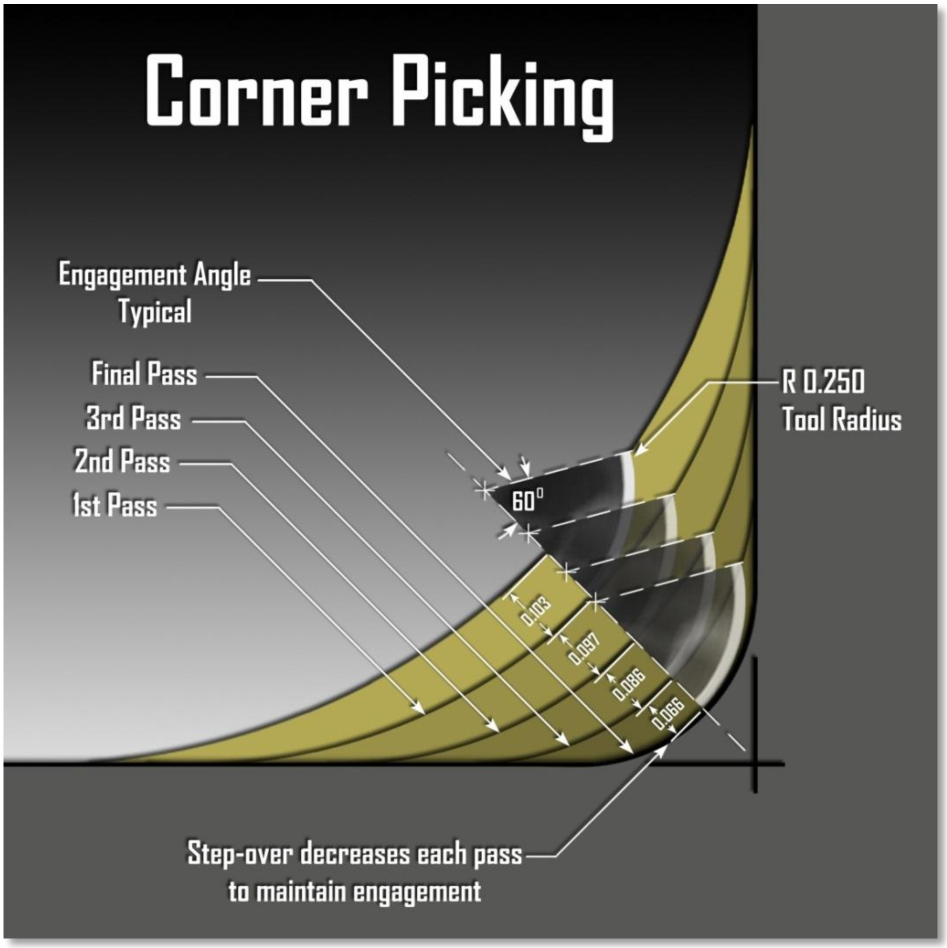
Cutting edge temperature depends on "Immersion Time" (engagement angle)

In non-engagement-generated toolpaths, engagement increases significantly whenever the tool encounters a sharp turn, which causes the cutting edges to be in contact with the material longer, increasing temperatures dramatically. In fact, cutting-edge temperature increases at an exponential rate as engagement increases, breaking down the cutting edge quickly, and reducing tool life.

Reducing the feedrate during periods of increased engagement partially offsets the heating effect, but creates another problem: increased friction and tool temperature caused by the chip being too thin.

Corner Picking with Engagement Generated Toolpath *See “Corner Picking” figure - Below*

Engagement-generated “corner picking” toolpaths control engagement between each pass, totally eliminating the all-too-familiar squeaking sounds and chatter machinists are so accustomed to when machining corners. In addition, the corner radii can be machined at a dimension very close to the radius of the tool (within 3 to 5 percent) without causing chatter, because the engagement never exceeds the value specified by the user. This eliminates the need for a separate, smaller tool to finish machining the corner.



No Chatter, constant engagement angle in corner picking

Tool Load

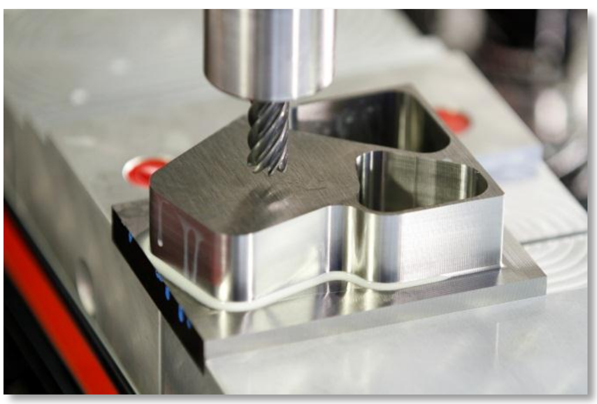
Tool load is primarily dependent on a combination of two factors: engagement and chip thickness. Because an engagement-generated toolpath maintains the user’s specified optimum cutting parameters throughout the toolpath, these two factors do not change, and the tool load remains constant.

A non-engagement-generated toolpath that uses feedrate to control the MRR does not maintain the user’s specified cutting parameters, so neither engagement nor chip thickness remain constant. Any toolpath that continuously changes these parameters is, by definition, changing the tool load.

Chip Thickness Variation in Non-Engagement-Generated Toolpaths
(for systems that use feedrate optimization techniques to manage MRR)
In the event that a CAM system has an option to use chip thickness instead of MRR to control the feedrate, the increased engagement/increased cutting-edge temperature problem still remains. Also, the system would no longer maintain the volume of material being removed (MRR), thus substituting one problem for another.

Machine Deep Pockets in Exotic Materials
Engagement-generated toolpaths allow cutting tools to machine at exceptionally high MRR, while cutting at a depth of 2 to 2.5 times the cutter diameter, and delivering significantly longer tool life. This is possible because of controlled cutting with constant engagement, and because the cutting is spread out over the length of the tool.

Conclusion *See photographs, "Before" and "After" Below*
The key to maximum MRR is using the optimum cutting parameters throughout the entire toolpath. Engagement-generated toolpaths achieve the highest possible MRR, because the cutting tool always "sees" the same cutting conditions, and therefore is always cutting at the *optimum user-specified cutting parameters.* The benefits of using optimum machining parameters that do not change are: lower machining costs and maximum profit margins, because of shorter machining times. The right machining parameters result in a huge increase in productivity, and the highest possible profitability.



Before and After - Machining Titanium at 5 cu. in per min with ½" tool at 1" in depth

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Machining Titanium at 5.02 cubic inches per minute

TRUEMill engagement generated toolpath machining 6AL4V titanium on a Haas VF-2SS
Cutting Tool: SwiftCarb ½" diameter, 7 flute RampMill with through coolant, Nikken tool holder
Machining Parameters: 3438 rpm, Feed rate 150 ipm, 30° engagement angle, depth of cut 1.000, chip thickness .0031"
Material Removal Rate: 5.02 cubic inches per minute
Material Entry: 5° Helix at 30 ipm

The chart below illustrates the advantages of an engagement-generated toolpath:

Cutting Conditions in Milling	Engagement-Generated Toolpaths	Non-Engagement-Generated Toolpaths
Constant Engagement/ Constant Cutting-Edge Temperature	YES	NO
Constant Chip Thickness	YES	NO
Constant Feed rate	YES	NO
Constant MRR (volume)	YES	YES†

† ***Note:*** *While continuously adjusting the feed rate of a non-engagement-generated toolpath can reduce the variations in MRR, it achieves this at the expense of continuously altering the user-specified cutting parameters throughout the entire toolpath. The user generally has no control over the final cutting conditions the system generates, regardless of the parameters that were input.*