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SPECIAL FOCUS: MACHINE TOOLS

Look-Ahead for Faster Machining

Rapid acceleration/deceleration key to high-speed machining.

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One of the reasons I hate the term "high-speed machining" is that the definition keeps changing.

For example, my first *Machinery's Handbook* had speed and feed charts only for carbon-steel tooling. But there were tools made of high-speed steel on the market that ran at higher speeds and feeds than carbon-steel ones. Then, carbide tools began to replace HSS tools because *they* could be run faster and harder. Now, ceramic and diamond cutters, which are capable of achieving even faster speeds and feeds, are steadily replacing carbide tools for numerous applications.

My point is that "high speed" is an evolving and relative term. It is relative to your perspective and applications.

Simply turning the spindle faster won't achieve the benefits of HSM. Many companies have tried HSM only to find that it didn't work for them. Closer scrutiny shows that they tried to machine faster and failed because they only implemented a partial HSM strategy.

In some cases, the failure was attributable to not grasping the concept in its entirety. A thorough understanding of HSM is required to successfully implement it.

For our purposes here, we'll limit the discussion to milling.

Faster Acceleration

When discussing HSM, the most misunderstood areas are the feed and rapid-traverse rates. Faster rapids are better only to a point. For example, a machine made to rapid at 2,400 ipm can move from one point to a distant point faster than a slow machine. But when the fast machine is called upon to move from one point to a close point, it may not move as fast as a machine with a slower rapid-traverse rate.

Acceleration is the reason. With the same motors, a slow machine accelerates to its top speed quicker than a faster machine can ramp up to its top speed (Figure 1).

The laws of physics dictate that the same motor can accelerate much faster if it's geared for a lower top speed. If you've ever driven a vehicle with a stick shift, you know what I mean. In city traffic, a lower gear provides better acceleration. While the fourth or fifth gear provides the fastest speed, being able to travel at highway speeds is useless in stop-and-go traffic.

For a CNC machine, however, the axis motor only has one gear ratio. The machine designers select the speed and acceleration range they think is best. Who did they have in mind when they chose the performance specs? Chances are they were trying to please their sales and marketing departments that were pleading for something with a higher top speed and feed.

The exponential relationship of acceleration to power means it takes four times the power to accelerate twice as fast. Alternately, with the same power, twice the top speed requires four times as long to decelerate. Therefore, a slower machine can indeed cut faster than one with a higher rapid-traverse rate.

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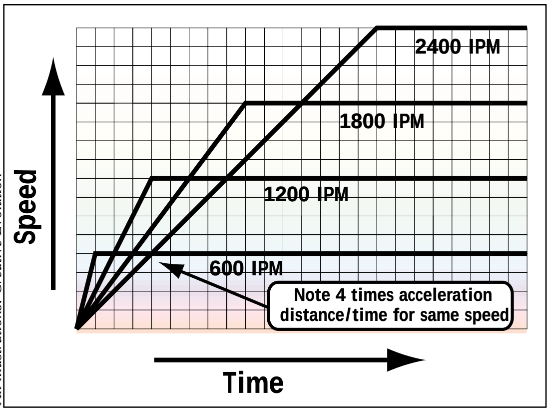
It's About Time!

There's an old business adage that says "watch the pennies and the dollars will take care of themselves." When it comes to machining, we can say "watch the milliseconds and the hours will take care of themselves." The more steps a CNC processes, the



All illustrations: Creative Evolution

Figure 1: The influence a machine's top speed has on its acceleration. Note that a machine with a top speed of 2,400 ipm takes four times as long to accelerate to 600 ipm as a machine whose top speed is 600 ipm.

more hours you stand to save—a microsecond at a time.

CNC mills can smoothly coordinate the movement of three linear axes to machine complex contours. For example, milling a circle appears as a constant procedure, a flowing cut, yet deep within the CNC program it is broken down into a complex series of commands and corrections. Transparent to the programmer and operator, the 3-axis CNC calculates and moves to a series of points that closely approximates a circle. The quality of this interpolation is dependent upon the performance of the CNC, which is measured in time. The faster the CNC, the smoother the interpolation.

When a CNC machine is milling an 8" arc at 200 ipm, you see a fluid motion, but the CNC is actually executing a series of short linear steps. The speed of the CNC determines the length of those steps. Older and slower controls often show faceting, or a series of flats, on a circular contour. Newer controls that are relatively slow compared to the fastest ones on the market either slow down or disguise the inaccuracy by smoothing over it, though the inaccuracy is still there.

The length of interpolation segments can be calculated if the time base for the machine is known. Using a feed rate of 200 ipm and a time base of 3 milliseconds, or 0.003 seconds, the linear segments, or chords, are 0.010". The time base cited wasn't arbitrarily chosen. It is the top speed of the most popular European high-speed controls. The industry's fastest controller features a time base of 400 microseconds, or 0.0004 seconds. That time-base improvement of seven-and-a-half times results in chord segments measuring 0.0013" (Figure 2). The obvious advantage is a truer contour is machined—no matter what its shape.

A less obvious benefit to the faster cycle time is increased accuracy. Twice the speed results in four times the accuracy. Extrapolated over the difference of 3 milliseconds to 0.4 milliseconds, that is a theoretical improvement of about 56 times.

In complex contouring, the toughest CNC programming challenge is point-to-point movement, since a CAD/CAM program generates a large mass of individual tool-path points with very short linear moves between them. The faster the control, the quicker the cutter moves.

Sharpening the Point

One of the real challenges for a CNC is to make the cutters produce precise details in spite of traveling rapidly. In the most extreme case, cutting a sharp corner, a faster CNC "stops" less. Stopping less while continuing the cut not only gets the job done faster, but also extends cutter life and improves performance because the cutter rubs less.

While most don't want to smooth surfaces and thereby lose details, a smoother machine motion results in improved accuracy and longer machine life. "Look-ahead" is the key to this important function (Figure 3).

Look-ahead also can be confusing, though, because it's a two-step process. During the first step of 2-D milling with cutter radius/diameter compensation (using codes G41 for cutter compensation left and G42 for cutter compensation right), look-ahead analyzes the geometry ahead of the milling tool to prevent cutter violations at intersections and achieve the correct contour.

Look-ahead's second step is the tricky one, and the one that makes a big difference in high-performance machining. In this step, the moves ahead are analyzed for their deviation from the current path and evaluated with respect to the programmed feed rate and the machine's performance. The feed is then adjusted for each move segment to ensure optimal speed and accuracy.

Therein lies the catch. Look-ahead, or geometric intelligence, can vary widely in performance and effectiveness from one make of CNC to another. The concept can be complex, and the implementation difficult for the CNC manufacturer. In some applications, this second step isn't important, but for high-speed machining of complex contours, look-ahead can be the most important element to combining speed and accuracy in a single CNC.

Look-ahead performance becomes pivotal to HSM because of data density. In older, slower systems, the machine moves slowly enough so that the axes can stop within any single-block move. Now, moving at hundreds of inches per minute, more distance is needed to stop. And, with the dense, successive moves required for accuracy, the design of complex contours

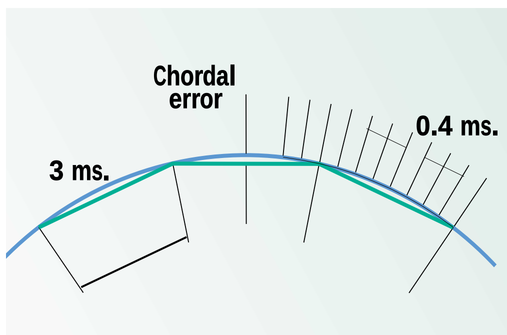


Figure 2: A controller with a time base of 3 milliseconds produces chord segments measuring 0.010" when feeding at 200 ipm, whereas a faster controller with a time base of 0.4 milliseconds generates a smoother circle with segments measuring only 0.0013" when feeding at the same rate.

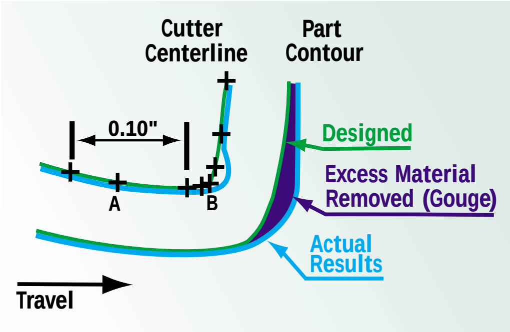


Figure 3: Look-ahead analyzes the geometry ahead of the milling tool to achieve the correct contour.

may not provide the time or distance to stop an axis and maintain accuracy.

It may sound as if look-ahead slows productivity by sacrificing the feed rate to maintain accuracy. On the contrary, it optimizes performance. The same look-ahead intelligence that slows the CNC for sharp corners also keeps the machine axes moving at the highest practical speed for less-radical directional changes.

Historically, where you might have had to program a slower feed to mill a complex contour, with effective look-ahead you can program the optimal feed for the cutter and material and let the CNC make the decisions about where it needs to slow down. The idea is that look-ahead tries its best to maintain the programmed feed without compromising accuracy.

The result is a higher sustained, or effective, feed rate. That's the average feed a machine maintains during a process. No matter how high the performance of the CNC, the actual milling time cannot match the theoretical cutting time reported by the CAD/CAM program because of physical limitations in acceleration. How close the actual time is to the theoretical time is a result of the sustained feed rate. The closer it is to the programmed feed rate, the better off you will be, in terms of both productivity and cutter life.

About the Author

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