

A Recipe for Successful High Speed Milling

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Take one machining center, add a high-speed spindle, say perhaps 20 HP and 30,000 RPM, and voila! High speed machining, right? Hardly! Over many years, this combination has provided frustration and bitter disappointment. Cutters wear out prematurely if they're just rubbing against the material faster without the proper chip load and accelerations provided by other necessary ingredients. Here's a recipe for success!

Start with one good machining center.

Add:

High-speed spindle
Well-tuned drive system
Intelligent CNC control
High-tech cutters.

Mix with conviction and determination.

Many today would have it that high speed requires some base amount of spindle RPM and/or horsepower. Some arbitrary feedrate might also be considered as prerequisite for

consideration as "high speed." While both higher spindle speed and feed rates are very important, the only sure thing about "high-speed" is that it is faster than the norm. With regards to machining, "high speed" is a constantly changing and evolving concept. Components in the mix include spindle speed and power, axis feedrates, acceleration, and cutter technology. High speed is relative to your own company's perspective, your material, your cutters, and even your budget.

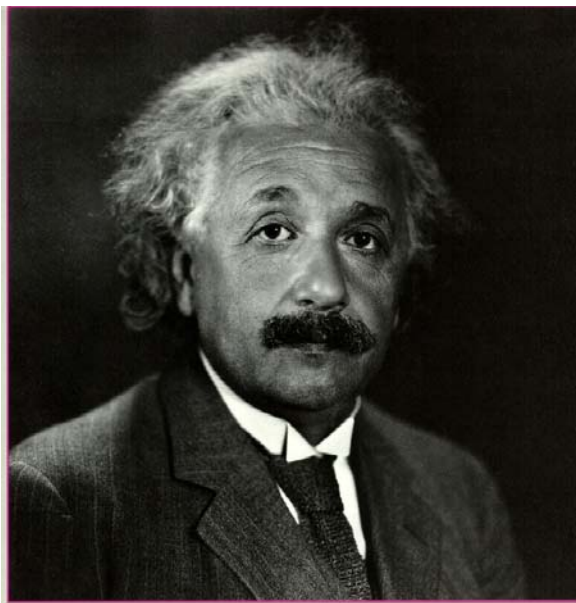
Analyzing high speed, our goal is simply to produce an equal or better part in less time, to get it billed and out the door in the shortest time. For feasibility sake, the cost of high

speed is also a consideration. Let's follow through on a thought process to evaluate successful implementation of high-speed milling.

Move the axes faster?

The quickest way to finish the job faster is to move the axes through their motion faster. Higher feedrates on your machine could do that, but then we need more spindle RPM to maintain a

reasonable chip load per tooth of the cutter.



Albert Einstein, Author of "Relativity"

Turn the spindle faster?

With a faster spindle speed, the cutters can maintain their proper chip load when moving at the higher speed, but can the cutter hold up? We need better cutters.

Hi-tech cutters?

The high tech cutters not only tolerate faster spindle speeds and higher chip loadings; they actually thrive on it! Exotic coatings set up a chemical reaction under the heat and pressure caused by cutting, to cut better and prolong the life. But what about entering and exiting the cuts? Even the high tech cutters don't hold up well to rubbing the material as one contour transitions to another. We need an intelligent CNC control.

Intelligent CNC?

The CNC must be intelligent in two ways. First it must know when the machine needs to slow down in order to maintain accuracy, and second, it must know how much the machine needs to slow down without overdoing it. The CNC must optimize the feedrates to keep the machine moving both as fast as practical, and accurately.

Combining all these ingredients with some perseverance and determination can produce stunning results. Again, we need faster feedrates, more spindle speed, better cutters and CNC control intelligence.

Studying Faster Feedrates

What do we really mean by "faster feedrates?" Most CNC machining centers built since the early '80s have rapid traverse rates to 400 IPM (inches-per-minute) or beyond. That's pretty fast, right? Immediately, we are faced with the relativity of high-speed! The definition of "high speed" depends upon whether we're cutting plastic, aluminum, steel, hard steel, or even titanium. The feedrates that are required to push the "high speed" envelope vary depending upon the ma-

terial you are cutting. Refer to figure 1, Einstein, the author of the theory of relativity.

More than just considering the material cutting, the feedrate is often confused with the rapid rate. Even focusing on feedrates can be confusing. What's important is the average feedrate. This is the feedrate that can be sustained or is the effective feedrate at which the machining is performed.

We need to dispel any confusion between rapid and feed-rates. On many popular machining centers, rapid traverse rates are often much faster than feedrates. Though the drive system for the machine is capable of moving the axes at a high rate of speed for rapid moves, the control can't move it accurately at those rates, because of control and/or axis drive issues. Overall, the faster the axes move on these machines, the poorer the control of that motion becomes, to a point where feedrate moves must be disallowed. Higher rapid rates don't necessarily infer higher feedrates, because most complex contouring programs have few rapid moves.

We often refer to the "hot zone" for axis feedrates, the range of feedrates that is useful for you in your application. For mold work and other complex 3, 4 and 5 axis contouring, the hot zone is typically around 200 to 400 IPM, usually topping at perhaps 600 IPM. The surprise is that when a machine is built for faster rapid rates, the acceleration for the feed rates in the "hot zone" decreases! It is simple physics. If the same motor is geared for a faster rapid/feed rate, the resulting maximum acceleration is decreased. **Accelerating the same load to twice the speed requires 4 times as long with the same motor!**

As you can see in figure 2, selecting a machine that is made to go "faster" can actually slow down your work if your "hot zone" is lower than the maximum rapid traverse rate.

3-D contouring on such a machine would be like driving heavy city traffic in 4th gear on a car with stick shift. You might get to the same place, but not as fast and easily.

High Spindle Speeds

Spindles come in many varieties today. Most machining centers are still supplied with gear or belt driven spindles featuring top speeds of 4,000 to 10,000 RPM. Staying toward that high end, 10,000 RPM is quite useful for most high speed machining of hard metals. Higher speeds to 20,000 or even faster can reap benefits, though there is a tradeoff.

same lines, we see that high-speed spindles made for 30,000 RPM have limited application below 5,000 RPM, because they lack power at that low range.

Spindle speed is a case where the “perseverance and determination” mentioned early on comes into play. Successful high-speed requires different strategies in many cases, not simply using faster and lighter cuts, but often requiring different approaches, like milling large holes rather than drilling them, and milling threads, rather than tapping them.

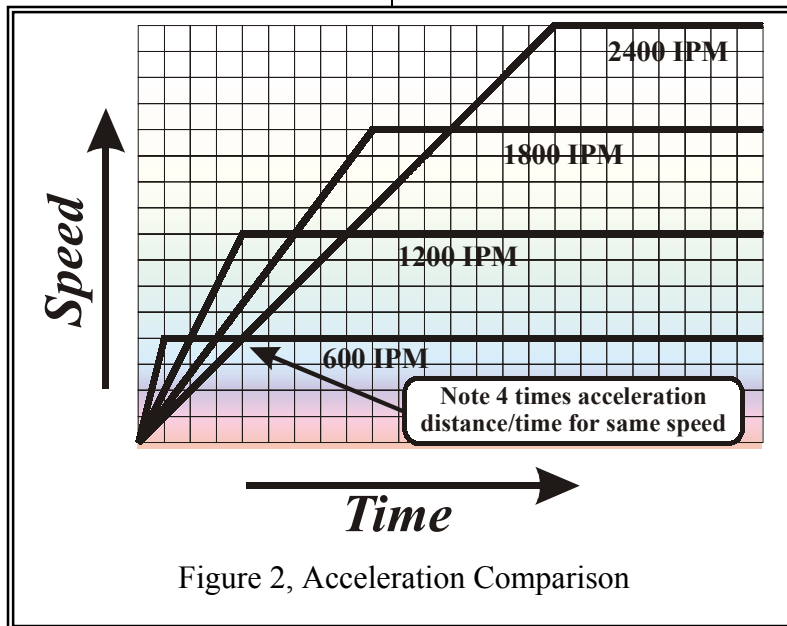


Figure 2, Acceleration Comparison

The popular high-speed spindle solutions today are direct motorized spindles, with the motor designed as an integral part of the spindle assembly. These gain the benefit of direct motor coupling, eliminating power-loss in the transmission. They also suffer less vibration than geared and belted spindles, the key benefit. This allows for higher spindle speeds.

Selection of a high-speed spindle requires careful consideration, though. Just like selecting the “hot zone” for your machine’s effective feedrates, selecting the spindle speed range impacts the useful power range. For example, a 10 HP spindle motor geared for 4,000 RPM maximum will do fine drilling a 1” diameter hole in mild steel. That same 10 HP will have a difficult time of the same job if geared for 10,000 RPM max. Along the

Higher spindle speeds allow faster feedrates and successful implementation of the exotic cutters by enabling the use of the proper theoretical surface speeds for the cutters. Can you imagine that a 1/16” diameter carbide cutter could last all day at 100 IPM feedrates in stainless steel? We’ve had such a report by a customer using 96,000 RPM for the cutter! Higher spindle speeds are key to productivity and to cutter life.

Higher spindle speeds also create two new problems, though. Cutting so much faster wears cutters in two ways, first by more “normal” wear of the cutter from cutting the same amount of material in less time, and second, from the increased abnormal wear of rubbing on the material.

Better Cutters For Better Results

Today we have more choices than ever in cutters. Choosing the right cutter can make an enormous difference in your cutter life and your end results. Choices include many grades of carbide, coated carbides like TiN, TiCN, TiAlN, TiCN, self-lubricating, and diamonds, ceramics, and even solid diamond composites. When the right cutter is combined with feed rates, spindle speed, drive parameters and control intelligence, the resulting cutter life can be surprising, even under difficult conditions.

So far, we've looked into optimizing feed rates and spindle speeds for better cutter life. For optimal cutter life, feed rates and chip loads need to remain constant. The question needs to be asked, "how do we maintain those feed rates in complex contours?" The very changes in direction that makes contours what they are, makes constant feedrates and chip loads impossible!

The simple answer is that you can't maintain constant feedrates and chip loads in complex contour milling. Physics makes it impossible. Directional changes in the cutting path require some amount of time and distance for acceleration and deceleration of the axes. For ideal cutter performance and life, we would like constant feedrates and chip-loads. In our flawed real world, we are stuck with striving to get as close as possible to constant. Along those lines, we will refer to a "more constant" feedrate.

Control Intelligence

For A More Constant Feedrate

One of the key factors for a more constant feedrate is the machine's acceleration and deceleration. The other key factor is intelligence or look-ahead. We've already taken a hard look at our "hot zone," the range of feedrates where we can practically work the materials for our 3, 4 and 5 axis contours, so let's look closer into that geometric intelligence or look ahead.

As faster drives and spindles allow successful milling at higher feedrates with our high-tech cutters, another problem arises. Many CNC's overshoot and gouge, shortcutting the corners, or they stutter and slow to swallow the masses of data used to describe the cutter path. Geometric intelligence or look ahead is the technology that overcomes the data roadblocks to successful high-speed milling.

In one case, the CNC may shortcut data points. This is the most common with older technology, where the CNC isn't checked for in-position, but rather assumes a proximity to the programmed dimensions and simply moves along with the next command before accurately completing the current command. The intelligent CNC analyzes data ahead, slowing as needed for changes in part geometry to cut more accurately. Refer to figure 3.

The more complex case is where the simple CNC overshoots because of hidden details with sud-

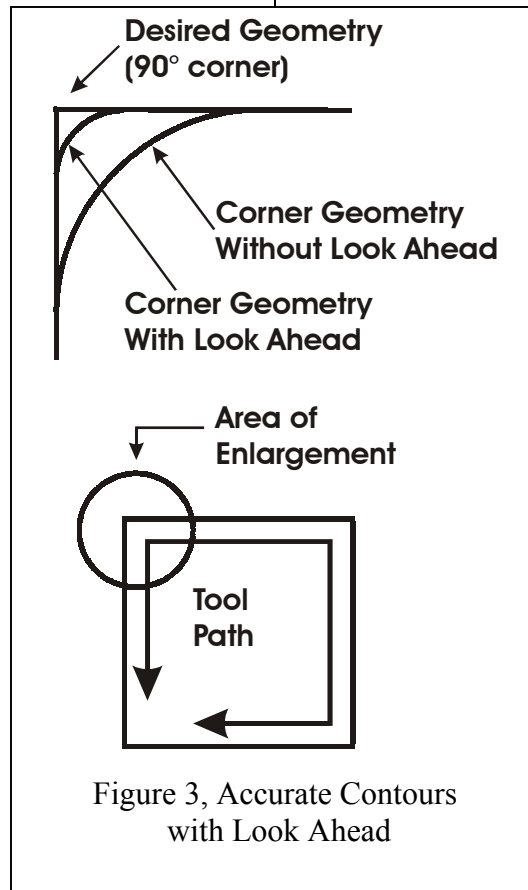


Figure 3, Accurate Contours with Look Ahead

den directional changes. The challenge is that the distance of one move may be less than what's needed for the machine axes to slow or stop to accurately reproduce the geometry. In this same case, the intelligent CNC "looks ahead" to anticipate the directional change and reduces the feedrate as needed to accommodate the machine's and its drive system's limitations. Deceleration to a lower feedrate that is feasible for the machine begins at the last possible moment, yet with sufficient distance to accurately reproduce the programmed geometry. For accuracy sake, it is really important that the CNC slow to a feedrate that is achievable. Alternately, for the sake of the cutter's life, it is equally important that the deceleration time be minimized.

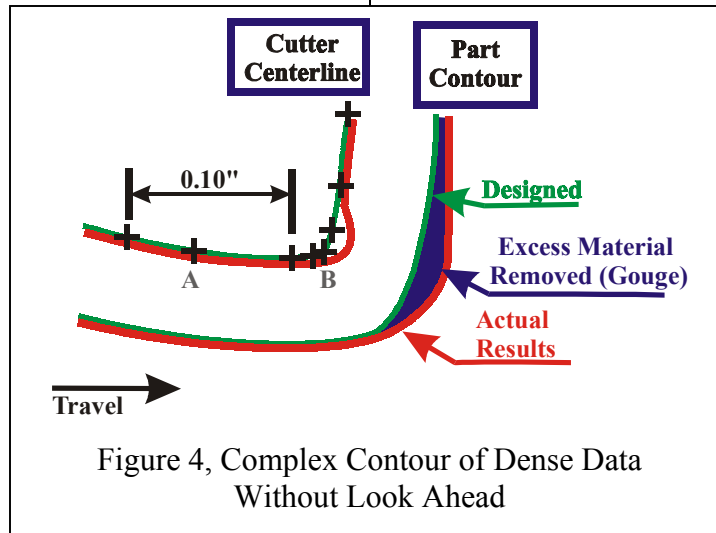


Figure 4, Complex Contour of Dense Data Without Look Ahead

down. Needless to say, the harder and/or abrasive the material being cut, the faster the cutting edge breaks down too. The importance of CNC intelligence becomes obvious, both to keep the cutter engaged and shearing the material, yet to also keep the cutter on an accurate path without gouges or rounded corners.

The reason that cutter life is best at the optimal feed and speed is that the cutter is doing the task it was designed for. When we slow below that optimal feedrate, the cutter's engagement in the material is reduced, somewhere between the optimal engagement to no engagement. The problem is that the cutters are made to shear metal, not rub it. When we rub the material, we break down the cutting edge. The higher the spindle speed, the faster the cutting edge breaks

Fast CNC For High Speed

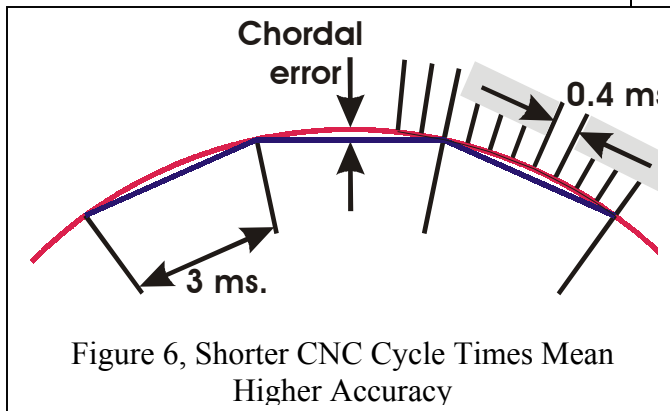
Another CNC feature that adds to the control's intelligence is its speed in terms of *faster cycle times*. We generally see CNC machines as moving the axes smoothly in a continuous path. In truth, the CNC control is breaking every move into much smaller moves, checking and updating the axes' positions along the paths. The CNC also checks position for each corner and detail.

The more often the CNC checks position and updates, the better the resolution of all contours. The CNC leaves less to chance by keeping the actual path closer to the programmed path. The chart in Figure 5 shows

Time Ms.	Cycles/Second	Distance Traveled		
		100 IPM	400 IPM	1200 IPM
20	50	.0333"	.1333"	.4000"
10	100	.0166"	.0667"	.2000"
3	333	.0050"	.0200"	.0601"
1	1000	.0016"	.0066"	.0200"
.4	2500	.0007"	.0026"	.0080"
.1	10000	.0002"	.0007"	.0020"

Figure 5, CNC Cycle Timers Relate To Distance

that the CNC's servo cycle time actually results in a known distance of travel at any given feedrate, showing specifically 100, 400



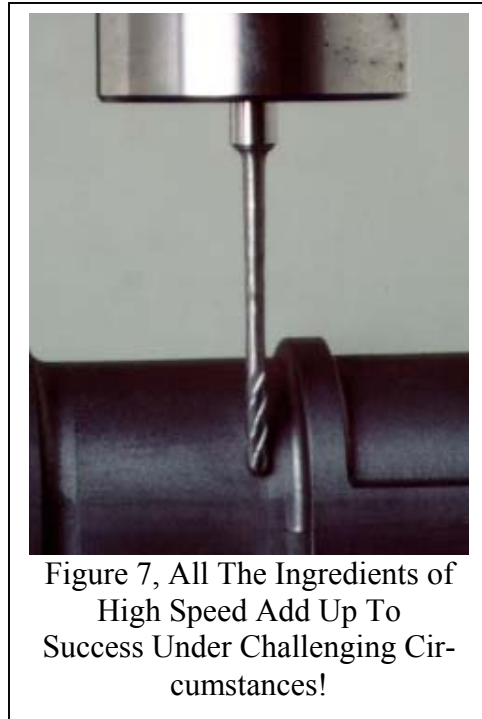
and 1200 IPM feedrates. You can see how today's fastest Creative Evolution CNC controls move a much shorter distance per 0.4 ms. servo-cycle than the average CNC today with a 3.0 ms. servo cycle. Figure 6 shows how this creates more accurate geometry.

Faster timers also relate to shorter dwells at geometry transitions. For example, when transitioning from a linear move along X to a linear move along Y, the CNC must stop motion on both axes for one servo cycle. The 0.4 ms. stop of the Creative Evolution CNC is just one-eighth the 3 ms. stop of other common CNC controls. These excessive delays of slower controls work to break down the cutters a lot faster. Again, the shorter dwells associated with faster cycle times mean longer cutter life for you.

The Web Of Success Or Failure

The recipe for successful high-speed milling is pretty simple. Just add a high-speed spin-

dle, high performance drive system, intelligent control and the latest, greatest cutter technology. As we've detailed each component, its optimal capability was only enabled by the implementation of the other components. To use the higher spindle speed and feedrate, we need the better cutters and the intelligence to cut accurately. To use the better cutters effectively, we need the faster spindle speeds and feedrates with faster acceleration and less dwell. To truly succeed with high speed milling, we need to add all the essential ingredients.



Credits:

- Figure 3, paraphrased from "High Performance Machining" by Miles Arnone, 1998
- Figure 7, photo of 1/16" diameter ball mill, 2" long, cutting complex carbon electrode, Pro Mold & Die, Roselle, IL, 1999
- All other illustrations by the author