**As Seen In March 1996 "Modern Machine Shop"**

# A Closer Look At
# Look-Ahead
# Speed and Accuracy Benefits

By Todd J. Schuett
President
Creative Technology Corp.

---

Is it possible that your existing ***fast*** CNC mills can mill your same 3-dimensional contours in ***1/10th the time***? Not just 10% faster, but 10 ***times*** faster? Is it possible that the part could be even more accurate at the same time? The answer to these questions is a resounding ***YES!*** from people who daily use controls featuring ***look-ahead***! Some are more conservative, citing 3 times or 5 times improvements, but in competitive industries like molds, dies, patterns and prototypes, the ability to mill accurate part surfaces in a small fraction of the historic time is still exciting.

If you mill 3-D surfaces from CAD/CAM data, look-ahead may be the single greatest productivity feature your CNC control can (or may not) offer you! Look-ahead for 3-D milling may be referred to as "automatic feedrate override", "geometric intelligence", or other things, but the bottom line is that look-ahead can improve your overall milling productivity dramatically!

"You can't talk about high-speed without look-ahead", says Dave Long, of Pro-Mold, Schaumburg, IL. "We bought our latest CNC machining center with feedrates to 600 inches-per-minute based on the promise of high-speed. We haven't realized the benefit from that machine, though, because it doesn't have look-ahead. The addition of new high-speed controls with look-ahead on four of our older machines has actually relegated our newest machine to mundane, slower work. The oldest machines all outperform the newest, primarily because of look-ahead." The importance of look-ahead is emphasized by the fact that they now prefer milling 3-D surfaces on a former tracing mill with a maximum 100 inch-per-minute feedrate! It can mill the same part as the newer and "faster" machining center in a fraction of the time, because of the look-ahead. A 100 inch-per-minute machine with look-ahead is actually faster than a 600 inch-per-minute machine without look-ahead! Dave Long's claims of 10 times faster milling are echoed by Merl Widup of Ehlert Tool, New Berlin, WI and David Simon of Simco Industries, Roseville, MI, and many others.

**Maximum Feedrates**

Imagine a machine capable of 1200 inch-per-minute feedrates milling a part whose total X/Y surface is only 1/2" square. The part isn't large enough to ever accelerate to the machine's maximum of 1200 inches-per-minute. Still, if your cutter and material allow cutting at 1200 inches-per-minute, why not cut as fast as possible? With look-ahead, the machine's CNC controller is responsible for maintaining the feedrate as close to the maximum programmed rate as possible without violation of the part's geometric integrity. The point is that the responsibility for establishing the balance of optimal feedrate for productivity with the required accuracy is no longer in the hands of the programmer or the operator, but rather rests on the computerized control. Imagine an operator capable of adjusting the feedrate override selector more than 2000 times per second to go fast where possible, and slow down just enough where needed! With a really fast control featuring look-ahead, that is the net effect. The fastest part possible, combined with the optimal accuracy.

**The Way Things Were**

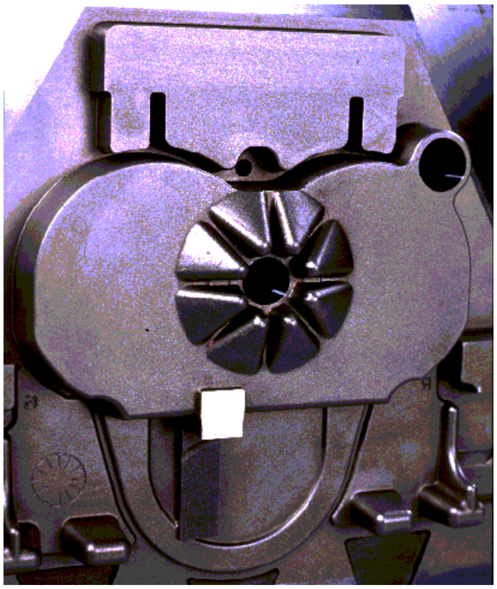

Fig. 1, Gearbox housing core

To really understand the challenge, a brief history on look-ahead in CNC can be helpful. As you read, you will see that look-ahead has had different connotations in the CNC industry. Then we'll look at what actually happens with look-ahead while we're milling 3-D contours.

When NC and CNC were developed, the idea was to pre-plan each move that an operator made, and cause them to be executed in rapid succession, without the thought, delays, and likelihood of error that accompanies manual operations. I can remember the first time I saw an NC machine drilling and milling a part as I watched in amazement! The same operation by hand would have taken easily 20 times as long, and wouldn't have been nearly as accurate. It would likely have had errors as well. The finish and detail locations were perfect! Feedrates for each move were identical! Tools lasted longer because of the consistency of their workload. NC brought about a new consistency to machined parts.

As NC developed, a buffer was added, to allow the control to read a block of data before it was ready to be executed, thus speeding up operation. This buffer gave a sort of "look-ahead" to anticipate the next move and minimize dwell time before execution of each move.

Things developed to where NC and CNC controls weren't just "point-to-point", limited to linear moves, but they came to have circular contouring, helical contouring, and so on. Dwell at any surface transition became less and less acceptable, so "no-deceleration" codes were added to suppress the normal delay at the end of each surface. No-deceleration modes didn't really look ahead, but allowed for the flow of data without dwells by eliminating the need to really get into an accurate position at the end of one move before continuing on to the next. This created a fluid motion of the machine axes, but introduced inaccuracies.

Cutter compensation developed, allowing controls to "automatically" adjust for worn or re-ground end mills, or even compensate for the entire cutter radius relative to actual part dimensions. This required a different kind of look-ahead to allow the compensation routine to see where the next cutter location would be. This 2-D look-ahead for cutter compensation didn't improve speed, but rather eliminated the need to program all tangent surfaces for programs to be compensated.

The 80's and especially the 90's have brought about a proliferation of really good CAD/CAM, with the ability to easily produce 3-D contours of all sorts. Generating 3-D surfaces with milling cutters creates new problems for the CNC control, though. These surfaces relegate the CNC to its old fashioned method of working, point-to-point. The CAD/CAM system creates a fine mesh of points over the surface. The CNC mill must then control the cutter over that contour quickly and accurately to combine productivity and accuracy.

Ideally, the most accurate part comes directly off the machine, with little or no handwork. To achieve this, the cusps are minimized by reducing stepovers to a minimum. That means more cutting time, but less chipload, allowing higher speeds and feeds, especially with the new technology cutting tools now available. Look-ahead is the essential ingredient in milling controls today to allow fast controls and axis drives to make accurate parts in minimal time.

Look at the changes that have taken place in just the last 20 years:

- Feedrates were 100 inches-per-minute, now 600 inches-per-minute is common and 1200 inches-per-minute is better.
- Data density of .040" point departures was close and accurate; now closer than .004" is common and may even be closer than .001".
- Files of 64 Kilobytes were ***very*** large; now files regularly exceed 10 Megabytes and may exceed 100 Megabytes.
- Sculptured surfaces were used occasionally for aesthetics; now sculptured surfaces are widely used for both function and appearance.

**What's The Problem?**

So with the new, fast CNC controls, what is the problem? Most CNC's built today can exceed 400 inches-per-minute feedrates. That's fast enough for anything, right?

Well, maybe. If all that is needed is to go fast from one location to another for drilling or tapping, or milling long segments, fine. Simply going fast may be enough. Again though, in 3-D contours, the shape comes from many points close together. ***That is the problem, the close points.*** Look at the photo of a mold core for a Kirby vacuum cleaner gearbox housing shown in figure 1. Now look at the wireframe view with a mesh of cutterpath points laid over it. To make the concept clear, figure 2 shows a coarse cutterpath gridwork, but in reality, we need to make the mesh quite tight to get the finish and accuracy for minimum handwork parts.

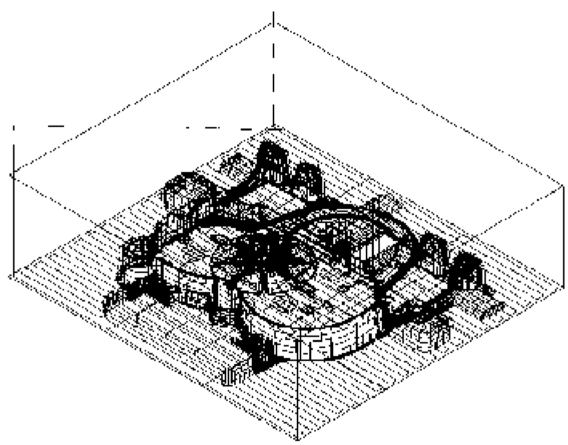

Fig. 2, Wiremesh with cutterpath
for sample part

Figure 3 shows just one "slice" of the path from a cross-sectional view, about midway through the part. Although this slice was picked at random, the cutterpath quickly demonstrated just how "real-world" the problems we are talking about really are. The transition area circled has a "bunching" of data points. These have slight transitions that must occur in very rapid succession.

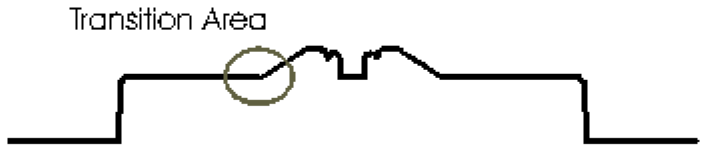


Fig. 3, Cross-Sectional "Slice" of Sample Part

The cutter travels from left to right in the diagram above. Within the detail area, there are 19 points. Three of those points define moves of just 0.0001"! Seven points describe moves of 0.0015" or less! Nine points describe moves of under 0.0030"! Again, half of the data to describe a transition over just 1.25" of linear travel is moves less than .003"! Here's the actual program data for that area, exactly as generated by the CAM system with a 0.0001" deviation specified for accuracy.

```
(slice at y-.5375)

N2056X-2.0515Z.6047
N2057Z.6048
N2058X-2.0501Z.6047
N2059X-1.7207
N2060X-1.7094Z.6048
N2061X-1.6981Z.6047
N2062X-1.1469
N2063X-1.1455Z.6048
N2064X-1.1426Z.6046
N2065Z.6047
N2066X-1.1092
N2067X-1.1078Z.6048
N2068X-1.105Z.6046
N2069Z.6047
N2070X-.9047Z.6048
N2071X-.8653Z.6047
N2072X-.8638Z.6048
N2073X-.8624Z.6047
N2074X-.8392
```

This bunching of data provides a high likelihood of gouging, and is common to many detail areas in precision cutterpaths. Figure 4 shows a detail of another example cutting area where gouging is likely to occur without look-ahead.

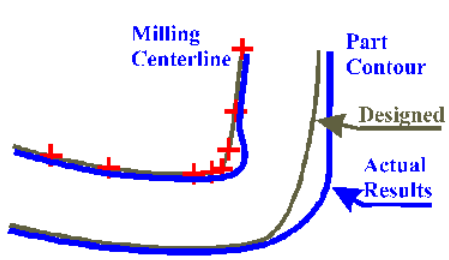


Fig. 4, Likely gouge area.

Looking ahead just one block, as with most contemporary CNC's, the machine has just one block's distance to decelerate the entire machine the needed amount. If we're indeed traveling at feedrates of 200 inches-per-minute or more, decelerating to 0 in just .010" or less is virtually impossible! A gouge will occur unless the control is prepared for this contingency with ***look-ahead***.

Another common problem without look-ahead is corner rounding. In this case, sharp corners are rounded by the control's efforts to execute data fast enough, going on to execute one move before its predecessor is complete. Mike Janes, vice-president of Damick Enterprises, Rochester Hills, MI reports that before adding a high-speed control with look-ahead to his Tarus finishing mill, corners were frequently rounded by .003" to .005". "That was when we milled at 40 to 60 inches-per-minute with the old control. Now we mill accurate parts with sharp corners at feedrates consistently around 150 inches-per-minute." Again, look-ahead is the part of the process which assumes responsibility for accuracy and smooth machine performance at any feedrate.

**How It Works**

Look-ahead does just what its name implies; it looks ahead of the data it needs to mill at any given moment to verify that the CNC will be able to handle the demands the path will put on the machine. If the data check reveals that there may be a problem, feedrates for intermediate points along the contour are added, adjusting the feedrate downward to the maximum feedrate which will still yield an accurate surface.

**How Much Is Enough?**

Look-ahead must evaluate the data ahead in several different ways. The most obvious check is whether or not the next point location deviates from the current path. In the simplest case, if the next point simply extends the current path further along a line and there is no deviation, no deceleration is required. Likewise, if the next point is at a 90° deviation from the current path, the axis must be stopped completely. With today's dense data for 3-D forms, the overall problem is not so simple. Milling data points which are only .004" apart at 400 inch-per-minute feedrates can really get a CNC into trouble. To stop from 400 inches-per-minute, a typical machine might require .400". This means that 100 blocks of CNC data must be checked to foresee vector changes. Each point and each combination of points between the current point and the maximum deceleration distance for each axis must be checked. Each tiny move between here and there may need a different feedrate to be calculated to press the performance envelope for speed while maintaining the part integrity. No set rule exists to say that X number of blocks is enough to look ahead. The amount of look-ahead required is dynamic, changing with different part details, different accuracy requirements, different machine performance and so on. However complex this data evaluation is, though, the faster and more thorough it is, the better the CNC can walk the fine line of performance and accuracy. In any case, it must all work transparently for the operator, without any penalty of time or effort. The operator should not be able to cause any violation through program input or operational oversight.

**Acceleration**

Milling machines vary widely in their ability to accelerate and decelerate. For discussion purposes, we often talk about accel/decel distances of .100" per 100 inches-per-minute. That then infers that at 300 inches-per-minute, the accel/decel distance would be .300", etc. Imagine then that we are milling the slice of data shown in fig. 4. We zoom along through the straight section at 200 inches-per-minute, encounter the points leading up to the sharp corner, and then make an abrupt change in direction, requiring that the X axis stop over just a .004" distance! Without look-ahead, the result might be a .190" or more gouge!

Dave Long of Pro-Mold says "With conventional controls, the feedrate is nearly constant. You can't run any faster than the slowest wall that you will encounter. If you have a wall that will overshoot at feedrates over 15 inches-per-minute, you basically have to run the whole job at 15 inches-per-minute. With look-ahead, the control is constantly adjusting the feedrate to balance speed and accuracy." To gain speed and still maintain accuracy on machines without look-ahead, many companies employ "manual look-ahead", using the machine operator to manually adjust the feedrate override selector to slow down for detail areas. Using their high-speed controls with look-ahead, Pro-Mold often uses just one operator for three machines. Look-ahead actually evaluates the data far in advance and adjusts the feedrates to allow the machine to cut any contour accurately in the least time practical. In spite of any problems with the motor and/or amplifier performance and machine dynamics, the control's look-ahead anticipates the geometry and ensures that the priority of an accurate part is paramount, and the speed is secondary, yet optimal just the same.

The following two photographs show a sample piece supplied courtesy of Classic Die, Grand Rapids, MI. This simple square boss provides an excellent test for look-ahead. The first part in figure 6 was milled without look-ahead. The second part shown in figure 7 was cut with the advantage of look-ahead. The same program was used for each part, and both parts were milled with a programmed feedrate of 300 inch-per-minute on a machine capable of 800 inches-per-minute. The only difference is look-ahead. The part milled without look-ahead shows both corner rounding and gouges. The second part looks as it should and will be equally perfect, even if programmed for 800 inches-per-minute! [Sample program and actual test pieces are available on request.]

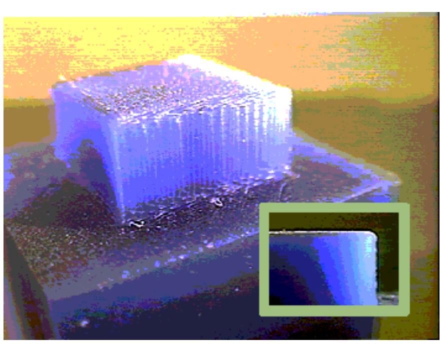

Fig. 6, Without look-ahead

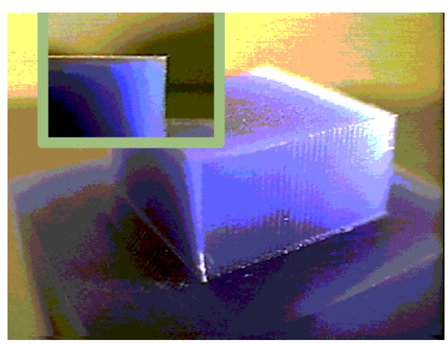

Fig. 7, With look-ahead.

Milling the accurate part takes more time as anyone would expect. Without look-ahead, milling at 300 inches-per-minute, the above part took just 3 minutes, 20 seconds. Milling it accurately without look-ahead took 21 minutes 15 seconds at 20 inches-per-minute feedrate. Look-ahead reduced that time to just 7 minutes 35 seconds. Larger parts with areas where the axes can feed at maximum rates can show even more dramatic results.

**Machine Optimization**

Recently, there have been new products introduced to add changing feedrates to the CNC program, allowing higher feedrates without the gouging and overshoot. This essentially creates an off-line look-ahead. After creating a cutterpath, that file is processed again by the off-line look-ahead program to add points in between some of the moves and modify feedrates so that the cutterpath can be accurately milled on a lower-performance control. Although this approach can provide some improvement in overall milling performance, it is generally a marginal improvement. This method creates larger data files with closer points, exacerbating any bottlenecks in the CNC with block execution speed or with the DNC communications link. Off-line look-ahead may be combined into products for pre-processing DNC data files, or may even be provided on-line in the DNC system. The bottlenecks of CNC and DNC performance still limit the benefits to only incremental improvements.

All the benefit of look-ahead cannot be realized without the careful optimization of a machine's accel/decel capabilities. Graphical drive tuning helps the control eke all the performance possible out of any machine's drive system, still taking the individual machine's dynamics into account. Figure 8 shows the tuning display for a Delta Tau PMAC machine axis controller card. This display helps the installer and the service technician alike to tune the amplifier and motor to optimally follow any commanded motion. Moreover, it is important to use all the performance your machine and drive system has to offer.

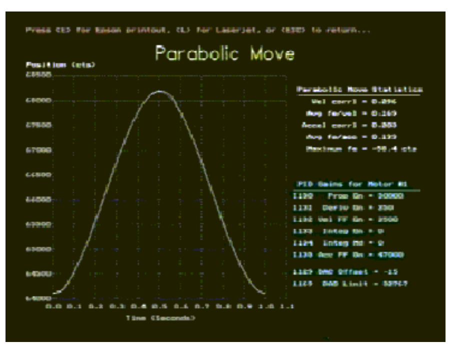

Fig. 8, Graphical drive tuning display.

It may seem contradictory, but a machine can actually run faster while running smoother! The benefits of graphical drive tuning combined with the intelligence of look-ahead can create a more fluid motion. Look at the smooth bell-shaped curve for acceleration in figure 8. This improvement over historic straight-line acceleration methods can help a lot. Used in conjunction with look-ahead's anticipation of geometry changes, the machine axes can flow through data, smoothly accelerating for wide open smooth surfaces, smoothly decelerating for tight, detailed areas. The machine's appearance while running is obviously more pleasing than the bumping and banging which often accompanies a lack of look-ahead. Another side benefit can be extended machine component life. In spite of the higher performance, look-ahead can help your machine perform better and last longer.

If the CNC program data can't get into the control fast enough, the ability to execute dense data fast and accurately is a non-issue. Recent articles about DNC and networking of CNC's detail the need to get more data into the control faster. As a rule, 3-D data closer than .020" between points requires direct CNC networking or else the bottleneck of DNC will be evident. When DNC is your bottleneck, the control may actually stop to wait for more data, or your axis motion may appear to stutter as the control quickly executes the deprived data it receives. High-speed communications is an important feature for the CNC to actualize the full benefit of look-ahead.

**Who Needs It?**

You say that high-speed milling is a lot of hype and you don't need it? Perhaps you need it more than you even know! Even milling in hardened mold and die steels can benefit from high-speed milling if you have look-ahead! The dwells and abrupt changes in feedrate that occur without look-ahead can be very destructive to high-tech tooling. Likewise, any tooling can benefit from better control of consistent feedrates and smoother accelerations. Ralph Oswald of Chicago Mold, St. Charles, IL says "From what we've experienced, you would be picking up at least 3 times faster, just in your cutting, your time on the machine. Even in steel!"

During a recent technical seminar, one attendee stated that there wasn't nearly as much need for high-speed milling with look-ahead as there was for new end mills capable of drilling hardened mold steels. That is one of the points here! High-speed milling with look-ahead can enable you to use the cutter technology available today to better advantage. You can take more fast and light passes which your cutters can take, rather than one heavy, destructive pass. With effective high-speed and look-ahead, your milling times can improve in spite of the extra distances traveled by the machine, your cutters can last longer, and your part can be more accurate. Even in tough steels and alloys, look-ahead is a key to competing these days.

Milling and finishing 3-D surfaces may be one of the great bottlenecks in your end product. Look-ahead can be the CNC feature that enables you to maximize your investment in your milling machines. Perhaps you have enough milling capacity, but can't get the surfaces polished fast enough. Look-ahead gives you the tool to mill faster with finer increments to reduce or even eliminate polishing! With look-ahead, you will be able to produce better parts in less time.

## For more information, visit http://www.creat.com