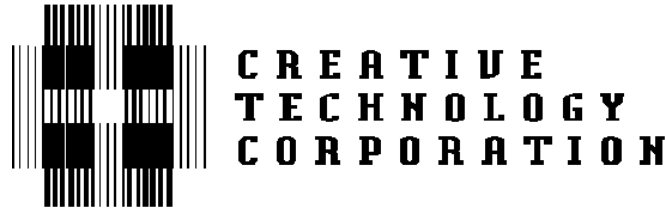


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## **Advanced Controls for High Speed Milling**

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Advanced high speed milling controls can impact 3-D milling productivity by 10 times or more! Not just 10 *percent*, but *10 times!* Imagine that over the next hour, your milling machines or machining centers could already be ahead of schedule, finished with this entire day's work! The latest of high speed controls can make that possible.

Although my company, Creative Technology Corporation, now makes CNC milling controllers for new machines, our market for the past few years has been solely used machine retrofits. Installing new controls on old machines has helped us to understand the pivotal importance that the controller has in the overall performance to achieve high speed. Simply changing the control on an existing machine with its existing drive system can actually impact productivity by 10 times or more!

### **Overview**

Over the following 40 minutes, we will first cover some of the benefits which high speed milling has to offer. This will be based largely on 3-D surface milling as seen in molds, dies, patterns, prototypes, etc., as is my main area of expertise. We will then get into a more technical study about some of the key factors in high speed:

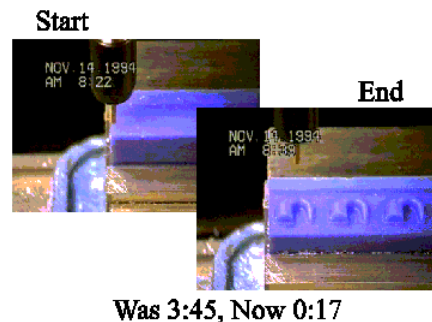
- Look-Ahead, the intelligence to analyze geometries before milling them to prevent gouges and overshoots.
- Accurate control at over 400 inch-per-minute feedrates.

- DCN (Direct CNC Networking) vs. DNC (Direct Numerical Control), or getting the data into the control for high speed performance.
- DSP (Digital Signal Processing), the processor technology that has miniaturized high-performance digital electronics.
- Open-systems architectures, the design of choice that empowers you with choices.
- Multi-processor strategies to take your CNC beyond just machine control.

## Benefits

In simple terms, high speed gives you and your control the ability to finish one task faster and move along to the next sooner. In drilling and tapping, this can result in faster hole-to-hole times, quicker spindle reversals for tapping, and moreover, when combined with higher power and improved cutter and holder technologies, can result in substantial cycle-time reductions.

The most dramatic demonstrations of high speed's benefits, though, come in 3-D contouring. Few, if any drilling and tapping jobs require a million lines of machine codes! In molds, dies, patterns, and prototypes, complex surfaces comprising a million or more line segments are not at all uncommon! Saving just a fraction of a second per move can result in substantial cycle-time improvements in cases as shown in figure 1.



**Fig. 1: Mo-Tech sample part**

Here's an example of a part which formerly took 3 hours, 43 minutes to mill *accurately* on a Leblond-Makino MH65 machining center with Fanuc 11M CNC controller. The part shown is being cut in wax, but is actually commonly milled in carbon as an electrode to burn cashew-shaped gates for plastic injection molds. A control retrofit enabled that same machine to mill a more accurate part in 17 minutes! The user enjoys greater productivity from his people and machinery. He also enjoys a distinct competitive advantage when selling his work, because he can deliver an equally good or better job for less money, in less time! I probably needn't emphasize that your customers' first consideration today is *delivery*.



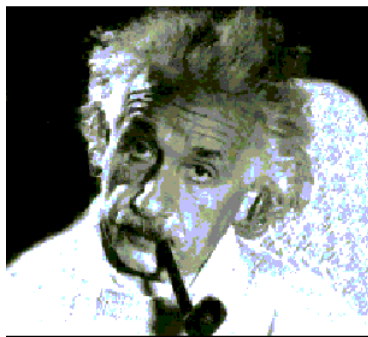
**Fig. 2: Kirby vacuum cleaner gearbox**

In a broader sense, high speed creates many other benefits. Improved accuracy, fit, finish, and cutter life are the most commonly reported peripheral benefits. Customers share the benefits of high speed through the entire manufacturing process, not just to produce more work in less time, but also improving the accuracy and finish and reducing polishing and fitting time. They do this by using the high speed to reduce the stepovers and the tolerances. Tools simply last longer because their chipload is more consistent.

Moreover, high speed milling can help you utilize your machinery and people better by wasting less time between machine commands. This doesn't just make more parts faster, but improves the entire process with less fitting and finishing time, better accuracy, and improved tool life.

## **Relativity**

What has actually brought us together here? "High Speed Machining" lured us with a promise of going faster. But faster than what? Each of us has a different perspective on what high speed is, depending on our experience, applications and our needs.



**Fig. 3: Einstein's relativity**

In one of Albert Einstein's two major papers on relativity, he stated that "all motion is relative". Speed is the velocity of motion. Speed is the way we measure how fast an object moves. Since all motion is relative, and speed is part of motion and thus is relative, the term "high speed" is also relative.

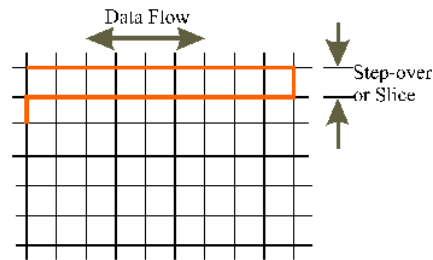
"High speed's" relative connotation is evidenced by talking with different people who utilize high speed milling on a daily basis. Going from 10 inches-per-minute roughing pre-hardened tool-steel to 30 inches-per-minute is definitely high speed in the mold business. Increasing milling speeds from 15 inches-per-minute up to 105 inches-per-minute while cutting aluminum or automotive head liner molds is really high speed. Still, if your application is the milling of foam patterns for automotive stamping dies, 800 inches-per-minute may not seem like it's fast enough!

There is no clear threshold where plain old milling becomes *high speed* milling. High speed is relative, based on your perspective, your materials, and your needs.

## **CAD To CAM To CNC**

### **Surfaces To Points To Surfaces**

The evolution of CAD/CAM into a powerful tool for 3-D surface creation is the main reason we talk about high speed milling for molds and dies.



**Fig 4: Gridwork of data, or point mesh**

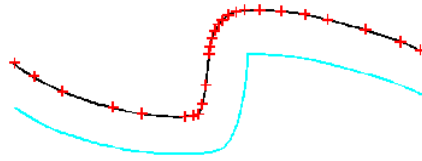
CAD (computer aided design) works with entities and surfaces. Points, lines, arcs, cylinders, spheres, planes and more all join in CAD to create surfaces. CAM (computer aided machining) then translates those surfaces into point meshes or wire frames of data for machines. Once that data is passed to the CNC, it executes one point at a time to reconstruct the surface. In order to do this efficiently, points are not milled at random, but rather organized into a data flow along slices or flow lines. These may be along any axis or across a combination of axes or even along a constantly changing flowline detail on a surface. In any case, the flow of data is from one point to another along the flow line or slice, then typically to step over and repeat that slice either in a single direction box-type cycle or in a zig-zag of back and forth movements along the flow.

Point-to-point then is the process of creating surfaces by milling from one point to another in succession. As we apply point-to-point to high speed milling, that succession from one point to another should ideally be quite fast.

### **Chordal Deviation**

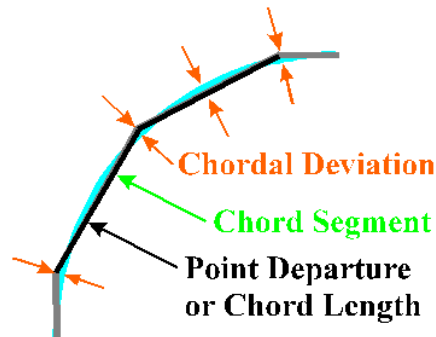
Although we have shown a uniform gridwork of points, CAM typically creates points with various distances between them. This is done by sorting points based on "chordal

deviation". An example of a slice with points sorted by chordal deviation is shown in the figure 5.



**Fig. 5: Slice of part, with points sorted by chordal deviation**

We can see that the deviations to the surface vary. If we step back a moment and just consider milling an arc by single point moves, we see that that arc really becomes a series of line segments. Those line segments deviate from the arc by a value commonly called the chordal deviation. This number is typically set in your CAM system to define what the acceptable deviation from surface or tolerance is. This deviation is set depending upon the accuracy required for individual applications. The natural desire is to be as accurate as possible but stating a deviation value which is too tight can result in enormous file sizes and high data density which can be difficult to handle. Chordal deviation must be properly set to lend balance to productivity and required job accuracy. As we proceed, we will see that high speed milling enables smaller chordal deviations and thus, higher accuracy, by executing the resulting mass of data more efficiently.



**Fig. 6: Arcs are milled by linear segments**

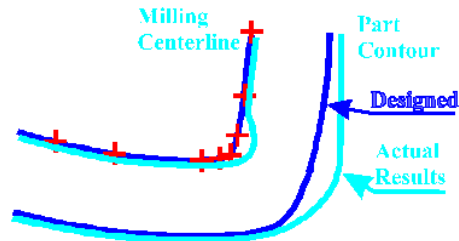
## **Point Departures**

The result of chordal deviation from CAM is a series of chord segments which are now becoming commonly referred to as point departures. This is the individual line segment lengths developed by the individual point-to-point moves which result from chordal deviation sorting (refer to figure 6). Point departures are the distances between successive point-to-point moves.

## **Look-Ahead**

Look-ahead is a fairly new feature found in only a few controls. Look-ahead has evolved from a need to prevent gouges while milling point-to-point in rapid succession. When NC

and CNC were first developed, data was executed one block at a time. Typical uses were drilling and tapping of holes and linear milling. Circular milling evolved over time. The big advantage to NC and CNC was that all moves were planned in advance and could happen much faster than a manual operator could execute the individual moves on the shop floor.



**Fig. 7: Dangerous curves for overshoot without look-ahead**

With the success of CAD/CAM, CNC has been used with increasing success to develop 3-D surface contours. In this application, the cutter must flow through the points without dwelling as older CNC and NC machines did. Most numerically controlled milling machines take from 0.100" to 0.200" to stop from a move at 100" inches-per-minute. If a CNC control and machine are instructed to flow through data at high feedrates, yet point departures are short, gouges can result at points of abrupt changes in the contour. Look again at the shape shown earlier in figure 5. There are several close data segments at the bottom of the contour. This is an area of great danger for gouging. The longer line segments going from left to right might easily permit high feedrates. As seen in figure 7, without look-ahead, the CNC might be surprised by the abrupt change in direction over a short move of only 0.010". If the feedrate is too high to stop in that distance, the result will be an overshoot. The centerline of the tool will miss its projected path, resulting in a gouge in the part.

Look-ahead must evaluate data many blocks ahead to prevent gouges. In most applications one or two or even ten or twenty block look-ahead is not enough. The amount of look-ahead needed varies based on contours, feedrates, and machine performance. In general, look-ahead can not be limited to any arbitrary value, because conditions are constantly changing. Ideally, look-ahead should be dynamic, varying the distance and number of program blocks based on the part profile and the desired milling feedrate.

### **Offline Look-Ahead**

Look-ahead is now offered by some companies either as a pre-processing step or as a part of the DNC system. To achieve the effect of look-ahead, the system must add data segments at varying slower feedrates. In this way, gouging and overshoots can be prevented. The drawback is that by adding program lines, the data throughput problem is exacerbated.

## High Feedrates

How accurate can a CNC really be at high feedrates? We can answer this by analyzing the entire machine system, starting at the CAD/CAM system and ending with the machine iron. Since we are talking specifically about the controls for this presentation, let's assume that everything else is in order, and that the control is the only issue.

**Servo cycle time** is the amount of time a CNC control takes for each measuring and command cycle. In other words, if the control's **servo cycle** time is 20 ms (milliseconds or thousandths of a second), then the axis positions are measured and a new direction commanded by the control 50 times a second. Though 20 ms servo cycles were thought to be good just 10 years ago, servo cycle times over 4 ms. are now considered inadequate. At a fairly common 3 ms. servo cycle time, positions are being measured and corrected 333 times per second. A machine moving at 100 inches-per-minute is moving 1.66 inches per second, so each time the axes are measured, the machine should be moving 0.005". This might be alarming to you if you are trying to hold tolerances to 0.0001" or so, since your machine is basically out of control for 0.005" increments at a time!

The accuracy problem gets worse when attempting to mill accurately at 400 inches-per-minute, where a 3 ms. servo cycle results in 0.020" moves between measurement and correction commands from the control! Recent trade publications have even touted high speed gantry-style mills and routers milling "accurately" at speeds to 1200 inches-per-minute using controls with 3 ms. servo cycle times. Each servo cycle is then commanding a 0.060" move. How can 0.060" moves be held to close tolerances over contoured surfaces?

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

**Chart 1: Distances moved at given feedrates and servo cycles**

Chart 1 shows a few sample servo cycle times, measuring speeds, and distances at feedrates. This chart demonstrates that to mill as accurately at 1200 inches-per-minute as at 100 inches-per-minute, the control must indeed be very fast.

The importance of fast servo cycle times becomes quite obvious as we look at these numbers. The faster the desired milling speed, the faster the servo cycle time must be.

Years ago, rapid traverse rates were increased to 400 IPM, then 800 IPM, and now faster. We couldn't dream of milling accurately at those speeds, though, because of the slower controls. The machines could withstand the stresses of quickly moving around from one point to the next, but the accuracy wasn't there for feedrates in those ranges.

Feedrates will continue to increase, and the need for faster servo cycle speeds will continue to grow. Cutter technologies are proving capable of supporting amazing speeds and feeds. The other supporting technologies like high speed spindles, end mill holders, and so on are all enabling amazing speeds and feeds. Machines with linear motors are now available with traverse rates to 3,000 IPM and more. They can accelerate to 3,000 IPM faster than most machines today can get to 300!

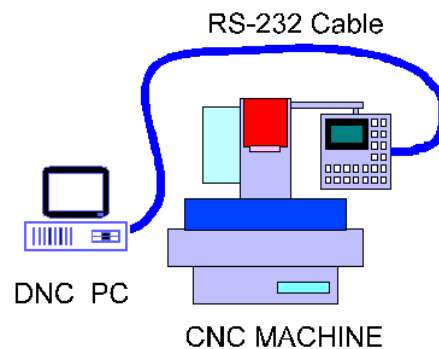
Fast servo cycle times are one of the key considerations for milling fast with accuracy.

### **Blocks-Per-Second**

The number of blocks-per-second the control executes or the *block transfer time* should not be confused with the servo cycle time. Ideally, the servo cycle time should be faster than the block transfer time. Still, it is possible for controls that execute a high number of blocks-per-second to execute at slower servo cycle times. In these cases, the number of blocks-per-second is misleading, indicating a higher speed than can really be achieved if each block is an actual discrete motion block. The combination of fast block transfer time with a still faster servo cycle time ensures high data throughput, with optimal accuracy.

### **The DNC Bottleneck**

Now that we've looked at the control's ability to mill accurately at high speeds, we have a new dilemma, how to get the program information to the CNC fast enough to avoid data starvation. Most anyone who has milled 3-D contours has watched as their CNC has stopped and waited to fill the buffers again to continue program execution. Loading the program into the control helps it run faster, yet that can often be impractical with the small CNC memories, or slow communications speeds.



**Fig. 8: Simple DNC**

First, let's consider DNC, the most common communications in use for CNCs today. DNC stands for Distributed Numerical Control, the distribution of numeric cutterpath data to CNC machinery, or Direct Numerical Control, the "drip feeding" or dynamic downloading of numeric cutterpath data "on-the-fly" as the CNC executes it.

DNC is typically performed through a serial communications link at data rates of 110 to 38,400 baud or bits-per-second. Most common is 9600 baud, resulting in potential throughput of up to 960 characters-per-second.

Program information for the CNC usually is in blocks or lines of program data averaging about 20 characters per line. For example:

```
G1 X123.456 Z234.567 <Enter> <Linefeed>
```

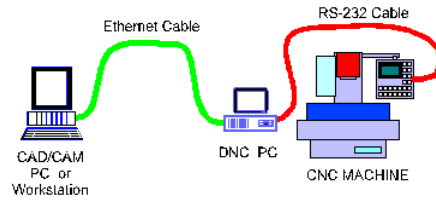
Even spaces and invisible "control" characters like the carriage return and the linefeed take time for transmission. The addition of 3, 4 or 5 axis definitions, line numbers, and feedrates simply add to the overhead in data transmission. Given a communications rate of just 960 characters-per-second, the CNC is then limited by DNC to just 48 blocks-per-second! In reality, DNC overhead commonly results in still lower performance, generally about half the theoretical potential. At this rate of 24 blocks-per-second with 0.010" point departures, the resulting DNC speed limit is just 14.4 inch-per-minute! That is too slow for high speed milling no matter where the observer's relativity is based!

Proponents of DNC are now promoting several techniques in order to optimize DNC performance:

- Use incremental data where points are measured from the last location, rather than absolute where all points are measured from one fixed location.
- Use integer data, where a dimension like .012 is instead shown as 120, eliminating the decimal point, but adding trailing zeros.
- Data compression, using mathematical algorithms to make data take less space.
- Pre-processing, to reduce data tolerances and eliminate unneeded data.
- Don't use cutter compensation or fixture offsets, mirror imaging, or scale factors.

Moreover, techniques like those above all increase the operator workload, increase the opportunities for errors, and reduce the operator's flexibility with the machine. DNC is operating too close to the limit for high speed milling.

Networking your DNC computer may help work flow, but does not solve the data flow problem. Many DNC computers are networked to get the data from the CAD/CAM to the DNC system fast, but the data flow is still restricted between the DNC PC and the CNC control by the limited bandwidth of RS-232 communications.



**Fig. 9: Networked DNC PC**

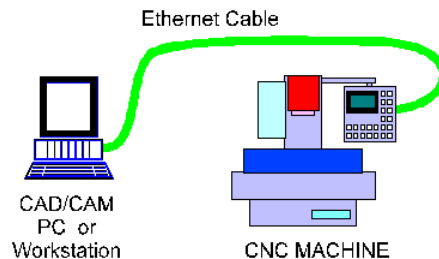
## Direct CNC Networking The Communications Solution

Direct CNC Networking or DCN offers a much better solution to the data flow problems in high speed milling. DCN simply uses existing networking architectures to provide a direct network link from the CAD/CAM to the CNC, eliminating the DNC system entirely. DCN is normally 1,000 times faster than DNC. This can best be illustrated by the fact that a 10 megabyte file which takes about 3 hours to transfer by DNC at 9600 baud, takes less than a minute by DCN!

While Ethernet is the most common network architecture in use today, Arcnet, Token Ring, and Fast Ethernet are examples of other common networks in use. Software protocols used include Novell's IPX/SPX specification, TCP/IP and NFS as found in most Unix systems, Netbeui as used by Microsoft's LAN Manager, and more.

The point is that Ethernet's performance of 10 Megabits per second translates to 1 million characters-per-second, about 1,000 times faster than most DNC! Networking architectures are already commonly available with data rates of 100 Megabits per second or more, even 10 times faster than standard Ethernet!

Direct CNC Networking eliminates any data bottlenecks getting the numeric program data into the CNC and has lots of room to grow to fill your changing needs.



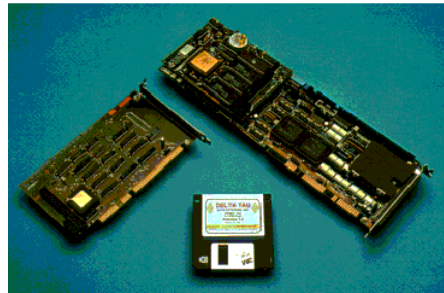
**Fig. 10: DCN layout**

DCN also provides infrastructure for growth, a foundation for expansion into the future. On PC-based (personal computer) controls, interesting possibilities include running CAD/CAM software right in the controller. Additionally, job control and quality control programs can be run right within the CNC. The data requirements for these types of

peripheral programs demands high network speeds rather than the outdated throughput of serial data communications as used with DNC.

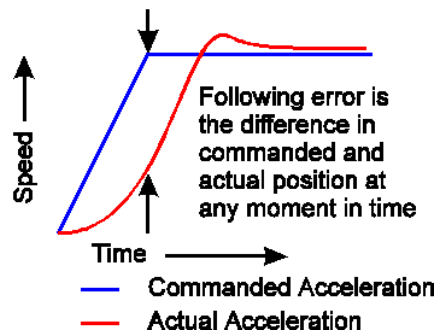
## DSP (Digital Signal Processing)

The technology that allows "plain old PCs" to act as high-performance CNC controls is known as DSP. Digital signal processing uses special dedicated processors to convert and interpret digital signals at very high speeds. Using DSP, a single board as pictured in figure 11 can control up to 8 axes at the fastest servo cycles discussed earlier! Not so long ago, a single board, much larger than this, would have been required for a single axis, operating at speeds 200 times slower!

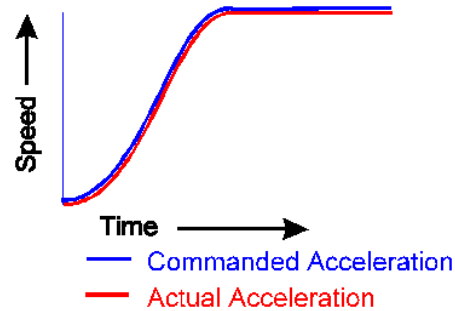


**Fig. 11: Delta Tau PMAC DSP board**

The incredible power of DSP for specific tasks is illustrated by the fact that a DSP chip can execute a multiply-accumulate (MAC) instruction, a fundamental operation, in a single clock cycle. This same operation on a current Pentium processor chip takes 11 clock cycles! Obviously a 120 MHz Pentium will still take nearly 4 times as long as a 40 MHz DSP processor!



**Fig. 12: Straight-line acceleration command**



**Fig. 13: Optimized acceleration command with DSP**

One of the big benefits of DSP is its speed. Earlier, we saw how dramatically the control's servo cycle time can impact the accuracy of the control. DSP is the key to fast servo cycles. DSP also influences the acceleration and deceleration "ramps" of the CNC control. Traditional CNC controls simply set up a ramp rate for accelerations. Because of machine dynamics and drive systems, the machine suffered "following error". With so much power, DSP systems allow tuning the acceleration for real conditions and specific machine characteristics. Acceleration is no longer simply a straight-line ramp, but rather is tuned as a sort of "bell" shape. This optimization minimizes following error, reduces strains on the machine, yet provides greater acceleration overall. DSP's speed allows better accuracy and speed, yet is gentler on the machines it controls.

There are many varieties of DSP, and those choices give control builders choices in their priorities for control functions. The variety of DSP available means that you as a user can obtain different control performance, functions, and capabilities to meet your specific needs.

DSP also has the ability to handle a variety of servo amplifier and measuring scenarios. While most traditional CNC controls are limited to interfacing with one specific drive type, many DSP boards allow the integrator the flexibility to work with several, or most available interfaces. Given the concept that technology will change over the life of a machine, this flexibility is reassuring.

One of the other great benefits of DSP is that the main CPU (central processing unit) in the PC is still free to perform other tasks. In reality, a PC equipped with a DSP for machine control is using multiple processors, gaining a tremendous performance advantage. The DSP can be measuring and commanding axis positions while the main CPU is handling the receipt of network data and pre-processing that data for look-ahead to optimize milling speeds and part accuracies at the same time. A Pentium PC using the 64-bit Intel Pentium processor, coupled with a Delta Tau PMAC using the 48-bit Motorola 56001 DSP chip offers amazing speed and processing power for tasks of all sorts, well beyond the dual 32-bit processors touted by many high speed CNCs today.



**Fig. 14: PC Enclosure**

Digital signal processing allows your modern CNC to be physically small with high-performance, while giving you a hedge on the future developments and changes.

### **Open-Systems Architectures**

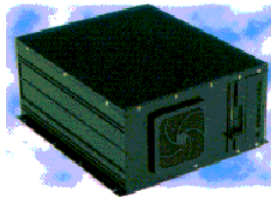
The use of an Intel x86 series processor in itself does not mean that a control is open architecture. Even using a PC-based design does not always mean that the architecture is really open. Open architecture can have many interpretations, none necessarily more right or wrong than another.

To me, open architecture implies two key components; *an ability to be serviced* and *an ability to be changed without proprietary parts and/or knowledge*. This means that open architecture should empower the owner to have choices in service and in expansion and updates.

Those neat looking hand-held control pendants that do everything, and special, custom high-performance processors may be claimed as today's best, but if they're proprietary in design, you can expect high maintenance costs and limitations for the future. Traditionally, CNC builders have sold new controls at or near cost to establish the lucrative, ongoing replacement parts business. Likewise, CNC builders often find it easier to completely redesign a new control, rather than designing improvements for existing controls. This helps encourage control replacements, at higher costs, rather than enabling the advantages of incremental advances in the technology as they are developed. Open systems architecture can really enable you to keep your maintenance costs down and to sustain capabilities current with the unfolding state-of-the-art.

There is a general convergence in the industry toward PC-based controls. This gives everyone the widest possible choice of design options and expansion flexibility. Personal computers, serviced by virtually anyone, in a variety of environments, have arguably proven to be as reliable or more reliable than the best of "hardened" CNC controls. The amazing development of PC features and performance has left the industrial CNC control market reeling to stay remotely in step with developments.

For use as a CNC, the PC may be used in a "shop hardened" configuration, available from a limited number of specialty PC suppliers. Alternately, virtually any common PC may be implemented within a variety of shop enclosures, providing protection from the contaminants in the shop atmosphere. If the air we breathe in a shop is worthy of our health risks, though, perhaps a PC need not even be protected from the shop atmosphere to be reliable. Many users of PCs for DNC would argue that plain old office-type PCs are perfectly fine for shop use.



**Fig. 15: Hardened PC**

One advantage which some industrial PCs offer is a "watchdog timer". This is an output which may be incorporated in the Emergency Stop circuit for a machine to add to the CNCs safety. A dedicated circuit in the computer constantly checks the integrity of the computer processes at very high speeds to ensure that the system is operating normally. If the system does not check out, the output can disable the machine motion by shutting off the drives as an Emergency Stop. This PC watchdog timer does not replace the DSP's watchdog timer, but rather compliments it with additional security.

As you can see, open-systems architecture with PC-based CNC controls can be a real boon to your bottom line, through a reduction in maintenance costs, up-time, and maintaining a highly competitive posture with ongoing up-to-date features.

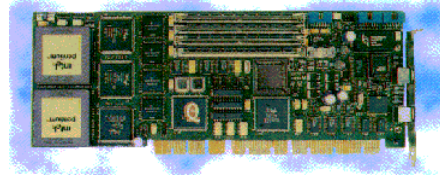
### **Multi-Processor Strategies**

Earlier we talked about the fact that a PC teamed with DSP is actually a multi-processing computer. This concept can be carried further in several ways.

Multi-processors can give the CNC operator the ability to multi-task. He may simply edit programs which are about to be run, or carry that further with graphical verification of programs submitted by the CAD/CAM department for operation. The operator may even use shop floor programming to prepare cutterpaths from IGES surface data right in the CNC control.

Within the PC marketplace, there now exists a number of computers which are equipped with or can be updated to multiple processors. For controls operating under Windows NT or UNIX, the multiple processors may offer performance benefits and the opportunity to use other programs effectively within the control while cutting.

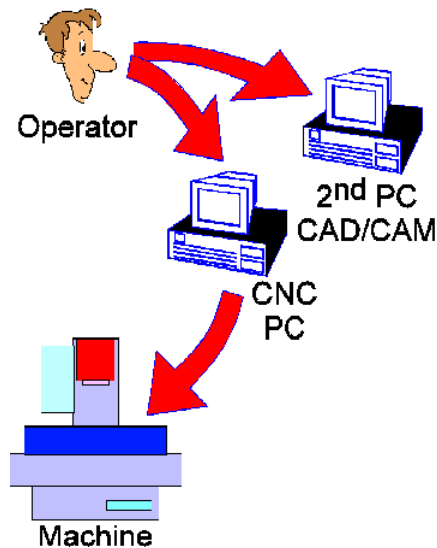
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**Fig. 16: Dual Pentium PC board**

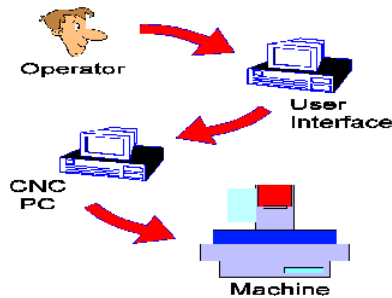
An alternative is the use of entirely separate computers, controlled by the same keyboard and monitor. There are several CNCs in the marketplace today using this concept to maintain a high level of CNC control integrity and security while still performing other tasks.

Multiple computers may be implemented in a number of different ways. Several companies have long offered dual-processor options, using a physical switch to select the "MS-DOS" mode or the CNC. Others use keyboard commands to select between the computers. Still others obscure the second computer, using one computer with multi-tasking as the user interface, and having it pass commands to the machine control computer. The multiple computer strategy can be very simple to implement, gives the operator multi-tasking capabilities, and offers security for the CNC process.



**Fig. 17: Dual processor CNC  
in parallel**

Moreover, multi-processors offer another level of performance for high speed milling, allowing the operators to perform multiple tasks quickly and efficiently at their machine control station.



**Fig. 18: Dual processor CNC  
in series**

## **A Look At The Future**

As we consider the future for CNC, the certainty is simply that CNC will continue to change. CNC will have to be able to accommodate the evolutionary changes in the industry without requiring the complete replacement of those controls as has been the norm with traditional CNC designs.

The example that I like to use to illustrate this is the word processor. When first introduced, it was an impressive contraption, consisting of a large work center with a green display screen, keyboard, printer, and built in logic, the firmware. When new features were introduced, the entire word processor required replacement at a cost of tens of thousands of dollars, and the old system was traded in for pennies on the dollar. Through evolution, today's word processor is now a shrink-wrapped piece of software that may be used on virtually any personal computer. Costs run in the tens or hundreds of dollars, and updates for new features are less than that. Installation of the update is performed by the user, generally in just minutes. Again, the evolution of the word processor parallels developments in many other computer industries, and is a good example of where CNC is likely to go.

Shrink wrapped CNC? It is possible? Imagine buying a fancy new CNC machine, and selecting your CNC as a software package for it, not an entire custom interface!

**Change  
is the one thing  
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**CNC  
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Think about new features evolving. They have historically made your CNC machine obsolete. Now imagine again getting updates at low cost, as with the word processor, or with your CAD/CAM system. We call these incremental advances in the technology. Simple, low-cost changes will keep your present equipment and entire company competitive!

All this is not just a pipe dream, but the developments are taking place right now to make it a reality! Change is the one thing we can count on in the future. CNC must be able to accommodate that change.

## **Summary**

In this study of high speed milling controls, we have seen that the controller itself plays a very major role in the overall performance of the high speed machine, as specifically evidenced in the retrofit of older machines with new CNCs. The controller enables the benefits of other high speed machine components to be maximized through:

- fast servo cycle times
- look-ahead
- Direct CNC Networking
- Digital Signal Processing

Open systems architecture gives you the flexibility to configure features as you want and need as you and the industry evolve.

Advanced controls for high speed milling can provide dramatic benefits for both new machines and existing machines, even bringing impressive performance gains to old technology drive systems and machine designs.

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