The Benefits And Data Bottlenecks Of HIGH SPEED MILLING

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High speed milling. ***What is it?*** High speed milling is a combination of techniques used to increase milling speeds from customary rates. There is no definitive threshold where milling becomes high speed milling. Over the next 20 minutes or so, we will discuss the benefits of high speed milling, concepts required to understand it, bottlenecks in the flow of data, techniques for isolating your specific bottlenecks, and some solutions for these bottlenecks.

Benefits

Higher Productivity

High speed milling can benefit you through higher productivity, faster deliveries, better finishes, less hand finishing, less fitting time, and better tool life. Ralph Oswald of Chicago Mold Engineering Company, Inc., reports that high speed milling has tripled their machine's productivity, even in hard tool steel. Pro-Mold, Inc. and Micro-Matic Tool Company are typical of high speed milling users who report improvements from 4 to 10 times or more when milling carbon electrodes. Dave Simon of Simco Industries reports quadrupling his speed in aluminum and gains of 10 times on another mill he updated.

Faster Deliveries

We often talk about the benefit of increased productivity, but this also translates to faster deliveries. If productivity is increased by 3 times, that means each delivery is cut to only 1/3 its normal or historic time. Likewise, if productivity increases by 10 times, an actual job might be accomplished in only one tenth its historic production time. This faster delivery allows your shop to be more dynamic, adjusting to the changing needs for customer response. Likewise, this translates into a very direct increase in prospective sales through your ability to respond to your clientele.

Improved Accuracy, Fit and Finish

Higher accuracy, less hand finishing and less fitting time all go hand in hand. Many users of high speed milling apply some of the speed to improve delivery and productivity, but also use some of the gains for finer stepovers to produce better finishes. This results in less hand finishing and of course, greater accuracy resulting from less sanding and filing. In this phase of the work, a big benefit can be the reduction of fitting time which normally results from surface degradation in polishing. Moreover, high speed milling can help you to produce a better part in less time.

Improved Tool Life

Tool life is also improved by high speed milling. The modern technology cutters can not only tolerate higher milling speeds, but need a constant chip load in order to last at any speed. High speed milling provides that constant chip load by flowing through the data at higher sustained feedrates. The modern technology cutters also provide better surface finishes. The high technology tooling available today can only meet design specifications in productivity with true high speed milling capabilities in the CNC control.

Higher Profits

The real big benefit for high speed milling, though, can be greater profits for you. Through higher productivity, high speed milling can pay for itself quickly. Through better parts and faster deliveries, high speed milling can help your business to grow and allow you to keep more of the profits.

Dave Simon at Simco Industries recently went so far as to claim an additional benefit. When projecting a recent major expansion phase in their business, Simco expected to need a second and third shift to keep up with production requirements. The results with high speed milling were so dramatic that the company has been able to maintain a single shift policy. Is it too much to claim that high speed milling might even improve your quality of life?

Basic Concepts

Terminology can vary, so before going further, we will discuss relativity, point-to-point data, chordal deviation, point departures, and look-ahead.

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. This is evidenced by talking with different people who utilize high speed milling on a daily basis. Going from 10 inches-per-minute cutting 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 high enough speed! Moreover, high speed is relative, based on your perspective, your materials, and your needs.

Point-To-Point

Point-to-point is the next topic for us to understand. 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 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 stepover 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.

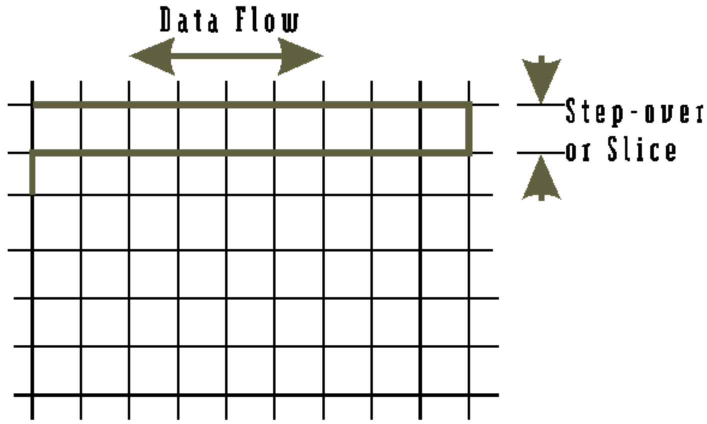

Fig 1: Gridwork of data, or point mesh

Chordal Deviation

Although we have shown a 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 following diagram.

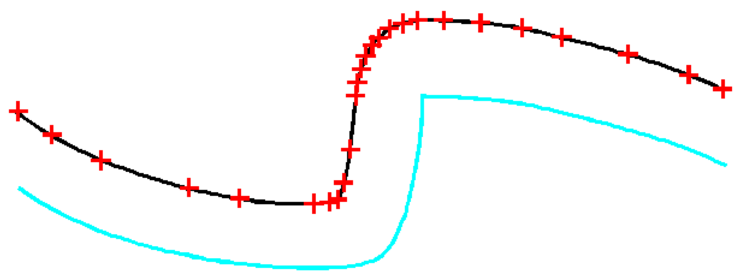

Fig. 2: Slice of part, with points sorted by deviation

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 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 low 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 efficiently.

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. Point departures are the distances between successive point-to-point moves.

Look Ahead

Look-ahead is a fairly new feature which has evolved from a need to prevent gouges while milling point-to-point in rapid succession. When NC and CNC were 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 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. 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. 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. Without look-ahead though, 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.

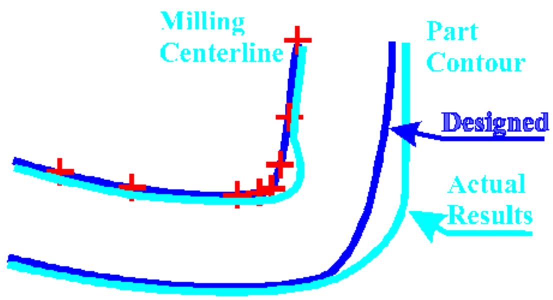

Fig. 3: Dangerous curves for overshoot without look-ahead

The Data Bottlenecks

Data Flow

In this modern age of computers, we sometimes loose sight of the fact that we can't just deliver pictures or CAD drawings of the parts. Rather, we must actually deliver real parts. To get from the part print out to a finished part, there are numerous bottlenecks. Data flows from the CAD/CAM system as a toolpath to the DNC system which in turn sends the data out to the CNC machine. We might break that down further with the specific machine bottlenecks by showing that the data within the machine enters at the control, goes out to the drives and then is applied to the machine tool iron where it suffers with the machine dynamics. The overall data path then is from the CAD/CAM system by Ethernet at 1,000,000 characters-per-second to the DNC computer. The DNC computer transfers information to the CNC control by RS-232, typically working at 9,600 baud or 960 characters-per-second. The CNC control then issues commands to the servo amplifiers by an interface which is typically analog but may be digital in more modern systems. These drives have a switching frequency of 2,000 to 18,000 Hz or more, meaning that they can change direction as much 2,000 times or more per second. Though this is greatly simplifying the concept of motor interface, it suffices to know that the motor and amplifier systems are typically capable of much higher performance than the CNC control or machine that they are attached to. The drives in turn create the motion on the machine tool. This bottleneck we call machine dynamics. Short of replacing the machine, there is typically little that can be done about this. It is redeeming, though, that the machine dynamics are seldom among the greatest bottlenecks in the data flow.

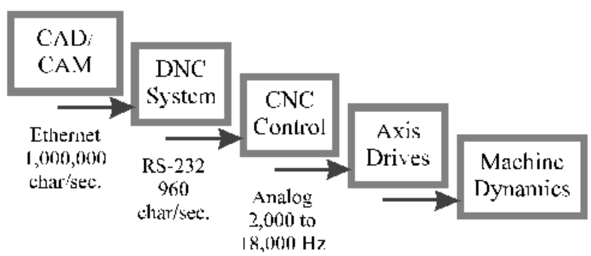

Fig. 4: CAD/CAM to part data flow

RS-232 Communications

Of all the bottlenecks we have shown here, the RS-232 interface at 960 characters-per-second is the worst. Typically the DNC computer receives information at a rate 1,000 times faster than its maximum output. Analyzing a typical CNC data block for 3-D milling shows about 20 characters per typical line as shown below. Note that this can vary widely depending on line numbers, three axis definitions in each line, etc.

G1 X123.456 Z234.567 <enter> <line feed>

We have seen that typical DNC can handle up to 960 characters-per-second which when divided by the 20 characters in a typical block results in 48 blocks-per-second maximum throughput. In everyday life, results are typically less than 24 blocks-per-second. If we analyze that further with point departures of .010" per point, 24 blocks-per-second results in .24" per second or 14.4" per minute maximum feedrate. Thinking back to our discussion on relativity, 14.4" per minute is too slow by any standard. DNC is usually the most common bottleneck in the flow of data from print to part.

CNC Processing Speed

Earlier we looked at bottlenecks which occurred when transferring data from one sub-system to another, but one of the biggest bottlenecks in the process is actually right in one of the components shown. That is the CNC controller. CNC controls typically transfer program lines to their execution buffer from 80 ms. to as little as 4 ms., but to as much as 15 minutes. This is because of auxiliary functions which the control manufacturer and/or machine builder might add to individual block executions. Auxiliary "M" functions and tool changes are examples of events which can dramatically slow block execution time. Still, 80 ms. per block is representative of performance for 5 and 10 year old machines. This means the control is capable of executing 12.5 blocks-per-second or 750 blocks per minute. With point departures of .010", 12.5 blocks per second results in .125" per second or 7.5 inch-per-minute feedrates. You can see that this is an even lower feedrate limitation than the DNC bottleneck. Again 7.5 inch-per-minute feedrate is low by any standard. Slow CNC block transfers are the second greatest bottleneck in CNC milling today.

CNC Overshoot Bottleneck

Even a fast CNC control can still be a bottleneck! Imagine a control that executes 1,000 blocks-per-second. There are a few controls in use today which are capable of this. With 0.010" point departures, these can execute up to 10" per second or 600" per minute! You might ask "how can the CNC be a bottleneck in this case?" Most CNC controls buffer only one data block ahead to speed the data flow. Most CNC controls look-ahead only for 2-D milling operations with G41 and G42, simply to prevent cutter compensation violations on internal corners. This is not at all what were talking about. Rather were talking about massive numbers of points flowing through the control; literally thousands of points-per-minute. Most CNC controls suffer from gouging when 3-D surface milling. This happens when point departures are less than the machines deceleration distance when the control is executing data faster than it can stop. To prevent this, the control must look ahead of the block being cut and adjust feedrates downward to prevent gouges and surface violations. Refer again to the earlier diagram for overshoots. The bottleneck in the case of controls without look-ahead, is that this violation can only be minimized by manually slowing down the feedrate. Unfortunately, the operator can't always see where the problems are and where they are not. Therefore, entire jobs get run at feedrates that are shamefully slow. The amount of look-ahead required varies with the feedrate desired, point departures, and the machine performance which consists of both the drive system and the machine dynamics. Look-ahead of 30 blocks for example with 0.004" point departures is 0.12" of look-ahead. This might still cause gouges at feedrates over 60 inches-per-minute on many machines. Ideally, the number of blocks of look-ahead should vary with cutting conditions. This is known as "dynamic look-ahead". The CNC control is arguably the greatest bottleneck in 3-dimensional CNC milling today. It is actually capable of commanding axis motion faster than it can think. Overshoot keeps many machines capable of 400 to 800 inch-per-minute feedrates or more, milling at only 5 to 20 inches-per-minute because of the gouging or overshoot bottleneck.

Isolating The Bottleneck(s)

We have seen now that there are two quite obvious bottlenecks when 3-dimensionally milling. These are the DNC system and the CNC controller. Further, the CNC control might suffer from a lack of speed, or a lack of look-ahead, or even both. Now we'll test performance a few different ways to isolate the importance of the specific bottlenecks in your specific environment.

Overshoot Testing

We will start by looking at the part accuracy resulting from an overshoot bottleneck in the CNC control. We will test this in two ways. First, by reviewing simple parts with long moves. If simply milling a large rectangle at high speed shows an undesirable overshoot in the corners, start by checking the machine, machines mechanical systems and the servo amplifiers. Moves of 5 or 10" per axis are longer than twice the deceleration distance for your machine, even at very high milling rates. If you suffer overshoots in this circumstance, look-ahead is not an issue so there is something more basic wrong on a lower level of your machine.

Fig. 5: Overshoots in corners of rectangular test

Next, try milling a 3-dimensional program with very tight data. Cut one part twice in soft material like wax or Renshape (to eliminate issues of cutter deflection), both at low and high feedrates. If your part accuracy varies significantly from slower to higher feedrates, you are gouging your part. A CNC controller with look-ahead will likely solve your problem.

CNC Speed Testing

Next, let's isolate whether your CNC control has a speed problem. Here, load a program of dense data into the CNC memory and test the performance while running. Note that running through the DNC system in this case does not help show us CNC speed because of the DNC bottleneck. Rather, this test must be done with the program loaded in the CNC memory. Perhaps the best test program is a set of 1,000 points in a row, 0.010" apart. This results in a 10" move that can quickly show the controls speed. In a perfect system, this test program run at 200 inches-per-minute would result in a 3 second execution time. Naturally, we must allow extra for acceleration and deceleration at the beginning and end of the 10" segment. Still, if the control is looking ahead and running fast, executing this program will appear as if you are milling a single 10" long program segment. Because there are no changes in direction in this program, it will immediately be obvious to you whether your control is slow or fast enough for you.

DNC Speed Testing

DNC speed is our next consideration. Here, we can actually use the same test program just run in the last step, a 10" linear move by 0.010" point segments. Obviously, this test cannot run faster than when the same program was loaded inside the control's memory. Alternately, if the CNC performed its tests satisfactorily but this DNC test is slow, you have isolated your problem.

We have seen that there are many components to the flow of data from drawing to actual finished parts. The most common bottlenecks are DNC and the CNC controller. Isolating your specific bottleneck enables you to eliminate it.

Solutions

The ancient Greek philosopher Aristotle wrote " the beginning is the most important part of the work". Unless you have isolated the problem it is hard to solve it. How unfortunate it would be to replace a CNC only to find that the DNC system was the fault of your problems. Be sure of the cause of your ills before you set out to repair them.

Now we will look at some of the solutions to the problems we have discussed, as well as a couple of more general solutions. Most specifically, though, we will discuss part accuracy and overshoot, the CNC speed, and the DNC performance.

Overshoot Solutions

When dealing with accuracy or overshooting problems, the first place to start is always with the mechanical aspects of the machine. Check all adjustments, the measuring system, ballscrews and so on. Also be sure to have drive tuning verified. Next, check with your control and/or machine builder for any available adjustments required or options or updates available for high speed operation. Most milling machine and control builders have learned a lot about high speed operation in the past 5 or 10 years. You might consider the radical solution, replacing the entire machine. Alternately, you might replace just the control with a high speed model featuring look-ahead.

CNC Speed Solutions

With regards to CNC speed, check with the control builder for high speed options or updates. Some controls are somewhat modular and can be enhanced with high performance options. Replacing with a new high speed control which features look-ahead is another valid consideration. Here again, the comprehensive approach of replacing the entire machine can have merit if it is not prohibitive in cost.

DNC Speed Solutions

DNC offers the widest range of potential solutions. If you are suffering from poor DNC performance, check with your DNC software source for performance increases. Perhaps the system can be set up to operate at a higher baudrate, providing higher throughput. Additionally, the computer system might be replaced with a higher performance model to improve the throughput. No doubt, if you bought your software more than 6 months ago, there will be improved versions of the software, sometimes offering increased performance. When dealing with DNC speed problems, make **sure** that the problem is not a DNC limitation to your **CNC control**. DNC systems are typically saturated to their maximum performance long before even relatively low high speed milling performance is achieved. This can make replacement of the DNC system with a network interface card very attractive. A few CNC controls in the market are just beginning to offer network interface cards to eliminate the DNC bottleneck. Some of these do not offer the full potential of networking, so verify that the network performance will provide you the expected improvement before you buy. Reviewing again, the DNC bottleneck occurs when the DNC computer receives information at a rate of 1,000,000 characters-per-second that passes it on to the CNC at 960 characters-per-second or less. A network interface card directly in the CNC can potentially allow throughput up to 1,000,000 characters-per-second directly to the CNC.

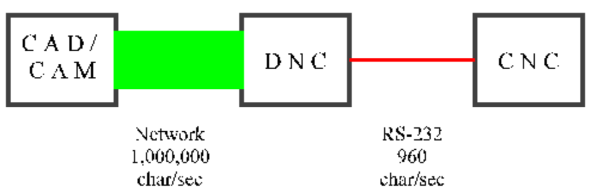

Fig. 6: Typical DNC network data flow

DNC problems can be entirely eliminated by the replacement of the CNC control with one featuring a network interface. Here again, the radical solution is complete replacement of the machine yet care must be taken to eliminate all of the potential bottlenecks. Many modern machines are still provided today with various data bottlenecks.

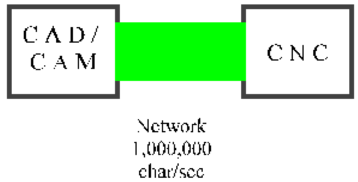

Fig. 7: CNC with network interface data flow

Your solution to high speed milling can vary. There are three basic approaches and infinite variations on them. The first school of thought is to replace all equipment as often as possible in order to keep up with the latest technology. At today's rate of change in technology, this could be a financially challenging approach. The next school of thought is to update regularly with incremental solutions to specific bottlenecks as they re needed. In a rapidly changing world, this approach can help keep overhead down, competitive posture healthy, and profits where they ought to be. The last school of thought is the worst, the mindset that 'this is a passing fancy so let's ignore the problem and ultimately get driven from the business'. Because of a lack of competitive capabilities. There is no right or wrong in this matter. There are endless approaches that can still be successful for you.

Summary

The bottom line of all of this is that high speed milling is here today and is proving its value to those who use it. We have shown an example from Mo-Tech where the replacement of a Fanuc 11M control run by DNC with a new high-speed control reduced milling time for a cashew gate electrode from 3 hours and 45 minutes to 17 minutes while maintaining accuracy and finish. High speed milling can increase your milling productivity, deliver your work faster, make more accurate parts with less hand finishing and less fitting time, and improve your tool life. It can help you attract more work by allowing you to respond to your clientele better. But the ultimate reward of high speed milling is higher profits.

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