FEBRUARY 2007 / VOLUME 59 / NUMBER 2

➤ BY BILL KENNEDY, CONTRIBUTING EDITOR, AND ALAN R. EARLS

Wall Smart

Thin-wall milling isn't for the faint of heart, but techniques exist for performing it efficiently.

Milling part features with wall thicknesses comparable to sheet metal stock—or even thinner—presents a challenge. Subjected to the forces generated by metal removal, a thin wall's relatively delicate structure will move relative to the tool, making it difficult to maintain dimensional accuracy and impart the specified surface finish. Those who have consistent success machining parts with thin walls (for this discussion, thicknesses of 0.010" to 0.060") do it by understanding the interconnected roles of the material, the tool, the machine and the toolpath.

Many manufacturers are finding that thin-wall machining can be a way to increase both productivity and profitability compared with fabricating thin walls. University of North Carolina at Charlotte professor Scott Smith, who with UNCC associate professor Matt Davies has performed extensive research into thin-wall milling, said, "One driver has been that for many assemblies—particularly in aerospace—labor is the greatest expense." Thus, machining a complex part with many thin sections from a single, monolithic workpiece can be dramatically less expensive than building up the part via traditional fabrication techniques. In one case, Smith said, replacing piece-by-piece assembly of a large, complex bulkhead for a fighter jet with thin-wall machining reduced the part's cost by more than a third.

An additional benefit of replacing assembly sequences with thin-wall milling, Smith said, is reduced workholding costs. Manufacturers that have made the switch "say one of the biggest savings is not having to make and store specialized fixtures," he said.

Successful thin-wall milling does, however, require careful consideration of multiple machining factors. "Vibration and chatter are absolute enemies," said Jeff Davis, vice president of engineering, Harvey Tool Co. Inc., Rowley, Mass. "You want to do whatever you can to bring them to a minimum. And we look at that in three parts: the workholder, the cutter and the part."

Davis said workholding issues are "obvious but still something you want to consider. You want to have the part locked down, very rigid. No chips under the clamps, nothing rocking on anything, no slop in your table." He said these are things good

'Success in thin-wall milling always involves a series of trade-offs as well as a careful blend of multiple factors in the entire machining process.'

This graphite EDM electrode milled at NyproMold has ribs 0.0152" thick. It is used in the production of a mold for a plastic container.

operators always think about, but "you want to take as many variables out of the equation as possible."

As for the cutter, its movement is influenced by the toolholder's integrity and concentricity. The setscrew of a conventional endmill holder pushes the tool out of concentricity; a better choice is a shrink-fit holder that grips the tool around its entire circumference. Other motion-control alternatives include holders with built-in mechanisms that damp vibrations before they can increase and degrade the cutting action.

The structure and condition of the machine tool also play important roles in successful thin-wall machining. A heavy cut on a lightweight machine or use of a machine with worn spindle bearings or other structural compromises can cause relative movement between the tool and part, producing chatter.

Although the increments of imprecision in workholding, tooling and machine tool may be very small, "they are going to add up to big problems if you don't check them first," Davis said.

Tooling Techniques

Professor Christopher Brown, director of the Haas Technical Education Center and the Surface Metrology Laboratory at Worcester Polytechnic Institute, said understanding thin-wall milling requires learning more about how cutting tools work. The metal-removal process generally involves shearing material from the workpiece, as opposed to breaking it away. "Even at high cutting speeds," Brown said, "the tool is deforming or shearing away the workpiece material, not fracturing it."

Fracturing may occur in some brittle materials, "but the dominant mechanism in most metals is shear," he said. A shearing action usually generates lower and more consistent cutting forces than fracturing or pushing the workpiece material. Accordingly, sharp tools that cut cleanly are most desirable for thin-wall milling.

According to Davis, large-core, rigid cutters work best. If there are no clearance problems, the larger the tool is, the more rigid it will be. "Many of our tools are on oversize shanks, so if you do have to hang it out, you get increased rigidity," he added.

Increasing the number of flutes on the tool can smooth out forces on a delicate part wall. As a 2-flute tool rotates, only one flute is in engaged in the part at any given time, exerting on-and-off forces on the thin wall. "When you have a multiflute tool, there aren't as many changes as the tool spins," Davis said.

Another way to facilitate thin-section milling is applying higher-helix tools. A straight-flute tool can have "more of a hammering effect," Davis said, while "with a helix that is laid over quite a bit, you are doing more shearing. It's almost like you are pulling up on the part, like the action of a screw. The part is more in tension and it's less likely to be pushed over."

For example, Harvey's upcoming 5-flute, 45° helix miniature mill, designed to rapidly evacuate chips in high-speed machining, is actually focused on high-performance applications. However, in thin-wall milling, "it can provide more shearing, a little more of a vertical component that pulls on the wall rather than horizontal forces that tend to push it," Davis said.

The multitude of factors involved make tool selection for thin-wall milling quite application-specific. Davis said some cases might merit investigation of a trade-off between rigidity and cutting forces; a shop may want to consider using a smaller diameter cutter. "With a smaller diameter cutter, the amount of tool engagement into the part is going to be quite a bit less than a larger diameter tool. All things being equal, that would reduce side forces," he said. However, the smaller diameter tool isn't as rigid as the larger one, so experimentation in the actual application should determine the best choice.

UNCC

Phillip Jacobs (left) and Scott Smith of the University of North Carolina at Charlotte hold an aluminum structural panel for an aerospace application. Jacobs, who at the time was a graduate student, machined the structural panel at UNCC utilizing thin-wall milling.

The following organizations contributed to this report:

CAMM/Creative Advanced Machining Methods
(937) 585-3483
www.cammhsm.com

Cavalier Tool & Manufacturing Ltd.
(519) 944-2144
www.cavaliertool.com

Harvey Tool Co. Inc.
(800) 645-5609
www.harveytool.com

Kennametal Inc.
(800) 446-7738
www.kennametal.com

NyproMold Inc.
(978) 365-4547
www.nypromold.com

University of North Carolina at Charlotte Department of Mechanical Engineering & Engineering Science
(704) 687-2303
www.mees.uncc.edu

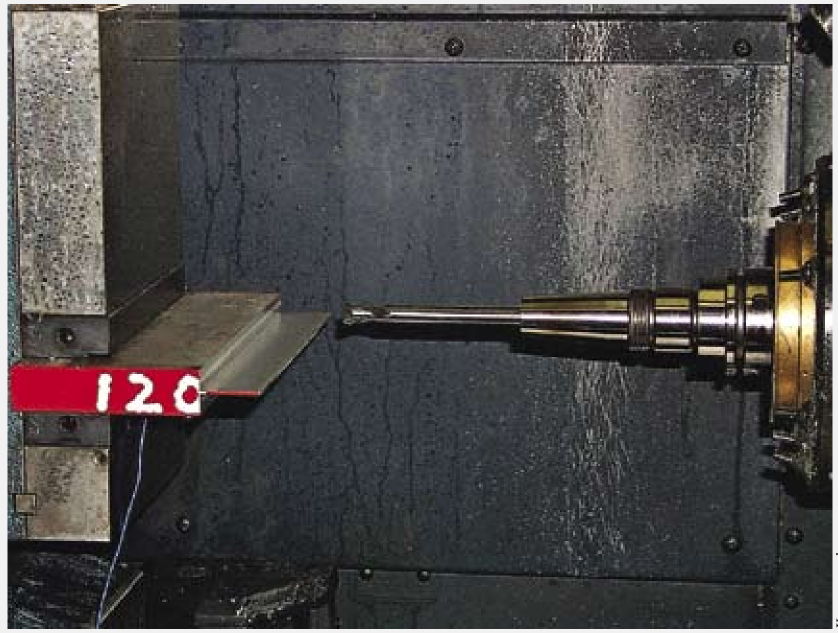
Worcester Polytechnic Institute's Haas Technical Education Center
(508) 831-5673

Extreme investigation

While it probably won't be featured in the next X Games tournament, extreme milling is getting a workout at Kennametal Inc., Latrobe, Pa. T.J. Long, global milling systems engineering manager, and his colleague, Ruy Frota, global tooling systems engineering manager, recently completed a 1-year study of high-speed machining. One area was thin-wall machining. Much of the work involved Kennametal's BestSpeed analyzer, which measures chatter frequency via a microphone and then recommends preferred speeds to stabilize the machining process and reduce chatter.

On the order of "don't try this at home," testing of thin-wall milling took place on an extreme setup that wouldn't be encountered in a sensible shop. The goal was to create exaggerated conditions that would clearly demonstrate the impact of changing machining system variables. In the arrangement, a ½"-thick piece of 2024 aluminum plate was clamped in a vise with about 4" hanging free. The plate was machined with an endmill mounted on a long holder that put the tool tip 10" from the spindle face. "It was a pretty flexible system; we did it to learn with a worst-case situation," Long said.

Tool clearance was critical in this setup. "The endmill featured relief as a standard feature," Long said. "But because we were hanging out there so far in our setup, we couldn't take the depth of cut that it was already relieved for. We relieved it ourselves even further." He noted that although use of mills with differential pitch (unequal flute spacing) is a common way to try to eliminate harmonic vibration, the researchers used cutters with equal pitch in their testing with the acoustic preferred-speed equipment. "When you throw in the differential pitch, it's harder to find a preferred speed because differential pitch is breaking up the harmonics," Long said. The bottom line is achieving a stable machining process.



Kennametal

This test setup at Kennametal, featuring a ½"-thick aluminum plate machined using an endmill with its tool tip 10" from the spindle face, was designed to create exaggerated conditions that would clearly demonstrate the impact of changing variables in the machining system.

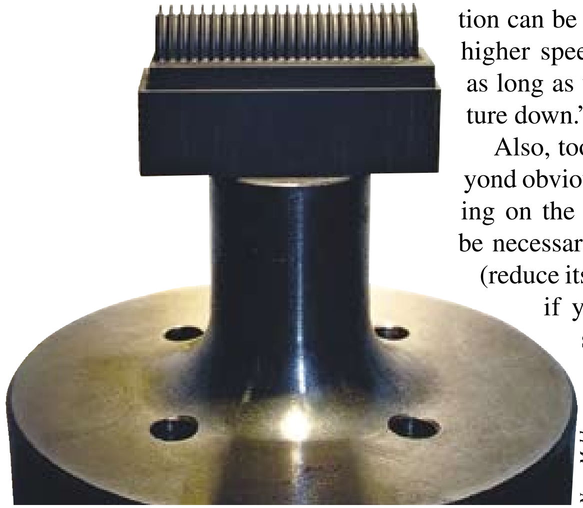
According to Long, the project confirmed the efficacy of climb milling for thin-wall applications. When climb milling, the part moves in the same direction as the milling cutter teeth. Each tooth engages the part at maximum chip load, and chip load tapers to nothing as the tooth leaves the cut. In conventional milling, where the part moves against the oncoming milling teeth, the opposite is true: chipload is at its maximum as the tooth leaves the cut. Therefore, Long said, climb milling "subjects the thin wall to minimal forces as the cutter tooth exits the part, resulting in less tendency for the part to vibrate."

Also regarding part programming, Long noted that when profiling a radius, "one critical thing is to make sure that the tool you are using is smaller than the radius." In other words, the full-depth capacity of the tool (half its diameter) must be smaller than the desired radius. "If you need a ½" radius, you want to use less than a 1"-dia. tool," he said, "If you use a 1"-dia. tool, it's going to come to a dead stop in the radius, sit there and dwell, and it will chatter. A smaller tool will generate that radius and make sure you always have a chip load."

Lastly, Long and Frota found that a machine tool's control protocols may be an unanticipated source of tool and part chatter when milling radii. "It's important to be aware of the machine tool's feed rate," Long said. "Some machines will decrease the feed rate when they generate a radius. We found that if feed rate goes too low, the tool will actually be doing more rubbing than cutting, and it will chatter in the corners."

The cure is increasing the chip load by boosting the feed rate, either in the radii alone or by maintaining higher feed rates throughout the entire cut. Long cautions that changing feed rates is "not something you want to go in and program right away because you probably won't know until you run the part if the feed rate is going to decrease." Every machine is different, though the situation occurs less often on modern machines with better look-ahead capabilities. However, Long added, "If you make a part, and you see that the tool is chattering in the corners, sometimes it is because the machine is decreasing the feed rate."

—B. Kennedy



NyproMold

Used to form part of the mold cavity block for a medical component, this graphite electrode milled at NyproMold has ribs 0.0147" thick.

Material Issues

WPI's Brown said the basic machining characteristics of the workpiece material are a key to successful thin-wall milling. For example, machining aluminum produces low cutting forces and is relatively easy to machine into thin sections, while workhardening materials, such as stainless steels, generate higher cutting forces that can distort a thin workpiece.

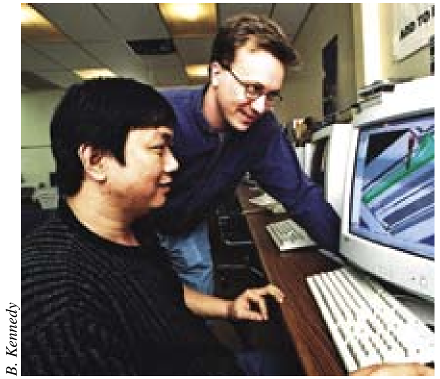
Another problem material is titanium, which is difficult to machine to thin sections. "The heat doesn't dissipate, and you tend to get chunky or discontinuous chip formation, vibration and poor surface finish," Brown said. When heat-related issues are involved, according to UNCC's Smith, the solution can be "lower spindle speeds—or higher speeds with less engagement, as long as you can keep the temperature down."

Also, tooling issues can extend beyond obvious considerations. Depending on the part configuration, it may be necessary to relieve the tool shank (reduce its diameter). "We found that if you are machining on the side of a thin wall for five or six passes it looks fine, but then on the next pass it chatters so badly it will rip the wall or even wrap the material around the tool," Smith said. "After a while, it dawned on us that we were cutting with the tip of the tool but making contact all along the side." He added that researchers determined that tools with back-tapered flutes and relieved shanks minimized the drag of the tool on the machined part wall.

Of course, such strategies are application-specific. When milling mold walls with the slight draft angles needed to assure release of a molded part, moldmakers use endmills that taper (typically 1°) slightly larger from tip to shank, according to Ed Mueller, CAM programmer at Cavalier Tool & Manufacturing Ltd., Windsor, Ontario. He agreed, however, that when milling straight walls, cutters that instead taper smaller from tip to shank, as well as tools with relieved diameter shanks, are appropriate.

Mueller said programming cutting parameters for thin walls usually involves a small DOC, "perhaps 0.0005", depending on the size of the cutter and the depth of the wall, with a fast cutting speed and feed rate, to avoid pulling the cutter into the wall."

Rethinking the cutting sequence is a critical requirement when programming a thin-wall part, Smith said. "Your machining experience may tell you that it is best to machine close to the finished dimensions and then make a finishing pass, but thin walls are so flexible that once you machine the rough pass, you really can't touch it again." The solution is to rough the part to a reasonable thickness, then make one finishing pass to produce the thin wall. "Never go back," Smith warned. He added that programming the optimal toolpath for thin-wall projects can be tricky. "The automated routines for making pockets presume that you are going to rough and finish all over, as with standard machining practice," he said.

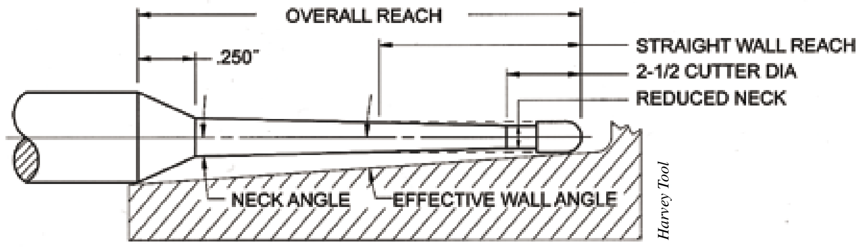


B. Kennedy

According to Cavalier Tool & Manufacturing CAM programmer Ed Mueller (right), here with fellow programmer Tin Nguyen, cutting parameters for thin walls usually involve small DOCs, with high cutting speeds and feed rates.

Bill Norberg, roughing department manager for moldmaker NyproMold, Clinton, Mass., said the one-pass strategy applies when cutting extremely thin features in EDM electrodes at his facility. "When you are cutting tall, freestanding thin walls, you may have to rough them to a wide enough cross section so they will stand on their own. When I cut a feature that is 0.010" wide with a large height-to-width ratio, which I do routinely, I will rough it out leaving 0.015" to 0.030" per side, then finish it in one pass. That's one secret to making a small width, but there are many others. Electrode design is another key success factor; this type of work is as much art as science, with no substitute for experience." Norberg noted that the same basic approach applies regardless of whether the electrode is made of graphite or copper, for example.

UNCC's Davies said the technique, basically treating the material itself as the fixture, works. "We made one piece that was 4" tall and 0.005" thick," he said.



Harvey Tool

Neck diameter relief behind the cutter head as well as the neck angle from head to shank are critical factors in avoiding contact between the cutting tool and a thin-wall workpiece.

Vibration and Harmonics

A variety of technologies can enable active control of vibration and harmonics, according to Randy Harper of CAMM/Creative Advanced Machining Methods, Claremore, Okla., a company specializing in software and consulting related to vibration. Harper said it is important to understand the specific vibration characteristics of the tool and the workpiece, adding that every tool has a dynamic signature—a frequency at which it tends to vibrate. If the tool's natural frequency is known, it is possible to calculate the best cutting speed for the work. That frequency can be determined through systems that employ microphones to record the sound of the tool in action (see sidebar on page 32) or via methods in which an accelerometer measures the response of the tool and workpiece when each is struck with a hammer.

Profit-Focused Reality

Harvey Tool's Davis provided a dose of machine shop reality, though. He said that much discussion about thin-wall milling involves "talking about an ideal case that's got nothing to do with cycle time, which is what it almost always comes down to." A shop has to "consider what is the ideal cycle time, because it wants to make money on the project." Quite often, the theoretically optimal combination of cutter and toolpath will produce "not necessarily the best cycle time for maximizing profits." Consequently, success in thin-wall milling always involves a series of trade-offs as well as a careful blend of multiple factors in the entire machining process. △