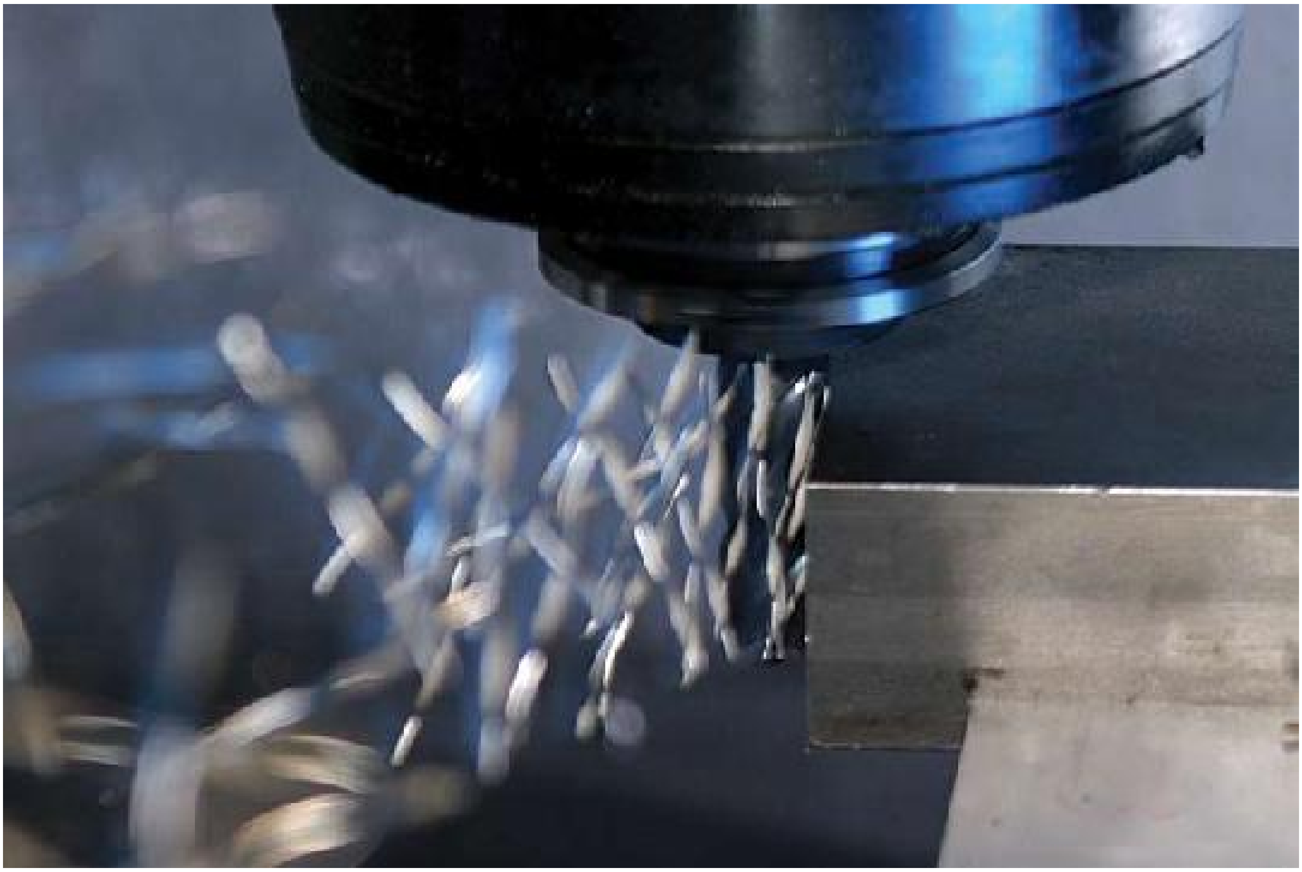
DECEMBER 2006 / VOLUME 58 / NUMBER 12

cover story

➤ BY CRAIG SEGERLIN, ISCAR METALS INC.



Bill Kennedy

Fast Lane

Milling expert says shops can boost productivity and tool life with high-speed milling.

Lean manufacturing initiatives and solid business practices demand that metalworking shops minimize waste. High-speed milling can help. By applying the principles of high-speed milling while avoiding traditional pitfalls—such as excess cutting forces—shops can increase productivity and reduce waste.

Old Habits

A classic waste-reduction strategy involves maximizing the utilization of expendable resources, such as tools. Long-accepted but inefficient tooling application practices are real opportunities to reduce waste.

For example, at each of more than 300 machine shops I visited over the last 5-plus years, I examined six worn endmills. My measurements revealed that more than 75 percent of the time shops used only half of the cutting edge length of their solid-carbide endmills.

As a result, shops utilize only 50 percent of their round tool investment. If you don't use it, you will lose it!

Shops typically use only a portion of their cutters' edges because when operating at traditional milling parameters, loading up the full axial DOC and radial WOC of the flutes can cause deflection that affects part accuracy and causes chatter. However, application of high-speed milling principles can reduce cutting forces and permit full utilization of a solid-carbide endmill's cutting edges.

The essence of high-speed milling is a significant reduction of radial WOC combined with increased chip load per tooth (three to five times greater), cutting speed (two to two-and-a-half times higher) and feed (five to seven times faster), leading to substantial productivity gains.

For example, when a 0.500"-dia. cutter is taking a 0.250" radial WOC, the cutter engagement is 50 percent and the arc of cut is 90°. Assuming the cutter is taking a 0.002" chip load per tooth (CLPT), the chip thickness at 50 percent cutter engagement is also 0.002".

If the radial WOC is reduced to 0.010" (1/25 of 0.250"), the arc of cut becomes 3.6° (1/25 of 90°). Cutter engagement is greatly reduced, and the thickness of the chip produced shrinks as well. Inadequate chip thickness can hasten heat buildup in the tool, accelerating tool wear. An adequately thick chip carries away heat, and producing a thick chip also assures a clean cutting action that minimizes rubbing and the heat it generates.

To maintain a chip thickness of 0.002" at a 0.010" radial WOC, the CLPT must be increased by three-and-a-half times, to 0.007". The formula for calculating chip load (CLPT × no. of teeth × rpm = feed rate [ipm]) in turn dictates a simultaneous increase in feed rate and cutting speed.

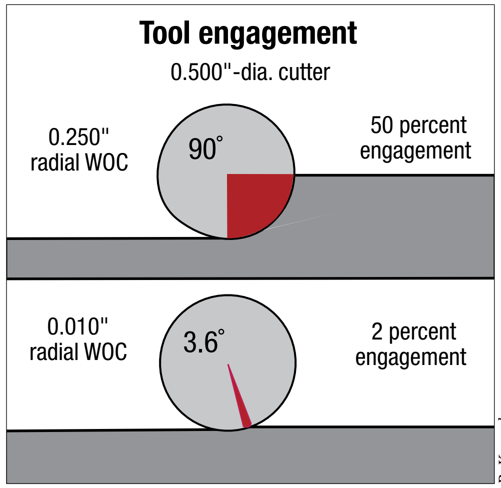
The combination of cutting parameters employed in high-speed milling provides many benefits. The small radial WOC results in a lighter cut that is smoother and produces less wear and tear on the machine tool's spindle bearings and ways. Heat, the enemy of cutting tool life, is reduced because the engagement time for the cutting edge is short; it spends a longer time in cooling air than it would when milling conventionally. In effect, the edge feeds into and out of the cut too quickly for heat to be absorbed.

High-speed milling also greatly reduces side loads on the cutter, permitting use of an endmill's entire cutting edge (its axial DOC). This is key to full utilization of the tool's cutting edges. The increased axial DOC directly boosts the volume of metal removed because the metal-removal rate is determined by the product of the radial WOC, axial DOC and feed rate (mrr = radial WOC × axial DOC × feed rate [ipm]).

Craig Simon, president of Walton Tool Inc., Albion, Ind., employs high-speed milling principles in his shop's mold manufacturing and repair operations. He said increased axial DOC is "an added advantage; it almost comes along for free." Simon said he runs ⅝"-dia. cutters 1½" deep in P-20 mold steel and "tooling deflection is so minimal that you don't have to compensate for it."

Walton Tool

Using high-speed milling methods and cutters with diameters as small as 0.60", Walton Tool Inc. completed this automotive fan mold in a total of 30 hours. The mold featured deep corners, ⅝"-high ribs and other details that otherwise would have required EDMing and electrode design and production that would have extended completion time to as much as 3 weeks.



B. Kennedy

High-speed milling techniques involve significant reduction of radial WOC, which decreases the percentage of cutter engagement and permits increased chip load per tooth, cutting speed and feed rate, producing substantial productivity gains.

With the ⅝"-dia. cutter, he said, "we have removed up to 45 in.^{3}/min. We're not talking about a 3" inserted cutter; when you think of a ⅝"-dia. cutter doing that, it is just phenomenal to me. At those metal-removal rates, we are doing fine cutting and leaving a 60µin. finish and 0.0004" flatness."

At Walton Tool, achieving the 45 in.^{3}/min. mrr in 4140 steel requires only 33 hp. The absence of heavy torque in the cuts reduces stress on the machine tool. "You don't ruin the finishing capability of your machine," said Simon. "We can move that much metal even though we've got the high-speed, low-torque head running on ceramic bearings. We can cut to a 0.0002" tolerance, no problem."

High-speed milling enables the shop to both rough and finish on its 24,000-rpm Parpas MAV 5-axis machining center, saving workhandling time and preventing tolerance buildup when moving from one machine to another.

Simon provided an example of an automotive fan mold the shop completed in 30 hours. The mold featured deep corners and ⅝"-high ribs that were machined with 0.060"-dia. cutters. Without the application of high-speed milling techniques, producing many of the mold's details would have required EDMing, according to Simon, and processing time would have been much longer. "If we had worked on the mold consistently and had to build some electrodes, it would have been a 3-week job," he said.

Simon pointed out that the method's high accuracy permitted cutting "to the numbers," and with a finish in the range of 10µin., the mold required no benchwork. "We go down to a 1/32"-dia. cutter and pick out the little radii," he said. "We typically run the very small cutters at 16,000 to 20,000 rpm, and feed them at 100 ipm."

Tens Machine

On this 4140 steel bell crank, aerospace shop Tens Machine cut roughing time from 80 minutes to 20 minutes by switching from an indexable endmill to a 5-flute solid-carbide mill.

According to Simon, adopting high-speed milling methods took a change of mind-set. "Believe me, it's a little bit scary putting in these cutters and letting them go. But after a while, you get comfortable with it," he said.

The combination of high-speed and 5-axis milling has eliminated EDMing in many cases and boosted the shop's competitiveness. "It has totally changed our business," Simon said. "They talk about overseas moldmakers and their cost advantages. We have competed with a number of low-cost suppliers on molds, and we're successful on about half of them." The new techniques and equipment, he feels, are "key to longevity in this business."

Jim Steele, the Fort Wayne, Ind.-based Iscar Metals Inc. applications representative who works with Simon, said, "There are places you can apply [high-speed milling] and places you can't. One factor is part geometry." He explained that conventional milling methods may be required in some situations to create the space needed to evacuate the high volume of chips produced by high-speed milling techniques. "There are certain times when you have to plow through the middle to get something opened up. You have to have room to get those chips out of there," he said.

However, when the path is clear, "and you've got that opening, watch out. It's amazing. When it comes down to cubic inches per minute, you start figuring this stuff out and it makes sense. We are shooting for 1 in.^{3}/ sec.

A snowstorm of chips

They know snow in upstate New York. So it's significant that Tony Panella and Chris Payment compared the results of their application of high-speed and trochoidal milling techniques to the output of a snowblower. Panella is president and Payment is vice president of Assured Quality Tool & Mold Inc., Spencerport, N.Y.

The example they cited was rough machining a 14"×26" mold base made of P-20 steel (28 to 32 HRC). They had milled similar jobs with a 4-tooth inserted endmill run at about 3,000 rpm (590 sfm), 60 ipm, 0.400" radial WOC and 0.150" axial DOC. The mrr was 3.6 in.^{3}/min., and machining the base took about 10 hours.

When they switched to high-speed trochoidal milling, machining time dropped to less than 2 hours. Payment programmed the trochoidal toolpath in CAM software. "You select a high-speed option of trochoidal, then you fill in the blanks—radial cut, step-over, speeds, feeds, etc.," he said. A ⅝"-dia. cutter, run at 6,000 rpm (982 sfm), 235 ipm, a radial WOC of 0.050" and a 1.328" axial DOC moved 17.63 in.^{3} of metal a minute, nearly five times the previous volume. "We filled a 55-gal. drum with chips," Payment said. "It was scary!"

Assured Quality applies high-speed milling methods on a number of jobs, but the aggressiveness depends on the machine and tools in use. In 2005, the shop acquired a Makino S56 VMC. "It's a high-speed machine, and it's got the rigidity and spindle strength to do all those things," Payment said. "We've got other machines that do the same things at reduced feeds and speeds."

Added Panella, "You can't do this without the right tool on the machine." For the mold base, the shop used a newly introduced 5-flute "CF" style endmill from Iscar. The tool's flutes are asymmetrically spaced to distribute the chip load and resist harmonic vibrations that can occur at high speeds and cause chatter. The endmills also feature Iscar's Altec coating, a predominately Al_2O_3 (alumina ceramic) composition.

Mike Polizzi of Iscar, who assisted with the tool's application, noted that the high-productivity machining methods consumed 90 percent of the VMC's 30 hp. In light of the blizzard of chips the endmill produced, Payment and Panella christened it the "snowblower" tool.

B. Kennedy

Mike Polizzi, Iscar sales and application engineer (left), discusses high-speed milling of a 14"×26" P-20 steel (28 to 32 HRC) mold base with Assured Quality Tool & Mold President Tony Panella (right) and Vice President Chris Payment.

Payment noted that, in addition to supplying machining thrills, high-speed machining techniques help the shop provide more value to its customers. For example, in the interest of speed, preproduction molds are often machined from aluminum. "These tools and techniques permit us to make preproduction molds out of P-20. We cut them out of the semihard material, nitride them later and the customer can get decent production life out of them. Steel is weldable, too, so it's easier to make changes and updates than with a mold made of aluminum," Payment said.

—B. Kennedy

mrr, not the typical 1 in.^{3}/min.," Steele said.

Obviously, removing material faster cuts cycle times. Aerospace manufacturer Tens Machine Co. Inc., Holbrook, N.Y., applied high-speed milling techniques when roughing a 4¼"×4¼"×7¼" bell crank made of 4140 steel and reduced cycle time per part from 80 minutes to 20 minutes. Previously, the shop machined the part with a 1¼"-dia., inserted endmill with three cutting edges, run at about 1,300 rpm, 21 ipm, a radial WOC of 0.625" and an axial DOC of 0.300" to 0.400". Switching to a 5-flute, ⅝"-dia., solid-carbide endmill, Tens Machine went to a 1.5" axial DOC and ran the tool at 6,000 rpm, 200 ipm and a 0.1" radial WOC.

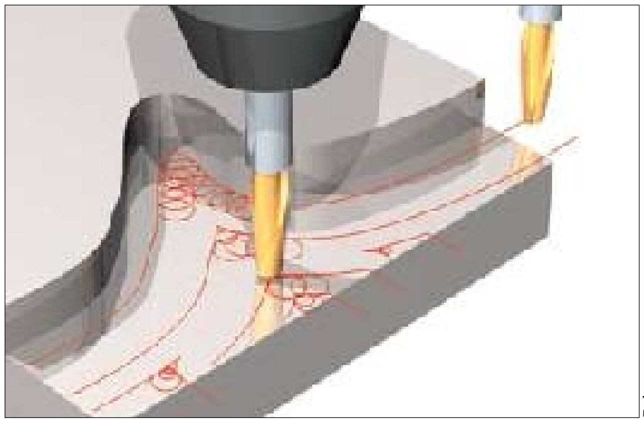
Co-owner and setup man Fabio Berlingieri said the workpiece weighs about 35 lbs. before roughing, and afterward "there are only about 11 lbs. left." Time savings over a production run of about 1,000 parts, he said, adds up to "a lot of hours."

Optimal application of high-speed milling and full utilization of a solid-carbide endmill's cutting edges require a new way of looking at cutter selection. The maximum required axial DOC determines what cutter diameter will be used.

As an example, shops seeking a 1.5" axial DOC would choose a 0.625"-dia. cutter, and apply 10 to 20 percent of the cutter's radial WOC. Similarly, when a 0.780" axial DOC is desired, a 0.312"-dia. cutter would be appropriate. To find the closest tool diameter, a rule of thumb is to divide the desired axial DOC by 2.5. For example, dividing a 1.25" axial DOC by 2.5 provides a cutter diameter of 0.500".

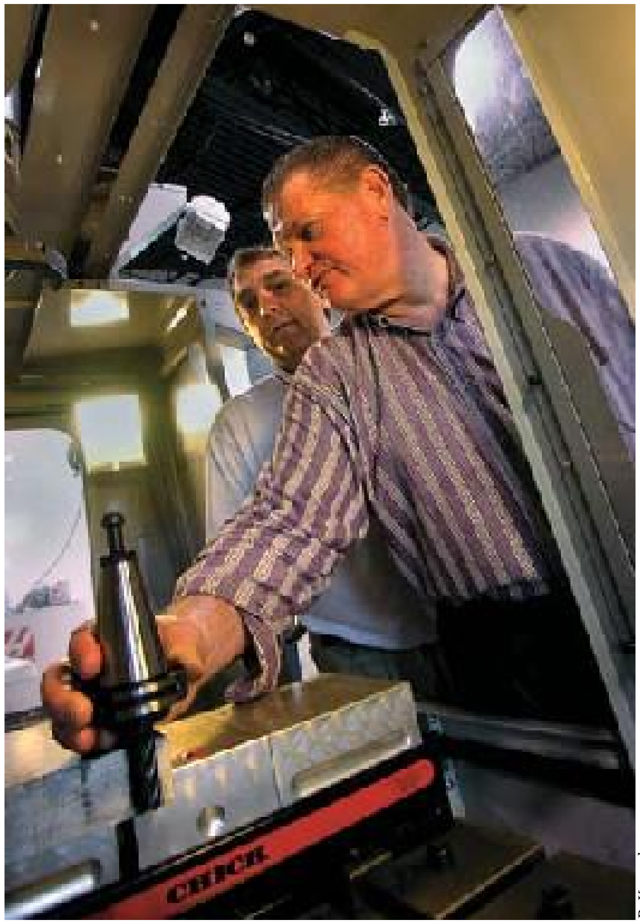
Trochoidal Toolpaths

A more specialized approach to high-speed milling involves the use of trochoidal toolpaths. Trochoidal milling, sometimes described as "nibbling," was first employed more than 20 years ago in hard-milling applications.



Delcam

The trochoidal milling technique involves moving the cutter in radius paths as it cuts, rather than in a straight line. The circular toolpath minimizes tool engagement, aiding in the cooling of the cutting edge, and makes side loads on the cutter lighter and more consistent.



B. Kennedy

Author Craig Segerlin (right) and Dominic DeCario, applications engineer at DSM Machinery's Haas Factory Outlet division in Warrendale, Pa., discuss setup for a high-speed milling demonstration on a Haas VF2 VMC.

Trochoidal milling involves cutting overlapping circles that are half on and half off the workpiece instead of cutting in a straight line. The constant looping motion used in trochoidal milling avoids over-embedding the cutting tool, keeps tool engagement at a constant level and thereby reduces side load on the cutter and permits higher feed rates.

While trochoidal methods were developed for milling materials hardened to 55 HRC and harder, they can also be beneficially applied when performing pocketing or slotting on softer materials, such as carbon, alloy, mold and tool steels, as well as 300- to 400-series stainless steels.

Rather than plowing into a slot with a heavy cutter engagement, using a smaller-diameter (and less expensive) tool in a trochoidal pattern will permit a higher mrr and put less stress on the tool and the machine. Similarly, when conventionally machining a pocket, the percentage of cutter engagement soars in corners, where the tool changes direction. Using a smaller cutter in the trochoidal mode keeps cutter engagement consistent.

A machine tool's CNC program directs the trochoidal toolpath. There are two basic approaches to trochoidal programming. One has the tool constantly making small circles throughout the cut, while the other applies the trochoidal pattern only when part geometry would result in a high percentage of tool engagement.

For deep roughing passes involving large step-overs, a constant trochoidal mode assures that the endmill's entire flute length can be applied without overloading the tool. On the other hand, shallower depths and step-overs can be handled with intermittent, situation-specific use of trochoidal movements, minimizing cycle time.

"The trochoidal action gets you into and out of the cut nice and smooth; the cutter is not jerking or stopping," said Walton Tool's Simon. However, the shop doesn't apply trochoidal cutting at all times. "If we are going around the perimeter of a block and not in a pocket or slot, we will just run it straight," he said.

According to Iscar's Steele: "A lot of guys will put a hole in the middle of a square pocket and start running the square. When they run into a corner, there's that momentary lag switching from the X- to the Y-axis, and there's a chance for the cutter to start chattering. Also, going into a corner like that wraps more material around the endmill." Trochoidal toolpaths maintain a constant load on the tool, which helps avoid these problems, he said.

Steele said he is somewhat reluctant to use the term "breakthrough," but feels "we are pretty close to redefining the way people ought to be machining. In our battle with offshore competition, we have to be smarter. Automation and techniques like this are going to help us win." △

About the Author

Craig Segerlin is national product manager for solid-carbide endmills and Multi-Master tools, Iscar Metals Inc., Arlington, Texas.

CTE Contributing Editor Bill Kennedy assisted in writing and editing this article.

The following companies contributed to this report:

Assured Quality Tool & Mold Inc.
(585) 349-9929
www.aqmold.com

Iscar Metals Inc.
(877) 294-7227
www.iscarmetals.com

Tens Machine Co. Inc.
(631) 981-3321
www.tensmachine.com

Walton Tool Inc.
(260) 636-2843
www.waltontoolinc.com