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Cutting Round in Circles

A demonstration application shows that trochoidal milling can cut narrow, wavy slots in hardened steel at up to 12 times the normal rates.

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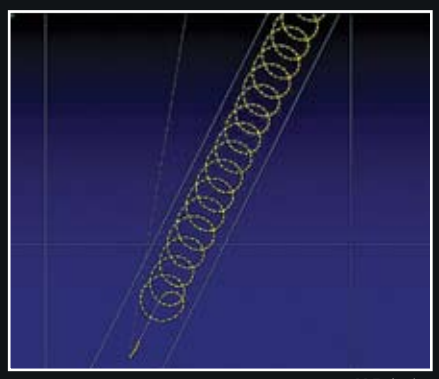

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Trochoidal milling is so named because a trochoid is the path traced by a point fixed on a circle that rolls along a line. When trochoidal milling, the cutter is programmed to move in a circular pattern with each circle advancing into the cut.

Cutting narrow pockets in hardened steel has long been one of the most difficult machining tasks. One problem is that a large proportion of the tool is continuously engaged with the workpiece, so cutting forces and heat are elevated. Another problem is that the chip load per tooth is uneven—high at the point where the cutter has advanced farthest into the workpiece and lower in other areas. A third problem is that, with the cutter filling most of the pocket's width, little room exists for chip evacuation, so the chance of recutting chips is high.

The challenge is even greater when the slots are relatively deep in relation to their width because this increases the difficulty of chip evacuation. And when the slots are curved rather than straight, chip evacuation becomes even more difficult. Machining a hardened steel workpiece adds to the challenge. These difficulties typically make it necessary to run at a low feed rate and DOC when machining slots to avoid premature cutting tool failure. Even at low feed rates, tool life tends to be short

CZS endmills from U.S. Union Tool are suitable for trochoidal milling steels hardened to 50 HRC.

when cutting slots.

A Potential Solution

Trochoidal, or spiral, milling provides a potential solution to this problem. The basic idea is to program the cutter to move in a circular pattern with each circle advancing into the cut. Trochoidal milling is so named because a trochoid is the path traced by a point fixed on a circle that rolls along a line. One key advantage of trochoidal milling is that only a small area of the cutting tool is engaged at one time. The feed rate is always constant. In addition, trochoidal milling makes it possible to apply an endmill with a diameter that is smaller than the pocket's width to allow room for chip evacuation.

Despite its potential, trochoidal milling also presents challenges. The cutter must undergo a complicated motion that is beyond the capabilities of conventional CNC software programming systems. In addition, the machine tool must be rigid and be fast enough to accommodate trochoidal cutting. The cutter likewise must be able to operate at high speeds and stand up to the material. Machine rigidity determines how aggressive the trochoidal cut can be. Other factors include the cutting tool's size, workpiece material and DOC.

Three Companies Collaborate

OKK USA Corp., a machine tool builder, U.S. Union Tool Inc., a cutting tool manufacturer, and DP Technology Corp., a developer of CNC software, teamed up to solve these problems. They started by designing a challenging part with wavy slots that are 12mm wide × 20mm deep. As previously noted, the slots' high depth and wavy pattern create major chip evacuation challenges. To add to the challenge, the workpiece is difficult-to-machine P-20 steel hardened to 35 HRC. "This part would be extremely difficult to cut using conventional milling methods," said Jonathan Hay, vice president-sales and marketing for U.S. Union Tool, Buena Park, Calif.

"The basic idea of trochoidal machining involves substantially increasing the cutting speeds and feed rates," said Richard Klein, applications manager, OKK, Glendale Heights, Ill. "We chose the OKK VM5III, a high-performance vertical machine that can be fitted with a pallet changer. It can deliver spindle speeds up to 20,000 rpm, depending on the spindle configuration."

The next step was to select the cutting tool. "We picked a CZS 10mm-dia., 4-flute, square-end tool, which is coated with a chrome-based UT coating," said Hay. The CZS endmills are for machining steels hardened up to 50 HRC and have a drilling geometry on their points so they can cut a slot or pocket without the need to drill a starter hole.

OKK

OKK's VM5III vertical machining center was selected to perform trochoidal milling for the demonstration.

DP Technology, Camarillo, Calif., provided its Esprit Mold CNC machining software, which provides 20 different 2½- to 5-axis milling strategies for creating optimized toolpaths. For example, the software's Z-plane concentric roughing functionality includes rounding of sharp angles and fluent step-over with chordal feed to avoid straight paths, allowing climb milling in all situations. When climb milling, the tool rotates in the same direction as the feed at the point of contact. Chips are cut to their maximum thickness at the initial engagement of the cutter's teeth with the workpiece and decrease in thickness at the end of engagement.

The toolpath is optimized based on the results of previous machine cycles, eliminating air cutting and minimizing retract movements. The software's rest roughing capabilities enable the remachining of previously cut areas of the model, producing a constant volume of remaining material.

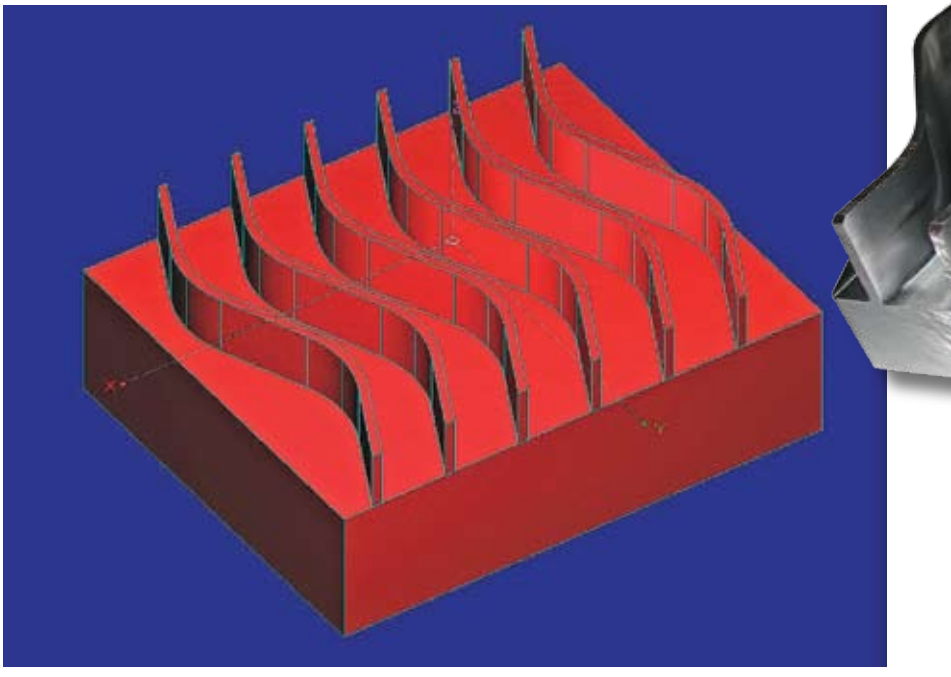
The Programming Challenge

Conventional CNC programming software typically cannot generate a program to perform trochoidal milling. Previously, the only way to perform trochoidal milling was for a programmer to manually code the complex tool motions involved. This is a challenging task, and the programmer can't visually check the program without running it on a machine. For this reason, trochoidal milling is seldom employed.

DP Technology recently added a special routine for trochoidal milling to Esprit Mold that reduces the amount of time required to produce a CNC program for that machining operation. It also gives the programmer access to the other capabilities of Esprit Mold, including the ability to graphically simulate machining. The user defines the solid model of the part to be cut, either by importing native CAD geometry from a CAD system or by using Esprit Mold's built-in geometrical editing tools. The user then selects "trochoidal milling" and is prompted to enter the advance per resolution and the circle's diameter. The software

then generates the program for machining the part.

"It only took 30 minutes to program the part," Klein said. "We entered a few parameters, and the software did all the work behind the scenes. We experimented with tools with different radii to improve the finished part's shape. We used the simulation and verification capabilities of Esprit Mold to render the complete cutting process with lifelike realism." The simulation is not limited to simple graphical effect, but provides the advanced detection of any unreachable position or collision of the machine's moving parts, the tool and its holder, and the part being produced. The spindle speed selected was 1,500 rpm and the feed rate was 15.1 ipm.



Productivity Improvement

"Trochoidal milling substantially improved productivity of slot milling operations," Hay added. "Normal practice when machining a slot is to feed at a rate of about 20 percent of the rate used in normal side milling. Using trochoidal milling, we were able to increase the feed rate to about 80 percent of the normal side milling feed. Also, it's typical in slot milling operations to cut at a depth of 2mm or 3mm, which would have required at least six passes to cut the part. In this case, we were able to cut at a depth of 10mm, which meant that only two passes were required." By employing trochoidal milling, the part was cut in 37 minutes and 42 seconds—about 12 times faster than usual.

"This application demonstrates clearly

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A solid model of the demonstration part, which has wavy 12mm-wide x 20mm-deep slots, and the finished part made of hardened P-20 steel.

how trochoidal milling reduces the stress and heat involved in cutting," Klein said. "Despite that fact that we used much higher speeds and feeds than in normal slot milling, the wear on the cutting tool was very light. After cutting several sample blocks, the cutter had little or no signs of cutting edge wear, and the tool and holder stayed cool to the touch. This is because trochoidal milling keeps the cutting tool load very consistent and provides for easy chip evacuation." In comparison, he noted that conventional slot cutting created higher tool temperatures and reduced tool life by 50 percent or more. Because only one side of the endmill is in contact with the workpiece at any time, cutting load and heat are reduced by as much as 90 percent because only 5 percent of the cutter is engaged with the workpiece material compared to 50 percent when conventional slotting. Usually, it's difficult to keep a tool cool when milling slots even when using coolant because it is difficult to keep the coolant directed at the tool/workpiece interface throughout the entire cut. At times, the coolant is not reaching the tool's cutting edge, causing the tool to heat up. When coolant contacts the cutting edge again, it causes it to break down quickly because of the rapid temperature change. But, in this application, only air was required to cool the tool/workpiece interface.

During the demonstration, six parts were produced with a single tool without any noticeable tool wear. "This demonstration indicates the advantages of trochoidal milling and its potential to improve productivity of slot milling operations," Klein said. **CTE**

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