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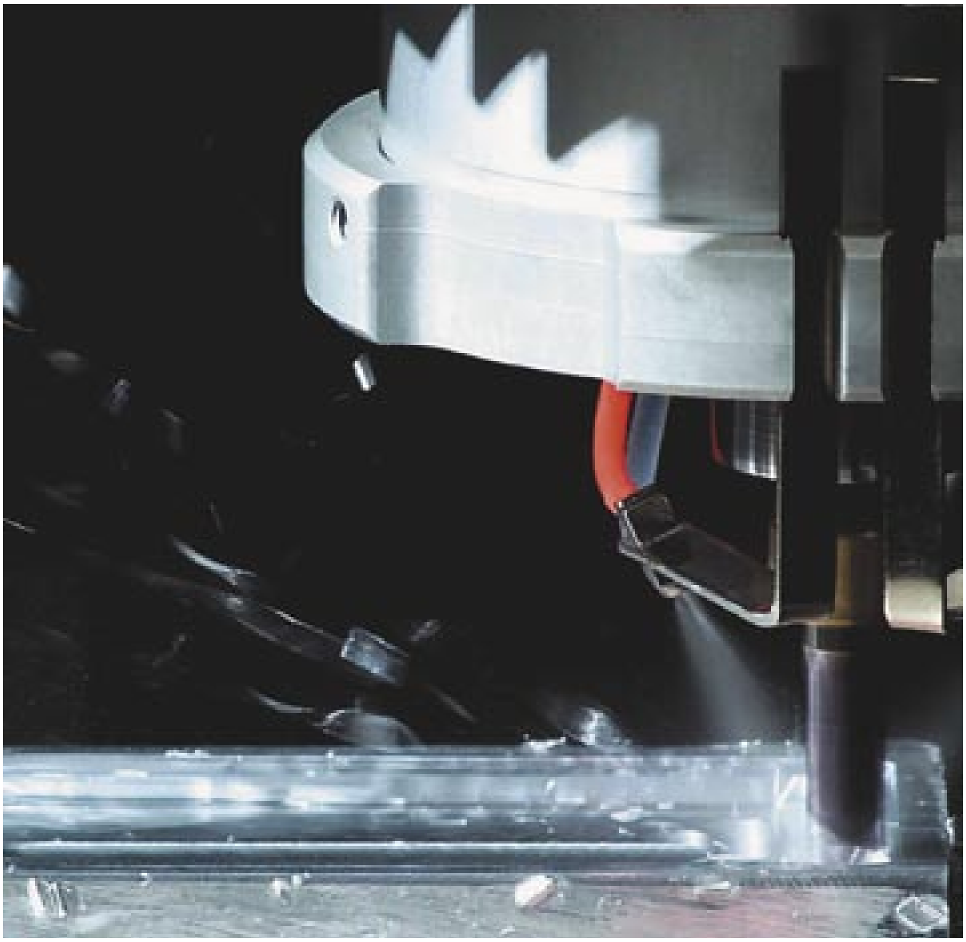
cover story

➤ BY ALAN RICHTER, EDITOR

Tool Geometries for a Shrinking World

Cutting tool geometry considerations when micromachining.


Datron Dynamics

A machine built for the sole purpose of high-speed machining with microtools delivers the efficiency and quality needed to manufacture most intricate, small parts.

"I keep saying that miniaturization is a growth industry. Somebody said that's an oxymoron, but it's true," said Thomas P. McDunn, director of advanced manufacturing for EIGERlab, the center for advanced manufacturing and commercialization of micromachining technology located in Rockford, Ill. "If you look around, everything is shrinking."

Micromachining can performed using a variety of manufacturing technologies, including EDMing and laser cutting. With chip-producing operations, such as drilling and endmilling, the microtools applied cut the tiny parts within about a 1-cu.-in. work zone. However, where the realm of macrotools stops and microtools starts is open to debate.

"We distinguish any tool ¼" in diameter and under as microtooling," said Walter Schnecker, president of the machining division for Datron Dynamics Inc., Milford, N.H.

Joshua Milbourn, applications engineer for Cameron Micro Drill Presses, Sonora, Calif., noted that many people do consider tools smaller than ¼" in diameter to be micro, but for him that's too large. "When talking about microtooling, I'm not talking about a ¼" drill," he said. "In my mind, micro is below ⅛"."

For others, that's still not "micro" enough. "I consider any tool 1⁄64" and under as when you really start getting into micromachining," said Mike Tibbet, senior development engineer for Kyocera Micro Tools, an Irvine, Calif.-based maker of tools from 0.0015" to 0.250" in diameter.

Of course, as the tools become smaller, they start encroaching into the world of nanomachining. Performance Micro Tool, Janesville, Wis., which supplies cutters to EIGERlab, offers endmills from its Nano Tools line with diameters as small as 0.0002", or about 5 microns.

"Nanomachining would start [with tools] at 0.0010"," Schnecker said. "That's where we draw line."

Geometry at Work

When it comes to geometric features, microtools aren't just shrunken versions of macrotools. “It’s not that you can take a ½" endmill and simply scale it down and build it at 10-thousandths,” Tibbet said.

Microtools need to be engineered to provide effective chip evacuation, especially when holemaking, while still being sturdy enough to withstand the cutting forces generated and not break. One altered feature is a drill’s web, the center portion of the tool that extends axially along the flute. “The web is thicker proportionally because there has to be some core to microtools,” Milbourn said. “On smaller tools, you can’t have a 0.0001" web; it’s just not going to work.”

To reduce stress on a microdrill and prevent it from binding up in the hole, back taper plays a major role. (Back taper is a slight decrease in diameter from the drill point to the shank.) The back taper on a microtool generally totals 0.0002" to 0.0005", because the flutes are often less than 1" in length. Ordinarily for a macrotool, back taper is 0.0005" to 0.001" per inch.

Another geometric consideration for microtools is edge sharpness, which becomes relative as the tool diameter gets smaller and can be a limitation to effective micromachining. What’s considered dead sharp for a macrotool, say, a 10µm cutting edge radius, isn’t for a microtool.

“If you have a 10-micron cutting edge radius for a microtool that’s taking a 2-micron chip load, it’s not [just] considered dull, it’s considered a highly negative rake,” said Kanwar J. Singh, Ingersoll Machine Tools Inc.’s principal investigator for the National Institute of Standards and Technology’s Advanced Technology Program. The Rockford, Ill., machine tool builder is an investing partner in EIGERlab and the individual recipient of funding from NIST for micromachining research conducted at EIGERlab.

Depending on its size, a microtool might only cut properly when uncoated. According to Milbourn, a coating’s benefit would be marginal, or even detrimental, for drills smaller than 0.020" in diameter. “Then, a coating is going to inhibit the ability of the drill, because it’s taking up too much flute space,” he said. “You fill up the flutes and then you just have a solid


Microtools are available in a variety of styles for milling and drilling.

Kyocera Micro Tools

piece of shank that you’re trying to drill with.”

Others take a different view of the impact of coatings, regarding them as extending microtool life, not causing loss of edge sharpness. “There’s a misconception that when you add a coating you lose that upsharp edge and get a rounded curve,” said Nika Alex, product specialist for the drilling line at Mitsubishi Materials USA Corp., Irvine, Calif. “When you use a PVD coating and reduce the width of the edge preparation, you can maintain sharpness.”

In other words, a heavy edge preparation provides a less-sharp edge, but one that is better able to withstand cutting forces. A light edge preparation offers a sharper edge, which allows freer cutting when drilling softer, gummier materials, but one that is more susceptible to chipping.


Alion Science

As power transmission systems become smaller, the mechanisms that power them and transfer that power into another form shrink in size, such as this propeller and gear produced using micromachining techniques.

Chips Away

Although there is no formula that can determine that X number of flutes is appropriate for a tool with a diameter of Y or less, the fewer the number of flutes, the greater the possible chip load and the more space available to evacuate the chip.

When micromachining, a high spindle speed is required—for example, upwards of 80,000 rpm for a 0.007" tool—to prevent the creation of too much cutting pressure, which can lead to tool breakage.

“We run into a lot of people trying to drill a 0.005"-dia. hole with a 5,000-rpm spindle and they can’t figure out why they are breaking drills,” said Kyocera’s Tibbet. If transferred to the macromachining world, that would be similar to drilling a 1"-dia. hole at an incredibly slow spindle speed. And feed rates can be off quite a bit when creating larger holes, but a large window doesn’t exist when micromachining in order to avoid breaking or dulling the tool.

End users sometimes try to overcome their machines’ low spindle speed by applying a tool with three or more flutes. That is OK for achieving the desired feed rate, “but it doesn’t provide you with adequate chip room to remove the chips while machining,” Datron Dynamic’s Schnecker said.

He added that by increasing the spindle speed, single-flute tools produce a greater chip load. “Our single-flute endmills create a huge chip load that allows us to really fling the chip out of the channel,” Schnecker said. “The chip is the enemy of such small tools.” He added while single-flute tools are the most efficient in terms of chip evacuation, they sometimes cut a little rough compared to multiple-flute tools.

When drilling, coolant can be effective for evacuating chips, but coolant works best when it’s able to reach down to the bottom of the hole to flush chips out. To promote this, at least a couple toolmakers offer through-coolant microdrills. One is Mitsubishi Materials, which makes them in metric sizes from 1mm to 3mm and inch sizes from 0.0394" to 0.1200". Currently, the microdrills are able to drill holes up to 5 diameters deep, and, Alex noted, the company plans to introduce drills that go 10 diameters deep within a few months. For deep-hole drilling, “we have a wavy cutting edge design and special flute geometry to promote smooth chip evacuation,” he said.

However, a through-coolant microdrill should be used in conjunction with a pilot drill. Alex recommends creating a starter hole 1 diameter to 3 diameters deep with a pilot drill to help with hole location and prevent breakage of the main drill. Ideally, if hole tolerance permits, the pilot drill should be slightly larger than the through-coolant drill. For example, the pilot drill should be 1.1mm when followed by a 1mm drill.

“That way, you reduce the premature wear on the outer margin of the drill,” Alex said.

In addition, if a through-coolant drill has a 140° included angle on its point, the pilot drill needs to have an included angle of 140° or greater. Using a pilot drill with a smaller angle might cause the main drill to hit one of its corners upon entry, diminishing tool life, hole-location accuracy and diametrical stability.

Another manufacturer of through-coolant microdrills is Mikron Corp. Monroe (Conn.). The diameter range is from 0.0394" to 0.1575", in increments of 0.00197", and the long version is able to drill holes up to 15 diameters deep with minimal pecking. Mikron also makes a line of drills for centering and pilot drilling in one step.

Mikron recommends using a cutting oil as a lubricant for best results, and, as alternatives, water-based coolant with extreme-pressure additives or minimum-quantity lubrication. “In our R&D lab, we use oil with a viscosity that allows us to do anything we want with a 2-micron filter before the pump and a few thousand psi,” said Robert Couture, manager of technical sales for Mikron. “A lot of people don’t have that, so they use coolant.”

Under Pressure

Although Mitsubishi Materials states that the coolant filter used must be able to capture particles smaller than 5µm to prevent blockage of coolant-through passages, Couture doesn’t view plugging of passages with coolant debris as the primary concern. “We’re not afraid we’re going to clog the hole with sludge,” he said, “but if one of the chips doesn’t get flushed out and gets stuck in one of those two little holes, that’s what we worry about. So pressure is important.”

He added that the smaller the drill, the more critical the pressure is. However, Mikron doesn’t recommend a minimum coolant pressure. “I’ve been successful with a 1.5mm drill going 15 diameters deep in tool steels and mold steels with just 350 psi, but that was with water-soluble coolant, not oil,” Couture said. “There is a big difference in their viscosities, so unless I had an oil with real-good viscosity, that might

Small machines for small-parts production

When micromachining workpieces within a 1-cu.-in. work zone, the level of accuracy required increases proportionally compared to macromachining.

“If a 1-cu.-meter machine can hold a tolerance of 0.0001", then a machine that is, say, 1/100th smaller, should be able to hold 0.000001",” said Kanwar J. Singh, principal investigator for NIST ATP at Ingersoll Machine Tools.


Alion Science

A 5-axis milling machine used for application research at EIGERlab that’s capable of producing miniature parts with complicated features, such as contours and undercuts.

He added that if you need to make small parts, you need small machine tools. “It’s not that you can’t [micromachine] on larger machines, but you will not achieve the required accuracy.”

But a machine for micromachining isn’t simply a scaled-down version of a larger machine. Some components need to be eliminated, such as collet chucks, so that tool runout is kept to an absolute minimum.

Although micromachining centers are commercially available, EIGERlab built its own 5-axis milling machine, duplicating a design developed by the University of Illinois at Urbana-Champaign. “They designed it as a test bed and we’re doing application research with it,” said Drew Witte, research engineer for Alion Science and Technoloy, Rockford, Ill. (Alion is an EIGERlab partner.)

He noted that the machine has a 160,000-rpm pneumatic spindle, a 30mm x 30mm x 30mm work zone, a microscope to monitor and inspect tool condition, and an encoder resolution, or positioning accuracy of the linear stages, of 20 nanometers. The workpiece is positioned on an X- and Y-axis table and a rotary table, and the spindle is on a B-axis stage. “Both the workpiece and tool move in and out,” Witte said.

The micromachining research center is looking to add a laser-based tool-monitoring system. “Eventually, the goal is to commercialize a machine like this,” Witte said.

—A. Richter

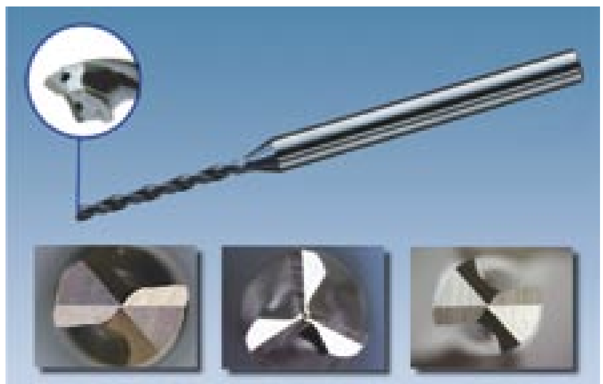
not have turned out so well."

Even on low-pressure machines, Mikron says its internal-cooling system provides optimal cooling and lubrication at the cutting edge. This is aided by the shank's Powerchamber for through-coolant drills up to 0.0984" in diameter. According to company literature, the Powerchamber guarantees a sufficiently large flow of coolant even at low pressure by ensuring that there is always some coolant in the chamber, which is behind the coolant passage.

Mitsubishi Materials, on the other hand, recommends a minimum pressure, which needs to be delivered from a positive-displacement-type coolant pump. "You have to have a minimum of 600 psi of coolant to evacuate the chips," Alex said. "If you can deliver more than 600 psi, that would be to your benefit."

This gripper part demonstrated how EIGERlab's tabletop microfactory is capable of machining, inspecting, assembling and welding.

As an alternative to through-the-tool cutting oil and water-based coolant, Datron Dynamics' Schnecker suggests ethanol. Ethanol is a form of alcohol that occurs naturally in the sugar fermentation process and exhibits a lower-than-water viscosity, which enables it to penetrate the tool/workpiece interface better than other coolants. The ethanol is delivered via a spray-mist system, and ethanol's low evaporation point makes it an efficient cooling and lubricating agent for machining at speeds up to 60,000 rpm or higher. "Flood coolant sometimes instills transfer energy, warmth and heat into the part and causes thermal growth of the part," Schnecker said. "We never have that problem with ethanol, because the part comes off the machine ice cold."



Drill point geometries, from left to right, for Mikron's CrazyDrill Steel, CrazyDrill Alu and PilotDrill. The through-coolant CrazyDrill Cool drill (top) is able to drill up to 15 diameters deep.

Because ethanol simply evaporates, the costs associated with disposal are eliminated. Also, ethanol does not leave any residue on parts, thus eliminating any secondary degreasing operations.

However, ethanol should only be used when machining nonferrous materials. "The reason why we don't recommend ethanol for ferrous materials is that steel-based materials have a tendency to spark," Schnecker said. "Flood coolant extinguishes those sparks while the ethanol would create a very volatile scenario."

However, like the macro world, applying a metalworking fluid isn't always needed when micromachining. EIGERlab micromachines dry "because we don't like the mess factor," McDunn said. Although coolant can aid chip evacuation, eliminating it may not be detrimental in connection with removing heat from the tool/workpiece interface. McDunn noted that the tool tip is exposed to a certain amount of heat, but the heat dissipates quickly. "The mass of the machine is such that the thermal effects we run into in the macro world sort of get scaled out in the micro world."

Regardless of their differences, all those interviewed for this article agree that micromachining is becoming more common. Nonetheless, it is a niche, but one that can complement the macromachining—and even nanomachining—worlds.

"The future is going to be about flexibility and the ability to integrate with changes in the manufacturing industry that are happening right now," Schnecker said. △

The following companies contributed to this report:

Alion Science and Technology
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Cameron Micro Drill Presses
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Datron Dynamics Inc.
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EIGERlab
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Ingersoll Machine Tools Inc.
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Kyocera Micro Tools
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