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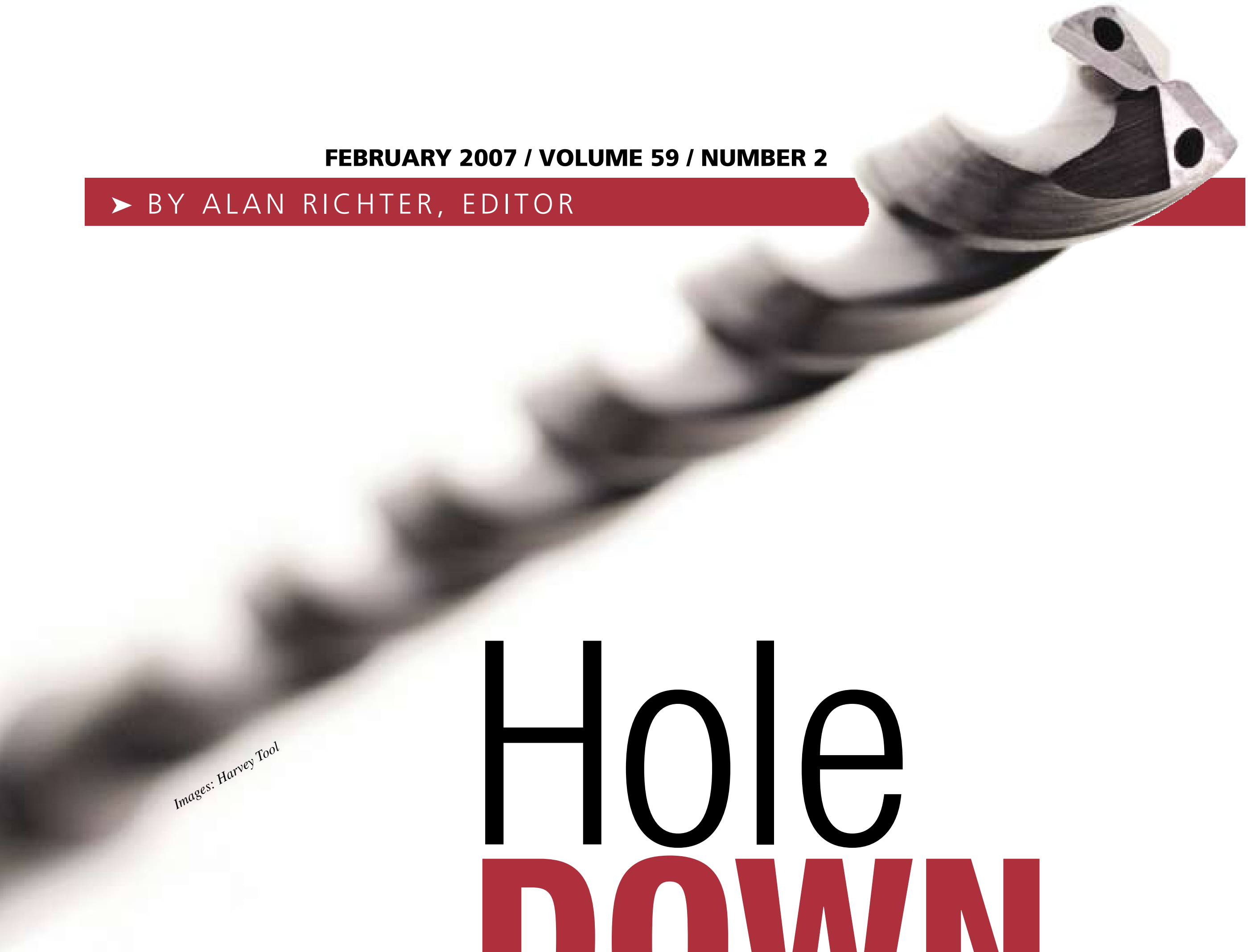
➤ BY ALAN RICHTER, EDITOR



Images: Harvey Tool

Hole DOWN

Options for and considerations when micro-holemaking.

Through-coolant capability is especially helpful when deep-hole microdrilling because the tools are delicate and prone to fail when experiencing recutting of chips, chip packing and too much exposure to carbide's worst enemy—heat.

As in the macroscale-machining world, holemaking is one of the most—if not the most—frequently performed operations for micromachining. Many options exist for how those holes are created. Each has its advantages and limitations, depending on the required hole diameter and depth, workpiece material and equipment requirements. This article covers holemaking with through-coolant drills and those without coolant holes, plunge milling, microdrilling using sinker EDMs and laser drilling.

Helpful Holes

Getting coolant to the drill tip while the tool is cutting helps reduce the amount of heat at the tool/workpiece interface and evacuate chips regardless of hole diameter. But through-coolant capability is especially helpful when deep-hole microdrilling because the tools are delicate and prone to failure when experiencing recutting of chips, chip packing and too much exposure to carbide's worst enemy—heat.

When applying flood coolant, the drill itself blocks access to the cutting action. "Somewhere about 3 to 5 diameters deep, the coolant has trouble getting down to the tip," said Jeff Davis, vice president of engineering for Harvey Tool Co., Rowley, Mass. "It becomes wise to use a coolant-fed drill at that point."

In addition, flood coolant can cause more harm than good when microholemaking. "The pressure from the flood coolant can sometimes snap fragile drills as they enter the part," Davis said.

The toolmaker offers a line of through-coolant drills with diameters from 0.039" to 0.125" that are able to produce holes up to 12 diameters deep, as well as microdrills without coolant holes from 0.002" to 0.020".

Having through-coolant capacity isn't enough, though. Coolant needs to flow at a rate that enables it to clear the chips out of the hole. Davis recommends, at a minimum, 600 to 800 psi of coolant pressure. "It works much better if you have higher pressure than that," he added.

To prevent those tiny coolant holes from becoming clogged with debris, Davis also recommends a 5µm or finer coolant filter.

Another recommendation is to machine a pilot, or guide, hole to prevent the tool from wandering on top of the workpiece and aid in producing a straight hole. When applying a pilot drill, it's important to select one with an included angle on its point that's equal to or larger than the included angle on the through-coolant drill that follows. The pilot drill's diameter should also be slightly larger. For example, if the pilot drill has a 120° included angle and a smaller diameter than a through-coolant drill with a 140° included angle, "then you're catching the coolant-fed drill's corners and knocking those corners off," Davis said, which damages the drill.

Although not mandatory, pecking is a good practice when microdrilling deep holes. Davis suggests a pecking cycle that is 30 to 50 percent of the diameter per peck depth, depending on the workpiece material. This clears the chips, preventing them from packing in the flute valleys.

Lubricious Chill

To further aid chip evacuation, Davis recommends applying an oil-based metalworking fluid instead of a water-based coolant because oil provides greater lubricity. But if a shop prefers using coolant, the fluid should include EP (extreme pressure) additives to increase lubricity and minimize foaming. "If you've got a lot of foam," Davis noted, "the chips aren't being pulled out the way they are supposed to be."

He added that another way to enhance a tool's slipperiness while extending its life is with a coating, such as titanium aluminum nitride. TiAlN has a high hardness and is an effective coating for reducing heat's impact when drilling difficult-to-machine materials, like stainless steel.

David Burton, general manager of Performance Micro Tool, Janesville, Wis., disagrees with the idea of coating microtools on the smaller end of the spectrum. "Coatings on tools below 0.020" typically have a negative effect on every machining aspect, from the quality of the initial cut to tool life," he said. That's because coatings are not thin enough and negatively alter the rake and relief angles when applied to tiny tools.

However, work continues on the development of thinner coatings, and Burton indicated that Performance Micro Tool, which produces microendmills and microrouters and resells microdrills, is working on a project with others to create a submicron-thickness coating. "We're probably 6 months to 1 year from testing it in the market," Burton said.

The microdrills Performance offers are basically circuit-board drills, which are also effective for cutting metal. All the tools are without through-coolant capability. "I had a customer drill a 0.004"-dia. hole in stainless steel, and he was amazed he could do it with a circuit-board drill," Burton noted, adding that pecking and running at a high spindle speed increase the drill's effectiveness.

The requirements for how fast microtools should rotate depend on the type of CNC machines a shop uses and the tool diameter, with higher speeds needed as the diameter decreases. (Note: The equation for cutting speed is sfm = tool diameter × 0.26 × spindle speed.)

Although relatively low, 5,000 rpm has been used successfully by Burton's customers. "We recommend that our customers find the highest rpm at the lowest possible vibration—the sweet spot," he said.

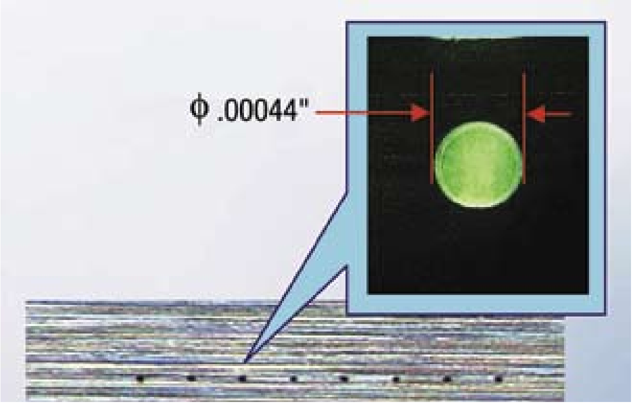
In addition to minimizing vibration, a constant and adequate chip load is required to penetrate the workpiece while exerting low cutting forces and to allow the rake to remove the appropriate amount of material. If the drill takes too light of a chip load, the rake face wears quickly, becoming negative, and tool life suffers. This approach is often tempting when drilling with delicate tools.

"If the customer decides he wants to baby the tool, he takes a lighter chip load," Burton said, "and, typically, the cutting edge wears much quicker and creates a radius where the land of that radius is wider than the chip being cut. He ends up using it as a grinding tool, trying to bump material away." For tools larger than 0.001", Burton considers a chip load under 0.0001" to be "babying." If the drill doesn't snap, premature wear can result in abysmal tool life.

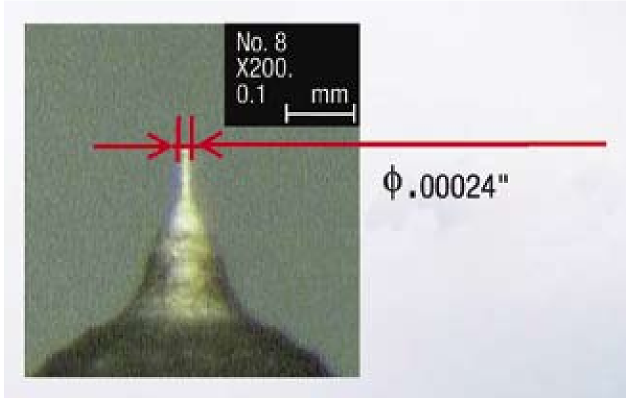
Too much runout can also be destructive, but how much is debatable. Burton pointed out that Performance purposely designed a machine to have 0.0003" TIR to conduct in-house, worst-case milling scenarios, adding that the company is still able to mill a 0.004"-wide slot "day in and day out."

He added: "You would think with 0.0003" runout and a chip load a third that, say, 0.0001" to 0.00015", the tool would break immediately because one flute would be taking the entire load and then the back end of the flute would be rubbing. The reason we decided it is actually working is because as the tool feeds along the mill path, the feed pressure against the material acts like a steady rest. It actually centers the tool for you."

When drilling, he indicated that up to 0.0003" TIR should be acceptable because once the drill is inside the hole, the cutting edges on the end of the drill continue cutting while the noncutting lands on the OD guide the tool in the same direction. Minimizing runout becomes more critical as the



Using its Edge2 sinker EDM with fine-hole option, Makino produced eight 0.00044"-dia. (11µm) holes in a tungsten-carbide workpiece. EDMing consumed 2 minutes and 40 seconds, and hole size and location repeatability was within 0.002mm.



Makino applied a 0.00024"-dia. silver-tungsten rod to produce the 0.00044"-dia. holes, achieving a ±0.00005" diameter tolerance, 0.004" positioning pitch between holes and ±0.00005" positioning pitch location accuracy.

Images: Makino

depth-to-diameter ratio increases. This is because the flutes are not able to absorb as much deflection as they become more engaged in the workpiece. Ultimately, too much runout causes the tool shank to orbit around the tool's center while the tool tip is held steady, creating a stress point where the tool will eventually break.

Taking a Plunge

Although standard microdrills aren't generally available below 0.002", microendmills that can be used to "plunge" a hole are. "When people want to drill smaller than that, they use our endmills and are pretty successful," Burton said. However, the holes can't be very deep because the tools don't have long aspect, or depth-to-diameter, ratios. Therefore, a 0.001"-dia. endmill might be able to only make a hole up to 0.020" deep whereas a drill of the same size can go deeper because it's designed to place the load on its tip when drilling. This transfers the pressure into the shank, which absorbs it.

Performance offers endmills as small as 5 microns (0.0002") but isn't keen on increasing that line's sales. "When people try to buy them, I very seriously try to talk them out of it because we don't like making them," Burton said.

Part of the problem with tools that small is the carbide grains not only need to be submicron in size but the size also needs to be consistent, in part because such a tool is comprised of fewer grains. "The 5-micron endmill probably has 10 grains holding the core together," Burton noted.

He added that he has seen carbide powder containing 0.2-micron grains, which is about half the size of what's commercially available, but it also contained grains measuring 0.5 and 0.6 microns. "It just doesn't help to have small grains if they're not uniform."

Microvaporization

Electrical discharge machining using a sinker EDM is another micro-hole-making option. Unlike hole poppers, which create small holes for threading wire through the workpiece when wire EDMing, EDMs for producing microholes are considerably more sophisticated, accurate and, of course, expensive.

The requirements for how fast microtools should rotate depend on the type of CNC machines a shop uses and the tool diameter, with higher speeds needed as the diameter decreases.

For producing deep microholes, a tube is applied as the electrode. For EDMing smaller but shallower holes, a solid electrode wire, or rod, is needed. "We try to use tubes as much as possible," said Jeff Kiszonas, EDM product manager for Makino Inc., Auburn Hills, Mich. "But at some point, nobody can make a tube below a certain diameter." He added that some suppliers offer tubes down to 0.003" in diameter for making holes as small as 0.0038". The tube's flushing hole enables creating a hole with a high depth-to-diameter ratio and helps to evacuate debris from the bottom of the hole during machining.

One such sinker EDM for producing holes as small as 0.00044" (11µm) is Makino's Edge2 sinker EDM with fine-hole option. In Japan, the machine tool builder recently produced eight such holes in 2 minutes and 40 seconds through 0.0010"-thick tungsten carbide at the hole locations. The electrode was a silver-tungsten rod 0.00020" smaller than the hole being produced, to account for spark activity in the gap.

When producing holes of that size, the rod, while rotating, is dressed with a charged EDM wire. The fine-hole option includes a W-axis attachment, which holds a die that guides the electrode, as well as a middle guide that prevents the electrode from bending or wobbling as it spins. With the option, the machine is appropriate for drilling hole diameters less than 0.005".

"Even with the attachment on, you can still do standard EDM plunge burns using the Z-axis," Kiszonas explained, adding that the W-axis and middle guide can be removed if needed.

Another sinker EDM for micro-hole-making is the Mitsubishi VA10 with a fine-hole jig attachment to chuck and guide the fine wire applied to erode the material. "It's a standard EDM, but with that attachment fixed to the machine, we can do microhole drilling," said Dennis Powderly, sinker EDM product manager for MC Machinery Systems Inc., Wood Dale, Ill.

He added that the EDM is also able to create holes down to 0.0004" using a wire that rotates at up to 2,000 rpm. The dressed wire protrudes about 0.100" to 0.200". "You might be able to go—on a good day—20 to 30 times the diameter," Powderly said.

Turn to Tungsten

EDMing is typically a slow process, and that holds true when it is used for microdrilling. "It's very slow, and the finer the details, the slower it is," said Dean Jorgensen, president and owner of Optimation Inc. The Midvale, Utah, company builds Profile 24 Piezo EDMs for micromachining and also performs microEDMing on a contract-machining basis.

Optimation produces tungsten electrodes using a reverse-polarity process and machines and ring-laps them to as small as 10µm in diameter with 0.000020" roundness. Applying a 10µm-dia. electrode produces a hole about 10.5µm to 11µm in diameter, and blind-holes are possible with the company's EDM. The workpiece thickness for the smallest holes is up to 0.002", and the thickness can be up to 0.04" for 50µm holes.

After working with lasers and then with a former EDM builder to find a better way to produce precise microholes, Jorgensen decided the best approach was DIY. "We literally started with a clean sheet of paper and did all the electronics, all the software and the whole machine from scratch," he said. Including the software, the machine costs in the neighborhood of $180,000 to $200,000.

Much of the company's contract work, which is provided at a shop rate of $100 per hour, involves microEDMing exotic metals, such as gold and platinum for X-ray apertures, stainless steel for optical applications and tantalum and tungsten for the electron-beam industry. Jorgensen said the process is also appropriate for EDMing partially electrically conductive materials, such as PCD.

"The customer normally doesn't care too much about the cost," he said.

The following companies contributed to this report:

The Ex One Co.
(724) 863-9663
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Harvey Tool Co.
(978) 948-8555
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Makino Inc.
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MC Machinery Systems Inc.
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Optimation Inc.
(801) 352-7779
www.edmmicromachining.com

Performance Micro Tool
(608) 755-0059
www.pmtnow.com

Machining parameters for through-coolant microdrills

Material	Steel series	Cutting speed (sfm)	Chip load per revolution (ipr based on cutter diameter in inches)				
			0.039-0.059	0.059-0.078	0.078-0.098	0.098-0.118	0.118-0.138
Carbon steel							
0 to 31 HRC	10XX, 11XX, 12XX	98 to 197	0.0024	0.0028	0.0031	0.0039	0.0047
31 to 41 HRC	13XX, 14XX, 15XX	66 to 164	0.0016	0.0020	0.0024	0.0033	0.0043
41 to 48 HRC	23XX, 41XX, 86XX	33 to 98	0.0012	0.0016	0.0020	0.0028	0.0035
Tool steel							
Nonalloyed	W1	66 to 164	0.0020	0.0022	0.0024	0.0030	0.0035
Low alloyed	L, O, W2, W5	66 to 131	0.0016	0.0018	0.0020	0.0026	0.0031
High alloyed	A, D, M, T, H, S	98 to 164	0.0012	0.0014	0.0016	0.0022	0.0028
Mold	P	66 to 131	0.0008	0.0010	0.0010	0.0014	
Stainless steel							
Ferritic and martensitic 400	66 to 131	0.0020	0.0022	0.0024	0.0030	0.0035	
Austenitic (sulfurized) 200S, 300S	49 to 115	0.0016	0.0018	0.0020	0.0026	0.0031	
Austenitic	200, 300	33 to 98	0.0012	0.0012	0.0012	0.0020	0.0028
Precipitation	15-5, 17-4	16 to 66	0.0004	0.0005	0.0006	0.0008	

Source: Harvey Tool

"We've done parts where there's $20,000 [in time and material] involved, and you can put the whole job underneath a fingernail. We do everything under a microscope."

Light Cutting

Besides carbide and tungsten, light is an appropriate "tool material" for micro-holemaking. Although most laser drilling is performed in the infrared spectrum, the SuperPulse technology from The Ex One Co., Irwin, Pa., uses a green laser beam, said Randy Gilmore, the company's director of laser technologies. (SuperPulse is a registered trademark of General Atomics.) Unlike the femtosecond variety, SuperPulse is a nanosecond laser, and its green light operates at the 532-nanometer wavelength. (A nanosecond is one-billionth of second, and a femtosecond is one-quadrillionth of second.)

The technology provides laser pulses of 4 to 5 nanoseconds in duration, and those pulses are sent in pairs with a delay of 50 to 100 nanoseconds between individual pulses. The benefits of this approach are twofold. "It greatly enhances material removal compared to other nanosecond lasers," Gilmore said, "and greatly reduces the amount of thermal damage done to the workpiece material" because of the pulses' short duration.

The minimum diameter produced with the SuperPulse laser is 45 microns, but one of the most common applications is for producing 90µm to 110µm holes in diesel injector nozzles made of 1mm-thick H series steel. Gilmore noted that those holes will need to be in the 50µm to 70µm range as emission standards tighten because smaller holes in injector nozzles atomize diesel fuel better for more efficient burning.

In addition, the technology can produce negatively tapered holes, with a smaller entrance than exit diameter, to promote better fuel flow.

Another common application is drilling holes in aircraft turbine blades for cooling. Although the turbine material might only be 1.5mm to 2mm thick, Gilmore explained that the holes are drilled at a 25° entry angle so the air, as it comes out of the holes, hugs the airfoil surface and drags the heat away. That means the hole traverses up to 5mm of material. "Temperature is everything in a turbine" he said, "because in an aircraft engine, the hotter you can run the turbine, the better the fuel economy and the more thrust you get."

To further enhance the technology's competitiveness, Ex One developed a patent-pending material that is injected into a hollow-body component to block the laser beam and prevent back-wall strikes after it creates the needed hole. After laser machining, the end user removes the material without leaving remnants.


Ex One

Ex One's SuperPulse technology uses a green light laser to drill holes as small as 45 microns.

"One of the bugaboos in getting lasers accepted in the diesel injector community is that light has a nasty habit of continuing to travel until it meets another object," Gilmore said. "In a diesel injector nozzle, that damages the interior surface of the opposite wall."

Although the $650,000 to $800,000 price for a SuperPulse laser is higher than a micro-holemaking EDM, Gilmore noted that laser drilling doesn't require electrodes. "A laser system is using light to make holes," he said, "so it doesn't have a consumable."

Depending on the application, mechanical drilling and plunge milling, EDMing and laser machining all have their place in the expanding micromachining universe. "People want more packed into smaller spaces," said Makino's Kiszonas. △