cover story

➤BY ALAN RICHTER, MANAGING EDITOR

Variations on a Theme

Toolmakers tout benefits of variable-helix endmills.

SGS Tool

By minimizing harmonic vibration, SGS Tool says its Z-Carb solid-carbide endmill, which features constant but different helix angles, maximizes stock removal.

When making music, harmonics are usually heard as pleasant, chimelike overtones. When cutting metal, harmonics can generate regenerative vibration and chatter, resulting in a poor surface finish, rework and, possibly, scrap.

One way to reduce chatter is by applying a variable-geometry endmill. Although these types of tools are commonly called "variable helix," variable geometry is a more encompassing term. Two basic designs exist. One features unequal, or different, helix angles that are constant along the length of the cutting edge.

The other has helix angles that vary along the length of the cutting edge. For example, the helix at the front of the tool could be 30° and end up at 45° at the back of the tool, with the angle being 37.5° at the half-way point. The helix could also start at, say, 37° and change to 30°. "The tool has a dampening effect within the cut because the endmill is cutting at different angles along the same helix," explained Paul St. Louis, president of Benchmark Carbide, Springfield, Mass.

Bob Srail, manufacturing manager for Melin Tool Co., Cleveland, added that the helix angle can vary within a wide range as long as a toolmaker's tool and cutter grinders are able to produce it. "Most machines are capable of grinding any angle," he said.

Both endmill styles have unequal flute spacing, or a differential pitch, to break up harmonics by creating an out-of-phase cutting action. For example, a 4-flute endmill's pitch, or index, could be 89° from flute No. 1 to flute No. 2, 91° from flute No. 2 to No. 3 and so on, eventually adding up to 360°.

"Basically, as a conventional endmill rotates it can set up constant harmonics, based on the fact the helix angles are equal and the cutting edges are spaced equally apart," said Jeff Burton, executive vice president of manufacturing for SGS Tool Co., Munroe Falls, Ohio. "Anything you can do to interrupt the harmonics minimizes the accompanying vibrations."

According to Dennis Noland, engineering manager for Niagara Cutter, the Amherst, N.Y.-based company's patent-pending rotary tool design improves on the variable-geometry concept by specifically addressing the sound patterns generated by the tool. The toolmaker not only changes the index and helix from flute to flute, but also alters the rake angle and relief as well. Therefore, regardless of how many, each flute's cutting edge is different from the others and the diametrical pitch is never the same. "Typically, you're looking at a range of 5° in all directions for a given set of geometries," he added. "You can't get excessive because then you create problems with stability."

The result is a tool in which each cutting edge produces its own distinct sound pattern as it interfaces with and moves along the surface of the workpiece. "Because [the cutting edges] are making different sound patterns," Noland explained, "the potential for harmonic vibration to take place is practically eliminated."

Although Niagara's variable-geometry endmills have constant geometric features along each cutting edge, Noland added that it's also possible for each cutting edge to vary completely—the rakes, reliefs and helixes—from the front to the back of the tool. This type of tool would change its sound pattern continually as it machines a part. "We haven't done that yet," he said. "It's a matter of programming the machines, which is very complicated to do."

While there are numerous designs for variable-geometry endmills on the market, it's important to note that each toolmaker's offering needs to be distinctive to avoid infringing on another company's patented design. When designing such a tool, "there are lots of different ways of doing it," said Martin J. Graglia, vice president of VRK Tool Manufacturing Co. Inc., Farmingdale, N.Y. "Ours is done differently—significantly differently—than others on the market. We developed it from the ground up."

VRK's patent-pending Silent Pitch 3-, 4- and 5-flute endmills have offset flutes and constant but different helix angles, with each endmill having only two identical helixes, Graglia said. The variable geometry allows the tools "to run nearly chatter-free," he added, "and to finish-cut at speeds nearing roughing speeds."

Sim City

Varying the helix of an endmill would be practically impossible without the advent of 3-D simulation software for grinding machines. "[The software] is mandatory in order to make the tool," said Jeff Davis, vice president of engineering for Harvey Tool Co. Inc., Topsfield, Mass.

Benchmark Carbide's St. Louis concurred that variable-helix endmills couldn't be designed and produced without the simulation software. "When it's grinding, the wheel is really changing how it attacks the grind," he said. "If I didn't use the simulator, I would have ruined hundreds of tools and probably a lot of wheels."

Niagara Cutter

Niagara Cutter's Stabilizer HT endmill has a differential pitch to provide chatter-reducing phase shifting and different helixes, rakes and reliefs to significantly reduce harmonic vibration when machining high-temperature, high-density alloys.

He added that the simulator, which enables several design changes to be made in a few minutes, also allows more engineering work to be accomplished in the office instead of consuming time on the production floor. "If I was making a ½" endmill on the grinding machine, it would take me 15 minutes," St. Louis said. "It takes me 2 or 3 minutes to make it on the simulator."

Davis noted that the need for special software and machines capable of grinding a variable helix prevents many end users of these tools from having their worn cutters resharpened. "Not just anybody can do it," Davis said.

Sending the tools back to the manufacturer for resharpening isn't always an option either. "We're not really a resharpening house, for starters," Davis noted, "and we feel our pricing is either competitive or low enough that instead of resharpening it might be better to buy another tool."

In contrast, Steve Abrams, product marketing manager for endmills and carbide rounds at Kennametal IPG, Evans, Ga., said that end users of the toolmaker's Hanita brand VariMill are able to regrind and recoat the endmills in-house or at their local regrind shop and achieve the same performance as a new tool. "The vast majority of end users expect to be able to resharpen an endmill after it's worn," Abrams said.

He explained that the VariMill

The following companies contributed to this report:

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Hanita Cutting Tools
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Harvey Tool Co. Inc.
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Melin Tool Co.
(800) 521-1078
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Niagara Cutter
(716) 689-8400
www.niagaracutter.com

SGS Tool Co.
(330) 688-6667
www.sgstool.com

VRK Tool Manufacturing Co. Inc.
(800) 665-9615
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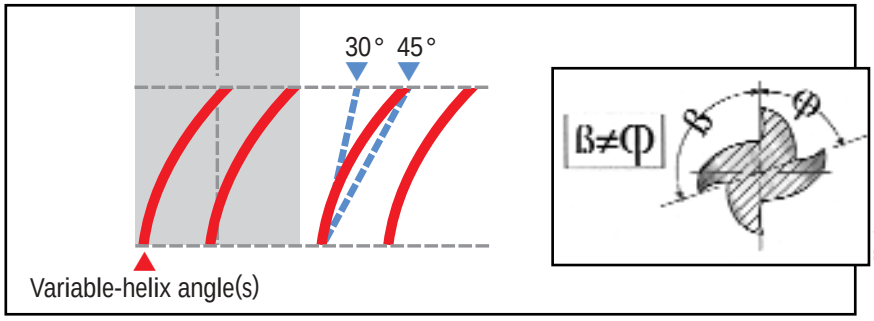

Benchmark Carbide

Hanita

An endmill's helix angle represents the sweep of the flutes as they go up the cutting length. An endmill with a variable-helix angle has a helix wrapped around the tool's cylinder that is not constant. Insert: Unequal flute spacing provides free machining without chatter.

doesn't have variable or different helix angles, but breaks up the harmonics with offset flutes and constant rake angles along the length of the flute. This allows, for example, a 4-flute endmill to work like two independent, 2-flute cutters.

Roughing Time

With chatter out of the picture, variable-geometry endmills are able to remove material at a high rate. "By eliminating the potential for harmonics to take place, you can literally, in some cases, double, triple or even quadruple the depths of cut you can take," said Niagara's Noland. "For instance, you can cut a slot in 4340 steel 2 diameters deep at surface footages up to 600-plus."

Although these endmills can also be applied for finishing, roughing "is where people often see some of the most obvious and immediate benefits, because they're able to increase the material-removal rate," said SGS's Burton. "You're able to increase, in a lot of cases, your depth of cut, width of cut and feed rate. You're able to increase all that because you're able to push the tool much harder when you're not dealing with harmful harmonic vibrations."

And without the tool bouncing along the surface of the workpiece, it is able to impart a finish that's equal to or better than what would be achieved by taking a light finishing pass with a standard-geometry endmill. "You very often see workpiece finishes that are acceptable without requiring additional finishing passes," Burton said of the variable-geometry tools.

He added that "even if you're not able to eliminate that finishing pass, you've been able to increase the roughing part of the operation, which still gets your work done much faster."

On the flip side, if an end user only needs to take light cuts, a variable-geometry endmill usually isn't the best choice of tool because it doesn't cut with a high enough chip load to be advantageous. "Some people call us and say they're just doing a light finish-cut and I'm thinking, get the cheapest tool you can because it isn't going to really matter much," said Benchmark Carbide's St. Louis. "If this tool is just taking a skim cut, it's not going to be able to do what it needs to do to slow down the vibration."

However, "for a lot of people doing a number of roughing cuts, they would like to finish with that same tool and they can," St. Louis added.

Machine Matters

Because variable-geometry endmills cost about 20 to 25 percent more than standard-geometry endmills, some feel they're not suitable for use on all types of machine tools. "Their use depends on the type of equipment," said Melin Tool's Srail. "Running them on old Bridgeports wouldn't justify the expense."

St. Louis said that to effectively apply these types of tools the appropriate machine has to have at least a 40-taper spindle. "With some of the 30 spindles, you get a lot of deflection," he said. "People can run the tool, but they have to cut back on the feed rates."

Although the productivity boosts are more pronounced on larger machines, others feel variable-geometry endmills help improve the performance of all types of equipment. Noland said: "For the average person, who has, say, a 15- to 20-hp, 40-taper machine with a maximum speed of 10,000 rpm, ½" and [smaller] tools can really make a big difference in cycle times. These tools can even make a big difference to someone with a Bridgeport."

Regardless of the machine, Noland emphasized that keeping the tool cool when taking heavy cuts—for example, slotting 2 diameters deep—is critical. Therefore, flood coolant needs to be applied at a high rate. "A critical element is to be able to get the coolant down into the cut to keep the chip-formation zone cool enough so it doesn't start to material-weld," he said. "Once that starts happening, the tool instantly packs up and breaks."

MATERIAL	SFM	CHIP LOAD PER TOOTH (IPT)			
		⅛"	¼"	½"	1"
Aluminum alloys	1,200	0.0010	0.0020	0.0040	0.0080
Carbon steel	300 to 600	0.0010	0.0015	0.0030	0.0060
Cast iron	350 to 550	0.0010	0.0015	0.0030	0.0060
Copper alloys	500 to 900	0.0010	0.0020	0.0030	0.0060
Steel (annealed)	350 to 500	0.0010	0.0020	0.0030	0.0050
Steel (18 to 24 HRC)	150 to 500	0.0004	0.0008	0.0015	0.0045
Steel (25 to 37 HRC)	125 to 200	0.0003	0.0005	0.0010	0.0030
Stainless steel (free machining)	250 to 400	0.0005	0.0010	0.0020	0.0030
Stainless steel (other)	150 to 300	0.0005	0.0010	0.0020	0.0030
Inconel, Monel	60 to 100	0.0005	0.0010	0.0015	0.0030
Titanium	175 to 300	0.0005	0.0008	0.0015	0.0030

Harvey Tool

Recommended starting speeds and feeds for variable-helix endmills.

Noland added that through-coolant tools are an option, but it adds expense. "We haven't done that yet, but it's definitely something we're looking at."

Kennametal IPG's Abrams noted that coolant is always recommended if available, but it's not mandatory. "The tool's geometry doesn't require coolant," he said.

Variable-geometry endmills are usually coated with titanium aluminum nitride or aluminum titanium nitride, both of which allow dry or near-dry machining, he added.

Systematic Design

Similar to maximizing productivity by optimizing every element of the machining system, the system approach applies to the cutting tool itself. According to Srail, the tool's geometry by itself will only take you so far. "The coating provides as much of an advantage as anything else," he said. "The marriage of the two [coating and geometry] maximizes output to the customer's advantage."

Add to that combination a high-quality carbide substrate and end users are presented with an endmill that allows them to machine deeper, faster, better. "Any time you are talking about a high-performance endmill, three things are required: the substrate material, the tool geometry and the tool coating," said Burton. "One is very much dependent on the other."

As for users' response to variable-helix endmills, Noland said it's "mind-boggling. They can't believe a tool can cut that much stock at those kinds of rates. It's one of those nifty items that if you can get it into their machine spindle, you walk out with an order."