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▶ BY BILL KENNEDY, CONTRIBUTING EDITOR

cover story

What's on Tap?

A look at recent advances in tap technology.

Workpiece material characteristics. Tool design. Machine tool capabilities. Speeds and feeds. As with any metalcutting operation, these basic process elements must be considered when tapping a thread.

But Dan Gajdosik, engineering manager for tapmaker Besly Products Corp., South Beloit, Ill., said tapping is, in many respects, the "most difficult of all machining" operations.

"The chip load per tooth on a tap is much higher than most cutting tools," he explained. "The tap is almost buried in the workpiece, and contact along the thread flank is very high. The tap has to contain or dispose of the chip it generates while producing a thread to precise finish size. It's a severe environment."

Tap manufacturers address multiple aspects of that environment in an ongoing effort to boost productivity.

Material-Specific

The machinability of the workpiece material is probably the key determinant of tapping performance. Vernon Hill, design engineer for The Hanson-Whitney Co., Windsor, Conn., said tapmakers are focusing on developing tools for specific workpiece materials. Hill said the major variable in creating material-specific taps is the geometry of the cutting edges. Specifically, their rake angle and amount of hook.

Rake is the inclination of the cutting edge, and hook is its degree of radius or curve (Figure 1). For tough-to-machine materials, rake angles and hook are generally lower, to strengthen the cutting edge and counter the high torque needed to cut the threads. In hard materials, too much hook or rake can cause a tap to break. Furthermore, Hill said, "if you have too much hook, it can grab and tear the threads."

On the other hand, long-chipping

materials require a steeper rake angle and hook, which curl and break the chip. The more acute angles result in a weaker cutting edge.

Another material-dependent geometric factor is the relief angle, or the clearance between the tap's flute and the hole's wall. Harder materials require more relief to reduce friction and permit coolant to reach the cutting edge. But larger relief angles offer less of a self-centering capability as the tap enters the hole.

In soft materials, too much relief can result in oversize threads. Harder and tougher materials may require full eccentric relief, which begins at the cutting edge. Con-eccentric relief, appropriate with less-difficult-to-machine materials, features an unrelieved margin behind the cutting edge followed by an angle of relief (Figure 2).

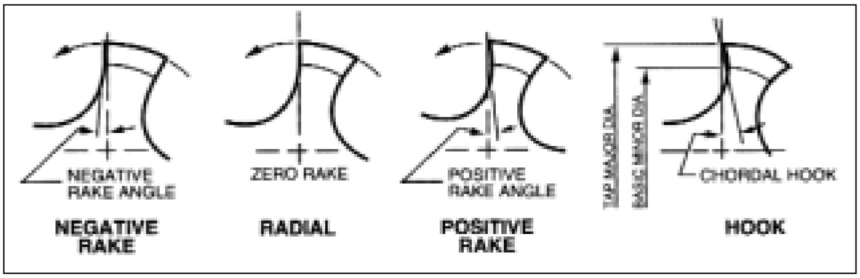
Spiral-flute taps designed to thread blind holes in tough-to-machine materials have lower flute helix angles, to improve structural strength. For example, Hanson-Whitney's ULTI-XT spiral-flute taps for tougher 400-series stainless steels feature 15° flutes, while the company's ULTI-XT 300 taps for 300-series stainless have 41° flutes (Figures 3a, 3b).

In addition, taps for tough-to-machine materials often have a shorter thread length. This reduces the amount of torque required in the cut. Materials with elastic memory, such as titanium, call for tools with greater back taper, or decreasing tool radius from tip to shank. The taper minimizes friction on the shank as the material "springs back" after machining.

When attempting to optimize tap performance, tapmakers also consider other factors than just the tool.

Alan Shepherd, technical director for Emuge Corp., Northborough, Mass., said newly developed high-performance taps can cut significantly faster than traditional tools. "In tapping cast iron, previously you might have run at 35 to 50 surface feet per minute, but the new taps enable you to tap as fast as 250 sfm," he said.

He pointed out, though, that the upper limits of performance can be realized only with a certain range of taps and machine tools with specific capabilities. "The most productive speeds are sometimes limited by the capacity



Illustrations: Allen Benjamin

Figure 1: Rake is the inclination of the cutting edge, and hook is its degree of radius or curve.

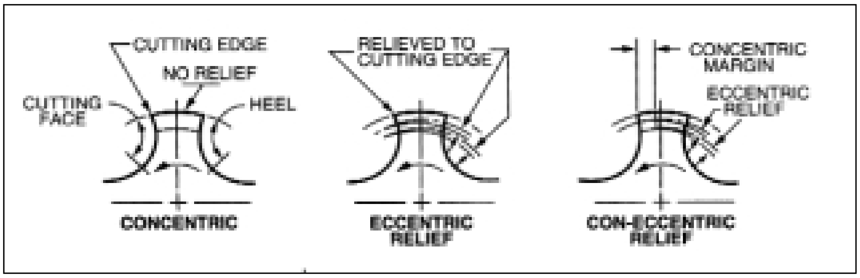


Figure 2: Harder, tougher materials may require taps with full eccentric relief to reduce friction. Taps for less-difficult-to-machine workpieces can employ con-eccentric relief.

of the machine tool," he said.

With smaller taps, the spindle speed required to achieve the desired surface speed [rpm = (sfm × 3.82)/tap diameter] may be beyond the spindle's rpm capacity. On the other hand, attaining high speeds with larger taps may require greater tapping torque and horsepower than the machine can provide.

"Where we might achieve 250 sfm with a 700-psi through-coolant tool, a machine without through-coolant might only be capable of 150 sfm," Shepherd said. "A tap, unlike most metal-removal tools, has an enormous surface area that comes in contact with the wall of the hole. Therefore, lubrication is important. If you overheat high-speed steel, the tool breaks down and burns up."

Newer high-performance taps are designed to take maximum advantage of a machine tool's spindle speed and horsepower. The geometries of Emuge's line of high-performance taps feature "higher rates of relief and higher back taper," Shepherd said.

And edge configurations are matched with a specific surface coating, such as TiN, TiCN, CrN or TiAlN. These heat-resistant and lubricious coatings extend tool life, reduce cutting forces and permit higher cutting speeds.

Carbide Rising

Just as carbide tools gradually replaced the HSS tools used for turning, carbide taps are beginning to thread more holes.

Carbide, traditionally, had problems handling the high chip loads of tapping because the material, while very hard, is also more brittle than HSS. Even so, carbide taps are proven performers in materials such as cast iron and aluminum, where the main failure mechanism is wear.

Amy Haywood, general manager of Allen Benjamin Inc., Tempe, Ariz., said: "Automotive manufacturers use carbide for the longevity, because they're machining a lot of aluminum and cast iron. A carbide tap will long outlast a HSS tap in those materials. Much of it depends on the end user's application and what they are trying to achieve in the long run. In the automotive industry, downtime to change taps is obviously a factor." The long life of carbide taps minimizes tool changes.

Development of submicron-grain carbide substrates has produced tools that offer significantly increased toughness without sacrificing carbide's wear-resisting hardness. Haywood said these tools extend tool life, compared to HSS tools, when cutting hardened steels, plastics and difficult-to-machine nickel-base aerospace alloys. The company says its PRX-series taps, under certain conditions, have been able to thread more than 200 holes in Inconel 718 before they require resharpening.

According to Gene Delett, national

sales manager for Regal Cutting Tools, South Beloit, Ill., carbide taps comprise one of the fastest growing markets for his company's products. "The new micrograin carbides are suitable for some general machining," he said. "You can run five or six times faster, and tool life can be 100 times greater. The cost is obviously many times that of a standard HSS tool, but the payback is greater than the payout, especially in high-volume situations such as automotive."

Haywood added that "a lot of operations, like hand tapping, aren't correct for carbide." But with the advent of synchronous tapping (see sidebar, page 31) and strong fixturing, carbide taps are a valid option for a growing range of materials and applications.

David Miskinis, technical specialist with Greenfield Tap and Die/Kennametal Greenfield IPG, Evans, Ga., agreed that state-of-the-art taps feature "bodies of premium steel, powder metal or carbide, are coated, and have lots of clearance and short thread lengths that allow them to run at high speeds."

And, leading-edge shops are taking advantage of the new tap technologies to boost productivity. An example of how Greenfield is serving this market can be found in its expanded offering of material-specific taps, which includes tools for threading aluminum containing 8 to 12 percent silicon. The taps combine lower-helix-angle flutes with clearances and rakes specifically designed for achieving top performance when threading these materials.

Miskinis added that the features and performance characteristics of many material-specific taps can also help boost productivity in other materials.

"It's almost like some of the specialized taps are becoming general high-performance tools rather than material-specific," he said. "For example, we've got a tool specifically for tapping nickel. It has premium steel, for heat-resistance, appropriate relief angles and a short thread length that make it highly productive in nickel. But it also works great in hard 4340, 38 Rockwell steel. It's got the right 'cake mix' of features for many tough materials."

Rigid rules of tapping

Machining faster with the same—or greater—level of accuracy is always desirable. But achieving the desired results requires use of the proper machine.

When it comes to high-speed threading, Pete Kainovic, machining center product manager for Okuma America Corp., Charlotte, N.C., said there are two classes of machines that are commonly used. First is the small, dedicated CNC drilling and tapping machine, such as those produced by Brother Industries, designed only to drill and tap small-diameter holes. These machines feature CAT 30 spindles, which operate at extremely high acceleration and deceleration rates, and CNCs optimized for tapping. Some permit tapping at speeds of 6,000 rpm or higher.

Kainovic also said that much of the threading performed today takes place on machining centers, employing synchronized, or "rigid," tapping cycles. When rigid tapping, the machine's CNC synchronizes the spindle speed and Z-axis ballscrew.

Rigid tapping contrasts with non-CNC tapping processes, which require taps to be held in nonrigid, or floating, holders to compensate for differences between the machine tool feed and the thread's lead.

Float is necessary because a tap's feed must equal its lead. For example, a 1/4-32 tap has 32 threads per inch (the tap advances 1" every 32 revolutions). Before present-day CNC technology, precisely matching machine feed and tap lead wasn't possible. Tap chucks, therefore, were designed with springs that permitted axial float, enabling the tap to feed exactly at its lead rate.

Kainovic said Okuma, like most machine tool builders, offers machining centers with standard rigid-tapping programs that synchronize the spindle speed with Z-axis movement to exactly match the tap's lead. Depending on the size and mass of the machine spindle, tap and workpiece, most machining centers can tap at around 2,000 to 3,000 rpm.


Tapmatic

A flexor machined into this tapholder compensates axially and radially for variations between programming and actual machine movement.

He noted that Okuma's OSP controls have a percentage override feature that withdraws the tap from the hole up to twice as fast as it enters, further reducing cycle times. Another standard feature is a tapping-torque-limit function that can be set in 10Nm, or 88.51 lb.-force/in., increments. To prevent tap breakage, the function will stop and withdraw a tap if it is dull or otherwise begins to require torque above the set limit, Kainovic said.

With a rigid-tapping program, a tap inserted directly into the spindle theoretically would make perfect threads. But minute discrepancies in the feed/lead match, plus the effects of spindle wear, can result in less-than-perfect threads and accelerated tap wear.

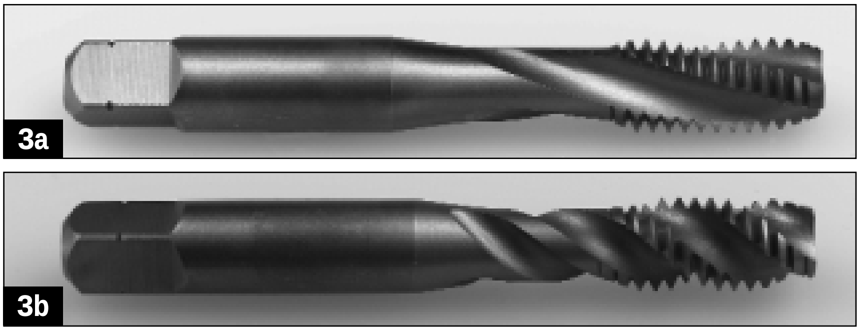
As a result, tapholder manufacturers are marketing holders for rigid tapping. These holders compensate for small differences between tap lead and actual machine tool performance. Emuge Corp. calls its compensating rigid tapholders KSN-Softsynchro holders. The units feature a tension and compression range of about 0.020" to compensate for spindle overrun and inherent inaccuracies in synchronous tapping cycles.

Tapmatic Corp. offers the SynchroFlex holder. It features a flexor machined into the holder between the tap and chuck to compensate axially and radially for variations between programmed and actual machine movements. Tapmatic says the patented technology has doubled tap life in field tests.—B. Kennedy

*For more information on Okuma America Corp., call (704) 588-7000, visit www.okumaamerica.com or circle **Information Services #292**. To learn more about Tapmatic Corp., call (208) 773-8048, visit www.tapmatic.com or circle **Information Services #293**.*

Despite advances in taps, Miskinis noted that the majority of callers to the company's technical inquiry line aren't interested in increasing speed. They seek advice for common tapping problems, such as tool breakage, oversize threads, chipping and galling. He said many shops still consider tapping a mystery and think that increasing productivity is difficult, if not impossible.

That's not the case. But boosting productivity requires planning.



The Hanson-Whitney Co.

Figure 3a: Spiral-flute taps with 15° flutes are ideal for threading 400-series stainless. Figure 3b: A 41° flute can more productively thread 300-series stainless.

Step by Step

To make tapping as productive as possible, you must follow basic steps, said Robert Couture, U.S. sales manager for Prototyp USA, Asheville, N.C. When beginning to tool a tapping operation, Couture said he asks five questions: "What is the material? What is its tensile strength? Is it a through or blind hole? How deep is the hole or how thick is the workpiece? And, finally, what is the size and class fit of the thread?"

While the class of tap for producing internal Unified threads—from 1B for easy assembly to 3B for close fit—is a guide for tool selection, it doesn't ensure the efficient production of accurate threads. Other factors also impact performance.

For example, Couture said, "many of the problems of tapping oversize result from holding or feeding the tool improperly. A lot of the time I'll look at size conditions of the thread and suggest a feed change or a holder change, or both, and the problem is solved."

Couture said there are many ways to find the right tap for the job, such as consulting catalogs and selector charts. Prototyp offers a Computerized Cutting Service (CCS) tapping database on a CD-ROM that can put "an industrial engineer in the programmer's pocket."

Couture said the program, loaded on a PC, leads a user through basic tap-selection questions and other criteria. Then the program presents a selection of appropriate taps and cutting-speed recommendations, as well as a tool-efficiency chart that determines the most cost-efficient way to carry out the particular threading operation.

Getting ahead with reversing heads

Tapping has traditionally been one of the slower metalworking operations. One way to reduce tapping time per hole is to expedite the process itself, said Mark Johnson, president of Tapmatic Corp., Post Falls, Idaho.

A major reason for tapping's deliberate pace is that the process requires running the tap into the hole, stopping it at the bottom of the thread and then reversing it out. Decelerating, stopping, reversing and re-accelerating the machining center spindle consumes time.

A self-reversing tapping head reduces cycle time with a mechanical transmission that reverses the tap when the machine retracts, while the machine spindle continues to turn in the same direction at constant speed.

Tapmatic

Self-reversing tapping heads employ a mechanical transmission that reverses the tap when the machine retracts; the machine spindle continues to turn in the same direction at a constant speed. In other words, the machine tool spindle simply cycles into and out of the hole. The lightweight spindle inside the head makes the shift almost instantaneously, saving the time and energy needed to slow, stop and reverse the machine tool spindle.

The timesavings can be significant. Tapmatic says a British machining subcontractor was applying an M3 size tap in a nonreversing head to thread two holes 125mm apart in a 3.2mm-thick aluminum cooling plate. The operation was performed at 3,000 rpm and took 1 minute, floor to floor. A switch to Tapmatic's NCRT25 self-reversing head eliminated spindle reversal for both holes and saved 30 seconds per plate, enabling the shop to turn out nearly 250 plates per hour.

Johnson said that a self-reversing head also increases tap life. That's because varying the speed during a cut usually has an adverse effect on tool life, and a self-reversing head virtually eliminates the time that the cutting edge is decelerating to a stop.

When a shop has a short run of threaded parts, Johnson admitted, cycle time, tap life and machine wear are less of a consideration. "But when you get into high production, those things all start to matter a lot," he said.

A wide range of self-reversing heads is available, from smaller versions (for sizes 0 to 6/M1 to M3 taps), which can be run as high as 6,000 rpm, to large heads, for tap diameters to ¾", with a maximum limit of 1,500 rpm.—B. Kennedy

Alternate threading methods, such as thread milling and roll forming, are included on the CD-ROM, too. The CCS program can enable a user to "get a full idea of what it costs for each hole," Couture said.

Continuing advances, like Prototyp's CCS, as well as better tap designs, tapholders and machine tool technology, are steadily improving tapping operations. While tapping more efficiently and accurately can initially appear to be a daunting challenge, a thorough understanding of the workpiece material and how a tap's geometric features interact with the metal throughout the entire operation enable users to tap new sources of threading productivity.

The following companies contributed to this article:

Allen Benjamin Inc.
(480) 968-9737
www.allenbenjamin.com

Besly Products Corp.
(815) 389-2231
www.besly.com

Emuge Corp.
(508) 393-1300.
www.emuge.com

The Hanson-Whitney Co.
(860) 687-6933.
www.hansonwhitney.com

Greenfield Tap and Die/ Kennametal Greenfield IPG
(888) 434-4311
www.gfii.com/it

Prototyp USA
(800) 490-9875
www.prototyp.de

Regal Cutting Tools
(815) 389-3461
www.regalcuttingtools.com