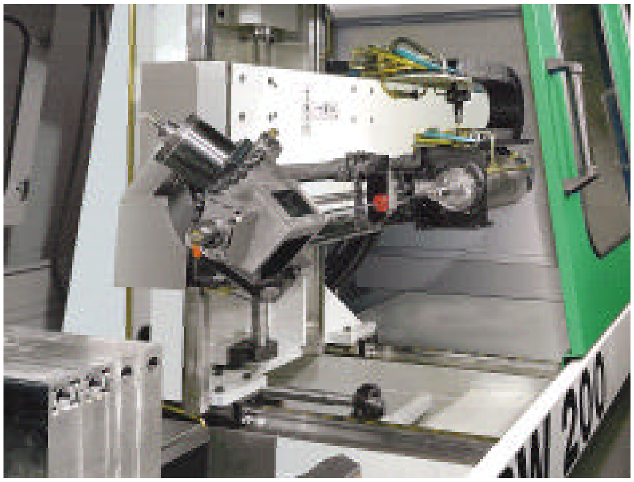
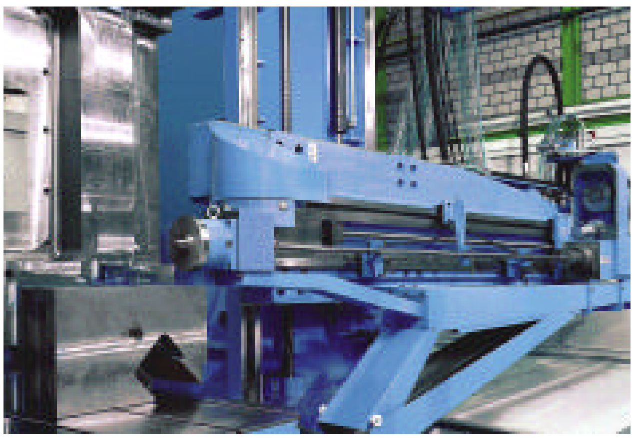
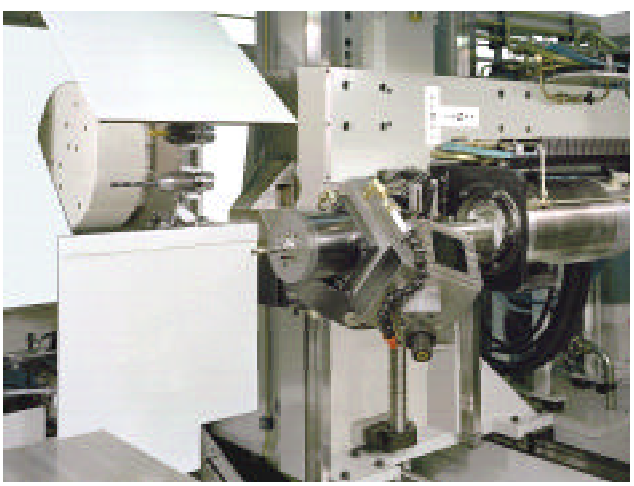
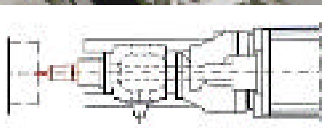








Productive deep-hole drilling

By **James R. Koelsch**
Contributing Editor

Drilling deep holes might not take as long as you think

Technological progress in deep-hole drilling has been slow but sure, like the process itself. This observation is especially true for gundrilling, the most popular of the deep-hole drilling processes. Although modern gundrilling machines are built better than their predecessors, come with modern controllers, and often monitor load and other variables to protect the tool, the process has not changed since the original machine was built, according to Russell Gilman, Jr, president, Dadson Corp (Grafton, Wis).

"The nuts and bolts of gundrilling are pretty much the same as they were because you can't really make a gundrill go any faster than it's designed to go," he says. "Otherwise the flute packs, and the tool breaks. So specifying the right feeds and speeds for the work material is the key to success at gundrilling." For normal carbon steel, for example, cutting speeds are usually between 300 and 350 sfm, and feed rates rarely exceed 5 ipm to manage the chips properly and avoid generating too much pressure and heat.

For applications that need greater speed, Dadson recommends the single-tube systems, such as the BTA-style tools offered by American Heller (Macomb, Mich). The deep-hole specialists at Dadson tend to favor the single-tube process over gundrilling for making thousands of pieces of a particular shape because it can be three or four times as fast and needs less machinery than a gundrill. The disadvantage, though, is that the machines running them are larger than gundrilling machines, need more power and greater volumes of cutting fluid, and typically require more time for setup, giving users another reason to reserve single-tube systems for production work.

Yet another fact favoring gundrills is that they produce smooth holes to tighter dimensional tolerances, for example 0.001 in. or better on diameter in 0.5-in.-diameter holes and 1 mm/m for concentricity. Because the pads on the opposite side of tool from the cutting edge create a kind of bushing and keep the drill on center, "gundrilling is a highly efficient and flexible machining method for both precise, deep holes and shallow ones," notes Jun Tanaka, vice president, Miroku Machine Tool Co (Schaumburg, Ill). "By going straight in, instead of pecking, you get a smoother finish quicker."

TBT's BW line of deep-hole drilling centers can cut with gundrills, single-tube drills, and conventional rotating tools. The enabling technology is a sliding drill-bushing carrier that holds a secondary spindle powered by the main spindle's motor. To convert to milling mode, the carrier swivels to bring the secondary spindle and drive shaft into position and slides away from the work to convert the machine into a machining center. To return to deep-hole drilling mode, the carrier swivels again to move the secondary spindle and drive shaft out of the way and slides toward the work to present the bushing

In one application producing balance shafts of JIS FCD45 steel for the automobile industry, a four-spindle MIG 300L-4 gundrilling machine from Miroku held a 0.237-in.-diameter, 9.280-in.-long hole within 0.0004 in. and created an 8 micron Rmax surface finish. Roundness and cylindricity of the holes were 0.0007 and 0.0011 in. At 4200 rpm and 4.0 ipm, cutting time in the Vickers 200–230 material was 2.4 min.

Although gundrilling can produce similar results in relatively shallow holes, Tanaka advises most users to reserve gundrilling for holes that exceed 10 times diameter because twist drilling and other conventional processes are usually more economical for shallow holes. On the other hand, gundrilling makes good economic sense for deep holes and is often the only way to produce one. The practical limitation for good results with gundrilling is usually 100 times diameter for holes with diameters larger than 2 mm.

Cool holes are slick

Use of high-pressure cutting oil, or occasionally soluble oil containing high concentrations of fatty acids and other lubricious agents, is central to gundrilling. The process relies heavily on assistance from the cutting fluid to keep the deep cut cool and to manage the chips. Besides cooling and lubricating the cutting zone, the high-pressure fluid helps the tool to break the chips into small pieces and then pushes the chips up the long flutes and out the top of the hole.

Unlike most other machining operations, gundrilling needs the oil for one more task — lubricating and cooling the portion of the tool not in the cut. "The wear pads opposite the cutting edge are being forced against their side of the hole and act as a bushing," says Charles Van Sickle, executive vice president, Kadia TBT Inc (Rockford, Ill). "Without enough lubricity [and cooling], the pads start picking up material from the wall and broken chips. Once you score a wear pad, you are within a few revolutions of breaking the drill."

To satisfy these demands on the fluid, most deep-hole drilling specialists specify cutting oils with good extreme-pressure (EP) ratings. Because thousands of formulations exist for deep-hole drilling, Van Sickle advises consulting a reputable supplier who can recommend one for the job at hand or for the type of work flowing through the shop.

He also suggests working with machine builders and tool manufacturers to deliver the oil in an optimal manner. Chip evacuation today is more than shooting high-pressure oil through as wide a flute as possible. Over the last several years, tool manufacturers have used finite element analyses to study the fluid mechanics and stress distribution in gundrills and design tools that allow maximum flow without weakening the cutting edge. The outcome at TBT, for example, has been the development of two designs for passing oil through the carbide head of the tool. The design for holes larger than 7.7 mm calls for two round ports, and the one for holes smaller than 7.7 mm uses an elongated, kidney-shaped port.

Another outcome of the computer analysis was three five-facet geometries, each of which includes a relief angle for the cutting fluid to allow maximum flow and efficient chip evacuation. The other four facets are the primary land, secondary land, clearance angle, and rake. TBT's tool engineers adjust the orientation of these facets in space to accommodate the forces encountered in different hole sizes: less than 5 mm, between 5 and 30 mm, and greater than 30 mm. "This geometry works very well in nearly all cases," says Van Sickle. "We don't see many advantages to the gimmick grinds that many people offer."

Working with Kadia TBT, which offers both machines and tools, should pay handsome dividends for one automotive supplier producing small, long parts. Besides helping with tool selection, TBT's application engineers were able to recommend a machine capable of delivering cutting oil at 2300 psi to solve a tool-breakage problem. "The hole is so small that you don't get much flow unless you have very high pressure," recalls Van Sickle. "Running at 2000 psi creates a lot of flow, even though it's a small stream." The pressure generated by the old machines was not much more than 800 psi, so the shop is negotiating with Kadia for some two to four-spindle TBT machines capable of 2000 psi plus.

Other aids for preventing wear and keeping the cutting zone cool include titanium nitride (TiN) coatings laid by either chemical or physical vapor deposition (CVD or PVD). Although some users prefer black carbon coatings, TBT normally sticks with recommending TiN, especially in sticky materials. "It improves finish by preventing the wear pad from scratching the bore," says Van Sickle.

The coating does little for the cutting edge, though, which is why he does not recommend some of the other titanium-based coatings available today. In fact, coatings can interfere with the cutting action. "In soft stringy materials like 10L14, coated tools often can't break the chip," he says. Too free a cutting action can cause the chips to form into long strings that jam and break the drill. "So, after we coat tools for these materials, we'll grind the TiN coating off the face of the cutting edge so that the chips will not slide easily."

Two-flute gundrills

When cutting rapidly is more important than holding tight tolerances, tool manufacturers often suggest a number of tools that they have introduced recently to boost productivity. Two-flute gundrills from Eldorado PCC Specialty Products Inc (Milford, Conn), for example, can double the feed rate of single-flute drills easily in relatively soft materials, such as aluminum, cast iron, and brass. "Depending on the hardness of the work material, two-flute gundrills offer penetration rates as much as 10 to 15 times faster than a single-flute gundrill," says Mike Klembara, product manager.

One reason is that the solid carbide tip is induction brazed to an aircraft-grade 4130 steel tube and has a formulation allowing the tool to withstand 25% more torque than conventional carbide-tipped drills. To prevent the tool from wandering off center, Eldorado grinds a split point into the carbide tip. A leading-edge margin and trailing-edge land also guide and support the tool in the cut. Although the geometry is different from a single-flute gun-drill point, "you're still working with 30° angles," says Klembara. "In this case, though, it is on both sides." Because the cutting edges are 180° from one another, the tool is counterbalanced and much more stable at high speeds than their single-flute counterparts.

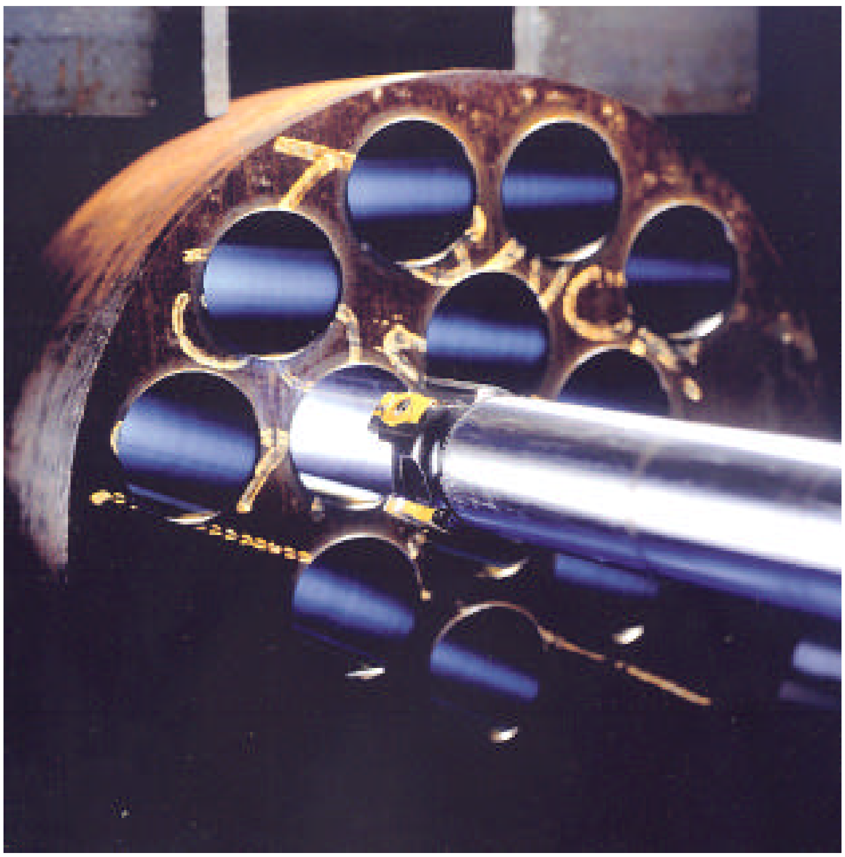
Two-flute tools are a response to the demands among users for faster gundrilling and to the growing use of soft, untraditional materials. Demand has been especially high in the automobile industry since the automakers began experimenting with lightweight materials to get better fuel economy and new manufacturing technology to exploit the properties of these materials to keep cycle times low. Klembara reports that two-flute gundrills are enjoying success in the production of aluminum engine blocks.

The tools run in any type of machine, from CNC stand-alone models to custom transfer machines rigid enough to perform gundrilling. Besides the rigidity of the machine and workholding apparatus, speed is an important parameter for guaranteeing the tool's success. "To get the most from this kind of tool, you have to start with the recommended parameters and work your way faster because the gundrill tends to wander if it is running too slow," says Klembara. "The rule of thumb is to leave the spindle speed alone and double the feed rate. Then work from there."

Although the two-flute tools will work in graphite, tool life is poor. Consequently, single-flute tools tend to be more practical and find more use in graphite. The situation could change in the autumn, however, when Eldorado hopes to unveil a new line of hardened gundrills for abrasive nonferrous materials, such as graphite and aluminum alloys with high silicon content. Research is under way for a polycrystalline diamond (PCD) edge for these materials.

Indexable inserts for economy

For holes with diameters between 30 and 65 mm (1.2 and 2.6 in.), Sandvik Coromant Co (Fair Lawn, NJ) has introduced a segmented drill that performs better than brazed tools and consolidates the various grades and geometries of brazed inserts into one style of indexable insert. The tool manufacturer claims that the CoroDrill 800, can produce deep holes at half the cost. The better economy comes from three advantages: multiple points from indexing the inserts, higher penetration rates, and 25 times the life of a brazed tool body.



A grade of submicron-grain carbide and a new chipbreaker let Sandvik consolidate a variety of grades and geometries of brazed inserts into one style of indexable-insert, segmented drill. According to the cutting tool manufacturer, CoroDrill 800 performs better than brazed tools, producing deep holes at half the cost

Although the new inserts work at the same lead angle as their brazed counterparts, they have a common chipbreaker for cutting a variety of materials. "Designing a chipbreaker that cuts well in deep holes in most materials, including soft ones, was a difficult task to achieve," says Tony Yakamavich, senior product specialist. "The new chipbreaker is deeper and wider to curl the chip more tightly and help it break the chip into as small pieces as possible so they exit the cutting zone easily." Brazed inserts, on the other hand, rely on chipbreakers dedicated to the material.

Another simplification comes from constructing the new insert from the latest fine-grain 1025 carbide. "Most brazed tools come in a variety of grades to withstand the cutting forces and heat that they encounter in particular materials," explains Yakamavich. "We've adapted today's fine-grain carbides to withstand the heat."

Besides simplifying the specification process, the fine-grain carbide also makes the inserts harder, tougher, and more heat resistant than brazed tools. Hardness of the new drill body is Rc 47, which is more than double that of the Rc 22 typically seen in brazed tools. The new inserts also have a titanium nitride coating to add lubricity and wear protection. Because of the greater hardness, toughness, and heat and wear resistance, Yakamavich reports tool life at 1500 in. per edge, rather than the 400 to 600 in. that a brazed tool lasts in steel when running at the recommended feeds and speeds.

Switching from a brazed tool to CoroDrill 800 does not sacrifice the hole's dimensional tolerance and surface finish. Like the previous generation of brazed tools, the head containing the new inserts fits the single-tube and ejector (double-tube) systems that Sandvik uses to extract the chips through the center of the tool. Hole tolerances remain as tight as +0.002/-0.000 in. in holes as deep as 100 times diameter for the single-tube system and as deep as 50 times diameter for the ejector system.

Despite the advantages of the new substrate and chipbreaker, Yakamavich continues to recommend brazed tools for holes with diameters less than 30 mm. These holes are simply too small to offer the clearance necessary for deploying the inserts containing the new chipbreaker. For holes larger than the 65-mm upper limit on CoroDrill's range, Sandvik offers a different family of indexable inserts.

An alternative to gundrilling

The economics of Sandvik's segmented drills make them an attractive alternative to gundrilling in many applications. "These tools are designed to run at penetration rates that are about five times faster on average than those for a gundrill," notes Yakamavich. "A gundrill's geometry is one-sided and crimped, which means they are unbalanced and weak and you have to use low penetration rates of about 0.001 ipr."

Segmented tools, on the other hand, distribute the forces around a 360° circumference, which gives them the strength to withstand cutting forces generated at 0.008 to 0.010 ipr and to cut larger diameters. "If we slowed them to the gundrilling feed rates, we would not be able to break the chips and would have the same packing problems as gundrills," adds Yakamavich. The tradeoff is that a gundrill holds tighter dimensional tolerances. Applied correctly, a gundrill can hold ±0.001 in., which is twice as good as a segmented drill. Surface finishes for the two methods, however, generally are identical.

Because a segmented tool trades five times the speed for only half the accuracy, cutting tool engineers often argue against gundrilling for jobs having loose tolerances. In mold-making, for example, the tolerances on most holes in the base are usually unimportant because they are cooling channels. A machining center using segmented tools fitted with brazed inserts, therefore, can produce holes that are good enough much quicker than a gundrill can. The advantage is that buying another machine is unnecessary.

Power and rigidity are factors that can limit the success of drilling deep holes on machining centers and turning centers with segmented tools. "The machine must generate enough power to move the tools at the required penetration rates and have the rigidity to feed past 10 times diameter," says Yakamavich. "Because of the high axial forces produced while running segmented tools, a solid mechanical feed is necessary." Rack and pinion drives can be acceptable, but ballscrews are best.

Although Yakamavich just fitted some machining centers in a shop in Maine with ejector systems to produce holes in turbine wheels, he is quick to point out that the time spent drilling and the machines available on the floor often can dictate a different decision. "If the time spent drilling holes versus performing other operations is high, it might warrant pulling the work off a machining center and putting on a drilling machine," he notes. "Gundrills are popular below 1/2 in. diameter, so many consumers use gundrills over 1/2 in. diameter simply because they have the machines."

A fit for moldmakers

Job shops with limited funds for capital investment need not choose between the two processes, though. Dadson offers machines that can run both gundrills and BTA single-tube tools. The latest example is the new horizontal deep-hole drilling center that the builder tailored to moldmakers. "It gives them the option of going either direction by letting them switch between the two tool systems without a major overhaul to the machine," says Gilman. "A conventional gundrilling machine would need major surgery to run a single-tube tool."

His spindle module, on the other hand, already contains the necessary channels, valves, and connections for attaching the components necessary for running either style of drill. He reports that converting the machine to run a different style takes about an hour. At the front of the spindle, the operator fits the module with either an air bushing and chip box for gundrilling or a pressure head and coupling for single-tube drilling. At the rear, the operator fits the spindle module with either a rotary union for gundrilling or a coolant discharge fitting and hose for single-tube drilling.

The changeable components accommodate the difference in the way the two drilling processes exploit the cutting oil. In gundrilling, high-pressure oil enters the delivery channel through the back of the spindle, travels down the center of the tool, and exits the tool into the cutting zone through a hole at the tool's tip. The oil flushes chips from the bottom of the drilled hole, driving them through the flute on one side of the drill and into the chip box. In single-tube drilling, a pump introduces the oil to the front of the spindle, injecting it into a pressure head that forces it down the OD of the tube into the cut and creates a vacuum in the center of the tube. The vacuum sucks the used oil and chips through the tube and out the back of the spindle.

Besides designing the spindle module to accommodate flow in both directions, Dadson's engineers fit it with a motor large enough to drive both processes. "As a rule of thumb, the single-tube process requires twice as much power as a gundrill because it cuts much faster," explains Gilman. "Most 1-in. gundrills will use a 5-hp motor, for example, but 1-in. single-tube tools need a 10-hp motor. So a conventional 1-in. gundrilling machine cannot make a hole with a 1-in. single-tube tool."

Eldorado is another builder that sees potential among moldmakers. To broaden its offering to this niche, it is working with Wesel Mfg Co (Scranton, Pa) to introduce a three-axis CNC column-type knee machine that can come with an optional fourth W-axis for the gundrill shelf. "Wesel will be putting our Mega 75 [3-hp, 1400–11,500-rpm] heads on two of its column machines," says Klembara. "They should be big sellers for us because many people are looking for a bigger table and a greater range of travel in the Y-axis." The worktables will be 48 x 54 and 48 x 72 in., and the X, Y, and Z travels will be 48, 54, and 48 in. and 72, 72, and 48 in.

Meanwhile, Eldorado also is developing a manual knee-type gundrilling machine fitted with a digital readout. "It's for small shops not drilling many holes," notes Klembara.

Milling on a gundrill

Over the last five years, TBT has redesigned its entire drilling machine line for offering more capability and performance. Perhaps the best example is the builder's BW series. The deep-hole drilling centers can cut with gundrills, single-tube drills, and conventional rotating tools, such as milling, chamfering, and tapping tools. The enabling technology is a clever drill-bushing carrier that holds a secondary spindle powered by the main spindle's motor. At changeover, the carrier swivels to bring the secondary spindle and drive shaft into position and slides away from the work to convert the machine into a machining center.

To return to deep-hole drilling mode, the carrier swivels again to move the secondary spindle and drive shaft out of the way and slides toward the work to present the bushing. Designed for deep-hole drilling, the main spindle then takes over. The main spindle has a direct-drive motor, and toolchangers and bushing changers are available.

Eliminating external drives was one of the design goals for another line, the ML series. Because the two models in this series are for drilling deep holes as small as 0.9 mm, TBT's engineers specified spindle motors that produce as little vibration as possible. "When drilling a 1-in. hole, the spindle drive doesn't make much difference," says Van Sickle at Kadia TBT, "You can use a timing belt, a V belt, or gears. When driving a 1-mm drill, however, we must use motor spindles that have no belts to slap and slip and no gears to chatter because they run as fast as 24,000 rpm. A little bit of vibration can shatter a 1-mm carbide drill."

Moreover, the design improves surface finish and dimensional accuracy. "You don't see the recurrence of harmonic lines," says Van Sickle. "For example, a timing-belt drive will produce a spiral pattern." The machines also can come with a tailstock that rotates the work in the opposite direction of the tool to reduce runout.

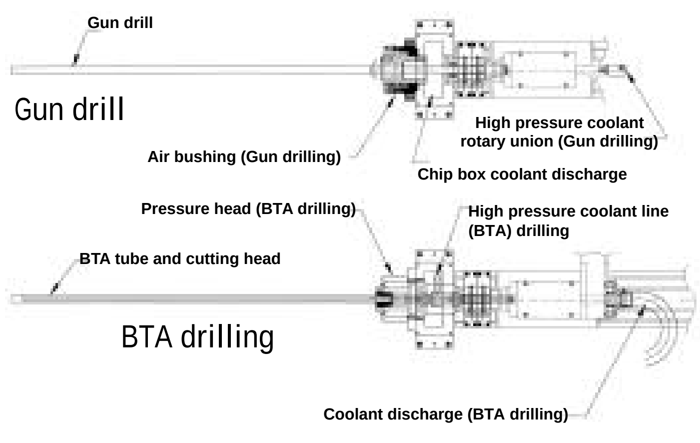
Transfer line too slow

To get both speed and accuracy from deep-hole drilling, Arcade Systems Inc (Macomb, Mich) fits its dedicated gundrilling machines with more than one spindle. In fact, a transmission plant in Indiana found that these machines were more productive than transfer machines at drilling 0.25–0.375-in. diameter blind holes axially in a family of five input shafts and sinking 0.188-in. diameter cross-holes from the outer surface to the center holes. Oil flows into the shafts from each end and out the cross-holes to lubricate the transmission.

The concept that Arcade and its customer developed was to put the deep-hole and cross-hole drilling operations onto separate multi-spindle machines. To create the axial holes, the builder created a gundrilling machine with two six-spindle modules that work on each end simultaneously. "Getting more than 150 pieces/hr from a gundrill at the required depth meant drilling six shafts at a time," explains Marble. "With chip loads of only 0.0005 to 0.001 in. and feed rates of 4 to 5 ipm, gundrilling takes a long time to make 6 to 7-in. deep holes. So we had to gang six of them to meet quotas." Cycle is 120 sec, and output at 100% efficiency is 180 shafts/hr.

Burr-free, straight holes are important specifications for the shafts. Because a rigid setup and a consistent feed are critical for delivering a clean and accurate hole, the shafts arrive at the machine clamped to V-grooves in a special quick-change fixture, and the machine clamps the guide bushing against the part hydraulically for starting the hole. To prevent any backlash or slop, the machine also uses preloaded linear bearings and ballscrews to feed the drills. The ballscrew is anchored on both ends for rigidity and has a fine pitch for creating a steady, uniform feed.

Once the hole is started, the hole becomes the guide bushing. The overriding concern then becomes controlling the chips to prevent packing. "A gundrill is essentially a long piece of extruded steel with a carbide tip brazed on it," notes Marble. "So it's not very durable. A good, consistent servodrive and rigid ballscrew with preloaded bearings and fine pitch are necessary to keep chip load constant." A uniform chip load ensures that the chip's thickness does not vary, becoming either too thin to break readily into small pieces or too thick to keep the torque on the tool within safe limits. High-pressure oil flowing through the tool between 600 and 1000 psi helps to break the chips and flush them from the hole through the flute.



Major surgery is unnecessary to convert this Dadson horizontal deep-hole drilling center to run both gundrills and BTA single-tube tools. The spindle has modular components on each end to allow the operator to switch drilling modes in an hour

To alert the operator to any problems that might damage the drill, the gundrilling machine contains three feedback systems. Vibration monitors from Montronix Inc (Ann Arbor, Mich) detect sudden jarring motions from chip packing or loose fixtures. Other indicators of packing are the flow meters that measure the oil flowing through the spindles. Low or no flow means that a flute is plugged and tells the machine to retract the units immediately to save the gundrill. The third group of sensors measures power consumption to guarantee a minimum draw, which indicates that the motor is driving the spindle. The purpose is to prevent the machine from feeding and cracking a tool idled by a broken belt or other spindle problem.

Another advantage to abandoning the transfer concept was the simplicity in changing from production of one shaft to production of one of the four others. "Changing nests and locating fixtures in a 10-station transfer line is a nightmare," notes Marble. "Operators at the transmission plant unscrew four bolts, remove the fixture plate, insert another fixture plate, and maybe change a tool if the diameter changes." Changeovers, therefore, are not time-consuming and cost-prohibitive.

Because the machine performing the cross-drilling operations is an adaptation of the builder's three-axis horizontal machining centers, the only extra step for that machine at changeover is selecting the appropriate program in the CNC. The 12-spindle machine spots, chamfers, drills, and deburrs the cross holes on one side. It then rotates the same tombstone fixture used in the gundrilling operation 180° to repeat the operations on the other side.

Retrofit an MC or lathe

Buying a gundrilling machine or a deep-hole drilling center is not always necessary, according to Doug Holley, managing director, Drill Masters of Vermont (North Bennington, Vt). When budgets are tight, he suggests retrofitting a CNC lathe or mill with his company's Spraymist dispenser and deep-hole drills. "The cost is $1500 as opposed to $100,000 for a new machine," says Holley.

He adds that his company's retrofit kit also is less expensive than a conventional retrofit with a new high-pressure pump and delivery system. The Drill Masters retrofit kit, contains four elements: a high-performance Spraymist dispenser; either stationary or rotary toolholders for the lathe or machining center; high-lubricity, water-based cutting oil; and some of the supplier's carbide tipped, coolant-fed drills.

"Our system can produce holes as deep as 70 times diameter and hold diameter, straightness, and surface finish to the same tolerances possible on a dedicated drilling machine," claims Holley. The only drawback is that overall speeds and feeds are generally 60 to 70% of those possible on a drilling machine. The ability to keep the work on the same machine cutting its other features can make this drawback irrelevant, however. The retrofit can eliminate the cost of outsourcing for shops that do not have dedicated drilling machines.

The Spraymist dispenser is key to the retrofit kit's economy and performance. Rather than supplying a stream of straight oil, the apparatus delivers a mixture of air and mist at 80 to 125 psi through the tool to the cutting zone. An extreme-pressure package in the oil-water mist enhances tool life and helps the outer pads on the tool to burnish the hole. Because the fine particles of water-based lubricant are traveling at high velocity, the fluid also produces a "refrigerant" effect at the tip of the tool by absorbing heat as it evaporates. The air stream blows dry chips from the hole.

With a conventional stream of cutting oil comes fluid filtration and maintenance, leaks, and disposal costs and liability. "Our system is much cleaner because the spray mist is absorbed almost completely by the cutting action," notes Holley. "Other high-pressure cutting fluid systems rely on the hydraulic action of the coolant to force the chips from the hole. So pound for pound the spray is much more efficient."

His company offers three styles of carbide-tipped drills to work with its spray coolant. The first two, a gundrill and a half-round drill, are single flute drills that cut on one side of the hole, have low power requirements, and are self-piloting once started with a bushing or in a short pilot hole. Both form chips that curl back upon themselves tightly to clear the hole easily and produce burnished holes with very little drift. Holley reports that his engineers recommend the half-round drill more often for the spray mist because of its 60% chip-clearance advantage over the V-flute gundrill. The gundrill has the advantage, however, in deep holes more than 30 times diameter and in some low-feed applications.

The third style, the Twinmaster, is a two-flute drill. Engineers at Drill Masters reserve this deep-hole tool for jobs that need speed more than accuracy. A Rota-V joint at the end of the tool rotates and angles the brazed surfaces on the tip and tube at 45° to enhance the strength of the carbide tip. According to the manufacturer, tests prove that the positive lock allowed an unbrazed version to drill through solid steel. Typical accuracy on mills and lathes with brazed tools is 0.002 in. on diameter and 0.002 ipi on straightness, but gundrilling machines using the tool can achieve better accuracy.