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INSIDE JOB

CNCs and bottle-boring tools allow the machining of complex profiles in deep bores.

For years, tool and machine limitations discouraged manufacturers from cutting complex profiles in the deep cavities of components. This prevented them from taking advantage of the weight savings and strength benefits inherent in such parts. They often settled for components that were cast, forged or consisted of subassemblies.

The reason why is because only single-point tools were available to produce internal profiles and contours in deep bores. Problems related to chip control and maintaining dimensional accuracy often arise when boring holes with depth-to-diameter ratios greater than 8:1.

The single-pass (or one-hit) bottle-boring tool—introduced in the early 1960s—was designed to counter these problems. Its single-action cutter opens after the tool passes through the narrow entrance to the bore and is inside the part's larger interior chamber. The cutter closes when the tool retracts.

The one-hit bottle-boring tool enjoyed limited success, primarily in the oil patch industry. However, the tool's inability to make multiple passes, combined with the limited sophistication of machine tools at the time, prevented one-hit bottle-boring tools' use on parts requiring tight tolerances and fine finishes. Many engineers considered bottle boring deep holes in high-value parts an unacceptable risk.

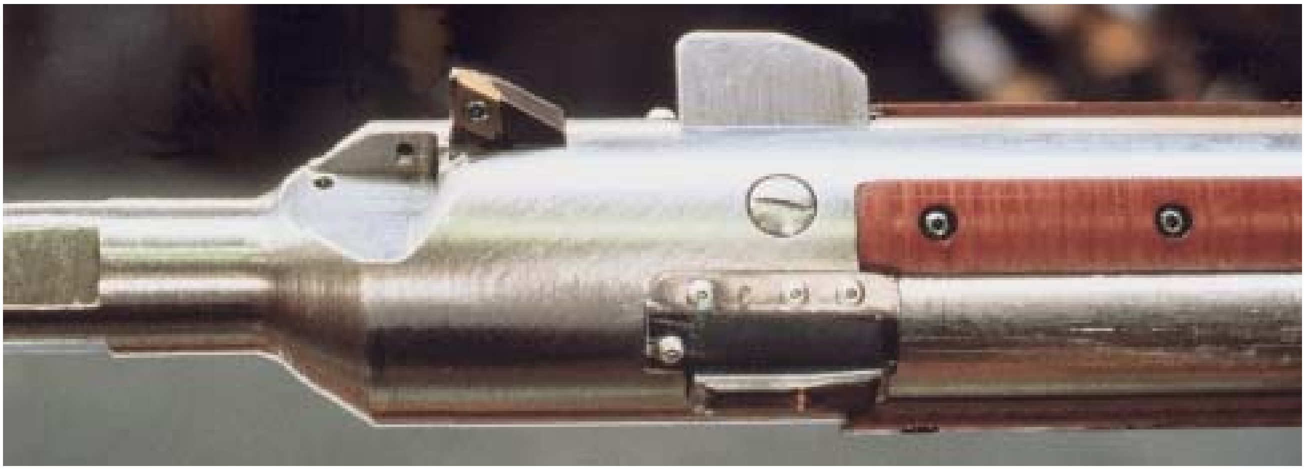
The marriage of the machine tool and CNC technology changed that. CNCs make it possible to interpolate complex and multiple cutter paths. This, in turn, allows bottle boring to satisfy industry's desire to machine deep, complex-profile bores.

CNC technology also spurred development of multiple-cutter bottle-boring tools, which initially were developed for aerospace applications in the early 1970s. These tools, designed with positive supports, produce high-quality bores. They are accurate and fast and permit the processing of a wide range of materials, including difficult-to-machine alloys such as AerMet 100. The tools feature replaceable cutter tips, are used to machine turbine shafts and landing gear components and are capable of remachining undersized bores.

Aerospace companies have been at the forefront in adopting the bottle-boring process, because it enables them to take advantage of stronger, lighter materials. Conversely, other industries continue to compromise design strength and look for ways to avoid whittling their components from a single piece of steel.

Process Parameters

Bottle boring, also called "chamber



American Heller

Bottle-boring tools are similar to form tools except that they must start with a bore diameter that is smaller than the interior of the workpiece. Shown is a chips-forward bottle-boring tool with its cutter and hydraulic guide pads extended.

boring," aptly describes the process. The tool first enters the workpiece through a "bottleneck." It then hollows out a deep, precise cavity before retracting.

The process is more difficult than it sounds, because the tool must efficiently evacuate all kerf and chips from the cavity. Chips are flushed from the part ahead of the tool when bottle boring through-holes. But in blind holes, chips must be drawn through the intricate, component-packed tool and exhausted out through the tool body, drive shaft and bottleneck.

A deep-hole drilling machine is recommended for bottle boring because of its long Z-axis travel and ability to introduce and circulate the tremendous amount of coolant needed for proper chip evacuation—usually 20 to 25 gpm per inch of tool diameter. Adaptive packages for bottle boring on conventional machines are available, but, with their shorter Z-axis travels than deep-hole drilling machines, insufficient coolant capacity and chip evacuation could result.

Another reason to use a deep-hole drilling machine is the crucial task of machining the "pilot bore." It must provide a dimensionally precise, concentric and straight support for the bottle-boring tool's head. All subsequent operations, including the machining of the chamber's features and its surface finish, depend on the quality of the pilot bore. To meet stringent requirements at the extreme depths involved usually necessitates the use of such a machine to produce the pilot bore.

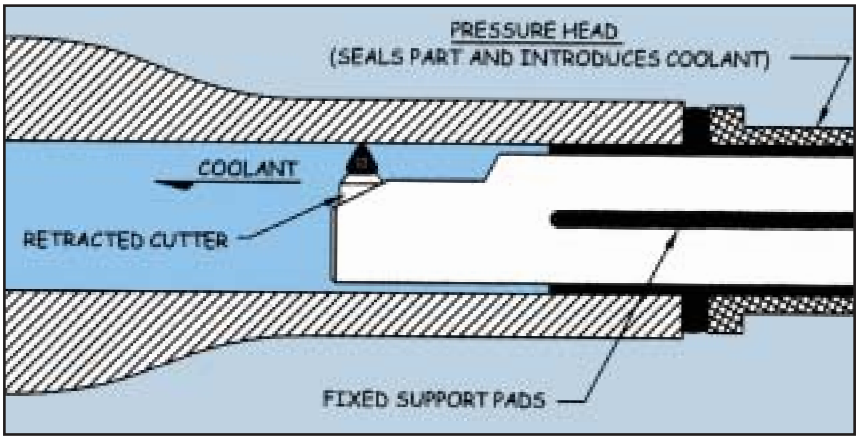


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Figure 1: Supported by its fixed support pads, a bottle-boring tool with its cutter retracted enters a through-bore workpiece. Coolant is forced through the workpiece by the pressure head and is exhausted out the opposite end.

(Deep-hole drilling machines cost some $600,000.)

In operation, the bottle-boring tool initially is supported and guided by fixed support pads embedded in the tool (Figure 1). The pressure head, sometimes called the coolant-induction unit, seals the opening of the bore and introduces a pressurized stream of coolant into the bore. Once inside the bore, the cutter emerges from the tool body and begins to feed out in the X-axis and cut material as it advances along the Z-axis.

(Because the tool is inside the part, gauging the efficiency of the cutting action requires the operator to examine the chips exhausted from the bore. Chips will be "6"- or "9"-shaped if the cutting parameters are optimal. The operator also should pay extremely close attention to all available machine tool and CNC instrumentation.)

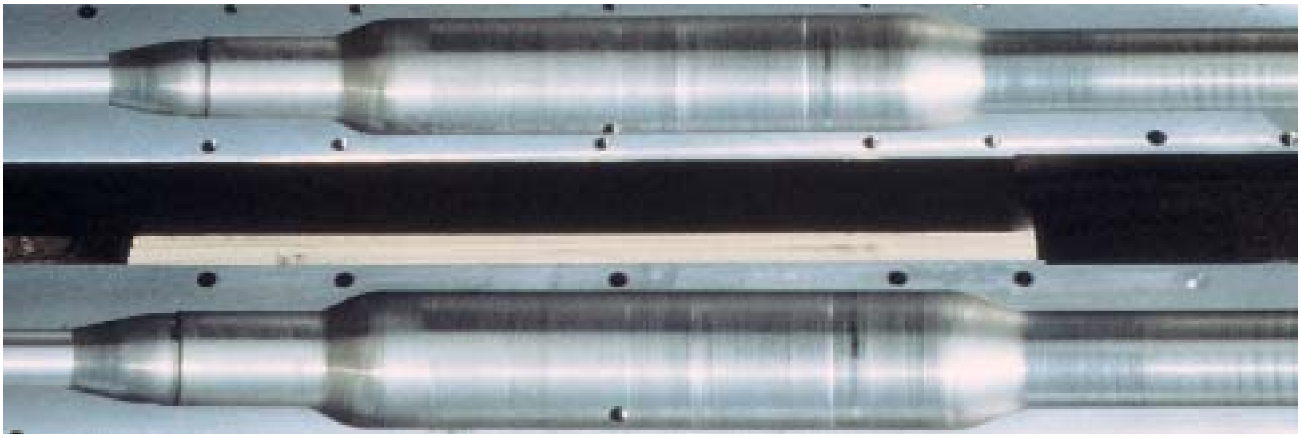
On subsequent passes, feeding in the Z-axis, the cutting tool extends further out to take the required DOC (Figure 2).

The NC processor interpolates the internal profiles with absolute precision, directing the tool's movement in all axes.

The diameter produced is guaranteed concentric to the pilot bore in the beginning from the support and guidance provided by the fixed support pads. When you get deep enough, an additional support pad is required. Housed within the bottle-boring head, the additional support pad is hydraulically actuated and controlled by the CNC.

Careful control of pad pressure is vital to ensure chatter-free cutting and minimal tool deflection, especially when boring tougher alloys. Pad pressure ranges from 50 to 300 psi.

At the completion of the Z-axis travel, the cutter and hydraulic support



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A bottle-bored prototype of a turbine shaft.

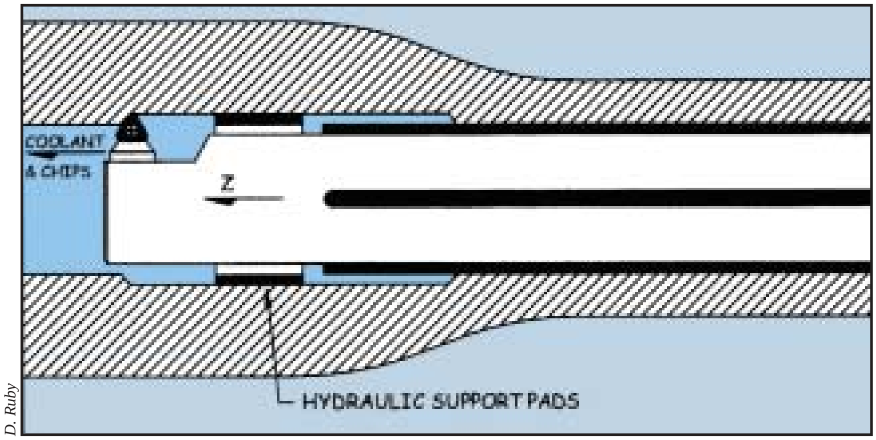

Figure 2: Having had its cutter extended and having made at least one pass along a workpiece's Z-axis, a bottle-boring tool reaches a depth where additional support is required and its hydraulically actuated support pads are extended via CNC.

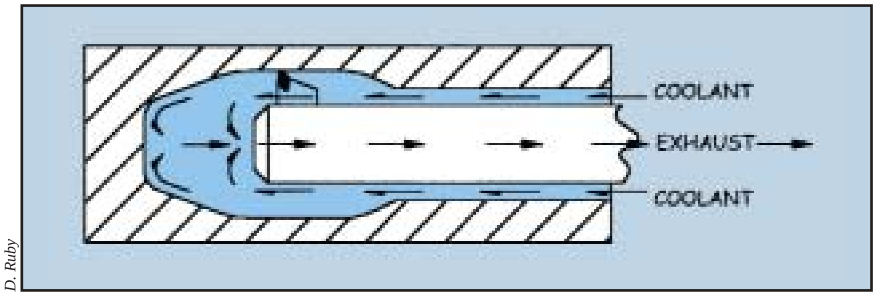

Figure 3: To evacuate chips from a blind-end bore, high volumes of coolant are forced into the bore along the outside of the tool. The coolant and chips are exhausted through the center of the tool.

pads retract into the tool, and the boring bar returns under rapid-traverse in the Z-axis direction.

The sequence repeats with increased values of cutter DOC, until the desired workpiece dimensions are achieved.

The final pass is at a reduced DOC and feed to produce the required finish.

Time Saver

When bottle boring, it's critical to adhere to recommended cutting parameters.

"Optimum cutting results in both roughing and finishing will be obtained when the speeds and feeds approach those specified by the carbide producer for turning with the carbide grade appropriate for the component's material," said Dick Sollich, vice president, American Heller Corp., which is headquartered in Macomb, Mich.

He added, though, that steps can be taken to fine-tune the operation. For example, careful adjustment of the support-pad pressure while manipulating the speed and feed can eliminate chatter.

The operation needs to be repeatable before any experimentation should begin, Sollich said. "Start with conservative cutting data and be aggressive with the coolant."

If done correctly, bottle boring can deliver accurate, machined features in far less time than other methods for producing deep bores.

Sollich said one aerospace customer recently chopped 20 hours off the time required to machine a deep-bore landing gear component by switching to bottle boring. The initial process for machining the modified 4340 alloy steel component by applying a single-point boring tool took 24 hours. Bottle boring the same part takes 4 hours.

The part is 36" long. The initial (blind) pilot hole is 1.750"×33.0". The finished bottle-bore ID is 2.497" (±0.003"). The bottle-bored hole finish is 63 rms maximum.

The bottle-bore starts at 21.0" deep, with a 30° opening angle and a 1.00" radius blend out to the 2.497" bore. The bottle bore end, or breakout, is at 32.5", with a 1.00" radius corner at a 45° angle.

The substantial reduction in machining time resulted from better chip control and the elimination of chatter and poor size control problems experienced with the original, single-point boring operation, which was performed on a conventional lathe.

Time to Rethink

Among man's most impressive technological feats is the engineering created to enable a jumbo jet to lift off the ground and take to the air. Of course, what goes up, must come down, and it is also no small accomplishment designing landing gear that can take the stress of that weighty plane touching down on a runway.

Bottle boring allows elongated landing gear parts to be machined out of one piece of material, delivering superior strength while reducing weight. Thanks to the experience suppliers have gained from these and other real-world applications, designers who have shunned deep-hole part configurations can revisit the premise and perhaps improve their products and their operations.

About the Author

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