Why gundrills?

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Gundrilling, one of the basic and frequently performed material removal processes in the automotive, die and mold, and turbine industries, is becoming increasingly more complex, demanding, and experiences an unprecedented growth. In spite of significant increase in the demand for economically producing holes and for process reliability, gundrilling and gundrill manufacture are still considered an esoteric art, and there still exists a lack of knowledge on the exact relationships between the point geometry, the grinding process parameters, and the process mechanics, resulting in many methods for drill production and, consequently, in wide variations in process performance.

The gundrill was developed by early gunsmiths (France, Russia) who found it the best way to drill straight, true holes in long gun barrels. While gundrills still used for this purpose today, their use has been extended to an increasingly wider variety of applications. Modern gundrills constitute a family of self-piloting tools with external chip removal. Most applications of these tools stem from the original purpose of the gundrill - to produce straight, true, deep holes - for therein lies its greatest value. When such tools are properly used, they are capable of maintaining hole size within *IT 6 - IT8* tolerances, surface finish within *Ra 26-32* (*0.6 - 0.8 mm*), and position tolerance (hole axis straightness) as good as *0.004" per 3 feet* (*0.1 mm per 1 meter*) of the machined hole. With these high capabilities, it was inevitable that the use of these tools should become much more widespread.

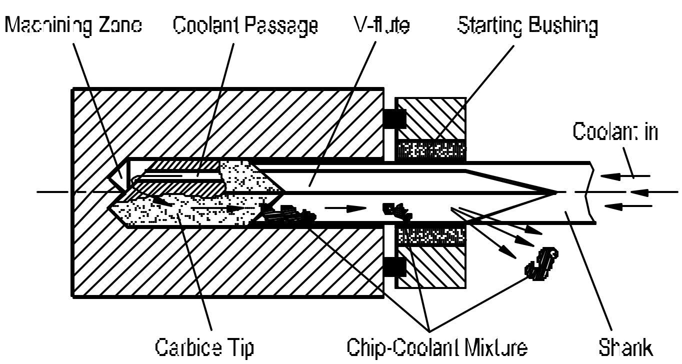

Fig. 1. The working principle of the gundrill.

The working principle of a gundrill is shown in Fig. 1. The coolant is supplied at high pressure to assure the sufficient flow rate to the tubular shank having V-shaped flute on its surface. Flowing through the coolant passage in the tip, the coolant enters the machining zone where is cools and lubricates the cutting edges and supporting (bearing) areas. Then the coolant enters the V-flute where it pick-ups chips formed at the cutting edges to transport them along the V-flute into the chip box.

Despite the gundrill's many obvious advantages, their usage is still restricted. There are several reasons for this. First, gun drilling is somewhat of a "black art" in that few individuals fully understand its working principles. As a result, gundrills are commonly misused, abused, and either under-utilized or over-worked. Lastly, the machines they are run in are often not entirely compatible with the gundrill's special requirements for rigidity, coolant pressure, and spindle to bushing alignment. Our survey on gundrill design and application has revealed that 85-90% gundrills used today have severe design errors and/or manufacturing errors.

Among the design mistakes, the most severe is improper tool geometry caused by misunderstanding the basics of drill geometry. The severity of this misunderstanding is due to the fact that the geometry of gundrills defines entirely all other design and working parameters of these tools (although this fact has never been pointed out). Also, it is forgotten that a gundrill is a combined tool, which actually carries out two machining processes simultaneously, namely, drilling (by the cutting edges) and burnishing (deforming of the walls of the hole being drilled by the supporting pads). The gundrill geometry defines compatibility of these two processes because it directly affects the uncut chip thickness (chip load), the cutting force and its distribution (particularly the force for burnishing), the coolant flow in the machining zone (the cooling and lubricating of the cutting edges and the supporting pads), chip curling and breaking (chip shapes suitable for transportation along the V-flute), and the pick-up of the chip formed for its further removal along V-flute. It should not be a surprise that the gundrill tool life and the quality parameters of the machined holes depend to a large extent on this geometry. Besides, complex and strict interrelationships exist between the geometry parameters of gundrill so that they cannot be selected independently on the basis of design convenience as with many other cutting tools.

Improper gundrill designs and applications were probably the prime foundations for a legend that the so-called STS (Single-Tube System) drills have overhauling advantage over gundrills showing up to five-fold higher productivity. This legend is actively promoted by Sandvik Coromat Co who climes that STS deep-hole drills double drilling throughput compare to gundrills (see for example "Single-tube systems doubles deep—hole throughput" – Machine Shop Guide Web Archive, 1999, http://www.machineshopguide.com/pdf/Singletubesystems.pdf; "Drilling deep in tough materials. Landing gear manufacturer gains 50% productivity" Tooling and Production, 1999, http://www.manufacturingcenter.com/tooling/archives/0299/299drl.asp) or that a STS drill is 4-5 times faster than a gundrill (http://www.coromant.sandvik.com/sandvik/0110/Internet/I-Kit1/se02673.nsf/Alldocs/Products*Drilling*Deep_Hole_Drilling*Brazed). Such comparisons are often unfair due to the difference in quality of the tools to be compared. A conventional gundrills having a number of design and manufacturing flaws and made of relatively low quality of carbide of not even suitable grade is compared with the STS drill optimized for a given operation and equipped with the cutting edges made of superior carbide selected for the application.

We shell show that this claim is not sufficiently supported by the known facts. Besides, the cost per unit length of the drilled hole, which is the proper measure of the process economy, should be of prime concern.

The working principle of a STS drill is shown in Fig. 2 The coolant is supplied at high pressure to the pressure head. Flowing through the annular coolant passage formed between the boring bar and the wall of the hole being drilled, the coolant enters the machining zone where is cools and lubricates the cutting edges and supporting (bearing) areas. Flowing into the chip passages made in the drill head, the coolant picks up the chip formed by the cutting edges forming the chip-coolant mixture. This mixture flows along the internal chip removal channel of the boring bar.

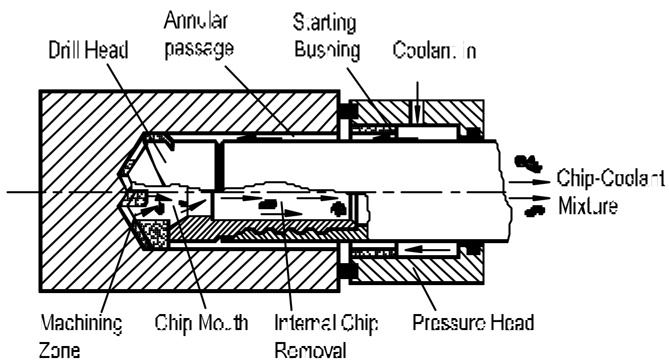

Fig. 2. The working principle of the STS (BTA) drill.

Comparing the theoretical productivity of drilling by the discussed two methods, we should remember that the drill penetration rate *P*, in/min (mm/min) is the product of the drill rotational speed in r.p.m., *n* and the feed per revolution, *f* , in/rev (mm/rev), i.e. $P = n \times f$. In turn, the drill rotational speed in r.p.m., *n* is only determined by the tool material providing that the parameters of the drilling system (alignments, accuracy of motions, clearance in the starting bushing, etc) are the same. Therefore, if the tool material for both gundrill and STS drill is the same, there is no ground to believe that the later can utilize a higher speed. The feed per revolution is mainly restricted by the so-called buckling stability of the shank (or boring bar in case of STS drills). It is true that the buckling stability is approximately 30% higher for the annular boring bars used in STS drill than for crescent shanks used in gundrills. However, when feed increases, the chip becomes thicker and breaks into larger pieces that present the problem in its removal through the smallest cross-section in the drill head called the chip mouth (Fig.2). Although the problem may be partially solved by using STS drills having multiple cutting edge, this solution is not feasible for STS drill having diameter less than 0.78” (20 mm).

Chip formation and chip removal are two serious issues in deep-hole machining. When gundrill is designed properly, these two present no problem in gundrilling. As such, drill wear normally does not significantly affect the shape of the chip and has no effect on chip breaking. The V-lute of the shank and the wall of the hole being drilled form the chip removal channel so that one side of this channel rotates relative to the other. It prevents chip the formation of chip plugs in the chip removal channel.

In the contrary, these two issues are always the problems in STS drilling particularly when the diameter of hole to be drilled becomes smaller. The chip shape is determined by the parameters of the chip breaking steps ground on the rake faces of the cutting inserts. When tool wears, these parameters change and so does the chip shape. The formed chip should pass through the chip mouth which minimum cross-sectional area is much smaller than the rest of the chip removal channel and thus often limits chip removal reliability. These two problems become more severe in drilling difficult-to-machine high alloys when ship becomes longer. The same problem is observed in drilling light metals such as aluminum when a great amount of chip is produced per unit time due to high feed rates used.

The application of STS drills requires higher coolant flow rate because the cross-sectional area of the chip removal channel is much larger. As such, if the chip is to be transported at the same velocity of the coolant flow, a much higher flow rate is needed. Consequently, larger pumps, filters, chip separators and other hydraulic equipment should be utilized. The coolant tank becomes larger because its minimum volume is determined as the minute flow rate times ten. As a result, the cost associated with coolant purchase, handling, and disposal grow significantly.

When a gundrill is properly designed, its tool life is always higher than that of an STS drill of the same diameter due to numerous reasons. The most significant among them are:

- The coolant pressure in the limited space "flanks of the drill-bottom of the hole being drilled" can be adjusted to **any** desirable value without affecting the overall flow rate. As a result, the coolant under high static pressure is supplied to the places where it is mostly needed, namely into the flank contact areas. In the contrary, it is impossible to increase the static coolant pressure in STS drills without affection flow rate. As the result, the static coolant pressure in the limited space "flanks of the drill-bottom of the hole being drilled" is very low and does not help much in protecting the flanks. Moreover, there are a number of stagnation zone in this space where partial vacuum instead of high pressure is the case.
- In the re-sharpening of gundrills, the only flanks are ground off. It opens a possibility to create any desirable profile of the cutting edge and the rake face shape to suit any pre-calculated distribution of the rake angles along the cutting edge. In STS drills, the rake face should be made with a chip-breaking step that limits is shape.

Another significant advantage of the gundrills is a possibility of their use on CNC machining centers as one of multiple operations with minimum efforts. As such, a predrilled hole is used as the pilot hole that eliminated the need of the starting bushing.

The comparison of the gundrill with STS (STS (BTA)) and Ejector drills are shown in the table. We have to point out that the reasonable range of the hole diameter for gundrilling is 0.08" (2mm) – 1" (25mm) where the gundrill shows the maximum advantage over STS and Ejector drills.

Gundrills

ADVANTAGES	DISADVANTAGES
1. Good surface finish and close tolerance of the machined holes. 2. Cab be used for drilling holes of small diameter (from 0.04" – 1mm). 3. The same nose geometry can be used for a wide variety of work materials (for example, most of mold and die shops use the same nose grind to drill 4130 steel and P20 high alloy). If necessary, this geometry can easily be changed on re-sharpening. When needed, geometry of the drill can readily be adjusted to suit practically any work material. 4. Simple tool design results in relatively low cost of gundrills. Moreover, after many re-sharpenings, the gundrill can be re-tipped at relatively low cost and used again. 5. A common gundrill allows 8-15 re-sharpening Simple re-grinding (re-sharpening) procedure and its inspection that can be accomplished by an operator in the shop floor. 6. When a gundrill designed properly, it had relatively (compare to STS (BTA) and Ejector drills) long tool life because it is possible to supply high-pressure coolant directly to the flank-workpiece interface. 7. Compare to STS (BTA) and Ejector drills, much less sensitive to the misalignment of drilling machines to the clearance between the starting bushing and the drill tip. It make it possible to use these drills on different kinds of machines ranging from versatile multi-spindle screw machines to high-volume special transfer lines in the automotive industry using pre-drilled (on the previous operation) hole instead of the starting bushing. 8. Simple change to another drill of different diameter. 9. Relatively (compare to STS (BTA) and Ejector drills) low coolant flow rate required. 10. Gundrilling machines and their accessories are much less expensive compare to those for STS (BTA) and Ejector drills.	1. Relatively (compare to STS (STS (BTA)) and Ejector drills) low productivity due to relatively slow feeds. 2. Difficulties in re-sharpening of long gundrills of small diameters. 3. Require higher coolant pressure. 4. Smaller allowable length-to diameter ratio. 5. Not economical for diameters more then 2" (50 mm).

STS (STS (BTA)) Drills

ADWANTAGES	DISADVANTAGES
1. High productivity. 2. The highest possible (compare to gun- and Ejector drills) length-to-diameter ratio. 3. The highest possible (compare to gun- and Ejector drills) length-to-diameter ratio. 4. Special tool heads that may combine a number of different operations (as counter/finish boring, reaming, skiving and roller burnishing, trepanning, pull boring, chamber boring, forming tools) can be used. 5. Theoretically, there are no restrictions on the upper limit of the diameter of the hole being drilled. 6. Different carbide grades can be used for different parts of the cutting edge.	1. Significant down time to change a STS (STS (BTA)) installation to another diameter. 2. High sensitivity to the machine alignment and the clearance in the starting bushing. 3. Complicated re-sharpening procedure that can be only done in a specialized tool room. As a result quite often STS (BTA) drill of small diameters (where no mechanically clamped cutting inserts and supporting pads can be applied) are not subjected to re-sharpening. It significantly increases the cost of the deep-hole operation. When use STS (BTA) drill with mechanically clamped cutting inserts, the inserts adjustment is complicated and thus requires to be accomplished in tool rooms. 4. High sensitivity to the shape of the chip produced. The parameters of chip-breaking steps ground on the rake faces of these drill are usually a matter of experimental finding for a given work material. As a result, a STS (BTA) drill ground for one work material may not be suitable for drilling another although the latter may be quite close to the first by its chemical composition and mechanical properties. 5. Require special drilling machines, high qualification of operators, engineering support, and complicated maintenance procedure. 6. Require highest (compare to gun- and Ejector drills) coolant flow rate. It turn, high flow rate require big coolant tanks, powerful pumps, big filters, etc. This makes the coolant associated cost very high (including the cost of coolant disposal). 7.

Ejector Drills

ADWANTAGES	DISADWANTAGES
1. Can be used on a wide range of versatile machines. 2. High productivity. 3. Require relatively low pressure of the cutting fluid. 4. Different carbide grades can be used for different parts of the cutting edge. 5. Simple change of a worn drill head. A number of different drill heads can be with the same boring bar.	1. Cannot be made for drilling holes of small diameters (less than 20 mm). 2. High sensitivity to the machine alignment and the clearance in the starting bushing. 3. Very high sensitivity to the shape of the chip produced. It should be clear that ejector drills cannot handle any chip pileups. Compare to STS (BTA) drills in which the cutting fluid pressure increases automatically when a chip pileup forms and thus "light" chip plugs can be pushed through, ejector drills cannot tolerate any chip pileup due to a specific design of their hydraulic circuit. This is the major disadvantage of Ejector drills.