AAM Colfor Gundrilling Problem Solutions: Research Report

Facility: AAM, Colfor, Minerva OH
Line: Turbine Shaft 1, Turbine Shaft 2, C1 Main Shaft
Tool: Gundrills $\varnothing$ 8, 8.9, 9.6, 13.02, 14 mm

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September, 2006
EXECUTIVE PAGE

SUMMARY Gundrilling problems at AAM Colfor manufacturing facility were analyzed. Five groups of problems were revealed, namely, chip breaking coolant problems, part locating and clamping, drill sharpening and drill drawings. The problems short description and supporting evidences as well as some basic background are presented in the report body and in the Appendixes. A feasible solution for each and every problem is provided.

CONCLUSIONS
1. The root cause of all the observed problems is poor chipbreaking. It is caused by the improper machining regime, insufficient coolant flow rate, incorrect design and grinding of chipbreakers (for the gundrill with chipbrekers).
2. The observed oversizing of the machined holes is caused by improper design of the gundrills’ supporting areas. Improper part locating and clamping make this problem more severe.

RECOMMENDATIONS
1. Change the machining regime as recommended by this report. Particularly, the feed rate should be increased to promote chipbreaking.
2. Select the proper parameters of the chipbreakers and assign the proper tolerances on the selected parameters. Do not apply any hones on re-sharpnings. Redesign the supporting area of gundrills with chipbreakers.
3. Set the machine to deliver the sufficient coolant flow rate. Install a digital flow meter on each machine and set the corresponding limits in the drilling control program.
4. Assign the end chamfers of each shaft as DATUMS on the process sheet for the preceding turning operation. Add tolerance on the runout of these datums with respect to the datums assigned by the corresponding part drawings; assign tolerance on the chafers angle; add requirements for surface finish on the surface of both chamfers.
5. Make double-chamfer end on the spline side assuring that the burr formed on spline rolling does not affect the locating part of the chamfer.
6. Use a grinding fixture capable of reproducing facet flanks and step chipbreakers.
7. Use a fine grit diamond wheel (finer than 200) for finishing of the flank surfaces of the outer and inner cutting edge as well as for grinding the chipbreaker.
8. Use an optical device (microscope, comparator, etc) to inspect the results of re-sharpening.
Introduction

This report is written to address the gundrilling problems at AAM Colfor manufacturing facilities. PSMi assistance was requested to resolve the problems with excessive gundrill usage (due to tool breakage), chipbreaking, hole oversizing, and low tool life. AAM Colfor has three manufacturing lines (Turbine shaft 1, Turbine shaft 2, C1 Main shaft) where new gundrilling machines produced by Nagel Precision (TBT Automotive) are used.

Gundrill common design components and basic terminology used in this report are presented in Appendix 1.

Appendix 2 presents the analysis of hardness of the work material.

Problems and Solutions

1. CHIP BREAKING: Chip breaking is probably the root cause of all other reported gundrilling problems (for example, insufficient tool life, tool breakage etc) at AAM Colfor. This problem occurs for all the gundrill diameters used and persists even if a chip breaker is ground on gundrills of 9.600 mm and 14.000 mm dia. Figure 1 shows a consequence of the chipbreaking problem. As seen, the unbroken chip coils around the drill tip and then shank causing chip.
This, in turn, causes an increase in drilling torque that eventually breaks the tip (Figure 2). If the torque censor does not capture this moment on time, the feed continues that leads to separation of the brazed tip from the shank and to deformation (buckling) of the shank as shown in Figure 3. Note that this is a common gundrill failure mode when parameters and components of the gundrilling system are selected/designed improperly.

**Problem: Inappropriate machining regime**

**Problem short description – gundrills without chipbreakers**: There are two fundamental causes for the chipbreaking problem at AAA Colfor. First one is the inappropriate machining regime used. The second is the inferior gundrill design including the carbide grade, tip coating, tool geometry etc.

Among deep-hole drills, only gundrills are normally known not to have chip-breaking steps ground on the rake face which makes re-sharpening of gundrills much simpler and faster using standard grinding wheels and fixtures. In gundrilling, the chip formed at the inner cutting edge (see Appendix 1) should impinge on the chip formed by the outer cutting edge and thus should serve as an obstacle chip breaker. In other words, the collision of these two chip flows should result in the formation of the so-called backbone at their interface which, colliding with the rotating bottom of the hole being drilled (or, at worse, the side walls of the hole being drilled), causes the breakage of these two chip flows. This point is illustrated in Figure 4a.

The problem is in the direction of motion of this backbone. It is understood that the discussed direction would be a function of the cutting edge approach angles, machining regime, cooling conditions of the machining zone as well as of the location of drill point \( m_d \) (Appendix 1). Therefore, the optimum value of the mentioned parameters should be selected not only as that resulting in the maximum tool life but also as that which improves chip breakability avoiding its collisions with the side wall of the gundrill. When the discussed collision takes place, the wear of the side wall of the gundrill takes place as shown in Figure 4b. The discussed collision results in a
significant force acting on the side wall of the gundrill that may seriously violate the tool static stability and even break the tip as shown in Figure 2.

Figure 4. (a) Interaction of the chip flows from the outer and inner cutting edges and (b) wear marks left on the sideface of the gundrill as the result of improper selection of the approach angles.
Finding the discussed optimum combination of the regimes, proper carbide grade and geometry parameters of gundrills is the sole responsibility for the machine builder and gundrill supplier, i.e. TBT Automotive. PSMi will provide guidelines and practical help in finding this combination.

Problem-fix suggestions: Problem-fix suggestion for gundrills of 8.9 mm dia are discussed as an example as they have the most severe chipbreaking problems.


- Change the machining regime. The current machining regimes used today at AAM Colfor are presented in Tables 1 through 3. Table 4 shows the suggested starting cutting regime. As the formed chip (Figure 5) is already continuous-fragmental, i.e. consists of arc-like fragments connected by weak joints, an increase in the feed per revolution should lead to breakage of this chip into small fragments.

Machining regimes currently used at Colfor

### Table 1. Turbine shaft 1

<table>
<thead>
<tr>
<th>Drill diameter mm</th>
<th>rpm</th>
<th>Feed rate mm/min</th>
<th>Cutting speed m/min</th>
<th>Cutting feed mm/rev</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.9</td>
<td>3250</td>
<td>150</td>
<td>90.87</td>
<td>0.046</td>
</tr>
<tr>
<td>9.6</td>
<td>2000</td>
<td>150</td>
<td>60.32</td>
<td>0.075</td>
</tr>
<tr>
<td>14</td>
<td>2075</td>
<td>200</td>
<td>91.26</td>
<td>0.096</td>
</tr>
</tbody>
</table>

### Table 2. Turbine shaft 2

<table>
<thead>
<tr>
<th>Drill diameter mm</th>
<th>rpm</th>
<th>Feed rate mm/min</th>
<th>Cutting speed m/min</th>
<th>Cutting feed mm/rev</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.9 (counter rotation)</td>
<td>3200/90</td>
<td>155</td>
<td>92</td>
<td>0.047</td>
</tr>
<tr>
<td>9.6</td>
<td>3000</td>
<td>First stage 160</td>
<td>90.48</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Second stage 150</td>
<td></td>
<td>0.050</td>
</tr>
<tr>
<td>14</td>
<td>1700</td>
<td>180</td>
<td>74.77</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Table 3. C1 main shaft 2

<table>
<thead>
<tr>
<th>Drill diameter mm</th>
<th>rpm</th>
<th>Feed rate mm/min</th>
<th>Cutting speed m/min</th>
<th>Cutting feed mm/rev</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>3300</td>
<td>105</td>
<td>82.94</td>
<td>0.032</td>
</tr>
<tr>
<td>13.02</td>
<td>Entrance 2100, Drilling 2500</td>
<td>Entrance 110, Drilling 115</td>
<td>85.90</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Suggested starting cutting regime

<table>
<thead>
<tr>
<th>Drill diameter mm</th>
<th>rpm</th>
<th>Feed rate mm/min</th>
<th>Cutting speed m/min</th>
<th>Cutting feed mm/rev</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.9</td>
<td>3000</td>
<td>Entrance – first 5 mm, 110, The rest of the hole 180</td>
<td>84</td>
<td>0.037</td>
</tr>
</tbody>
</table>

Figure 5. Chip formed by the outer cutting edge of a gundrill 8.9 mm dia. on Turbine shaft 2 line.
Problem: Improper parameter of the chipbreakers

Problem short description - gundrills with chipbreakers: There are two basic problems with these gundrills. The first one is the incorrect design parameters of the chipbreakers. The second one is improper re-sharpening of the chipbreakers (see the analysis of the re-sharpening problems below).

Three basic parameters of a step chipbreaker are shown in Figure 6, namely length \( b \), depth \( h \), and radius \( R \). These are selected depending primarily on the cutting feed used (Astakhov V.P., Metal Cutting Mechanics, CRC Press, 1998/1999) and then refined experimentally by testing a tool for a given application. The found values of these parameters are valid only for the conditions of the test. Figure 7 shows the parameters of the step chipbreaker used at AAM Colfor. In my opinion, these parameters are incorrect that causes the above-discussed chipbreaking problems. First of all, the same parameters of the said chipbreakers are used for gundrills 14.000 and 9.600 mm dia. although the feed rate is twice lower for the later drill. Second, the radius \( R \) is not specified and thus controlled on sharpening and re-sharpenings.

Figure 6. Parameters of a step chipbreaker.

Figure 7. Parameters of step chipbreakers used at Colfor.
Another problem is an excessive hone applied on the rake face in the region of the cutting edge. Normally, a step chipbreaker should curve the partially formed chip to bring its end into the contact with the rotating bottom of the hole being drilled. This contact causes chip breaking in the root of the partially formed chip as shown in Figure 8a. However, if an excessive hone is applied on the rake face in the region of the cutting edge, the same chipbreaker would not work as the chip passes over it as shown in Figure 8b. Unfortunately, the latter is the case for gundrills used at AAM Colfor. An excessive hone can be clearly observed on a ground gundrill shown in Figure 9 that causes chipbreaking problems.

Figure 8. Step chipbreakers: (a) without hone, (b) with excessive hone.

Figure 9. Excessive hone.
Problem fix suggestions:

- Select the proper parameters of the chipbreakers. The optimum length (size $b$ in Figure 6) of the step chipbreaker should be selected around 13–14 times the uncut chip thickness. The depth $h$ should be equal to four times the uncut chip thickness, since the cutting forces become minimum at those parameters. So these parameters should be properly calculated and assigned by the drawing of each particular drill. The radius $R$ (Figure 6) should no exceed 0.7 mm.
- Assign the proper tolerances on the selected parameters. The tolerances on the dimensions $b$, $h$, and $R$ should be $\pm 0.1$ mm.
- Run the gundrilling test to find the optimal cutting feed. The optimal cutting feed in this context means the feed at which the most suitable (for removal) shape of the chip is produced in drilling.
- Do not apply any hones on re-sharpnings.

Problem: Improper design of supporting area

Problem short description – gundrills that enlarge the existing holes. Improper design of the supporting areas causes instability of gundrills 14.000 and 13.03 mm dia. as they are actually gunreamers and thus should be designed as such. Unfortunately, this is not the case so these two tools MUST be re-designed.

When a gundrill works, the cutting force is generated due to the resistance of the work material to cutting. This force is a 3-D vector applied at a certain point of the cutting edge as shown in Figure 10. The cutting force $R_c$ can be resolved into three components, namely: the power (tangential) component $F_T$, the axial component, $F_a$, and radial, $F_r$ forces, respectively (Astakhov, V.P., Galitsky, V.V., Tool life testing in gundrilling: an application of the group method of data handling, International Journal of Machine Tools and Manufacture, Vol.45, pp. 509-517, 2005). The axial force is balanced by the axial force of the feed mechanism of a deep-hole machine while the tangential and radial forces sum to create force $F_{xy}$ (acts in the $xy$-plane) which (in contrast to other axial tools as twist drills, reamers, milling tools) generally is not balanced. To prevent drill bending due to this unbalanced force, some special measures should be taken. The term ‘deep-hole drilling’ has grown to mean that the unbalanced cutting force generated in the cutting process is balanced by the equal and opposite force due to supporting pad(s), which bears against the wall of the hole being drilled. As such, the ‘deep-hole drill’ guides itself initially in the starting bushing and then in the hole being drilled so that it can be considered as self-piloted (Astakhov V.P., Gundrilling Know How, Cutting Tool Engineering, Vol. 52, pp. 34-38, 2001).

The above-discussed definition of self-piloting, however, refers to stable drilling conditions and is restricted only to the case where all forces acting on a gundrill are completely balanced as shown in Figure 11a. As such, the line of action of force $F_{xy}$ is within the angle $\alpha_{ab}$ of supporting continuum $ab$. This condition assures gundrill stability. However, if the same gundrill is set to enlarge an existing hole, i.e. when
only a part of the outer cutting edge is involved in cutting as is the case for gundrills 14.000 and 13.020 mm dia, the discussed force balance is violated so that the line of action of force $F_{xy}$ does not intersect the supporting continuum $ab$ as shown in Figure 11b. As such, an additional tilting moment arises that rocks the gundrill with respect of point $a$ towards the side cutting edge (Astakhov V.P., Galitsky V.V., and Osman M.O.M., An investigation of the static stability in self-piloting drilling, International Journal of Product Research, Vol. 33(6), pp. 1617-1634, 1995). As a result, the hair-line thin heavily deformed chip is produced (called SHAVINGS at AAM Colfor) that coils around the shank because there is no means for its breakage.

Because this side edge is not meant to cut, a significant force is generated during such cutting. This force ruins the side cutting edge as shown in Figure 12. Such a failure (chipping) greatly decreases the overall gundrill life as a gundrill worn in such a manner requires significant material to be removed on re-sharpening.
Moreover, the oversize hole is produced as the side cutting edge enlarges the hole being machined.

![Chipping of the side cutting edge in the region where this edge should not even be in contact with the workpiece](image)

**Problem-fix suggestion**: Redesign the supporting area as suggested in Figure 13a. As proposed, the supporting area consists of two supporting pads, namely \(ab\) and \(cd\) located angularly as shown in Figure 13a. As such, the line of action of force \(F_{xy}\) is within the supporting area that assures stability. An actual application of the discussed solution on a gunreamer is shown in Figure 13b.

![Figure 13. Proposed configuration of the supporting area: (a) force balance, (b) realization in a gunreamer.](image)
2. **COOLANT PROBLEMS:** These problems are of the same level of importance as the chip-breaking problem.

**Problem: Insufficient coolant flow rate**

**Problem short description:** High-pressure coolant delivery is necessary to cool the workpiece and the tool, to provide lubrication between tool and workpiece as well as to carry away chips from the cutting area along the flute to the chip box. The cooling action dissipates both the external heat of friction and the internal heat of plastic deformation due to cutting and burnishing. Lubrication between the workpiece and the drill contact areas reduces contact stresses and amount of the thermal energy generated on these areas so it reduces adhesion and/or diffusion wear of the gundrills. To effectively carry chips away, the coolant should possess a sufficient combination of viscosity and velocity. Improper selection of this combination causes chip plugs in the flute that lead to an increase in torque and drill breakage (Astakhov V.P., Farazao J., and Osman M.O.M., *Effective tool geometry for uniform pressure distribution in single edge gundrilling*, ASME Journal of Engineering for Industry, Vol. 116 (4), pp. 449-456, 1994).

The major problem with the coolant at AAM Colfor is in the coolant pressure and flow rate. The coolant flow rate and pressure are two important system parameters falling in the category of frequently asked questions on gundrilling because of the discrepancies in the data provided by different gundrill and gundrilling machine suppliers. It causes an ever-going endless discussion on the coolant pressure and flow rate – which one is more important and thus should be controlled in gundrilling? The answer to this question is unconditional and straightforward: **the coolant flow rate**. The coolant pressure must only be considered as means to assure the required flow rate (Astakhov V.P., *High penetration rate gundrilling for the automotive industry: system outlook*. SME Paper TPO4PUB249, p. 1-20, 2004). Unfortunately, this issue is not well understood by gundrill and gundrilling machine manufactures and end users. This misunderstanding causes a lot of problems.

There are two specific flow rates commonly considered in gundrilling. The first one is the critical 1 flow rate that assures the proper cooling and lubrication of the gundrill tip (reduction of tool wear) providing at the same time sufficient cooling of the forming chip and thus enhancing its breakage. The second one is critical 2 flow rate that assures reliable chip removal along the V-flure. Normally, the critical 2 flow rate at least twice greater than the critical 1 flow rate so the former is reported in gundrilling companies recommendations (Astakhov V.P., and Osman M.O.M., *An the improvement of tool life in self-piloting drilling with external chip removal*, Journal of Engineering Manufacture, Part B, Proceeding of the I.Mech.E. , Vol. 210, pp.243-250, 1996).

Apparently, the coolant flow rate provided by the gundrilling machines at AAM Colfor is less than the critical 1 flow rate as the inspected gundrills have severe burns along the bearing areas as clearly seen in Figures 14 and 15. Provided that Nagel (TBT Automotive) selected a suitable coolant for gundrilling applications, burns on the gundrill tip can occur if and only if the actual coolant flow rate supplied into the machining zone (a region around the tip) is a way too low. As a result, the tip
becomes so hot that even a temperature resistant TiN coating fails. As known (http://www.brycoat.com/tin/physprop.html), TiN coating begins to oxidize at 600°C (1112°F). Therefore, the temperature of the gundrill tips was higher than that as TiN coating fails as seen in Figures 14 and 15. Moreover, the lack of coolant flow rate causes poor chip breakage as the partially formed chip very hot and thus too soft to be broken (Astakhov V.P., Shvets S.V. and Osman M.O.M., Chip structure classification based on mechanism of its formation, Journal of Materials Processing Technology, Vol. 71/2, pp.247-257, 1997).

Figure 14. Burn on a gundrill on the front supporting area.

Figure 15. Burns on the both ends of the tip.
Problem fix suggestions:

- Request that Nagel (TBT Automotive) set the coolant supply systems to deliver the sufficient coolant flow rate. Figure 16 shows an example of the flow rate required (Botek). Note that the flow rate read from Figure 16 should be multiplied by four (the number of gundrill spindles used in each machine). For example, for a gundrill of 8.9 mm dia, the flow rate per drill should be 30 l/min per drill or 120 l/min for the corresponding gundrilling machine.

- Request that Nagel (TBT Automotive) installs a digital flow meter on each machine and set the corresponding limits in the drilling control program. As such, the coolant pressure can be excluded from the list of the controlled parameters. The mentioned flow meters are available at Nagel (TBT Automotive). This flow meter is similar to Omega flow meter [Link](http://omega.com/manuals/manualpdf/M4183.pdf#search=%22%20gundrill%20coolant%20flowrate%22).

![Figure 16. Recommended flow rates for gundrilling (Botek). As the length/diameter L/D) ration for the gundrills used at AAM Colfor is in the rage 40-50, the reading should be taken in the middle of the ban shown.](image)

**Problem: Unknown coolant brand**

**Problem short description:** The chemical management service to AAM Colfor is provided by Henkel Chemical Management. Unfortunately, Henkel was not given a chemical composition of the coolant used for gundrilling as well as the corresponding maintenance guidelines. It makes it next to impossible to figure out if this coolant is suitable for gundrilling operations at AAM Colfor at all. As per my discussion with Mr. Wheeler, Henkel sales manager, Henkel might have a better product for the application.

**Problem fix suggestions:**

- Request and obtain from Nagel (TBT Automotive) or coolant supplier the chemical composition and physical properties of the coolant currently used.

- Compare it with the products offered by Henkel and decide which coolant brand is most feasible for the application.
Problem: No coolant maintenance

**Problem short description:** An oil-based gundrilling coolant normally contains the so-called extreme pressure (EP) additives as sulfur, chlorine, fatty acids etc. The main objective of EPs is to reduce the heat generation during gundrilling and thus to improve chip breakage and tool life. Although the chemical composition of the coolant used is not known, strong smell of sulfur indicates the presence of this EP.

When performing its basic functions, the coolant deteriorates. For example, it losses EPs concentration, become contaminated with foreign materials, and develop foul odors. Other examples are reduced concentration, presence of tramp oil, water and foreign components (for example, zinc). Therefore, the maintenance of the coolant composition and its cleanness are of prime importance in gundrilling. Unfortunately today, there are no coolant control and maintenance schedule set for gundrilling operations. This might cause poor tool life, drill breakage problems and low quality of the machined holes.

**Problem-fix suggestions:**
- Request and obtain the chemical composition of the coolant currently used from the supplier.
- Check EP concentration on a weekly basis and, if necessary, add the required EP(s) to maintain the targeted concentration.
- Check particle count in coolant on a weekly basis keeping the maximum size of particles found in the coolant no more than 5 micrometers. (Particle count - the number of particles present greater than a particular micron size per unit volume of the coolant often stated as particles > 5 microns per milliliter. This parameter is of prime importance in gundrilling operations due to close tolerances of drilled holes).

3. PART LOCATING AND CLAMPING

**Problem: Improper part locating**

**Problem short description:** In all gundrilling operations at AAM Colfor, the part is located on the two end chamfers as shown by an example in Figure 17 (the gundrilling process sheet for C1 Main Shaft). There are two major problems with such a locating:

- First, the end chamfers are NOT DATUM SURFACES so the locating on these chamfers cannot assure the requirements to the drilled hole runout with respect the datums A and B set by the process sheet (Figure 17).
- Second, the gundrilling operation follows the spline rolling operation. As the spline rolling operation is accomplished by plastic deformation of the work material, burr forms on the corresponding chamfer (the right-end chamfer shown in Figure 18). This burr affects the locating accuracy.

Improper locating causes part wobbling on its counter rotation that leads to the drilling of oversize holes. When there is no counter rotation, the drill axis deviates from its true position.
Problem fix suggestions:

- Designate the said chamfers as the DATUMS on the process sheet for the preceding turning operation. Add tolerance on the chamfer angle; add requirements for surface finish on the surface of both chamfers.

- Make double-chamfer end on the spline side assuring that the burr formed on spline rolling does not affect the locating part of the chamfer.

Problem: Insecure part clamping

Problem short description: The part is clamped by applying the axial force so that the frictional force created on the locating chamfers secures the part and withstands the drilling torque. However, the presence of the oil-based coolant significantly lowers the coefficient of friction on the clamping surface so the excessive axial force should be applied to generate sufficient frictional force to secure the parts on drilling. This might cause part buckling. Moreover, the drilling torque grows with gundrill wear so the applied axial force might become insufficient for secure clamping. It is observed that part sometimes spins during drilling that causes drill breakage problems.
Problem-fix suggestions: Work with Nagel (TBT Automotive) to find more require part clamping. PSMi will suggest a feasible solution when Nagel (TBT Automotive) provides design of the clamping mechanism.

Figure 18. Right-end chamfer of a C1 Main shaft.
4. DRILL SHARPENING

Problem: Poor quality drill re-sharpening

Problem short description: There are three basic problems with gundrills re-sharpening. First, the manual Eldorado sharpening fixture (Figure 19) used is not suitable to reproduce faced flank surfaces as required by the gundrill drawings. Second, the diamond grinding wheels used for re-harpening are too coarse (grid 80) and of small diameters (insufficient grinding speed as the spindle rpm is constant on the sharpening machine used) that result in rough ground surfaces. Third, the results of re-sharpening are not inspected. The later is particularly important for chipbreakers as they are ground manually. The tolerances on the dimensions b, h and R (Figure 6) should be ±0.1mm.

Figure 19. Eldorado sharpening fixture.

Problem-fix suggestions:

- Use a grinding fixture capable of reproducing facet flanks with the required accuracy. Probably the most suitable fixture available in the market today is a TBT grinding fixture (Figure 20). A Hyper Tool sharpening fixture shown in Figure 21 can also be used.
- Use a fine grit diamond wheel (finer than 200) for finishing of the flank surfaces of the outer and inner cutting edge as well as for grinding the chipbreaker.
- Use an optical device (microscope, comparator, etc) to inspect the results of re-sharpening.
Figure 20. TBT Grinding fixture.

Figure 21. Hyper Tool Grinding fixture.
5. DRILL DRAWINGS

Problem: Drill drawings lack of important information

Problem short description: The drawings provided by Nagel (TBT Automotive) lack technical information necessary to the quality control of the drills, re-sharpening and cutting regime optimization. An example of the said drawings is shown in Figure 22.

Problem fix suggestions: Request that Nagel (TBT Automotive) add the following information to all the gundrill drawing:

- Include the grade of carbide used and parameters of coating (thickness and properties).
- Indicate surface finish particularly on the tip.
- Show information on back taper and minimum allowable length of the carbide tip (for re-sharpenings).
- Mark datum(s).
- Show runout of the tip relative to the datum.
- Show the angle of the flank surface ground between the flank surfaces of the other and inner cutting edges.
- Show the width of the cylindrical margin at the side cutting edge.
- Show the radial relief on the tip.
- Show the angular location of the supporting area with respect to the outer cutting edge.
- Show the exact location of the cutting edge with respect to the drill horizontal axis (x-axis in the tool coordinate system). This is particularly important for the gundrills with chipbreakers.
- Show shank profile and specify the corner radii.
- Indicate the required coolant flow rate.
- Remove note “CUTTING EDGE SLIGHTLY HONED.” If a hone is needed to apply to the cutting edge then specify its shape and exact parameters.
- Include the information marked on the drill – show a place of marking.

For terminology assistance, please refer to Appendix 1.
Figure 22. Example of drill drawings.
Appendix 1: Basic gundrill components and geometry

Gundrilling is a highly developed and efficient technique for producing deep holes in a wide variety of materials from plastics, such as fiberglass and teflon, to high-strength metals, like P-20 and Inconel. The process also enables size, location and straightness accuracy where tight tolerances and fine finishes are critical.

However, successful gundrilling requires complete understanding and integration of the gundrilling system, which includes everything related to the operation: the cutting tool, machine, fixtures and accessories, workpiece, cutting fluid, programming, control, and operator skill. Optimum performance is achieved when the combination of cutting speed, feed, tool geometry, carbide grade and cutting fluid parameters is selected properly. This selection depends upon the hardness, composition and structure of the workpiece, deep-hole machine conditions, and the quality requirements to the drilled holes.

In terms of tool type, the straight-flute gundrill is the most common (Fig. A1). It has a solid- or brazed-carbide tip, depending on the tool’s diameter, with an internal cutting fluid channel running through its driver, shank and tip. Gundrill manufacturers have adopted various shapes for the cutting fluid passage in the tip: either one or two circular holes or a single kidney-shaped hole. Standard gundrills produce holes from 2 to 50mm in diameter ($D_w$) and up to 100 $D_w$ deep in one pass, with custom length roughly doubling this amount.

![Figure A1. Common gundrill and its components.](image)

The design and geometry parameters of a commonly used gundrill are shown in Fig. A2. The gundrill consists of a drill body having a shank 1 and a tip 2. The tip is made up of a hard wear-resistant material such as tungsten carbide. The other end of the shank incorporates an enlarged driver 3 having the machine-specific design. The shank is of
Figure A2. Gundrill geometry.

tubular shape having an elongated passage 4 extending over its entire length and connects to the drilling fluid supply passage 5 in the driver. The shank has a V-shaped flute 6 on its surface which serves as the chip removal passage. The shank length depends mainly on the length of the drilled hole and also on the length of the starting point of the bushing and its holder, chip box, etc.

The tip is larger in diameter than the shank that prevents the shank from coming into contact with the walls of the hole being drilled. Flute 7 on the tip, which is similar in shape to flute 6, extends along the full length of the tip. This flute is bounded by side faces 8 and 9 known as the cutting face and side face, respectively. The depth of this flute is such that the cutting face 8 extends past the axis 10 (distance c) of the tip, which is also the axis of the drill body. The angle $\alpha$, between the side and cutting faces is known as the profile angle of the tip, which is usually equal or close to the V-flute profile of the shank.

The terminal end of the tip is formed with the approach cutting edge angles $\alpha_1$ and $\alpha_2$ of the outer 11 and inner 12 cutting edges, respectively. These cutting edges meet at the drill point $P$. The location of $P$ (defined by the distance $md$ in Fig. 5.2) can be varied for
optimum performance depending on the work material and the finished hole specifications. One common point grind calls for the outer angle, \( \theta_1 \), to be 30° and the inner angle \( \theta_2 \), to be 20°. The geometry of the terminal end largely determines the shape of the chips and the effectiveness of the cutting fluid, the lubrication of the tool, and removal of the chips. The process of chip formation is also governed by other cutting parameters such as the cutting speed, feed rate, work material, etc.

The flank surface 13 having normal clearance (flank) angle \( a_{n1} \) is 8–20° is applied to the outer cutting edge 11 and the flank surface 14 having normal clearance (flank) angle equal to \( a_{n2} \) (normally \( a_{n2} \) is 8–12°) is applied to the inner cutting edge 12. To assure drill-free penetration, i.e. to prevent the interference of the drill’s flanks with the bottom of the hole being drilled, the auxiliary flank 15 and shoulder dub-off 16 are ground. Their location and geometry are uniquely defined for a given gundrill.
Appendix 2. Grade and hardness of the work material

Background:

Requested By: Dave Slaughter
Part Description: X6R Turbine Shaft
Customer: GM Powertrain-Ypsilanti
Customer Part Number: 24224155
Colfor Part Number: 2183T
Engineering Revision Level: —
Colfor Facility: Salem
Forging Temperature: —
Forging Press: —
Colfor MS: MS2262
Customer Specifications:
Steel Grade: AISI 1040
Steel Supplier: MacSteel
Heat Number: —
Heat Code: —
Colfor QCP: —
Heat Treat Process: —
Heat Treat Supplier: —
Purpose of Report: Documentation of as-forged core hardness of 2183T shafts. Hardness will be evaluated at multiple locations to develop a hardness map of shaft.

Summary:

Disposition: See report for results.

Completed By: Jim Kibler
Title: Metallurgical Engineer
Date: 20 March 2006

Approved By: John Macabobby
Title: Metallurgy Manager
Date: 30 March 2006
Figure 1: Photographs of sectioned 2183T shafts showing HRB core hardness at multiple locations. Hardness of sample 1 ranges from 87.6 to 104.1 HRB. Hardness of sample 2 ranges from 88.7 to 105.0 HRB.