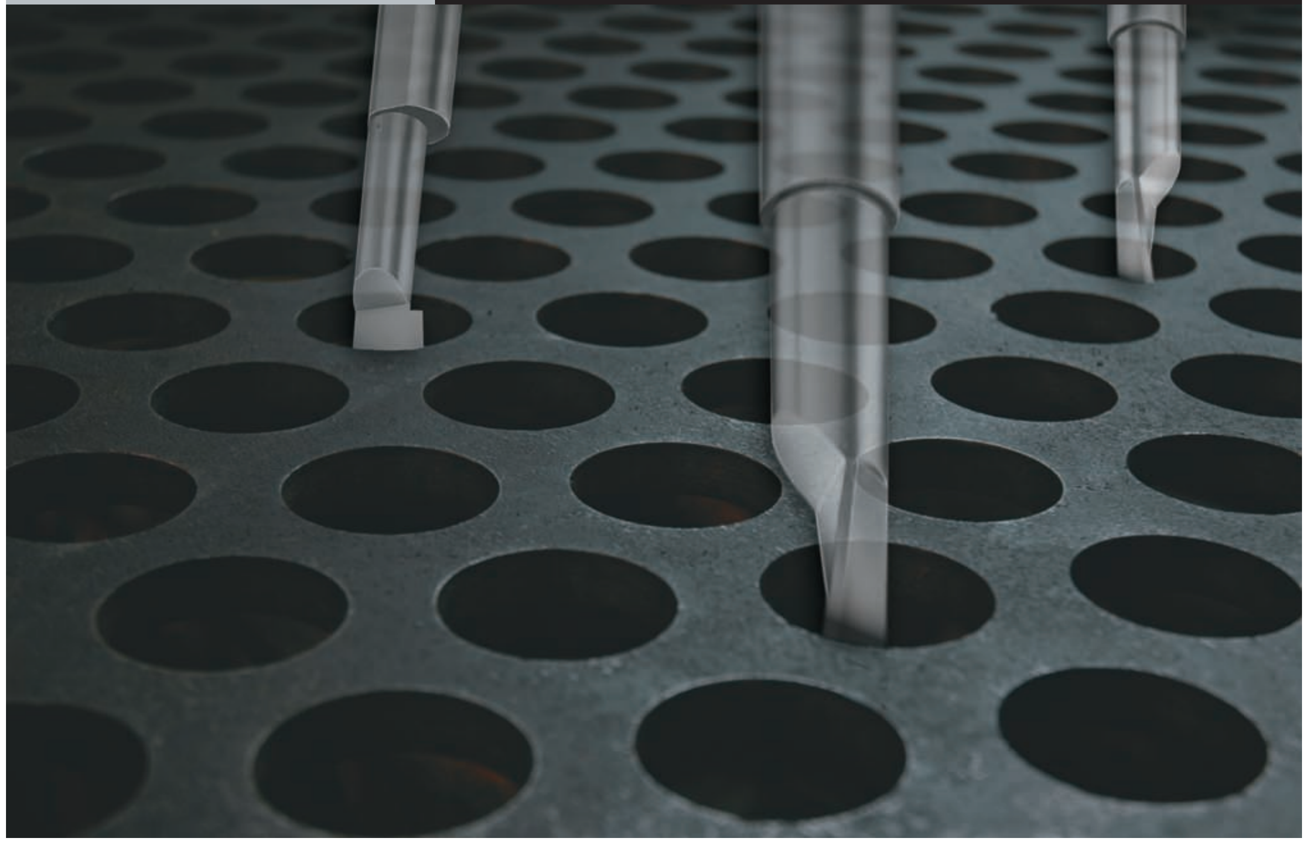
DECEMBER 2005 / VOLUME 57 / NUMBER 12

➤ BY UWE HEINRICH, MICRO 100



Stable ENVIRONMENT

Minimizing tool deflection is critical to successful boring.

Today's rising quality standards for precision metal parts demand the highest accuracies, narrowest tolerances and finest surface finishes for every hole in those parts. Boring bars offer an effective solution whenever the part's hole diameter and depth permit their application.

Producing holes that meet such standards requires maximum boring stability. This is accomplished by controlling the machining forces that cause the boring bar to deflect and vibrate, which can lead to tool chatter.

The first steps in gaining control are to understand what these forces are and how they are generated.

Understanding Forces

Tangential and radial cutting forces develop during boring (Figure 1). These forces cause the cutting edge to move away from the point of engagement. This tool deflection is both horizontal and vertical.

The tangential cutting force pushes the tool downward and away from the centerline. Due to the curved wall of the hole, the boring bar's clearance angle is reduced. When boring smaller-diameter holes, it is especially important to apply a tool with a sufficient clearance angle to prevent it from contacting the wall.

The radial cutting force reduces chip thickness and has a negative impact on the dimensional accuracy of the hole. Furthermore, depending on the workpiece material, chip thickness changes as the cutting force does. This leads to tool vibration.

In addition to the tangential and radial cutting forces generated, tool deflection is influenced by tool diameter and overhang. A rule of thumb is that the larger the tool diameter and the shorter the tool overhang, the smaller the tool deflection.

Boring Operation Troubleshooting Guide

PROBLEM/CAUSE	SOLUTION
Tool Breakage	
Feed rate too heavy	Reduce feed rate
Cut too heavy	Decrease cutting width and depth
Excess tool overhang	Increase clamping length; use shorter bar
Excessive Tool Wear	
Speed too fast	Decrease spindle speed
Difficulty cutting hard materials	Use coated boring bar
Speed and feed too low	Increase speed and feed
Recutting chips	Increase tool clearance angle; use one-size-smaller tool; improve chip evacuation with coolant or air
Short Tool Life	
Excessive cutting friction	Regrind tools more frequently; apply coolant; use coated boring bar
Tool Chipping	
Feed rate too heavy	Reduce feed rate
Lack of rigidity (machine or toolholder)	Use more rigid machine or toolholder; change cutting parameters
Inadequate tool rigidity	Use shorter boring bar; increase clamping length
Cutting edge too sharp	Use tool with chamfer or small radius; hone cutting edge
Speed too slow	Increase cutting speed
Tool Chatter	
Speed and feed too high	Use correct feed and speed
Lack of rigidity (machine or toolholder)	Use more rigid machine or toolholder; change cutting parameters
Poor setup	Improve tool-clamping rigidity
Cut too heavy	Decrease cutting width and depth
Excessive tool overhang	Use shorter boring bar; increase clamping length
Poor Dimensional Accuracy	
Cut too heavy	Decrease cutting width and depth
Lack of accuracy (machine or toolholder)	Use better machine or holder
Lack of rigidity	Use more rigid machine or holder; change speed and feed parameters

Material composition significantly influences a boring bar's ability to resist deflection. Generally, a steel bar can be used to bore to depths equaling three or four times its diameter. Deflection can be an issue beyond that depth.

A solid-carbide bar is recommended for most applications. Carbide's high hardness allows bars made from it to resist deflection up to 7 diameters deep.

Fortunately, the negative effects of tool deflection can be countered. This is achieved by first calculating the amount of tool deflection for the specific operation and then compensating for it during the machining setup.

Tool deflection is calculated with the formula:

$$\text{Tool deflection} = \frac{F \times L^3}{3 \times E \times I}$$

where

F = cutting force (lbs.); L = overhang (in.); E = elasticity coefficient (psi); I = moment of inertia

$$I = \frac{3.14 \times D^4}{64}$$

where

D = tool diameter.

If the amount of tool deflection is known in advance, the effects of tangential deflection can be negated. This is accomplished by positioning the cutting edge of the boring bar above the centerline by the distance of the tangential deflection. The result is that the tool will be in the correct position during machining.

Radial deflection is compensated for by setting the machine to cut at a depth greater than the distance of the radial deflection. When the tool engages the workpiece, the radial cutting force reduces the cutting depth by a distance equal to that of the deflection.

In reality, tool deflection will exceed what is calculated when using the aforementioned formula. This is because the formula is based on the assumption that the boring bar will be clamped with absolute rigidly, which is impossible in general machining.

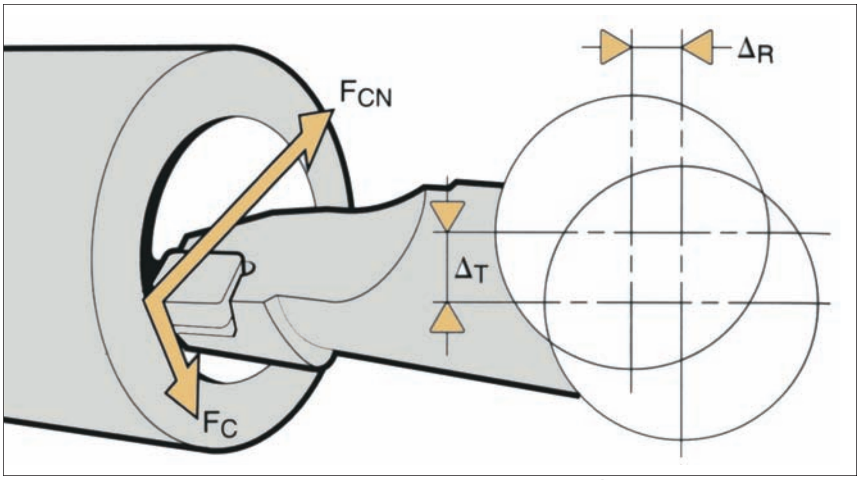
To obtain exact values for tangential and radial deflection, conduct tests under the same machining conditions as the actual operation. The radial deflection, which can be easily measured, will equal the difference between the set and the actual hole diameter.

To determine the exact tangential deflection, measurement equipment must be used that incorporates a sensor positioned near the cutting edge.

Clamp Down on Deflection

Proper tool clamping is critical in boring, because any mobility in the fixed end of the boring bar can cause tool deflection and vibration. It is important that the internal surfaces of the toolholder have a fine finish and high hardness.

A fine finish ensures that the clamping



All illustrations: Modern Metal Cutting

Figure 1: The effect of cutting forces results in horizontal (Δ_R) and vertical (Δ_T) tool deflection. The tangential cutting force (F_C) pushes the tool downward and away from the centerline. The radial cutting force (F_{CN}) reduces the chip thickness and has an impact on dimensional accuracy.

area is as large as possible. High hardness helps prevent the toolholder from deforming under load. If that occurs, tool overhang can become excessive.

The recommended values for toolholders are a finish of 32µin. R_a and a hardness of at least 45 HRC.

A toolholder that completely encases the boring bar provides the greatest stability. Two styles of holders do this: those that are flange-mounted and those that consist of a divided block that clamps the tool when tightened (Figure 2).

Holders that incorporate setscrews that clamp the boring bar in place are less efficient (Figure 3). Only a small percentage of the bar's surface is clamped with this type of holder. Moreover, the setscrews can push the boring bar out of center, which may lead to vibration.

The clamping length—the amount of the bar that is clamped—significantly impacts stability. The "lever rule" states that the clamping length should be at least three to four times the tool diameter.

According to the lever rule, increasing the clamping length reduces the force acting on the fixed end of the boring bar. Consequently, stress at the point of clamping is reduced, which increases stability.

The lever rule:

$$F1 \times L1 = F2 \times L2$$

where F1 = cutting force; L1 = tool overhang; F2 = force at the fixed end of the boring bar; L2 = clamping length.

Therefore, the acting force at the fixed end of the boring bar is calculated:

$$F2 = \frac{F1 \times L1}{L2}$$

The following example illustrates how a longer clamping length decreases the acting force.

Short clamping length:
F1: 40 lbs.
L1: 7× tool diameter
L2 : 3× tool diameter

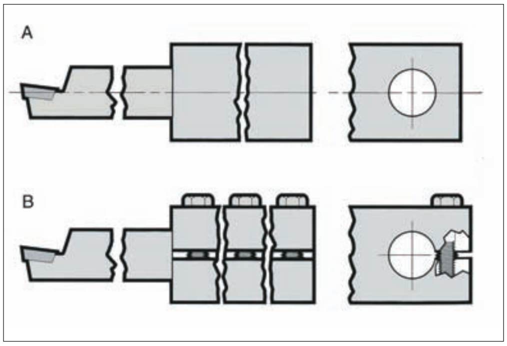


Figure 2: Two styles of toolholders that are best for holding boring bars: a rigid, or flange-mounted, bar (A) and a divided block that clamps the tool when tightened (B).

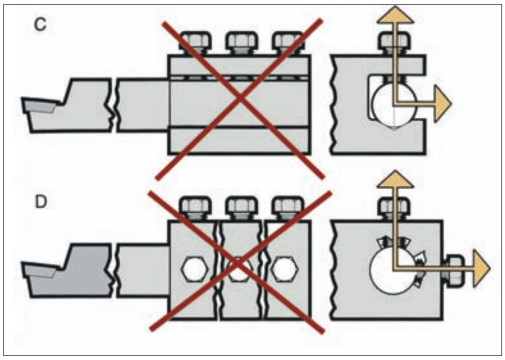


Figure 3: Toolholders that incorporate setscrews don't clamp the boring bar as securely as flange-mounted and divided-block styles.

$$F2 = \frac{40 \times 7}{3} = 93.3 \text{ lbs.}$$

For equilibrium:

$$F1 + F2 = F3$$

40 lbs. + 93.3 lbs. = 133.3 lbs. acting force at the end of the tool.

Long clamping length:
F1: 40 lbs.
L1: 7× tool diameter
L2 : 5× tool diameter

$$F2 = \frac{40 \times 7}{5} = 56 \text{ lbs.}$$

For equilibrium:

$$F1 + F2 = F3$$

40 lbs. + 56 lbs. = 96 lbs. acting force at the end of the tool.

The longer clamping length reduces the acting force by 37.3 lbs., which would significantly improve stability and, thereby, part quality.

Such improvements are only possible by understanding and controlling the forces that develop during boring. That knowledge, along with selecting the optimal tool geometry, toolholder, cutting parameters and machine setup, are required to meet today's standards for precision metal parts. △

About the Author

Uwe Heinrich heads up international business for Micro 100 Tool Corp., Meridian, Idaho. For more information on the company's boring tools visit www.micro100.com, call (800) 421-8065.