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Steadying The Bar

Factors to consider when selecting a boring bar and insert.

Boring on lathes has always been one of the most difficult machining operations. When applying cutting tools, the rule of thumb is to select as short a tool as possible. In external turning this rule is easy to follow. Even with a long workpiece, tool overhang can be kept to a minimum.

But with boring, an internal turning operation, the depth of the bore dictates the tool's overhang. Long tool overhangs can lead to vibration, which causes poor surface finish and makes it difficult to hold size.

This article examines ways to reduce vibration when boring. First, though, let's look at what causes the tool to vibrate. In metalcutting, the chip-formation process generates cutting forces. These forces apply pressure to the boring bar, causing it to bend or deflect. When the chip breaks away from the workpiece, the cutting forces are reduced. The boring bar then returns to its original position and this movement generates harmonics, or vibration.

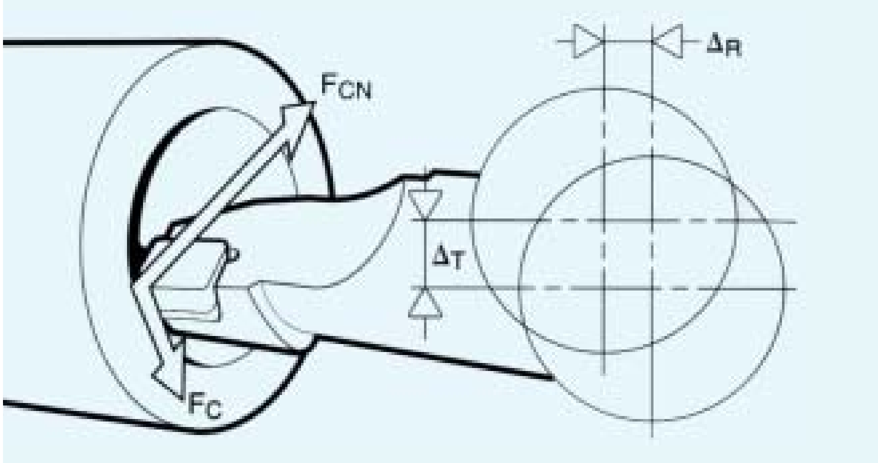

Figure 1: Cutting forces cause the boring bar to deflect, leading to vibration. F_C = tangential cutting forces, F_{CN} = radial cutting forces, Δ_T = tangential deflection, Δ_R = radial deflection.

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There are two different types of cutting forces: radial and tangential. Radial cutting forces push the tool away from the bore. Tangential forces push the tool downward, below the centerline (Figure 1). The features of the boring bar and insert determine the amount of force applied to the cutting tool and the likelihood of vibration.

Selection Parameters

When selecting a boring bar and insert, there are many factors to consider: diameter, length, shank design, lead angle and material. In most cases, the boring bar is selected first. The goal is to choose a bar with the highest static and dynamic stiffness. Static stiffness is the bar's ability to resist deflection from radial and tangential cutting forces, and dynamic stiffness is its ability to dampen vibration.

Always pick as large a boring bar diameter as possible, but be sure the diameter is not so large as to prevent chips from evacuating the bore. Increasing the diameter with the same tool overhang will increase static stiffness. In large bores, the size of the machine turret or tool post will most likely restrict the boring bar diameter.

The amount of tool overhang and the bar diameter will determine what material the boring bar should be made of. The most common materials are steel and carbide. Steel bars—the more economical choice—are usable when the bore depth does not exceed a tool-length-to-diameter ratio of 4:1. For bores ranging from 4 to 7 diameters, steel does not have adequate static or dynamic stiffness. Therefore, a carbide boring bar is a better choice.

The dense structure of carbide increases the tool's static stiffness, allowing it to bore at L/D ratios greater than 4. Carbide bars have three times as much static stiffness as steel bars. But carbide's dense structure also makes it more brittle than steel. Therefore, proper handling of carbide boring bars is essential. If an operator drops a steel bar, it may only be scuffed. If the same bar were made of carbide, it would most likely break.

Carbide's brittleness also affects L/D ratios greater than 7. Tools boring at this range will deflect, and too much deflection causes a carbide tool to break.

For depths equaling 4 to 10 diameters, a steel bar that incorporates a dampening mechanism is the best choice. Steel allows the bar to bend—not break—when tool overhang is excessive. But if the bar deflects too much, it will vibrate. To counteract this condition, a dampening mechanism is installed inside the bar that increases dynamic stiffness. The mechanism consists of a heavy metal slug, held on each end with rubber grommets, in a chamber filled with silicon oil (Figure 2).

The slug vibrates at a different frequency than the steel bar. This helps to counteract vibration rather than intensify it. In special applications with tool overhangs from 10 to 14 diameters, the shank of a dampened boring bar can be reinforced with carbide.

Dampened boring bars are designed without flats on their shanks. A cylindrical shank offers two benefits. First, it provides maximum surface contact for the toolholder. Second, flats reduce the amount of material on the shank, which in turn reduces the static stiffness of the bar. Whether boring with steel or carbide tools, pick a cylindrical shank whenever possible.

After determining the type of bar, the next decision involves the lead angle.

A boring bar with a 0° lead should be the first choice. With a 0° lead, the radial cutting forces are minimized and most of the forces are directed in an axial direction. This puts the cutting forces back into the clamping mechanism, which is ideal. When the lead angle is greater—for instance, 45°—the cutting forces are directed in a radial direction. An increase in radial cutting forces increases deflection and the chance for vibration.

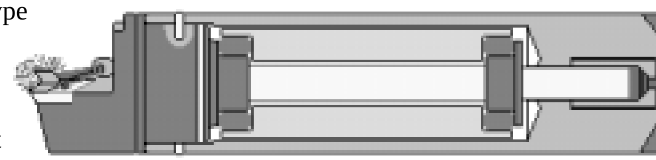

Figure 2: Cross-section of a dampened boring bar.

Insert Selection

The insert selected also affects whether vibration will occur. The two main types of inserts are positive and negative, which refer to the insert's inclination angle in the cutting tool pocket. A positive insert shears the material more easily than a negative insert. This means a positive insert will generate a lower tangential cutting force.

However, a positive rake angle will decrease the amount of flank clearance. And if the clearance is too small, the flank of the insert will rub against the workpiece and this friction will create vibration (Figure 3).

When boring with an insert that has a high-positive rake and high-positive clearance angle, the insert's sharper cutting edge penetrates the material more easily, reducing the cutting forces. But be careful, a high-positive insert can be easily damaged if the boring bar vibrates, and it's more prone to flank wear.

When choosing a tool, opt for as positive a geometry as possible, ensuring that the tool chosen is strong enough for the application. In addition, use an insert with a small edge preparation. Generally, PVD-coated inserts are sharper than CVD-coated inserts. A periphery-ground insert also will have a sharper cutting edge than a direct-pressed insert.

And, lastly, an extremely hard grade of carbide is not always the best choice. A hard grade in combination with an extra-positive, sharp cutting edge can easily chip if vibration occurs. Instead, start with a medium-hard carbide grade that has the toughness to withstand edge chipping. Then, test a harder grade if everything works correctly.

Cutting Parameters

Nose radius and depth of cut go hand in hand. When finish boring, a small DOC is recommended, as is a small nose radius. A smaller nose radius minimizes the contact between the insert and workpiece, which results in lower

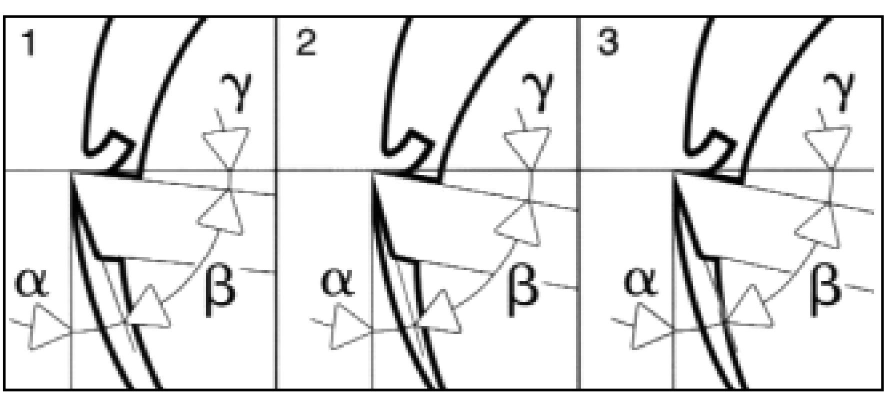

Figure 3: 1) A positive rake angle with positive flank clearance; 2) an extra-positive rake angle with insufficient flank clearance; and 3) an extra-positive rake angle with positive flank clearance. γ = positive rake angle, β = edge angle, α = clearance angle.

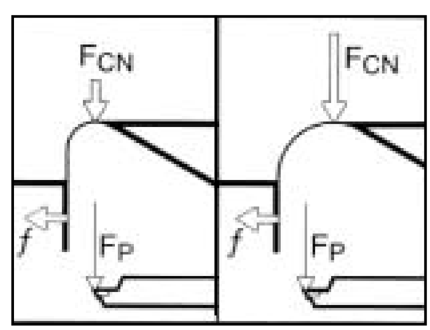

Figure 4: An insert with a small nose radius will reduce the tangential and radial cutting forces. f = feed per revolution, F_{CN} = radial cutting forces, F_P = axial forces.

tangential and radial cutting forces (Figure 4).

A good starting place is to choose a 0.016" nose radius and a 0.020" DOC. The DOC should always be larger than the nose radius, because a DOC smaller than the nose radius will direct the cutting forces in a radial direction (Figure 5). If a smaller DOC is required—0.012", for example—then choose an insert with a 0.008" nose radius.

Feed rates for boring should be the same whether tool overhang is short or long. The feed should be based on the insert's chipbreaker capabilities. Avoid an extremely high feed rate when roughing, because this increases the tangential cutting forces. When finish boring, the required surface finish will usually determine the maximum feed rate.

One mistake made when trying to minimize vibration is the tendency to reduce the rpm. Reducing the rpm decreases productivity. A low surface speed also leads to built-up edge. BUE affects the insert's cutting geometry, which can then change the direction and size of the cutting forces. Instead, check the other variables to see if they can be improved. And, in some cases, increasing the rpm can eliminate chatter.

The most overlooked criterion for successful boring is tool clamping. It is quite common to clamp boring bars in a cylindrical bore with setscrews (Figure 6). This is the worst possible method. The boring bar only contacts the setscrews and about 10 percent of the bore. This is due to the clearance in the holder required for assembling the boring bar. Also, because carbide boring bars are brittle, they can break or crack when clamped with setscrews.

The best solution is to use a split tool block (Figure 7). This design allows maximum surface contact by collapsing around the shank. A split block, in conjunction with a cylindrical-shank boring bar, results in the greatest clamping stability.

Keep in mind, too, that a poor finish in the toolholder's bore will reduce the clamping surface. A holder with a surface finish of R_a 32 is recommended.

Along with the finish of the toolholder's bore, consider its hardness. A soft toolholder will deform, or "bellmouth," under heavy cutting loads. This can negatively impact the effective clamping length. A minimum hardness of HRC 45 is required. When assembling the tool in the toolholder, the clamping length should be at least 3 to 4 diameters.

There certainly are many variables to consider in boring applications. If you are experiencing vibration, look at the current setup to see if it can be improved. Sometimes a change as simple as applying an insert with a smaller nose radius can make all the difference.

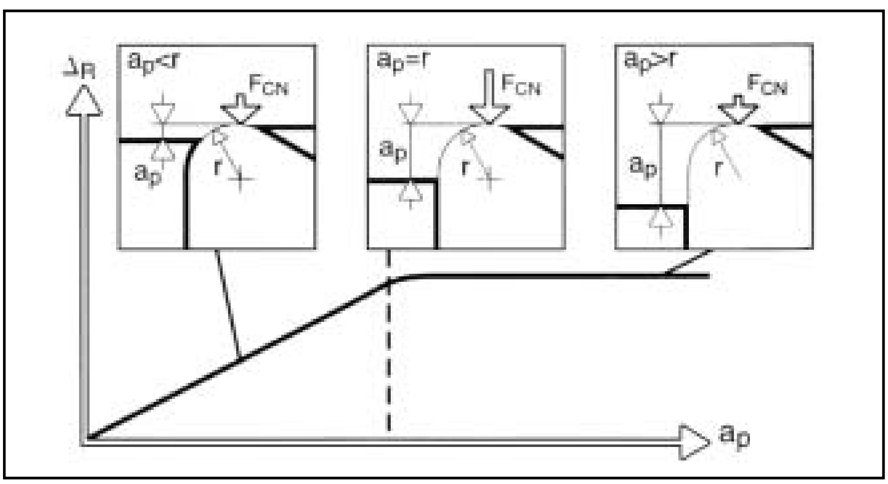

Figure 5: When the DOC is smaller than the nose, the radial cutting forces will increase with the DOC. When the DOC is equal to the nose radius, the radial cutting force will not increase. a_p = depth of cut, axial, r = nose radius, F_{CN} = radial cutting forces, Δ_R = radial deflection.

About the Author

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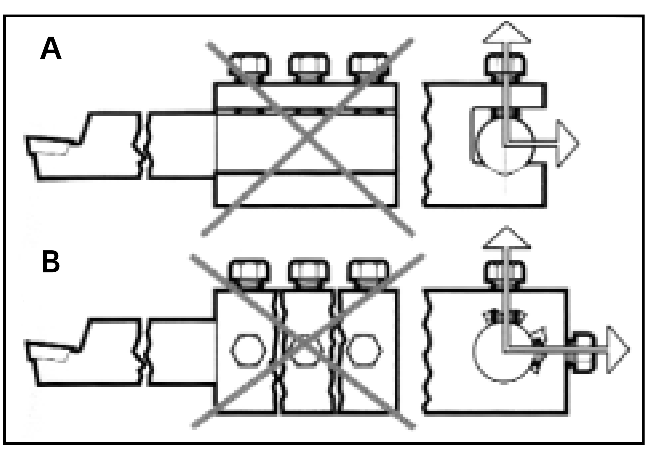

Figure 6: A) Setscrews and a V-block hold the boring bar. B) Setscrews hold the boring bar in a cylindrical bore, which is the worst possible method.

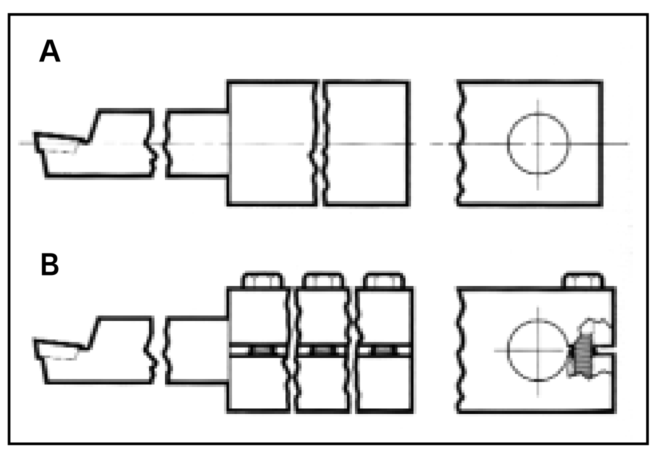

Figure 7: A) The boring bar and mounting block are one piece. B) A split block clamps around the circumference of the boring bar.