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FUNDAMENTALS OF HARD TURNING

An Indepth Look at the Process

2012

INTRODUCTION + CONTENTS

Hard turning is an important process because all manufacturers are continually seeking ways to manufacture their parts with lower cost, higher quality, rapid setups, lower investment, and smaller tooling inventory while eliminating non-value added activities. The migration of processing from grinders to lathes can satisfy each and every one of these goals. We'll expore what hard turning is, its advantages and limitations, the best machine for the job, and how to be successful when implementing hard turning into your operation.

We would like to thank the experts at Hardinge for providing the content for this white paper. Their invaluable expertise and knowledge on not only the products but also the hard turning process shows their commitment and support for the machining industry.

01 WHAT IT IS AND WHEN TO CONSIDER IT

WHAT IT IS

Hard turning is defined as the process of single point cutting of part pieces that have hardness values over 45 Rc. Typically, however, hard turned part pieces will be found to lie within the range of 58-68 Rc. The approach to machining hardened steel depends on the degree of hardness and its depth (if case hardened). The hard turning process is similar enough to conventional "soft" turning that the introduction of this process into the normal factory environment can happen with relatively small operational changes when the proper elements have been addressed.

Hard turning is best accomplished with cutting inserts made from either CBN (Cubic Boron Nitride), Cermet or Ceramic. Since hard turning is single point cutting, a significant benefit of this process is the capability to produce contours and to generate complex forms with the inherent motion capability of modern machine tools. High quality hard turning applications do require a properly configured machine tool and the appropriate tooling. For many applications, CBN tooling will be the most dominant choice. However, Ceramic and Cermet also have roles with this process.

The range of applications for hard turning can vary widely, where at one end of the process spectrum hard turning serves as a grinding replacement process, it can also be quite effective for pre-grind preparation processes. The attractiveness of the process lies in the performance numbers.

A properly configured hard turning cell would typically demonstrate the following:

- Surface finishes of 0.00011" (.003 mm)
- Roundness values of .000009" (.00025 mm)
- Size control ranges of .00020" (.005mm)
- Production rates of 4- 6 over comparable grinding operations

Hard turning is a technology-driven process that requires certain performance features of the machine tool, workholding, process and the tooling.

WHEN TO CONSIDER IT

Hard turning can certainly be considered for most pre-grind applications, which are followed by an abbreviated grinding cycle. In some cases, the hard turned surface may complete the operation and will completely eliminate the grinding cycle altogether.

If one were to list the current applications of hard turning, it would certainly be a voluminous document. On a daily basis, parts are being hard turned in the following industry segments: automotive, bearing, marine, punch and die, mold, hydraulics and pneumatics, machine tool and aerospace. While these industries are representative, this list is certainly not conclusive and new applications and industry segments are constantly being added.

The typical materials, which are routinely hard turned, include those of the following broad category descriptions:

- Steel alloys,
- Bearing steels
- Hot and cold work tool steels
- High speed steels
- Die Steels
- Case hardened steels
- Waspoloy, Stellite and other aerospace alloys
- Nitrited irons and hard chrome coatings
- Heat treatable powered metallurgy
- Unique hard materials and aircraft types that fall within the hardness range

Hard turning is a viable process that has real and measurable economic and quality benefits. This is particularly true with a machine tool that has a high level of dynamic stiffness and the necessary accuracy performance. The more demanding the application in terms of finish, roundness and size control, the more emphasis must be placed upon the characteristics of the machine tool.

11 WAYS HARD TURNING REDUCES YOUR COST:

1. You can "soft turn" and hard turn on the same machine.
2. It has a smaller floor space requirement.
3. There's a lower overall investment.
4. Metal removal rates are 4-6 times greater.
5. You can turn complex contours.
6. Multiple operations can be performed in a single setup.
7. It allows for low micro finishes.
8. It's easier to configure changes.
9. There's a lower cost tooling inventory.
10. There are higher metal removal rates.
11. It's easier on waste management (chips vs. "swarf").

02 THE ADVANTAGES + LIMITATIONS

KNOWING THE ADVANTAGES & LIMITATIONS

Grinding does--and likely always will--have a place in manufacturing, as all components can not be hard turned due to tolerance requirements and the surface integrity of the part.

However, hard turning does offer distinct advantages when machining, including:

Price. Compared to grinding machines, lathes are relatively inexpensive to purchase. Higher level grinders can perform multiple operations but are often more expensive to operate due to setup and cycle times and require more support equipment, such as balancers and dressers. With lathes, you get reduced machine tool cost which adds up to greater productivity, better production control, shorter throughput and greater profits.

Versatility. You can “soft turn” and hard turn on the same machine tool. Multiple operations can be machined with one set-up, resulting in less part handling and less opportunity for part damage

Metal Removal. You can achieve up to 4-1 and 6-1 higher metal removal rates. Low micro-inch finishes can be achieved from 4 to 16 micro.

Flexibility. Changes are easier if the part configuration changes. And lathes can handle small lot sizes and complex shapes much more efficiently than a grinding machine. Single-point turning of complex contours can be accomplished, eliminating costly form wheels

Environmental Issues. Lathes produce chips, which are less costly to dispose of than the swarf produced by grinding machines.

From the process standpoint, there are several areas of consideration. With the correctly chosen cutting tools, the hard turning process can support either coolant cutting or dry cutting.

Dry Cutting

If the processing choice is to cut dry, then the temperature of the chips and the workpiece need to be taken into account from both a safety and operational standpoint.

Other considerations when dry cutting:

- Consider the workpiece temp when gaging
- Expect higher tool temperatures and lower tool life
- Surface finish is generally not as good as cuts made with coolant
- Protection from high temperature chips is required
- Correctly choose tool material (i.e., not Ceramic)
- The chip salvage may be more cost effective

Some applications may be sensitive to the surface condition caused by "white layer" formation, which appears as a white layer at the surface of the material under metallographic examination. This layer depth can vary greatly but for general discussions it is in the area of 1 micro-meter (.0000040"/.00010mm) thick.

The white layer cannot be seen visually but requires a metallographic examination to detect its presence. According to Griffiths (1987), white layer can be caused by either 1) severe plastic deformation that causes rapid grain refinement or 2) phase transformations as a result of rapid heating and quenching. White layer formation is not limited to hard turning operations but is also routinely found in grinding applications. It is not desirable in products which have high contact stresses and where fatigue failures can occur.

Coolant Cutting

Wet operations refer to processes under flood or high-pressure with a water-soluble coolant. The decision to produce under wet or dry conditions is normally made at the individual factory level. Some facilities have a local philosophy or mandate regarding the preference to operate one way or the other and fortunately, either form of hard turning can be accommodated.

There are several key items when choosing to operate wet, and the first of these is the type of fluid to be used. Generally, straight oils should be avoided because of the inherent fire hazard. This is particularly true if during a cut the coolant flow is disrupted and the unquenched, high temperature chips contact the oil. Under these conditions, oils with a low flash point could start and sustain a fire.

Another point for wet operations is the importance to properly direct the coolant flow by applying fluid to both the top and the bottom of the tool tip simultaneously. Generated chip strings will frequently shield the coolant from the tool until the chip breaks away. The result is thermal shock and a process of degradation of the cutting edge. Anticipate this when establishing the coolant nozzle locations from a slight sideward vantage point. High-pressure coolant at pressures of approximately 68-95 atmospheres seems to be beneficial in keeping the chips small and manageable and in making the overall process more robust. As previously stated, the shorter chip results in a reduced amount of coolant blockage and less thermal shock to the cutting edge.

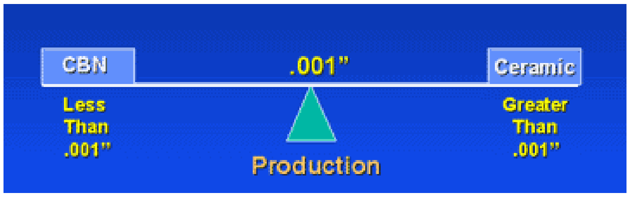
Another variable in coolant cutting operations that can easily sabotage a fine-tuned process is an improper coolant mixture. Concentration, cleanliness and pH levels cannot be ignored for a proper application.

The one possible exception to coolant cutting is on interrupted surfaces, which seem to perform better in a dry environment. Logically, this is due to the higher degree of thermal shock caused during the interruption when the coolant has a better access to the tool tip and then immediately is followed by a re-entry into the workpiece and the severe temperatures.

03 FINISH REQUIREMENTS + SPECIFICATIONS

FINISH REQUIREMENTS & SPECIFICATIONS

When considering the tooling material, it's important to understand the application and critical attributes such as size and finish requirements. An acceptable part length-to-diameter ratio is up to 4:1 for unsupported workpieces, and up to 8:1 for parts with tailstock support. A harder part and tighter tolerance requirement may change these guidelines.



The typical brazed tip CBN insert has a cost structure 3-4 times that of carbide. Ceramic, on the other hand, has a cost structure more similar to carbide but would not be used for applications which have a tolerance range smaller then .001" (.02540mm). Parts requiring a greater accuracy would logically use CBN.

Cubic Boron Nitride (CBN)

If the hardness ranges between 50-68 Rc and the depth of hardness is greater than the depth of material to be removed, then Cubic Boron Nitride (CBN) is the best medium. CBN will give good tool life and wear properties. Surface finishes of 11-15 micro-inches can be achieved and maintained. ISO inserts are available with multiple grades to suit different machining requirements. Insert hardness; and therefore, wear rate are traded for toughness and ability to withstand shock loading from interrupted cuts, (i.e., keyways).

- Hardest (suitable for plain diameters only)
- Medium (suitable for moderate interruption)
- Toughest (suitable for machining gear o/d)

Typical cutting data for CBN:

- 315 - 335 feet per minute (96-102 m/min)
- .008" - .010" (0.2-0.25 mm) depth of cut
- .004" IPR (0.1 mm/rev) feedrate

The size of the insert nose radius determines the surface finish achieved within the limits of machine and component rigidity. CBN is undoubtedly the best option provided the workpiece material is uniformly hard. It will work on steel with a hardness above 50Rc.

Ceramic

Ceramics in hardened steel turning have applications and are very economically priced compared to other types of inserts. The nature of the material necessitates the use of blunt edge geometry, which inevitably increases cutting forces and reduces surface finish potential.

Typical cutting data for steel at 60 Rc:

- 315 feet per minute (96 m/min)
- .005 “ (0.127 mm) depth of cut
- .005” IPR (0.127 mm/rev) feedrate

Cost per edge can be low, but failures on ceramic inserts can be catastrophic, in which case all edges may not be usable. Ceramic also does not perform well in the presence of high thermal shocks, so it is not generally a good candidate for coolant cutting.

Cermet (Solid Titanium Carbide)

Cermet inserts for hardened steel turning applications have some benefits over CBN and ceramics under particular conditions. If the application involves turning through a hard case into a soft core, then cermet will respond better than CBN. It does not have the wear resistance of CBN, but the tool tip will wear proportionally under most circumstances rather than fail due to breakage.

Cutting data:

- 315 feet per minute (96 m/min)
- .005” (0.127 mm) depth of cut
- .004” IPR (0.101 mm/rev) feedrate

Cost per edge is equivalent to the latest type of multi-coated carbides. Cermet inserts are available in most ISO shapes and nose radii.

Natural & Synthetic Diamonds

Natural diamond and synthetic diamond are the least preferred options for operations involving machining of hardened steel. They have high costs per edge and poor reliability in terms of interrupted cuts and wear mode. Brazing cannot always be guaranteed and re-grinding is not always possible. Diamond also interacts chemically with steels and can cause failure.

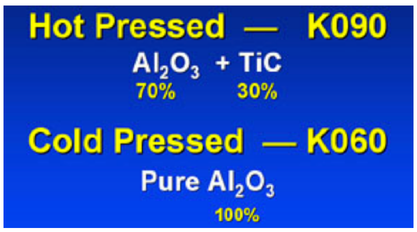
Understanding Material Science

Certainly, an understanding of material science is vital to the heat treat operator so that the correct process and hardness range is accomplished. Material not properly drawn back might crack prematurely because of the high hardness. The best hard turning results will be achieved when the hardness range is as small as possible (a spread of less then 2 point is ideal), and the case depth is maintained consistently.

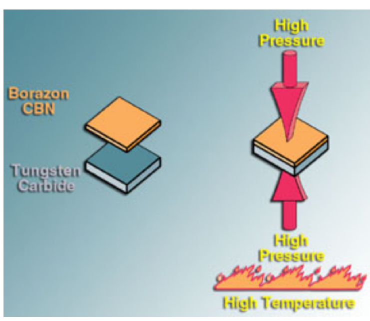
The key to success is optimizing the hard turning process to reduce overall cost(s). Factors that affect this are: purity of material, tool life, surface finish, and accuracy.

Hot Pressed v. Cold Pressed

Hot pressed Ceramic and PCBN are made in a similar fashion. The material is mixed/formulated, then placed into a die cavity. For PCBN material that is to be used for tipping carbide inserts, a carbide backing layer is placed into the die before the raw material.



Under extreme pressure and temperature, the blank is formed and then ground, honed, and lapped.



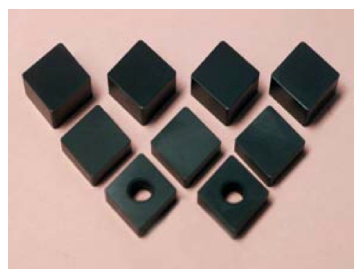
Different types of binders are used:

- TiC -- TiCn
- Tantalum -- Cobalt -- Tungsten.

Hot Pressed Al2O3 + TiC (Black) Ceramics offer the following features/benefits:

- Can hold +/-.001” (/.0254mm) on diameter
- Best for open tolerance parts
- Up to eight edges per insert
- Economically priced
- Use for roughing and finish with PCBN
- Good Toughness (has the ability to withstand interrupted cutting)
- Good Hardness
- For continuous cutting, tool life can be as good as PCBN

A specific example of a hot pressed ceramic insert: Kennametal K090 (Ceramic) is a TiC/alumina ceramic (Black) Excellent edge wear provides good size repeatability. Excellent Hot hardness permits higher SFM, and better toughness and thermal shock resistance. It’s recommended for high speed/low-moderate feed applications, and semifinishing and finishing of cast iron to 60 HRC, Steels to 65 HRC, and Nickel-base alloys. Recommended SFM is 300 to 600; IPR .004” (.1016mm) to .012” (.3048mm)



Cold Pressed Al2O3 (White) Ceramics offer the following features/benefits:

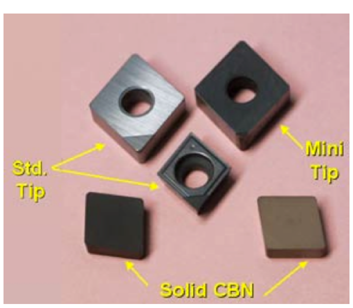
- Excellent wear resistance
- Relatively low toughness
- Thermal shock resistance
- Recommended for high speed/low feed finishing of cast iron to 35 HRC, Carbon steel to 35 HRC

Most applications for Cold Pressed Ceramic are soft steels and soft irons, though due to the high Al2O3 content,

they offer excellent edge wear resistance, and may apply to light finish machining of hardened steel.

PCBN (CBN) INSERTS

CBN inserts are produced through powdered metal processes using Borazon/ceramic powder. Wafers are cut into slices and brazed to a carbide insert, then edge preparation is done.

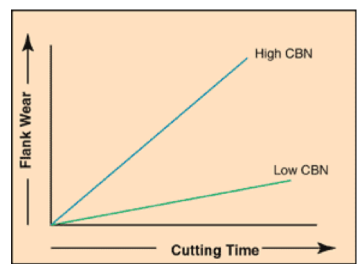


There are only a few manufacturers of PCBN blanks; Kennametal works with GE and Deberrs material.

PCBN/CBN inserts offer the following features/benefits:

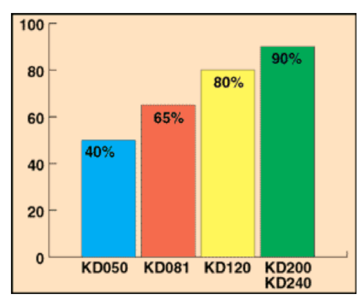
- Can hold +/- .0004” (.010159mm) on diameter. Only grinding can hold better
- Up to 8 edges per insert
- Low per-unit production cost
- PCBN holds better surface finishes due to finer micro-structure
- Excellent toughness permits interrupted cutting
- Excellent hardness provides superior edge wear
- Chips take heat away from the part and tool

The chart (*right*) shows the comparative performance of finish machining hardened bearing steel (60 HRC) with high and low CBN content inserts.



The level of CBN content directly affects the edge wear resistance and impact.

The chart (*right*) shows the relationship of PCBN Grades to CBN Content.



Low CBN Content provides improved edge wear; high CBN content offers higher strength.

04 THE IDEAL MACHINE FOR THE JOB

THE IDEAL MACHINE FOR HARD TURNING

When considering hard turning, the question is not "*Can* it be done?" because many machine tools can hard turn. Instead the question is, "*How well* can it be done?" Success in hard turning is largely a measure of the machine construction and design along with the workholding and tool holding. The level of rigidity and damping in a hard turning application cannot be minimized. That's where Hardinge has a competitive advantage.

Success in Hard Turning is defined by a number of factors:

- Machine rigidity
- Workholding Rigidity
- Good vibration damping characteristics
- Rigid tool location
- Component part rigidity
- Rigid cutting tools and advanced insert materials

Hardinge lathes meet these requirements with the following key features.

- Machine Rigidity: Heavy-duty linear guideways on Hardinge QUEST lathes are typically 40-60% heavier-duty units than those fitted to most competitive machine tools of the same size. The low-stress drive systems on QUEST machines have larger axis motors and shorter pitch ballscrews than most competitive machines, making for high dynamic stiffness--critical for successful hard turning.

- The patented Hardinge spindle design on Hardinge QUEST and ELITE series lathes ensures that the workpiece is seated as close as possible to the spindle bearings for maximum rigidity and accuracy. This greatly improves the Hard turning process compared to competitive workholding solutions.

- In addition, Hardinge is the largest manufacturer of lathe spindle tooling systems in the world. This ensures that the workholding systems made for our machines are designed specifically for our machines.

- QUEST lathes are built on a rigid cast iron base with HARCRETE Polymer Composite reinforcement. Vibration damping is critical to the successful application of hard turning. HARCRETE is located in key positions of the base to assure maximum rigidity. This unique design can help you save 30% or more on cutting tool expenses, and reduce vibration at the spindle by 60%.

- All external tools on QUEST machines equipped with Hardinge turrets mount directly into the tool slots provided in the turret body. The close proximity of the cutting tool to the coupling reduces the risk of vibration, thus improving the Hard Turning process.

- QUEST lathes feature digital glass scales incorporated for both the X and Z axes. The spindle motor and collet closer assemblies are dynamically balanced. And X and Z axis error compensation is performed to fine tune positioning and compensate offset at the tool tip.

In short, Hardinge machines offer the ideal machining process from the standpoint of part cost, capability, and accuracy.

05 TECHNIQUES FOR HARD TURNING SUCCESSFULLY

HARD TURNING SUCCESSFULLY

Machining success depends largely on component rigidity, the geometry to be turned, lathe rigidity, and vibration damping characteristics.

Rigidity is critical for successful hard turning. The rigidity of tooling, workholding, and the machine tool itself are all crucial elements that will affect your ability to successfully hard turn. Hard turning is a technology-driven process, dependent upon:

- Machine technology
- Process technology
- Materials and tooling technology
- Workholding technology

In the area of hard turning, it's well-established that the presence of vibration is not desirable from multiple standpoints. A machine which has improved damping will demonstrate improvements in lowering the amplitude of vibration and the time to decay, all while maintaining static stiffness. The real and measurable results are longer tool life, better surface finishes, improved accuracy, increased productivity and higher overall part quality. System rigidity is of utmost importance.

Machine Dynamic Stiffness (MDS) is one of the most important attributes for hard turning. MDS is a ratio of the force to displacement at the exciting frequency, a function of the static stiffness and the system damping. When the static stiffness cannot be increased, then it's necessary to increase the damping to increase the MDS. The upper bound in part surface finish quality is determined by MDS as is the upper bound in tool life.

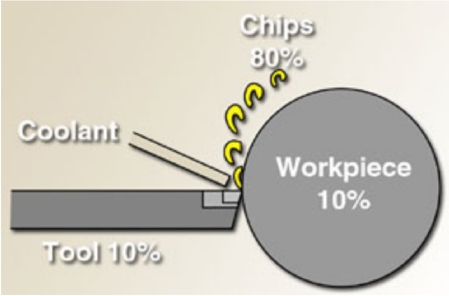
The benefits of high dynamic stiffness include:

- Lower operating vibration
- Substantially improved tool life
- Substantially improved part quality
- Higher through-put
- Less machining parameter adjustments

HARD TURNING TECHNIQUES

Feed Speed

When hard turning, the cutting zone temperature is approximately 1700 degrees (Fahrenheit). The majority of the heat from the cutting application should be carried away with the chip. Excessive heat increases tool wear and reduces tool life, so proper application of speed and feeds are critical.



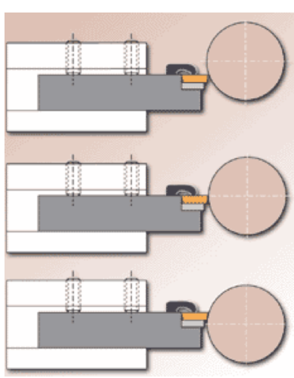
above: The illustration shows how this heat should be dispersed.

Machine Setup

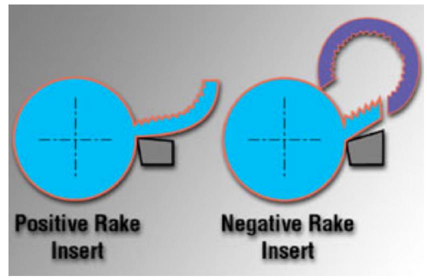
The key is to maximize rigidity. You should attempt to achieve the smallest possible tool overhang, and spindle rotation should put cutting forces into the machine bed. Stop cutting if chatter occurs. Coolant (spray mist or flood) is appropriate for continuous cutting--you can achieve up to a 20% increase in tool life with high-pressure coolants. Spray mist is often used in Europe, due to the high cost of disposal (since less coolant is used in all applications), and dry machining is being investigated aggressively in Europe. For intermittent cutting, do not use coolant. Dry cutting may benefit from the application of compressed refrigerated air.

Positioning

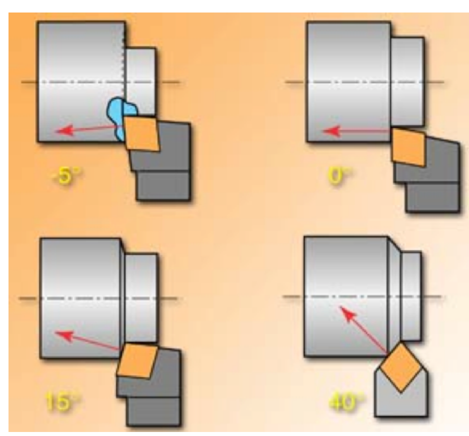
Centerline position is important in hard turning. The smaller the diameter, the more critical the position. The tool should range from on-center, to a little below. Never above center.



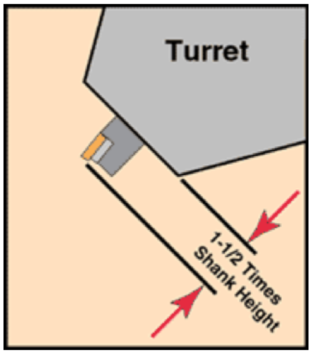
In many cases, the workpiece dictates the insert geometry and rake angle. Negative rake consumes 20% more horsepower. Cutting forces are higher with negative rake.



Cutting forces are at right angles to the insert cutting edge. Lead angle geometry helps reduce edge chipping. Lead angles help to protect the nose radius from surface conditions, and permit the use of the 100 degree corner of the 80 degree insert. **ALWAYS** cut at a right angle to the cutting plane, and increase the lead angle to protect the nose radius (*see illustration below*).

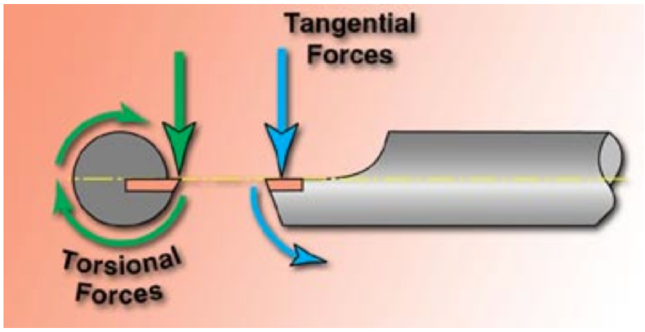


Tool overhang should be kept as short as possible. The maximum is 1 to 1-1/2 times the shank height (*see illustration below*) Eliminate any shim or spacer.



Boring

There are versatile options for boring. Both Ceramic and PCBN inserts are available in ANSI-standard geometries. Most standard combination boring bars can be converted with a simple seat change to use thick ceramic inserts.



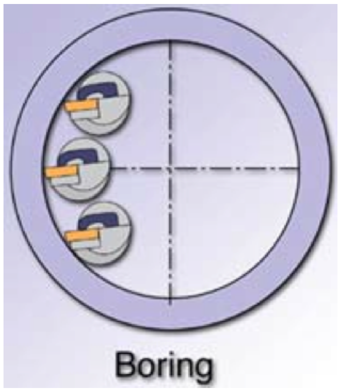
In general machining, you'll experience tool deflection and chatter. In hard turning, the problems resulting from tool pressure are multiplied, and forces are magnified (*see illustration above*):

- Torsional forces try to twist he bar
- Tangential forces try to deflect the bar away

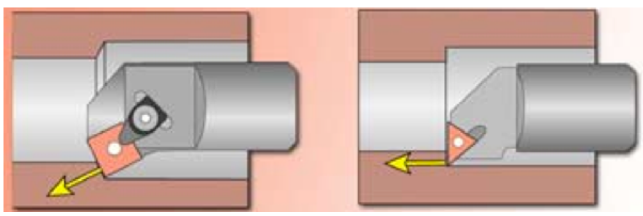
To reduce tool pressure while boring:

- Use positive rake tool geometry; use sharper 55- and 35-degree styles
- Use the smallest possible nose radius
- Reduce the depth of cut (two cuts are better than one)
- Reduce feedrate
- Increase cutting speed

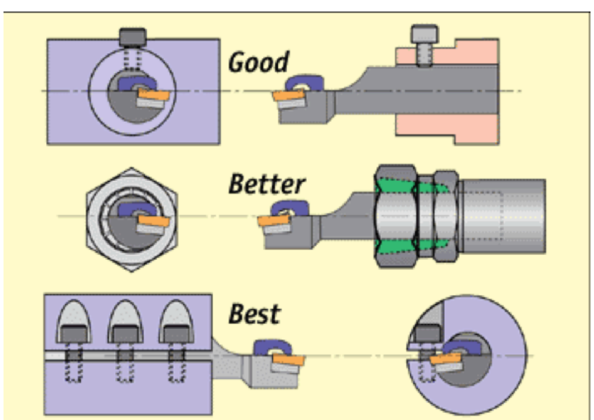
When boring, cutting deflection will lower the effective centerline. To counter this "centerline effect," set the tool either on center or slightly above — **NEVER** below. (*see illustration below*).



Lead angle cutting forces are at right angles to the insert cutting edge. Lead angle geometry helps to reduce edge chipping, and lead angle help protect the nose radius from surface conditions. The lead angle permits the use of the 100-degree corner of the 80-degree insert. Use 0-degree whenever possible to send pressure back to the spindle (*see illustration below*).



The illustration (below) shows various clamping styles and their relative merits. Single-point contact is "good," Ericson or Collet Style is "better", and Full-length split sleeve is "best."

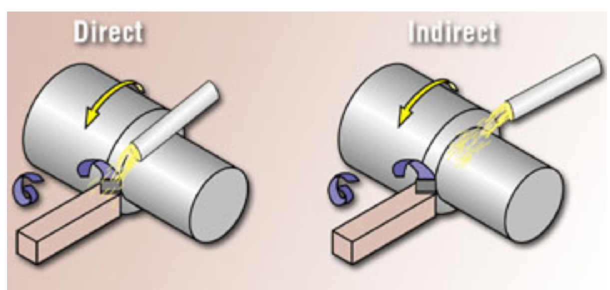


The chart below shows the relationship to length:diameter ratio and the type of boring bar to be used.

LENGTH:DIAMETER RATIO	BORING BAR
Up to 4:1	Steel
From 4:1 to 6:1	Steel with DeVibrator
From 4:1 to 6:1	Tungsten Carbide
From 4:1 to 6:1	Heavy-Metal Shank
From 6:1 to 8:1	Tungsten Carbide & DeVibrator
From 8:1 to 10:1	Tungsten Carbide & DeVibrator
Over 10:1	Special Tungsten Carbide Composite with DeVibrator

Coolant Application

The illustration below shows the correct application of coolant. The ideal application would be coolant supplied from above and below. The concept is simple. Get coolant to the shear zone and flood it.



Correct Incorrect

06 NEXT STEPS

NEXT STEPS

If you still have questions about hard turning or are ready to include it in your operaton, that's where the applications experts at Gosiger can help. As a nationally respected machine tool provider with an unequalled technical service and support staff, we can help you analyze your process and find a machine that best suits your needs. Contact us to find out more at www.gosiger.com/contact.

Gosiger would like to thank Hardinge for their continued dedication to further develop the hard turning process by providing the technology, expertise, and equipment to allow this segment to grow.

ABOUT GOSIGER

Since 1922, Gosiger has served the machine tool industry selling and servicing top CNC machine brands including, Okuma and Hardinge. From Aerospace to Clean Energy to Medical, Gosiger supplies the CNC machining centers, equipment and technology you need to meet the challenges of today's manufacturing business.

Our customers live in a world of intense pressure to make parts and products better, faster and cheaper. They need a solution focused partner who understands the connection between productivity and profitability, capacity and efficiency and can offer invaluable insight.

At Gosiger, we recognize that time is money. Our goal is to help you make it right each and every time. We're not simply a distributor of CNC machine tools and accessories. We're a problem-solving company that helps manufacturers improve their processes so they can be more competitive and profitable. To accomplish this goal, Gosiger offers a full array of support and services such as Factory Automation, Financing, Engineering, High Volume, and Parts & Service.

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