While grinding is the traditional finishing technique for hardened steel gears, hard part turning provides quite a few benefits that may improve your process, and your product.
Since its broader introduction in the mid 1980s hard part turning has evolved considerably as a machining process. Developments of machinery, component material, hardening processes, cutting tools, and complete set-ups has made the metal cutting of hardened parts an attractive alternative to grinding, and easily accessible for any machine shop involved in gear manufacturing.

**History of Hard Turning**

The conventional solution to finishing hardened steel parts has been grinding, but there are a number of clear benefits to the machining of hard parts with a cutting tool. These have justified many existing applications that are growing in number, especially involving turning and milling. Hard part turning (HPT) should not be seen as the alternative to all grinding operations, however, and there are also applications where the two processes complement each other.

HPT was early recognized and pioneered by the automotive industry as a means of improving the manufacturing of transmission components. Gear-wheel bearing surfaces are a typical example of early applications converted from grinding to HPT using inserts in polycrystalline cubic boron nitride (CBN). Today hardened components are machined widely across many different industries. Case hardened steel components are typical, often having a hardness-depth of just over 1 mm, giving it a wear resistant case and a tough core. Components that make use of this combination of material properties include gears, axles, arbors, camshafts, cardan joints, driving pinions, and link components for transportation and energy products, as well as many applications in general mechanical engineering.

**Defining Hard Part Turning**

In its broad definition, HPT is the single-point turning of workpieces with a hardness of above 45 HRC although most frequently the process concerns hardnesses of 58 to 68 HRC. The workpiece materials involved include various hardened alloy-steels, tool steels, case-hardened steels, superalloys, nitrided irons and hard-chrome coated steels, and heat-treated powder metallurgical parts. It is mainly a finishing or semi-finishing process where high dimensional, form, and surface finish accuracy have to be achieved. The following benefits of HPT have been experienced by users of the process:

- easy to adapt to complex part contours
- quick change-overs between component types
- several operations performed in one set-up
- high metal removal rate
- same CNC-lathe as used for soft turning is possible
- low machine tool investment
- environmentally friendly metal chips
- elimination of coolants in most cases
- small tool inventory
- occupies relatively small machine shop space
- advantageous surface finish in many cases.
**Hardness**

When steel is hardened it may become twice as hard as it is in the soft condition. Hardness adds to the resistance of a material to be plastically deformed and to be penetrated by another material, but the harder the metal, the harder it is to cut. In machining the hardness of the workpiece material generally makes a considerable difference in how well a cutting edge stands up to demands. For application purposes there is hard steel (45-55 HRC) and extra-hard steel (55-68 HRC). Generally, the harder the material the lower the cutting speed, or shorter the tool-life. When component hardness exceeds a certain limit, a change to a harder tool material is needed: a hard cemented carbide insert will perform satisfactorily within a lower hardness range (up to 45 HRC), much harder and they are usually not a practical solution. Most hard components are in the region of 55 to 68 HRC, and this requires a harder, stable tool material such as CBN or ceramic inserts to provide the cycle times and quality consistency needed today. CBN is much harder than cemented carbide and ceramics, while diamond is harder than CBN but useless in ferrous materials. It should also be noted that CBN should be avoided in materials with a hardness lower than 45 HRC due, somewhat surprisingly, to rapid tool wear.

**Toughness**

This is also an issue in hard part turning, in that mere hardness leads to brittleness. Some hard components have long, continuous cuts in stable conditions, which make high demands on hardness for wear resistance but low demands on toughness. Some components, however, have various degrees of intermittency, and some have unstable conditions, needing edge toughness. Component intermittency may be in the form of gear teeth, slots, surface unevenness, burrs, etc. Instability comes from weak machines, set-ups, and components, as well as overhangs. These phenomena generate various magnitudes and directions of compressive or tensile stresses and strains on the cutting edge. Very hard tool materials such as CBN and ceramics thus need varying combinations of toughness for edge strength. Generally speaking, high hardness is needed for the material demands on the tool while toughness is needed for the mechanical loads on the tool.

**Expected Results**

The absolute majority of operations in hard part turning are finishing operations, many with very high dimensional, form, and surface finish tolerances. The first indicator of excessive tool wear is usually the deterioration in maintaining these tolerances, emphasizing the need for selecting the right cutting tool as well as for it to be correctly applied.

In well-optimized hard part turning set-ups a surface finish Ra 0.25, Rz 1 micron have been achieved and accuracy levels of 0.01 mm on a diameter. Other typical values that may be part of demands on hardened components are roundness, conical accuracy, and surface profile bearing, all of which HPT responds to well. A minimum amount of working allowance is vital for both HPT as well as grinding, depending upon form and tension-conditions from the hardening process. The minimum value depends upon component size and cross-sectional differences, but if 0.1 mm is suitable for grinding, the HPT-value should generally be an additional 0.1 mm, bringing it to 0.2 mm.

**HPT Demands and Priorities**

When selecting cutting tools for HPT the hardness of the workpiece material, machining conditions, and tolerance limits are the main points to consider.

CBN is the most widely used HPT tool material because it fulfills the requirements made in most applications. Today there are various CBN insert grades available that cover the different operational demands of HPT, including cutting speed, feed, continuous or interrupted cuts, and surface finish demands and conditions. Ceramic inserts represent a lower tool cost but are limited to continuous cuts when thermal shocks are small. Also, they are not as suitable for super finishing as CBN inserts are.

HPT is more demanding than soft turning because of the higher cutting forces involved, in combination with the tight dimensional and surface finish limits. As an indicator, hard steels typically have a specific cutting force of 3250 N/mm2 at 45 HRC, while extra hard steels has 6450 N/mm2 at 65 HRC. The harder workpiece material needs a strong cutting edge, and this means a relatively blunt edge. The insert cross-section has to be large and strengthening lands and micro-edges need to be added, depending upon the operation at hand. The result of this is often even higher cutting forces and, consequently, the higher demands in HPT for rigidity, stiffness, and stability throughout the set-up, from the cutting edge to the machine tool base.

The general stability, rigidity, and condition of the machine tool are directly decisive as to the level of cutting data, type of cuts, and results that can be achieved. The effects of intermittent cuts and the demands of achieving super-finish limits should not be underestimated in HPT. The dynamic stability and the behavior during the cut of the machine often determine the practical limits. Knowledge of the machine behavior during the stress of HPT and the condition of the machine are therefore quite important. Minimizing the amount of overhang of the workpiece and the tooling is always critical to determining overall rigidity, but even more so in HPT.

The setting up and orientation of cutting tools is also more vital when it comes to HPT. Centerline setting of the cutting edge should be very accurate, and the direction of and support against cutting forces in the form of well-supported parts of the toolholder, turret position, and machine should be assessed. Insert locking needs to be uncompromising, as does the tool holding, where only the most stable solution should be considered. A basic success factor of HPT is minimizing any movement or vibration tendency of the system.
elements such as the insert, toolholder, and tool clamping, as well as the machine turret, spindle, slides, frame, and base. Whereas in the past only a few CNC lathes could be picked on the basis of suitability for HPT, or could be modified to stand up to the higher demands, many of today’s CNC lathes can perform HPT with good results and cycle times.

Tackling the Soft Issues

The HPT operation will inherit any form and dimensional deviation from previous soft turning. For example, an excessive tolerance for soft turning on the working allowance for HPT can mean unsatisfactory results, partly because HPT uses such small depths of cut. It is therefore vital that sufficiently-close tolerances are established for the soft turning based on the experience gained from HPT operations.

The soft turning should reflect the demands made on HPT results especially as it regards form and dimensional accuracy. The soft turning should not be seen as just a roughing operation but as the close semi-finishing operation, as the HPT operation should not be expected to correct deviations or distortions. Thus, the quality of the soft turning operation—as well as that of the hardening process—will directly affect the quality, tool life, and productivity of HPT.

Furthermore, variations of the working allowance and form passed down from the soft turning also lead to cutting force levels varying in HPT, which means compromising cutting data to cope with the highest force level. This is often in the form of feed rate having to be lowered to minimize tool or component deflections during the cut. As the feed directly influences the machining time, this becomes a productivity as well as a quality and security issue. It is always more cost-efficient to tackle the soft-turning issues than the those related to HPT.

Fig. 3: Crater wear is the dominant type of wear in hard part turning as a result of the high pressure that the chip exerts on the cutting edge. This is countered by selecting the most suitable insert grade for the application in question.

Fig. 4: Insert geometry is an issue for hard part turning. The right entering angle, edge nose radius, chamfer, and honing make a significant difference to performance. Wiper inserts can provide an advantageous feed rate and surface finish combination.
Cutting Tool Developments

As productivity is an increasingly important factor for HPT today, tool developments play a more-important role. Trends include that of cutting speeds having been elevated to present potential levels—well above 200 m/min with some grades—with longer, more-predictable tool lives. Feed rates have also been pushed higher to achieve shorter cutting times, though resulting in higher cutting forces. These forces, however, are countered with various geometrical cutting edge designs and larger or different insert nose-radius concepts.

Insert grades are becoming ideally positioned to respond to today’s operational demands in HPT. These include continuous cuts of various lengths, light intermittent cuts to heavy intermittent cuts, as well as differences in machining conditions. CBN grades are generally the first choice, backed by a ceramic grades, and recent developments have been considerable, resulting in a new generation of more-capable insert grades.

Tool wear in the form of craters forming on the cutting edge dominates in HPT as a result of the high pressure from large cutting forces combined with high temperatures in the concentrated machining zone. CBN is the tool material best equipped to stand up to the demands involved in HPT with high hardness and varying amounts of toughness. The most recent CBN-grade development has provided the means to limit tool wear further, improve edge security, and extend the application area, as well as to allow cutting speeds to rise by some 20 percent.

Today’s HPT needs a range of tool materials that can optimize different conditions, operational demands, and quality results. The following is one such range of different grades that complement each other:

- Low-content CBN for continuous cuts which may include occasional, light intermittent cuts with stable machining conditions at high cutting speeds, primarily for case-hardened steels (CB7015);
- Medium-content CBN for operations characterized as having substantial amounts of light to heavy interrupted cuts mixed with continuous cuts at medium cutting speeds, often characterized by poor entry-into-cut conditions such as burrs and unchamfered corners on mainly case hardened steels (CB7025);
- Extremely hard CBN grades with high edge toughness for severe conditions where the

Fig. 5: To tackle hard part turning successfully you need a range of tool materials to enable the selection of the best insert for optimization. Continuous cuts, light intermittent cuts, and heavy interruptions and distortions need the right cubic boron nitride insert grade.
component shape varies considerably and major distortions may prevail, or where there are unchamfered interruptions primarily on hardened steels (CB7050);

- A mixed aluminium oxide-based ceramic grade with good heat-resistant properties and high wear resistance, but limited to light, continuous finishing in good, stable machining conditions (CC650).

**Alternative Insert Geometries**

When it comes to insert geometry, cutting edges for HPT are relatively dull because bluntness is needed for high edge strength. This, however, does not mean that geometrical issues are nonexistent. Although chipbreakers are not part of the insert face, edge chamfers, honing, nose radius, wiper radii, and entering angle combinations are critical new carefully-developed features to achieve higher performance and results.

As an example, a correctly designed 30-degree edge chamfer on a CBN edge for HPT helps to direct the crater-making forces further away from the edge, reducing the weakening effects of this type of wear. There are mainly two types of chamfers: the S-type, where the land is complemented by light honing for added strength, and; the T-type with no honing, giving rise to the lowest cutting forces and best surface-finish generating capability. The wiper insert is based on a sophisticated radii-combination edge concept that has revolutionized finishing turning, and has come to improve HPT as well. There are now specially developed wiper inserts for HPT for both finishing and semi-finishing operations. A WH geometry generates the best surface finish, while providing high feed rate capability with either T- or S-land edges. A WG geometry is suitable for semi-finishing operations when performed at stable machining conditions, when cutting forces are higher but so is the feed rate capability. In comparison, the standard nose-radius insert generates the lowest cutting forces with low stability requirements, but it does not have the high productivity/surface finish combination of wipers.

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**Fig. 6:** The locking of the cubic boron nitride corner on multi-corner inserts for hard part turning needs to be very secure so as not to be a source of instability. Safe-loc mechanical interlocking provides an absolute bond for a corner that copes with most types of cut.
A subsequent new innovation involves an insert geometry with a straight cutting edge, presented at a carefully balanced, smaller entering angle, blended with a wiper edge. An Xcel geometry insert generates a chip with an even thickness, eliminating extremes as regards wear mechanisms. Thanks to the load from a more-constant chip and the reduction in heat development in the cutting zone, slower and more advantageous tool wear development is achieved for this and many other HPT operations. Benefits are especially high when the whole edge is used for one-pass operations.

This insert leads with a very small entering angle (10 degrees) along the main cutting edge, which reduces the chip thickness relative to the feed rate. This then allows much higher feed rates to be used, leading directly to shorter cutting times.

Multi-corner indexable inserts for HPT are typically cemented carbide inserts with CBN corners. In the past this has meant a potential source of instability or weakness at the joining of the two materials in the insert. The locking of the CBN cornerpiece onto the basic carbide insert needs to be very firm, with no inherent instability or weakness. It also needs to accommodate enough capability for the insert to perform the frequently occurring cuts in turning such as profiling, facing, back turning, undercutting, and chamfering. Today’s brazed CBN/carbide insert—in addition to taking long, continuous cuts—also needs to cope with relatively severe intermittent cuts and elevated cutting data in order to provide higher productivity in HPT operations.

A new, solid, mechanical interlocking method and brazing design has provided a longer, multicorner CBN edges with high insert stability, removing a multicorner inserts limitation. With the brazed joint being further away from the intense heat of the HPT machining zone, the insert has become more capable of continuous cuts at higher cutting speeds.

Safe-lok mechanical interlocking provides an absolute bond, resisting higher pressure from larger feed rates, depths of cut, and the added severity of more-substantial intermittent cuts.

Movement and vibrations of the insert in the seat is a well-recognized culprit that affects the component quality and leads to premature edge breakdown. For this reason clamping the insert in the toolholder is the next vital step in the stability link. A rigid clamping system, type RC, combines the downward force of a clamp on the insert with precise, well supported tip-seat positioning. The result is very rigid insert clamping and high indexing repeatability to suit a majority of turning applications, and especially to hold and support CBN and ceramic inserts in HPT. Indexing of insert and shim is facilitated by the design of the clamp set.

**Tool-Path Strategies**

An HPT application can be optimized using wiper inserts or conventional nose-radius inserts by adopting either a one- or two-cut strategy for machining. The one-cut way of HPT is the quickest but entails achieving the required finish and accuracy in one cut. Demands are made on tool life for the tool to maintain component limits, and good stability is necessary throughout, as all material is taken in the one pass. On the other hand, the machining time is short, and only one tool is needed.

The two-cut way needs two tools—one for semi-finishing, and one for finishing—and the tool dedication means better quality consistency and longer life per tool. More consistently maintaining higher surface finish and closer tolerances (best process stability) are the main advantage to be weighed against longer machining time. The right type of insert needs to be selected to suit each application.
Machine Shop Experience
Correctly applied, hard part turning with modern cutting tools and methods can lead to advantages over grinding and outdated HPT such as higher productivity through shorter cycle times; higher production flexibility through the use of CNC lathes; and higher operational capability of turning giving good quality surfaces. Lower machine costs with lower-cost machinery can also be realized, and there are also environmental advantages in using a metal cutting process that requires no coolant. Some of the necessary conditions for success include:

- A good CNC lathe is recommended, having the right capability, where general stability, high tailstock pressure, and suitable slides are factors without necessarily being a HPT-dedicated design.
- Good workholding equipment and minimized overhang are necessary as stability is vital for example solid center instead of live and well-dimensional spindle bearings.
- Ensure that the quality level of hardened workpieces is consistent, in size, form, hardness, run-out, etc.
- Use the best of the latest cutting tools, carefully selected for the job at hand with correct machining methods, and get qualified support
- Establish the optimum cutting data range to give the best combination of productivity, quality, and security

With regard to cutting tool requirements, make sure there is good accessibility for tools for various shapes of components, very stable insert clamping, strong and stable tool mounting, and predictable and sufficiently long tool-life in order to eliminate tool changes during the course of the operation. Also make sure there is sufficient tool accuracy and stability, especially concerning the insert, to enable tolerances to be kept consistently and to minimize adjustments required during the process, and that you have qualified application back-up.

Fig. 7: Hard part turning has come a long way and today is an efficient manufacturing method. Certain conditions need to be in place for applications to be successful, but these can be accommodated relatively easily, especially with knowledgeable support.

ABOUT THE AUTHOR:
Christer Richt is with Sandvik Coromant and can be reached at christer.richt@sandvik.com. Also go online to [www.sandvik.com].